RULE THINNING: A FIELD METHOD FOR MEETING STOCKING GOALS IN OAK STANDS[1/]

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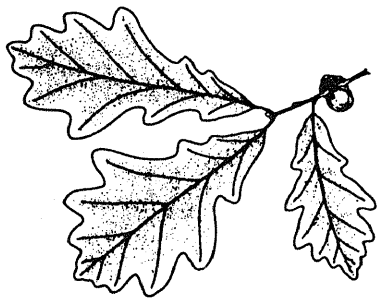

ABSTRACT. Many foresters use the stocking chart for upland central hardwoods as a guide for thinning oak stands. Several field methods are currently used to select trees for retention to meet a given stocking goal. All these methods require a pre-thinning inventory of stand density plus subsequent checks of stand density during the selection process. Swapping leave trees for remove trees is usually necessary to assure that the target stocking level is met. However, the outcome is usually inconsistent because different trees will be removed from the same stand by different markers or by the same marker on different occasions. Rule thinning is an alternative based on the stocking equations used to derive the stocking chart for upland central hardwoods and other mathematical considerations. Application of the rule produces consistent results and eliminates the need for successive adjustments in marking to meet a given stocking goal. In addition, the resulting spatial distribution of leave trees is as close to optimal as possible for a given initial stand spacing. This paper describes the derivation of the rule and outlines the steps for applying it in the field.

If the production of high quality sawlogs in the shortest time is a forest management objective, then the key to achieving that objective is the regulation of stand density by thinnings. Over the past 25 years, stocking charts have been developed for evaluating stand density in many forest types throughout the eastern United States (Gingrich 1967, Leak et al. 1969, Marquis et al. 1969, Frank and Bjorkbom 1973, Philbrook et al. 1972, Benzie 1977, Schlesinger and Funk 1977, Roach 1977, Rogers 1983, and Stout et al. 1985[3/]). These charts graphically depict the relation among average stand diameter and two measures of stand density: basal area and number of trees. Measured stand density then can easily be compared to standards or norms of stand density. Stocking charts depict density standards in a way that can be used to meet management objectives, such as maximizing growth and regenerating the stand. Thus, stocking charts can be used to thin stands to meet specific stocking goals.

Gingrich's stocking chart for upland hardwood forests is widely used in the central hardwood forest. His chart is well suited for use in stands that have a large oak component because it was developed from data collected from stands containing a high proportion of upland oaks, particularly white and black oaks (Quercus alba L. and Q. velutina Lam.). Furthermore, the charts present the limits of stocking and density for full site utilization based on open-grown and forest-grown tree-area requirements. Tree-area requirements are obtained by applying Chisman and Schumacher's (1940) tree-area ratio equation to stand data from Central States hardwood forests. The ratio is based on the premise that the growing space used by a tree depends on the size of the tree and is related to stem diameter by a second-degree polynomial.

Stocking charts are generally used to evaluate stand stocking from inventory data. When used with such data, Gingrich's stocking chart for upland hardwoods can show how well an oak-hickory stand is utilizing available growing space and how much stand density should be reduced to meet a given stocking goal.

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[3/] Stout, S.L., D.A. Marquis, and R.L. Ernst. 1985. A relative density measure for mixed species stands. Unpublished manuscript, Northeastern Forest Experiment Station, Warren, PA. 31 p.

Thinning guides for oak describe methods for measurement and evaluating stocking and stand density (Gingrich 1967, Roach and Gingrich 1968, and Sander 1977). Although these methods can be used to determine present stocking and to indicate the amount of basal area to be removed to attain a residual stocking goal, the process of selecting trees for removal relies chiefly on the discretion of the person doing the marking.

Selecting trees for removal typically requires a pre-thinning inventory of stand density plus checks of stand density during the selection process. Swapping leave trees for remove trees usually is necessary to assure that the stocking goal is met. However, the outcome of the marking process is inconsistent because different trees will be removed from the same stand by different markers or even by the same marker on different occasions. Moreover, there is no guarantee that residual stand density will be evenly distributed throughout the stand. The purposes of this paper are to describe an alternate method of selecting remove trees called "rule thinning" and to illustrate how it can be applied.

THE DERIVATION OF RULE THINNING

Rule thinning is based on two factors. The first is the tree-area ratio as defined by Chisman and Schumacher (1940); the second is the characterization of spatial pattern in oak-hickory stands as defined by Rogers (1983[4/]).

Tree-area ratio is based on the idea that area (A) occupied by a tree in a stand can be related to its d.b.h. by a second degree polynomial:

$$A = b_0 + b_1 DBH + b_2 DBH^2. \qquad (1)$$

Furthermore, the area occupied by all trees in the stand (growing space) can be obtained by summing the growing spaces of all the individual trees. Thus, a site would be fully occupied when the stand's growing space equalled all the space available in the stand.

