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DENSITY PREDICTION IN LODGEPOLE PINE STANDS BY DIAMETER GROWTH ANALYSIS

by

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R. F. ACKERMAN[1]

INTRODUCTION

Although overstocking is recognized as a major problem in the management of lodgepole pine, *Pinus contorta* (Dougl.) var. *latifolia* (Engelm.), in Alberta and British Columbia information available to show the effect of density on stand development is insufficient to permit either adequate assessment of the problem or effective management. This information will eventually be obtained from remeasurement of permanent sample plots but in the interim, there is a need for suitable methods of using single examination data to reveal the influence of density on stand development.

The diameters of the trees in a mature stand can be determined, by diameter growth analysis, for any age in the life of that stand. It is proposed that comparison of the diameters of the retrojected mature trees with the diameters of appropriate trees in younger stands, on an equivalent site, should indicate which of the younger stands represent earlier stages of development of the mature stand in question. If successful, application of the procedure to the range of site, age and density present in the region would permit accurate determination of stand development, from single examination data, for any desired number of site and density classes.

The main problem in this approach is mortality, for it is necessary to know the position occupied in the diameter sequence of the young stands by the trees that will survive to maturity. Several assumptions are possible, including:

1. Over a period of time, mortality is confined largely to those trees which were initially the smallest. The trees alive in a mature stand, or a given number of them, are therefore represented in younger stands by an equal number of the *largest* trees.
2. Over a period of time, mortality occurs at random throughout all size classes. The trees alive in a mature stand are therefore represented in younger stands by the diameter distribution of *all* the trees.

To illustrate the technique and investigate the applicability of the above assumptions, the number of stems at ages 21 years and 32 years necessary to produce an acceptable mature stand has been determined. A comprehensive study would involve a similar procedure for the range of site, age and density present in the region.

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METHODS AND MATERIALS

Description of the Stands

The mature stand chosen to illustrate the method is located in the Foothills Section of Alberta (Rowe 1959). The site is considered better than average and density is such that the stand can at present provide a harvest of pulpwood, poles or sawtimber. The stand was sampled in 1952 by two adjacent $\frac{1}{2}$-acre plots (Plots 1 and 2; Table 1). The two samples were of the same age (155 years) on similar physiographic sites, though they differed in density.

TABLE 1. CHARACTERISTICS OF THE MATURE STAND

Item	Plot 1	Plot 2
Total age (years)	155	155
Total basal area per acre (square feet)	207	199
Number of stems per acre	332	414
Average diameter breast high (inches)	10.7	9.4
Range in diameters (inches)	3–15	3–15
Total volume per acre (cubic feet)	7490	7080
Dominant height (feet)	87	87
Site index at 80 years (feet)	67	67

The young samples, also located in the Foothills Section, are 1/10-acre plots selected to provide a range of density from stands with dominant heights equal to the dominant height of the mature stand at the same age. The young stands were 21 and 32 years of age respectively, corresponding to the dates 1818 and 1829 in the life of the mature stand. Table 2 lists the number of stems per acre for each sample.

TABLE 2. TOTAL AGE AND NUMBER OF STEMS PER ACRE—YOUNG STANDS

Total Age: 32 Years		Total Age: 21 Years	
Plot	Number Stems	Plot	Number Stems
1	630	5	2,600
2	1,120	6	2,770
3	2,460	7	3,340
4	2,720	8	3,360
		9	4,660

Field Measurements and Compilation

The following field measurements and compilations were made for the various plots.

(a) Determination of stand age.

(b) A diameter tally of all living stems 0.5″+d.b.h. followed by the construction of cumulative and per cent diameter frequency curves.

(c) Sufficient heights, taken throughout the diameter range, for the construction of height-diameter curves and the compilation of volumes.

(d) For the mature plots, stem analysis of the 25 largest trees to determine the dominant height-age relationship throughout the life of the stand.

