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FORESTRY COMMISSION OF N.S.W.

TECHNICAL PAPER

No. 2

OBSERVATIONS ON THE GROWTH OF COACHWOOD

(Ceratopetalum apetalum D. Don)

IN A SELECTION FOREST

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(originally prepared, January, 1959)

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Introduction.

Present ideas on the management of the Coachwood (Ceratopetalum apetalum) rainforest type in the Dorrigo Plateau area are based on a selection system of silviculture in which logging reduces the stand to a B.A. of about 120 sq. ft. per acre, about 60% of the typical B.A. in a healthy, virgin stand. Logging is preceded by tree-marking which aims to remove overmature stems and to thin out denser stands of smaller stems, conserving the more valuable growing stock. Useless stems should be destroyed by ringbarking, frill-girdling or falling.

For management purposes it is essential that some indication of the growth rate of Coachwood be known so that yields can be calculated and mill quotas can be fixed at realistic values. Unfortunately experience shows Coachwood to be a slow growing species and with one exception growth plots in the Coachwood type are of too recent establishment to be of any use in this regard. The exception is a plot situated near Bo Bo Plantation. A plot was established in the Coachwood type at Styx River S.F. in 1944 and has recently been remeasured, but not all stems were measured originally, and thus it cannot be used fully at this stage.

The Bo Bo Plot.

This plot was first established in 1945 in a stand that had previously been selectively logged so that few trees larger than 20 inches d.b.h. remained. The area was particularly rich in Coachwood itself, and in the plot of area 0.313 ac. only 3 stems of other species were present, and these were ringbarked after the first year's measurements were taken. The plot was remeasured in 1946 and 1947, and since then at two-yearly intervals. In 1955, following the preparation of a d.b.h. - log length volume table for Coachwood, log lengths were recorded for all stems over 10 inches d.b.h., and in 1957 trees covering the full range of diameter classes were measured for total height.

The plot is located in the floor of a typical Eastern Dorrigo valley at an altitude of about 2000 ft. No signs of crown die-back are in evidence and there are ample quantities of suppressed, but potentially valuable, regrowth in the lower forest strata.

Stem Distribution.

When the plot was established all stems down to 1 inch d.b.h. were measured: indeed one stem was less than 1 inch in diameter. 182 stems were measured, but during the 12 years of the plot's existence 7 of these have died. These seven all came from the smallest diameter classes and must have been moribund in 1945. They have been neglected in all subsequent calculations.

The distribution of the 175 measured stems (560 per acre) at various stages during the 12 years period is shown in Table 1.

Table 1.

Stem Distribution during 12 years Period.

Diam.Class	1945	1949	1953	1957
-2"	20	14	14	14
2 - 4	57	54	52	47
4 - 6	27	31	31	34
6 - 8	19	19	20	22
8 -10	13	15	12	11
10 -12	17	19	17	13
12 -14	14	13	15	20
14 -16	5	7	10	10
16 -18	2	0	1	1
18 -20	0	2	2	2
20 -22	1	1	1	1
	175	175	175	175

Effect of Minimum Diameter.

The measurement of all stems down to 1 inch d.b.h. is contrary to present practice by the North Coast Research Centre, where 4" is the smallest diameter normally measured in native forest growth plots. Thus the Bo Bo plot enables a comparison to be made of the effects of various minimum diameters on the general presentation of plot results (Table 2).

Table 2.

Effects of Minimum Measured Diameter.

Min.Diam.	in Year	No. Stems 1945	No. Stems 1957	B.A. 1945	B.A. 1957	Mean Diam. 1945	Mean Diam. 1957
1"	1945	175	175	52.84	65.04	7.45	8.26
2"	1945	155	155	52.57	64.65	7.90	8.75
2"	1957	-	161	-	64.85	-	8.59
4"	1945	98	98	49.70	60.53	9.66	10.65
4"	1957	-	114	-	62.25	-	10.01

Under present practice 98 stems with a B.A. of 49.70 sq.ft. and a mean diameter of 9.66 inches would have been measured in 1945, and 114 stems (62.25 sq.ft. B.A., 10.01 inches mean diameter) in 1957. Thus the current method would have measured only 56% of the stems in 1945 and 65% in 1957, to include 94% of the B.A. in 1945 and 96% in 1957. Since B.A. growth is basic to the proposed system of management, and since the effect on total B.A. of measuring to 4 inches only is so slight, this suggests that the smaller stems can quite safely be excluded from plot measurement. However, their effect on mean diameter is great, in this case reducing it by over 2 inches at the 1945 measurement. Similarly the effect of recruits is considerable: when recruits to the 4 inch class over the 12 years period are included, mean diameter increment over the same period falls from 0.99 inches (10.65 - 9.66) to 0.35 inches (10.01 - 9.66). This stresses the point that growth plot summaries for irregular stands can only give a very general picture of the state of the plot, and do not give any indication of the distribution of size classes or of the actual rate of growth of individual stems.

Age of Stand.

Basic to the selection silvicultural system is the knowledge that the community being managed is a climax one whose dominant species are capable of regenerating in the virgin stand. In such a stand all age classes should be represented. Microscopic examination of increment borings taken from Coachwood stems at Bo Bo reveals no satisfactory growth rings that can be tied in with annual growth, but certain other attributes of the stand can be used to indicate whether a stand is truly of all ages or whether it is even-aged, with the smaller stems being merely suppressed trees. Bruce and Schumacher (1950) note that the distribution of stems, by size classes, in an even-aged stand tends to give a normal curve whereas in an all-aged stand the curve is J shaped. Graphing the information in Table 1 clearly presents a curve of the J type, and this, coupled with what is known of the ecology of Coachwood (Baur, 1957 a and b) strongly suggests that the Bo Bo stand is all-aged. Other Coachwood growth plots similarly studied confirm this suggestion.

Growth Rate Determination.

Discussing the growth of all-aged stands, Bruce and Schumacher list two main problems for solution:

(a) The prediction of the future growth of an actual stand left after logging.

(b) The prediction of the future growth of a hypothetical stand following prescribed selective logging.

In the Bo Bo plot future growth determinations were wanted for

diameter growth determination, B.A. growth, height growth and volume growth. Diameter growth prediction is essential before the others can be tackled.

Methods of Diameter Growth Prediction.

As can be seen from Table 2, the mean diameter increment for all 175 stems between 1945 and 1957 has been 0.81 inches, giving P.A.I. of less than 0.07 inches. The range of individual diameter increments, however, varies greatly, from no growth in one stem and less than 0.1 inches over the 12 years in 17 stems, to more than 2.0 inches in 8 stems. Stems showing relatively great diameter increments are found in all diameter classes though the percentage of such stems is greatest in the larger classes. These facts are shown in Table 3.

Table 3.

Distribution of Fast-growing Stems.

Diam.Class.	No. Stems 1945.	No. stems with incr.of 2" +	No. stems with incr.of 1" +	% Stems 1" +
1.0 - 1.99	20	0	1	5
2.0 - 3.99	57	0	10	18
4.0 - 5.99	27	2	8	30
6.0 - 7.99	19	1	6	32
8.0 - 9.99	13	0	7	54
10.0 - 11.99	17	4	10	59
12.0 - 13.99	14	1	7	50
14.0 - 15.99	5	0	3	60
16.0 - 17.99	2	0	2	100
18.0 - 19.99	0	-	-	-
20.0 - 21.99	1	0	0	0
Total	175	8	54	31

Trees showing fairly rapid growth are usually found on inspection to have good light conditions and well developed crowns. In the case of stems under 8 inches d.b.h., not yet reaching into the main canopy, they are usually associated with a marked opening in the canopy above. The greatest diameter increment, of 2.75 inches, was put on a tree with an initial diameter of 7.28 inches. This is equivalent to a P.A.I. of 0.23 inches. Thus while some stems of virtually all diameter classes show a P.A.I. of over 0.1 inches, and in exceptional cases of over 0.2 inches, suggesting that the best stems could attain a d.b.h. of 20 inches in 150 years or less, the average rate of growth is considerably slower than this.

This great variation in individual increments creates many difficulties in attempting to obtain useful figures on diameter growth. Various methods have been used to develop some information on this topic; these include:

(a) Miller's Simple Proportion Method.

(b) Continuous Inventory Method.

(c) Osmaston's Mathematical Method.

(d) Cofrequency Line Method.

(e) A new, graphical method.

Miller's Simple Proportion Method.

Miller (1952) was interested in determining the rotation length for a species in Northern Rhodesia and used the progression of stems from one diameter class to another between successive measurements as the basis for his method. For the Bo Bo plot the essential data is given in Table 1, and its development will be seen in Table 4, using the period 1945 - 57.

Table 4.

Diameter Growth - Miller's Method.

Diam.Class.	No. Stems 1945.	No.Stems Passing Out.1945 - 57.	Ratio No. 1945 / No. Passing.	Years in Class.	PAI
- 2	20	6	3.3	40	0.050"
2 - 4	57	16	3.6	43	0.047
4 - 6	27	9	3.0	36	0.056
6 - 8	19	6	3.1	37	0.054
8 - 10	13	8	1.6	19	0.104
10 - 12	17	12	1.4	17	0.118
12 - 14	14	6	2.3	28	0.072
14 - 16	5	1	5.0	60	0.034
16 - 18	2	2	1.0	12	0.168
18 - 20	0	0	-	-	-
20 - 22	1	0	-	-	-

The "Ratio" column expresses the number of trees originally present as a proportion of those growing out of the class during the 12 years period. Multiplying this ratio by the number of years in the period, the time taken by an average stem to pass through each class is obtained. Since each class is of 2 inches width, the P.A.I. can then be simply obtained.

