The upper limits of radiata pine stem-volume production in NZ

R.G. Shula

ABSTRACT

For radiata pine in New Zealand, 43 $m^3/ha/yr$ is the estimated upper limit of stem-volume production rate calculated as the average of a dataset (0.24% of a total database) having a mean annual increment greater than $40m^3/ha/yr$. This dataset was derived from more than 56,000 research records in the Forest Research Institute's Permanent Sample Plot system. Excluded from the PSP system are very young plots representative of the most recent genetically improved breeds of radiata pine. The single greatest production rate was $52m^3/ha/yr$ at stand age 24 years, while the single greatest stem-volume production was $2188m^3/ha$ at stand age 49 years. This article includes descriptions of the growing conditions and management practices under which these upper limits were achieved.

Introduction

New Zealand is well suited to commercial forestry for a variety of reasons, most important of which are its favourable climate and soils. This is illustrated by the large proportion of land area on which radiata pine can achieve excellent growth with a site index in excess of 25 metres – 53%, or nearly ten million hectares (Eyles 1984). By definition, site index (mean top height at age 20 years) provides a quantitative measure of growth potential attributable to the site (soil), but also it is an expression of the biological potential of tree species.

In New Zealand, site index for radiata pine has been reported to reach 37-38 metres (Hunter and Gibson 1984), while site indices up to 39 metres have been used in the development of regional stand growth models. At such high site indices, high stem-volume production is possible.

In the following discussions and unless stated otherwise, stem-volume production is cited as yield per hectare (m^3/ha) and/or mean annual increment (MAI, $m^3/ha/yr$), each on the basis of total standing stem-volume inside-bark, and excluding mortality and thinnings.

In New Zealand State-owned radiata pine forests, the average MAI peaks at about 20 $m^3/ha/yr$(or $25m^3$ MAI for total standing stem-volume) on the basis of merchantable stem-volume likely to be recovered (about 80% of total standing stem-volume) (Shirley 1984). On an international scale, this average MAI is notable – equalled by coppiced eucalypts in Brazil, and five times greater than spruce in Nordic countries (Sedjo 1984).

However, much higher maximum yield predictions with MAI's nearly double ($49m^3$ MAI) the State average were obtained when five regional stand growth models were run at maximum site indices using various management regimes. Additional evidence for such high yields was obtained from a close-spaced stand of radiata pine (Madgwick and Oliver 1985) which had an estimated $42m^3$ MAI at age 13 years (based on a reported 16 oven-dry tonnes/ha/yr stemwood production and assuming a wood basic density of $381kg/m^3$).

The author, Bob Shula, is a scientist with the Mensuration and Management Systems Research Field, Forest Research Institute, Rotorua, New Zealand.

Two important questions are raised by these results:

First: "What are the measured upper limits of radiata pine stem-volume production in New Zealand?", and

Second: "What are the growing conditions and management practices under which these upper limits were achieved?"

Answers to these questions were obtained using the Forest Research Institute's Permanent Sample Plot (PSP) record system as the source of data.

METHODS

The PSP database

The advantages of using PSP data include:

- New Zealand-wide coverage,
- the country's largest single database for radiata pine,
- a mix of both historical and current data,
- data collected and stored with high mensurational standards, and
- ease of access.

The obvious disadvantage of using only PSP data is the omission of data from other sources. This disadvantage is acknowledged, but given the extent of the PSP database, it is considered unlikely that any excluded data is significantly better than that present in the database.

During the analysis, the extent of the radiata pine PSP database was over 10,000 plots and 56,000 plot measurements. Regional coverage included all of New Zealand, including both State and private forest ownerships. Plot status encompassed current, felled, and abandoned plots (including Old Crop).

Selection of upper-limit production data

MAI was used as the indicator of upper-limit stem-volume production. Data selection was by individual plot measurements, not by individual plots. The upper limit of selection was subjectively set at two levels to produce two datasets – measurements with MAI's equal or greater than 35 $m^3/ha/yr$ ("35+") and 40 $m^3/ha/yr$("40+"). The use of these two overlapping datasets was employed to provide latitude when evaluating and reporting the results, i.e., attention can be focussed at either the uppermost echelon of data, or one step removed.

