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RESEARCH NOTE No. 24

ANALYSIS OF GROWTH IN A MIXED EUCALYPT FOREST

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SUMMARY

The results from a continuous inventory system on Yarratt State Forest are analysed to give growth data on species associations containing Bloodwood, White Mahogany, Grey Gum, Ironbark and other hardwoods. Useful growing stock increased from 5,280 super feet per acre in 1960 to 5,600 super feet in 1966. An average of 185 super feet per acre was removed from the forest each year and of this 36 super feet were sold and 49 super feet were rejected or felled in Timber Stand Improvement (T.S.I.) operations. Other mortality, mostly from fire, accounted for the remaining 100 super feet per acre.

Average annual recruitment into the 4 to 8 inch size class was 5·2 trees per acre.

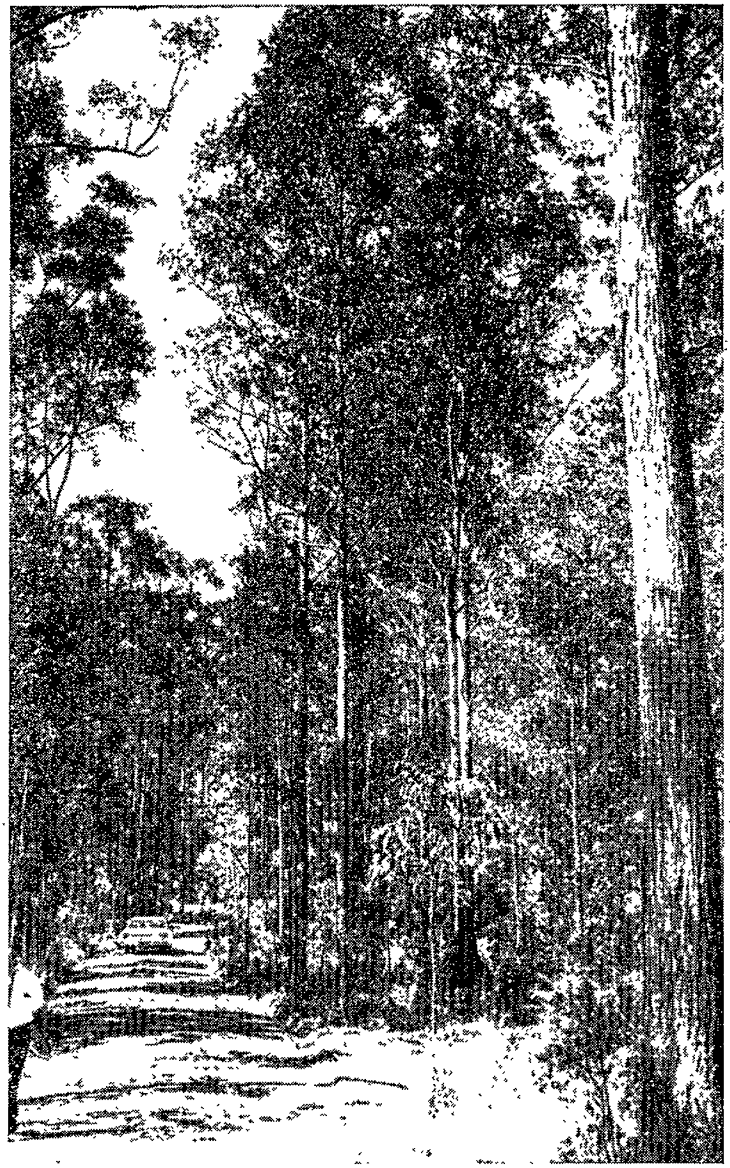
Survivor growth of useful trees was 137 super feet per acre per annum. Growth rates by species, species associations, site classes, size classes and dominance classes are also given. The average annual diameter increment of useful trees was 0·13 inches and remained stable over the size classes.

The apparent effect of wildfire was to reduce the increment by more than 50 per cent, and the frequency of tree injuries is listed. Crude models are presented for the estimation of total growth from stand basal area and diameter. T.S.I. was found to have a strong positive effect on growth.

ANALYSIS OF GROWTH IN A MIXED EUCALYPT FOREST

INTRODUCTION

Yarratt State Forest No. 654 has an area of 8,251 acres and is economically located a few miles northwest of Taree on the mid-north



Mixed eucalypt stand, containing Red Mahogany, Grey Gum, Spotted Gum, White Stringybark, White Mahogany and Ironbark. Classed as High Site Quality Pole type, and given timber stand improvement treatment in 1953. Yarratt State Forest, compt. 16

coast of New South Wales. The species associations which occur on this forest are predominantly those which contain Bloodwood, White Mahogany, Grey Gum, Ironbark, Spotted Gum and Red Mahogany (for botanical names, see appendix 1). These species are widespread in many forests of the North Coast of N.S.W., and although these forests are of low site quality relative to the intensively managed Blackbutt forests, they do constitute a major proportion of the forest estate and are a significant source of forest products.

Despite the importance of these forest types, there has been an acute shortage of reliable growth data which is necessary for planning the extensive type of forest management now being practised in these areas.

A continuous forest inventory (C.F.I.) system, consisting of 93 permanent quarter-acre circular plots on a 30 chain grid, was established on Yarratt State Forest in December, 1960–January, 1961. This initial inventory was used to prepare a formal working plan which has been in operation since July, 1961. The C.F.I. system was remeasured in September–October, 1966 and the results of this remeasurement have provided a large amount of growth data which should have wide application to other North Coast forest areas which have similar histories and stand structures. This report attempts to summarize much of the available data in sufficient detail for future planning.

GROWING STOCK COMPARISONS, 1960–1966

Inventory data are available for five merchantability classes, but the salvage log and sleeper tree classes are virtually negligible. To avoid unwieldy tables sawlogs, poles and sleeper trees have been combined to

TABLE 1: GROWING STOCK PER ACRE IN 1960 AND 1966

Parameter	Year	Useful	Useless	Total
N	1960	54·9	36·3	91·2
	1966	75·9	43·0	119·0
	Change	+21·0	+6·7	+27·8
BA	1960	37·9	31·8	69·7
	1966	42·5	31·7	74·2
	Change	+4·6	−0·1	+4·5
V	1960	5,280	4,328	9,608
	1966	5,600	4,053	9,653
	Change	+320	−275	+45

NOTE: N = No. stems per acre.
BA = Basal area in square feet per acre.
V = Volume in superficial feet Hoppus per acre.

give a general "useful" class, while the salvage class has been grouped with useless trees to give a "useless" class. The numbers per acre (N)*, basal area in square feet per acre (BA), and volume in super feet per acre (V) for merchantability and 4-inch diameter classes are given in appendix No. 2. The overall totals are compared in table 1.

