Kauri – response to thinning of second-growth stands

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Tree form typical of second-growth kauri forest

Abstract

Six thinning trials established in natural second-growth kauri (*Agathis australis)* forest were analysed to compare the effects of thinning with un-thinned controls, and to develop models of growth and productivity for this forest type.

Thinning resulted in statistically significantly greater diameter increment compared to the un-thinned controls within each site. Diameter increments of 0.25 to 0.37 cm/yr were recorded in thinned treatments, while basal area increased by almost 90%. Thinning also reduced the variance in diameter mean annual increment (MAI) by almost 30% and made substantial changes in species composition in some stands.

Treatments that combined thinning and fertilising (one site) had the greatest improvement in diameter growth. It also indicated the effects of both persistent high stand density and poor site qualities that are common growth limitations for these forests. In un-thinned controls, basal area increased by on average 50% with diameter increments of 0.11 to 0.24 cm/yr. The basal area removed at thinning had not been replaced in the up to 50 years that the trials were monitored.

Stand-level models predicted slow volume development in both thinned and un-thinned treatments with MAI exceeding 5.0 m^3/ha/yr only by age 200 years. Thinning had little impact on annual height growth with kauri predicted to take 25 years to reach 1.4 m in height. A comparison of models of productivity between second-growth stands and planted kauri has shown that natural stands have significantly less volume per hectare at all ages.

Introduction

Throughout its natural range there is estimated to be 60,000 to 100,000 ha of second-growth kauri forest. These stands were identified as a future source of high-quality lumber if its growth and productivity was better understood. Second-growth forests are defined as naturally regenerated stands on sites previously occupied by kauri forest (Steward, 2011). They are at all stages of development and scale and have mainly arisen through human-induced disturbance – both pre- and post-European settlement.

Typically, these sites include steep slopes and poorer quality soils and would initially have a mix of primary and seral vegetation cover, likely dominated by

Table 1: Thinning trials (north to south)

Trial	Location	Assessments		Estimated age (years)		Thinning intensity (%)
		First	Last	Average	Maximum	
Herekino	Herekino Forest	1936	1974	148	209	39.1
Papakauri	Russell Forest	1963	2006	163	197	48.2
Kaiarara	Great Barrier Island	1963	1998	153	179	73.5
Whangaparapara	Great Barrier Island	1958	1971	153	179	26.4
Mangatangi	Hunua Ranges	1979	2010	150	155	68.2
Waitengaue	Kaimai Ranges	1957	2008	226	371	80.7

mānuka (*Leptospermum scoparium*) and kānuka (*Kunzea ericoides*). Most kauri within these stands are in the 'ricker' form of younger kauri, although some breakout of the canopy into a semi-mature form may also be occurring in a minor component. Only a third of these forests were initially classified with the potential to be managed for timber production (Halkett, 1983).

The establishment of thinning trials – forest types A3, C1 and C4 (Nicholls, 1976) – began in Herekino Forest in 1936, with further trials initiated over the species range until 1979. The objectives were to improve growth and productivity by reducing within-stand competition in comparison to un-thinned controls. Thinning was predicted to increase diameter growth, although it was expected to be variable (Halkett, 1983). Productivity was estimated to be 5.0 to 9.0 m^3/ha/yr in untended stands, with thinning assumed to increase productivity to an estimated 6.0 to 10.0 m^3/ha/yr. Sustainable management of second-growth kauri forest on private land requires an understanding of its growth and productivity in stands representative of those likely to be harvested. This study therefore focused on the response to thinning at different intensities.

Methods

Trial sites

The six trials covered almost the entire current latitudinal range of the species, including two on Great Barrier Island (Table 1). Apart from the Herekino trial, they were mainly towards the eastern side of the North Island (Figure 1). Trials were established as paired-plots (thinned and un-thinned) on each site. Before thinning, some variation existed between plots on the same site, but careful siting of treatments minimised the effect on results.

Thinning intensities averaged 56% across all sites, but varied in method and intensity and included thinning-to-waste through felling and/or ringbarking, and production-thinning (two sites). Thinning-to-waste was the standard treatment in areas of kauri regeneration that were inaccessible for log recovery, or where piece-sizes were too small for commercial use. It was effectively for the kauri component a thinning from below by the reduction in stand density in the smaller diameter classes.

Conversely, where production-thinning was undertaken, the emphasis became the removal of dominant trees to stimulate growth of the residual crop. Removing kauri before they developed a large spreading-canopy would reduce the damage to crop trees that future harvesting would likely result in. Trials were measured for periods from 13 to 51 years. During that time, in-fill growth of new kauri was recorded in most sites. For the purposes of this analysis only kauri that were present from the first measurement are included.

