SOILS
ROTORUA 2024

WEAVING SOIL SCIENCE ACROSS CULTURES & ENVIRONMENT

New Zealand Society of Soil Science

SOIL SCIENCE AUSTRALIA

Joint NZSSS and SSA Conference "Te Kiri o Papatūānuku"

2nd to 5th December 2024, Rotorua Energy Events Centre, NZ

FUNTASTIC FORESTS FIELD TRIP HANDBOOK

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Funtastic forests - Kaingaroa Forest (the largest plantation forest in the Southern Hemisphere) on Pumice soils derived from the 232 AD Taupo eruption

Megan Balks, University of Waikato, Michael Wilson, Timberlands, Loretta Garrett, SCION.

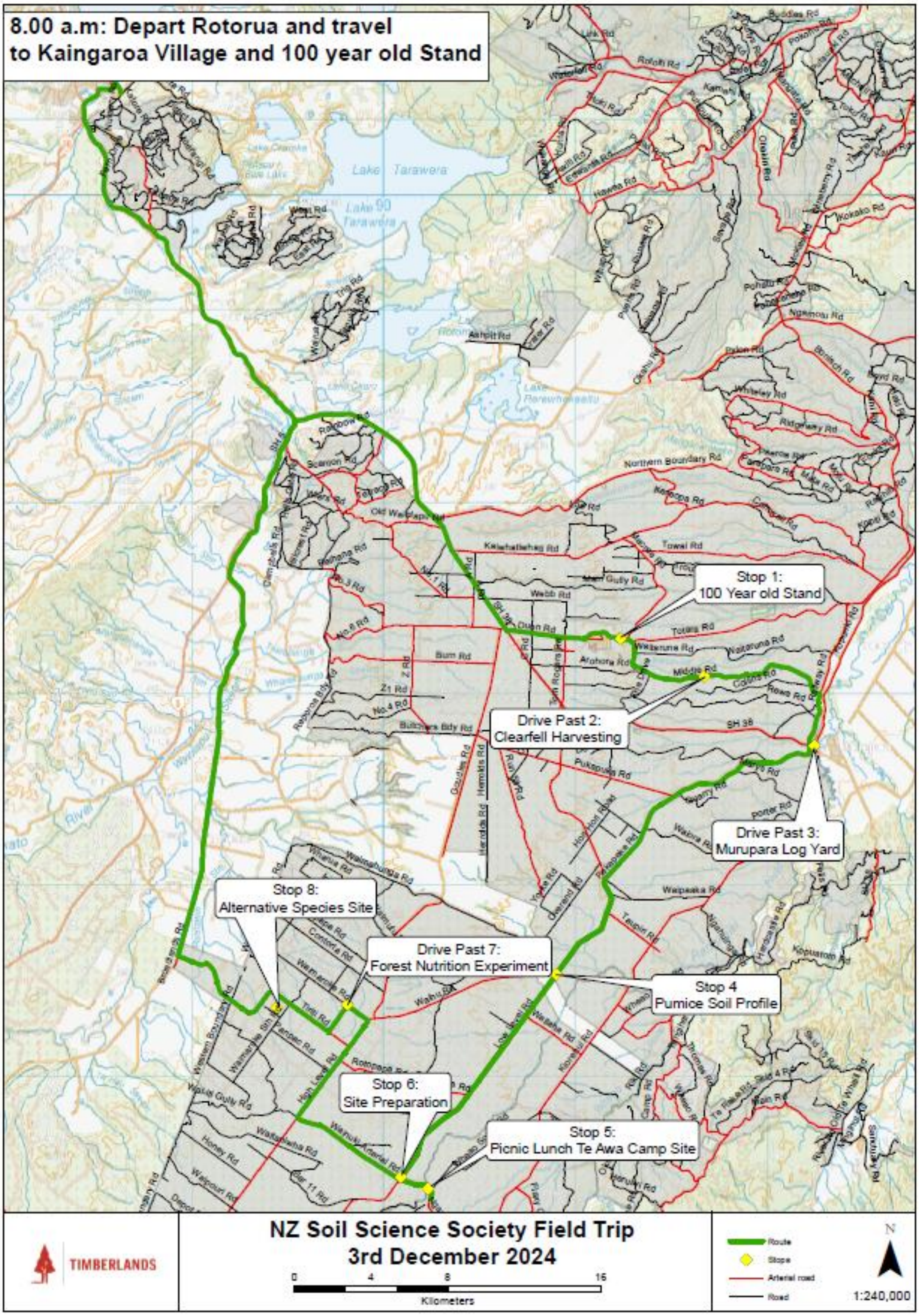
- ***8.00 am depart Rotorua***
- ***9.00 – 9.45 am History of Kaingaroa Forest, 100-year-old tree stand***
- ***9.45 - 10.30 Murupara log loading and possible harvesting*** – (drive by view from bus – no offload).
- ***11.00 – 12.00 Pumice soil profile*** on corner of Waihu and Low Level roads – history of Taupo Pumice eruption and other volcanic eruptions.
- ***12.20 – 1.00 Picnic Lunch at Te Awa Camp Site***
- ***1.15 - 2.00 Forest rotations and replanting*** – soil disturbance (site near lunch stop).
- ***2.30 Forest nutrition trial*** – drive by and talk on bus
- ***3.00 – 4.00 Alternative species (eucalypts)*** Compartment 333/5/6 Walk in from Tiriti Rd
- **4.30 – 5.00 Photo stop at boiling mud near Waiotapu** (if time allows)
- **5.30 arrive Rotorua**

Health and safety:

We want you to have a safe and enjoyable day. While we will not be visiting any operational areas on this field trip, the following hazards still exist:

- Road traffic
- Uneven surfaces, soak holes
- Blackberry and low hanging branches
- Trip hazards (hidden undulations and slash)
- Windthrown and hung-up trees, falling branches and cones
- Dehydration and sunburn if it is hot, or hypothermia if it is cold and wet
- Dust from roads and vegetation
- Wasps

All participants are required to wear a hi-viz vest at all times on the field trip and to have appropriate closed toe footwear. You should also wear clothing that is suitable for all weather conditions. Participants must stay with the group, not wander off and obey all instructions from Timberlands staff. If you have any allergies, please let a Timberlands staff member know. Similarly, if you observe anything that concerns you, please notify one of the Timberlands staff on the field trip. All Timberlands staff members have first aid training, and first aid kits are available in all Timberlands vehicles and on the bus. In an emergency, please follow the instructions of Timberlands staff.


8.00 a.m: Depart Rotorua and travel to Kaingaroa Village and 100 year old Stand
Lake Tarawera
Stop 1: 100 Year old Stand
Drive Past 2: Clearfell Harvesting
Drive Past 3: Murupara Log Yard
Stop 4 Pumice Soil Profile
Stop 5: Picnic Lunch Te Awa Camp Site
Stop 6: Site Preparation
Drive Past 7: Forest Nutrition Experiment
Stop 8: Alternative Species Site
TIMBERLANDS
NZ Soil Science Society Field Trip
3rd December 2024
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Geological Setting of New Zealand *(Reproduced/adapted from Hewitt, Balks and Lowe 2021).*

"New Zealand lies on the collisional plate boundary between the Pacific and Australian tectonic plates which are moving towards each other at about 40 mm/year (Figure 1). In the North Island the Pacific plate is being subducted beneath the Australian plate resulting in current volcanic activity in the central North Island and Taranaki. To the south of the South Island the Australian plate is being subducted beneath the Pacific plate. Through the central part of New Zealand, the boundary of the two plates is marked by the Alpine Fault, a transform or strike-slip fault which passes mainly along the western margin of the Southern Alps. The crumpling, uplift, and lateral movement, are marked by numerous hill and mountain ranges, and fault-lines, in both the North and South Islands.

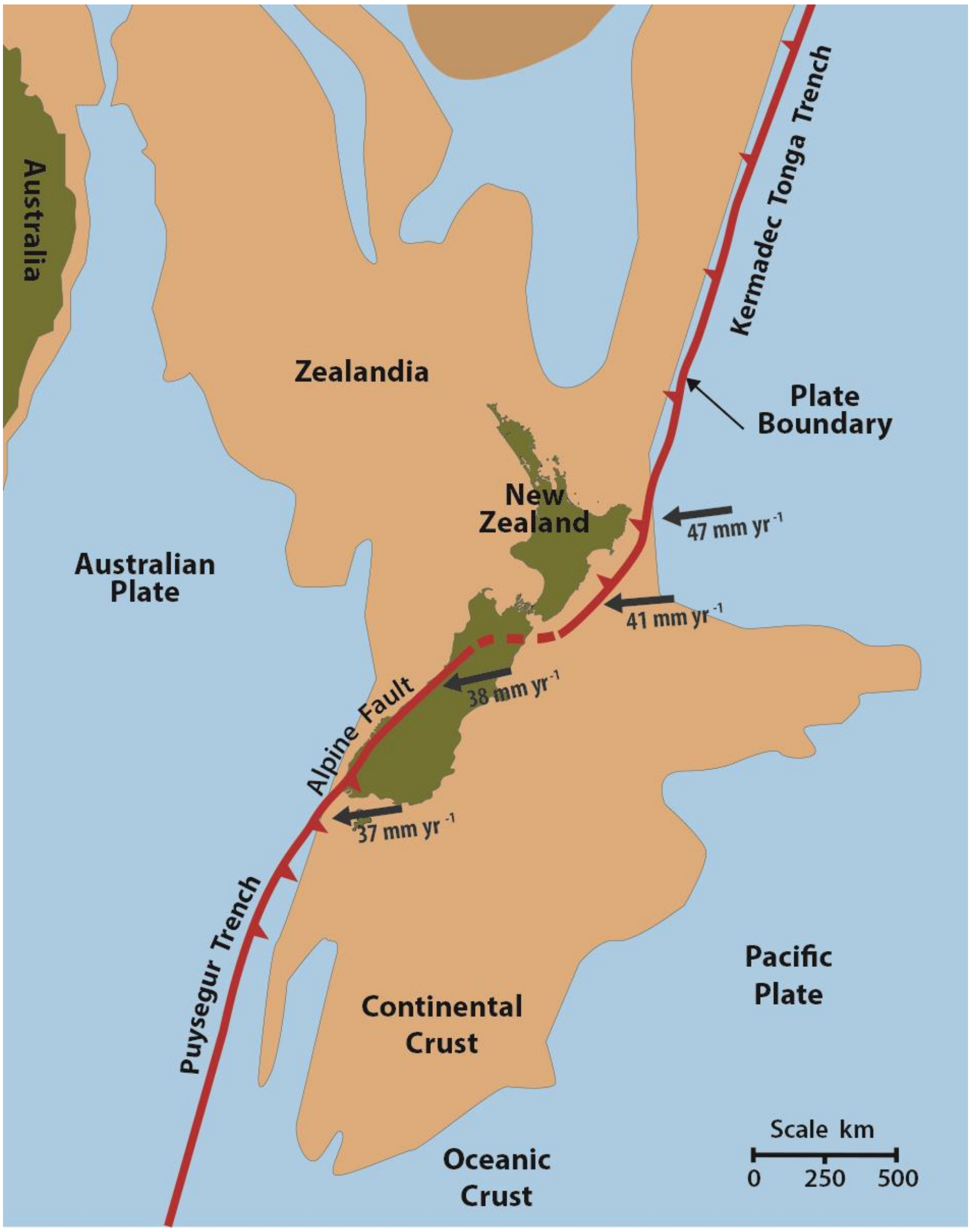


Figure 1. The Zealandia continent and plate tectonic setting of New Zealand (Adapted from Q-map GNS)

As the Pacific plate descends into the Earth's hot mantle, the crustal rocks are heated causing magma to form. The magma is mostly made up of materials low in silica called basalt. This evolves into andesite, with intermediate silica content, that erupts to form cone or stratovolcanoes such as Mt Ruapehu. Heat from the basalt magma causes the continental crust (mainly greywacke) to melt, leading to huge rhyolite eruptions, with high silica content, that can result in collapse of the land to form calderas such as those occupied by Lakes Taupo and Rotorua.

