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Thinning of a Planted Kauri (*Agathis australis*) Stand

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EXECUTIVE SUMMARY

A planted kauri (*Agathis australis* (D.Don) Lindl.) forest in the Hunua Ranges was thinned to determine the growth response of residual trees. The aim of the study was to provide data for developing a thinning function. Wood samples were removed and assessed for density and stiffness.

There were two distinct sites within the study area based on topography and growth and performance of planted kauri, a lower 'high river' terrace site and a sloping site located at the base of the foothills of the Hunua Ranges. At age 38 years, kauri on the best site (terrace) had a mean top height of 18.6 m and mean top diameter of 21.9 cm. On the slope site, kauri had a mean top height of 11.9 m and mean top diameter of 15.4 cm. Pre-thinning stand stocking was 4422 stems/ha with mortality at 36%. Thinning reduced stand stocking by 75%, with post-thinning stand stocking of 1055-1070 stems/ha. The average DBH of retained stems post-thinning had increased by 1.4-3.0 cm. Basal area was reduced by 56-65% to 3.7-10.3 m^2/ha. Kauri averaged 440 kg/m^3 for density and 15.6 GPa for stiffness.

The information from this trial will be used to develop a thinning function in the recently developed kauri calculator once a response has been observed, while data will be added to the kauri growth models. The response to thinning in this stand will add to the understanding of the management of this species in planted forests, while the results of wood quality tests support previous studies indicating the suitability of kauri timber from planted forests for production of specialty timber.

INTRODUCTION

Kauri has been planted in New Zealand since the early days of kauri logging. Very little management of the numerous plantings has occurred [1]. A recently completed University of Canterbury Masters study into the development of kauri grown in plantations indicates a real opportunity to grow the species for timber. Models of height growth, basal area and volume production were developed [2]. There is a large information gap relating to the response of planted kauri to management options designed to enhance growth and productivity.

Growth of kauri in planted forests differs significantly from that in natural stands [2]. The average predicted volume from planted kauri forests was 600 m^3/ha at age 50 years, compared to 50 m^3/ha for natural stands at the same age. Where thinning treatments have been applied to highly-stocked, relatively young second-growth natural stands, the delay in growth response to thinning and the long delay in basal area and volume replacement may not be directly applicable to kauri grown in planted forests.

Prior to this current study, only two planted kauri forests are known to have been thinned (both located in the Taranaki region) [3]. In these cases, the thinning operations followed stand health and public safety issues, rather than being designed to develop a timber resource.

The establishment of a thinning trial to identify the response to thinning of kauri grown in planted forests and further identify the potential to manage the species for timber production is seen as an important step in the development of silvicultural treatments for the species. Although older planted forests of kauri exist elsewhere, this stand had the advantage of being planted in plots, which greatly simplified the process of establishing new treatments. These trees have been measured over the past 30-40 years, thus a full picture of early growth and response to thinning could be obtained. Of equal importance is the opportunity to apply continuous cover management concepts to this stand [4]. Thinning was done using continuous cover principles which are intended to induce kauri regeneration. If this succeeds the costs of growing future kauri forests will be greatly reduced.

Objectives

The study had three objectives:

1. to establish a thinning trial from which to identify the response to thinning of a well-established but overstocked planted kauri forest;
2. to apply continuous cover management principles to a planted kauri forest as part of tree selection during the thinning operation; and
3. to assess the wood property traits of density and stiffness of 38-year-old thinned stems.

TRIAL SITE

The thinning trial was located in planted kauri forest on an east facing slope on the edge of the Mangatangi Stream Catchment, Hunua Ranges, approximately 25 km east of Papakura (Figure 1). It was originally established in 1973 to test the effects of fertiliser treatments and planting stock size on growth and survival. At age 38 years, those early treatments were considered to have been subsumed into a relatively homogenous general planted stand. The trial is within a native forest managed by the Auckland Council as a water catchment area for Auckland City.

