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by

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The expression of stocking levels in forest stands has been the subject of many research efforts and much discussion over the past decades. Quantification of stocking levels has been the goal of much of this effort. This paper suggests a growth-per-tree approach to the quantification of stocking levels. The technique is illustrated through the development of preliminary stocking levels for natural stands of lodgepole pine (*Pinus contorta* Dougl.) in Colorado and southern Wyoming. The levels of stocking sought are those of minimum and maximum occupancy of the site. Minimum occupancy is defined as the level of stocking at which the density is such that the trees present have the potential of just occupying the site but with an absence of crown competition. Maximum occupancy is interpreted to mean the density level where the annual growth per acre, calculated on the basis of individual tree growth, culminates.

Determination of Maximum Occupancy

The growth variable employed to measure individual tree performance in relation to stocking is annual basal area growth in square feet. Cubic volume was considered as a measure of growth but was discarded in favor of basal area. Since cubic volume is so closely correlated with basal area (Hawley and Smith, 1954; Spurr, 1952), there appeared to be little advantage in using the more complex and indirect measure.

Crown Competition Factor (Krajicek and Brinkman, 1957) was chosen as the measure of stand density because regression analyses indicated a closer correlation between annual basal area growth and C.C.F. than with either basal area or number of stems per acre. A thirty-year period was selected as the time interval for growth analysis. A shorter period failed to satisfactorily show growth events in slow-growing natural stands of lodgepole pine. For analyses, tree diameters as they existed thirty years ago, determined from increment cores, were labeled initial diameters and current diameters, measured with a diameter tape, were termed present diameters. Diameter classes one through six inches based on initial diameters were included in the study. Approximately five thousand trees from fifty-three plot locations in Colorado and southern Wyoming were included in the final computations.

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The step by step procedure used to establish the maximum occupancy values is as follows:

Step 1.—The annual basal area growth rate per tree as a function of stand density was the fundamental relationship upon which the procedure was built. Before the correlation between growth rate and density was computed, it was first necessary to determine if annual basal area growth per tree in natural lodgepole pine stands was significantly related to site quality.

The plots were classified by decadal Site Index classes from thirty to ninety. An analysis of variance was then used to test the hypothesis that there was no difference in basal area growth per tree due to site quality. The F value did not indicate that the hypothesis should be rejected at the five percent significance level; therefore the plot data were treated independently of Site Index.

Step 2.—A regression of annual basal area growth per tree (BAG/T), independent of diameter, on initial Crown Competition Factor (CCFI) was computed using values from all 53 plot locations. The resulting linear equation, $(1/BAG/T) = -649 + 7.6016(CCFI)$, was used to obtain an estimated basal area growth per tree (BAG/T) value. The regression had a correlation coefficient (r) of .78, and the slope of the line was statistically significant at the one percent level.

Step 3.—The data from the 53 plot locations were next grouped by one-inch diameter classes based upon mean initial tree diameter. A linear equation was then calculated for each diameter class showing the relationship between initial Crown Competition Factor and estimated basal area growth per tree. The regression equations are presented in Table 1.

TABLE 1. Linear equations by diameter classes, showing the relationship between annual basal area growth per tree and initial crown competition factor.

DBH Class (inches)	Equation	r	Level of Significance
1	$BAG/T = .00462 - .000009636(CCFI)$	.77	5%
2	$BAG/T = .00852 - .000023420(CCFI)$	.82	1%
3	$BAG/T = .00589 - .000021290(CCFI)$	.80	1%
4	$BAG/T = .00460 - .000014510(CCFI)$	.92	1%
5	$BAG/T = .00710 - .000031460(CCFI)$	.92	>5%
6	$BAG/T = .00760 - .000033660(CCFI)$	.98	5%

Step 4.—Column references in the following refer to Table 2 which is a tabulation of the computations used to obtain the regression of basal-area growth per acre over density (CCF) for the one-inch diameter class. The data for the other diameter classes were treated similarly.

TABLE 2. Values used to obtain regression of annual basal area growth per acre on Crown Competition Factor for the one-inch diameter class.

