General Technical Report PNW-78
January 1979

RELATIVE DENSITY: The Key to Stocking Assessment in Regional Analysis --

A Forest Survey Viewpoint

Colin D. MacLean

Pacific Northwest Forest and Range Experiment Station
Forest Service U.S. Department of Agriculture

ABSTRACT

Relative density is a measure of tree crowding compared to a reference level such as normal density. This stand attribute, when compared to management standards, indicates adequacy of stocking. The Pacific Coast Forest Survey Unit assesses the relative density of each stand sampled by summing the individual density contributions of each tree tallied, thus quantifying the effects of mixed species, mixed age, and irregular spacing on total stand density. Each tree's contribution reflects its stage of development, species, and social position. Plot clusters are designed to permit assessment of the effect of irregular spacing.

KEYWORDS: Stand density measures, stocking density.

Forest Survey is a nationwide project of the U.S. Forest Service now known officially as Renewable Resources Evaluation Research. The Portland Resources Evaluation Work Unit of the Pacific Northwest Forest and Range Experiment Station conducts the survey in California, Hawaii, Oregon, and Washington.

Contents

Introduction

Most timber inventories include stocking assessments. Stocking data are used to assess management levels, prescribe silvicultural treatment, and forecast yields. They are used to justify forestry incentive programs and to evaluate their success. Minimum stocking standards are often established by law. Despite this widespread use, opinions vary as to how stocking should be defined, measured, and interpreted.

Stocking data are useful only to the extent they answer questions of interest to the forest manager or planner. Forest Survey resource analysts use stocking data to answer specific questions about forest conditions and their implication for future timber supply. We who conduct and analyze the Forest Survey inventories of the Pacific Coast States have spent much time developing a methodology for answering analytical questions that are dependent on stocking. I believe that an account of the development of this methodology will be of interest to others. While the specifics are tailored to Forest Survey needs, the principles have broader application.

WHAT IS STOCKING ?

For many years, *Forestry Terminology* defined stocking as "...an indication of the number of trees as compared to the desirable number for best growth and management..." (Society of American Foresters 1958). Although other definitions were recently added, (Society of American Foresters 1971), this statement is the basis for the definition used in this paper: That stocking is stand density expressed as a percentage of the density of trees desired to meet a management goal.

Stocking estimation is a two-part process: first stand density is estimated; then it is compared to the desired level for a stand of that species and stage of development. Stand density may be expressed in absolute terms such as trees per acre or in relative terms "...as a coefficient, taking normal number, basal area, or volume (from yield table data) as unity..." (Society of American Foresters 1971). In the interest of clarity, I will reserve the term stand density for absolute measures and use the term relative density to describe relative measures such as percent of normal number of trees.

Relative density is the more useful of the two density measures for broad resource evaluation, since it permits comparisons of stands with differing stages of development and, sometimes, species. Normal stands, for example, have been identified and described by the authors of normal yield tables, thus making possible the comparison of the density of any stand to that of a normal stand of similar type and stage of development. The resulting ratio, expressed as a "percent of normal," measures crowding within a stand independent of its stage of development. Assuming a reasonably consistent definition of normality, density also can be compared between stands of differing type.

STOCKING NEEDS OF FOREST SURVEY

Stocking is an important ingredient both in assessments of forest condition and estimates of future timber supply. But what is a suitable stocking standard for resource analysis? To answer this question we need the ability to examine alternatives to our traditional goal of maximum wood production.

Relative density is a stand attribute while stocking is more of an analytical tool. A relative density estimate can be compared to two or more stocking standards, possibly identifying stands that are well stocked by one criterion and poorly stocked by another. In order to facilitate this type of analysis, we have refined our measure of relative density. I will briefly describe the new procedures and their development.

CHOOSING A MEASURE OF RELATIVE DENSITY

Forest Survey measures of relative density have changed over the years. In the early years, we used crown closure--a measure that was easily identified on aerial photos and correlated with timber volume. More recently, our attention has shifted from timber volume to forest condition, opportunities for silviculture treatment, and future timber supply. For these objectives, we needed a better measure of relative density--one that accounted for the effects of species, stage of development, and tree clumping on the space requirements of trees.