(e) For the mature plots, a single core, taken at breast height from each living tree to determine d.b.h.o.b. of the survivors throughout the life of the stand. In this compilation the following relationship was employed:

$$\text{d.b.h.o.b. at any decade} = \text{d.b.h.i.b. at any decade} \times \frac{\text{d.b.h.o.b. now}}{\text{d.b.h.i.b. now}}$$

From these data cumulative and per cent frequency curves were derived for the years 1829 and 1818.

(f) For the young plots, measurement of the heights of dominant trees. Examination of all frequency curves failed to show indications of any disturbance or temporary reduction in vigour, such as would result from insect attack in these stands.

RESULTS

Cumulative diameter frequency curves for the years 1818 and 1829 are shown in Figure 1 for Plot 1 of the mature stand. The curves for Plot 2 are similar except for the expected difference in position due to the variation in number of stems. On the assumption that the trees alive now in the mature stand are represented at any younger age by an equal number of the largest trees, the cumulative frequency curves for the young stands are shown for comparison. For the latter curves only the number of largest trees equal to the number in the mature stand have been included.

The cumulative frequency curves for the young stands are, with one exception, in correct order with regard to their respective densities. However, the pronounced difference between their slopes and the slope of the frequency curves of the retrojected mature stand makes the desired estimate of the number of stems at these dates impossible. The only explanation for the observed divergence is mortality among the 332 largest trees in the period between 1818-29 and 1952. Apparently many trees that were among the smallest in 1818-29 have survived to maturity.

Although it is doubtful if any group of trees remains entirely free of mortality over a period of 120 years, the error caused by mortality can be reduced appreciably by using fewer of the largest trees in the density index. This is illustrated in Figure 2. Divergence of the basal area of the largest trees of the retrojected mature stand from the basal area of existing young stands increases with the number of largest trees employed. The error does not appear great however for either the 50 or 100 largest trees.

To illustrate this effect further and obtain the desired estimates of number of stems per acre, free-hand curves have been drawn to show the relationship between number of stems per acre and the basal area of the 50, 100, 330 and 410 largest trees for the young stands (Figures 3A and B). Entering these curves