In a data search to identify upper extremes, the potential exists to select data points representing erroneous measurements. To lessen the chance of selecting observations which might involve measurement error a minimum of two observations per plot (not necessarily consecutive) were required to meet the selection criteria. After data selection, the 40 + MAI dataset was examined to identify and omit observations with irregularities indicating possible measurement or sampling error.

Evaluation of the upper-limit production data

Stand variables including age, top height, basal area, and stocking for both MAI datasets were evaluated for central tendencies: mean, standard deviation, and range. The 40 + MAI dataset was further characterised by descriptive information obtained from plot summary and history sheets, such as ownership, establishment and management history, and environmental details.

RESULTS

Selection of upper-limit production data

The database search confirmed the upper limits subjectively set for radiata pine stem-volume production. Above the limit of 40m^3 MAI, 0.19% of the total number of radiata pine PSP measurements were selected. Above the limit of 35m^3 MAI, 0.90% were selected. On the basis of plots identified in the two MAI datasets, the percentages of radiata pine PSP's involved were 0.24% and 1.13%, respectively.

Upper limit stem-volume production rate averaged 43 and 39m^3/ha/yr based on the two MAI datasets comprising 106 and 503 plot measurements, respectively. The single greatest MAI was 52m^3 at stand age 24 years (Mangatu Forest), while the single greatest stem-volume production was 2188m^3/ha at stand age 49 years (Karioi Forest). Table 1 presents a breakdown by region of the number of plots and plot measurements. Table 2 identifies the forests included in the 40 + MAI dataset.

TABLE 1 - Number of plots and measurements by region for the two MAI datasets

Region	% Radiata Net* Stocked Area	Stem-volume MAI (m^3/ha/yr) 35+ Number of Mea.	35+ Number of Plots	35+ % Plots	40+ Number of Mea.	40+ Number of Plots	40+ % Plots
Rotorua	50	301	55	48	64	14	58
Wellington	13	119	32	28	40	9	38
Nelson	12	37	12	11	-	-	-
Auckland	16	26	10	9	2	1	4
Southland	9	20	5	4	-	-	-
TOTAL	100	503	114	100	106	24	100

* Collins, McGregor and Novis (1988)

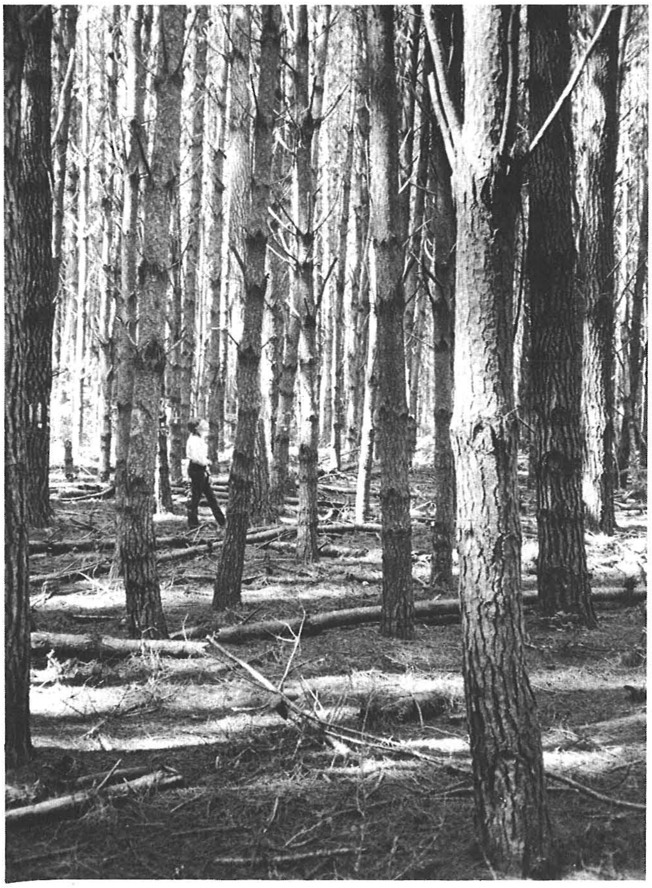
TABLE 2 - Forests included in the 40+ MAI dataset