The method is a very approximate one and is prone to inaccuracies dependent upon the fortuitous distribution of stems within diameter classes. These can be overcome to some extent by graphing the calculated P.A.I. against the respective diameter class and then drawing a curve of best fit through the points, thus giving harmonised P.A.I. values. Such a curve is shown in Graph I, and the harmonised P.A.I.'s become:

Diam. Class.	P.A.I.
- 2	0.050 inches
2 - 4	0.051
4 - 6	0.053
6 - 8	0.058
8 - 10	0.065
10 - 12	0.075
12 - 14	0.087
14 - 16	0.102
16 - 18	0.117
18 - 20	0.135
20 - 22	0.152

Continuous Inventory Method.

Meyer (1942) discusses another method of determining diameter increment based on the movement of stems through diameter classes over a period. Using the same data and period of measurement, the calculations for the Bo Bo plot are shown in Table 5.

Table 5.

Diameter Growth - Continuous Inventory Method.

Diam.Class	No.1945	No.1957	No.Rising	No.Stationary	D.R.	D.E.	Per. Incr.	P.A.I.
23	0	0	0	+ 1	0	2	0	-
21	1	1	0	0	2	2	1.00	.166
19	0	2	2	0	3	3	1.00	.166
17	2	1	1	+ 4	7	15	.47	.078
15	5	10	6	+ 8	18	34	.53	.088
13	14	20	12	+ 5	20	30	.67	.112
11	17	13	8	+ 5	14	24	.58	.096
9	13	11	6	+ 13	15	41	.37	.062
7	19	22	9	+ 18	25	61	.41	.068
5	27	34	16	+ 41	22	104	.21	.036
3	57	47	6	+ 14	6	34	.18	.030
1	20=175	14=175	0=66	0=109				

In this table the "number rising" is the number of stems moving out of a diameter class during the period and the "number stationary" is the number staying within the diameter class. The sum of these two classes gives the total number of trees in the stand. "Double rising" (D.R.) is the sum of each consecutive pair of figures in the "number rising" column (0 + 0 = 0; 0 + 2 = 2; 2 + 1 = 3; etc.), while "double effective" (D.E.) is obtained by doubling each value in the "number stationary" column and adding to this the corresponding value in the "double rising" column((2x1) + 0 = 2; (2x0) + 2 = 2; (2x4) + 7 = 15; etc.). The ratio of double rising to double effective gives a measure of the periodic increment, and this is converted to P.A.I. by dividing by 12 (number of years concerned) and multiplying by 2 (because each class is of 2 inches).

This method evens out many of the extreme fluctuations which are so evident in Miller's method, and by plotting the individual P.A.I.'s calculated, harmonised values can be obtained. This is shown in Graph 1, with the new values becoming:

Diam. Class	P.A.I.
- 2"	0.024 inches
2 - 4	.038
4 - 6	.054
6 - 8	.070
8 - 10	.086
10 - 12	.102
12 - 14	.118
14 - 16	.134
16 - 18	.150
18 - 20	.162
20 - 22	.174

Osmaston's Mathematical Method.

In a discussion of Miller's work, Osmaston (1956) proposed a simple mathematical method of obtaining either increment rates or conversely rotation lengths. The stems are arranged in diameter classes of convenient size or (to give equal weight to all classes) of uneven width, but with each containing the same number of stems, and then the P.A.I. is calculated directly from the plot measurements over the period. Once again, if thought desirable, the calculated P.A.I.'s can be graphed to obtain harmonised values with the fluctuations evened out. Table 6 shows the P.A.I. of 25 groups of 7 trees, grouped according to the 1945 diameters.

Table 6.

Diameter Growth - Osmaston's Method.

Diam. Class	Class Width	Mean DBH. 1945	Mean Incr. (7trees) 1945 - 57	P.A.I.
0.94 - 1.44"	0.50"	1.19"	0.380"	0.0317"
1.45 - 1.71	0.26	1.57	0.137	0.0114
1.71 - 2.00	0.29	1.91	0.320	0.0267
2.01 - 2.29	0.28	2.18	0.584	0.0487
2.30 - 2.62	0.32	2.44	0.501	0.0418
2.63 - 2.80	0.17	2.74	0.612	0.0510
2.81 - 2.98	0.17	2.93	0.798	0.0665
2.99 - 3.21	0.22	3.08	0.676	0.0563
3.22 - 3.40	0.18	3.29	0.478	0.0398
3.41 - 3.71	0.30	3.53	0.516	0.0430
3.72 - 3.98	0.26	3.92	0.571	0.0476
3.99 - 4.21	0.22	4.07	0.873	0.0728
4.22 - 4.70	0.48	4.41	0.846	0.0705
4.71 - 5.51	0.80	5.10	0.580	0.0483
5.52 - 6.10	0.58	5.77	1.035	0.0863
6.11 - 6.85	0.74	6.56	0.596	0.0497
6.86 - 7.28	0.42	7.13	0.973	0.0811
7.29 - 8.59	1.30	7.88	1.021	0.0851
8.60 - 9.48	0.88	9.18	1.107	0.0923
9.49 -10.50	1.01	9.98	1.313	0.1094
10.51 -11.30	0.79	10.87	1.553	0.1294
11.31 -12.20	0.89	11.70	0.814	0.0678
12.21 -12.69	0.48	12.50	0.877	0.0731
12.70 -14.16	1.46	13.28	1.522	0.1268
14.17 -20.13	5.96	16.47	1.076	0.0897

The curve of P.A.I. against initial diameter is shown in Graph II, and from this the following harmonised P.A.I.'s have been obtained:

Diam. Class	P.A.I.
- 2"	0.020 inches
2 - 4	0.042
4 - 6	0.061
6 - 8	0.078
8 - 10	0.090
10 - 12	0.100
12 - 14	0.107
14 - 16	0.112
16 - 18	0.115
18 - 20	0.118
20 - 22	0.120

This illustrates clearly the depressing effect of the lower diameters: for example, the 2 - 4 inch class has a P.A.I. of 0.042 inches, yet 10 out of the 57 trees in this class have shown P.A.I.'s of twice this rate or more, and it is logical to assume that these are the stems that will go on to form the future merchantable trees in the stand.

Cofrequency Line Method.

Smithers (1949) has discussed in some detail the application of Dwight's Cofrequency Principle in predicting growth rates. A cofrequency line is drawn by plotting the mean diameter of groups of stems arranged in order of size at the start of the period of measurement, against the mean of equal sized groups arranged in order at the end of period. In other words the diameters of the same trees are not being directly compared, but rather the diameters of trees holding the same position in the stand at the start and finish of the period of measurement. Table 7 shows the data of the Bo Bo plot arranged in this way, using 25 groups each of 7 trees.

Table 7.

Cofrequency Group Averages.

Group No.	Mean Diam. 1945.	Mean Diam. 1957.
1	1.19 in.	1.32 in.
2	1.57	1.78
3	1.91	2.31
4	2.18	2.65
5	2.44	2.97
6	2.74	3.21
7	2.93	3.43
8	3.08	3.61
9	3.29	3.94
10	3.53	4.19
11	3.92	4.40
12	4.07	4.75
13	4.41	5.28
14	5.10	6.04
15	5.77	6.68
16	6.56	7.25
17	7.13	7.90
18	7.88	9.16
19	9.18	10.29
20	9.98	11.11
21	10.87	12.19
22	11.70	12.75
23	12.50	13.44
24	13.28	14.82
25	16.47	17.68
Mean	6.15	6.93

The line drawn from this data is shown in Graph III. It will be seen that the scatter of points falls very close to a straight line, and it is possible to calculate the regression formula for this line:

$$\text{Diam. } 1957 = 0.335 + 1.073 \text{ (Diam. } 1945)$$

Using this formula, one can readily calculate the expected diameter in 1957 for any given diameter in 1945, and thus work out the P.A.I. for each diameter class. This has been done in Table 8.

Table 8.

Periodic Annual Increment - Cofrequency Method.

Diam.Class	Diam.1945	Expected Diam.1957	Increment,1945-57.	P.A.I.
- 2	1.00"	1.41"	0.41"	0.034"
2 - 4	3.00	3.55	0.55	.046
4 - 6	5.00	5.70	0.70	.058
6 - 8	7.00	7.85	0.85	.071
8 - 10	9.00	9.99	0.99	.083
10 - 12	11.00	12.14	1.14	.095
12 - 14	13.00	14.28	1.28	.107
14 - 16	15.00	16.43	1.43	.119
16 - 18	17.00	18.58	1.58	.132
18 - 20	19.00	20.72	1.72	.143
20 - 22	21.00	22.87	1.87	.156

This method contains one serious fallacy: it assumes that the diameter P.A.I. will increase steadily as the diameter increases. In an all-aged stand this is probably fairly correct for much of the life of any stem, but for the larger stems, where diameter increment tends to slacken off, all the evidence suggests that it is not so.

