2020 Re-Measurement of Regenerating Farm Tōtara Permanent Sample Plots

Ref. TUR 2020 -048

Project results

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Project overview
This MPI funded project (TUR_1BT-2020_048) was undertaken by Tāne's Tree Trust on behalf of the Northland Tōtara Working Group. It involved the remeasurement of the tōtara silviculture trial plots established by the Northland Tōtara Working Group since 2007 across a range of pole and semi-mature regenerating totara dominant forest. Data from 50 Permanent Sample Plots (PSPs) yields valuable information on growth rates, carbon sequestration, and management prescriptions for timber production. It also includes some implications for effects on indigenous biodiversity associated with silvicultural interventions in pole-stands of regenerating tōtara.

Background and Introduction

Thinning and pruning trial
A thinning and pruning trial was established in naturally regenerating tōtara-dominated pole stands in Northland in 2007 (Quinlan et al., 2014). Stands were located in three clusters – Whangarei/Glenbervie, Kaeo/Okaihau and Herekino. Depending on stand size, two or more PSPs (Permanent Sample Plots) were established within each of 14 stands at nine farm sites across the three clusters. This allowed establishment within each stand of a randomly chosen control PSP with no silvicultural treatment and one or more thinned and pruned PSPs, thus allowing a direct comparison to be made of the effects of silviculture with an unmanaged stand. A total of 38 PSPs were installed.

All PSPs were measured in 2007 before any silviculture using the methods of Ellis and Hayes (1997). Diameter at breast height (DBH at 1.4 m above ground) was measured for all stems with DBH ≥5 cm. Heights of a sample of canopy trees were also measured. Before thinning, mean DBH ranged from 10-23 cm and mean tree height from 6-14 m. The thinned plots were re-measured immediately following silviculture. All plots were re-measured five years later in 2012. An analysis of the 2012 data showed that stem volume periodic annual increment (PAI) over the period 2007 – 2012 averaged just under 8 m^3/ha/yr in the thinned plots, but only 3 m^3/ha/yr in the control plots (Quinlan et al., 2014). The lower net volume PAI in the control plots was mainly caused by higher mortality in these plots compared to the thinned plots.

Evaluation of the 2007 thinning treatments also indicated that some plots had been too conservatively thinned. Because of this, a further thinning was carried out in 12 of the original thinned plots in 2012. In 2015, an additional eight PSPs (four thinned and four control) were installed at a new site (Titoki). This report also includes data from a control PSP in a pole stand installed in 2010 which has no matching thinned PSP (BOYD).

Remeasurement in 2020

The thinning trial was remeasured in 2020 providing growth data over the eight-year period from 2012 – 2020 (five-year period for Titoki plots). For the 2020 remeasurement, it was not possible to access seven of the original PSPs at one site (OXBO1-7) while two another PSPs (COOP7 and RENW1) were not included in the analysis due to changes in stand management issues. The 2020 analysis is based on 21 thinned and pruned PSPs and 18 control PSPs.

During assessment in 2020, each PSP was subjectively scored for indigenous biodiversity in the understory using a 1-5 scale (1 = low biodiversity/understory development, 5 = high biodiversity/understory development). The presence/absence of evidence of grazing or browsing was also noted for each PSP. A copy of the assessment sheet used is included in Appendix 1. The comparison of scores between thinned and control plots reveals differences in the understory development as a result of silvicultural treatment.

Merchantable stands

In 2017-18, 11 PSPs in five stands containing merchantable-sized trees were installed. In two of these PSPs, a selection harvest of several trees per plot was carried out just prior to the 2018 measurement whilst the other nine PSPs had had no recent harvest history. These PSPs therefore provide growth data for more mature regenerating tōtara stands and allow a comparison of growth in stands where recent selective harvesting has occurred compared with stands with no recent harvesting.

Analysis of tree growth

A height-diameter function was fitted for each PSP measurement to enable heights of all trees to be estimated. As no specific volume function has been derived for tōtara, the function developed for pole rimu by Ellis (1979) was used to give an approximate stem volume for each tree using the measured DBH and estimated height. Total carbon in the tree biomass (above and below ground) was estimated using the methods of Beets et al. (2012).

