GROWTH OF FIRST ROTATION RADIATA PINE IN GOLDEN DOWNS STATE FOREST, NELSON, FOR COMPARISON WITH SUBSEQUENT CROPS

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ABSTRACT

Normal records of growth and yield of eight unthinned permanent sample plots of radiata pine (**Pinus radiata** D. Don) were supplemented to provide direct estimates of total stem volume under bark from sectional measurements. Volume/basal area lines were used to assess standing volume at time of felling, and stand volume lines based on stand height and basal area per unit area were computed from these data and from similar data based on stem analysis, to estimate standing volume at different ages.

These basic data are intended to provide a reliable record of how the first crops grew, so that productivity in second and successive crops tended in the same way may be compared. Thus, each permanent sample plot has been relocated in the naturally regenerated second rotation and their initial stockings have been reduced to the same level as in the first crop.

INTRODUCTION

One way of assessing whether or not there is a decline in productivity of a given species from one rotation to the next is to relocate permanent sample plots with good records of establishment, tending, and growth for the first crop on exactly the same area, and to recreate as nearly as possible the same non-edaphic conditions for growth in successive crops as in the first. This approach, however, yields answers only after a long period of time has elapsed, answers which may be somewhat academic if new practices in establishment and tending are generally prescribed for later crops of the species.

Nevertheless, assessing the long term productivity of a site in terms of the yield of a crop grown in a given way is of fundamental importance to the continuity of production forestry. It is particularly pertinent in a region such as Waimea Country, Nelson, where soil deficiencies for agriculture, horticulture, and forestry are known to exist (Chittenden *et al.,* 1966).

The opportunity to assess productivity of a first crop of *Pinus radiata* in Golden Downs forest arose when 30- to 41-yr-old stands containing permanent sample plots where periodic measurements and remeasurements had been taken for about 16 yr, were subjected to substantial windthrow and were about to be salvaged in 1968. Eight sample plots, each of 0.16 ha and respectively numbered N79/8, 17, 18, 19, 24, 31, 33, and 39, were assessed.

These sample plots were measured first in 1952 and again in 1957, 1961, 1965, and finally in 1968. The first four are close together and the second four form another closely spaced group.

Permanent plots such as these are usually processed to yield good direct estimates of over bark (o.b.) basal area from diameter measurements, and of stand height from height measurements of sample trees and a curve of height on diameter. Total stem volume, however, is usually obtained in one of two ways from measurements of diameter at breast height (d.b.h.)* of all trees in the plot and height of a few sample trees; either a height-diameter curve and a regional two-dimensional volume function are used, or the volume of sample trees is computed from a regional two dimensional volume table, a volume/basal area line is computed and then applied to all trees in the plot. Although those methods of calculation may be generally satisfactory for working plan continuous forest inventories of extensive populations, provided that the volume functions are representative, they are not well suited to detailed studies of productivity of individual sample plots.

METHODS OF MEASUREMENT

To supplement the basic data and results available for the sample plots, it was considered worthwhile to assess a good measure of present total stem volume of each plot, and provide a good indication of basal area and volume increment trends of individual trees in each plot.

Present total stem volume in each plot was assessed in the following way:

(1) Overbark diameters at breast height of all trees were measured and recorded to the nearest 2.54 mm (breast height had been marked previously, so that there was no difficulty in locating this point even on windthrown trees),

(2) The diameters were arranged in ascending order.

(3) Four normal trees were selected by a random procedure in the upper 15% of the d.b.h. range and four more from the lower 15%, but after excluding the bottom 5% of the range; however, in sample plot N 79/24 six trees in each sector were used.

(4) Before measuring, it was necessary to ensure that the total length of any windthrown Sample trees could be reconstructed, but where this was impossible, such a tree was rejected and another substituted, again by a random procedure (e.g., sample plot 79/8 was so badly windthrown that an insufficient number of individual trees could be reconstructed with certainty and, hence, no sectional measurements were made in this plot).