The Waitengaue trial was the most southern trial and contained the oldest kauri with individuals estimated, from increment cores, to be up to 371 years old. The Mangatangi trial also incorporated fertiliser treatments that were superimposed over additional thinned and un-thinned plots. Nitrogen fertiliser was applied at rates of product of either 715 or 1,430 kg/ha, and for this analysis they were combined into either a

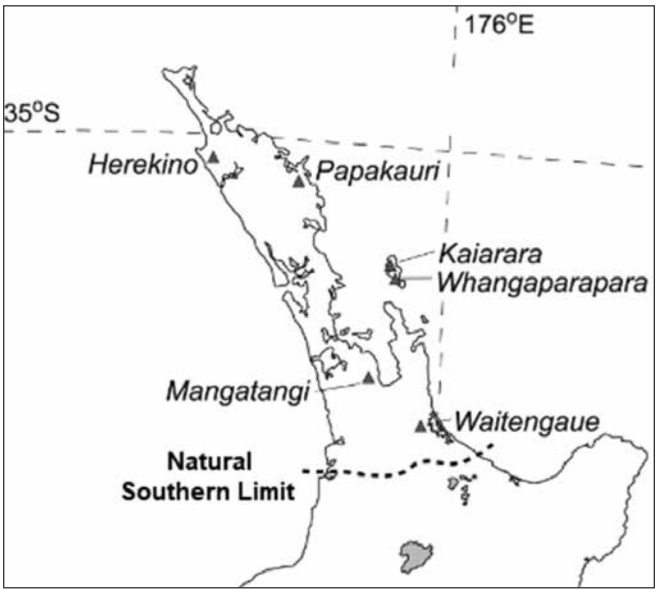

Figure 1: Trial locations

Table 2: Forest composition pre-thinning (stems/ha)

Trial	Herekino		Papakauri		Kaiarara		Whangaparapara		Mangatangi		Waitengaue	
Species	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Kauri	811	94.9	222	60.8	830	41.5	206	33.1	2,200	80	1,650	89.6
Conifers	–	–	141	38.6	220	11.0	–	–	550	20	83	4.5
Hardwoods	–	–	2.0	0.6	210	10.5	–	–	–	–	108	5.9
Other species	44	5.1	–	–	740	37.0	417	66.9	–	–	–	–
Total	**855**	**100**	**365**	**100**	**2,000**	**100**	**623**	**100**	**2,750**	**100**	**1,841**	**100**

thinned/fertiliser treatment or an un-thinned/fertiliser treatment and compared to un-thinned control and non-fertilised thinned treatments.

Before thinning, stand density ranged from 365 to 2,750 stems/ha for all species, and 206 to 2,200 stems/ha for kauri (Table 2). Kauri was the dominant canopy species in all stands, except Whangaparapara. At Whangaparapara, kauri comprised only 33% of the forest composition (Table 2), with large residual kānuka overtopping much of the forest structure. Rimu (*Dacrydium cupressinum*) and tōtara (*Podocarpus totara*) were found at only three sites and combined were <8% on any site. Tānekaha (*Phyllocladus trichomanoides*) was found at four sites and comprised over 30% of the forest canopy at Papakauri. The two Great Barrier Island trials contained the largest species diversity, while conversely, Herekino had the least with kauri being almost 95% of this forest. The two most southern stands (Mangatangi and Waitengaue) contained a small, relict component of hard-beech (*Nothofagus truncata*).

Growth modelling

Three forms of sigmoidal growth function – von Bertalanffy-Richards (Richards, 1959; von Bertalanffy, 1949), Schumacher (Schumacher, 1939) and Weibull (Weibull, 1939) – were tested for developing models of height and basal area in both thinned and un-thinned control plots. All models incorporated three parameters – asymptote (a), slope (b) and shape (c). To enable comparisons between treatments on the same site, stand density (stems/ha), basal area (m^2) and volume (m^3) were adjusted to per hectare equivalents.

Standing volume was calculated using Ellis's pole-kauri volume table (Ellis, 1979). The volume table uses total tree height, so volumes derived are total standing volumes. An alternative was the mature-kauri equation which uses merchantable height data, thus providing standing merchantable volume estimates. However, this would have resulted in larger estimated volumes of between 20% and 30% over the diameter classes found in the six trial sites.