All analyses were restricted to stems ≥5 cm in DBH and included all species. Stand density, quadratic mean DBH, MTD (mean top diameter – the mean DBH of the 100 largest stems per hectare), MTH (mean top height – mean height of the 100 largest DBH stems per hectare), BA (basal area), stem volume, SDI (Reineke's stand density index, SDI = 0.00229 x Stocking x $DBH^{1.6}$), and species mix (% tōtara by volume) were calculated for each PSP measurement. Annual mortality, and PAI (periodic annual increment) for DBH, MTD, MTH, BA, volume and carbon were calculated for each PSP over the period between measurements. Plot means were analysed using ANOVA (analyses of variance) using the R lme function. These ANOVAs tested the effects of thinning (thinning trial) or harvesting (merchantable stands) as a fixed effect, with stand treated as a random effect.

The biodiversity score was also analysed using ANOVA to determine whether thinning affected biodiversity and development of a vegetative understory, and whether this was higher in PSPs with evidence of grazing or browsing.

Results

Effect of thinning on stand characteristics
Mean stand characteristics of thinned and unthinned pole stand PSPs at the 2020 measurement are summarised in Table 1. This shows that unthinned PSPs had a mean stand density of about 2300 stems/ha, were 85% tōtara, and trees averaged about 18 cm in DBH and 15 m in height. Thinned PSPs averaged about half the stand density of unthinned PSPs. They also had lower total volume, BA and carbon. Individual trees in thinned plots had larger diameters than those in unthinned plots but did not differ significantly in height. Note that because thinning tends to remove smaller diameter trees, it is expected that thinning will result in an increase in mean DBH.

Table 1. Mean stand characteristics of control and thinned & pruned PSPs in regenerating tōtara pole stands measured in 2020. Statistical significance of differences between control and thinned PSPs is indicated as follows: NS not significant, * significant ($p<0.05$), ** significant ($p<0.01$).

Treatment	Stand density (stems/ha)	DBH (cm)	MTD (cm)	MTH (m)	BA (m^2/ha)	Volume (m^3/ha)	Carbon (tCO_2eq/ ha)	SDI	Species (% tōtara)
Control	2323	18.1	33.1	15.7	52.4	330	441	484	85
Thinned & pruned	1143 b	22.6 b	33.6	15.3	38.5 b	252 b	326 b	326 b	95 b
Sig.	**	**	NS	NS	**	**	**	**	**

Table 2 summarises mortality and the periodic annual increments of important stand characteristics between the two measurements, i.e., over a period of eight years for the original trial, and five years for the Titoki plots. Annual mortality was significantly lower in thinned plots, and the DBH PAI significantly higher at 0.4 cm/yr compared with 0.25 cm/yr in unthinned PSPs. Because thinning tends to leave larger, faster growing trees, the increased DBH PAI may not necessarily indicate a genuine growth response to thinning. However, the MTD PAI also was significantly greater at 0.54 cm/yr in thinned compared with 0.35 cm/yr in unthinned PSPs. This shows that thinning induced a genuine diameter growth response as the MTD PAI summarises the growth in the largest diameter trees only. Thinning had no significant effect on height growth which averaged 18 cm/yr in control plots. Annual increments in stem volume and carbon per hectare were both significantly higher in thinned than control PSPs.

Table 2. Mean PAI (periodic annual increment) of stand characteristics of control and thinned & pruned PSPs in thinning trial over the period 2007 – 2020 (2015 – 2020 for Titoki stand). Statistical significance of differences between control and thinned PSPs is indicated as follows: NS not significant, * significant ($p<0.05$), ** significant ($p<0.01$).

Treatment	Annual mortality (%/yr)	DBH PAI (cm/yr)	MTD PAI (cm/yr)	MTH PAI (m/yr)	BA PAI (m^2/ha/yr)	Volume PAI (m^3/ha/yr)	Carbon (tCO_2eq/ha/yr)
Control	1.27	0.25	0.36	0.18	0.72	7.5	9.0
Thinned & pruned	0.02	0.40	0.54	0.14	1.22	9.7	11.8
Sig.	**	**	**	NS	**	*	*
s.d.(Stand)	0.67	0.06	0.11	0.05	0.21	2.0	2.2

The standard deviation between stands shown in Table 2 indicates the variability between sites that can be expected for each characteristic. It can be expected that 95% of sites fall within two standard deviations of the mean. For example, mean carbon sequestration in unthinned stands is 9.0 tCO_2eq/ha/yr with standard deviation 2.2. This indicates that 95% of stands fall within the range 6.8 – 11.2 tCO_2eq/ha/yr.