* Appropriate conversions to the metric system are given in appendix 3.

Untreated High Site Quality Pole type, containing large useless trees of Bloodwood (left centre) and Grey Gum (right centre). Yarratt State Forest, compt. 4

There has been considerable increase in the number of trees per acre because of ingrowth into the 4–8-inch size class. Both the BA and V of the useful class have increased and there has been a substantial decrease in useless volume. All of these changes are a result of ingrowth, removals and merchantability changes, and these factors will be considered in detail below. Appendix 2 shows that in general the size classes from 4 inches diameter breast height (D.B.H.) to 20 inches D.B.H. have increased for both useful and useless groups. However the over 20-inch size class is of major importance because this class contains those trees which can be sold now, as well as those useless trees which are occupying a major share of the growing space. This size class is summarized in table 2.

TABLE 2: GROWING STOCK PER ACRE OVER 20 INCHES D.B.H. IN 1960 AND 1966

Parameter	Year	Useful	Useless	Total
N	1960	1·8	3·0	4·8
	1966	1·9	3·0	4·9
	Change	+0·1	0·0	+0·1
V	1960	1,486	2,797	4,283
	1966	1,242	2,481	3,723
	Change	−244	−316	−560

While the number of stems over 20 inches has remained virtually constant, there has been a substantial reduction in both useful and useless volume per acre. This reduction in useful volume per acre must cause some concern as to whether the existing sawlog yield can be maintained at its present level. Appendix 2 shows that a reduction in useful volume has only occurred in the 28-inch + class, amounting to 359 super feet* per acre. The main reason for this reduction has been a reclassification of very large Bloodwood trees from useful in 1960 to useless in 1966. Large Bloodwood trees are notoriously difficult to sell and this reclassification seems wise. It must be stressed however that Bloodwood and Turpentine still make up 70 per cent of the 1966 useful volume in the 28-inch + class, and further reclassification may prove to be necessary. On the credit side it is reassuring to note an increase in useful volume in all size classes from 4 inches to 28 inches.

The 1966 reclassification of merchantability for all size classes has resulted in 497 super feet per acre (1960 estimate) changing from useful to useless while 81 super feet was transferred from useless to useful. Consequently the 1960 useful volume requires a reduction of (497 − 81) or 416 super feet per acre to be strictly comparable with the 1966 growing stock. Similarly, the 1960 useless volume should be increased by 416 super feet per acre. These adjustments would make the volume comparison of table 1 much more attractive and must be considered in a calculation of growth.

While there has been a substantial decrease in the useless volume over 20 inches D.B.H., this size class still makes up 26 per cent of the total volume, and the early removal of these large dominant trees would lead to a large increase in space for the development of the existing useful growing stock, as well as regeneration, at a relatively minor cost.

* As is usual in commercial log measurement in New South Wales, log volumes are quoted in the super (superficial) foot Hoppus measure. A super foot is one-twelfth of a cubic foot (i.e., a plank one foot square and one inch thick), while the Hoppus system gives a log volume that is only 78·5 per cent of the true volume. Thus 1 super foot Hoppus is equivalent to 0·1061 cubic foot true measure, or to 0·0030 cubic metre. A volume of 100 super feet per acre is similarly equivalent to 10·6 cubic feet true per acre, or to 0·74 cubic metre per hectare.

THE REMOVALS

During the 6-year period eighty-four trees were removed from, or died in, various plots of the C.F.I. system. These removals have been converted to an estimated super feet per acre per annum basis over the whole forest for ease of comparison. Consequently these figures do not refer to actual yields per acre from compartments logged, since the cutting cycle for this forest is approximately 25 years. The volume per acre per annum of the removals is given in table 3. This volume is the 1960 inventory estimate.

TABLE 3: THE VOLUME REMOVED PER ACRE PER ANNUM BY CATEGORIES AND 1960 MERCHANTABILITY CLASSES

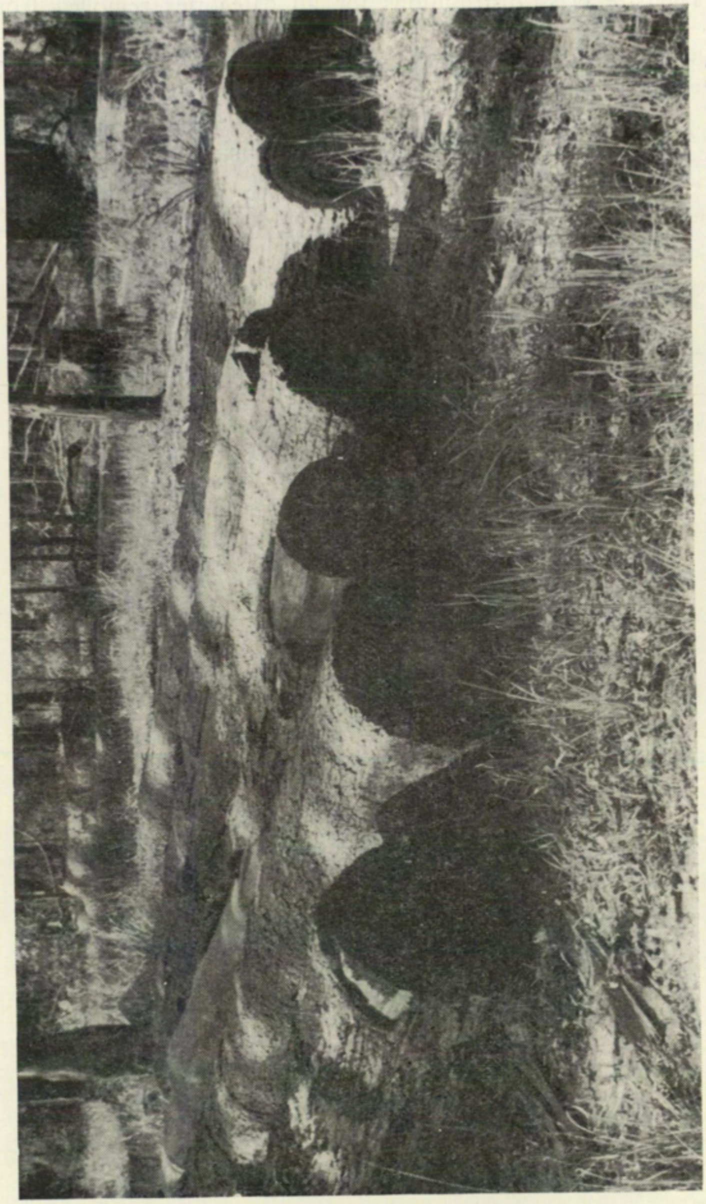
(in super feet Hoppus)