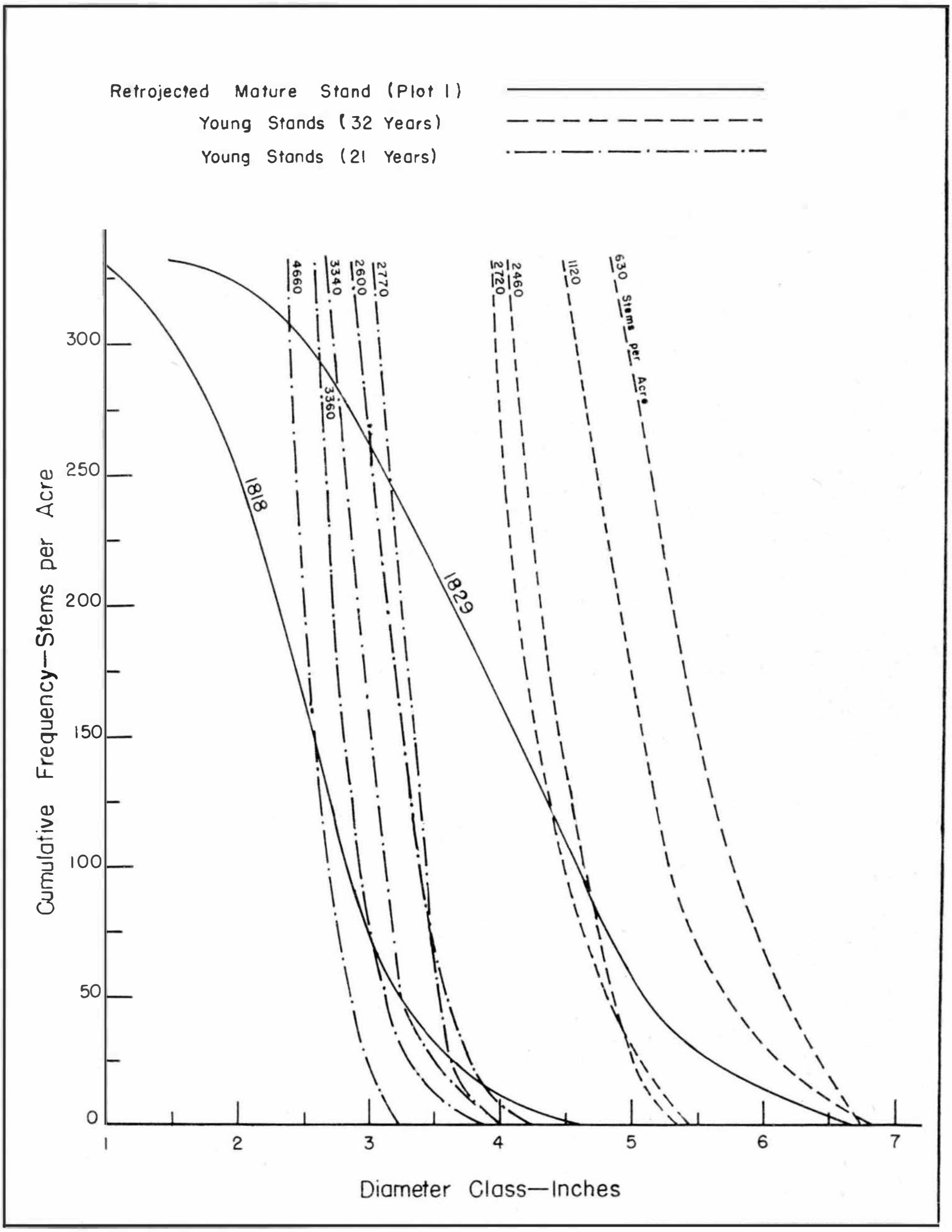

FIGURE 1. Comparison of cumulative frequency curves of young stands with frequency curves of the retrojected mature stand.