Effect of thinning on biodiversity/understorey
The mean biodiversity score was significantly higher in thinned than control PSPs, and significantly higher in plots with no evidence of grazing or browsing compared with those with evidence of grazing (Table 3). The higher biodiversity scores in both thinned and non-grazed/browsed plots of an understorey vegetation tier are clearly illustrated in a range of photographs taken during the 2020 remeasurement period provided in Appendix 2.

Table 3. Mean biodiversity score in control and thinned PSPs, and in grazed and ungrazed stands in regenerating tōtara pole stands in 2020.

Treatment	Biodiversity score	Sig.
Control	2.05	**
Thinned	3.62	
Evidence of grazing/browsing	1.89	**
No grazing/browsing	3.78	

Statistical significance of differences between control and thinned PSPs and between grazed and ungrazed PSPs indicated as follows: ** significant ($p<0.01$).

Merchantable stands
Results for the merchantable stands are summarised in Tables 4 and 5. Average DBH and height in these stands were about 40 cm and 22 m respectively, and average stand density about 500 stems/ha. Height and DBH growth rates were similar to those in unthinned pole stands. Annual increments per hectare of BA, volume and carbon increments in merchantable stands were generally similar to or a little higher than those of pole stands. There was no significant difference in any characteristic between stands with recent harvest activity and unmanaged stands, although the small sample size made this comparison unlikely to yield significant results.

Table 4. Mean stand characteristics of control and harvested PSPs in merchantable regenerating tōtara stands in 2020.

Treatment	Stand density (stems/ha)	DBH (cm)	MTD (cm)	MTH (m)	BA (m^2/ha)	Volume (m^3/ha)	Carbon (tCO_2eq/ha)	SDI	Species (% tōtara)
Control	516	40.9	64.7	22.4	68.6	625	726	450	97
Harvested	449	36.6	59.0	22.1	45.7	587	641	300	93

Table 5. Mean PAI (periodic annual increment) of stand characteristics of control and harvested PSPs in merchantable stands over the period 2018 – 2020.

Treatment	Annual mortality (%/yr)	DBH PAI (cm/yr)	MTD PAI (cm/yr)	MTH PAI (m/yr)	BA PAI (m^2/ha/yr)	Volume PAI (m^3/ha/yr)	Carbon (tCO_2eq/ha)
Control	0.00	0.28	0.40	0.19	0.93	12.6	13.7
Harvested	0.00	0.25	0.15	0.21	0.64	11.3	12.3

These trials provided fairly precise estimates of annual increments in stem volume and carbon in naturally regenerating tōtara-dominated stands which are summarised in Table 6.

Table 6. Means and 95% confidence intervals of mean annual volume and carbon increments in three types of naturally regenerating tōtara-dominated stands.

Stand type	Stem volume (m^3/ha/yr)	Carbon (tCO_2/ha/yr)
Unthinned pole stands (13 d.f.)	7.50 ± 1.86	8.95 ± 2.16
Thinned pole stands (13 d.f.)	9.66 ± 1.75	11.80± 2.01
Merchantable stands (6 d.f.)	12.36 ± 4.93	13.49 ± 5.64

Size/density chart

Size/density charts, where the quadratic mean DBH is plotted against stand density, are useful tools that can be used to assist with decisions concerning the timing and intensity of thinning (Reineke 1933). Figure 1 presents a size/density chart showing measurements from the thinning trial and merchantable stands. The chart can be used in conjunction with Reineke's SDI (Stand density Index) which can be calculated for each PSP measurement from the quadratic mean DBH and stand density ($SDI = 0.00229 \times Stocking \times DBH^{1.6}$).

The line labelled "Fully Stocked" in Figure 1 represents stands with SDI=700. The data suggests that 700 is the maximum SDI for tōtara. According to theory, stands cannot consistently exceed the maximum SDI. As trees in an unthinned stand grow, the mean DBH increases until the SDI approaches the maximum. When this occurs, such stands undergo self-thinning which reduces the stocking ensuring the SDI does not exceed the maximum. Most of the unthinned PSPs in the thinning trial clearly follow this process with their DBH vs Stocking following a trend close to or a little below the "Fully Stocked" line.