(5) The sample trees were sectionally measured in mid-internodal taper steps of 25.4 mm as explained by Whyte (1971).

(6) Total stem volume under bark was computed using computer programme RI 105, for an Elliott 503 computer, the specifications for which are presented in an earlier report (Whyte, 1969).

(7) The volumes of the sample trees were then used to calculate a volume/basal area line for the plot, and from this, together with the d.b.h.o.b. of all trees in the plot, total stem volume of the plot was derived.

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* Breast height was taken at 1.37 m.

Trends in under-bark basal area were obtained from each of the sectionally measured trees as follows:

(1) In the laboratory, ring widths on discs taken at breast height were measured on each of the four cardinal radii to the nearest 0.5 mm.

(2) Annual basal area trends were then computed from computer programme RI 121 (Whyte, 1969).

Stem analysis was carried out only on N 79/24, where the procedure was as follows:

(1) A disc was cut at each mid-internodal point where a sectional measurement of diameter had been taken.

(2) In the laboratory, ring widths on the disc were measured on each of the four cardinal radii to the nearest 0.5 mm.

(3) Annual volume and volume increment trends were then computed from computer programme RI 124 (Whyte, 1969).

These constituted the basic data employed in this study to supplement the usual information available from Forest Service permanent sample plots.

RESULTS

Table 1 contains tree numbers, their d.b.h.o.b., height, sectionally measured volume and, for the sake of later comparison, volume interpolated from the 1952 two-dimensional volume table for unthinned stands of *Pinus radiata* in Nelson (Duff and Burstall, 1955), for each sample plot.

Volumes derived from stem analysis of the 12 sample trees in plot N 79/24 at five different ages and their corresponding d.b.h.o.b.'s squared were obtained through TRIP (van der Voort, 1968), a computer package which can, among other capabilities, give access to basic data for individual trees in Forest Service permanent plots stored on computer files.

Table 2 contains least-squares regression parameters for the volume/basal area lines computed for each of the sample plots separately, and also the volume/basal area lines in the years 1952, 1957, 1961, and 1965 for N 79/24. The regression parameters listed are the regression constant, b_0 the regression coefficient, b_1 the standard error of b_1 and the coefficient of determination, r^2.

Table 3 gives the compartment and age of the stand, number of stems, stand height, H_0 (Beekhuis, 1967) basal area, and volume of the plots (with standard error) and their equivalents per hectare, $\mathbf{G}$* and $\mathbf{V}$. All these values were obtained from field measurement of height and d.b.h.o.b., and from the volume/basal area line for each plot except N 79/8, for which estimates of volume were obtained from a stand volume line, explained below.

Table 4 is a summary of the development of sample plot N 79/24 and lists basal area, number of stems and total stem volume per hectare at 22, 27, 31, 35, and 38 yr of age.

Values for H_0, $\mathbf{G}$, and $\mathbf{V}$ in Table 3 for seven of the eight sample plots (N 79/8 was omitted) were used to compute a stand volume line by the combined-variable formula $\mathbf{V} = b_0 + b_1 (\mathbf{G} \times \mathbf{H}_0)$.

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* Bold letters denote mean values.