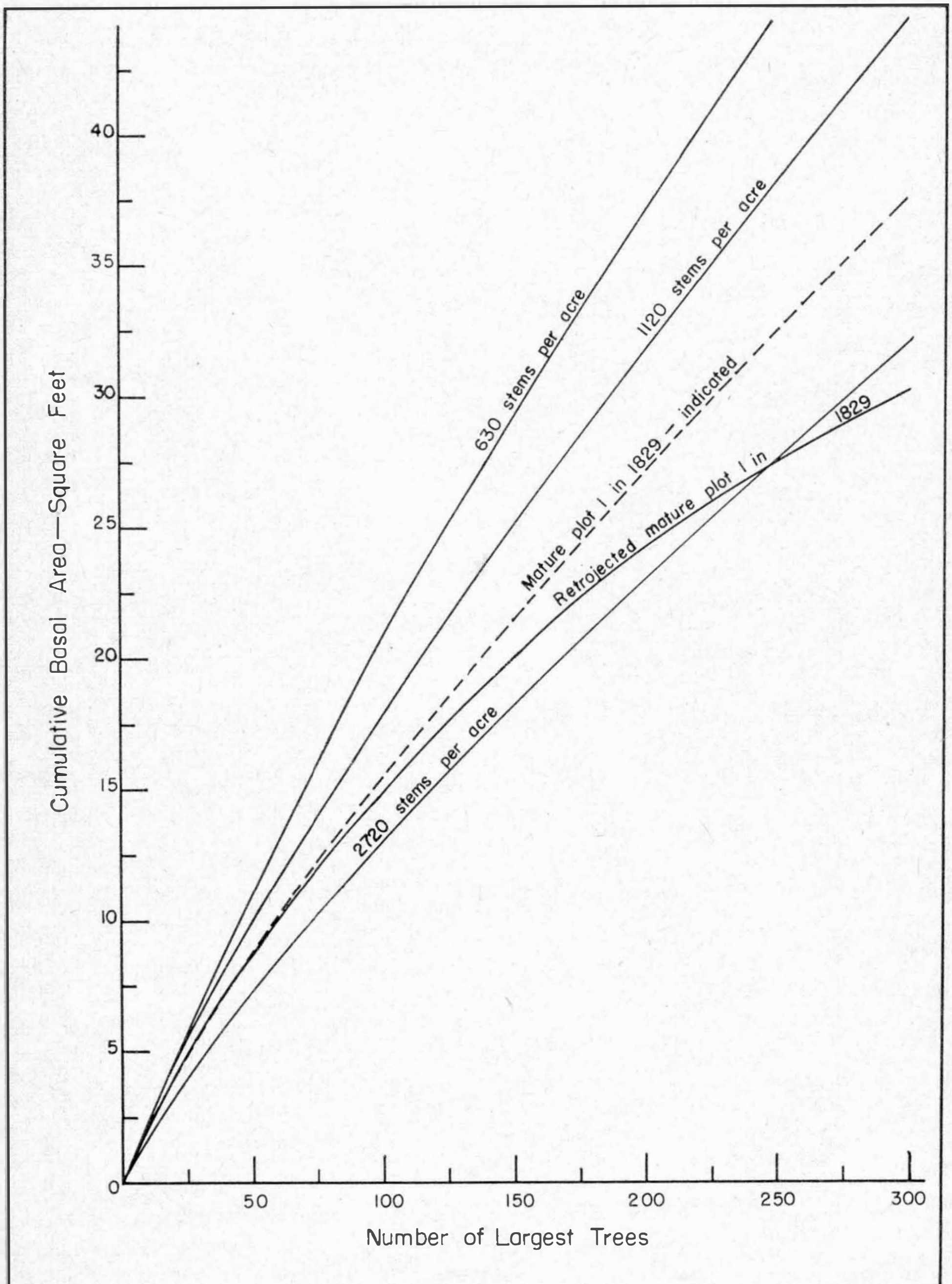

FIGURE 2. Divergence of the basal area of the largest trees in the mature stand, obtained by retrojection, from that indicated by young stands.