Category	Product	1960 Merchantability Class		
		Useful	Useless	All Classes
Products actually sold ..	Sawlogs.. ..	9·8	1·6	11·5
	Poles	9·8	..	9·8
	Salvage logs ..	..	15·0	15·0
	Subtotal ..	19·6	16·6	36·2
Deliberately felled	Rejects	1·6	21·7	23·3
	T.S.I. removals	0·7	25·2	26·0
	Subtotal ..	2·3	46·9	49·3
Mortality from operations ..	Logging ..	0·3	0·1	0·4
	T.S.I.	0·4	0·1	0·6
Other mortality	Fire	4·5	67·4	71·9
	Wind	0·1	7·3	7·4
	Other	0·6	19·1	19·7
Total	Total	27·8	157·6	185·4

Table 3 contains some very interesting features. In general the deliberate removals agree with the original estimate of merchantability. The majority of the sawlogs and poles were obtained from the useful class, while very few of the logs felled, but rejected as unmerchantable, or of the logs removed during timber stand improvement (T.S.I.) operations came from this class.

Accidental mortality from logging and treatment only amounts to 1·0 super feet per acre per annum and can be considered to be quite satisfactory.

During the 6-year period wildfire burned 2,121 acres of forest and resultant mortality (damage to living trees is considered later) amounted to 72 super feet per acre per annum, or 39 per cent of the total volume



Logs of Bloodwood rejected as unmerchantable because of gum rings and shakes. Yarratt State Forest, compt. 2

removed. This appears to be a very heavy loss for these fire resistant species, but fortunately the majority of fire-killed trees were previously estimated to be useless and only 5 super feet of useful volume has been fire-killed per acre per annum.

The generally high "other mortality" volume in fact results from a few relatively large 28-inch + trees.

The size class distributions for all categories removed from the plots over the 6-year period are given in table 4. These numbers are not per acre per annum data, but are the actual numbers of trees removed from all plots during 1960–1966.

TABLE 4: THE SIZE CLASS DISTRIBUTION FOR PLOT TREES REMOVED DURING 1960–1966

Category	4–8 in	8–12 in	12–16 in	16–20 in	20–24 in	24–28 in	28 in +	All
Sawlogs ..			3	2				5
Poles		3	7	1				11
Salvage logs ..							1	1
Rejects ..			3				1	4
T.S.I.	7	7	4			1	2	21
Logging mortality ..	6	1						7
Treatment mortality ..	2	1						3
Fire	6		4	1		3	2	16
Wind	4		1	1			1	7
Other	5	2	1				1	9
Total	30	14	23	5	..	4	8	84

It is interesting to note that no sawlogs or poles over 20 inches D.B.H. were removed from the plots, and that the majority of rejects were in the 12–16-inch class and probably tried for poles.

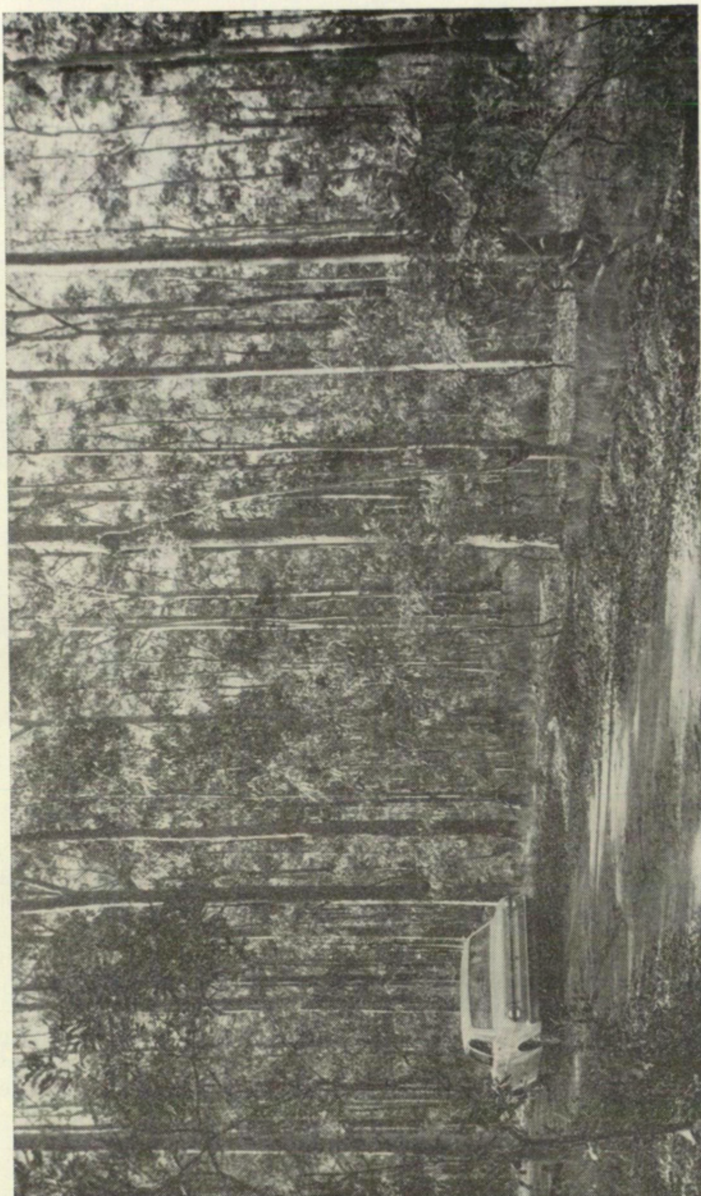
THE INGROWTH

The average ingrowth per acre per annum into the smallest measured size class is given in table 5.