Curtis (1970, 1971) has compared the usual measures of relative density. All use either normal stands or open-grown trees as a point of reference. All are developed for use with even-aged, uniformly stocked stands of a single species. How can such standards be applied to uneven-aged, mixed species stands, with variable spacing? And how do we rate stands too young to be included in the yield tables?

There are no simple answers. Twenty years ago, a Society of American Foresters committee (Bickford et al. 1957) noted a lack of knowledge about how the components of tree growth are affected by variations in spacing. Today, still lacking this basic knowledge, we must make some arbitrary assumptions, remembering however, that they are assumptions--to be altered when more information becomes available.

Our Forest Survey project measures relative density by normal density--the actual number of trees per acre expressed as a percent of the number of trees in a normal stand of the same quadratic mean diameter and species. Our choice was dictated by the widespread availability of normal yield tables rather than a belief in the desirability of growing normal stands.

Although normal yield tables describe even-aged, single species stands, inventory plots frequently sample irregular stands of mixed species and age. To accommodate such stands, we developed a weighted average density standard that reflects the species and sizes of trees present (McArdle et al. 1961) in the stand. Our approach is one first used in the 1950's for the Timber Resources Review (USDA Forest Service 1958). The density contribution of each tree is calculated individually, as though it were growing in a normal stand of like trees. By knowing the density contribution of each tree, we are able to identify the contribution of each stand component, thus obtaining maximum flexibility to meet various objectives.

THE DENSITY CONTRIBUTION OF INDIVIDUAL TREES

In any stand, the water, light, and nutrients available for tree growth are limited. The contribution of an individual tree toward normal density is the share of those resources--water, light and nutrients--that would be available to it if it were growing in a normal stand. Although the share of the resource that a tree uses is best described by the development of its roots and crown, these are so difficult to measure that we have chosen more easily identifiable characteristics--stage of development, species, and crown position.

Although stage of development is frequently defined by site and age, normal stands of the same quadratic mean diameter have been found to be "...much more alike in everyway than stands of the same site and age..." (McArdle et al. 1961). Thus two stands of the same average diameter--one a young stand growing on a good site and the other an old stand growing on a poor site--are usually more similar than stands of the same site and age but differing average diameters. As a stand increases in average diameter, trees per acre decrease, thereby increasing the growing space per tree. Reineke (1933) has shown that the space occupied by average trees growing in normal stands increases exponentially with increasing quadratic mean diameter at a rate of approximately $D^{3/2}$. The exact relationship varies slightly between species.

From yield tables and yield table data, we established, for most species, the relationship between mean diameter and the average growing space available to trees growing in normal stands. Although these relationships were developed from stand data, we assumed that they account for the effect of stage of development on the area occupied by individual trees. Still unaccounted for was the effect of the tree's competitive position within the stand. We knew that a dominant tree occupies more space than an overtopped tree of the same diameter. Within an even-aged stand the relationship between a tree's diameter and the area that it occupies reflects its competitive position as well as its size, since the largest trees are dominant and the smallest are overtopped. Thus an accurate assessment of the density contribution of a single tree should recognize the combined effects of species, size, and social position.

The space occupied by individual trees growing within even-aged normal stands also varies with their diameter. Stage (1968) had shown that this space is related to the tree's diameter cubed (D^3). Curtis (1971) adds that the appropriate exponent is smaller in less dense stands, approaching $D^{3/2}$ in open stands. The reason for this difference is competition. Intermediate and suppressed trees, which occupy less space than dominants, are more common in dense stands. Thus, competitive stress accounts for the difference between the $D^{3/2}$ relationship of open stands and the D^3 relationship of dense stands.