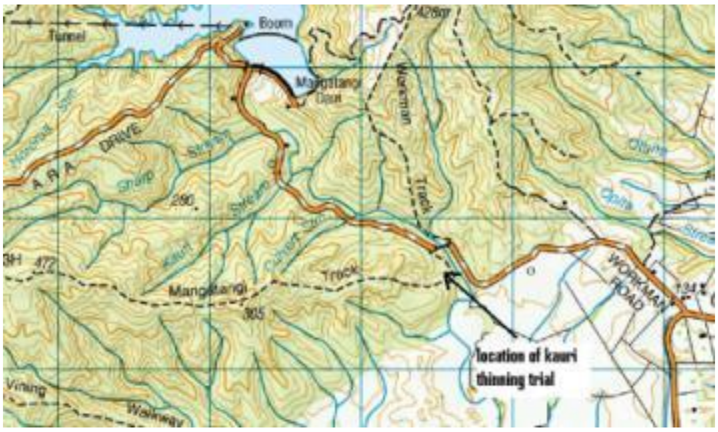

Figure 1. Location map showing the location of the thinning trial in planted kauri forest at Mangatangi in the southern Hunua Ranges.

The site variables of elevation, rainfall, sunshine hours, daily mean temperature and latitude for Mangatangi are well within the natural range of site factors typical of the species (Table 1).

Table 1. Stand and site variables for Mangatangi (from Steward, 2011).

Elevation (m)	Annual Rainfall (mm)	Annual Sunshine (hrs)	Daily Mean temp. (^{0}C)	Latitude
100-200	1816	1922	13.4	37.1 ^{0}S

The trial site can be subdivided into two distinct areas based on topography and growth and performance of planted kauri, a lower 'high river' terrace site and a sloping site located at the base of the foothills of the Hunua Ranges. The two sites are within 20 m of each other, with kauri on each exhibiting very different growth rates. Prior to thinning, the ground within the kauri stand was almost bare apart from small ferns and occasional grasses, and minor early regeneration of podocarps.

Nutrient levels on the terrace were slightly higher for most elements, although these elements were at relatively low levels for kauri at both sites (Table 2). Nutrient levels do not explain the large discrepancy in growth rates at this site [5, 6]

As a general rule soil moisture content increases from ridge to flat, the ridge having considerably lower values than the flat. The slope site, where the upper thinned and control plots are located, has intermediate soil moisture levels (Table 2). Soil hardness increases from flat to ridge, with seasonal measurements revealing soils to be hardest in autumn and softest in spring.

The fact that the soil on the slope, where the two plots of slower growing kauri are located, is for most of the growing season drier and harder than the soil on the flat is the most likely reason why these trees are growing more slowly [7].

Table 2. Soil characteristics (from Barton 2009).

Soil character	Unit	Terrace	Slope
Soil moisture	%	37	22
Phosphate	Olsen µg/ml	3	5.7
Potassium	me/100g	0.3	0.2
Magnesium	me/100g	1.4	0.8
Total Nitrogen	%	0.7	0.3

METHODS

The trial was originally established in the early 1970s, with the first planting of kauri occurring in 1973. Kauri seedlings were grown from the local Mangatangi seed source, and were raised in the Auckland Regional Authority nursery at Hunua. Planting continued in the individual plots until 1977. The trial area was divided into 6 × 6-m (36 m^2) plots with various treatments applied. Initial height growth was slow, so for the purposes of this report it was assumed that all seedlings were planted in 1973. Thinning treatments were superimposed over existing subplots irrespective of earlier applied treatments. Early observations of the growth of kauri throughout the trial area showed considerable difference between the terrace and slope sites. To account for this, a thinned block was established in each site type paired with an unthinned control block. Each thinned block consisted of 16 contiguous original plots with a thinned buffer. Each thinned block was 1152 m^2 with an internal measured plot of 576 m^2 (0.058 ha). Control blocks were 8 × 8 m, and included a minimum of 31 measured trees in each. Control blocks included an unthinned buffer.

All trees within the thinned blocks and unthinned control blocks were measured for DBH before thinning, and selected heights were measured. All data were added to the previous measurements of the site dating back to establishment. Early heights were measured using height poles, while the latest heights were measured with a Digital Hypsometer Vertex with transponder, although small trees were still measured with a height pole. Diameters were measured with diameter tape.

To enable comparison between site types and treatments, measurements were converted to a per hectare basis, and mean top height (MTH), mean top diameter, average diameter (DBH), mean annual increment (MAI) for both height and diameter, basal area/ha (m^2/ha), and survival (%) were calculated. Mean top height and mean top diameter were calculated as the average height and diameter respectively of the 100 largest-diameter stems/ha.

Site index refers to the timber potential for a site for a particular species, usually at a fixed age somewhere near the expected rotation length for the species. In forestry, the usual method of developing site index is from stand height records, as good site quality is also often reflected in good height growth [8]. For kauri in planted stands, site index was defined as MTH at age 50 [2]. Site index was calculated for each of the two site types at Mangatangi.