New Method.

To overcome this difficulty a new method is suggested, based on both the Cofrequency and Osmaston's methods. As in the Cofrequency method, stems are grouped according to size for the 1945 and 1957 measurements. The mean increment for each group of trees can then be readily determined and hence the P.A.I. for each group. The P.A.I. can then be plotted against initial diameter to give an increment curve based directly on field measurements. Using the same groups as in Table 7, the increments obtained are shown in Table 9; in addition larger groups of 35 trees (5 smaller groups) have also been taken to give point of even further weight on the graph.

Table 9.

Diameter Increment - New Method.

Diam. 1945.	Incr.,1945-57.	P.AI.
1.19 in.	0.13 in.	0.011 in.
1.57	0.21	0.017
1.91	.40	.033
2.18	.47	.039
2.44	.53	.044
2.74	.47	.039
2.93	.50	.042
3.08	.53	.044
3.29	.65	.054
3.53	.66	.055
3.92	.48	.040
4.07	.68	.057
4.41	.97	.081
5.10	.94	.078
5.77	.91	.076
6.56	.69	.057
7.13	.87	.072
7.83	1.28	.107
9.18	1.11	.092
9.98	1.13	.094
10.87	1.32	.110
11.70	1.05	.087
12.50	.96	.080
13.28	1.54	.128
16.47	1.21	.101
1.86	0.35	0.029
3.11	0.56	0.047
4.65	0.80	0.067
8.15	1.10	0.092
12.96	1.22	0.102

Graph IV shows the P.A.I. curve, and from this can be obtained the P.A.I. corresponding to the various initial diameters:

Diam. Class	P.A.I.
- 2	0.011 in.
2 - 4	.046
4 - 6	.070
6 - 8	.085
8 - 10	.095
10 - 12	.100
12 - 14	.103
14 - 16	.105
16 - 18	.107
18 - 20	.108
20 - 22	.109

Comparison of Methods.

The P.A.I. for various diameters has now been calculated by five different methods, and it is of interest to compare these (Table 10 and Graph V).

Table 10.

Comparison of Diameter P.A.I.-Various Methods.

Diam.Class.	Miller's.	Cont.Invent.	Osmaston's.	Cofrequency.	New.
- 2	0.050"	0.024"	0.020"	0.034"	0.011"
2 - 4	0.051	0.038	0.042	0.046	0.046
4 - 6	.053	.054	.061	.058	.070
6 - 8	.058	.070	.078	.071	.085
8 - 10	.065	.086	.090	.083	.095
10 - 12	.075	.102	.100	.095	.100
12 - 14	.087	.118	.107	.107	.103
14 - 16	.102	.134	.112	.119	.105
16 - 18	.117	.150	.115	.132	.107
18 - 20	.135	.162	.118	.143	.108
20 - 22	.152	.174	.120	.156	.109

It will be seen that, while the curves cover generally the same range of values, there is considerable divergence between them. Miller's method has in this case given a concave graph. This is the simplest and least accurate of the methods: its values are highest for small diameters and the lowest in the middle diameter range. The Continuous Inventory and the Cofrequency methods both give fairly straight line graphs, while Osmaston's and the new methods both give convex curves lying close together. These last two, being based directly on actual measurements of diameter increment, must be regarded as having the highest degree of accuracy: their divergence from each other is due to Osmaston's method giving the average diameter growth of individual trees of a given diameter, whereas the new method refers to trees having a certain relative position in the stand. All methods suffer from the general paucity of data above 16 inches.

Using these P.A.I.'s, it is easy to determine the average length of time taken to grow a stem from one size to another. Table 11 shows the calculations to grow from 2 inches to 20 inches, using both Osmaston's and the new values.

Table 11.

Time taken to Grow a Mill-log (20").

Diam.Class.	Osmaston's.		New.	
	P.A.I.	Years in Class.	P.A.I.	Years in Class.
2 - 4	.042	48 yrs.	.046	43 yrs.
4 - 6	.061	33	.070	29
6 - 8	.078	26	.085	24
8 - 10	.090	22	.095	21
10 - 12	.100	20	.100	20
12 - 14	.107	19	.103	19
14 - 16	.112	18	.105	19
16 - 18	.115	17	.107	19
18 - 20	.118	17	.108	18
Total		220 yrs.		212 yrs.

The periods given, 212 and 220 years, agree closely and could be regarded as estimates of rotation length (though rotation length does not truly occur in a selection forest), to which it would be necessary to add the period required to reach 2 inches d.b.h. from seed.

It must, however, be stressed here that these are averages for the entire stand: the P.A.I.'s are being considerably depressed by the large number of very slow growing small stems, many of which will never reach mill-log size. If the fastest stems only are considered, these "rotations" can be considerably reduced. In Table 12 the 5 fastest growing stems in each successive group of 35 stems have been taken and the P.A.I.'s of these groups calculated. If the growth rate shown by these were to be maintained throughout their life, one tree in 7 would reach 20 inches in about 130 years from seed, and an odd tree could possibly grow to this size in 100 years.

Table 12.

Growth of Fastest Stems. (Groups of 5 in 35).

Group No.	Group Range.	1945 Group Width.	Mean D.B.H. 1945	Mean D.B.H. 1957.	Mean Incr.	P.A.I.	Yrs. in Group.
1	1.00 - 2.60"	1.60"	1.99"	3.11"	1.12"	0.093"	17 yrs.
2	2.60 - 3.60	1.00	3.11	4.57	1.46	0.112	8
3	3.60 - 6.00	2.40	4.64	6.67	2.03	0.169	14
4	6.00 - 10.50	4.50	8.11	10.14	2.03	0.169	27
5	10.50 - 20.00	9.50	12.26	14.40	2.14	0.178	53
							119 yrs.

119 yrs. required from 1-20", and say 11 yrs. from seed to 1" = 130 years.

Effect of Various Factors on Growth.

The Bo Bo plot has received no treatment since its establishment. Table 2 shows that it then had a B.A. of 52.84 sq.ft. (169 sq.ft./acre), which had increased to 65.04 sq.ft. (208 sq.ft./acre) in 12 years. There has thus been a steady increase in stand density during this period, and this can be used to indicate whether the growth rate of Coachwood is likely to fluctuate to any extent with changes in stocking, etc. Taking all stems, the P.A.I. can be calculated for 3 successive periods, each of 4 years:

Period.	P.A.I.	Mean Ann.Rainfall(Coff's Hbr.)
1945-49	0.076"	53.5"
1949-53	0.066	78.6
1953-57	0.056	80.9
1945-57	0.066	71.0

There has been a steady decline in the diameter increment during this period, and the decline has certainly not been associated with any drought. This suggests that under the suggested logging system, in which B.A. is to be reduced to 120 sq.ft./acre and then allowed to climb to 200 sq.ft./acre, the growth rates obtained above might be further slightly increased. Other growth plots more recently established, and covering a range of stockings, should give confirmation to this trend in a few years time.

Basal Area Growth.

As stated above, the 175 measured stems have increased their B.A. from 52.84 sq.ft. in 1945 to 65.04 sq.ft. in 1957 (on a per acre basis, from 168.8 to 207.8 sq.ft.). If only stems over 4 inches are considered, the increase is from 158.8 to 198.9 sq.ft. per acre. Thus the plot has been passing through the B.A. range of greatest interest if the 120/200 sq.ft. logging system is to be used. Table 13 shows how this increase in B.A. has been applied to the various diameter classes.

Table 13.

Distribution of B.A. and B.A. Increment.

Diam.Class.	No.Trees.1945.	B.A.,1945.	% Total B.A.	B.A. Incr., 1945-57.	% Total Incr.
- 2"	20	0.26 sq.ft.	0.5%	0.12 sq.ft.	1.0%
2 - 4	57	2.88	5.5	1.24	10.1
4 - 6	27	3.44	6.5	1.29	10.5
6 - 8	19	5.08	9.6	1.38	11.4
8 - 10	13	5.82	11.0	1.51	12.4
10 - 12	17	11.20	21.2	2.77	22.7
12 - 14	14	12.55	23.7	2.33	18.4
14 - 16	5	5.98	11.3	0.82	7.5
16 - 21	3=175	5.62=52.84	10.7=100.0	0.74=12.20	6.0=100.0

The interesting point brought out by this is that the smaller diameter classes, although contributing little to the total plot B.A., have shown a greater relative increase in B.A. over the period than have the larger stems. Thus the 2 - 4 inch class, with only 5.5% of the total B.A., provided 10.1% of the B.A. increment over the period. Table 14 expresses this in a different fashion, with the B.A. increment over the period being shown as a percentage of the initial B.A. for each diameter class.

Table 14.

B.A. increment as Percent of Original B.A.

Diam. Class	% B.A. incr.,1945-57 / B.A.,1945
- 2"	46.3%
2 - 4	43.1
4 - 6	37.4
6 - 8	27.3
8 - 10	25.9
10 - 12	24.7
12 - 14	17.8
14 - 16	13.6
16 - 21	13.2
Average	23.1

Thus on the plot as a whole the B.A. has been increasing at the rate of about 2% per annum, but on the stems over 14 inches it has been barely 1% whereas on stems under 6 inches it has been from 3 - 4%.

