DRY MATTER CONTENT AND PRODUCTION OF CLOSE-SPACED PINUS RADIATA

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ABSTRACT

The weight and production of the above-ground components of a stand of **Pinus radiata** D. Don were estimated between ages 5 and 13 years. Initial stocking was approximately 6900 stems/ha.

The weight of 1-year-old and total foliage peaked at about age 7, with older foliage forming an increasing percentage of total foliage weight as the stand aged. Live branch weight remained approximately constant but weight of dead branches increased with time. Loss of dead branch material through decay and shedding was about 5% per year. Maximum mean annual increment was 21 t/ha/yr and current annual production about 36 t/ha/yr.

The allocation of increment among components indicated a shift to stemwood production at the expense of needle, branch, and bark production throughout the 8 years of growth.

Keywords: biomass; mean annual increment; above-ground components; close-spaced stands; **Pinus radiata**.

INTRODUCTION

In a previous paper preliminary results were presented on the dry matter content of a young, close-spaced, *Pinus radiata* stand between ages 5 and 10 years (Madgwick 1981). It was postulated that maximum mean annual increment was reached at about age 10 years independent of whether stem or total above-ground dry weight was considered. The measurements have been continued on an annual basis and this paper reports results to age 13 when measurement was discontinued.

MATERIALS AND METHODS

Between 1970 and 1975, 50-tree rows of *P. radiata* were planted once or twice a month in the Long Mile area of Rotorua (lat. 38° 09′ S, long. 176° 16′ E). Nominal spacing was 1 m within and 1.5 m between rows. Each February from 1980 to 1984 the diameter of each tree was measured, excluding the five outermost trees in each row. Before the experiment was abandoned actual spacing was measured and an area equal to row length times half the distance between each pair of adjacent rows was used to calculate the effective area available to each row of trees.

A total of 72 trees were felled for detailed analysis comprising 22 in 1980, 20 in 1984, and 10 in each of the intervening years (Table 1). In 1980 the sample included a preponderance of young age-classes but in 1984 the bias was towards older trees. In each of the other 3 years two trees were sampled from each age-class present. The pattern of sampling resulted in the detailed measurement of eight individuals of each age-class from 5 to 13 years. The sample trees comprised a stratified random sample based on five diameter classes within each age-class. One tree was sampled from the smallest and the largest diameter classes and two each from the intermediate-small, medium, and intermediate-large diameter classes.

TABLE 1—Distribution of sample trees by age-class and year of sampling

Sampling year	Tree age (years) 5	6	7	8	9	10	11	12	13
1980	8	6	4	2	2	*	*	*	*
1981	*	2	2	2	2	2	*	*	*
1982	*	*	2	2	2	2	2	*	*
1983	*	*	*	2	2	2	2	2	*
1984	*	*	*	0	0	2	4	6	8

* No trees of this age-class present

Each felled tree was measured for diameter at breast height (d.b.h.) and stem diameter 10 cm below the lowest branch bearing green needles ("live branch"). Diameters were measured at 2-m intervals from the base to the top of the tree both inside and outside bark in order to calculate total volumes over and under bark. Total height and length of live crown (the distance from the lowest live branch to the apex) were recorded.

For each tree cones were removed and bulked for the whole crown. Branches within the live crown were removed and kept separate by 2-m height zones. Branches from the dead crown zone were pooled. Branches in the live crown were divided into live and dead, based on the presence or absence of green needles. Live branches were divided into needle-bearing and non-needle-bearing portions, and the needle-bearing shoots were divided into their yearly age-classes. Categories of material weighing more than 1 kg were weighed fresh and subsamples of known weight taken for further examination. Each 2-m stem section was weighed fresh and a disc was removed from each diameter measurement point and also weighed before separation into wood and bark.

Sample material was oven-dried at 70°C to constant weight to determine dry matter content. Needle-bearing twigs were dried, separated into needle and twig components, redried, and weighed.

Tree height in metres (ht) was related to d.b.h. in centimetres within each age-class using the Petterson curve:

$$\ln\,(\mathrm{ht} - 1.4) = a + b/\mathrm{d.b.h.}$$

Examination of the regression coefficients, a and b, indicated that they were both related to tree age and consequently data for all 72 trees were combined to fit the equation:

$$\ln(ht - 1.4) = a + b/d.b.h. + c.age + d.age^2 + e.age/d.b.h.$$

where age was in years, and a, b, c, d, and e were regression coefficients.

Generally, logarithm component weight was related to both logarithm d.b.h. and tree age. For total branch weight the age term was not significant. For cone weight the relationship with d.b.h. and age was best expressed using untransformed data. All estimates based on logarithmic regressions were corrected for bias (Finney 1941).

Total basal area and component dry weights of live trees on a per hectare basis were calculated for each row and each measurement date. The weight of branches and stem of each dead tree was calculated using d.b.h. and age at the last measurement date where the tree was recorded as alive or, for the trees which were dead at the initial measurement, from d.b.h. and current age.

Trends in productivity from row to row within the plantation were examined by estimating basal area and component weights for each row at age 9 years from the two measurements nearest to age 9, assuming a linear growth curve. After examination of the trends, data were scaled by the row mean values at age 9. Stand weights for each annual age-class were obtained by averaging results for the 10 rows nearest in age to the required age.