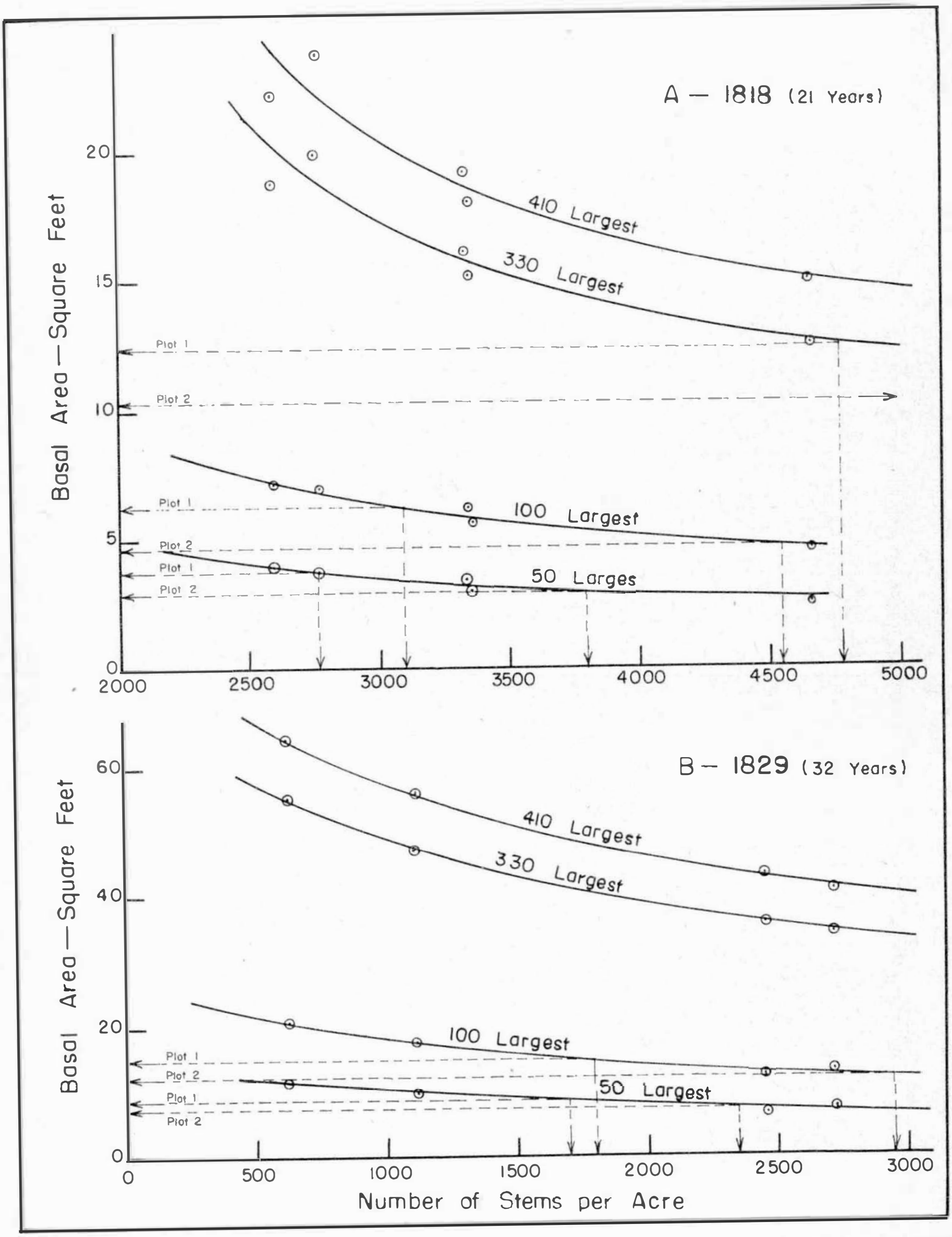

FIGURE 3. Relationship between the basal area of given numbers of the largest trees and number of stems for young stands corresponding in age to the years 1818 (A) and 1829 (B) in the life of the mature stand.

with the basal area of the appropriate number of the largest trees of the retrojected mature stand permits an estimate of the number of stems required in 1818 and 1829 to develop a stand similar to the mature stand. These estimates are tabulated below for Plots 1 and 2.

Employing all trees alive in 1952	*Number Stems per Acre* *Plot 1*	*Plot 2*
21 years (1818)	4775	5000+
32 years (1829)	3000+	3000+
155 years (1952)	332	414
Employing 100 largest trees		
21 years	3100	4550
32 years	1800	2950
155 years	332	414
Employing 50 largest trees		
21 years	2775	3800
32 years	1700	2400
155 years	332	414

The trends are as expected. The greater the number of largest trees employed in the density index the higher the estimate of number of stems due to increasing mortality error.

The estimates of mortality derived from the use of basal area of the 50 largest trees appear reasonable and compare well with trends indicated in yield table studies of lodgepole pine in Alberta (unpublished) and British Columbia (Anon. 1936).

It is evident that over a retrojection period of 120 years mortality is not confined to those trees that were initially the smallest. The alternative hypothesis is that mortality occurs at random. If so, the number of trees that die in each diameter class will be proportional to the number in each diameter class at the start of the period. The cumulative per cent frequency curves of the mature stand, retrojected to 1818 and 1829 should therefore be comparable to the per cent frequency curves of the young stands. This comparison is shown for Plot 2 in Figure 4.