TABLE 1—Sectionally measured volumes

Plot No.	Tree No.	D.b.h.o.b. mm	Height m	Sectionally Measured Volume m^3	Volume Table Estimate m^3
N79/17	45	597	43.3	3.794	3.831
	107	660	42.1	4.103	4.519
	76	610	45.1	4.278	4.140
	88	577	41.8	3.222	3.458
	35	345	32.3	0.988	1.039
	17	292	26.2	0.705	0.626
	60	295	31.4	0.714	0.759
	81	274	29.0	0.595	0.617
	Mean			2.299	2.371
N79/18	77	546	43.0	3.404	3.194
	86	559	42.1	2.849	3.268
	102	521	44.2	2.840	3.002
	18	597	43.3	3.474	3.831
	74	343	37.2	1.121	1.175
	98	318	38.1	1.008	1.051
	134	376	37.5	1.441	1.351
	151	310	32.9	0.793	0.869
	Mean			2.115	2.217
N79/19	3	541	42.7	2.897	3.115
	22	640	42.4	4.171	4.284
	68	549	45.4	3.010	3.418
	90	653	43.0	4.284	4.516
	114	297	33.5	0.949	0.824
	52	254	23.8	0.388	0.442
	47	272	23.5	0.555	0.493
	53	330	33.2	0.900	0.983
	Mean			2.144	2.260
N79/24	47	328	37.8	1.073	1.102
	53	356	31.4	0.835	1.062
	49	318	28.7	0.515	0.793
	34	338	35.3	1.053	1.090
	46	330	32.9	0.787	0.974
	65	353	37.5	1.334	1.252
	23	592	44.2	3.356	3.845
	40	533	43.3	2.820	3.075
	122	671	39.0	4.443	4.307
	52	559	46.6	3.132	3.653
	119	599	40.5	3.166	3.622
	1	551	39.6	2.509	3.004
	Mean			2.084	2.316

TABLE 1 (continued)

Plot No.	Tree No.	D.b.h.o.b.	Height	Sectionally Measured Volume	Volume Table Estimate
		mm	m	m^3	m^3
N79/31	16	572	46.6	3.695	3.794
	87	617	43.0	4.347	4.055
	11	559	42.4	2.758	3.290
	14	556	45.1	3.435	3.486
	3	325	34.4	0.784	0.991
	39	307	26.8	0.558	0.699
	101	297	25.9	0.643	0.637
	1	333	31.4	0.866	0.940
	Mean			2.135	2.237
N79/33	5	589	43.6	3.744	3.763
	17	559	45.7	3.744	3.568
	101	531	41.5	3.053	2.920
	77	518	41.1	3.234	2.772
	9	274	32.6	0.762	0.680
	37	318	34.4	1.034	0.951
	51	343	31.7	1.141	1.005
	8	279	29.9	0.609	0.657
	Mean			2.163	2.039
N79/39	124	531	39.9	2.605	2.812
	102	505	33.5	1.674	2.155
	119	495	37.5	1.994	2.319
	44	406	36.0	1.365	1.546
	62	279	26.8	0.456	0.592
	47	201	25.6	0.249	0.309
	34	277	30.5	0.612	0.657
	36	246	28.3	0.436	0.496
	Mean			1.172	1.359

TABLE 2—Summary of equations for individual plots

Year	Plot No.	b_o	b_1	$s_{(b_1)}$	r^2
1968	17	-0.2205	10.8191	0.6628	0.978
	18	-0.0677	10.3188	0.7813	0.967
	19	-0.1904	10.5821	0.2458	0.997
	24	-0.2225	10.0993	0.5530	0.971
	31	-0.5390	12.3817	0.7944	0.976
	33	-0.2175	12.0481	0.5618	0.987
	39	-0.1079	8.5193	0.8164	0.948
1965	24	-0.1710	9.5156	0.5838	0.964
1961	24	-0.2323	9.2127	0.7418	0.939
1957	24	-0.1935	8.5061	2.6027	0.907
1952	24	-0.2022	7.5493	4.0160	0.780

TABLE 3—Plot statistics in 1968

Plot	Cpt	Age	No. of Stems In Plot	H_o	Plot BA	Plot Volume	SE ($\bar{V}$ Plot)	BA	Volume	SE ($\bar{V}$)
		yr		m	m^2	m^3	m^3	m^2/ha	m^3/ha	m^3/ha
N79/3*	14	41	104	43.9	15.050	193.23	5.61	93.0	1192.0	34.71
N79/17	34	38	91	43.9	12.635	153.73	1.59	77.8	949.7	9.80
N79/18	33	38	107	43.0	15.422	194.88	1.16	95.0	1203.9	7.14
N79/19	35	38	70	43.3	11.241	137.96	1.02	69.3	852.2	6.30
N79/24	60	38	94	42.4	14.772	169.25	1.56	91.4	1045.5	9.59
N79/31	55	37	67	44.2	12.728	164.71	1.53	78.7	1017.8	9.38
N79/33	53	37	99	43.0	13.192	180.58	1.16	81.5	1115.6	7.21
N79/39	64	30	108	37.2	10.219	99.68	0.91	63.4	615.8	5.67