The volcanoes, and associated geothermal activity, are concentrated in a linear zone stretching from Ruapehu in the south to Whakaari (White Island) in the north called the Taupo Volcanic Zone (TVZ) (Figure 2). Large volumes of pyroclastic material or tephra has been explosively erupted from volcanoes in the TVZ and deposited over the landscape of the central North Island and beyond. Hence many soils in the central North Island are formed from tephra deposits which, because of their intermittent deposition, often comprise multiple layers of tephra with buried soil horizons (paleosols) within them. Such soils are said to be formed by "upbuilding pedogenesis" whereby the deposition of tephra on the land surface causes the land to rise at the same time top-down soil-forming processes modify and transform the tephra materials to form soil horizons.

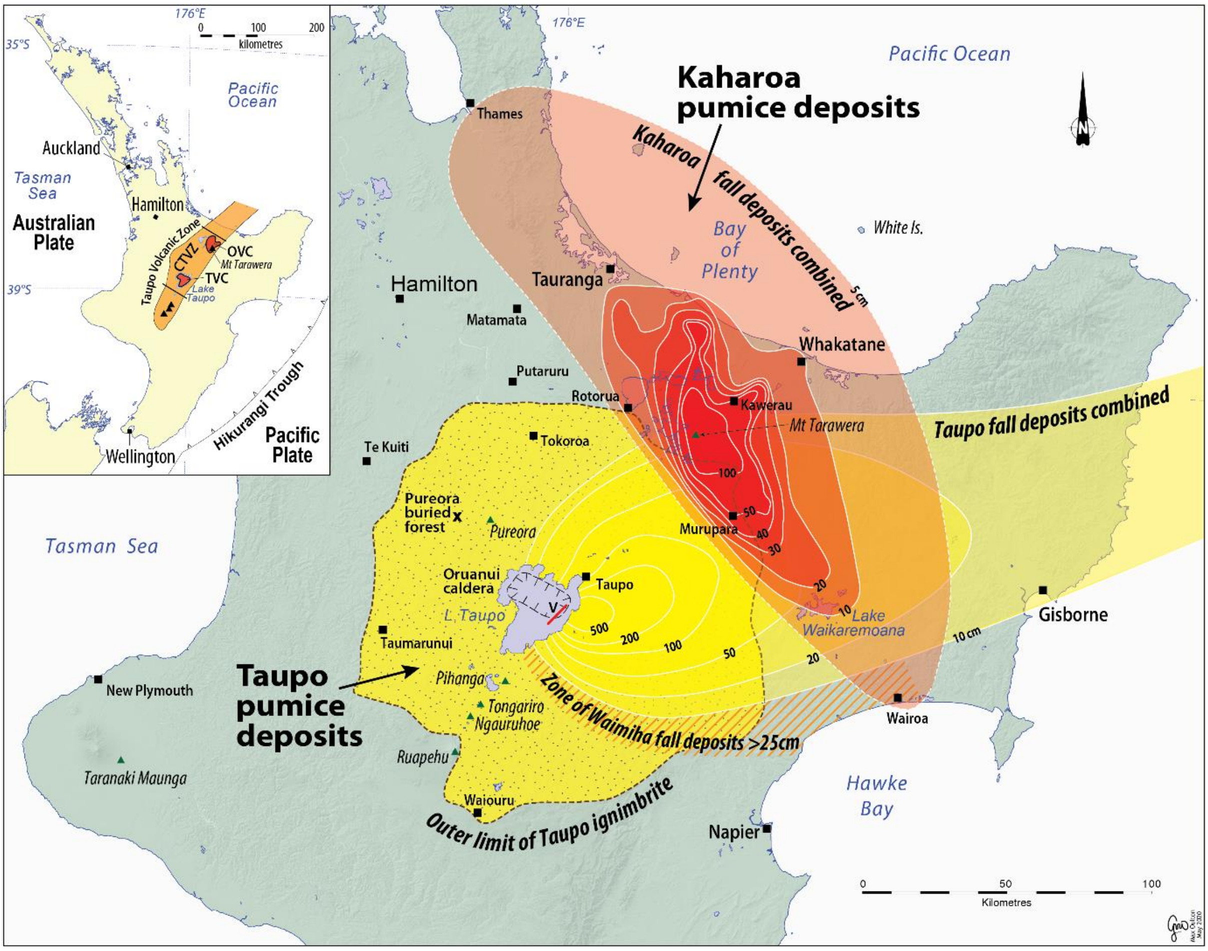


Figure 2 Taupo volcanic Zone and thickness of deposits from the Taupo (232 AD) and Kaharoa (1314 AD) eruptions. From Hewitt, Balks and Lowe 2021, Chapter 12.

The last glaciation, which extended from about 115 000 to 11 700 years ago, with a glacial maximum between about 31 000 and 18 000 years ago, had marked impacts on New Zealand. The average temperature in New Zealand was about 6 to 6.5 °C colder, and it was about 25% drier, frostier, and windier. Sea level was about 135 m lower than that at present. The treeline was lowered by about 800 m, and forest in most places (except Northland) was replaced by grassland or shrublands, or both, except in refugia where small patches of forest remained."

The Taupo Pumice 232 AD Eruption *(Adapted from Balks and Zabowski, 2016)*

"Lake Taupo fills the caldera formed following some of the largest rhyolite volcanic eruptions known (Figure 2). Over 500 km^3 of material have been blasted into the atmosphere and spread across the surrounding landscape with at least 28 recognized eruptions in the last 26 000 years.

The most recent major eruption from Taupo occurred about 1 800 years ago (232 AD +/- 10 years), which was before humans reached New Zealand. Tephra was blasted about 50 km up into the atmosphere. When the eruptive column collapsed, hot ground-hugging (pyroclastic) debris flows raced across the landscape for up to 80 km from the source leaving deposits over 100 m deep near the present-day lake. Some of the finer material would undoubtedly have stayed in the atmosphere for some months and circled the Southern Hemisphere.

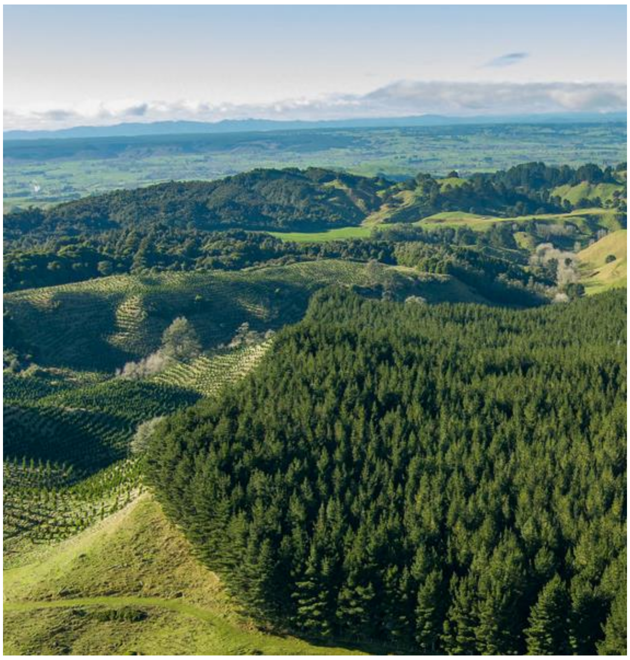
The resulting Taupo pumice deposit mantles the landscape around Lake Taupo with thicker deposits ponded in former valleys and thinner coatings on ridges. The pristine forest was knocked over in the blast, incinerated, and buried. Within the pumice the charcoal remains of the burnt forest are easily seen. Scientists have mapped out the angle of the fallen forest trees and, like a set of compass needles, they all point back to the source of the blast near the northeastern edge of Lake Taupo. The charcoal has been carbon dated to help determine the date of the eruption.

For some time after the Taupo pumice eruption the central North Island landscape would have resembled a moonscape with frequent dust and sandstorms as the winds picked up and moved material around. All the rivers and streams were choked with pumice for many years as each successive rainstorm eroded more unconsolidated material into the overloaded waterways. Even today, if you visit beaches in the North Island of New Zealand you can find Taupo pumice washed up with the tide as the pumice material is still being gradually redistributed, via the rivers, through the landscape.

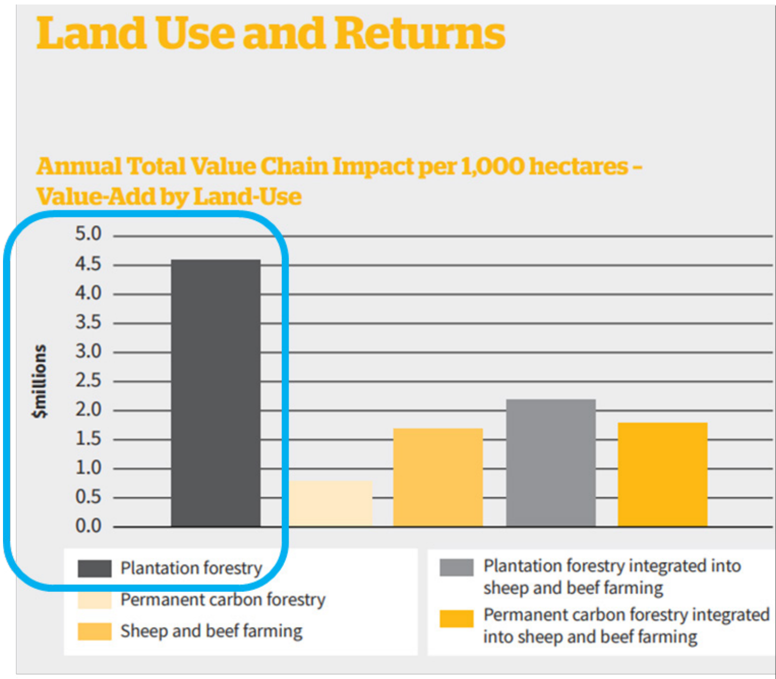
Vegetation became re-established, until covering the surface and stabilizing the new landscape. Over time organic matter built up to create a thin topsoil. Where the pumice layer was not so thick the plants gradually got their roots into underlying buried soils, and thus could thrive, in turn contributing organic matter to help build the new topsoil."

New Zealand forests

- 34% of NZ's total land area is classified as forest (9.1 M ha)
- Of this, 26% of NZ (~7 M ha) is native forest, most of which is in the conservation estate and is protected (i.e. no harvesting takes place)
- 2.1 M ha are planted of which 1.7 M ha is managed for timber. The remainder are for protection or are carbon forests.
- Forestry is one of New Zealand's major export industries, with a high economic contribution on a per hectare basis.