Examination of the data indicated that the proportions of major components (total needles, total branch, stemwood, and stembark) agreed well between sample tree averages and estimated stand weights for each age-class. Estimates for subcomponents (needle age-classes and live *v.* dead branches) indicated discrepancies between measured sample tree and estimated plot values. Consequently, the weights of needle and branch subcomponents were estimated for each age-class by apportioning estimated total component weights by the fractions found in each subcomponent of each age-class of sample trees.

Current rates of production were estimated from the annual production of needles and the annual increments in cone and stem weights. Since the weight of live branches remained approximately constant, branch increment was estimated from the weight of branches per metre of stem in the zone above the lowest live branch and the annual change in the height of the lowest live branch. Bark and cone shedding were assumed negligible and dry matter increment of needles after the first year of growth was assumed to be zero.

RESULTS

At the first measurement rows varied in age from 4.7 to 9.0 years and at the last measurement from 8.7 to 13.0 years. The estimated total basal area for each row at age 9 years was not significantly correlated with position in the stand as indicated by row number ($r = 0.078$, $n = 86$). Mean basal area at age 9 was 50.67 m^3/ha with a coefficient of variation of 14% (Table 2). Estimated total tree weight at age 9 was similarly not significantly related to position ($r = 0.156$, mean 183.5 t/ha, C.V. 17%). Coefficients of variation of other stand variables, based on single row estimates, varied from 4% for height to 23% for total needle weight.

TABLE 2—Mean and coefficient of variation of variables based on the interpolated values at age 9 years for each of 86 rows

Variable	Mean	C.V. (%)
Stems/ha	6900	9.1
Total basal area (m^2/ha)	50.7	14.1
Top height (m)	17.1	3.7
Needle mass (t/ha)	13.6	23.0
Total branches (t/ha)	27.2	17.0
Cones (t/ha)	5.5	12.1
Total stem (t/ha)	137.9	17.5
Total tree (t/ha)	183.5	17.5

The nominal stocking was 6670 stems/ha. Actual stocking allowing for measured spacing and the number of stems forked below breast height was 6900 stems/ha (Table 3). Mortality, in terms of stem numbers, was erratic but by age 13 the number of live stems had declined to about 5190 stems/ha. Mortality in terms of basal area was less erratic and increased with the fifth power of stand age from 0.05 m^2/ha at age 5 to 7.0 m^2/ha at age 13.

Stand top-height, based on the tree of largest diameter in each row, increased from 8.9 m at age 5 to 23.2 m at age 13. The height growth pattern failed to match site index curves for the region (Burkhart & Tennent 1977). Projecting the height growth curve suggests a site index for *P. radiata* of about 30 m at age 20.

The estimated total weight of the above-ground portion of live trees increased from 83.4 to 278.2 t/ha between ages 5 and 13. Both 1-year-old and total needle mass peaked at age 7 with estimated weights of 10.6 and 14.8 t/ha, respectively. Total branch mass increased with stand age but the weight of live branches remained approximately constant at 13 t/ha.

Marked changes in the relative distribution of standing biomass occurred with increasing age. At age 5 needles and branches comprised 15 and 19% respectively of the total above-ground tree. By age 13 branches comprised only 12% and needles 4% of the above-ground dry matter. Within the needle component there was also a significant shift in age distribution with current needles comprising half the total on 5-year-old trees but only one-third of the total on 13-year-old trees.

Mean annual increment (MAI) of the above-ground portion of live trees varied between 20.5 and 21.4 t/ha/yr between ages 8 and 13, with no clear peak. Including the weight of dead trees (stems and branches only) delayed the estimated time of peak MAI to at least age 13 with a maximum value of 23.7 t/ha/yr. The time of peak MAI for live stems was similarly displaced. Given the current estimated stemwood production of about 28 t/ha/yr, the MAI of live stems would be expected to continue to rise but would be overtaken by increased mortality.

Total current annual increment of the trees (above-ground) averaged 35.9 t/ha/yr (standard error 0.8) with no significant trend with age (Table 4). The distribution of

TABLE 3—Stocking, basal area, height, and weight for close-spaced **Pinus radiata**