In the thinned blocks, crop trees were selected prior to measurement to achieve three goals:

1. to reduce competition between planted kauri within the stand and improve growth rates;
2. to achieve a uniform stocking; and
3. to adjust forest structure from an even-aged stand to a mixed height/diameter stand to potentially allow future management using continuous cover forestry principles.

From each of 19 of the largest-diameter trees selected for thinning in the terrace site, a 5-mm pith-to-bark increment core was taken at breast height. Increment cores were divided from the bark end to provide, firstly, a 50-mm outerwood section for the assessment of outerwood density. The remainder of the core was cut into a series of 30-mm segments to provide regular measurement points for characterising the breast-height radial density pattern. Core segments were analysed for basic density using the maximum moisture content method [9]. A whole core density was also derived for each core.

Stiffness was assessed by the acoustic velocity method [10] on log sections removed from the butt end of thinned stems. The stems tested for stiffness were not the same stems from which increment cores were removed for density testing. Acoustic speed was measured by using longitudinal-wave fundamental mode resonance frequency determined from the spectrum of an impulse response measurement. The impulse response measurement was obtained by hitting the end of the log with a hammer and recording the sound produced at the end of the log using a microphone. The average dynamic (acoustic) stiffness of each log was determined by combining the acoustic speed with the average total density of the log. The total density of the log was estimated by weighing the log and determining the volume from the length and dimension measurements at each end of the log. This stiffness includes the bark, which is normally soft and may have resulted in an underestimate of the stiffness of the wood. An estimate of the average dynamic stiffness of the green timber in the log was produced by measuring the bark thickness and assuming that the bark has zero stiffness, and density similar to the wood density (the density of a section of bark was measured to determine this). An estimate of the average static stiffness of the dry timber in the log was produced assuming a 10% increase from the average dynamic stiffness of the green timber (based on average *Pinus radiata* experience - Grant Emms, pers. comm.).

Regeneration within the adjacent unthinned control plots was assessed shortly after application of the thinning, and during seedfall in the 2012 seed season. All kauri, podocarp and hardwood seedlings were counted in the two 8 m × 8 m plots and identified by species. For kauri, seedlings were differentiated into cotyledonary and "permanent" or well-established seedlings. No seedling counts were made in the thinned plots, as thinning slash covered most of the ground.

RESULTS

Growth

Initial stand stocking was 6950 stems/ha. Height and diameter growth at Mangatangi has followed a typical trend for this species, with slow early development after planting. Until age 10 years height MAI averaged 0.18 m/yr across both site types. From age 10 to age 38 years height MAI increased to 0.52 m/yr for kauri planted on the terrace site and 0.30 m/yr for kauri on the slope. At age 18 DBH MAI was 0.14-0.25 cm/yr. For the two site types, the number of stems/ha was similar at age 38 (Table 3, Figure 2). Mean top height of planted kauri in the terrace site was 6.7 m more than in the slope site, while mean top diameter was twice that of the slope site (Figures 3, 4, 5 and 6). Site index at age 50 indicates the differing site productivity potential. Despite similar stand stocking for both sites, the terrace site had 2.2 times the basal area of the slope site. Mortality was similar for both site types.

Table 3. Growth performance prior to thinning at age 38 years (MAI in brackets). Mean top height and DBH were for the largest 100 stems.

Site Type	Mean Top Ht (m)	Site Index @ age 50	Mean Top DBH (cm)	Av. DBH (cm)
Terrace	18.6 (0.5)	22.1	21.9 (0.58)	6.9 (0.18)
Slope	11.9 (0.3)	15.4	10.9 (0.29)	4.9 (0.13)

Site Type	Basal Area (m^2/ha)	Stems/ ha	% mortality
Terrace	23.6 (0.6)	4422	36.3
Slope	10.7 (0.3)	4440	36.0

Figure 2. Terrace site prior to thinning. Initial stand stocking approached 7000 stems/ha (photo M. Bergin).

Thinning

Thinning reduced the number of stems/ha for both sites from nearly 4500 stems/ha to 1070 stems/ha in the terrace site and 1055 in the slope site (approx. 3 × 3 m spacing) (Table 4). The average DBH of residual kauri was 9.8 cm for the terrace site, an increase of almost 3.0 cm. The average DBH was 6.3 cm for the slope site, an increase of 1.4 cm after thinning. Basal area decreased by 13 m^2/ha to 10.3 m^2/ha for the terrace site and by 7.0 m^2/ha to 3.7 m^2/ha for the slope site (Table 4, Figure 6 and 7).