FOA facts and figures 2022/23



FOA facts and figures 2022/23

NZ planted forest timber investment is valued at about $60 billion

STOP 1 – History of Kaingaroa Forest and 102-year-old stand

The 1913 Royal Commission on Forestry concluded that indigenous forests would not be able to supply New Zealand's future timber requirements. Indeed, by attempting to do so, these forests would have been depleted in a short period of time. Instead, they recommended that afforestation with fast growing species to meet the projected future demand for timber. Radiata pine was identified as a potential species due to its ability to produce industrial quality timber in a short period of time. After World War 1, the government established a dedicated forestry agency (this became the New Zealand Forest Service) which was responsible for management of native forests and afforestation.

Despite being mostly flat, the land under which Kaingaroa Forest sits was not deemed suitable for pastoral farming due to a cobalt deficiency which meant that animals struggled to survive. Therefore, it was identified as being suited for afforestation. Experimental planting of Douglas fir and radiata pine began on a 5-acre (2.0 ha) block at Kaingaroa in 1901 and continued from 1906 using Wai-o-tapu prison camp labour. Much of the stock for these early plantings was grown at the Whakarewarewa Nursery which was located where Scion's Rotorua offices sit today. The newly created New Zealand Forest Service began an afforestation programme in the 1920s. This programme continued for many years. While radiata pine was a key species in this planting programme, many other species were tested including *Pinus muricata*, *Pinus strobus*, *Pinus nigra*, *Pinus contorta*, *Pinus ponderosa* and *Larix decidua*. These early stands were typically established at high initial densities (in some cases by aerial seeding) and were mostly un-thinned as labour to carry out thinning operations was not available (the outbreak of World War 2 resulted in a substantial labour shortage). Stands typically thinned themselves and were eventually harvested in the 1970s when they were around 50 years of age. The stand KANG1200 is one of the early plantings (1922) and has been retained for various reasons. These early stands were referred to as the "old crop".

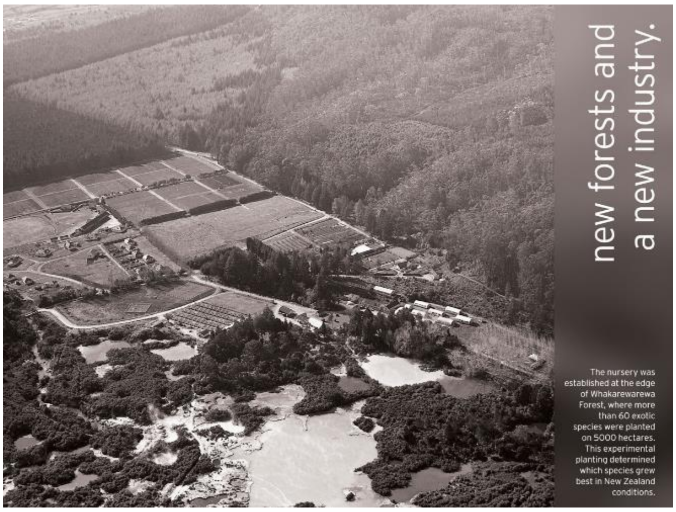


Figure 3. Aerial image of the Whakarewarewa Nursery in Rotorua. Image from Scion.

The “old crop” stands were replaced with material from the first tree improvement programmes. Nursery management and planting techniques had also advanced from when the first stands were planted. Establishment practices had also improved, particularly the understanding of the need to mitigate the risk posed by frost. Ground frosts as severe as -10 °C can occur in the winter months on the higher elevation sites in the southern part of Kaingaroa Forest and on these sites, frosts can occur any month of the year. These improvements in establishment practices resulted in a dramatic improvement in tree survival from less than 50% to more than 95%. This improved survival, coupled with better tree form through tree breeding, has seen the initial planting densities decrease from 2 500 trees/ha (and sometimes greater) to 800-1 000 trees/ha today. Rotation ages have also decreased from 50 years to current levels of approximately 25-28 years. Most areas of Kaingaroa Forest are on their third rotation of radiata pine, with some areas entering their fourth rotation. In other parts of the world, concerns have been expressed about multi-rotation productivity declines. There is a large network of permanent growth sample plots in Kaingaroa Forest, including approximately 80 which have been re-established at the same location as a plot from the previous rotation. Data from these plots clearly show that productivity has increased from rotation to rotation, however close attention is paid to soil nutrient levels (and more recently to levels of biological activity) to ensure that gains in productivity from tree breeding and management are not masking decreases in soil properties.

From 1987 onwards, the New Zealand Forest Service was disestablished as part of a programme of government asset sales. In many cases only the trees were sold, with the land underneath them used to settle Treaty of Waitangi claims by Māori. Kaingaroa Forest was one of the last of the Forest Service assets to be sold. Prior to this, it was managed as a state-owned corporation (Forestry Corporation). In 1996, it was finally sold to a consortium led by Fletcher Challenge. This consortium managed the forest under the Fletcher Challenge Forests name, until it went bankrupt in 2004. The forest was bought from the receivers by the Harvard Endowment Fund in 2004 and Timberlands was established to manage the forest on behalf of the new owners. Harvard has sold its shares, and the forest is now owned by the New Zealand Superannuation Fund, the Public Sector Pension Investment Board (from Canada) and Kakano (a group of central North Island iwi whose land the forest sits on). Kaingaroa Forest is approximately 160 000 ha in area and makes up the majority of the Kaingaroa Timberlands estate which has a total net stocked forest area of 190 000 ha. This scale makes it one of the largest, if not the largest land-based businesses in New Zealand. Approximately 15% of the total volume of wood harvested in New Zealand each year comes from the Kaingaroa Timberlands estate. Most of this wood is sold to domestic customers in Bay of Plenty and the central North Island, creating an economic benefit of hundreds of millions of dollars each year and providing direct and indirect employment to thousands.

KANG 1200 – 102-year-old stand

This is the oldest remaining stand in Kaingaroa Forest. It was planted in 1922 and for various reasons it has not been harvested even though surrounding stands have been felled. In recent years it has received quite a lot of attention (Figure 4), including visits by the previous Minister of Forestry. Much of this interest has stemmed from the debate around the use of radiata pine for carbon forestry and the fate of older stands. Most of this centres on the fate of the radiata pine trees as radiata pine is not a late successional species and the development of the understory beneath a canopy of radiata pine.

Figure 4. Recent visit by a delegation from Scion and New Zealand Carbon Farming to KANG 1200.

The stand contains a permanent growth sample plot that was installed in 2003. It has been measured several times since then, most recently in 2024. It has also had LiDAR data captured from it (Figure 5). The stand has a relatively low tree density (123 trees/ha) and a total volume of almost 1400 m^3/ha. A typical radiata pine stand being harvested today would have total volume of approximately 650 m^3/ha and a tree density of approximately 325 trees/ha (more recently planted stands typically have a higher density than this), giving a average volume per tree of approximately 2 m^3. By contrast, the average tree size in KANG 1200, is 11.3 m^3 with the largest trees being almost 20 m^3 (Figure 6).

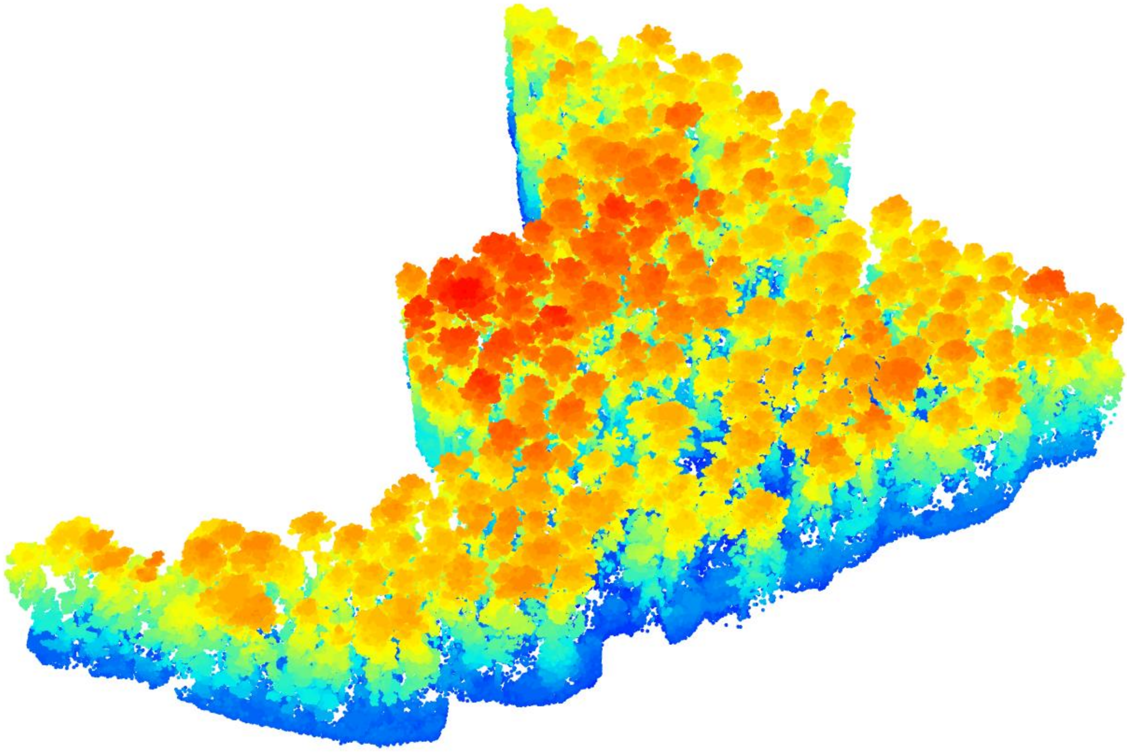


Figure 5. Canopy height model derived from the 2017 LiDAR campaign showing the individual tree crowns.

Figure 6. Measurement of a tree in the permanent sample plot (left) and one of the largest trees in the stand (right).

STOP 2 Murupara log loading and forest harvesting – (drive by view from bus)

Timberlands harvests approximately 4.8 million m^3 of trees each year. Laid end to end, these trees would circle the world twice! This wood is harvested by 33 crews who are independent businesses contracting to Timberlands. All the crews are fully mechanised which has improved worker safety and crew production. The pumice soils that underly Kaingaroa Forest enable harvesting to occur all year round, although some harvest areas are reserved for the summer when soils are drier. The porous nature of the pumice soils also means that compaction from harvesting is less of an issue compared to forests on different soil types. Minimising soil disturbance (including the forest floor) from harvesting, included associated roading and tracking, is a key focus for Timberlands. Harvesting residues are not burned (which was the practice 50-60 years ago) but are raked into lines facilitate planting and to ensure that nutrients and carbon remain on site.

Logistics and supply chain management are major components of Timberlands' business. The growing cycle of a forest is approximately 25 years (closer to 40 years if you include tree breeding), but most of the value realisation decisions happen in the last two weeks of this cycle. Timberlands conducts inventory programmes to describe the forest resource (volumes by log grade), runs a mathematical model to determine the optimum age to harvest a stand, matches available log supply with customer demand, schedules the order in which stands are harvested, the optimal product mix for an individual stand and the movement of logs from the forest to customers. Onboard computers help the processor (machine that cuts logs into stems) operator to optimise the value from each stem by ensuring that highest value logs are cut from it and these logs are within specification.

Figure 7. Oversize truck carrying whole tree stems destined for the KPP.