DEVELOPING DISCOUNTS FOR CROWN POSITION

As previously explained, our relative density equations--based on the assumption that the space occupied by a tree is proportional to its diameter raised to the 3/2 power--account for the influence of stage of development on the area that a tree occupies but not for the effect of competition as indicated by a tree's social position in the stand. To determine that effect, I analyzed available plot data from approximately normal stands. After calculating the relative density (percent normality) of the plot, I partitioned this value among the trees tallied in two ways: (1) by assigning a density percent to each tally tree that was proportional to its diameter to the 3/2 power, and (2) by repeating the process with the individual density percents proportional to D^3. For these even-aged normal stands, I assumed that the D^3 relationship was the correct one. By adjusting the $D^{3/2}$ values upward or downward, depending upon crown position, I was, however, able to approximate the D^3 density values.

This suggested a system of crown class discounts to correct our equations for the effect of social position on a tree's contribution to stand density. By multiplying the density percents of dominant, codominant, and open-grown trees (with a crown ratio of 30 percent or more) by 1.1, overtopped trees by 0.4, and intermediate and thinly crowned overstory trees by 1.7, I was able to redistribute the density percents with a given stand to approximate the D^3 relationship. Another test, using different data, produced similar results. Since both tests were informal in nature and based on limited data, additional refinement of the discount values may be needed.

WHAT ABOUT SMALL TREE DENSITY?

Small tree density is a special problem, since normal yield tables seldom include trees smaller than the 2-inch (5-centimeter) class. Actually, the normality concept has little meaning in stands too young for much intraspecific competition.

Many regeneration survey designs rely on standards that reflect an anticipated density level at the time of first commercial harvest--usually a thinning--and avoid estimates of current density. This philosophy is consistent with our major objective for such stands--the prediction of future timber supply. Locally, commercial thinning is not considered feasible until the quadratic mean diameter of a stand is at least 8 inches (20.3 centimeters). Our standard for smaller stands is the number of trees needed to achieve normality by the time such stands reach 8 inches (20.3 centimeters), with an appropriate allowance for anticipated mortality.

Since seedlings and saplings growing in an understory constitute advance regeneration, overstory and understory density are calculated separately with the understory treated as regeneration. When the overstory is heavy, the understory density is discounted for anticipated logging damage.

DETERMINING PLOT SIZE

Plot density is seldom merely the sum of density contributions from individual trees. Many stands are irregular--a mozaic of clumps and holes that have lower current productivity, greater thinning and planting needs, and a lower growth potential than evenly distributed stands. Thus we need information on tree distribution.

For years Forest Survey has measured stand density on a cluster of 10 points, each with a fixed-radius plot for small trees and a variable-radius plot for large trees. Although the design permits point-by-point analysis, a careful plot size selection is needed to insure proper measurement of cluster variability. For instance, a cluster of very small plots can indicate variability in a perfectly spaced plantation because some plots may include trees while others fall in open spaces. On the other hand, a large plot may include both clumps and holes within the plot boundary, thus hiding variation in density. We looked for a plot that was small enough to reflect density variations that affect growth, but large enough to obscure minor variations in spacing. We wanted a plot size just large enough to allow a single point to be analyzed independently, so that a single unoccupied point would indicate unutilized space and an overstocked point would indicate excessive crowding.

We made our choice by deduction. If an open-grown tree crown indicates the maximum are occupied by a tree of a given size (Krajicek et al. 1961), an appropriate plot radius would just place the tree within the plot from a point at the edge of the tree's crown. Our inventory plots are now designed to approximate this specification. Trees between 7 inches (17.78 centimeter) and 35 inches (88.9 centimeters) in d.b.h. are sampled with a 30-factor (5.24 diopter) prism, and larger trees are sampled from a fixed-radius plot with a radius equal to the limiting distance of a 35-inch (88.9-centimeter) tree. Trees less than 7 inches (17.78-centimeter) in d.b.h. are tallied on a plot with a radius equal to the limiting distance of a 7-inch (17.78-centimeter) tree. This 113th-acre (0.0036-hectare) plot is large enough to assess relative density in widely spaced plantations.