In Table 15 the B.A. increment for various diameter classes is shown and these have been plotted to give an increment curve in Graph VI.

Table 15.

B.A. Increment by Diameter Classes.

Diam.Class	No.Trees	B.A.,1945	Mean B.A.	B.A. Incr., 1945 - 57	Mean B.A. Incr.	B.A. P.A.I.
- 2	20	0.26sq.ft.	0.013	0.12 sq.ft.	0.0061	0.0005
2 - 4	57	2.88	0.050	1.24	.0218	.0018
4 - 6	27	3.44	0.127	1.29	.0476	.0040
6 - 8	19	5.08	0.267	1.38	.0729	.0061
8 - 10	13	5.82	0.448	1.51	.1162	.0097
10 - 12	17	11.20	0.660	2.77	.1628	.0136
12 - 14	14	12.55	0.896	2.33	.1593	.0133
14 - 16	5	5.98	1.196	0.82	.1630	.0136
16 - 21	3	5.62	1.874	0.74	.2465	.0205
Total	175	52.84	0.302	12.20	.0697	.0058

From the graph, harmonised increment values can be obtained:

Diam.Class	Mean B.A.	B.A. P.A.I.	Class Width (B.A.)	Years in Class
- 2"	.006 sq.ft.	.0004 sq.ft.	-	-
2 - 4	.049	.0017	.065 sq.ft.	38 yrs.
4 - 6	.136	.0040	.109	27
6 - 8	.267	.0067	.153	23
8 - 10	.442	.0095	.196	21
10 - 12	.660	.0121	.240	20
12 - 14	.922	.0146	.284	19
14 - 16	1.227	.0162	.327	20
16 - 18	1.576	.0173	.371	22
18 - 20	1.969	.0184	.415	23
20 - 22	2.405	.0196	.458	23

This gives a period of 236 years to grow from 2 to 22 inches, and value agreeing well with period obtained by considering diameter growth,

Effect of Proposed Cutting System on Plot.

In 12 years the Bo Bo plot has increased its B.A. from 159 sq.ft. (4" d.b.h. +) to 198 sq. ft. per acre. At the start of the period it was thus at the stage to be expected about halfway between cutting cycles, and it has now reached the stage where a further logging operation is due to reduce the B.A. down to 120 sq. ft., using the 120/200 sq. ft. system. Table 16 shows the B.A. distribution now:

Table 16.

B.A. Distribution, 1957.

Diam. Class	No. Trees	Plot B.A.	B.A. / ac.	Summation of B.A./ac.
4 - 6	34	4.28 sq.ft.	13.6 sq.ft.	198.2
6 - 8	22	6.01	19.1	184.6
8 - 10	11	5.04	16.1	165.5
10 - 12	13	8.46	26.5	149.4
12 - 14	20	18.01	57.7	122.9
14 - 16	10	12.42	39.6	65.2
16 - 18	1	1.67	5.3	25.6
18 - 20	2	4.06	13.0	20 .3
20 - 22	1	2.30	7.3	7 .3
Total	114	62.25	198.2	

About 80 sq.ft./acre has to be removed and, assuming this all comes from the largest trees, the logging operation would take all trees down to 14 inches, plus a further 16 per acre (5 per plot) from the 13 - 14 inch class. The stem distribution would then be as shown in Table 17, and by applying the B.A. P.A.I. values previously obtained it can be seen that the remaining stems would increase in B.A. by 0.844 sq. ft. each year. Since the B.A. has to increase by 25 sq. ft. on the plot (80 sq.ft./acre) before a further cutting is due, it can be simply calculated that the next cutting would not occur for 29 - 30 years.

Table 17.

Stand Composition after Logging.

Diam.Class	No.Stems	Mean B.A.	Tot.B.A. Now.	B.A. P.A.I.	Ann.B.A. Increase.	Total B.A. 30 years.
2 - 4"	47	0.049 s.f.	2.59 s.ft.	0.0017s.ft.	0.080s.ft.	4.99
4 - 6	34	.136	4.28	.0040	.136	8.36
6 - 8	22	.267	6.01	.0067	.147	10.42
8 - 10	11	.442	5.04	.0095	.105	8.19
10 - 12	13	.660	8.46	.0121	.157	13.17
12 - 14	15	.992	13.83	.0146	.219	20.40
			40.21		0.844	65.53

The final column in Table 17 gives an estimate of the B.A. composition after 30 years from logging. Thus the 15 stems in the present 12 - 14 inch class will then have a total B.A. of 20.40, or an average B.A. of 1.36 sq.ft. (15.8 inches d.b.h.). This mean figure, however, does not indicate the true distribution of stem diameters: some will have grown considerably faster than average, while others will almost have stayed stationary.

An estimate of this dispersal can be obtained by studying the increment rate of individual stems during the period 1945 - 57. In Table 18 these increments have been studied for the classes (3) of greatest concern: 8 - 10", 10 - 12" and 12 - 14". By multiplying the 12 year increment by 2.5, an indication of the possible 30 year increment is given, and these possible 30 year increments are tabulated in inch classes.

Table 18.

Stem Increments after 30 years Growth.

Diam.Class.	% Stems increasing Diameter By						
	0 - 1"	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7
8 - 10	0	31	31	31	7	0	0
10 - 12	6	18	23	23	6	18	6
12 - 14	7	36	14	14	22	7	0

These percentages can then be applied to the number of stems present in the same diameter classes after the present logging (Table 17). In Table 19 the present mid-diameter for each class (e.g. 13" for the 12 - 14" class) has been used as the basis, and the dispersal of stems at present in each class has been tabulated from this.

Table 19.

Dispersal of Stems at present from 8 - 14 inches, after 30 years.

Diam.Class after 30 yrs.	No. of Stems at present in: 8 - 10" class	10 - 12" class	12 - 14" class	Total
9 - 10	0	-	-	0
10 - 11	3	-	-	3
11 - 12	4	1	-	5
12 - 13	3	2	-	5
13 - 14	1	3	1	5
14 - 15	-	3	6	9
15 - 16	-	1	2	3
16 - 17	-	2	2	4
17 - 18	-	1	3	4
18 - 19	-	-	1	1

Obviously the total numbers to be expected in the future classes of less than 12 inches are incorrect, as no account has been taken of stems under 8 inches diameter at present.

Now from Table 17 it can be seen that, to reduce the plot B.A. by 25 sq. ft. after 30 years, it will be necessary to take all the stems at present in the 12 - 14 inch class, plus 5 from the 10 - 12 inch class, a total of 20 trees in all. Table 19 shows that, in 30 years' time, it should be possible to extract these stems without taking any stem of less than 14 inches diameter.

Height Growth.

The measurement of the height of trees covering the whole gamut of diameters present in 1957 has enabled the construction of a D.B.H. - height curve (Graph VII). From this the general diameter-height relationship expressed in Table 20 has been obtained.

Table 20.

Diameter-Height Relationship.

Diam.	Ht.
1"	18'
2	29
4	47
6	59
8	69
10	78
12	85
14	90
16	94
18	97
20	99
22	101

A similar study at Moonpar showed average heights of about 110ft. at 20 inches diameter. Using the length of time taken by an average stem to pass through the various diameter classes (Table 11), an indication of average height increment can be obtained. This is shown in Table 21.

Table 21.

Height Increment.

Diam.Class	Yrs. in Class (Table 11,new method)	Increase in Ht.in Class (Table 20)	Height P.A.I.
2 - 4"	43 yrs.	18 ft.	0.42 ft.
4 - 6	29	12	.41
6 - 8	24	10	.42
8 - 10	21	9	.43
10 - 12	20	7	.35
12 - 14	19	5	.26
14 - 16	19	4	.21
16 - 18	19	3	.16
18 - 20	19	2	.11
20 - 22	18	2	.11

Stem Mortality.

It has not been possible to obtain other than an outline of possible mortality trends in such a stand. During the 12 years of measurement, 7 out of an original 182 trees have died, giving a mortality rate of 0.32% per year. Of the 7, 5 were in the 1 - 2" class, one was in the 2 - 3" class, and one in the 4 - 5" class. Measurements for a longer period over a larger number of stems are needed before any true indication of the likely mortality rate can be made.

Volume Growth.

Volume was first measured in the Bo Bo plot in 1955. Log lengths were estimated (with numerous checks) to the nearest 5 ft. length, and the Coachwood Volume Table was used to give the log volumes. Trees over 10 inches d.b.h. were regarded as containing merchantable timber. The distribution of volume by diameter classes is shown in Table 22.

Table 22.

Volume Distribution, 1955.

Diam.Class	No.Stems	Mean Diam.	Mean Log Length	Mean Vol.	Total Volume
10 - 11"	8	10.50"	44.4ft.	172.1s.ft.	1377 s.ft.
11 - 12	7	11.60	42.9	185.7	1300
12 - 13	12	12.50	41.7	202.8	2433
13 - 14	5	13.33	42.0	233.2	1166
14 - 15	7	14.59	36.4	234.4	1641
15 - 16	3	15.52	48.3	341.7	1025
16 - 17	1	16.98	20.0	191.0	191
17 - 18	-	-	-	-	-
18 - 19	2	18.97	57.5	522.5	1045
19 - 20	-	-	-	-	-
20 - 21	1	20.44	45.0	452.0	452
Total	46	13.17	42.3	231.1	10630

The Total volume is equivalent to 34016 s.ft. per acre.