TABLE 5: INGROWTH PER ACRE PER ANNUM

	N	BA	V
Useful	3·7	0·63	21·3
Useless	1·5	0·19	4·9
Total	5·2	0·82	26·2

This average annual ingrowth of 3·7 useful trees per acre is well in excess of the annual losses of useful growing stock from all causes of 0·2 tree per acre. Consequently it would appear that there is no substantial problem in obtaining regeneration, and that useful growing stock should continue to increase. On the other hand, the ingrowth of 1·5 useless trees is more than keeping pace with the annual removals of 0·4 useless tree per acre, so that useless growing stock will also tend to increase unless a vigorous programme of cutting and poisoning is continued.



Spotted Gum forest type, treated for timber stand improvement in 1955–56. Yarratt State Forest, compt. 11

In 1966, the C.F.I. plots were also measured for non-commercial species which were over 4 inches D.B.H. These species mainly consist of sheoaks, wattles, paperbarks and rainforest species and can reach considerable stockings in some plots. Over the full sample, these species averaged twenty-seven trees per acre, with a basal area of 6·5 square feet and an estimated volume of 539 super feet per acre. Because these species were not included in the 1960 inventory, they have not been included in any calculation of growth or any table of growing stock.

FOREST GROWTH

The calculation of growth is a complex subject which has been well discussed by Beers (1962). The data is available to calculate both gross and net growth, with and without ingrowth. All of these estimates of growth are of importance to the forest manager and have been listed in table 6, together with the data used in their calculation. In the calculation

TABLE 6: GROWTH PARAMETERS FOR THE CALCULATION OF BASAL AREA INCREMENT AND VOLUME INCREMENT PER ACRE PER ANNUM

(for explanation of Parameter and Increment symbols, see text)

Parameter	Useful		Useless		Total	
	BA	V	BA	V	BA	V
GS_{60}	37·9	5,280	31·8	4,328	69·7	9,608
GS_{66}	42·5	5,600	31·7	4,053	74·2	9,653
L	3·0	497	0·7	81		
E	0·7	81	3·0	497		
C	0·8	118	0·4	99	1·3	217
M	0·4	49	5·0	846	5·3	895
I	3·8	128	1·2	29	4·9	155

Increment per acre per annum	Useful BA	Useful V	Useless BA	Useless V	Total BA	Total V
GGii	1·35	150	0·50	42	1·85	193
GG	0·72	129	0·30	37	1·03	167
NGii	0·90	73	0·50	−29	0·97	44
NG	0·27	52	−0·15	−34	0·15	18
NI	0·77	53	−0·02	−46	0·75	7

of merchantability class growth, it is necessary to recognize the effect of reclassification in that certain trees from the initial inventory have entered a new class (E) and have left the original class (L) at the time of the second inventory. The 1960 volume or basal area of these trees can be treated in the same way as trees sold (C) or mortality (M) by a suitable adjustment to the initial growing stock (GS_{60}). Similarly the ingrowth (I) can be used to adjust the final growing stock (GS_{66}). Since a 6-year period is involved between the determination of GS_{60} and GS_{66}, all other parameters must be the volume or basal area per acre entering, leaving, dying or sold over the whole period. The growth thus calculated is divided by 6 to give a final estimate of growth per acre per annum. The following estimates of growth have been made:

(1) Gross growth (including ingrowth): GGii

$$GGii = GS_{66} - (GS_{60} - M - C - L + E)$$

(2) Gross growth (initial volume): GG

$$GG = GS_{66} - I - (GS_{60} - M - C - L + E)$$

(3) Net growth (including ingrowth): NGii

$$NGii = GS_{66} - (GS_{60} - C)$$

(4) Net growth (initial volume): NG

$$NG = GS_{66} - I - (GS_{60} - C)$$

(5) Net increase: NI

$$NI = GS_{66} - GS_{60}$$

These growth rates are given in table 6.

The *gross growth including ingrowth* (GGii) is a measure of performance of the complete management system, and the useful growth is 150 super feet per acre per annum. *Gross growth of initial volume* (GG, which excludes ingrowth) is synonymous with survivor growth and is the best measure of the growth performance of the original stand in 1960, with a growth of 129 super feet. *Net growth* (NGii) adjusts the calculation for trees actually sold, but regards all other mortality, including rejects, fire-killed trees and all other mortality, as a growth loss. The useful net growth of 73 super feet is therefore considerably lower and can be compared with the allowable cut (sawlogs and poles) for the forest of 59 super feet.

While the gross growth of the useless volume is a considerable 42 super feet per acre per annum, the various cultural operations and other causes of mortality have been successful in achieving a net decrease in the useless volume of 46 super feet per annum.

While all of these growth calculations are valid it is stressed that gross growth of initial volume (or survivor growth) is the real increment of the surviving trees, and the survivor growth of species and classes will be considered in the following sections. These survivor increments have been computer calculated by processing individual trees and do not completely agree with the data of Table 6 because of rounding errors and the rejection of abnormal individual tree data. For these reasons the computer calculated estimates will be accepted as correct and are listed in Table 7.

TABLE 7: SURVIVOR GROWTH PER ACRE PER ANNUM, DERIVED FROM INDIVIDUAL TREE DATA

Merchantability Class	Useful	Useless	Total
Basal area increment (BAI)	0·84	0·34	1·18
Volume increment (VI)	137	40	177

THE GROWTH OF INDIVIDUAL SPECIES

The C.F.I. system has recorded sixteen individual commercial species, many of which grow in intimate mixtures. Table 8 gives the percentage of the total volume and useful volume contributed by each species (1960 basis), together with their contribution to the volume increment (VI) and the useful diameter increment (DI). The species in Table 8 are in order of their 1960 useful growing stock, but it will be seen that volume is a relatively poor indicator of volume growth because of the variation in species diameter increments. The highest diameter increments are given by Flooded Gum (0·31 inch per annum), Sydney Blue Gum (0·23), Tallowwood (0·18), and Blackbutt (0·17). Smooth-barked Apple (0·06), Bloodwood (0·07), Cabbage Gum, Grey Box, Turpentine, Red Mahogany (0·10), and Brush Box (0·11) are the slowest growing species.