Timberlands harvesting operations differ from those of other companies in New Zealand. It has a centralised processing facility located next to Kaingaroa Village, which is known as the Kaingaroa Processing Plant (KPP). The KPP receives whole stems (up to 28 m; Figure 7) and runs an optimising algorithm over these stems (once they've been scanned) to maximise the value recovered from them. This requires the transport of large stems from harvesting operations to the KPP and logs from the KPP to customers. Approximately one-third (1.7 million m^3) of wood produced from the Kaingaroa Timberlands estate is processed through the KPP. Most (65-70%) of the wood produced from the Kaingaroa Timberlands estate is sold to domestic customers, who are mostly located within 60-100 km of the forest (with a few exceptions). These customers produce the majority of New Zealand's structural timber, packaging materials, toilet paper and roundwood for fencing and construction.

Most of the 30-35% of logs that are exported are handled by the Murupara Log Yard (MLY). This equates to around 25% of the total production from the Kaingaroa Timberlands estate. The MLY has a rail line that runs to the Port of Tauranga enabling logs to be delivered to the port without being transported by truck. Each train transports approximately 950-1000 m^3 of logs, with six trains running per day, seven days a week. The 42,000 m^3 of logs transported by rail each week avoids approximately 1400 truck trips to the Port of Tauranga each week. The recent installation of a debarking facility at MLY (Figure 8) is in response to export customer requirements and to aid in the reduction in the use of methyl bromide (which is used as a fumigant to control insects and pathogens from being exported).

Figure 8. Logs exiting the de-barker at the MLY with rail wagons being loaded in the background.

STOP 3 - Pumice soil profile on corner of Waihu and Low Level roads

Please see Pumice Soil Chapter of Hewitt et al, (2021, copy supplied to fieldtrip participants) for more detailed information about Pumice Soils.

Pumice soils are considered one of the inherent advantages of Kaingaroa Forest. Not only do their free draining nature enable operations to happen all year round, but radiata pine tree roots can extend deep into the soil which enables the trees to extract nutrients and moisture from underlying paleosols (Figure 9).

Figure 9. Immature Orthic Pumice Soil near Lake Rotoma where P. radiata roots with fungal hyphae extend 3 m deep (Garrett *et al.*, 2021).

At this site there is a relatively thin (approx. 1 m) mantling of materials deposited from the AD 232 Taupo eruption over a small hill, exposed in a road cutting (figure 10). In contrast in some of the drainage pits along the roadsides you will see thicker layers of Taupo Pumice.

W.A. Pullar, one of the key people who worked out the tephra-stratigraphy of the Central North Island, by careful hand-over-hand mapping, described this site (Pullar 1980) as well as mapping the depth and thicknesses of all the visible tephra layers through the Kaingaroa Plateau. Working from the oldest to youngest deposits:

The lower part of the cutting is a welded Rangitaiki ignimbrite (Pullar, 1980) which Grindley (1960) mapped as underlying much of the northeastern part of the Kaingaroa Plateau. There is a distinct, sharp boundary (unconformity) between the

ignimbrite and the overlying tephra suggesting severe erosion during the last glaciation.
Above the ignimbrite are two distinct paleosols with underlying B horizons, each about 60 – 80 cm thick. Both these units comprise multiple tephras (Figures 10 and 11).

The top meter or so of the profile comprises the multiple units of the Taupo pumice eruption. See Hewitt *et al*., Section 12.2.3 for a detailed description of the Taupo eruption and its products. At this site we see the major pyroclastic fall deposits of the Taupo Ignimbrite (comprising 6 phases Y1-Y6, Fig 12.5 of Hewitt *et al.,* 2021). Notable towards the bottom of the Y6 pumice lapilli layer is a dense sandy loam layer which is a limitation to penetration of pine roots and has been managed by deep ripping at many sites in the forest. The disturbance in preparing for replanting breaks up this layer and mixes the upper pumice with some of the finer underlying material to make a bed that is more conducive to pine tree survival with no impermeable layers and a higher water holding capacity.

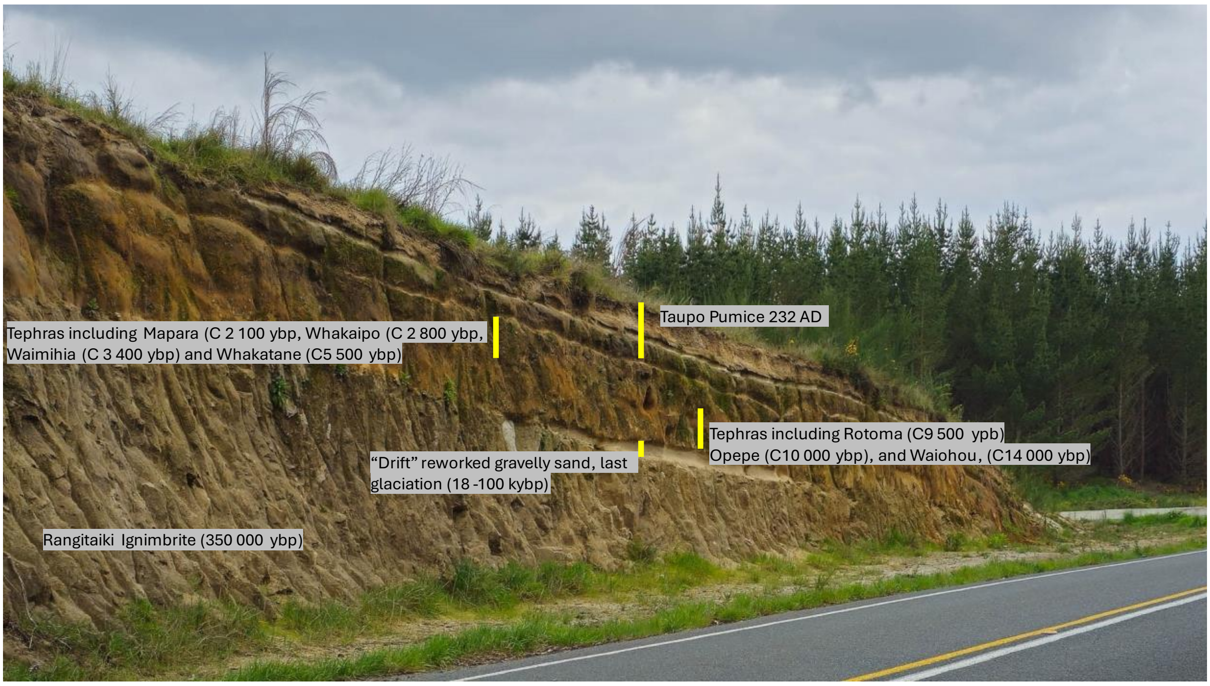


Figure 10 Profile at corner of Low Level and Waihu roads.

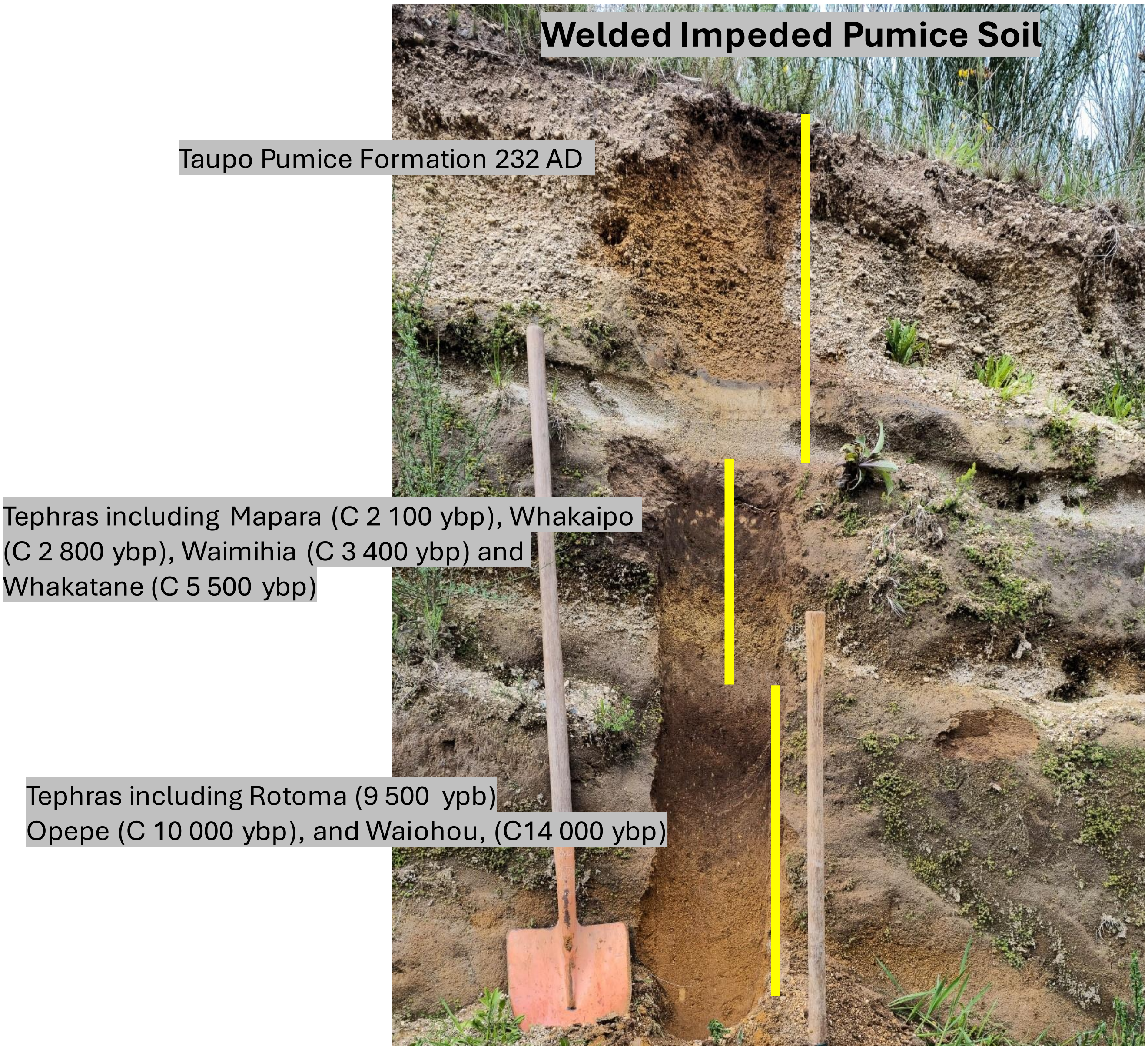


Figure 11 Soil profile at corner of Low Level and Waihu roads (Tephras after Pullar 1980, dates from Lowe *et al.,* 2013)

The sources of the tephras are (Pullar 1980): Rangitaiki ignimbrite – Okataina (east of Lake Rotorua), Waiohou - Taupo, Opepe - Taupo, Rotoma - Okataina, Whakatane – Okataina (Mt Tarawera), Waimihia – east of Lake Taupo, Whakaipo - Taupo, Mapara - Taupo, and Taupo – north end of Lake Taupo.