If the 46 stems are divided into 6 groups, 4 of 8 stems and 2 of 7 stems, the mean B.A. and mean volume of each group can be obtained, and these values can then be used to prepare a B.A. - volume line (Graph VIII). From this volume line a table can be prepared showing the average volume for each diameter class (Table 23).

Using this volume table and the stem distribution at various periods, it is possible to determine estimates of volume for years other than 1955. This has been done in Table 24, where a volume of 8521 s.ft. is estimated for the plot in 1945 and of 11,152 s.ft. in 1957.

Table 23.

Coachwood Log Volume Table.

Diam. Class	Volume
10 - 11"	161 s.ft.
11 - 12	184
12 - 13	209
13 - 14	236
14 - 15	266
15 - 16	298
16 - 17	332
17 - 18	368
18 - 19	407
19 - 20	448
20 - 21	491
21 - 22	536

Table 24.

Table 24.

Volume Estimations, 1945 and 1957.

	1945		1957	
Diam.Class	No.Stems	Volume	No.Stems	Volume.
10 - 11"	10	1610 s.ft.	8	1288 s.ft.
11 - 12	7	1288	5	920
12 - 13	10	2090	13	2717
13 - 14	4	944	7	1652
14 - 15	4	1064	5	1330
15 - 16	1	298	5	1490
16 - 17	-	-	-	-
17 - 18	2	736	1	368
18 - 19	-	-	-	-
19 - 20	-	-	2	896
20 - 21	1	491	1	491
Total	39	8521	47	11152

On a per acre basis, volume has increased from 27,267 s.ft. in 1945 to 35,686 s.ft. in 1957, an increase of 8419 s.ft./acre in 12 years. This equals an annual increase of 702 s.ft./ac./ann. or of 74.5 c.ft./ac./ann. If the present stand were reduced to 120 sq.ft. B.A. by removal of the largest stems, a yield of 5755 s.ft. gross would be obtained off the plot (18,416 s.ft./ac.), leaving 5397 s.ft. standing in the plot on stems of 10 inches d.b.h. or larger (17,270 s.ft./ac.).

General Conclusions.

The measurements of the Bo Bo plot have been treated in some detail, as it was intended to find how much information could be obtained from the results to use in predicting future growth, and also what would be the best way of treating the results of other plots established more recently to obtain the most beneficial information.

Dealing with results applicable to the Bo Bo plot alone, the following results have been obtained:

1. Both ecological and mensurational considerations suggest that the stand is all-aged.

2. Average figures for the diameter growth have been obtained. (Table 10, Graph IV).

3. From these figures it is suggested that it takes on the average, about 220 years to grow from 2 to 20 inches d.b.h. (Table 11); but one seventh of the stand (taking trees of all size classes) will reach mill-log size in a little over half this time (Table 12).

4. The smaller stems are contributing relatively more of the B.A. increment than the larger ones (Tables 13 and 14).

5. B.A. growth figures have been calculated, and these agree well with the diameter growth figures (Table 15, Graph VI).

6. The stand is now ready (on B.A. considerations) for a further logging.

7. A logging now would need to remove stems down to the 13" class.

8. It is possible to make an estimate of growth after logging, and this suggests that 30 years would elapse before B.A. regains the figure of 200 sq.ft./acre, at which stage the next logging could remove stems down to the 14" class. (Tables 16 - 19).

9. The rate of height growth has been estimated, showing that top height is unlikely to exceed 110 ft. (Tables 20 and 21, Graph VIII).

10. Using the general Diameter-Log length Volume Table for Coachwood, a local Diameter Volume Table has been constructed (Table 23).

11. Volume increment in the past has averaged 75 c.ft./acre/annum on stems over 10" d.b.h., of which 12 c.ft./annum has come from the recruitment to smaller stems to the 10 inch class (Table 24).

12. A present reduction in the B.A. to 120 sq.ft. would remove about half the volume standing.

It should be added here that, in the suggested logging operations, it has been assumed that size alone would be the criterion for falling. In practice this is unlikely to be so: both silvicultural and management considerations would urge the retention of some of the larger diameter trees and the removal of an equivalent B.A. of smaller ones.

The Bo Bo stand is clearly already deficient in larger diameter stems (16 inches +) and oversupplied with medium sized stems (10 - 16 inches), so that this retention of part of one group and removal of much of the other is made all the more pressing.

Taking a broader view, the lessons learnt when treating the plot figures given have application to a much wider field than Bo Bo.

1. Current practice of measuring down to 4 inches only, and including recruits to this size at subsequent measurings, receives endorsement (Table 2).

2. The proposed "new method" (Table 9, Graph IV) of calculating diameter increment makes no assumptions about the nature of diameter growth and appears to give reliable results.

3. Diameter growth appears to fall off with increased stocking.

4. B.A. and height increment can be estimated (Tables 15, 20 and 21, Graphs VI and VII).

5. Likely growth and the final distribution of size classes after logging can be estimated and the period elapsing between successive loggings suggested (Tables 17 to 19).

6. Local one-way volume tables can be constructed and should be of much value in predicting growth in future stands (Table 23, Graph VIII).

By applying these techniques to other growth plots in the Coachwood type (now numbering about 24), much further information about the growth and behaviour of Coachwood under various conditions of site and stocking can be expected. All other plots contain varying proportions of other species, no single one of which is very numerous. This will necessitate calculating growth figures separately for Coachwood and "other species". Because of the slow growth of Coachwood (and probably of its associates) it is felt that at least 6, and preferably 10, years should elapse before treatment in this way would be warranted.