Over a retrojection period of 120 years, the assumption of random mortality results in frequency curves that correspond well in slope and shape with those of existing young stands. Estimates of density can be obtained by comparing the per cent frequency curves of the retrojected mature stand with those of the young stands at the 50 per cent level (the median diameter) in a manner similar to that outlined for cumulative basal area. A curve of median diameter on number of stems is prepared for the young stands and this curve is entered with the median diameter of the retrojected mature stand to derive the desired estimate. The procedure is illustrated in Figure 5.

The estimates of density for the years 1818 and 1829 are presented below. Estimates obtained by use of the basal area of the 50 largest trees are included for comparison.

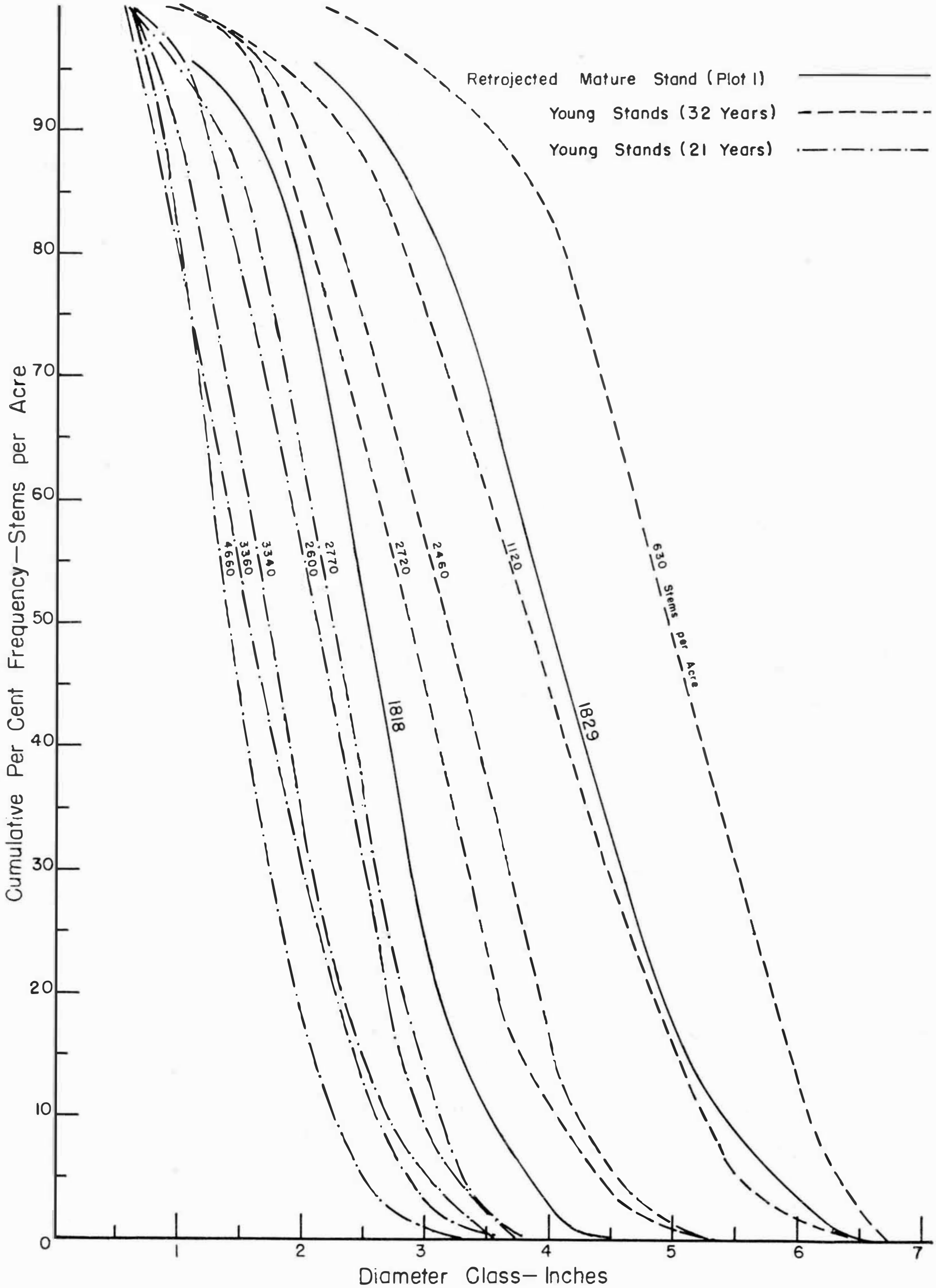

FIGURE 4. Comparison of cumulative per cent frequency curves of young stands with frequency curves of the retrojected mature stand