Table 4. Stand parameters post-thinning at age 38 years (MAI in brackets).

Site type	Mean Top Ht (m)	Mean Top DBH (cm)	Av. DBH (cm)	Basal Area (m^2/ha)	Stems/ ha
Terrace	18.6 (0.5)	21.9 (0.58)	9.8 (0.26)	10.3 (0.3)	1070
Slope	11.9 (0.3)	10.9 (0.29)	6.3 (0.17)	3.7 (0.1)	1055

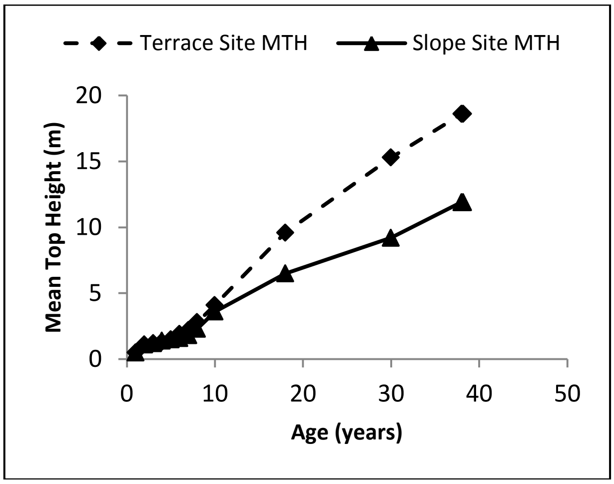

Figure 3. Mean top height (m) of kauri in the terrace and slope blocks.

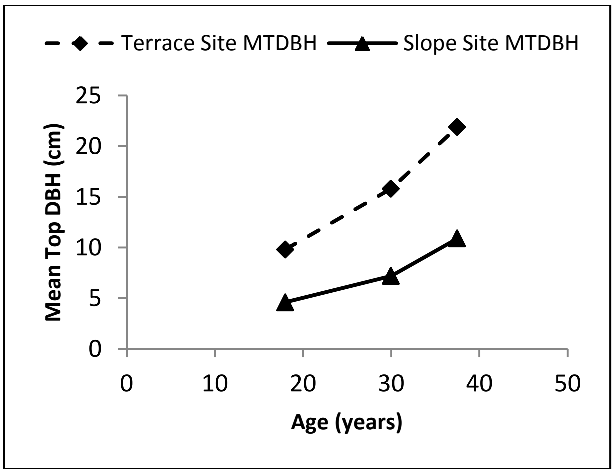

Figure 4. Mean top DBH of kauri in the terrace and slope thinned blocks at Mangatangi from 18 years to 38 years of age. DBH was not measured across all plots until the stand was nearly 20 years old.

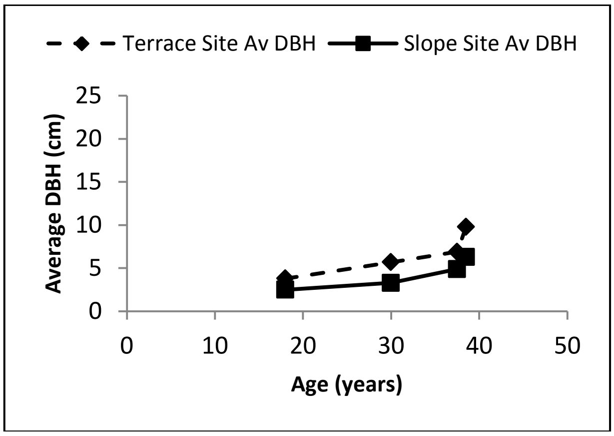

Figure 5. Average DBH of kauri before and after thinning in the terrace and slope thinned blocks at Mangatangi. DBH was not measured across all plots until the stand was nearly 20 years old.