A simple measure of species efficiency can be obtained by dividing useful volume increment by useful standing volume. This gives a simple increment per cent and is listed in the last column of table 8. In general

Table 8: Percentage Useful, and Total Volume for each Species in 1960, with Their Respective Increments

Species	Total Volume per cent	Useful Volume per cent	Cumulative Useful Volume per cent	Total VI s.ft/acre/ annum	Useful VI s.ft/acre/ annum	Useful DI in/annum	Useful VI per cent (efficiency)
Bloodwood	25·0	20·2	20·2	20·2	11·6	0·07	1·1
White Mahogany	13·1	11·7	31·9	29·6	18·5	0·13	3·0
Ironbark	9·0	9·3	41·2	22·9	18·1	0·15	3·7
Spotted Gum	8·7	8·4	49·6	16·1	13·9	0·12	3·2
Red Mahogany	8·5	8·4	58·0	10·7	9·8	0·10	2·2
Turpentine	5·9	8·2	66·2	8·1	5·8	0·10	1·4
Grey Gum	10·1	7·9	74·1	25·3	17·4	0·15	4·2
Blackbutt	6·1	7·0	81·1	3·7	3·6	0·17	1·0
White Stringybark	4·5	6·6	87·7	14·4	12·2	0·15	3·5
Tallowwood	2·1	3·7	91·4	8·5	8·4	0·18	4·3
Flooded Gum	1·9	3·2	94·6	15·4	14·1	0·31	8·4
Brush Box	2·5	3·2	97·8	−1·3	1·4	0·11	0·8
Smoothbarked Apple	1·3	1·0	98·8	..	0·4	0·06	0·7
Cabbage Gum + Grey Box	1·2	0·9	99·7	2·2	0·5	0·10	1·1
Sydney Blue Gum	0·2	0·3	100·0	1·2	1·2	0·23	6·7
Total	100·0	100·0	100·0	177	137	0·13	2·6

Cut-over Flooded Gum stand. Yarratt State Forest

there is good agreement between this efficiency index and diameter increment. Unfortunately both of these indices are strongly related to tree size, so that the diameter distribution of each species can be expected to influence this measure of performance. Species which have a large representation in the 20 inches + size class (such as Bloodwood, Turpentine, Blackbutt and Brush Box) will generally have lower increment percents than those species which are strongly represented in the smaller size classes.

THE GROWTH OF SPECIES ASSOCIATIONS

The previous section gives the growth rate of species no matter where they occur in the forest. However the forest has been mapped into species types and the C.F.I. plots are also classified for type. The classification of types includes the low site quality pole, high site quality pole, and semi-moist hardwood types. However Baur (1965) has pointed out that these 3 types are part of the Grey Gum–Grey Ironbark league (types 60 and 62). Basically the 3 types form a gradient passing from dry sclerophyll to mesic wet sclerophyll forest, all having major species in common and making up about 70 per cent of the total forest area. The other major types which occur are Spotted Gum, Blackbutt, Flooded Gum, and some non-commercial types (see Baur 1965, types 70, 37, 48, 32 and 26 respectively).

In addition to a classification of species types, each C.F.I. plot has been given a site quality classification, based on estimated mature stand heights of less than 90 feet, 90 to 130 feet, and over 130 feet. The diameter and total volume increments (i.e., all merchantability classes combined) for these forest type and site quality classes are given in table 9.

TABLE 9: DIAMETER INCREMENT (DI), AND TOTAL VOLUME INCREMENT (VI) IN SUPER FEET PER ACRE PER ANNUM, FOR SPECIES TYPES AND SITE QUALITIES

Species Type	Site Quality	No. of Plots	DI	VI
Flooded Gum	130+	3	0·21	413
Semi-moist Hardwood	130+	9	0·10	206
	90–130	2	0·15	161
	All	11	0·11	198
High S.Q. poles	130+	14	0·10	161
	90–130	37	0·12	193
	−90	1	0·04	35
	All	53	0·11	179
Low S.Q. poles	90–130	3	0·12	155
All pole types	All	56	0·11	178
Blackbutt	130+	1	0·13	165
	90–130	4	0·08	137
	All	5	0·09	143
Spotted Gum	90–130	10	0·11	186
	−90	1	0·13	156
	All	11	0·11	183
Non-commercial	All	5	0·03	15

Flooded Gum is clearly the best producer, while there is a gradient in production from low site quality poles at 155 super feet per acre per annum through to the semi-moist type at 198 super feet. The Blackbutt type on Yarratt State Forest has the appearance of being marginal, and it is one of the lowest producing types at 143 super feet. However there are only five plots in the sample, which contains overmature trees and a large proportion of species other than Blackbutt.

In general there is an expected trend of increasing production with site quality. Exceptions to the rule may occur because of variations in stand density and the ratio of useless to useful volume. There is also a trend for the medium site quality plots to have higher diameter increments than the high site quality plots. This trend has also been observed in the comparison of moist and dry Blackbutt increment in other C.F.I. systems. The reasons for this phenomenon are obscure but could be related to differences in stand structure as well as increasing competition from understorey species.

THE GROWTH OF SIZE CLASSES

Because existing methods of yield calculation rely heavily on the average time taken for useful trees to move through the various 4-inch size classes, the average diameter increment of these classes is of major importance.

These diameter increments (and volume increments) for each size class and merchantability class are listed in table 10 and compared with the weighted diameter increments previously used for the 1960 calculation of yield. The superscripts represent the total number of trees in each class and indicate the reliability of the increment listed.

TABLE 10: DIAMETER AND VOLUME GROWTH BY SIZE CLASSES

(Diameter increment in inches per annum; volume increment in super feet per acre per annum; superscripts indicate number of trees in class)

Size Class	Estimate in 1960 DI	Actual Annual Increments 1960–1966					
		Useful		Useless		Total	
		DI	VI	DI	VI	DI	VI
4–8 in	0·24	0·14^{547}	31·7	0·08^{388}	10·7	0·12^{935}	42·5
8–12 in	0·19	0·14^{379}	44·1	0·09^{162}	9·8	0·13^{541}	53·9
12–16 in	0·12	0·14^{213}	38·1	0·07^{74}	7·1	0·12^{287}	45·2
16–20 in	0·11	0·09^{76}	12·5	0·09^{23}	5·2	0·09^{99}	17·7
20–24 in	0·09	0·15^{17}	5·6	0·07^{20}	3·8	0·11^{37}	9·3
24–28 in	0·10	0·14^{8}	2·3	0·11^{15}	0·2	0·12^{23}	2·5
28 in +		0·07^{10}	2·8	0·02^{30}	3·2	0·03^{40}	6·0
All		0·13^{1250}	137·1	0·08^{712}	40·1	0·11^{1962}	177·2

The estimated diameter increments used for yield calculation in 1960 were based on the limited knowledge available at that time and assumed a gradually reducing increment with increasing size. However there is little evidence in table 10 to suggest that this does in fact happen. The reduced growth in the 16–20-inch and 28 inches + classes appears to be due to the higher proportion of slow growing species (Bloodwood and

Red Mahogany) in these classes. The 1960 estimate for the time taken for a tree to grow from 4 inches to 24 inches was 152 years, while the actual increments in table 10 give a period of 157 years. Although these two periods are similar, a crucial question arises as to the time taken for a seedling to reach 4 inches D.B.H. If the assumption is made that the increment of the 0–4-inch class is the same as the 4–8-inch class, then an initial period of 29 years is required to reach measurable size, as opposed to the 17 years assumed previously. However existing research plot data suggest that this period is considerably less than 29 years.