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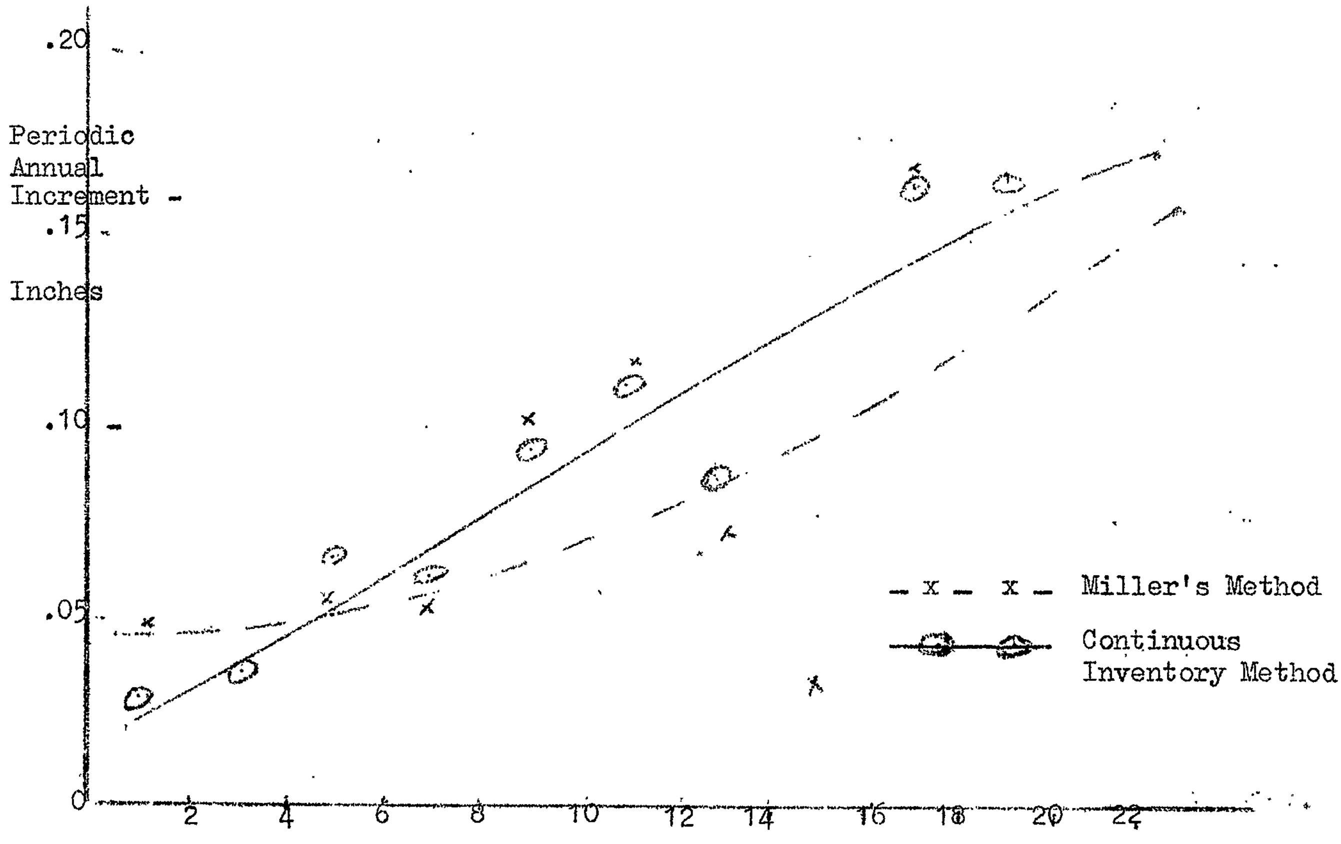
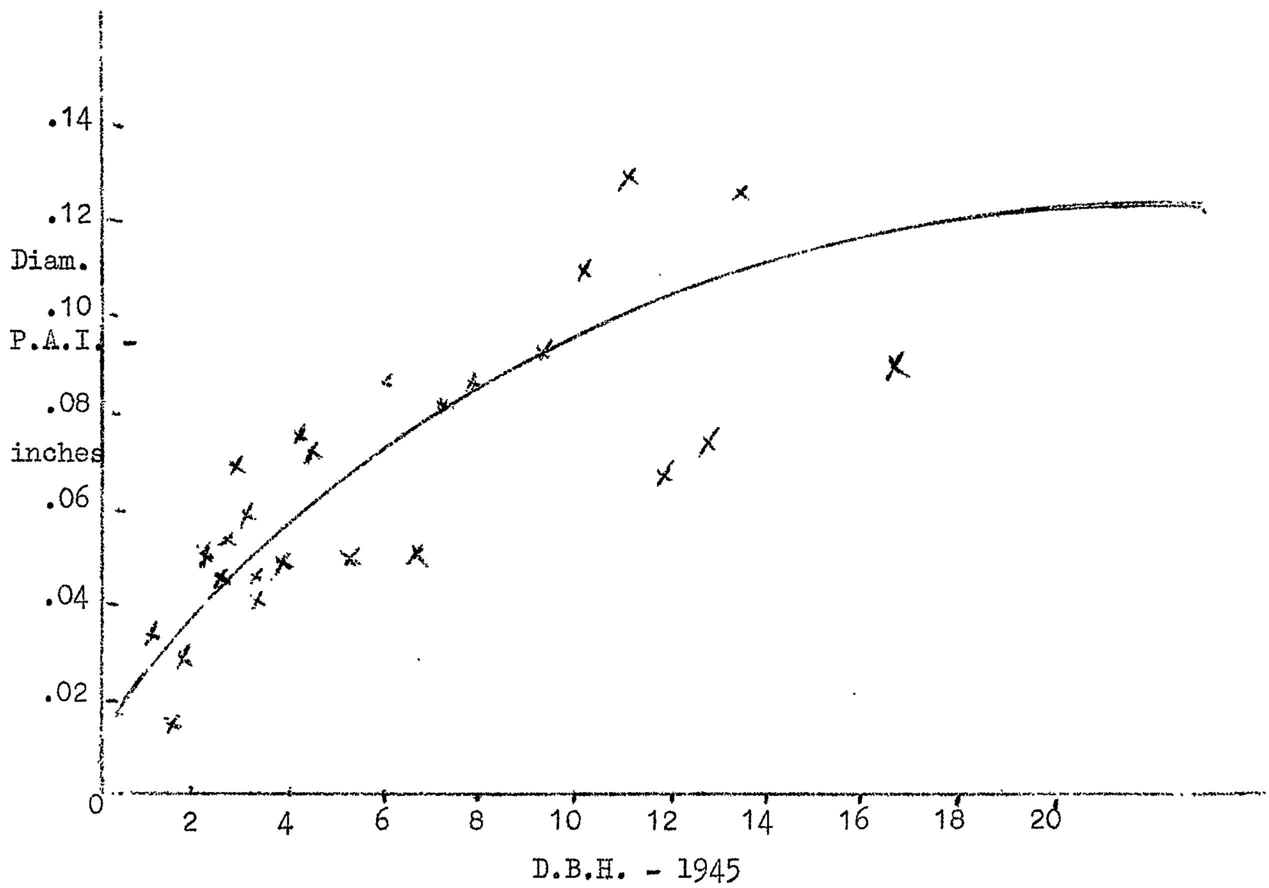
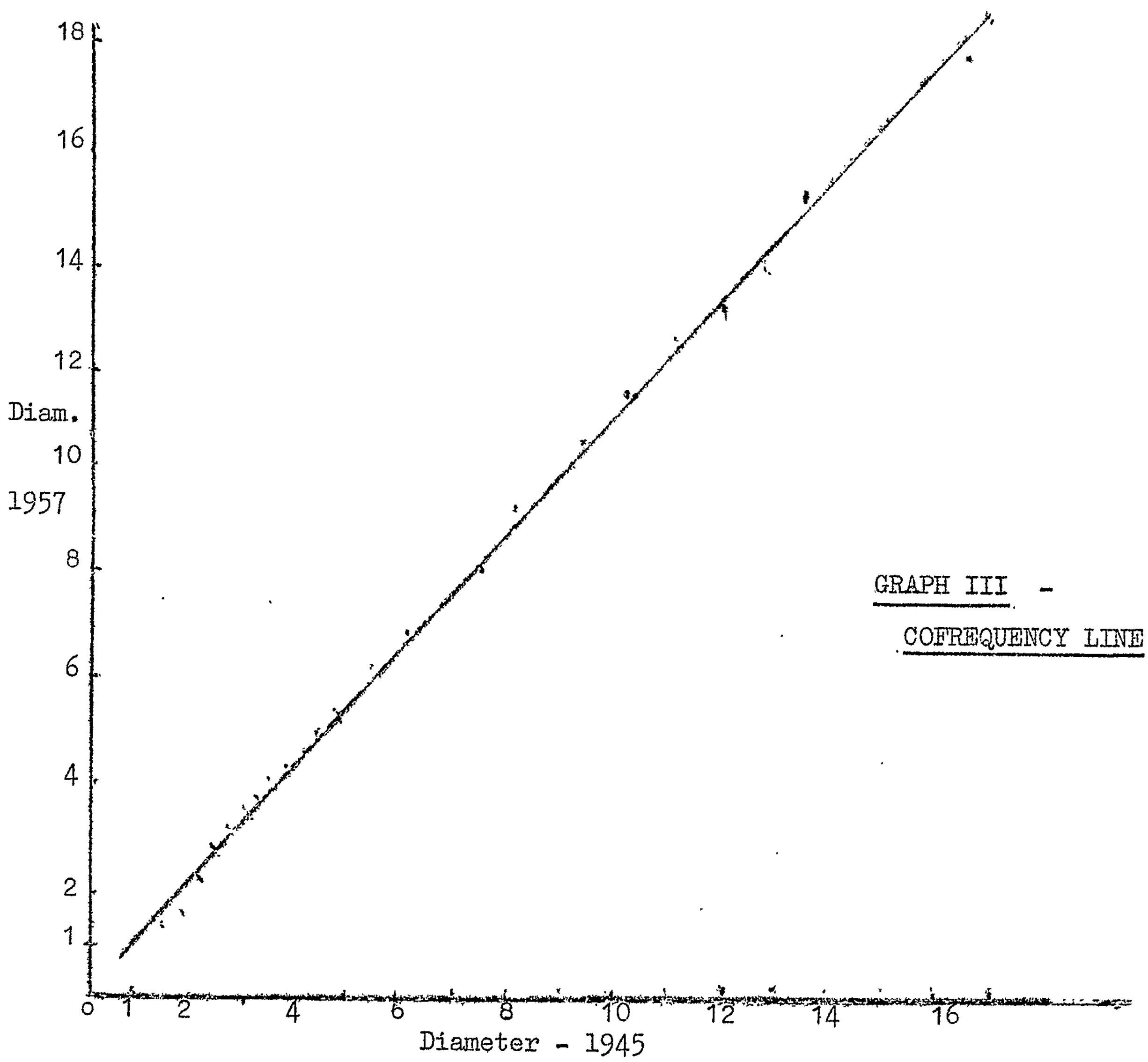