* Volume calculated from stand volume line, $V = 108.516 + 0.319125(H_0 G)$

TABLE 4—Growth statistics for N 79/24

Age	BA	Stems	Volume	Net PMAI of Volume
yr	m^2/ha	No./ha	m^3/ha	m^3/ha
22	61.8	754	441.1	
27	72.5	684	653.2	42.4
31	80.1	625	794.6	35.3
35	85.9	598	938.0	35.8
38	91.4	581	1045.5	35.8

Table 5 contains three sets of regression parameters. Equation 1 refers to the seven pairs of variables taken from Table 3; it is described by the number of samples used, b_0, b_1, $s_{(b1)}$, r^2 and the standard error of the mean predicted value of volume per hectare, $s_{(v)}$, in m^3 and percent. The remaining two equations will be explained later.

TABLE 5—Stand volume lines

Equation No.	No. of Samples	b_o	b_1	$s_{(b_1)}$	r^2	$s_{(\bar{V})}$ m^3/ha	%
1	7	-121.252	0.322604	±0.045270	0.911	±23.931	±2.5
2	8	-108.516	0.319125	±0.034189	0.936	±20.473	±2.2
3	8	- 95.384	0.315313	±0.027305	0.957	±20.527	±2.3

Table 6 compares two *independent* estimates of volume per hectare for N 79/24 at time of earlier measurements. The first estimate is obtained from recorded measurements of d.b.h.o.b. and the computed volume/basal area lines for years 1952, 1957, 1961, and 1965 (Table 2), obtained from volumes by stem analysis. The second estimate was obtained from measured basal area per hectare and height (Table 3) and the first of the stand volume lines in Table 5, which was based on direct estimates of volume per hectare for all seven plots for the year 1968.

TABLE 6—Volume per hectare for N 79/24 from stem analysis and plot volume/basal area line compared with stand volume line

Age	$\bar{V}$ from		Difference	
	Stem Analysis	Stand Volume Line		
yr	m^3/ha	m^3/ha	m^3/ha	%
35	938	959	-21	-2.3
31	795	793	2	0.2
27	653	642	11	1.7
22	441	419	22	5.0

The good correspondence of the two independent estimates will be discussed later. One of the immediate consequences, however, of this satisfactory rsult is the acceptability of including one other estimate of volume per hectare for N 79/24 in the first stand volume line. Equation 2 was calculated from the original seven values plus **V** and (**G** × $\mathbf{H}_0$) for age 27, and equation 3 from the seven values plus data for age 22. Equation 3 is shown graphically in Fig. 1.