Table 10 also illustrates that most of the useful growth in volume is being accumulated by the small-sized trees because these are the most abundant. 55 per cent of the useful growth is on trees less than 12 inches D.B.H., 83 per cent on trees less than 16 inches D.B.H. and 92 per cent on trees less than 20 inches D.B.H.

There is also a marked difference in growth rate between useful and useless trees of the same size class. This difference does not appear to be associated with any other external character such as dominance and vigour. The influence of dominance on merchantability is summarized by the average diameter increments per annum given in table 11.

TABLE 11: THE AVERAGE DIAMETER INCREMENT IN INCHES PER ANNUM FOR MERCHANTABILITY AND DOMINANCE CLASSES

Merchantability Class	Dominance Class				
	1	2	3	4	Total
Useful	0·16	0·14	0·11	0·08	0·13
Useless	0·09	0·10	0·08	0·04	0·08
Total	0·14	0·13	0·10	0·05	0·11

THE INFLUENCE OF BURNING ON GROWTH

During the 1964–1966 drought more than 2,000 acres of Yarratt State Forest were burnt by wildfire, so that the growth rates already discussed have been influenced by both fire and drought. The C.F.I. plots were classified as whether burnt by wildfire or by prescribed burning and as whether the fire intensity was light, moderate or severe. The average diameter increments for these classes, for grouped dominant and codominant trees and grouped intermediate and suppressed trees, are given in table 12.

Overall the apparent growth of trees burnt by wildfire is only 50 per cent of the growth of unburnt trees. However it must be remembered that these fires occurred towards the end of the measurement period, so that excessive bark losses would not have been made up. Consequently it is not possible to say whether the data of table 12 represents a real growth loss, but the C.F.I. estimate of growth, by its very nature as a broad sample of the whole forest, incorporates these figures as if they

High Site Quality Pole type, lightly burnt by wildfire in 1968 and subsequently logged. Stand untreated. Yarratt State Forest, compt. 3

were a real loss. Bark thickness was measured during the 1966 remeasurement in anticipation of this result and more factual data will be obtained at the next remeasurement.

TABLE 12: AVERAGE DIAMETER INCREMENTS FOR BURNT AND UNBURNT TREES

Fire Intensity	Dominants	Suppressed	Total
Unburnt	0·15	0·11	0·13
Prescribed burning	0·12	0·09	0·11
Wildfire—Light	0·13	0·10	0·11
Moderate	0·10	0·06	0·08
Severe	0·05	−0·01	0·02
All wildfire	0·08	0·04	0·06
Total	0·13	0·09	0·11

THE FREQUENCY OF TREE INJURIES

A major criticism of the selection system in eucalypt management is that excessive damage or mortality will result to useful growing stock during logging and other operations. The low mortality from these causes, of a super foot per acre per annum, on Yarratt State Forest has already been listed in table 3. The percentage of the numbers of trees which are still alive, but show visible signs of injury caused by various agencies, is listed in table 13.

It will be seen that only 2 per cent of the sample trees have been damaged in all operations over a 6-year period. During this period approximately 1,800 acres were logged and 360 acres treated for T.S.I. Pole operations probably covered a greater area. Fire and insects are the most common agencies for tree damage.

TABLE 13: THE PERCENTAGE NUMBER OF TREES DAMAGED BY VARIOUS AGENCIES

Agency	Useful	Useless
	per cent	per cent
Fire	6·9	10·2
Insect	1·3	3·6
Wind	0·2	1·5
Falling	0·9	2·2
Snigging	0·9	1·6
T.S.I.	0·2	..
All operations	2·1	3·8
Other causes	3·6	6·6
Nil damage	84·2	70·2
Total	100	100

THE INFLUENCE OF STAND STRUCTURE ON GROWTH

The computer programmes currently used for C.F.I. analysis assemble growth data for similar classes of trees and plots, but unfortunately do not calculate the growth and structure of individual plots. However it is possible to group various plots together using different sort keys and so to obtain information on the influence of structure on growth. The plots have been grouped into stand density classes and the increments of the total stand calculated. These are listed in table 14.

TABLE 14: THE TOTAL INCREMENTS PER ACRE PER ANNUM FOR STAND DENSITY CLASSES

Total Basal Area per acre in 1960 sq ft	No. of Plots in class	DI inches	BAI sq ft	VI super ft
Less than 40	20	0·16	0·79	116
40–60	21	0·12	1·16	176
60–80	18	0·11	1·37	209
80–100	18	0·09	1·18	184
100–120	9	0·10	1·70	263
120–140	3	0·11	1·34	238
Over 140	4	0·07	0·98	142

When these increments are graphed against the midpoints of the basal area classes, they show an expected trend of decreasing diameter increment (D.I.) with increasing basal area, but the volume increment rises to a maximum at 110 square feet and decreases thereafter. Because this asymptote might be an artefact caused by the particular structure and composition of certain groups of plots, this aspect was investigated further.

The ninety-three plots had been sorted into thirty-one different groups depending on the type of logging and treatment previously experienced, as well as on basal area density class. By using the midpoints of the basal area classes (BA) and the number of trees in each group, it was also possible to approximate other structural variables such as the number of trees per acre (N), the sum of diameters per acre (SD), mean diameter equivalent to the tree of mean sectional area (D), BA/D, and N/D. Because it is known that Flooded Gum stands grow much faster than the other species, three groups containing this species were discarded and the remaining twenty-eight were subjected to unweighted regression analysis. Basal area increment and volume increment were used as the dependent variables, and various combinations of the six structural variables tested as independent variables.