Forest	Locale
Glenbervie	Northland
Kaingaroa	Rotorua
Tarawera	Rotorua
Mangatu	East Cape
Wharerata	East Coast
Te Wera	Taranaki
Esk	Hawkes Bay
Gwavas	Hawkes Bay
Mohaka	Hawkes Bay
Karioi	Tongariro

TABLE 3 - Indicative stand variables for the two MAI datasets

Stand variable	35+ (503 measurements) Mean	Std dev.	Min-Max	40+ (106 measurements) Mean	Std dev.	Min-Max
Age (yrs)	21	7	8-57	20	6	11-49
Stocking (sph)	1280	638	247-4761	1368	455	457-2184
Nett volume (m^3/ha)	800	284	282-2188	875	270	464-2188
Basal area (m2/ha)	73	15	44-146	79	14	53-138
Mean top ht (m)	33	7	16-57	33	7	20-51
Mean top diam (mm)	424	105	181-828	425	88	243-955
DBHq (mm)	295	90	117-676	286	73	177-544
Mean tree vol (m^3)	0.89	0.8	0.06-6.7	0.81	0.6	0.21-3.7
MAI (m^3/ha/yr)	39	3	35-52	43	3	40-52

(Stem-volume MAI (m^3/ha/yr))



A plot in the 40+ MAI dataset; age 23 years, 1219 sph, 930m^3/ha, 40m^3/ha/yr.

Dataset evaluation – stand variables and age distribution

On average, upper-limit data represent stands having:

- site indices greater than 30m with high stockings (greater than 1200 sph) and age of about 20 years.

These results indicate that stocking maintained nearer to full site occupancy maximises stem-volume production. The implication is that intensively managed stands do not recover volumes of trees removed in thinnings, and thereby are unable to match standing volumes of unthinned stands of similar age.

Table 3 presents indicative stand variables for the two MAI datasets, while Figures 1, 2 and 3 present data for the 35+ MAI dataset.

Figure 1 illustrates the high stem-volume production-rates

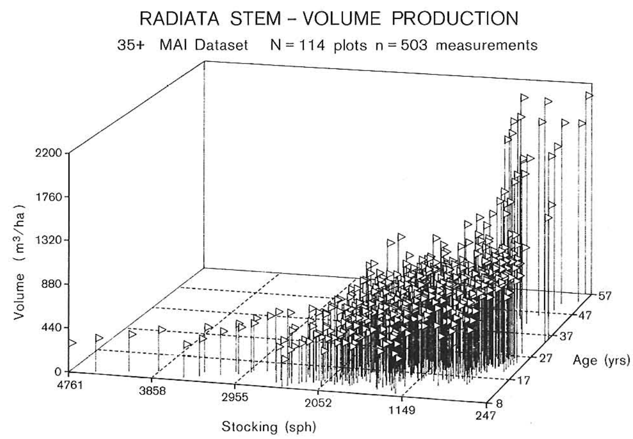


Figure 1. Total standing stem-volume by stocking and age in the 35+ MAI dataset

that can be achieved even in eight-year-old stands, with a stocking range from about 1100 to 4700 sph. High production rates can also occur in mature stands well over 30 years old, but with a more limited stocking range from about 250 to 1050 sph. Figure 1 emphasises that high production rates occur within a wide range of high stockings relative to stand age.

From Figure 2a we see that high stem-volume production rates can be achieved at site indices ranging from about 24 to 38 metres. Figures 2b and 2c reveal that basal area of about 100m^2/ha and total stem volume of about 1000m^3/ha can each be approached by stand age 20 years.