All height models had 0.5 m as the starting height. For basal area, the same model forms were tested, except that an intercept of zero was used. It is accepted that some basal area would exist but would be small.

Forest composition

Thinning removed all or most of the competing species except at Waitengaue (Table 3). In the Mangatangi (see photos on page 30) and Waitengaue trials, thinning also removed substantial numbers of small diameter sub-canopy kauri, reducing the total kauri component by almost 75%. The number of kauri/ha remained comparatively constant from the first to last assessment in all stands.

Kauri growth

Thinning significantly increased diameter mean annual increment (MAI) (Table 4) on all sites. Diameter MAI increased in the thinned sites by 0.32 cm/yr and in control plots by 0.15 cm/yr for all sites combined. Emergent, larger diameter kauri tended to have greater DBH MAI irrespective of treatment (Figure 2). Thinning also significantly reduced the variability in DBH MAI by

Table 3: Forest composition at last assessment (stems/ha)

Trial	Herekino		Papakauri		Kaiarara		Whangaparapara		Mangatangi		Waitengaue	
Species	Control	Thinned	Control	Thinned	Control	Thinned	Control	Thinned	Control	Thinned	Control	Thinned
Kauri	767	333	222	112	810	220	194	345	2,200	700	1,150	313
Conifers	–	–	137	5	200	7	–	–	550	–	25	38
Hardwoods	–	–	2	–	150	–	–	–	–	–	8	275
Other species	0	–	–	–	130	–	417	0	–	–	–	–
Total	**767**	**333**	**361**	**117**	**1,290**	**227**	**611**	**345**	**2,750**	**700**	**1,183**	**625**

Pre-thinning (above left); Post-thinning comparisons (above right), Mangatangi trial

almost 30% compared to control treatments. In control treatments, DBH MAI variability averaged 65.8% but was as high as 80.6%.

Thinned treatments averaged 38.1% variability and was relatively consistent across sites, apart from Herekino, which had the highest variability in both treatments. Kauri basal area increased on average by 51.6% in control plots and 80.1% in thinned plots. At the final assessments, kauri represented on average 90% of the stand composition and 93% of the stands basal area for the thinned treatments. Thinning had only a small influence on height growth.

In the Mangatangi trial the effect of thinning and the application of varying rates of nitrogen fertiliser on diameter growth was immediate, but not lasting. Four years after treatments were applied, diameter periodic annual increment (PAI) for the thinned and thinned/fertilised treatments had peaked at 0.9 cm/yr and 1.6 cm/yr, respectively. At their last assessment the thinned/fertilised treatment had a DBH MAI five times that recorded in the control plots, and twice that in the other two treatments.

The un-thinned/fertilised and the thinned stands had similar DBH MAI, but were still significantly greater than the untreated control. The greatest basal area response was in the fertilised/thinning treatment where an almost 150% increase was recorded (16.7 m^2/ha to 41.7 m^2/ha). The control and the thinned treatments recorded similar percentage (50%) increments in basal area. The fertilised/un-thinned treatment had responded by almost 95%, and in 1998 had a basal area of 58.3 m^2/ha.

Table 4: Diameter and basal area development – kauri only

Trial	Treatment		Diameter (cm)		Basal area (m²/ha)	
		Final	MAI ± S.E.	MAI CoV	Final	Incr. (%)
Herekino	Control	38.6	0.11 ± 0.01	80.6	89.7	30.6
	Thinned	44.3	0.26 ± 0.01	73.6	51.4	31.9
Papakauri	Control	41.9	0.20 ± 0.01	38.1	30.5	59.5
	Thinned	46.7	0.30 ± 0.02	36.5	19.2	94.8
Kaiarara	Control	25.9	0.14 ± 0.01	67.0	43.1	63.9
	Thinned	32.5	0.31 ± 0.02	34.1	18.3	130.3
Whangaparapara	Control	34.4	0.24 ± 0.01	34.0	18.1	15.2
	Thinned	35.6	0.37 ± 0.01	36.6	34.2	33.6
Mangatangi	Control	16.8	0.11 ± 0.01	72.1	49.5	73.7
	Thinned	25.6	0.24 ± 0.02	38.6	37.0	105.6
Waitengaue	Control	29.4	0.13 ± 0.01	77.1	75.8	65.5
	Thinned	47.7	0.31 ± 0.02	29.9	55.9	114.9

