United States
Department of
Agriculture

Forest Service

Pacific Northwest
Research Station

General Technical
Report
PNW-GTR-482
March 2000

Deconstructing the Timber Volume Paradigm in Management of the Tongass National Forest

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Conservation and Resource Assessments for the Tongass Land Management Plan Revision

Charles G. Shaw III, Technical Coordinator

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Published by:
U.S. Department of Agriculture
Forest Service
Pacific Northwest Research Station
Portland, Oregon
General Technical Report PNW-GTR-482
March 2000

Abstract

Caouette, John P.; Kramer, Marc G.; Nowacki, Gregory J. 2000. Deconstructing the timber volume paradigm in management of the Tongass National Forest. Gen. Tech. Rep. PNW-GTR-482. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 20 p. (Shaw, Charles G., III, tech. coord.; Conservation and resource assesments for the Tongass land management plan revision).

Timber volume information and associated maps have been widely used in the Tongass National Forest for land-use planning and timber and wildlife management. Although considerable effort has been expended to improve timber volume maps, little has been done to evaluate the suitability of timber volume as a descriptor of forest character. We established a rough indicator of forest structure that uses trees per acre and quadratic mean diameter to examine the relation between timber volume and forest structure. Results indicated that timber volume and forest structure are not interchangeable attributes. Results also indicated that the original photinterpreted timber volume stratification did not always capture differences in timber volume but may have captured differences in forest structure. The recently revised timber volume stratification provides more reliable timber volume information, but it sacrifices structural information in the process.

Keywords: Tongass National Forest, timber volume, forest structure, trees per acre, quadratic mean diameter, aerial photointerpretation, canopy texture.

Contents

Introduction

Mapping the Tongass National Forest (Tongass) has generated confusion and controversy for many years. Land-use managers need accurate information for responsible planning and on-the-ground implementation, but inventorying the Tongass's 17 million acres, distributed over remote and rugged island terrain, has been difficult. Aerial photography has been used to complement or supplement labor-intensive, ground-based surveys to provide forest managers and research scientists with inventories of the Tongass.

A photointerpreted land and vegetation stratification of the Tongass was created in 1977 (Esca-Tech 1977). The vegetation component of this database, referred to as "timber type," delineated forested areas into polygons of relatively homogenous character. Each polygon was assigned photointerpreted estimates of tree size and species, volume class (hereafter referred to as "stratum"), crown closure, and degree of decadence. In 1988, the land and timber type stratification was converted into digital format, transferred into a computer-based geographic information system (GIS), and displayed in color-coded maps. A single attribute of these maps, timber volume stratum, received extensive use. Timber volume strata were used for estimating Forest-wide timber volumes, planning timber sales, modeling wildlife habitat capability, and implementing proportionality,[1] as mandated by the 1990 Tongass Timber Reform Act (U.S. Public Laws, Statutes 1990).

As use of the timber volume stratification increased in Tongass management, questions about its accuracy emerged. Analyses and litigation revealed problems with the timber volume strata. In 1997, the Forest Service revised the timber volume stratification to provide stronger, more statistically defensible timber volume data (Julin and Caouette 1997). The revision generated a new volume stratification by using a combination of the original timber volume strata and soil and slope information from the common land unit (CLU) database (USDA 1990). Although the revised timber volume stratification provided more reliable volume data, many were still unsatisfied because they felt the revised stratification did not identify the "highest volume" stands (see "Discussion" for further explanation).

In short, neither the original nor the revised timber volume strata satisfied all or even most potential users. Brickell (1989), a USDA Forest Service inventory specialist, provided several explanations for many problems and shortcomings associated with the timber volume stratification. Brickell suggested that an often overlooked problem may be "the recording of stratum only defined by net [board-foot] volume." He questioned whether timber volume is the best measure to relate to what can be seen in aerial photographs. He stated that photointerpreters often delineate the forest by focusing on attributes such as crown closure, crown diameters, tree heights, and species, and then have to process this information into a single timber volume stratum. Brickell recommended that "the photo variables mentioned can be related not

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[1] Proportionality required that high-volume old growth, identified as timber volume strata 6 and 7, be harvested in proportion to its distribution in the surrounding management area. The provision was intended to prevent overharvesting of the most valuable forest (greater than 30,000 net board feet [Scribner rule] per acre).

only to timber characteristics, but to other characteristics important to other resources." Throughout the debate over the accuracy of the timber volume strata, few have heeded Brickell's recommendation and questioned timber volume as the standard by which to assess photointerpreted information for the Tongass. Our research posed the often overlooked question, Is timber volume the best attribute to use for photointerpretation, mapping, and managing the Tongass National Forest?