Gingrich (1967) recognized two conditions under which all available space could be fully utilized by trees in oak-hickory forests. The first condition occurs in natural undisturbed stands where the average tree has the minimum space necessary to survive; this condition represents maximum stand density. The second condition occurs when each tree has all the growing space it can use but no more as determined from measuring crown areas of open-grown trees. Using the work of Krajicek et al. (1961) on crown competition, Gingrich found that minimum tree-area requirements range from 57 to 59 percent of maximum usable area for trees from 4 to 20 inches in diameter. Thus minimum stand density for full utilization of growing space is from 57 to 59 percent of the density of fully stocked stands.

If we assume that trees occupy circular areas, then the radius (R) associated with a tree's minimum growing space requirements can be calculated from the tree-area ratio equation under maximum or 100 percent stocking:

$$R = (43.56/pi) * area \qquad (2)$$

where area= tree area (milacres)= -.0507 + .1693D + .0317D

(coefficients are from Gingrich (1967); $s_{y.x}$ = 29.6). We can see that the radius associated with a tree's minimum growing space requirements is directly related to the tree's d.b.h. This radius defines the boundaries within which no other tree would be expected to occur and still satisfy the 100 percent stocking requirements of the stand. Thus, one might imagine a fully stocked stand in which all the trees are arranged so they conform to the specifications just described, i.e., no individual tree's growing space would overlap another's. Because such a perfect arrangement probably does not exist in natural stands, some trees are deficient in growing space while others have excessive growing space.

Rule thinning provides the forester with a means of removing trees in a stand so that the growing space requirements of each of the remaining trees are satisfied as nearly as the existing spatial pattern of trees in the stand will permit. In order to do this, we need a thinning radius derived from the tree-area ratio equation for trees of different diameters. In practice, we should provide more space than the minimim space that occurs at 100 percent stocking. Thus stocking percentages less than 100 would be used in association with the tree-area equation to provide appropriate increases in thinning radii.

Our original formulation for the oak-hickory thinning radius (TR) was:

$$TR = (((pi/4)(TA)\ (1/s))/pi)^{(0.5)} \qquad (3)$$

TA = tree area
s = stocking (percent)

This formulation resulted from a consideration of a rearrangement of the formula for the area (C) of a circle,

$$C = pi(Radius)^2 . \qquad (4)$$

However, two adjustments need to be made to this formula to develop an expression for thinning radii. The first is an adjustment to tree area to account for the inability of non-overlapping circles (i.e., tree crowns) to account for all of the space on a given area. Actual growing space can be partitioned much easier if square areas are used in the formulation rather than circular areas. To

[4/] Rogers, R. 1983. Spatial pattern and growth in a Missouri oak-hickory stand. Ph.D. Thesis, University of Missouri-Columbia, Missouri 65211.

facilitate this, we can use the ratio (r) of circular to square area:

$$r = pi(radius)^2 \cdot (2radius)^{-2} = 0.25pi. \quad (5)$$

The second adjustment to the formula is needed to account for the proportion of growing space required by trees to attain a specific stocking goal compared to trees having a minimum amount of growing space at 100 percent stocking. Thus trees at 60 percent stocking would need 1/.6 more tree area than trees growing at 100 percent stocking.

Simplifying the thinning radius equation yields:

$$TR = ((0.25)(TA)(S^{-1}))^{(0.5)}. \quad (6)$$

Note that tree-area ratio can be used in this formulation for thinning radius. Substituting the metric form of the tree area equation for 100 percent stocked upland hardwood stands (Rogers 1980) results in:

$$TR=((.25)(-.20518+.27053D+.019884D^2)(s^{-1}))^{0.5} \quad (7)$$

where D = d.b.h. (cm) and TR is expressed in meters. When d.b.h. is measured in inches, D is multiplied by 2.54 and TR is multiplied by 3.28 to determine thinning radius in feet.

Having derived the thinning rule, we wondered whether its application would meet a given stocking goal. We considered actually thinning oak-hickory stands using the rule, but abandoned that approach in favor of simulating the thinning process on a computer.

The first step was to construct a stand that we could thin. Using data collected from natural unthinned stands on the Sinkin Experimental Forest located in the Missouri Ozarks, we could characterize the diameter distribution of a "typical" oak-hickory stand at full or 100 percent stocking (fig. 1).