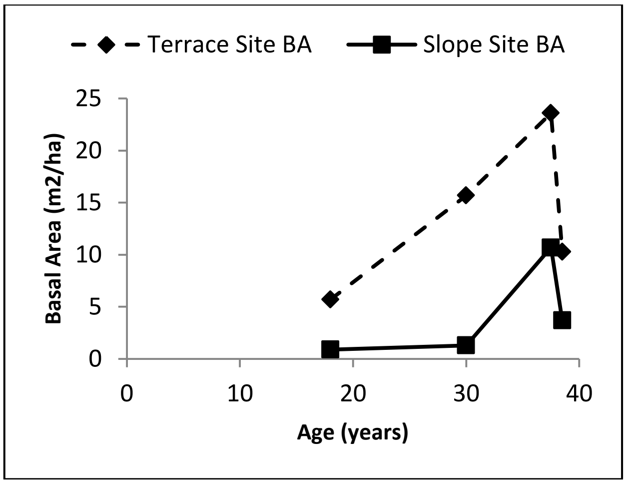

Figure 6. Basal area of kauri before and after thinning at age 38 years in the terrace and slope thinned blocks at Mangatangi.

Figure 7. Post-thinning in the terrace block (photo M. Bergin). Thinning reduced stand stocking to 1070 stems/ha.

Wood quality

Density

The 5-mm pith-to-bark cores removed from 19 thinned stems showed no heartwood development at age 38 years for kauri up to 18 cm DBH (Figure 8). The average density of kauri at Mangatangi was 440 kg/m^3, but was as high as 478 kg/m^3 (Table 6). The wood density was plotted for individual cores against DBH (Figure 9). Wood density was not influenced by DBH and DBH MAI (R^2 = 0.01). Whole core density was similar to outerwood density (439 kg/m^3).

Figure 8. Kauri up to 18 cm DBH showed no signs of heartwood development at age 38 years.

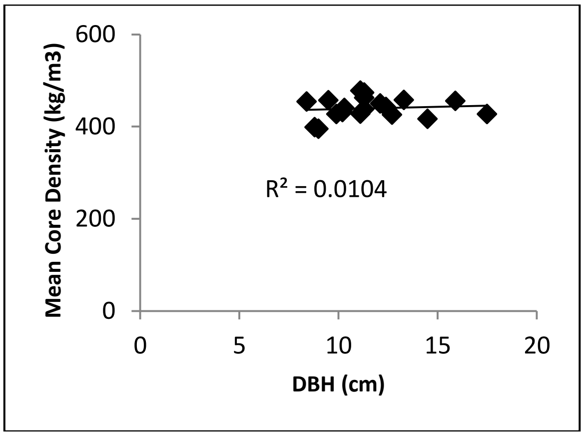

Figure 9. Wood density at 1.4 m above ground of 19 kauri stems sampled from the Mangatangi thinning trial.

Stiffness

Log sections tested for stiffness averaged 1.5 m in length and were recovered from the lower point of 21 felled stems. These stems reflected the larger diameter stems felled during thinning (Figure 10).

Figure 10. Billets prior to stiffness testing (photo M. Bergin).

- Acoustic speed of kauri logs ranged between 3400 and 4100 m/s (Table 4).
- Stiffness ranged between 13.0 and 19.0 GPa and averaged 15.6 GPa.
- Stiffness was plotted by DBH (Figure 11). Stiffness was not influenced by DBH and DBH MAI (R^2 = 0.12).

Table 5. Density and stiffness assessments of kauri logs thinned in the Mangatangi stand.

	Density		**Stiffness**		
	Sample diameter (cm)	**kg/m³**	**Sample diameter (cm)**	**Sound velocity (m/s)**	**(GPa)**
Mean	11.6	440	12.7	3762.6	15.6
Max	17.5	478	23.9	4096.5	18.5
Min	8.4	395	8.0	3424.7	13.1
s.e.	0.55	5.2	0.98	39.8	0.34
s.d.	2.4	22.7	4.5	182.6	1.55

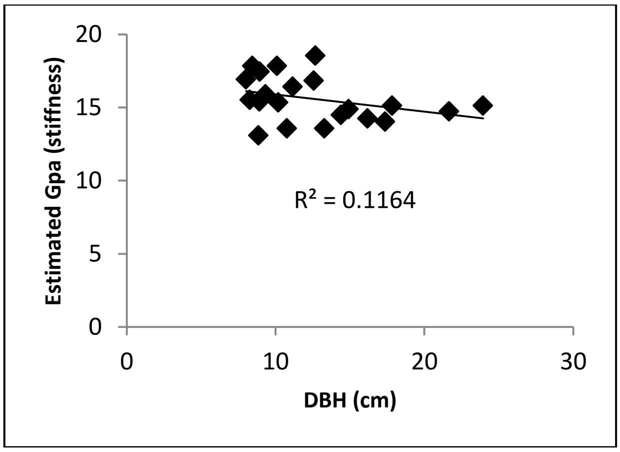

Figure 11. Stiffness of kauri stems from the Mangatangi thinning trial measured by acoustic velocity and converted to GPa.