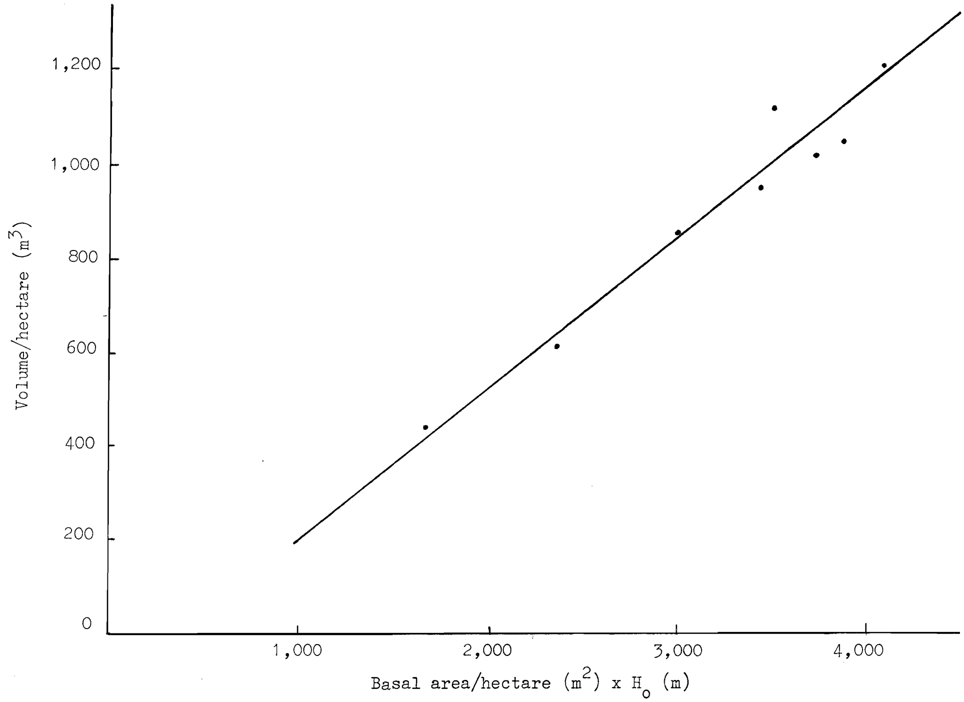

FIG. 1—Graph of equation 3 (see Table 5).

DISCUSSION

The sectionally measured volumes of trees do not always show good correspondence with the two-dimensional volume table estimates, particularly in plots N 79/24, N79/31, and N 79/39, although the mean difference for N 79/31 was close to the mean for all plots (*see* Table 1). Because diameter measurements were taken at mid-internodes in this study, one would anticipate that volumes computed from those diameters would be smaller on average than the volume table estimates. This is because the trees from which that table was compiled were sectionally measured at fixed height intervals, although obvious nodes were deliberately avoided in measuring those trees. This statement is generally true for all plots except N 79/33, where the sectionally measured volumes are significantly larger statistically than the volume table estimates. Such a surprising result for that plot merely serves to underline the importance of having good direct estimates of volume rather than functionalised values with unknown bias for particular stands. Furthermore, it is possible that the regional volume function will be changed from time to time. Most of the basic data used to produce the 1952 table, for example, were from smaller trees than those measured in this investigation (458 of the 526 sample trees used in preparing the table were less than 406 mm (16 in.) in diameter and 450 were less than 30.48 m (100 ft), but the average tree in this study was considerably greater than 406 mm in d.b.h.o.b. and 30.48 m in height). Thus it is again imperative to have good direct estimates of volume as permanent records.

Table 2 shows the good fit to all the volume/basal area lines based on 1968 data, as judged by the high coefficients of determination (mean = 0.975) and low standard errors of regression slope (mean = ±6.0%). This satisfactorily high degree of precision was obtained with so few trees because the basic data were restricted to near both ends of the basal area range and did not include intermediate values, which contribute little if anything to the regression parameters, provided that a straight line fit is the correct model, which it is believed to be in this case.

The precision of the volume/basal area lines for N 79/24 at the years of measurement before 1968 declines with increasing time between the 1968 and earlier measurement. This is mainly due to the fact that the basal areas were spread more and more evenly throughout the *entire* basal range at each successive earlier time of measurement. Nevertheless, the very close agreement between the two independent estimates of volumes per hectare for these earlier years of measurement (*see* Table 6), even at age 22 yr, where $\mathbf{G} \times \mathbf{H}_0$ is outside the range of basic data used in constructing stand volume line number 1, suggests that these volume/basal area lines are accurate although a little imprecise.