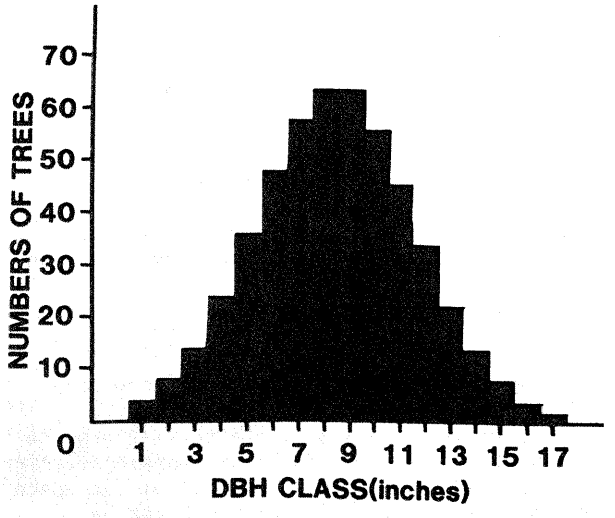

FIGURE 1.--A typical diameter distribution in an oak-hickory stand averaging 9 inches d.b.h. at full or 100 percent stocking.

To locate trees in the simulated stand, we used Rogers' (1983) data on spatial pattern in Missouri oak-hickory stands that showed that trees are arranged randomly within a stand. We used this information and a computer to assign random x,y coordinates to each of the trees in our hypothetical stand to establish their spatial position. Having done that, we used the computer to visit each tree in order of declining d.b.h. and applied the thinning rule repeatedly until the entire stand was covered. The stocking percent of the residual stand was calculated and compared to the target stocking level. This entire process was repeated 50 times.

Unfortunately, the two stocking percents did not agree. Actual stocking percents were always significantly lower than that specified in the thinning rule. This meant that the thinning rule removed too many trees. Although this outcome was unexpected, we finally realized that the only way the thinning rule requirements could be satisfied was to have each of the leave trees arranged so that the distance requirements of the thinning rule were perfectly met. Since this was not possible, we needed to make an adjustment to our thinning rule to account for the natural variation from the ideal spatial pattern in oak-hickory stands.

The initial thinning radius formula was modified to include an adjustment for variation in spatial pattern that we called the thinning factor, TF.

$$TR= ((0.25)(TA)(TF))^{(0.5)} \quad (8)$$

$$\text{where } TF = (b_1S)^{-1} - b_0b_1^{-1} \quad (9)$$

S = stand stocking (percent)

The constants b_0 and b_1 in the TF equation were determined empirically by using linear regression on additional simulated thinning data and the model

$$S^{-1} = b_0 + b_1TF. \quad (10)$$

Residual stand stocking observed after stands were thinned using the thinning radius formula with varying thinning factors from 3.3 to 0.5 ranged from 43 to 88 percent. The equation and its characteristics are:

$$S^{-1} = 0.008318 + 0.004063TF \quad (11)$$

$$s_{y.x} = .0015, \; r^2 = .998$$

Since the value of r^2 is so close to 1 and $s_{y.x}$ is so small we can rearrange the equation to give TF as a function of stocking. This rearrangement makes using the thinning radius formula easy because the stocking percent we wish to achieve is readily known while thinning factors associated with those stocking percents are not. Thus,

$$TF = 246.124\ (s^{-1}) - 2.293. \quad (12)$$

The final complete equation used to establish thinning radii for upland hardwood forests dominated by white and black oaks and hickory is:

$$TR=((.25)(-.20518 + .27053D + .019884D^2)(246.124S^{-1} - 2.9293))^{.5}. \quad (13)$$

We have used thinning radii calculated from this equation to thin several real stands in combination with the techniques outlined in the second section of this paper. The results indicate close agreement between stocking goals and residual stand stocking actually achieved (table 1). The greatest difference observed in stocking was 3.4 percent.

TABLE 1.--A comparison of stocking goals to residual stocking achieved by rule thinning in actual stands.

	STAND			
	1	2	3	4
STOCKING GOAL	60.0	60.0	80.0	80.0
ACTUAL RESIDUAL STOCKING	61.9	57.5	80.7	83.4

APPLYING RULE THINNING IN THE FIELD

Before any trees are marked, a stocking goal must first be decided upon. Marking then can be started by entering the stand at any point and selecting the largest tree near the marker. Given that this tree is a suitable leave tree, according to predefined criteria, its d.b.h. is measured or estimated. Then a table containing thinning radii for trees of various diameters, species (or species groups) and residual stand stocking is consulted to determine the thinning radius associated with the d.b.h. of the leave tree (table 2).

A measuring tape can be used to locate the limit of the thinning radius of the leave tree. Any tree found within the boundary of the thinning radius is marked for removal. The leave tree is also marked to identify it as a tree that is to remain. Marking both leave and remove trees allows the marker to recognize which trees have been considered in the marking process and which ones have yet to be visited.