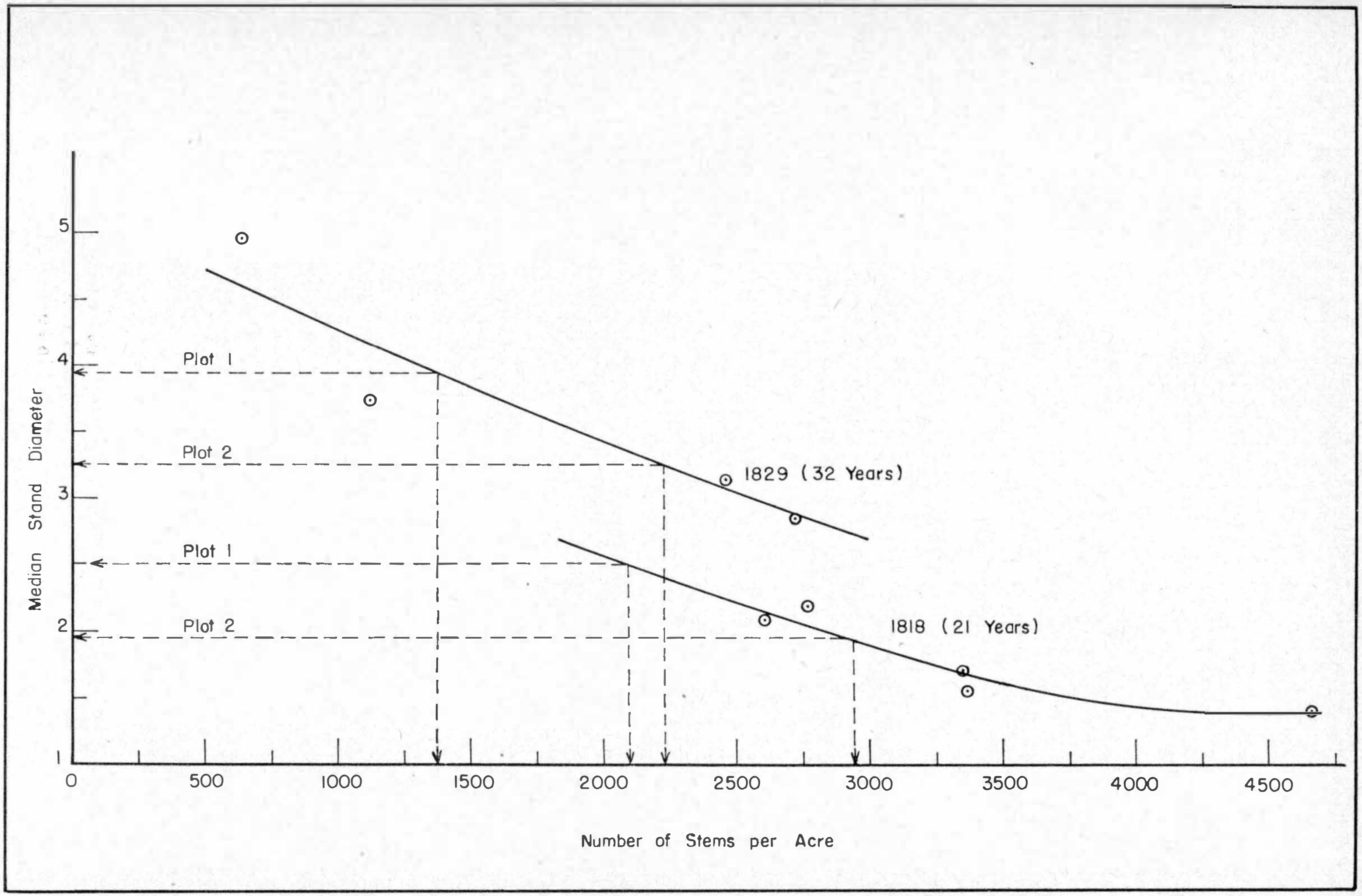

FIGURE 5. Relationship between median stand diameter and number of stems per acre for young stands corresponding in age to the years 1818 and 1829 in the life of the mature stand.

	Number of Stems per Acre					
	Plot 1			Plot 2		
	1818	1829	1952	1818	1829	1952
By median diameter................	2100	1400	332	2950	2225	414
By basal area of the 50 largest.......	2775	1700	332	3800	2400	414

With the assumption of random mortality the estimates are consistently lower than those obtained by assuming that a number of the largest trees are mortality free. This difference is to be expected since any mortality among the 50 largest trees will result in a high value while divergence from the assumption of random mortality, which undoubtedly occurs among the smallest and largest trees, results in a low estimate.

DISCUSSION

Considerable mortality does take place among the largest trees in a young stand before maturity is reached. Observation in any stand will reveal that it is the smaller, suppressed trees that are either dying or have died. The two statements are not at odds if one considers that the death of a suppressed tree is the culmination of a long process initiated when the tree slows in growth relative to its neighbours. It is quite possible that many of these trees, at an earlier date in the stand history, occupied a much higher position in the stand sequence.

To compare the two proposed methods of prediction one must consider the length of the retrojection period employed. If the median diameter is employed, assuming random mortality, predictions should be based on very long retrojection periods. Conversely, if a number of the largest trees are assumed mortality free, predictions should be based on retrojection over a relatively short period. It is believed that the use of the largest trees over a period not longer than 40 or 50 years will find more practical application than a technique which dictates retrojection periods of 100 years or more.