Figure 2a. Mean top height by age in the 35+ MAI dataset

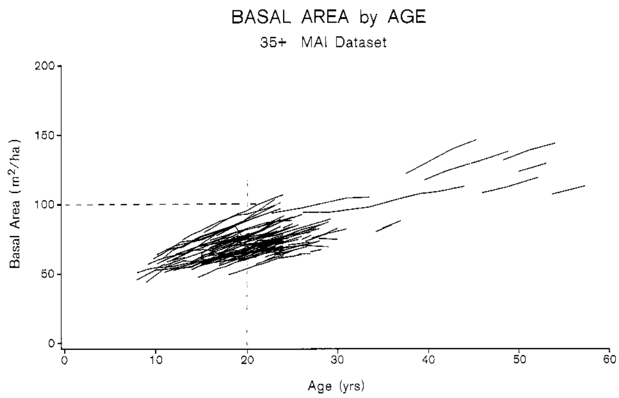


Figure 2b. Basal area by age in the 35+ MAI dataset

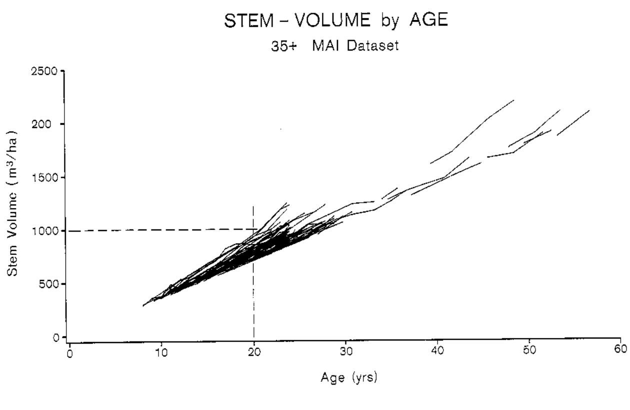


Figure 2c. Total standing stem volume by age in the 35+ MAI dataset

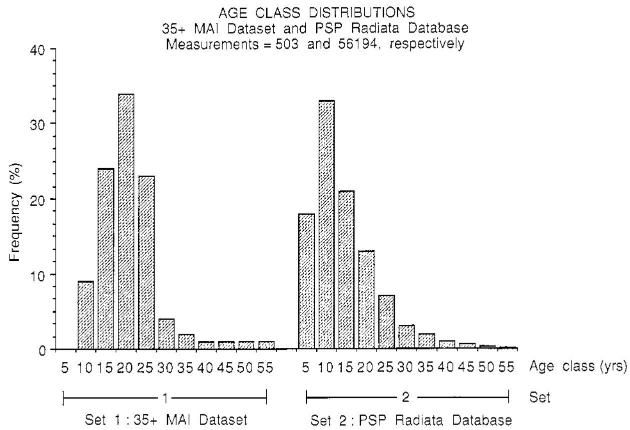


Figure 3. Age class distributions in the 35+ MAI dataset and the PSP radiata pine database

Figure 3 shows that the age class distribution of the 35+ MAI dataset is concentrated between stands aged 14-28 years, but extends beyond age 50. (The age class distribution of the 40 + MAI dataset is similar.) The likelihood of maximising MAI at various stand ages can be inferred from a comparison of the age class distributions of the 35 + MAI dataset and the complete radiata pine PSP database (set 1 and 2, respectively).

These results suggest that upper-level MAIs are less likely to occur in stands younger than 14 years, and are most likely to occur in stands aged 14-28 years. The basis for these inferences is the disproportionate percentage of measurements by age group between the two sets. For stands younger than 14 years, only 9% of the upper-level MAI measurements come from an age group representing over 50% (about 29,000 measurements) of the radiata pine PSP database. Conversely, for stands aged 14-28 years, over 80% of the upper-level MAI measurements come from an age group representing 40% (about 23,000 measurements) of the radiata pine PSP database.

For stands older than 28 years, the likelihood of maximising MAI is difficult to assess because there are relatively few PSP measurements at these older ages. Interestingly though, there is a similar percentage of measurements occurring in the sets (about 9%).