STOP 4 – Forest re-establishment/nutrition

Each year, approximately 7000 ha of stands are harvested across the Kaingaroa Timberlands estate, which means that the same area is re-established. Most of the Kaingaroa Timberlands estate is on its third rotation with some areas going into their fourth rotation. Forest establishment is a critical operation for Timberlands as future success (or otherwise) depends on the outcome of this operation. The key aspects of forest establishment are:

- Site preparation
- Planting
- Control of competing vegetation

Site preparation practices have evolved and changed significantly in the past 100 years. These changes have been built on the back of research and operational experience. As the forest transitions from one rotation to the next, the importance of managing nutrients between rotations has been highlighted by the long-term trials that Scion has undertaken (see notes on the impact of harvest residue removal on soil). Root raking, piling of debris and burning have been replaced with careful slash raking that aims to only move enough material to facilitate planting of the next generation of trees. There is no longer any burning of slash piles. Because the majority of Kaingaroa Forest has flat to rolling terrain, spot cultivation (ripping and mounding) is required to mitigate the risk of frost risk and also to break through the pan that occurs on many sites (a large proportion of soils in Kaingaroa Forest are classified as welded impeded pumice soils – MIW). Without this cultivation, vertical root development would be limited which would compromise growth and tree stability. Creating a mound that is 40-50 cm above the surrounding ground is sufficient to raise the minimum temperature by 1-2 °C which is enough to prevent wide-scale mortality from frost. Approximately 3 000 ha of terrain are spot mounded each year. This operation is done using an excavator with a specially designed ripping and mounding head (Figure 12). Site preparation is typically done at least three months prior to planting to give the mounds time to consolidate. Research trials have been undertaken to compare the current practice of spot cultivation with an alternative which is line ripping and mounding. These trials have consistently shown that survival and early growth is better under line ripping and mounding, which is also cheaper than the current practice. The challenge with line ripping and mounding is the stump configuration from the previous rotation and Timberlands is working to find ways to overcome this challenge, so that it can operationalise this new method.

Figure 12. Excavator with a ripping and mounding head being used to prepare a site for planting.

The basic method for planting a tree has not changed in 100 years. Planting in the Kaingaroa Timberlands is done by contractors using a planting spade to cultivate the site before planting the tree. What has changed are the systems for growing trees in the nursery, stock handling practices, education and supervision. Timberlands grows almost all its own tree stocks. It has a nursery at Te Ngae (near Rotorua Airport) producing bare rooted and containerised stock and is developing a new nursery at Rerewhakaaitu that will initially produce bare rooted stock but with the potential to be expanded to produce containerised stock as well. Initial planting densities have been more than halved since forests were first established on the Kaingaroa Plateau. Today, stands are either established at a density of 800 trees/ha (milder sites) or 1000 stems/ha (harsher sites). The planting season runs from early May through to late September/early October with somewhere between 7 and 8 million trees planted.

Most of the stock are from vegetative cuttings, which radiata pine is ideally suited to producing. Planting stock are lifted in the nursery, graded, packed in boxes and transported to the planting site in special pods that are designed to keep the stock in good condition prior to planting. Both the planting boxes and pods are white to reflect the sun and to stop the stock heating up and drying out. Stock deliveries are timed to provide sufficient stock for the crews but to avoid having stock sit on site for too long. Planting techniques have been refined to minimise root disturbance at planting while ensuring that the tree is planted to the correct depth. Training and supervision are carried out to ensure that this happens. The consequences of poor planting can be toppling, lean or tree death. A typical planter can plant between 1200-1600 trees per day. Higher productivity is discouraged as quality is usually sacrificed to achieve this. Fertiliser (10 g of Osmocote) is only applied at establishment on the harsher sites. In recent years, mechanised planting has been investigated. Two M-Planter machines were imported from Finland and Timberlands worked with one of its land preparation contractors to modify the machine for use in New Zealand conditions and to operate it (Figure 13). The trials have shown that the benefit of the M-Planter is its ability to simultaneously do land preparation and planting, with productivity levels similar to that of a spot mounding machine. It can also be modified to apply other treatments at planting such as water, fertiliser and hydrogels. If it was simply used as a planting machine, it would have lower productivity than a person with a spade and a considerably higher operating cost.

Figure 13. M-Planter machine operated by HA Fear Ltd. The machine head consists of a spot mounding implement and planting tube. The carousel holding the trees is visible on top of the planting head.

Control of competing vegetation is also critical for establishment success. Not only do weeds compete with newly planted trees, but weeds insulate the soil preventing it from capturing heat energy from the sun during the day and re-radiating this at night. Therefore, good weed control is important for reducing the risk of frost damage. Timberlands typically conducts three weed control operations in a stand. The first is a pre-plant spray to kill any existing weeds and a pre-emergence treatment to kill any weeds that germinate subsequently. Following planting, up to two releasing treatments are done, the exact nature of which depends on the weed species present and their abundance. The most common weed species in the Kaingaroa Timberlands estate are gorse, broom, Yorkshire fog, Himalayan blackberry, and fleabane. All weed control operations are done aerially using a helicopter, with GPS tracking of flightlines. The contractor uses dispersion modelling software coupled with on-the-ground information on wind speed and direction to minimise the risk of spray drift into non target areas. Buffers are placed around sensitive areas such as streams and wetlands. Timberlands is actively working to ensure that only the minimum amount of the active ingredients necessary to achieve acceptable levels of weed control are used.

Fertiliser is currently only applied to small areas of the forest. Timberlands, like most forest managers historically only applied fertiliser to correct chronic nutrient deficiencies. The main element added was boron, due to the link between boron deficiency and poor tree form. Each year, Timberlands conducts a foliage sampling programme in four-year-old stands to determine foliar boron levels along with levels of other key nutrients for tree growth, such as N, P and K. Stands with inadequate levels of boron receive a boron fertiliser treatment to correct this. The data were also used to identify stands with low levels of nitrogen, but adequate P as candidates to receive urea fertiliser. A small programme was run each year, provided that the cost of urea and its application did not exceed a cost threshold. Many of the areas where urea was applied had growth monitoring plots installed in them along with plots in untreated control areas. Analysis of data from these plots showed that results were mixed, with some treated areas showing a positive response compared to the control, while others showed no response or even a negative response. Since 2018, Timberlands has worked with Scion to develop and test different approaches to forest nutrition. The research has focussed on developing the “optimum” blend of N, P and K and to test this blend at different rates. Large plot (2.4 ha treatment areas) trials were installed at three sites across the forest. The NPK blend was applied to plots in these fully replicated trials at the following rates of N: 0, 75, 150, 300 and 450 kg N ha^{-1}. Lysimeters were installed in selected treatments in two of these trials to monitor N leaching. Permanent growth sample plots were installed to monitor tree growth. Data from these trials showed that relative to the untreated controls, the treated areas were growing substantially faster for the equivalent level of growing stock. In particular, the areas that had received the fertiliser blend at rates of 300 kg N ha^{-1} and 450 kg N ha^{-1}, were growing 25 to 50% faster than the untreated controls (Figure 14). Data from the lysimeters showed that even at the highest rates of fertiliser application, nitrogen leaching was low (below 1 kg N ha^{-1} yr^{-1}). These trials are continuing to be monitored and at the same time Timberlands has started operational pilot trials to quantify the gains that can be achieved when applying the blend at a rate corresponding to 190 kg N ha^{-1} under operational conditions. In these trials, Timberlands has targeted stands in the 4–7 year age range as the research from Scion has shown that this corresponds to the peak difference between N demand from the trees and N supply from the soil. This is a departure from previous practice which targeted 10-12 year-old stands at the time of thinning.

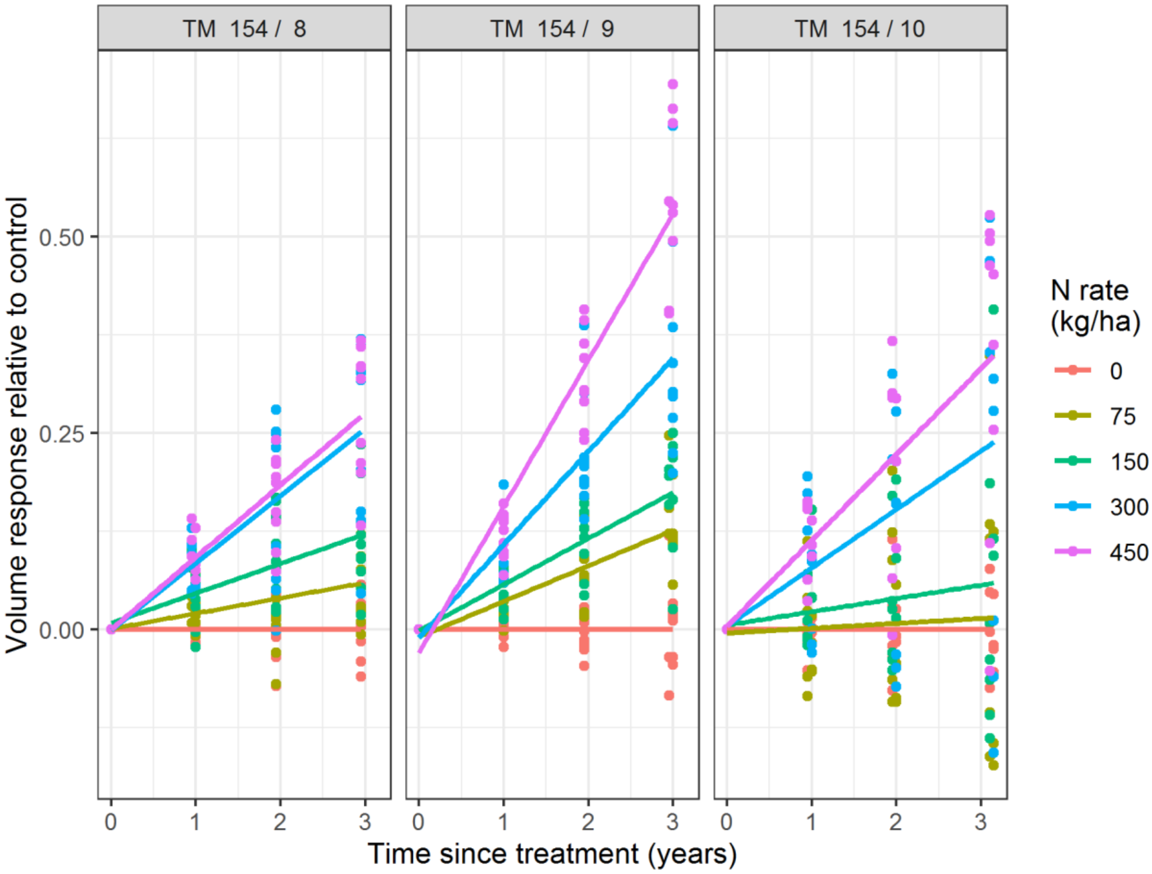


Figure 14. Growth response during the first three years after fertiliser application in the balanced nutrition trials developed by Scion and Timberlands. Each panel represents an individual trial installation and the response is the proportional increase in growth relative to the untreated control.

Harvest residue removal impacts on soil – important lessons

Adapted from: Garrett, et al. (2021).

1. *What biomass is removed from what site matters*

Different forest biomass components (stem, crown, roots, forest floor and weeds) hold varying amounts of nutrients (Figure 15). With targeted biomass extraction it is important to understand how much nutrients are being removed and what percent of the forest nutrient pool the biomass pool represents.