Although this study has emphasized density prediction, the methods described and the principle involved are applicable also to prediction of all stand variables or prediction of stand development from single examination data. The procedure immediately suggests application to yield table construction in lodgepole pine. Provided site control is adequate, yield plots in the same development series can be recognized and growth curve shape can be accurately defined within density classes for all stand variables with a minimum number of single examination plots.

During diameter growth analyses of the mature plots, marked changes were noted in the ordering of individual stems as the stand developed. These changes in sequence can result in error in the determination, by retrojection, of a density index based on a number of the largest trees at each age. This error can be avoided by examining a greater number of the largest trees than will be employed in the density index.

Although the estimates of density derived in this study appear reasonable, the sample used to illustrate the technique could not be expected to define the curvilinear relationships involved with any degree of certainty. The results are encouraging, however, and the technique promises to be useful in growth studies of lodgepole pine.

SUMMARY

A method is proposed for density prediction in lodgepole pine stands, utilizing diameter growth measurements obtained from single examination. One of two assumptions concerning mortality is necessary to apply the method: either a number of the largest trees are assumed to be mortality free or mortality is considered to occur at random over the prediction period.

To illustrate the technique the density at 21 and 32 years of age has been determined employing both assumptions for a stand which is now 155 years of age. The results suggest that the two hypotheses concerning mortality are not alternatives, but that the choice depends upon the length of the prediction period. If predictions are required over a very long period, the assumption of random mortality is applicable; for short periods, best results can be obtained by assuming that a small group of the largest trees are mortality free.

Density prediction over relatively short periods i.e. 40 years, utilizing a small group of the largest trees as a density index is believed to have the greatest application and will be particularly valuable in the construction of stand density yield tables for lodgepole pine.

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