Dataset evaluation – growing conditions

Average growing conditions for upper-limit stands were typified as:

- North Island latitudes (mean of 38.6 degrees south),
- 360m altitude,
- northerly aspects on uniform slopes (about 15 degrees), and
- sandy loam or volcanic soils with site indices greater than 30 metres.

Information on more specific growing conditions (rainfall, air temperature, solar radiation) was unavailable, although the expected optimums for temperature and rainfall are about 12 degrees C and 1500+mm, respectively (I. Hunter, pers. comm.).

Dataset evaluation – establishment and management histories

The establishment and management histories for upper-level stands were typified as:

- stand establishment (1960-64) on scrub land at a nominal spacing of 2.4×1.8 metres (2315 sph) using stock from unclassified seed,
- PSP establishment for purposes of general growth monitoring (an average of 135 trees per plot),
- absence of thinning, or thinning to a high residual stocking (1700 sph),

- absence of pruning, or pruning of selected crop trees to about 5 metres, and the
- absence of the use of fertiliser.

The limited occurrence of phenotypically screened seed types (felling or climbing select) and the absence of the use of fertiliser was unexpected. The implications are that (a) stocking level took precedence over seed selection in fostering rapid tree growth, and (b) fertiliser was not applied to produce above-normal tree growth, but rather to correct nutritional site deficiencies and foster normal growth.

DISCUSSION

The upper limits of radiata pine stem-volume production in New Zealand have been identified. The premise that the reported figures represent upper limits for radiata pine in New Zealand is supported by the extent of the database.

As a relative measure stick, a comparative analysis was performed based on Lewis' alignment charts for predicting total standing yield of unthinned radiata pine (Lewis 1954). The greatest stem-volume production derived was 1743m^3/ha (metric equivalent) at age 47.5 years (based on step-wise use of Lewis' figures 1 and 2 with input variables at the maxima). The greatest stem-volume production rate derived was 52m^3 MAI at age 25. These results support the upper limits set by the present investigation.

After 35 years since Lewis' work, one might expect that the effects from improvement in plantation management techniques and seed selection efforts would promote greater differentials between Lewis' and the present investigation's upper-level production estimates. Perhaps, the two important questions that now arise are:

First: "Do the identified upper-level stem-volume production limits represent biological limitations for radiata pine in New Zealand?" and

Second: "What is the stem-volume production potential of stands of genetically improved breeds of radiata pine that are well fertilised and maintained at higher stocking levels?"

ACKNOWLEDGEMENTS

The author acknowledges C. Goulding for his advice and encouragement in initiating this investigation; C. Pilaar and J. Skinner for their computer work with the PSP record system; and M. Carson, I. Hunter, and B. Tennent for their review of this manuscript.

REFERENCES

Collins, J.; McGregor, F.; Novis, J. 1988: A national exotic forest description system. National Exotic Forest Description Steering Committee. Working Paper No. 3.3. Ministry of Forestry. Wellington, New Zealand. March. 107 p.

Eyles, G.O. 1984: *Pinus radiata* site index rankings for New Zealand. New Zealand Forestry 31(2):19-22.

Hunter, I.R.; Gibson, A.R. 1984: Predicting *Pinus radiata* site index from environmental variables. New Zealand Journal of Forestry Science 14(1):53-64.

Lewis, E.R. 1954: Yield of unthinned *Pinus radiata* in New Zealand. New Zealand Forest Service. Forest Research Institute. Forest Research Notes 1(10). July. 28 p.

Madgwick, H.A.I.; Oliver, G.R. 1985: Dry matter content and production of close-spaced *Pinus radiata*. New Zealand Journal of Forestry Science 15(2):135-141.

Sedjo, R.A. 1984: An economic assessment of industrial forest plantations. Forest Ecology and Management 9(4):245-257.

Shirley, J.W. 1984: Average yield of radiata pine in New Zealand State forests. New Zealand Journal of Forestry 29(1):143-144.