The best single independent variable to estimate both basal area increment (BAI) and volume increment (VI) was the sum of diameters per acre (SD). This variable explained 55 per cent of the total variation in BAI, but only 35 per cent of the variation in VI. The best combination of two independent variables was BA and D, which together account for 58 per cent and 39 per cent of the variation in BAI and VI. The inclusion of additional structural variables did not significantly improve the estimation. The equations listed below were accepted as approximate models for the estimation of growth on Yarratt State Forest:

$$VI = 268 + 0{\cdot}96\,BA - 13{\cdot}3\,D \qquad (1)$$

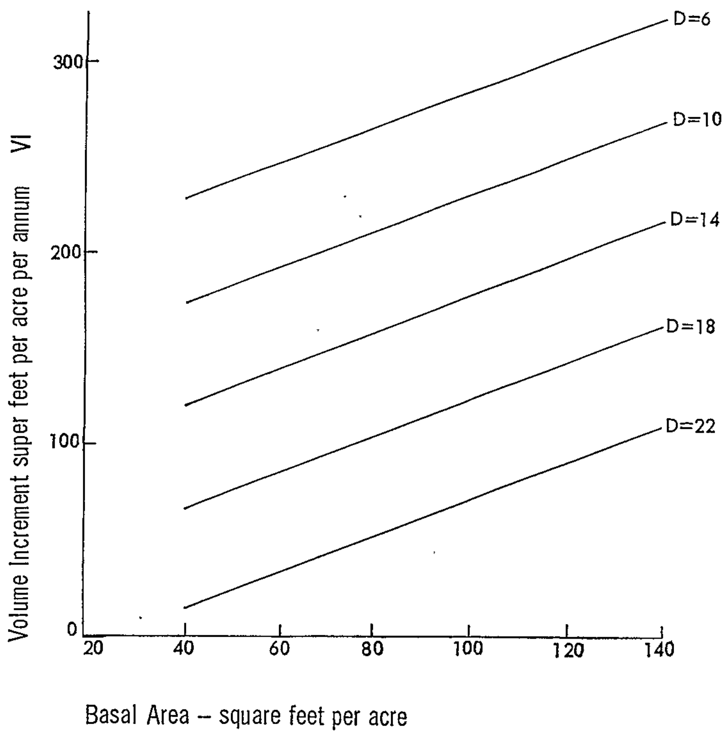
$$BAI = 1{\cdot}88 + 0{\cdot}0085\,BA - 0{\cdot}11D \qquad (2)$$

Equation (1) is illustrated in figure 1, which shows an increasing increment with increasing stand basal area and a decreasing increment associated with increasing mean diameter. Equations (1) and (2) are essentially crude models, and the linear relationships shown should probably be curved from the origin (Curtin, 1968). However because the data used were approximate only and a weighting procedure was not readily available no further analysis was attempted. However the models do serve to indicate that the apparent rapid reduction in increment at very high basal areas (see table 14) is an artefact, caused by the large mean diameters of the two highest density groups.

FIGURE 1 The relationship between volume increment (VI) in super feet per acre per annum, total basal area in square feet (BA) and mean diameter in inches (D).

$$VI = 268 + 0.96\ BA - 13.3D$$

$$R^2 = 0.39$$



When the 1960 growing stock data of 69·7 square feet with a mean diameter of 11·8 inches is substituted in equations (1) and (2), total increments can be estimated. These are compared with the actual increments in table 15.

Table 15: Comparison of Estimated Growth from Growth Models, with Actual Growth

	BAI	VI
Estimated	1·17	178
Actual	1·18	177

THE INFLUENCE OF TIMBER STAND IMPROVEMENT ON GROWTH

Approximately half of the twenty-eight groups of plots used in deriving the structural growth models had received some form of silvicultural treatment in the past. Consequently T.S.I. was also used as a dummy variable in the regression analysis. T.S.I. proved to be the second most important variable for estimating growth, and was a highly significant variable in most of the combinations used. The best models, using both structural and silvicultural variables, were:

$$VI = 165 + 1{\cdot}18\ BA - 8{\cdot}9\ D + 60\ TSI \quad (3)$$

$$BAI = 1{\cdot}49 + 0{\cdot}0093\ BA - 0{\cdot}09\ D + 0{\cdot}24\ TSI \quad (4)$$

Equation (3) explained 56 per cent of the total variation in VI, while equation (4) explained some 64 per cent of the variation in BAI.

Both these growth models show that silvicultural treatment has a definite and unique effect on growth rate, but some caution is needed in their interpretation. For example, the act of T.S.I. requires the removal of useless trees, so that BA and usually D are immediately reduced, thus causing a drop in growth through reduced BA, an increase in growth through a reduced D, and a bonus of 60 super feet per acre per annum because of the silvicultural improvement. In earlier sections it has been shown that the useful trees of the same size and dominance class grow faster than useless trees, and it is probable that the T.S.I. terms in equations (3) and (4) are simply reflecting this fact. Unfortunately the twenty-eight sets of data available for analysis do not permit the separation of useful and useless components of growing stock or growth. Similarly equations (3) and (4) do not recognize the varying intensity of T.S.I. on different areas, nor the elapsed time since treatment occurred. All of these factors will be examined when more data and individual plot records become available. It is also stressed that the growth models derived are concerned with survivor growth and do not recognize the greatly increased ingrowth which usually follows a T.S.I. operation. Nevertheless the real effect of silvicultural treatment in these types has been demonstrated and the increase of 60 super feet per acre annum is a considerable relative response in a forest with a total increment of only 177 super feet.

THE EFFECT OF DROUGHT ON GROWTH

While the growth data covering the 1960–1966 period are factual it would be desirable to know whether the severe drought during 1964–1966 has resulted in atypical increments. To provide some insight into this problem a random sample of eight plots was selected from the semi-moist hardwoods, pole types and the Spotted Gum types, and was remeasured

Fine stand of Ironbark poles in Semi-moist Hardwood Type, silviculturally treated 30 years previously. Yarratt State Forest, compt. 2

in October, 1969. In general the 1960 growing stock and the overall growth rate from 1960–1966 of this small sample was similar to, but slightly lower than, the full system (see table 16).