AGGREGATING STAND DENSITY

Stand density data from a single point is relatively easy to analyze. Assume full-site utilization at 60 percent of normal density. If conifer density of 60 percent and less productive hardwoods add an additional 20 percent, timber yields can be increased by removing the hardwoods. Comparison with results from an earlier inventory may show that conifer density is changing--a variable input to future yield prediction.

But how do we analyze data from several points in an irregular stand? A cluster with six points at normal density and four points without trees might need both thinning and planting. Reliance on average density, however, would mislead us into thinking that the stand was just right--60 percent of normal. Or we could recalculate the average density, limiting the contribution of any single point to 60 percent (full-site occupancy). Then average density would be 36 percent--indicating that the site was underutilized but obscuring the overcrowded condition in 60 percent of the stand.

We interpret relative density point by point and aggregate answers to questions. In the stand described, six points are fully productive and four are nonproductive; thus, the stand is currently utilizing 60 percent of its productive capacity. Silvicultural treatment opportunities include thinning and, possibly, spot planting. If all points had been nonstocked at the previous inventory, then the change in productivity would be from 0 to 60 percent.

Conclusions

In uniform, even-aged, single species stands, a single relative density measure is adequate for assessing current productivity and identifying opportunities for silvicultural treatment. When tree species or sizes are mixed, the relative density of each of the stand components is needed. In stands with irregular spacing, averaging is like to obscure important information, even when relative density is broken down into stand components.

In Forest Survey, we collect information on stand irregularities by assigning a density percent to each tree tallied on a cluster of sample points. The value assigned to each tree is approximately proportional to the space that the tree would occupy, if growing in a normal stand. These relative density data depict the way in which the site is utilized by the various stand components, thus facilitating inferences about stand condition and present and future productivity. Since averaging of point data often obscures important information, analysis begins at the point level. Consequently, full use is made of the information collected.

Literature Cited

Bickford, C. Allen, et al.
1957. Stocking, normality, and measurement of stand density. J. For. 55(2):99-104.

Curtis, Robert O.
1970. Stand density measures: an interpretation. For. Sci. 16:403-414.

Curtis, Robert O.
1971. A tree area power function and related stand density measures for Douglas-fir. For. Sci. 17:146-159.

Krajicek, John E., Kenneth A. Brinkman, and Samuel F. Gingrich.
1961. Crown competition--a measure of density. For. Sci. 7:35-42.

McArdle, Richard E., Walter H. Meyer, and Donald Bruce.
1961. The yield of Douglas-fir in the Pacific Northwest. USDA Tech. Bull. 201 (revised). 74 p., illus.

Reineke, L. H.
1933. Perfecting a stand-density index for even-aged forests. J. Agric. Res. 46:627-638.

Society of American Foresters.
1971. Terminology of Forest Science, technology practice, and products. F. C. Ford-Robertson, ed. 345 p., illus. Washington, D.C.

Society of American Foresters.
1958. Forestry terminology. 84 p., illus. Washington, D.C.

Stage, Albert R.
1968. A tree-by-tree measure of site utilization for grand fir related to stand density index. USDA For. Serv. Res. Note INT-77, 7 p., illus. Intermt. For. and Range Exp. Stn., Ogden, Utah.

USDA Forest Service.
1958. Timber resources for America's future. USDA For. Serv. Resour. Rep. No. 14, 713 p., illus. Washington, D.C.

GPO 987-722

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.

2. Developing and evaluating alternative methods and levels of resource management.

3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research are made available promptly. Project headquarters are at:

Anchorage, Alaska
Fairbanks, Alaska
Juneau, Alaska
Bend, Oregon
Corvallis, Oregon
La Grande, Oregon
Portland, Oregon
Olympia, Washington
Seattle, Washington
Wenatchee, Washington

Mailing address: *Pacific Northwest Forest and Range Experiment Station*
P.O. Box 3141
Portland, Oregon 97208

The FOREST SERVICE of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

The U.S. Department of Agriculture is an Equal Opportunity Employer. Applicants for all Department programs will be given equal consideration without regard to age, race, color, sex, religion, or national origin.