In constructing the stand volume lines, the combined variable formula $\mathbf{V} = b_0 + b_1 (\mathbf{G} \times \mathbf{H}_0)$ was used instead of the Australian formula $\mathbf{V} = b_0 + b_1 \mathbf{G} + b_2\mathbf{H} + b_3 (\mathbf{G} \times \mathbf{H}_0)$, because there are few enough degrees of freedom for standard errors of predicted values even for the former, and indications are (e.g., Spurr, 1952) that there is little to choose between the two formulae anyway. Since the independent estimates of volume per hectare from earlier measurements of N 79/24 agree so closely it was considered desirable to include at least one of these estimates from the stem analysis in the basic data for a new stand volume line.

Two possibilities were tried, one using data for age 27 and the other for age 22 yr. Although estimations from the former are very slightly (0.1%) more precise than the latter, it seems better to include the values of $\mathbf{V}$ and ($\mathbf{G} \times \mathbf{H}_0$) for age 22 yr as this provides a wider range of data. This reconstituted stand volume line could be used as a standard for the first crop of radiata pine, particularly if other independent volumes per hectare obtained from direct measurement could be added to the small size of sample of eight pairs of $\mathbf{V}$ and ($\mathbf{G} \times \mathbf{H}_0$). Volumes of the seven plots (excluding N 79/24) can be both accurately and precisely estimated from this stand volume line, in years when overbark measurements of diameter and sample heights were taken. This obviated the necessity for tedious stem analyses in these plots. Plots in the second and successive crops could be assessed to provide information about basal area production and stand height (H_0) development. If direct measurements of volume are also obtained, the analyses outlined here could be repeated and the two stand volume lines used to compare volume production in different rotations, *independently* of any change in either basal area per hectare or stand height with age.

Trends in annual development of basal area and volume, and therefore in basal area, and volume increment of single trees may be useful information for future reference. These data are not functionalised in any way at present, but in the future, one may wish to compare regressions of growth in, for example, volume over a 4-yr period in terms of volume at the beginning of the period, and periodic volume increment immediately preceding the beginning of the period for the two different rotations. The information necessary for this type of analysis is available at the Forest Research Institute, Rotorua.

Each of these permanent plots has been relocated in the second rotation. Where natural regeneration has taken place it is necessary to ensure that the same levels of initial stocking as in the first crop exist. The first crop was unthinned, and so, even though commercial thinning is planned for the whole of the second crop, these sample plots plus a generous surround should be maintained in the same unthinned condition as the first crop for comparative purposes. The same would apply to an artificially re-established crop but with the further proviso that the seedlings planted come from the same seed source as the first crop.

CONCLUSIONS

The basic data and results included in this report supplement information available from original measurements made in the sample plots and existing results obtained from these measurements. In particular, they provide more detailed and more reliable information on growth in volume than would otherwise have been obtained. They can be used, therefore, as a standard with which to compare productivity in the second and successive crops, treated in the same manner.

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REFERENCES

BEEKHUIS, J. 1967: Cited in "Standard Methods for Inventory and Growth Measurement of Exotic Forests" by H. M. N. Lees, N.Z. Forest Service, Wellington.

CHITTENDEN, E. T.; HODGSON, L., and DODSON, K. J. 1966: Soils and agriculture of Waimea county, New Zealand. **New Zealand Soil Bureau Bulletin 30.**

DUFF, G., and BURSTALL, S. W. 1955: Combined taper and volume tables for unthinned stands of **Pinus radiata** in Nelson. **New Zealand Forest Service, Forest Research Institute, Research Note 1.**

SPURR, S. H. 1952: Chapter 12 **in** "Forest Inventory". Ronald Press, New York.

van der VOORT, C. R. 1968: TRIP — a tree record interrogation package for the Elliott 503 computer. **New Zealand Forest Service, Forest Research Institute Research Leaflet 20.**

WHYTE, A. G. D. 1969: Some computer programmes dealing with size and growth of individual trees. **New Zealand Forest Service, Forest Research Institute, Mensuration Report 25** (unpublished).

——— 1971: Sectional measurement of trees: a rationalised approach. **New Zealand Journal of Forestry Science, 1 (1):** 74-9.