Regeneration

Regenerated seedling quantities calculated on a per ha basis are shown in Table 5. The most common species to regenerate to date has been tanekaha (*Phyllocladus trichomanoides*), with older kauri seedlings being well represented. Regeneration of kauri (both classes) on the terrace site was 2.7 times more frequent than on the slope site. Rewarewa was the only species more common on the slope site than the terrace site.

Table 6. Regeneration in the unthinned control plots.

Species	Terrace Control (N/ha)	Slope Control (N/ha)
Kauri – cotyledonary	156	-
Kauri – older seedlings	1094	469
Tanekaha	3594	1719
Totara	469	469
Kahikatea	156	-
Rewarewa	156	625
Total / ha	**5625**	**3281**

DISCUSSION

Growth of kauri within the stand has been significantly affected by site. The trial area was divided into two distinct site types defined by the growth and appearance of the planted kauri. Site indices were calculated from the height model [2] at age 50 for both site types. At 15.4 m for the slope site and 22.1 m for the terrace site, these compare to a mean of 20.4 m (at age 50) for all planted kauri based on the height model developed from 25 planted stands [2]. The terrace site was above average in its potential productivity, while the slope site was significantly below average. The performance of the kauri on the terrace site at Mangatangi indicates an estimated current 350-400 m^3/ha for whole tree volume and an estimated 400 t/ha of stored carbon. These post-thinning estimates for whole tree volume and stored carbon were made from similar stands at similar ages [2].

Thinning has dramatically reduced the within-stand competition and has been timely as tree crowns had not as yet become significantly affected by overcrowding. In the New Plymouth stands, thinning did not occur until age 60, and by that time significant crown collapse had occurred [11]. Kauri growth in these New Plymouth stands did not respond to thinning until crown area had been replaced, and a delay of 2-3 years was observed. This same pattern occurred at Mangatangi in the original thinning plots put into natural kauri pole stands in the 1960s. On poor sites, where there was considerable competition, it took 2 -3 years before the diameter growth rate picked up, even on plots that were fertilised with nitrogen. On better sites with lower stockings, the increase in growth rate was almost immediate. It is expected that kauri in thinned sites at Mangatangi will respond in the first growing season. Thinned stems have been left *in situ* and may provide some beneficial nutrients in the coming years as they deteriorate.

Maintaining the stand at high stand stocking (4400 stems/ha) until thinning has resulted in an almost clear understorey, especially as a remnant kanuka overstorey exists. It is expected that the removal of 75% of the kauri crop and competing species will see an in-fill of new species as a result of increased light to the forest floor, and hopefully an increased component of kauri regeneration, some of which is already present on site. The removal of all overtopping kanuka was not undertaken, as the felling of stems with large spreading crowns was likely to damage too many kauri.

The assessment of wood quality traits of stiffness and density has yielded interesting and positive results. Acoustic speed within kauri logs ranged between 3400 and 4100 m/s, and from 13.0 to 19.0 GPa, exceeding that of *Pinus radiata*. Structural *Pinus radiata* with stiffness values of 10.0 GPa is regarded as being good (Grant Emms, pers. comm.), while values for New Zealand-grown D-fir (*Pseudotsuga menziesii*) are 8.8 to 9.0 GPa [12]. Stiffness of sapwood kauri timber tested from the New Plymouth stands averaged 13.6 GPa, but was as high as 15.0 GPa at age 68 years. Wood density was also high in comparison to exotic forest tree species, and was similar to other planted kauri assessed from Northland, Bay of Plenty and Taranaki. The average value of wood density for stems sampled in this study was similar to that used for calculating kauri carbon sequestration (435 kg/m^3) reported during the development of the kauri growth and yield models [2].

The kauri die-back disease *Phytophthora* taxon Agathis (PTA) has not been observed in this or surrounding stands [13]. *Phytophthora* taxon Agathis has been identified affecting kauri from Great Barrier Island and natural and planted kauri forests of Northland and Auckland. It has been the identified cause of death and ill-thrift in regenerating stands on poorly drained sites. During all operations to undertake measurements, application of thinning treatments and retrieval of wood samples, equipment, including footwear, was cleaned and treated with TriGene both before entering and upon exit of the stand.

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