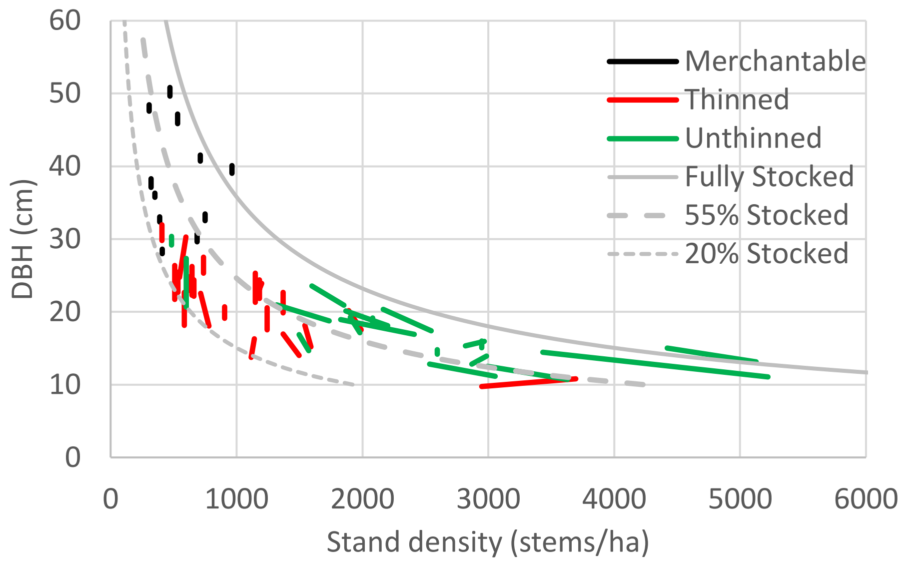

Figure 1. Size/density chart showing thinned and unthinned pole stands and merchantable stands.

Each line shows the trajectory of a PSP in the DBH/Density space over the 2–8-year periods between measurements.

Recommended thinning schedule for tōtara

Overseas experience suggests that for a wide range of species, stands benefit from thinning when the stocking is greater than 55% of the maximum, and that stands should be thinned down to 25% of the maximum stocking. Based on this rule, a thinning schedule table was developed for tōtara providing the stocking above which a stand should be thinned, and the stocking it should be thinned down to, tabulated against mean DBH (Table 6).

Table 7. Recommended thinning schedule for young naturally regenerated tōtara-dominant pole stands.

For any given quadratic mean DBH, a stand with stocking greater that 55% of the fully stocked stand density should be thinned down to 25% of the maximum.

Mean DBH (cm)	Stem density (stems/ha)		
	Fully stocked	55% stocked	25% stocked
10	7,686	4,227	1,921
11	6,599	3,629	1,650
12	5,741	3,158	1,435
13	5,051	2,778	1,263
14	4,486	2,467	1,122
15	4,017	2,210	1,004
16	3,623	1,993	906
17	3,288	1,809	822
18	3,001	1,650	750
19	2,752	1,514	688
20	2,535	1,394	634
21	2,345	1,290	586

22	2,177	1,197	544
23	2,027	1,115	507
24	1,894	1,042	473
25	1,774	976	444
26	1,666	916	417
27	1,569	863	392
28	1,480	814	370
29	1,399	769	350
30	1,325	729	331
31	1,257	692	314
32	1,195	657	299
33	1,138	626	284
34	1,085	597	271
35	1,036	570	259
36	990	544	247
37	947	521	237
38	908	499	227
39	871	479	218
40	836	460	209
41	804	442	201
42	774	425	193
43	745	410	186
44	718	395	180
45	693	381	173
46	669	368	167
47	646	355	162
48	625	344	156
49	604	332	151
50	585	322	146
51	567	312	142
52	550	302	137
53	533	293	133
54	517	285	129
55	502	276	126
56	488	268	122
57	475	261	119
58	462	254	115
59	449	247	112
60	437	240	109

Implications

Revised thinning recommendations
This latest remeasurement of the tōtara silvicultural PSPs in Northland indicates that thinning of tōtara can be carried out to lower stocking rates than indicated in previous studies (Quinlan et al., 2014). For example, the previous measurement of these stands in 2012, 5 years after the PSPs were established, showed that a stand with an average DBH of 16 cm would benefit from thinning if its stocking is greater than 3,300 stems/ha and should be thinned down to about 1,500 stems/ha. The latest remeasurement in 2020 a further 8 years later, indicates the same stand with a mean stem diameter of 16cm could be thinned down to a stocking of 900 stems per hectare (Table 6).