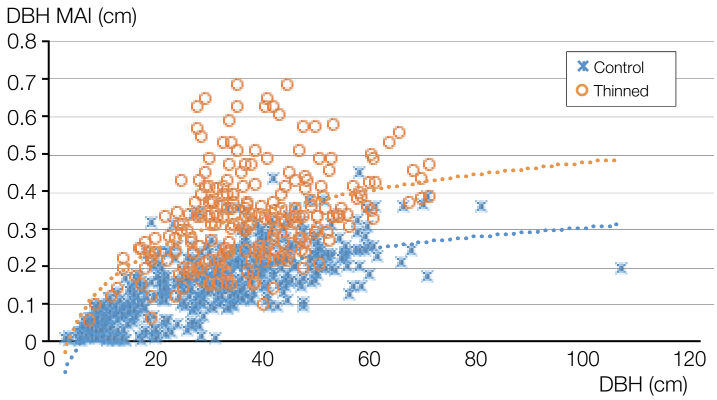

Figure 2: Kauri DBH mean annual increment for all sites

Growth modelling

Height

The anamorphic Schumacher model with a local slope parameter (Table 5) produced sigmoidal curves that best reflected the height data. Early forms of Schumacher growth functions predicted height growth linearly and resulted in extreme estimates for the asymptote (a parameter). A value to bound the height equation was determined from a sample of 60 kauri with mature and semi-mature form in five forests of the Northland region. Maximum height was 52.2 m, with 25% of the sample taller than 35.0 m; for kauri in second-growth stands up to 38.0 m in height was recorded.

A height of 45.0 m was therefore deemed an acceptable compromise between the extreme maximum (60.0 m) and the heights found in comparatively young stands. Site index (at age 50) was calculated for each stand and treatment. Mean site index was similar at 7.0 m (control) and 8.9 m (thinned). Mean top height (MTH) trajectories showed that height growth began slowly in both stand types and did not reach 10.0 m by age 50 (Table 8). Height MAI peaked at age 100 years for control (0.19 m/yr) and thinned treatments (0.2 m/yr).

Table 5: Height model

MTH = mean top height; T = age; 0.5 = starting height of seedlings; a = bounded asymptote parameter estimate; c = shape parameter estimate; LN = Natural Log; SI = Site Index				
Parameter	**Parameter estimates**			
	Control	**S.E.**	**Thinned**	**S.E.**
a	44.5	–	44.5	–
c	−1.0488	0.0928	−0.9867	0.0514

Basal area

The unbounded polymorphic von Bertalanffy-Richards equation in difference form with local slope parameter gave the best fit to the data (Table 6). Both the control and the thinned stand basal area models displayed some bias and resulted from underestimation of the basal area in the Waitengaue stand, for both treatments. There was good agreement when the model was plotted against actual data points. Basal area development began slowly in second-growth stands (Table 8). The control treatments reached 23 m^2/ha by age 75 (0.31 m^2/ha/yr), while thinned treatments took 100 years to reach over 20 m^2/ha (0.2 m^2/ha/yr). Basal area removed in thinning was not predicted to be replaced until age 200 years.

Table 6: Basal area model

The form for projecting a measurement of basal area Gi at age Ti forward to age T is: G = predicted basal area; Gi = basal area at initial measurement; T = age of prediction; Ti = age of initial measurement; a = asymptote parameter estimate; c = shape parameter estimate				
Parameter	**Parameter estimates**			
	Control	**S.E.**	**Thinned**	**S.E.**
a	152.4	23.752	319.1	720.1
c	2.3382	0.4662	2.1968	1.1266

Volume

Predicted basal area and MTH values were used in conjunction with the stand-level volume function to provide predicted volumes (Table 7). Volume developed slowly in both stand types, with volume MAI only exceeding 5.0 m^3/ha/yr in the control treatments at age 200 (Table 8). Volume periodic annual increment for both stand types reached its maximum (8.0 m^3/ha/yr) in the thinned treatments at age 200.

Table 7: Volume model

Vol = volume; G = basal area; MTH = mean top height, a = asymptote parameter estimate; b = slope parameter; c = shape parameter estimate				
Parameter	**Parameter estimates**			
	Control	**S.E.**	**Thinned**	**S.E.**
a	0.956	0.1557	0.956	0.1278
b	0.703	0.4160	0.703	0.0467
c	0.883	0.0727	0.883	0.0971

Discussion

The objective of these trials was to determine whether a reduction in competition through various thinning intensities would result in increased diameter growth and productivity of kauri. The volume MAI predicted by Halkett (1983) of 5 to 9 m^3/ha/yr was not supported by the current models for either stand type. Volume MAI for both un-thinned and thinned second-growth stands peaked at 5.5 m^3/ha/yr. The diameter and height growth of kauri in second-growth stands is most likely restricted by a combination of