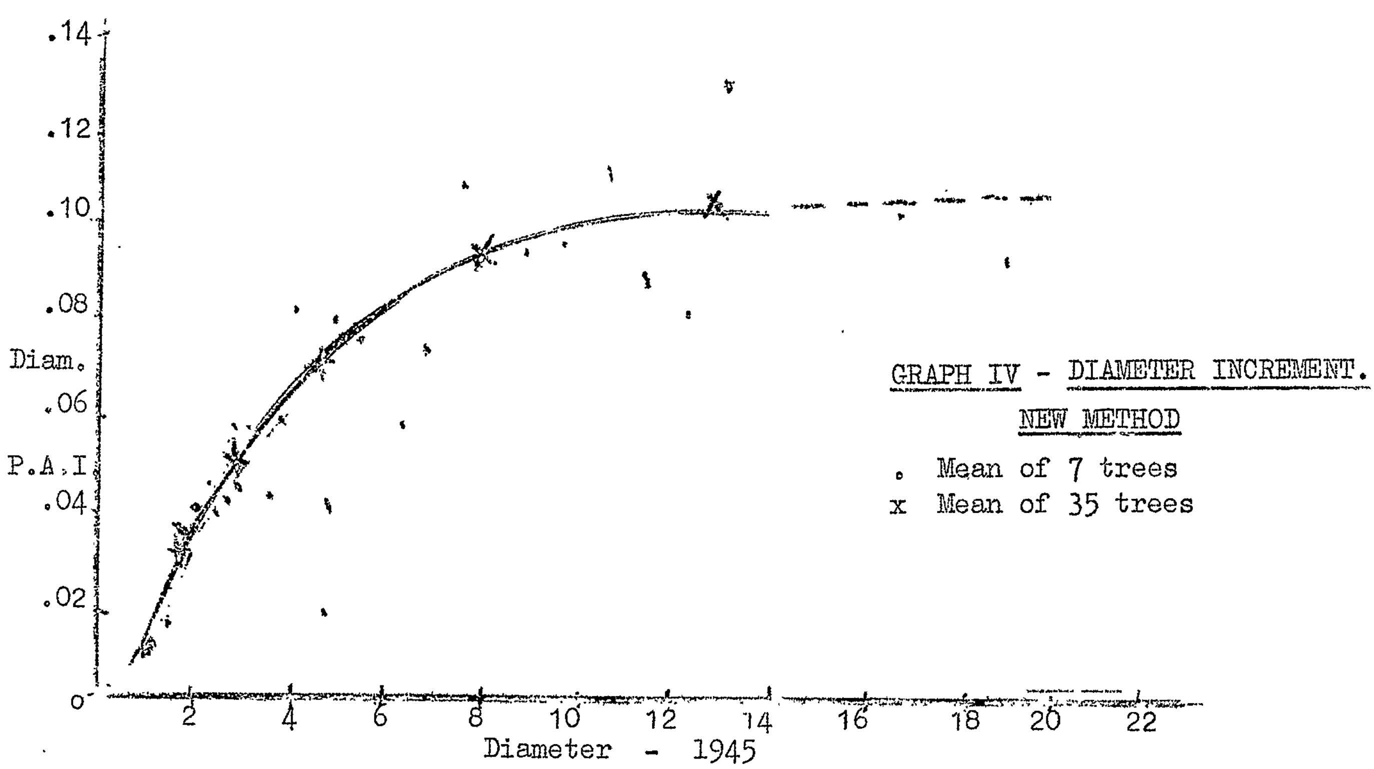
GRAPH I - DIAMETER P.A.I., HARMONISATION CURVES



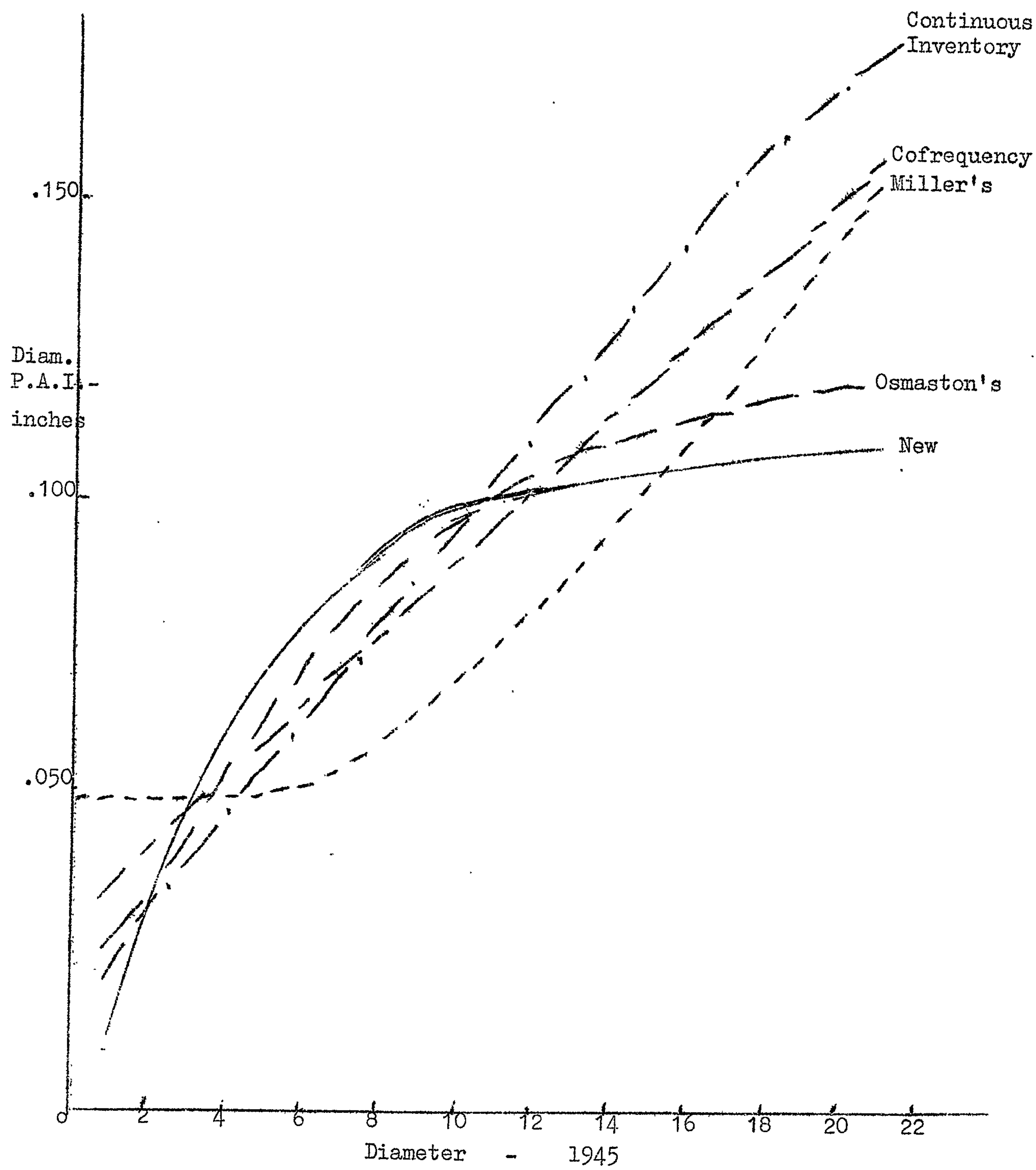
GRAPH II - DIAMETER/INCREMENT CURVE - OSMASTON'S METHOD



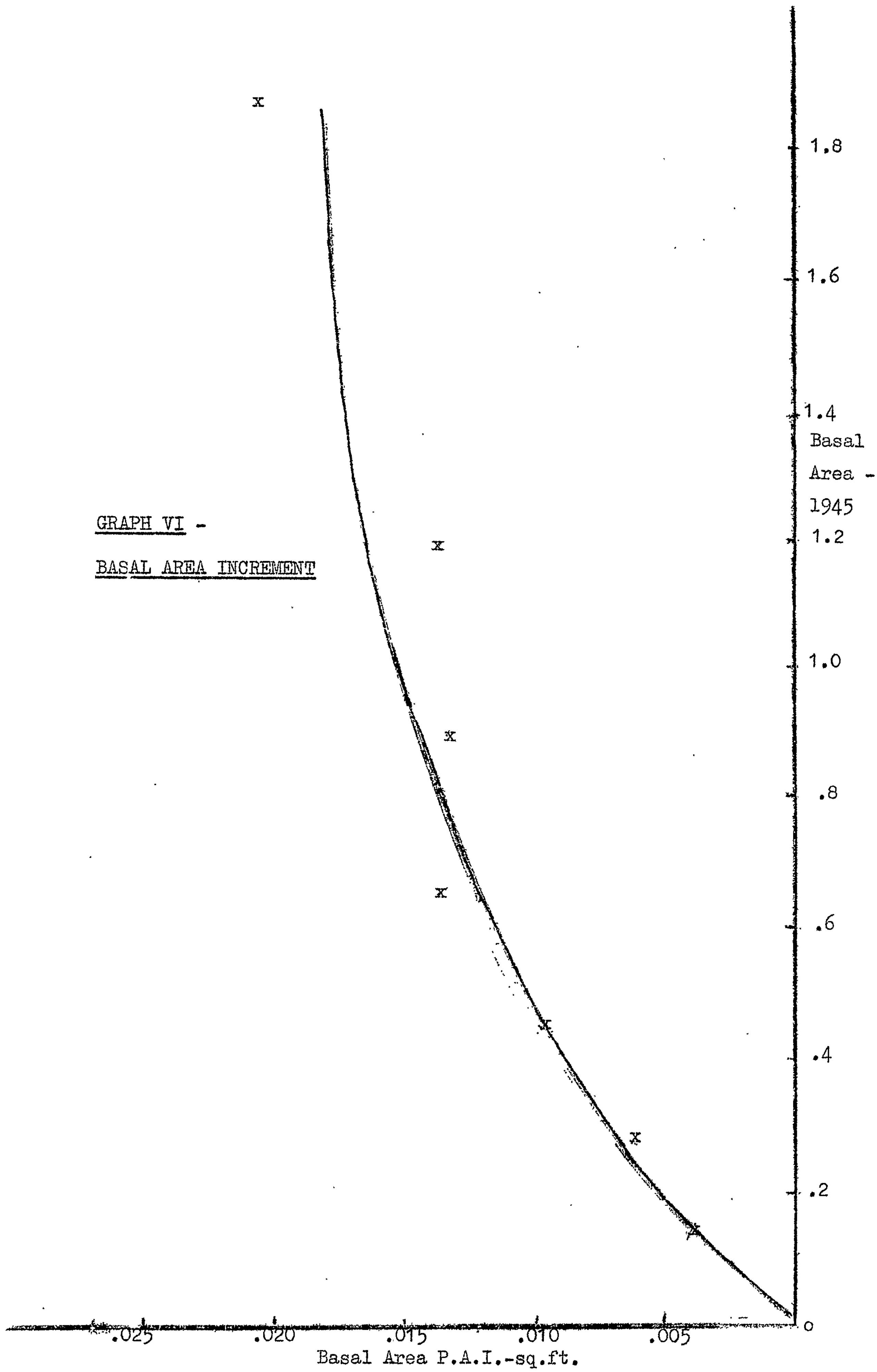
18
16
14
12
Diam.
10
1957
8
6
4
2
1
0
1
2
4
6
8
10
12
14
16
Diameter - 1945
GRAPH III -
COFREQUENCY LINE