The data in table 16 do not contain any trees over 24 inches because the randomly selected subsample of eight plots did not have any surviving trees in these size classes. However it appears that the subsample is

TABLE 16: COMPARISON OF 1960 GROWING STOCK AND 1960–1966 GROWTH OF 8 PLOTS WITH THE FULL INVENTORY

(24 inches + trees have been deleted)

		C.F.I.	Sample
Useful	N	54·0	51·0
	BA	31·5	27·2
	DI	0·14	0·13
	BAI	0·84	0·71
Total	N	88·3	83·0
	BA	50·0	46·3
	DI	0·12	0·11
	BAI	1·18	0·97

sufficiently similar to the inventory in terms of growing stock and 1960-1966 growth to enable valid conclusions to be drawn about subsequent growth rates. These growth rates for the 1966–1969 and 1960–1969 periods by size classes are compared with the 1960–1966 period in table 17.

TABLE 17: SIZE CLASS DIAMETER INCREMENTS FOR THE 1960–66, 1966–69 AND 1960–69 PERIODS

Size Class	Useful			Total		
	1960–66	1966–69	1960–69	1960–66	1966–69	1960–69
4–8 in	0·12	0·14	0·13	0·11	0·15	0·12
8–12 in	0·13	0·14	0·14	0·12	0·13	0·12
12–16 in	0·12	0·13	0·12	0·10	0·10	0·10
16–20 in	0·18	0·17	0·18	0·11	0·14	0·13
20–24 in	0·17	0·30	0·21	0·13	0·13	0·13
Total	0·126	0·146	0·133	0·110	0·134	0·118
Basal Area Increment	0·699	0·859	0·753	0·971	1·234	1·058

In general the 1966–1969 useful diameter increments are 16 per cent higher than for the 1960–1966 period, while the useful basal area increment was 23 per cent higher than for the earlier period.

However when taken over the full 9-year period from 1960–69, which includes both good and bad years, these increments are only 6 per cent and 8 per cent higher respectively than in the 6-year period.

Droughts of comparable severity to the 1964–1966 period are probably quite rare and there seems to be some justification for adjusting the size class increments given in table 10. An appropriate adjustment would be to increase each increment in that table by 0·01 inch, giving an average useful increment over all size classes of 0·14 inch per annum. Such an adjustment to table 10 will be useful for management planning until a further remeasurement of the full C.F.I. system in a few years time.

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APPENDIX 1

LIST OF SPECIES MENTIONED IN TEXT

Common Name	*Botanical Name*
Apple, Smoothbarked	*Angophora costata* Domin.
Blackbutt	*Eucalyptus pilularis* Sm.
Bloodwood	*Eucalyptus gummifera* (Gaertn.) Hochr. and *E. intermedia* R.T. Bak.
Box, Brush	*Tristania conferta* R.Br.
Grey	*Eucalyptus moluccana* Roxb.
Gum, Cabbage	*Eucalyptus amplifolia* Naudin
Flooded	*Eucalyptus grandis* Hill ex Maiden
Grey	*Eucalyptus propinqua* Deane and Maiden
Spotted	*Eucalyptus maculata* Hook
Sydney Blue	*Eucalyptus saligna* Sm.
Ironbark	*Eucalyptus siderophloia* Benth. (formerly known as *E. decepta* Blakely) and *E. fibrosa* F.Muell. (formerly known as *E. siderophloia* Benth.)
Mahogany, Red	*Eucalyptus resinifera* Sm.
White	*Eucalyptus acmenioides* Schau. and *E. umbra* R.T. Bak. ssp. *carnea* (R.T. Bak.) L. Johnson.
Paperbark	*Melaleuca* spp.
Sheoak	*Casuarina littoralis* Salisb. and *C. torulosa* Ait.
Stringybark, White	*Eucalyptus globoidea* Blakely
Tallowwood	*Eucalyptus microcorys* F. Muell.
Turpentine	*Syncarpia glomulifera* Sm.
Wattle	*Acacia* spp.

NOTE: "Rainforest species" mentioned in the text refer to a number of species, mostly of Indo-Malaysian floristic affinities, forming a mesic understorey in some of the better gully sites. None of these species reaches commercial size on Yarratt State Forest.

APPENDIX 2

GROWING STOCK DETAILS, 1960 AND 1966

(Figures quoted are per acre)

Parameter	Class	Year	Size Class (DBH, inches)							
			4–8	8–12	12–16	16–20	20–24	24–28	28 +	Total
No. Stems (N)	Useful	1960	24·6	15·8	9·4	3·2	0·9	0·4	0·5	54·9
		1966	41·5	17·3	10·6	4·6	1·1	0·4	0·4	75·9
	Useless	1960	18·9	7·8	4·6	2·0	1·0	0·7	1·3	36·3
		1966	24·8	8·3	5·0	2·1	1·2	0·6	1·2	43·1
	Total	1960	43·6	23·7	14·0	5·2	1·9	1·1	1·8	91·2
		1966	66·2	25·6	15·6	6·6	2·2	1·0	1·6	119·0
Basal Area (BA) (square feet)	Useful	1960	4·8	8·7	10·1	5·6	2·3	1·4	5·0	37·9
		1966	7·2	9·1	11·0	7·7	2·8	1·6	3·2	42·5
	Useless	1960	3·4	4·2	4·9	3·4	2·6	2·6	10·8	31·8
		1966	4·2	4·2	5·2	3·5	3·0	2·2	9·5	31·7
	Total	1960	8·2	12·9	15·0	9·0	4·9	4·0	15·7	69·7
		1966	11·4	13·3	16·2	11·2	5·8	3·7	12·6	74·2
Volume (V) (super feet)	Useful	1960	307	1,091	1,535	861	352	211	923	5,280
		1966	381	1,106	1,633	1,238	448	230	564	5,600
	Useless	1960	164	386	562	419	338	426	2,033	4,328
		1966	180	375	591	426	407	320	1,754	4,053
	Total	1960	472	1,477	2,097	1,280	689	637	2,956	9,608
		1966	562	1,481	2,224	1,664	855	550	2,318	9,654

APPENDIX 3

METRIC CONVERSIONS

(for measures used in text)

Measure Used	*Metric Equivalent*
1 acre	0·405 hectare
1 chain	20·12 metres
1 inch	0·025 4 metre (2.54 cm)
1 mile	1·609 kilometres
1 square foot	0·092 9 square metre
1 square foot per acre	0·230 m^2/ha
1 super foot (Hoppus)	0·003 0 cubic metre
1 super foot per acre	0·007 4 m^3/ha

V. C. N. Blight, Government Printer, New South Wales—1972