Table 8: Predicted stand growth and productivity

Age (years)	Height (m)		Basal area (m²/ha/yr)		Volume (m³/ha)		Volume MAI (m³/ha/yr)	
	Control	Thinned	Control	Thinned	Control	Thinned	Control	Thinned
25	1.6	2.2	2.7	1.7	2.6	2.3	0.01	0.09
50	8.0	9.0	11.0	7.0	43.7	31.4	0.87	0.63
75	14.4	15.2	23.0	15.4	150.7	106.0	2.01	1.41
100	19.3	19.8	36.8	26.2	307.2	222.9	3.07	2.23
150	25.9	25.9	64.5	52.6	681.0	549.8	4.54	3.67
200	29.9	29.6	88.4	81.9	1043.8	947.1	5.22	4.74

factors, including persistent shading from an overhead canopy and within-stand competition (Bieleski, 1959). These are the same factors limiting expansion of kauri from existing natural stands as a shade-tolerant but slow-growing seedling under natural forest conditions (Barton, 1983).

A combined self-thinning relationship for kauri in planted and natural stands was developed by Steward (2011). Before thinning in the current study, all stands were at or near full-site occupancy based on the relationship of quadratic mean diameter with stand density for all species. Thinning resulted in only the Papakauri and Kaiarara stands dropping well below the self-thinning line whilst the other stands remained close to the line.

At their final assessment, all thinned treatments were once again at or near full-site occupancy, which suggests that the thinning intensities could have been substantially higher than that undertaken. Kauri may still be at relatively high stand density when they emerge through the overtopping canopy and will continue to compete for growing space and resources. However, kauri appear to be able to persist in this state for extended periods of time and retain some ability to respond as and when growing conditions improve (Barton & Madgwick, 1987).

The sites where these stands established appear to be typical of the current second-growth kauri resource. However, they are not necessarily representative of the wider kauri population prior to human arrival in New Zealand. The current sites tend to be upland, where kauri's tolerance to low levels of soil fertility and moisture gives it a competitive advantage but results in reduced growth. Where soils have higher fertility, other species tend to out-compete kauri. The results of growth and productivity seen in this study should therefore be seen in the light of site characteristics.

The results from the Mangatangi stand where fertiliser was applied in combination with thinning treatments supports observations of site impact on growth. Another potentially confounding issue influencing kauri growth is the abundance and genetic diversity of the parent population contributing to the regeneration on individual sites. The current population is characterised by disjunct, small stands of isolated and potentially closely-related individuals. The effect of this on the diversity and growth of kauri is, as yet, largely unknown.

Models of height, basal area and volume have been developed for plantation-grown kauri (Steward et al., 2014) and indicate considerably better growth and productivity when grown on higher-quality sites at appropriate stand densities of 650 to 1,000 stems/ha. This was irrespective of the lack of after-planting maintenance. When the median volume projections were plotted, planted kauri stands had significantly higher volume than natural stands at all ages (Figure 3).

The difference observed between kauri in natural stands and those in plantations was largely a result of the initial height growth in natural stands being slow. At age 50 years, kauri in planted stands were over twice the height (20.0 m) of kauri in natural stands (un-thinned 8.0 m, thinned 9.0 m). By age 80 years, kauri in planted stands were predicted from actual data to be 25.7 m. In natural stands at age 75 years height was predicted to be similar at 14.4 m (un-thinned) and 15.2 m (thinned).

Wood quality assessments were undertaken from logs extracted from Russell Forest (Colbert & McConchie, 1981). The average DBH of trees sampled was ~44 cm. At their final assessments in the current study, kauri in four of the treatments had an average DBH that exceeded 40 cm, three of which were thinned

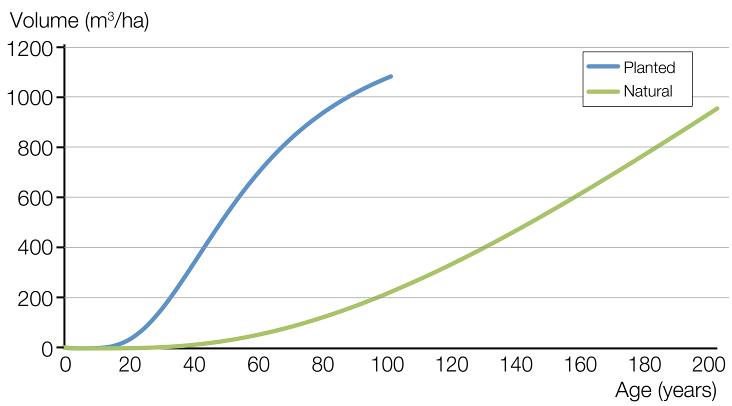

Figure 3: Median volume estimates in planted and second-growth kauri stands (Steward, 2011)