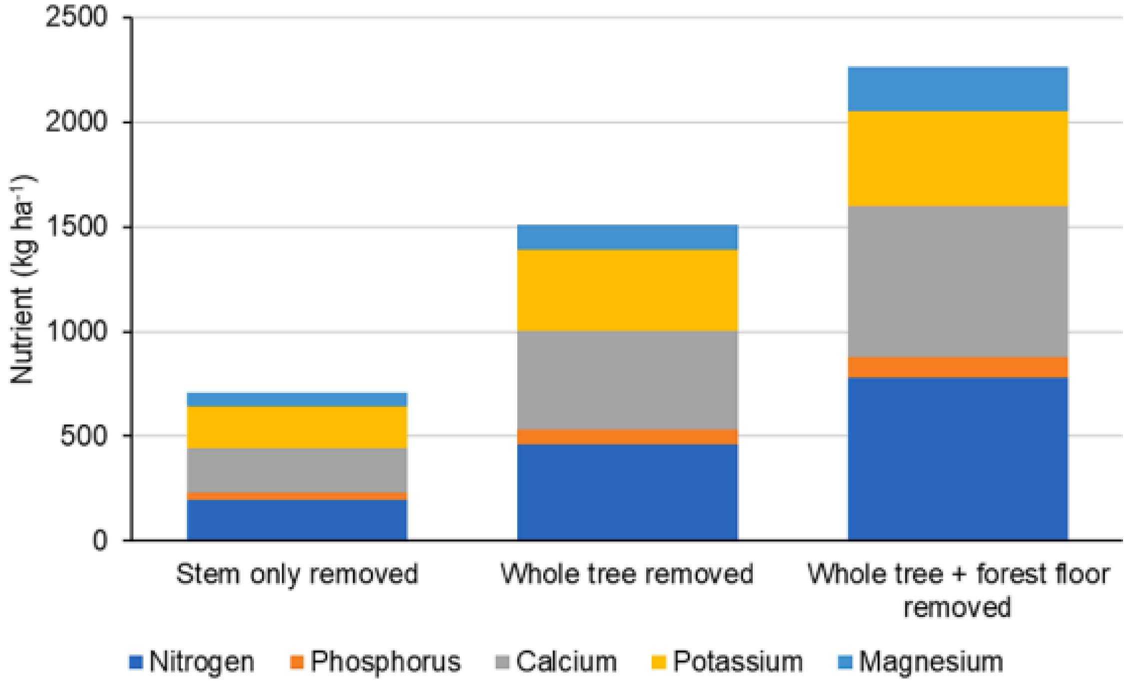


Figure 15. Nutrient export with three different harvest residue and forest floor removal methods, stem only, whole tree removal, and whole tree plus forst floor (Garrett *et al*., 2019)

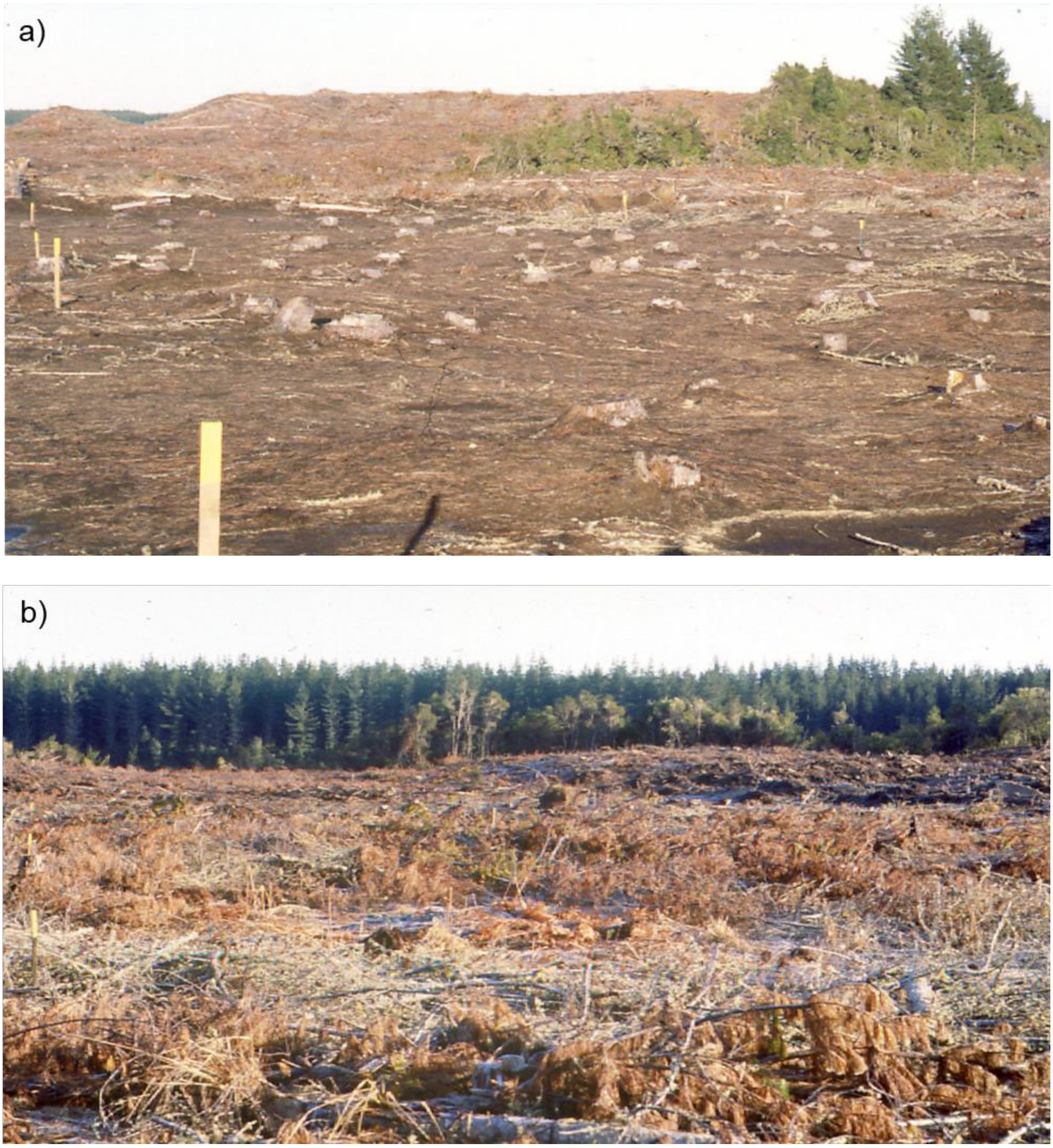


Figure 16: LTSP treatments a) whole tree plus forest floor and b) stem only removal.

2. *Low nutrient sites are vulnerable to biomass removal*

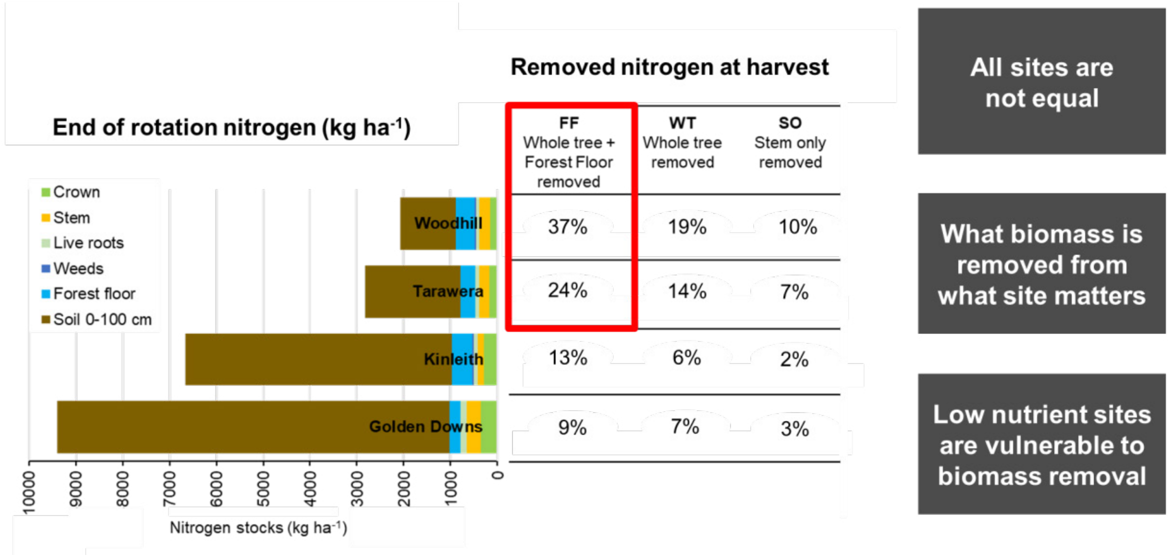


Figure 17: Nitrogen distribution in planted forest biomass and soil and impact of harvest residue removal on nitrogen stocks

3. *Site specific management matters*

Site-specific nutrient management planning for sustainable and productive planted forests matters (Figure 18).

When is the greatest nutrient demand for a planted radiata forest?

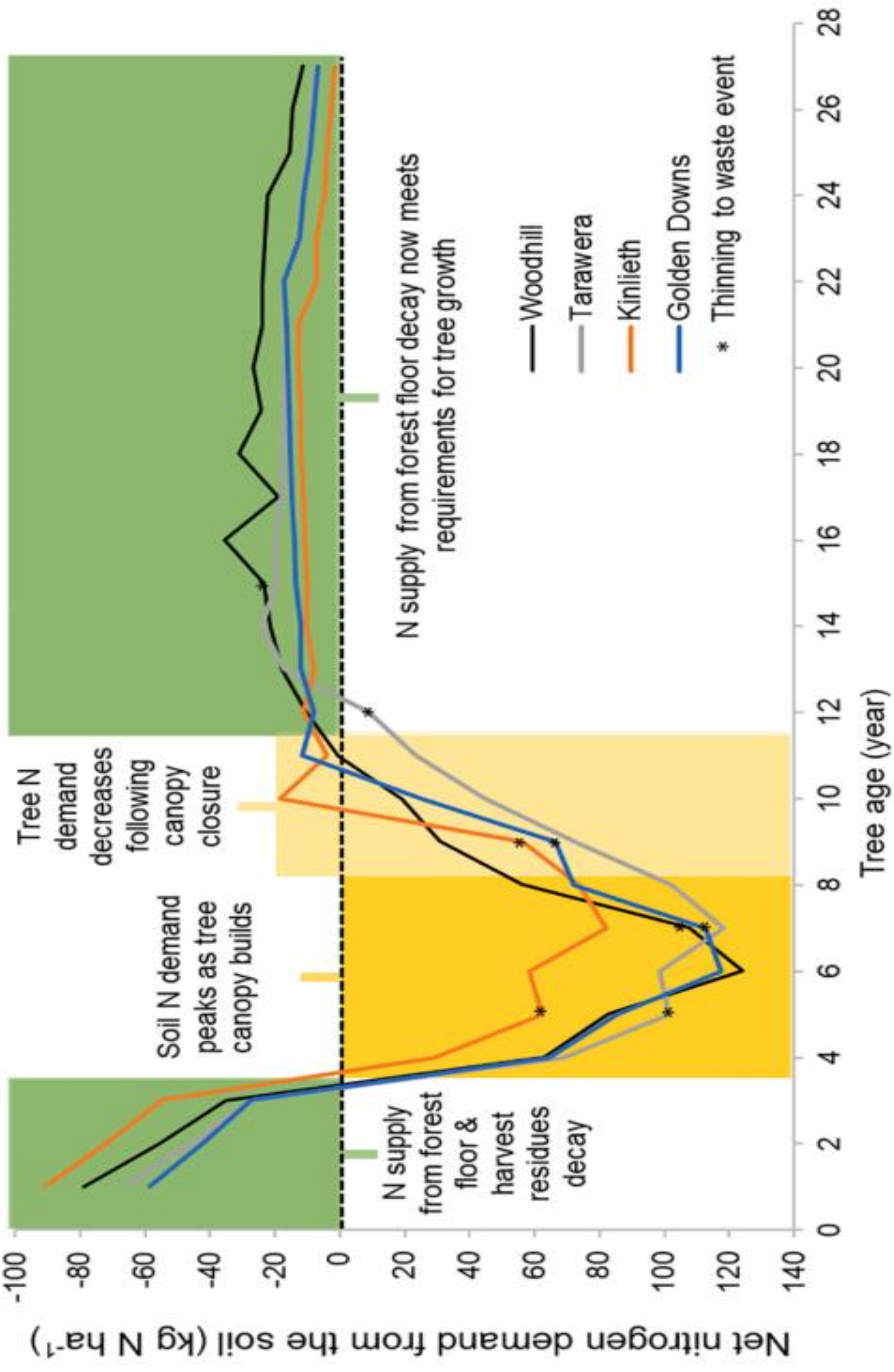


Figure 18 Forest stand annual net nitrogen demand from the soil to grow the live biomass and forest floor as predicted using the nutrient balance model (Smaill et al., 2011) for stem only harvest and no fertiliser addition at Woodhill, Tarawera, Kinleith and Golden Downs LTSP trial sites.