The use of a specially calibrated stick called a rule stick greatly facilitates the application of rule thinning because it eliminates the need to consult a table and to measure intertree distances and allows direct recognition of trees to mark for removal (fig. 2)[5/]. The d.b.h. scale of the stick is used to measure tree d.b.h. The stick also contains an angle gauge that is adjusted so the the gauge marker aligns with the d.b.h. reading on the thinning radius scale. Trees immediately surrounding the leave tree are visited and from each, the leave tree is viewed using the angle gauge. If the stem of the leave tree cannot be competely blocked from view by the angle gauge, the candidate remove tree is marked for removal.

TABLE 2.--Thinning radii in relation to d.b.h. for attaining a given residual stand stocking in upland central hardwood stands.

D.B.H. (inches)	RESIDUAL STAND STOCKING (Percent) 40	60	80
	---thinning radius (feet)---		
2	4.2	2.9	1.9
3	5.6	3.8	2.5
4	6.9	4.7	3.1
5	8.2	5.6	3.7
6	9.4	6.4	4.2
7	10.6	7.3	4.8
8	11.8	8.1	5.3
9	13.0	8.9	5.9
10	14.2	9.7	6.4
11	15.4	10.6	7.0
12	16.6	11.4	7.5
13	17.8	12.2	8.0
14	18.9	13.0	8.5
15	20.1	13.8	9.1
16	21.3	14.6	9.6
17	22.4	15.4	10.1
18	23.6	16.2	10.7
19	24.8	17.0	11.2
20	25.9	17.8	11.7
21	27.1	18.6	12.2
22	28.3	19.4	12.7
23	29.4	20.2	13.3
24	30.6	20.9	13.8

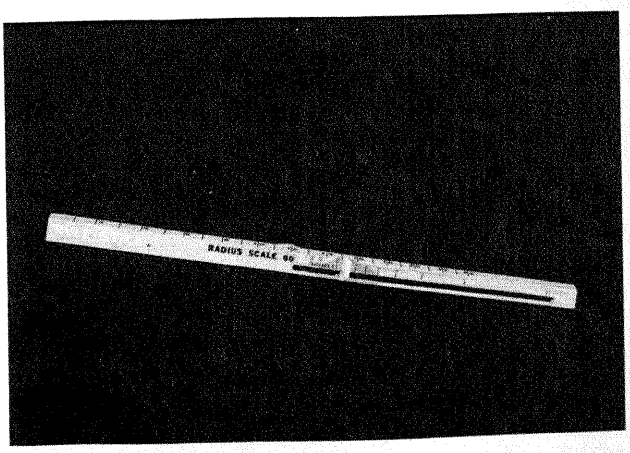

FIGURE 2.--A rule stick is used in rule thinning to identify trees for removal.

[5/] VR Foresters, Box 871, Stevens Point, WI 54481.

After the leave tree and the surrounding remove trees have been marked, the largest unmarked tree near the marker is selected as the next leave tree and the marking process is repeated. Once at the leave tree, the marker should survey the surrounding area to determine if a tree larger than the leave tree is nearby. If so, that tree should be considered as a leave tree. If the larger tree is unsuitable as a leave tree, than the original leave tree should be retained. However, whether the larger tree is marked as a remove tree or not depends on the d.b.h. of the larger tree and not on the d.b.h. of the leave tree. Thus, to avoid having to constantly change thinning radii associated with trees of differing d.b.h.s, the convention of visiting the largest tree and considering it as a leave tree is simply a matter of convenience and efficiency in applying the method.

DISCUSSION

We believe rule thinning is an effective and efficient means of selecting leave and remove trees in a thinning operation that requires meeting a stocking goal.

The rule was developed from accepted tree-area ratio equations and has direct relation to the stocking charts that Gingrich (1967) developed for the upland hardwood forest. Therefore it has a sound theoretical base. The formulation is general enough to be applied in any forest type for which there is a tree-area ratio equation or for which one could be derived from existing stocking charts.

One advantage in rule thinning is that stands need not be inventoried before nor during the marking operation. A second advantage is that little training is required to correctly apply the method. Seasoned and novice foresters as well as general woodsworkers can apply the method with equal proficiency. Moreover, tree marking is consistent from marker to marker as well as by the same marker on different occasions. That feature makes field checks not only possible but practical. And finally, area-wide thinning and individual crop-tree release can be accomodated using the same thinning rule. In the former case, the rule is applied to every tree in the stand. In the latter case, the rule is applied only to selected crop trees in the stand.

We believe the possible disadvantages of the method are minor compared to its advantages. Tree diameters and distances between trees need to be measured or estimated. However, this task can be made easier and quicker by using the rule stick instead of measuring tapes. Identifying trees that have been selected as leave and remove trees can be a problem. But the problems in marking trees also exist with other methods.

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