As with previous recommendations, thinning usually involves the removal of poorly formed trees, followed by the removal of small and suppressed trees which can cause an increase in mean DBH. Thinning of only poorly formed and the smaller diameter suppressed trees may or may not achieve an adequately thinned stand. In order to ensure thinning meets the 25% stocking target of the original stand, a sample of trees should be measured to check whether the thinning has resulted in a significant shift in the stand's mean DBH. If not, this may mean that further trees should be thinned to achieve the target stocking for the mean DBH of the stand. Alternatively, mark-up the selected residual 'future crop trees' to stay, at the right stocking rate, and thin the rest (i.e., the unmarked trees).

Growth rates
In Table 6, the mean annual stem volume increment in the merchantable-sized stands is 12.36 m^3/ha/yr and 9.66 m^3/ha/yr for the thinned pole stands. These results will be of interest to Te Uru Rākau who administer part 3A of the Forests Act. There may be implications for growth modelling, allowable harvest intensities, and minimum target stocking rates for silvicultural interventions etc. under approved Sustainable Forest Management Plans and Permits. The enhanced understorey development in thinned pole-stands will also be of interest.

Carbon
Table 6 also shows respectable mean (PAI) carbon sequestration rates of 11.8 tCO_2/ha/yr for thinned pole stands and 13.49 tCO_2/ha/yr for the merchantable stands. Most of these tōtara stands still have considerable potential to sequester more carbon. However, because these forests would have established prior to 1990, they are ineligible to enter the New Zealand Emissions Trading Scheme.

Biodiversity management
The results indicate that silvicultural management, comprising thinning and pruning in tōtara pole stands, can be compatible with enhancing biodiversity values. While these regenerating farm stands are typically dominated by tōtara, it is recommended that other native tree species are retained to maintain biodiversity values. In Northland regenerating tōtara forest, even in the presence of grazing, can have occasional poles or trees within the canopy such as kauri, kahikatea, rimu, tanekaha, and miro, puriri, taraire, and kohekohe.

Similarly, the removal of grazing clearly has a positive effect with increased understorey development and likely increased species diversity. The development of a diverse understorey including potential replacement of canopy trees comprising a range of native conifers and hardwoods, will depend on having local seed sources. Such regeneration will be essential to long term management and species diversity within these currently totara-dominant regenerating farm stands. Excluding livestock and controlling pests in such stands, particularly when thinned to allow more light and reduced competition, will likely provide opportunities for development of mixed species/mixed age forests in the long term. This is likely to enhance the natural character values and create more resilient native forests.

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Appendices follow over page.

Appendix 1. Biodiversity/understory development score field sheet.

Biodiversity score sheet

Plot descriptor:
Paired with:

Assessor:
Date:

Score (1-5) 1 =very poor little or no understory, 3= average (some regrowth but not so dense that you can't see each other in plot), 5= very good (lots of regrowth, mostly natives, very dense and can't see each other across plot).	
Browsing (Y/N)	
Species:	
Other notes	
Photos (north to south)	

Appendix 2. Photographic examples of comparative understory development between thinned and unthinned PSPs.

Tōtara biodiversity comparison images from Titoki thinning trial plots
Michael Bergin, August 2022

Above: Control plot (no thinning) and grazed

Above: Thinned and grazed five years after thinning

Above: Control (no thinning) and no grazing

Above: Thinned and no grazing five years after thinning.

Above and below: the effect of grazing in thinned plots. Note the fence line running down the hill.

Above; control (no thinning) plot with no grazing.

Below: thinned plot with no grazing five years after thinning.

Left: control (no thinning) plot with no grazing. Right: thinned plot with no grazing five years after thinning.

End.