Improving the soil for multi-rotation sustainable production – Accelerator trials

Adapted from:
Smaill et al 2023. Data in Brief, 47 108991.

The Accelerator trials (Figure 19) represent an ambitious research goal that will take planted forest productivity to a new level of enhanced long-term forest productivity without compromising the sustainable management of future forests.

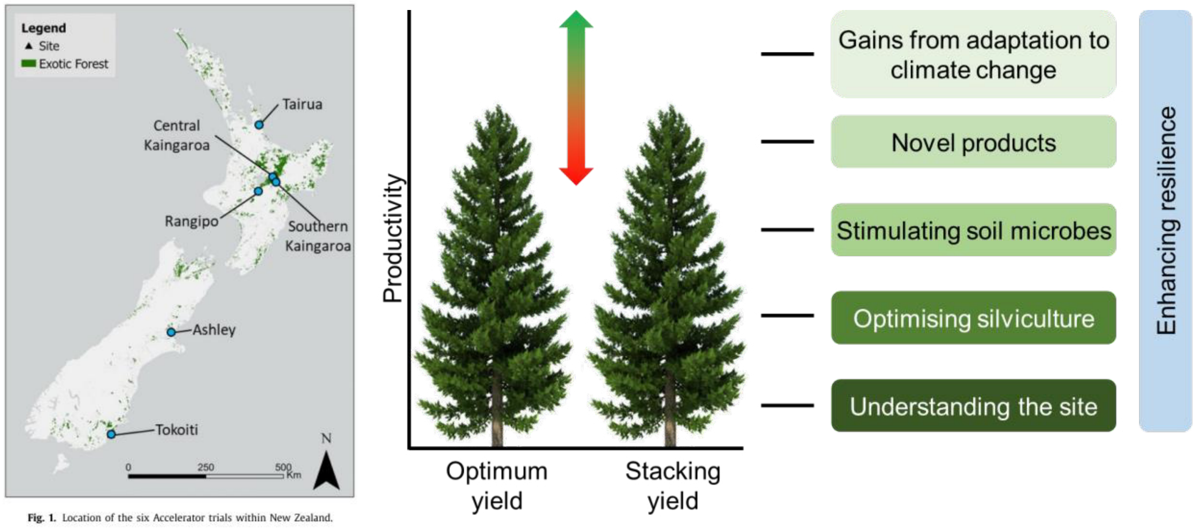


Fig. 1. Location of the six Accelerator trials within New Zealand.

Figure 19 Accelerator trials

Nutrient leaching from forests

Adapted from:
Davis et al., 2012; *Forest Ecology and Management*, *280*(0), 20-30
Davis, M. (2014). *New Zealand Journal of Forestry Science*, *44:2*.

Nitrogen leaching losses in planted forests are low. Figure 20 is from stream water from a planted forest catchment. The past land use was a productive farm – fertile soil.

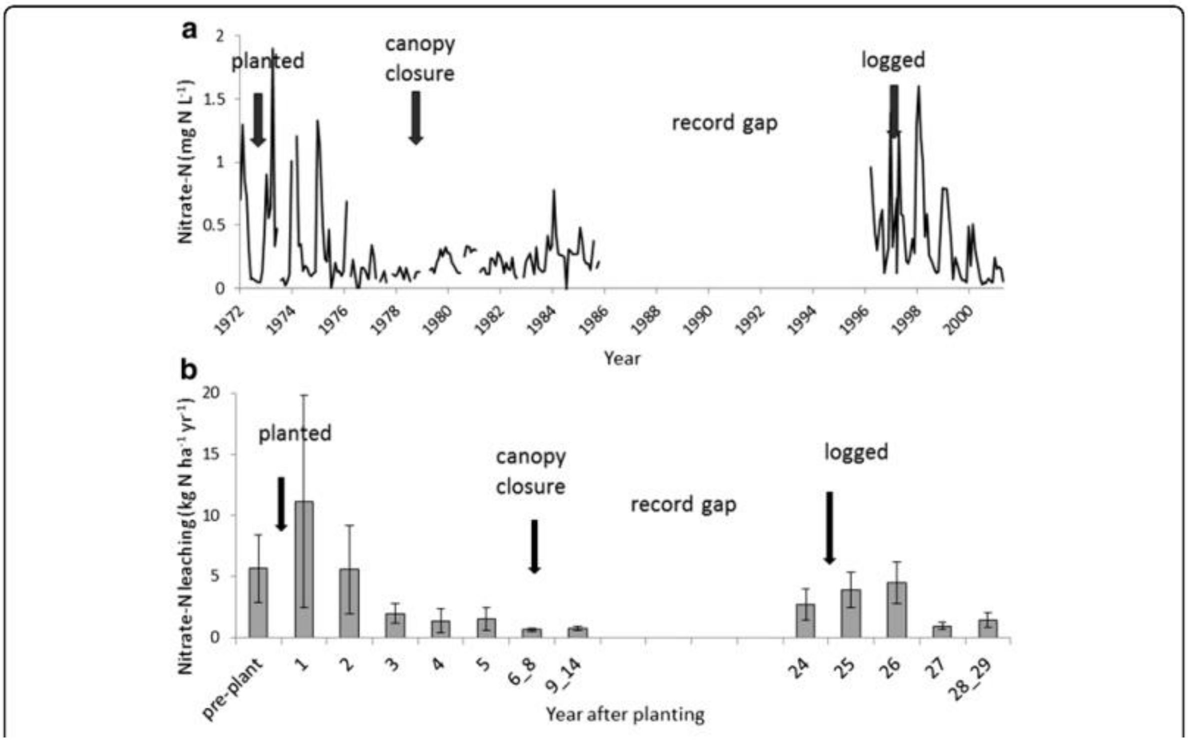


Figure 20 Long term variation in (a) nitrate concentrations and (b) leaching losses in stream flow from Puruki catchment of pasture before radiata pine planting, through tree planting, growth and logging to regrowth of the second crop. Monthly data. Bars show standard errors. After Quinn and Ritter 2003.

Nitrogen fertiliser application to 7–9 year-old *P. radiata* stands at an application rate of 200 kg ha^{-1} of N increased nitrate-N leaching at eight of the 10 study sites from between 0 and 15 kg ha^{-1} (average 6.4 kg ha^{-1} or 3.2% of the N applied) in the 2 years following fertilisation (Table 1).

Table 1:

Potential nitrate-N leaching (kg ha^{-1}) from the root zone of control and N fertilised plots after fertiliser was applied and the period (months) over which potential leaching was measured. Values in the difference column indicate the total amount of nitrate-N potentially leached from a single application of urea (200 kg ha^{-1} of N) except for sites 1, 2 and 4 where N fertiliser enhanced leaching of nitrate-N had not ceased 2 years after the fertiliser was applied.

Site	1	2	3	4	5	6	7	8	9	10
Control	43.2	1.5	1	0.4	0.3	5.8	0.3	2.7	0.1	0.8
Fertilised	54.7	29.9	2.7	12.5	0.2	96.6	15.5	2.9	0.3	11.1
Difference	11.5	28.4	1.7	12.1	-0.1	90.8	15.2	0.2	0.2	10.3
Period	24	24	20	24	24	10	22	22	17	19

Table: soil order, texture and land use prior to pine plantation

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Soil order	Pumice	Podzol	Recent	Allophanic	Allophanic	Brown	Pallic	Brown	Brown	Brown
Soil texture	Sandy loam	Loamy sand	Gravelly sand	Loamy silt	Sandy loam	Sand	Silt loam	Stony sandy loam	Stony silt loam	Clay loam
Land use prior to pine plantation	Fertilised pasture	Indigenous forest	Indigenous shrubland	Reverting grassland	Indigenous grassland	Fertilised pasture	Reverting grassland	Indigenous shrubland	Reverting grassland	Reverting grassland
			Kaingaroa Forest							

Deep soil carbon

Adapted from:
Oliver et al., 2004, Garrett et al submitted, Garrett et al., 2024.

Forests are carbon (C) rich ecosystems. Soil C underpins forest productivity, resilience and the resulting forest plant biomass which alone comprises over 80% of the world's terrestrial biomass carbon (Figures 21, 22 and 23). Soil organic carbon can be found to depth and can be a substantial amount (Table 2).

Table 2:

Mineral soil C content and variance with cumulative depth (0–3.0 m) of the <2 mm soil fraction in second rotation pine plantations and pasture land adjacent to Kaingaroa

Soil depth (m)	Number of pits[a]	C content (<2 mm) (Mg ha^{-1})				Number of pits required to detect percentage difference in C content		
		Pine	Pasture	Difference	S.E.[b]	10%	20%	50%
Kaingaroa								
0–0.1	5/5	22.6	42.2	−19.6*	5.9	65	18	4
0–0.5	5/5	53.2	79.8	−26.6	11.7	61	17	4
0–1.0	5/5	62.4	91.6	−29.2	13.3	59	16	4
0–2.0	5/5	78.2	120.3	−42.1*	17.4	61	17	4
0–3.0	5/5	161.7	213.9	−52.2	41.2			
0–base	5/5	198.6	256.9	−58.3*	18.9			

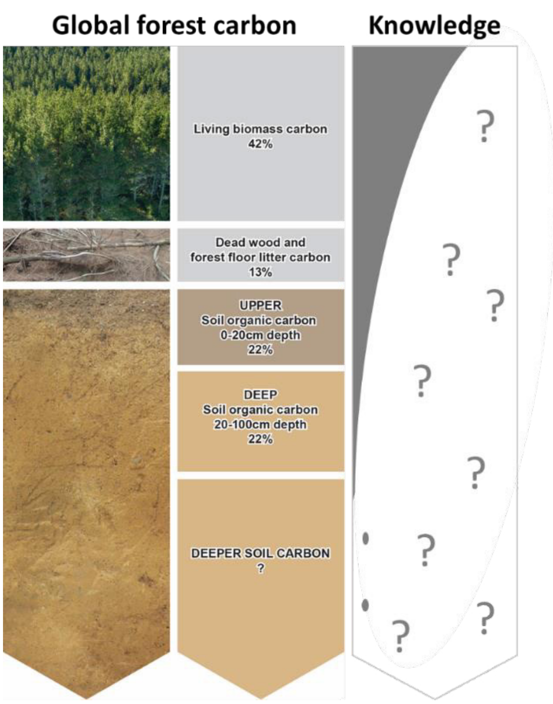


Figure 21 Global Forest soil carbon knowledge.