	Stand age (years)								
	5	6	7	8	9	10	11	12	13
Stocking (stems/ha)	6780	6847	6686	6575	6242	5919	5381	5289	5190
Basal area (m^2/ha)									
Live	31.90	39.10	43.00	46.80	48.30	50.10	50.30	51.90	55.30
Dead	0.05	0.05	0.33	0.59	2.38	3.61	6.14	6.78	7.01
Height (m)									
Top	8.94	10.81	12.84	14.96	17.10	18.75	20.58	21.99	23.17
Mean	7.72	9.23	10.73	12.13	13.46	14.71	15.92	16.55	17.05
Lowest live branch	1.26	3.47	4.85	6.05	6.55	7.99	9.64	10.25	10.96
Dry weight (t/ha)									
Needles									
1-year	6.26	8.97	10.55	8.74	6.55	4.91	3.83	3.78	3.54
2-year	5.49	5.57	3.99	5.33	5.51	5.43	4.79	3.73	3.63
3-year	0.72	0.23	0.27	0.59	1.57	1.87	2.41	2.76	3.13
Total	12.47	14.77	14.81	14.67	13.64	12.21	11.03	10.27	10.32
Branches									
Live	13.40	13.59	11.71	13.06	13.98	12.62	12.45	16.91	11.47
Dead	2.47	6.89	11.53	12.83	13.23	15.31	16.28	13.36	21.23
Total	15.87	20.48	23.24	25.89	27.21	27.93	28.73	30.27	32.69
Cones	0.00	0.63	2.35	4.11	5.51	6.62	7.45	8.26	9.00
Stems									
Wood	50.33	71.19	88.36	107.83	123.96	139.09	156.37	180.18	208.20
Bark	6.90	9.24	10.98	12.80	14.09	15.18	16.37	18.08	20.14
Total	57.20	80.43	99.37	120.67	138.09	154.28	172.68	198.07	227.97
Total live tree	83.43	114.73	138.52	164.33	183.74	200.54	219.34	245.83	278.22
Total dead tree	0.02	0.13	0.63	1.38	7.18	13.18	23.10	28.79	29.99

TABLE 4—Estimated annual production of dry matter (t/ha)

Component	Stand age (years)							
	5–6	6–7	7–8	8–9	9–10	10–11	11–12	12–13
Needles	8.97	10.55	8.74	6.55	4.91	3.83	3.78	3.54
Branches	5.14	4.34	3.73	3.24	2.84	2.51	2.23	1.99
Cones	0.63	1.72	1.76	1.40	1.11	0.83	0.81	0.74
Stemwood	20.86	17.17	19.47	16.13	15.13	17.28	23.81	28.02
Stembark	2.34	1.74	1.82	1.29	1.09	1.19	1.71	2.06
Dead trees	0.11	0.50	0.75	5.80	6.00	9.92	5.69	1.20
Total	38.05	36.02	36.27	34.41	31.08	35.56	38.03	37.55

increment among components varied markedly. At age 9 almost 20% of this current increment was in new needles but by age 13 had dropped to less than 10%. Branch increment also decreased in relative importance from 14% to 5% over the period of observation. At the same time, stem (wood + bark) increment rose from 61% to 80% of current increment. Within stems there was an apparent shift from bark to wood.

DISCUSSION

Three more years of observation and a doubling of the number of sample trees have not materially changed the estimated maximum MAI of 21 t/ha/yr (Madgwick 1981). Several other conclusions must be modified. The extended data set indicates a peak of foliage mass at age 7 years at which time a high proportion of needles were in the 1-year-old age-class. Total needle mass and particularly the production of new needles are now seen to decline and needle longevity to increase after age 7. This is in contrast with quasi constant values reported earlier (Madgwick 1981) but agrees more closely with data from another age series of *P. radiata* stands located about 35 km south-east of the present site (Madgwick *et al.* 1977). The weight of live branches agrees with the value reported earlier but the weight of dead branches rose at a slower rate.

Estimating current production from standing crop raises several difficulties, especially when decomposition and shedding of dead parts are not measured. Needle growth was assumed to be confined to the first year. Increases in weight of needles beyond the first year are suggested for a variety of species by the data of Smith (1972) and Laar (1976) as well as personal observations on *Picea abies* (L.) Karst. needles. Such increases may be of the order of 5% per year and will have only relatively small effects on the estimated total production. Estimates of branch production appear consistent with a loss in weight of dead branches from decomposition and shedding of approximately 5% per year. Cones on *P. radiata* tend to be persistent but the apparent reduction in rate of cone production beyond age 8 could be due in part to shedding, though few cones were observed on the forest floor. Similarly, the falling ratio of bark to wood in stems might be explained by shedding of bark. However, some change in the ratio of bark to wood production appears real. Examination of the uppermost three sample discs from the stems of the largest trees in each age-class indicates that the ratio of bark to wood (R) was related to stem diameter outside bark (D) by the relationship:

$$R = 0.473 - 0.16 \ln D$$

with an r of 0.87 and a standard error of estimate of 0.025. Residuals were not significantly related to tree age. The data used in this equation come from the top 4 m of the stem. They indicate that within this part of the stem, the ratio of bark to wood production is not affected by tree age within the range 5 to 13 years. But there is a strong suggestion that the ratio of bark to wood production varies markedly along the stem. Assuming that the difference in the ratio of bark to wood on stems of 13-year-old trees compared with 5-year-old trees is due to bark shedding would give an estimated loss of bark of 8.4 t/ha over the 8 years of stand development, which is equivalent to an estimated annual attrition of approximately 7%.

Stands of *P. radiata* grown under a regime similar to that reported here are unlikely to be found in managed forests in New Zealand. However, the high MAI attained at a young age and the protracted period over which this MAI is sustained could have advantages if stands of *P. radiata* were to be grown for energy supply. The relatively small stem diameters which reached a maximum of only 22 cm at breast height by age 13 would allow efficient mechanisation of felling which could leave a clean site for replanting without need for major site preparation.

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