treatments. Assuming a minimum average DBH of 40 cm as a prescription to trigger another harvest, the average number of years to reach 40 cm DBH would be ~75 years in the remaining control treatments and ~30 years in thinned stands. Theoretically, if the observed diameter increments were consistent from the last assessment until the present, then all sites would currently have an average DBH >40 cm, except for Kaiarara and Mangatangi (both treatments), and the Waitengaue (control treatment).

Species composition tended to reflect both site characteristics and available seed sources, as well as dispersal mechanisms available for the colonisation of newly disturbed sites. Applying thinning treatments of varying intensities resulted in, at first glance, considerable change in some of the stands. While thinning reduced species composition, this was already naturally occurring, particularly for the light-demanding pioneer species. The original nurse-crop was still present in several sites when thinning treatments were applied.

Much of this component of the forest was removed during thinning, particularly where large kānuka were present in the canopy. In these situations, this species often had large spreading canopies that were either suppressing young kauri or were predicted to collapse over a short time, likely causing significant damage to small kauri. Ring-barking these stems in-situ allowed them to disintegrate gradually over a period not likely to exceed 24 months. While the thinning influenced stand dynamics, it has therefore only brought forward the change in forest composition that would have naturally occurred within a decade or two of thinning or was already occurring.

In-fill regeneration of kauri was prolific in most sites (both thinned and un-thinned controls), particularly at Mangatangi and Waitengaue. This shows the potential for the species to regenerate and develop under its own canopy, and also identifies the potential for uneven-age continuous cover management principles to be applied to these and planted stands (Barton, 2008). The two northern trials showed the least evidence of new in-fill growth of kauri, although some regeneration was occurring. These stands had a dense ground cover dominated by kauri grass (*Astelia trinervia)* and the sedge *Gahnia setifolia* through which newly germinated seedlings of kauri or other native conifer species struggle to develop.

Conclusions

Thinning was presumed to reduce within-stand competition and result in better growth and productivity than in stands with no silvicultural intervention. Diameter growth of kauri in thinned stands was consistently higher than in control stands, but not substantively enough to replace the basal area or volume that was removed during thinning. The greater basal area and volume productivity in control treatments was entirely attributable to higher stand density (stems/ha).

However, thinning did not result in the diameter growth, basal area increment, or volume production as was expected. Second-growth kauri stands displayed substantive variance in all measured parameters from stand density to growth and productivity. Many of these are presumed to be site related. Thinning of second-growth stands resulted in performance and productivity becoming more similar between individual stands that received a thinning treatment. Thinning removed much of the variance found between natural stands.

The models produced for second-growth stands were asymptotically stable for control treatments. In thinned treatments, the models had difficulty fitting one site (Waitengaue) but gave a good result for all other sites. In combined datasets, the models were stable. The models of kauri growth indicate substantive differences in performance and productivity between planted and second-growth kauri. The worst of the planted stands performed better than the best of the natural stands for height and basal area, and for volume productivity. The reasons for this were not examined in this study, but differences in site quality, time to emergence from the canopy, and stand structure are all potential explanations that can be tested in the future. Models developed in this study are relevant only to kauri that are in the 'ricker' form, irrespective of age.

Much of the second-growth kauri forest identified for future harvesting is now contained in New Zealand's conservation estate and, therefore, no longer available for harvesting. While this paper is not advocating for further harvesting in these stands, it does provide an insight into how similar stands on private land might respond to harvesting under the sustainable forest management plans and permits administered by Te Uru Rākau.

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In Masterton this year, we have an inspiring line-up of speakers and CPD sessions to showcase the pride and passion in our forestry workforce

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Monday 29 June	Speaker sessions, followed by a Pre-election Policy Panel exclusive to NZIF, featuring forestry representatives from each major political party
	Networking drinks and Conference awards dinner – showcasing building with local wood products
Tuesday 30 June	Women in Forestry breakfast – with guest speaker
	'Breaking Down the Barriers' (open to the public) – two sessions focussed on forestry in our communities
	Field trips: Town Tour (log distribution and processing) or Forest Tour (farm forestry and advanced logging systems)

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