CCF	BAG/T (sq. ft.)	BA/A (sq. ft.)	Trees/A	BAG/A (sq. ft.)
100	.00366	14.12	1177	4.30782
200	.00269	42.69	3558	9.57102
250	.00221	56.98	4748	10.49308
260	.00211	59.83	4986	10.52046
265	.00207	61.26	5105	10.56735
270	.00202	62.69	5224	10.55248
275	.00197	64.12	5343	10.52571
300	.00173	71.26	5938	10.27274
350	.00125	85.55	7129	8.91125
400	.00077	99.83	8320	6.40640

For each diameter class, the equation as computed in step 3 was solved for a series of CCF levels (column 1), thus obtaining estimated basal area growth per tree values that appear in column two.

Next the basal area per acre represented in each CCF level was obtained by solving the CCF equation for basal area. The CCF equation for lodgepole pine is: $CCF = 50.58 + (5.25BA/DBH)$; where BA is basal area per acre, and DBH is average stand diameter (Alexander, 1966). Inserting the average diameter for the class and the CCF level, the only unknown remaining was basal area per acre which appears in column three.

The number of trees per acre (column 4) corresponding to each basal area level was obtained by dividing the basal area per acre by the cross-sectional area of the tree of average diameter.

Annual basal area growth per acre (column 5) was then computed for each CCF level by multiplying the estimated basal area growth per tree (column 2) by the computed number of trees per acre (column 4).

Plotting the basal area growth per acre values (column 5) over density (column 1) yielded a curve which revealed the culmination of basal area growth for the diameter class. As can be seen in Table 2 the basal area growth per acre for the one-inch diameter class culminated at a CCF level of 265.

The procedure as shown in Table 2 was followed for each diameter class. The resulting values at the peak of basal area growth for each class are presented in Table 3.

TABLE 3. Basal area and Crown Competition Factor values at the peak of basal area growth by diameter classes and number of plots in each diameter class.

Diameter Class (inches)	No. of Plots in Dia. Class	Basal Area Per Acre (sq. ft.)	Crown Competition Factor	Average Diameter Per Class (inches)
1	10	61	265	1.51
2	13	65	205	2.25
3	10	74	165	3.44
4	12	102	175	4.26
5	4	87	135	5.42
6	4	103	135	6.38

Step 5.—Weighting the values by the number of plots in each diameter class, the regression of the peak values of basal area per acre on the corresponding Crown Competition Factors was computed. The slope of the equation, $1/BA/A = .00389 + .0000488$ (CCF) with a correlation coefficient of .78, was significant at the one percent level.

Step 6.—In order to identify particular points on the maximum occupancy curve; i.e., levels representing particular diameter values, a weighted regression of peak basal area per acre over average class diameter was computed. The values in Table 3 were used to compute this regression.

The regression equation resulting from the above values was: $BA/A = 45.4 + 9.9857(DBH)$; with an r value of .87. The F test indicated statistical significance at the one percent level.

Step 7.—The basal area per acre values for diameters 1.0 through 8.0 inches were computed using the equation developed in Step 6. These values appear in column 4, Table 4. The basal area per acre value for each diameter was then divided by the cross-sectional area of a tree of the corresponding size to obtain the number of trees per acre represented by each basal area level, column 5, Table 4.

Determination of Minimum Occupancy

The minimum occupancy level is based on the capability of lodgepole pine trees to occupy space in the absence of crown competition. Open-grown trees were measured and a regression of crown width to D.B.H. was calculated ($C.W. = 3.94 + 1.44$ DBH, $r = .951$; Alexander, 1967). From these data, crown areas by D.B.H. classes were calculated and number of trees and basal area per acre determined by each D.B.H. class. These data combined with maximum density values appear in Table 4.

TABLE 4. Minimum and maximum occupancy values for natural stands of lodgepole pine in Colorado and southern Wyoming.

Average Stand DBH (inches)	Minimum Occupancy Basal area per acre (sq. ft.)	Minimum Occupancy Number Stems per acre	Maximum Occupancy Basal area per acre (sq. ft.)	Maximum Occupancy Number Stems per acre
1.0	12	2200	55	10,090
2.0	26	1195	65	2,980
3.0	40	815	75	1,530
4.0	51	585	85	975
5.0	61	450	95	700
6.0	69	350	105	535
7.0	76	285	115	430
8.0	81	230	125	360

The techniques suggested in this presentation depart from the traditional stand analysis approach. Consequently, the aggregated influences of accretion, ingrowth, and mortality cannot be appraised. The values presented in Table 4 represent only the minimum and maximum occupancy levels as defined earlier in the paper.

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