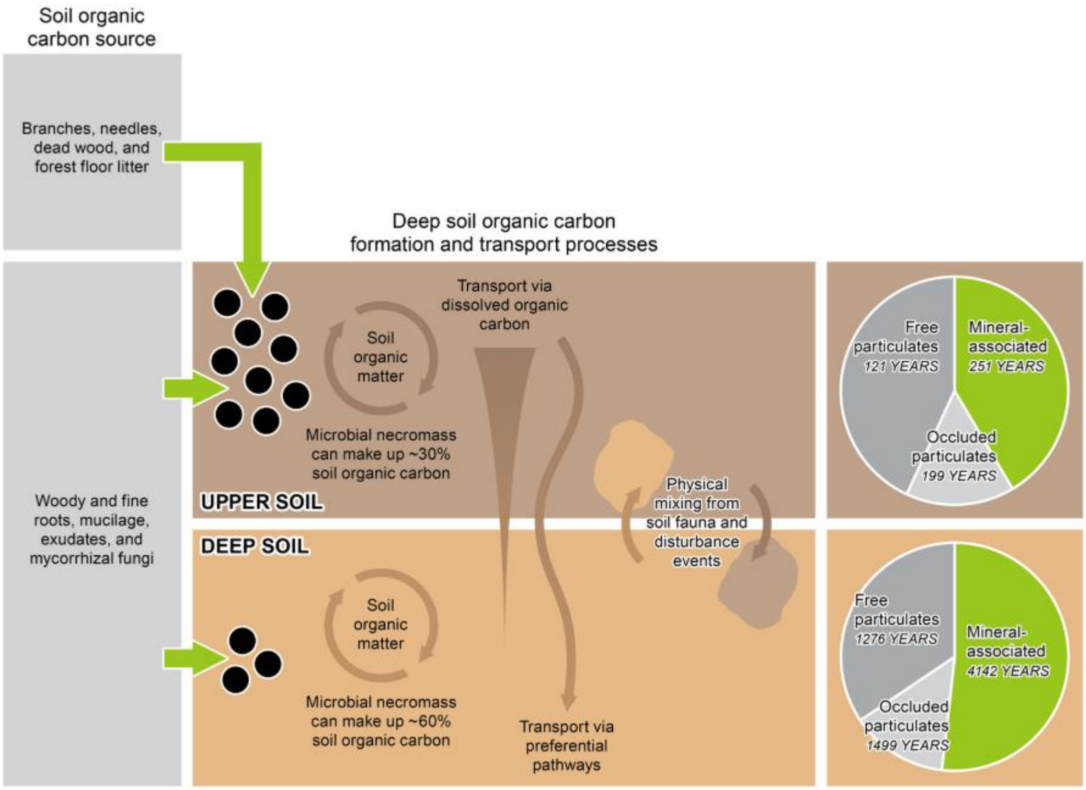


Figure 22. Generalised forest systems deep-SOC source, SOC formation and transport processes and resulting SOC fraction pools, their dominance and turnover time compared to upper soil.

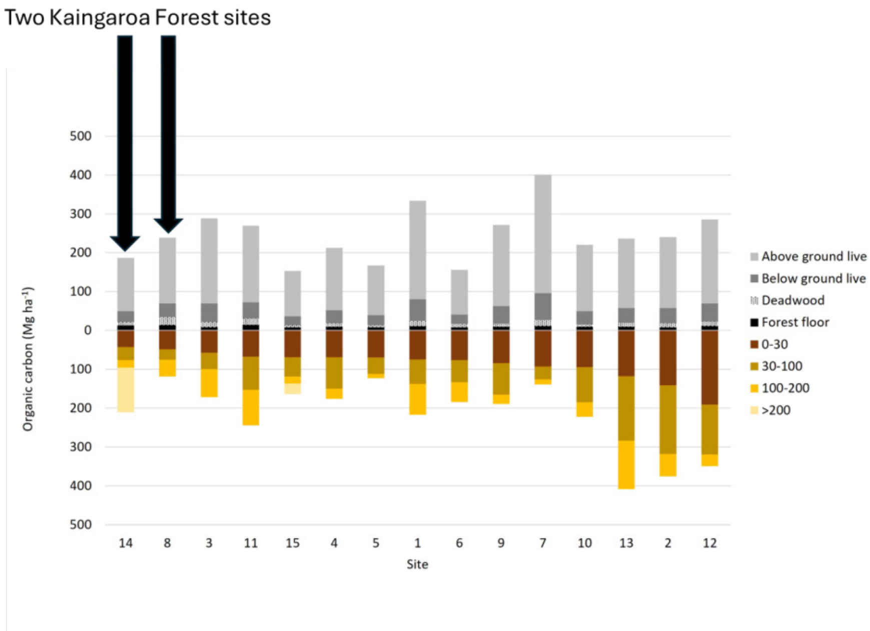


Figure 23: Forest carbon stocks for above ground live (tree crown and stem), below ground live, forest floor, and deadwood (decayed stem and roots), and mineral soil organic carbon stocks (<2 mm + >2 mm soil fractions).

STOP 5 – Alternative species site (eucalypts)

Radiata pine is the main species grown in the Kaingaroa Timberlands estate and across the entire New Zealand plantation forest estate. This is no accident, as the species grows well on a wide range of sites, produces wood that is suitable for a wide range of end uses (although not necessarily great for all of these) and has been the subject of over 70 years of breeding and improvement to the point where it has effectively been domesticated.

However, this heavy reliance on radiata pine represents a substantial concentration risk. There are also characteristics that are not well served by radiata pine (e.g. natural durability, strength, and stiffness) that could potentially be better met by other species. Therefore, Timberlands has an active programme to investigate the potential of species other than radiata pine. Much of the focus of this programme is on eucalyptus species, with the following broad objectives:

- Ensure there is a supply of best genetic material.
- Determine site suitability for different species.
- Determine best silvicultural regimes for the different species.
- Collect information on growth and yield.
- Understand risks to these species from biotic and abiotic agents.
- Quantify wood properties and link these to end product requirements.

The two stands in KANG 333 address several of these objectives. There are two species planted here and the field trip stop is at the boundary between them which enables you to compare differences. The first is *Eucalyptus regnans* and the second is *Eucalyptus fastigata*. Both are monocalyptus species belonging to the ash group. They are generally considered healthy and are not susceptible to insect attacks in the way that other species, notably *Eucalyptus nitens*, are. These stands contain material from a Scion progeny trial. The *Eucalyptus regnans* has material from second generation selections, while the *Eucalyptus fastigata* (Figure 24) has material from third generation selections from a previous stand in Kaingaroa Forest. Both stands were established in 2009 and were thinned last year to remove material with lower genetic worth. This has effectively converted them into seed stands. Wood quality assessments were done on some of the material that was removed. Permanent growth sample plots have been installed in both stands to provide data on growth and yield. The most recent measurement data from 2024 (at age 14.5 years) showed that the *Eucalyptus regnans* was 31-34 m tall and had a mean annual volume increment between 24 and 35 m^3/ha/yr. The *Eucalyptus fastigata* is growing at slightly slower rate with a mean top height of 28-38 m and a mean annual volume increment of 17-21 m3/ha/yr. The growth rates were higher than this before the stands were thinned to convert them to seed stands. These growth rates are considerably higher than those of radiata pine on an equivalent site. Timberlands is currently planting 75-100 ha of eucalyptus stands each year to test this species.

Figure 24. Eucalyptus fastigata stand in KANG 333 in 2020. The poorer genetic quality trees have now been removed to create a seed stand.

6 Photo stop at boiling mud near Waiotapu (if time allows)

The boiling mud here is an "acid steam feature" powered by geothermal heat. Groundwater is heated to steam deep beneath the ground surface. The steam rises through the ground, interacting with the earth materials. The mud is generally about 60°C and the steam 100 °C. The form of the boiling mud varies depending on the moisture content. The acids are derived from sulphur and CO_2 dissolved in the water. The combination of water, heat, and acidity makes the steam highly reactive, dissolving and precipitating out minerals, and altering the materials that it moves through to a variety of clays.

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Hazard Management: Australia/NZ Soil Science Conference 2024 Fieldtrip

Date: 3 December 2024. **Field Trip Leaders:** Megan Balks/Michael Wilson

First Aid: An appropriate first aid kit will be carried on the bus. Timberlands Staff have 1st aid training.

F/T Supervisor Mobile Phone: Megan Balks 021 025 84628. Michael Wilson (Timberlands) 0274 664013

Other Contributor's Mobile phone(s): Loretta Garett 027 296 7786 On Cue: Lea Boodee 021 117 0916

Emergency contacts: Dial 111. On Cue Conference organiser: Lea Boodee 021 117 0916
Location and Route: Kaingaroa Forest, Waiotapu Boiling mud site
Transport arrangements: Commercial bus: departs/returns to Rotorua Energy Events Centre
Departure Time: 8 am **Return Time:** approx 5.30 pm at Rotorua Events Centre
Emergency Plan: Staff ensure site safety – traffic direction - then provide first aid and seek emergency help - police, fire, ambulance call 111.

Alcohol and Drugs

"All persons engaged in field activities have a responsibility to ensure that they are not, through the consumption of alcohol or a drug, in a state that may endanger themselves or any other person."

Smoking

No smoking in vehicles or buildings during the field trip and smoking outdoors should be limited to areas where non-smokers are unaffected. Care must be taken to ensure that wild-fires are not started in dry vegetation. Please do not leave cigarette butts in the environment.

Participant Capability

Participants must be physically capable relative to the terrain and conditions likely to be encountered. Those with a medical condition which may require special consideration must inform the trip leader. It is the responsibility of the participant to ensure the availability of the necessary medication(s). Other individual factors may also compromise safety of the individual or group and should similarly be notified to the organisers before departure. Personal capability may also change during the field trip, such as through exhaustion or injury. Significant loss of capability should be immediately notified to the field trip leader.

Location 1: Kaingaroa Forest	**Time:** Most of trip
Hazards: See page 1 of this guide	
Mitigation: Participants to bring warm, wind and waterproof clothing, strong covered footwear, and sun hat. Retreat to shelter of bus if necessary. Only nominated, suitably fit, people to use digging equipment, others to keep back. Participants to follow instructions of Timberlands Staff. Participants to stay with group, no wandering off unaccompanied. Ensure boots are clean to prevent import of pest plant seeds. Ensure any smoking products are fully extinguished – preferably refrain from smoking.	

Location 2: Waiotapu mudpool	**Time:** varies depending on decisions on the day
Hazard: Cars in carpark, cold, sun, getting separated from tour group, severe burn hazard of falling into acidic boiling mud, fire hazard.	
Mitigation: Participants to remain with group, on formed boardwalk and behind barriers. Wear appropriate clothing, seek shelter in bus if necessary. Preferably no smoking. Watch for other cars and be courteous to other visitors to the site.	

Participant Information

Soil Science Conference Fieldtrip, Mt Tarawera, 2024.

My name:
My mobile phone number:
Emergency contact person (name):
Emergency contact person's relationship to me:
Emergency contact person's phone number:
Special requirements dietary and/or health relevant to this field trip:

I have been advised about the physical and safety requirements and the hazards and their mitigations of this field trip and have been given the opportunity to advise the field trip organisers of any special requirements I have. Under the Privacy Act 1993, I agree to the NZSSS collecting this information for the purposes of ensuring that information necessary for Health & Safety in an emergency is available.

Signed: ________________________

Date: ________________________2021

NOTES

NOTES

New Zealand Society of Soil Science

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