.14
.12
.10
.08
Diam.
.06
P.A.I
.04
.02
0
2
4
6
8
10
12
14
16
18
20
22
Diameter - 1945
GRAPH IV - DIAMETER INCREMENT.
NEW METHOD
∘ Mean of 7 trees
x Mean of 35 trees

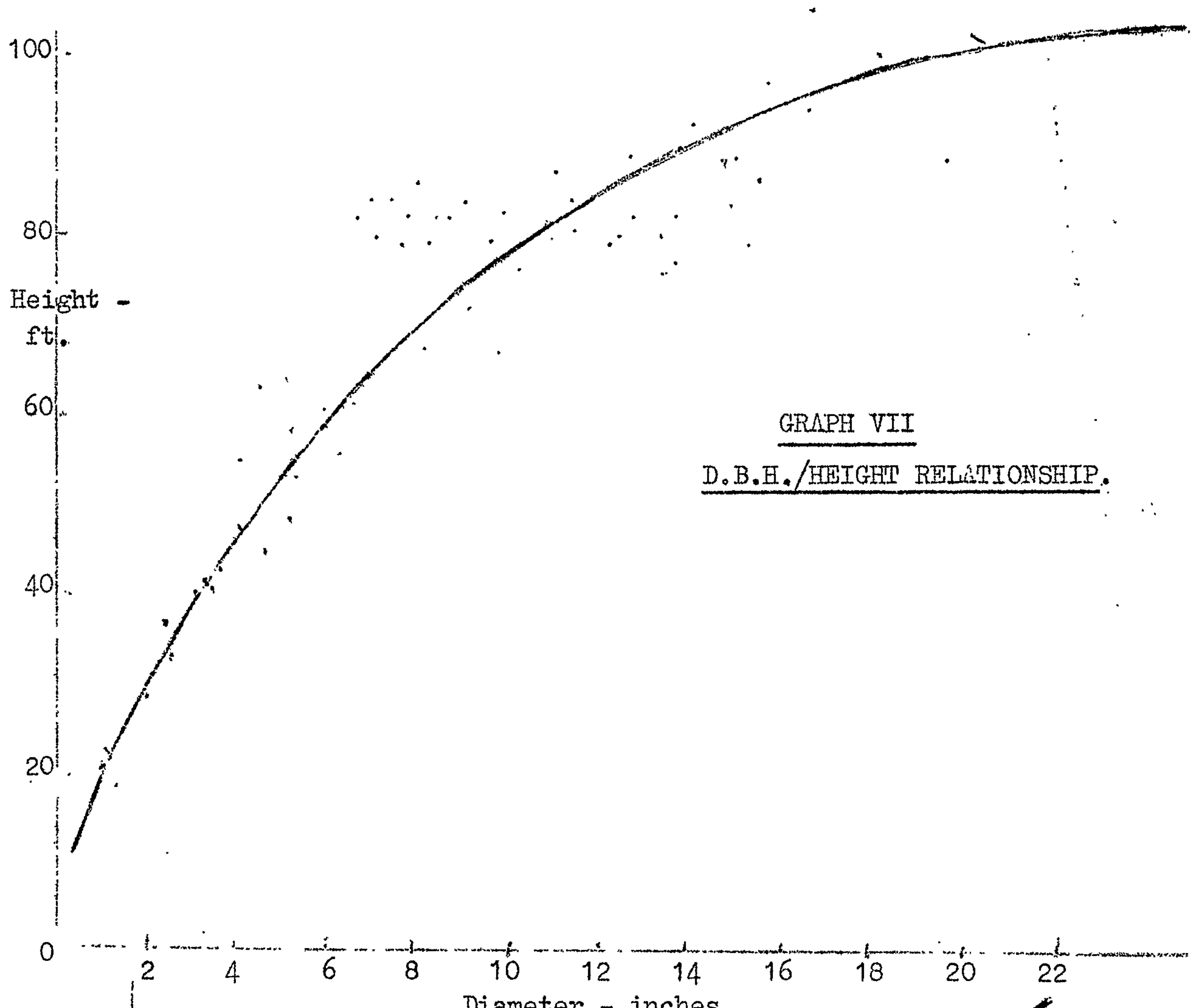


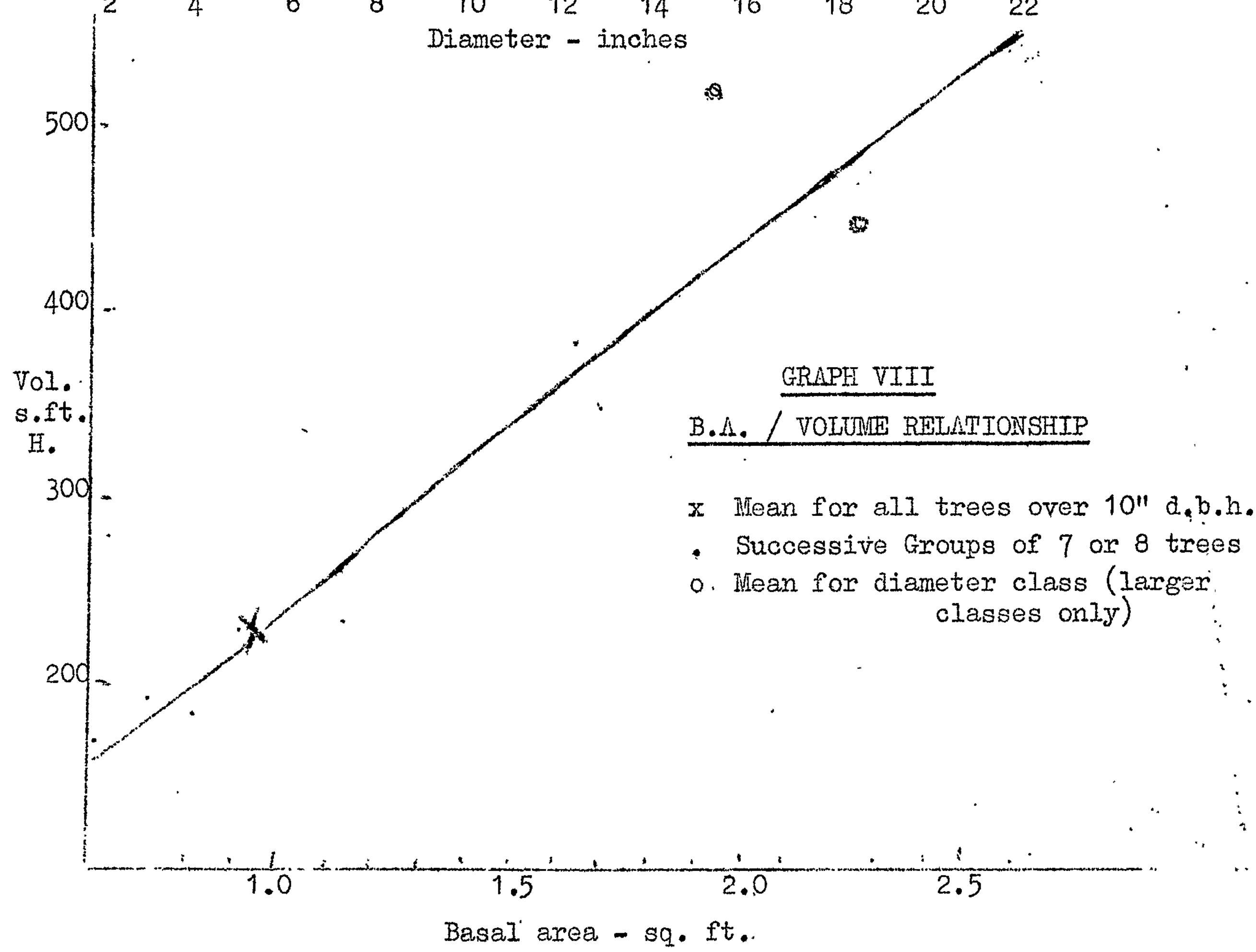
GRAPH V - COMPARISON OF METHODS



GRAPH VI -

BASAL AREA INCREMENT


GRAPH VII
D.B.H./HEIGHT RELATIONSHIP.
Height - ft.
100
80
60
40
20
0
2
4
6
8
10
12
14
16
18
20
22
Diameter - inches


GRAPH VIII
B.A. / VOLUME RELATIONSHIP
x Mean for all trees over 10" d.b.h.
• Successive Groups of 7 or 8 trees
o Mean for diameter class (larger classes only)
Vol. s.ft. H.
500
400
300
200
1.0
1.5
2.0
2.5
Basal area - sq. ft.