The analysis in this paper proceeds as follows: first, we establish a quantitative model that uses trees per acre (TPA) and quadratic mean diameter (QMD) as rough indicators of forest structure in the Tongass. We then use this model to analyze:

- The relation between timber volume and forest structure
- The original timber volume strata (4-7)
- The recently revised timber volume strata (low, medium, and high)
- Aerial photointerpretation of forest canopy texture

Materials

Our analysis used four Tongass databases: (1) the original land and timber stratification, (2) the CLU stratification, (3) the revised timber volume stratification, and (4) the 1980s Tongass forest inventory and analysis.

1977 Land and Timber Type Stratification

The Tongass land and timber type inventory was created in 1977 by contractors under the direction of the USDA Forest Service (Esca-Tech 1977). Photointerpreters used stereo pairs of aerial photographs (1:15,840) to delineate the Tongass into several hundred thousand polygons according to land and forest type.[2] Polygons encompassed a minimum of 5 to 10 acres and averaged 60 acres. The photodelineation of the forest involved several sequential steps: (1) areas were classified as land or water; (2) land was classified into forested or nonforested areas; (3) forested land was classified as productive[3] or unproductive; and (4) productive forest lands were further classified by tree size, species composition, timber volume, stand density, and degree of decadence.

Productive forests occupy roughly 5.1 million acres of the Tongass, most of which was photointerpreted as being well-stocked (over 70 percent crown closure), old-growth sawtimber (over 150 years old and 11 inches in average diameter). All productive forest polygons were classified into one of four timber volume strata (4-7): 4 = 8,000-20,000 net board-foot per acre (NBFT, Scribner 16-foot rule); 5 = 20,000-30,000 NBFT; 6 = 30,000-50,000 NBFT; and 7 = over 50,000 NBFT. Other stand-delineating criteria included species composition (hemlock, spruce, cedar, etc.) and health (disease, insects, windthrow, etc.).

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[2] A polygon is an area interpreted as having relatively similar forest condition.

[3] Productive forests are those estimated to be greater than 8,000 net board feet per acre.

Common Land Unit Stratification

Another land and vegetation inventory of the Tongass, the CLU (USDA 1990), was created in the late 1980s and early 1990s. Like timber type, CLU was created by using aerial photographs (1:15,840) to delineate the Tongass into polygons. CLU polygon delineation focused on basic site and soil characteristics such as landforms, soil composition, and slope. Polygons with similar land and forest characteristics were grouped under a particular soil management unit code (SMU). About 800 SMUs were used to describe over 100,000 CLU polygons across the Tongass.[4] The CLU polygons were delineated and classified without reference to the original land and timber type polygon information. With a minimum mapping size of 20 acres, CLU polygons tend to be larger than land and timber type polygons.

Revised 1997 TLMP Volume Stratification

Several options were proposed for improving the timber volume stratification during revision of the Tongass land management plan (TLMP) (Julin and Caouette 1997). The selected option followed Brickell's recommendations (Brickell 1989) to collapse the original timber volume strata 5, 6, and 7 and use additional Forest-wide data to improve existing timber volume information. Soil and slope information from the CLU database was combined with the original timber volume strata to create new timber volume designations. The new volume stratification provided statistically defensible differences in Forest-wide volume averages (Julin and Caouette 1997).

1980s Forest Inventory and Analysis

In the 1980s, the three Administrative Areas of the Tongass undertook separate efforts to test, or "ground-truth," the original timber type strata (USDA 1982). All three efforts used land and timber type polygons as the fundamental sampling unit in their designs. Land and timber type polygons were randomly selected and ground-sampled by using either five-point clusters (Ketchikan and Stikine Areas) or multipoint transects (Chatham Area). Each point was sampled with a variable radius sampling technique. Data collected at each point included slope, aspect, elevation, soil type, tree species, tree diameter, tree height, tree age, crown closure, defect, decadence, disturbance history, and understory composition. Stand-level attributes such as timber volume, trees per acre, density, basal area, and quadratic mean diameter were calculated from field-measured data.[5] Using these data, Rogers and van Hees (1992a, 1992b, 1992c) developed summary statistics for each Administrative Area.

A total of 516 land and timber type polygons were sampled across the Tongass.[6] We used information from 390 of these polygons. The following polygons were omitted: 59 in nonproductive forests, 60 with three or fewer sample points, 4 in forests significantly altered since the timber type photointerpretation, and 3 on private lands (Julin and Caouette 1997). The 390 plots were combined from three separate inventories across the Tongass, but the data were compatible when used to estimate Forest-wide means (Brickell 1989).

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[4] Most wilderness areas were not included in the CLU database.

[5] Trees less than 9 inches in diameter were excluded.

[6] Wilderness areas were not sampled.

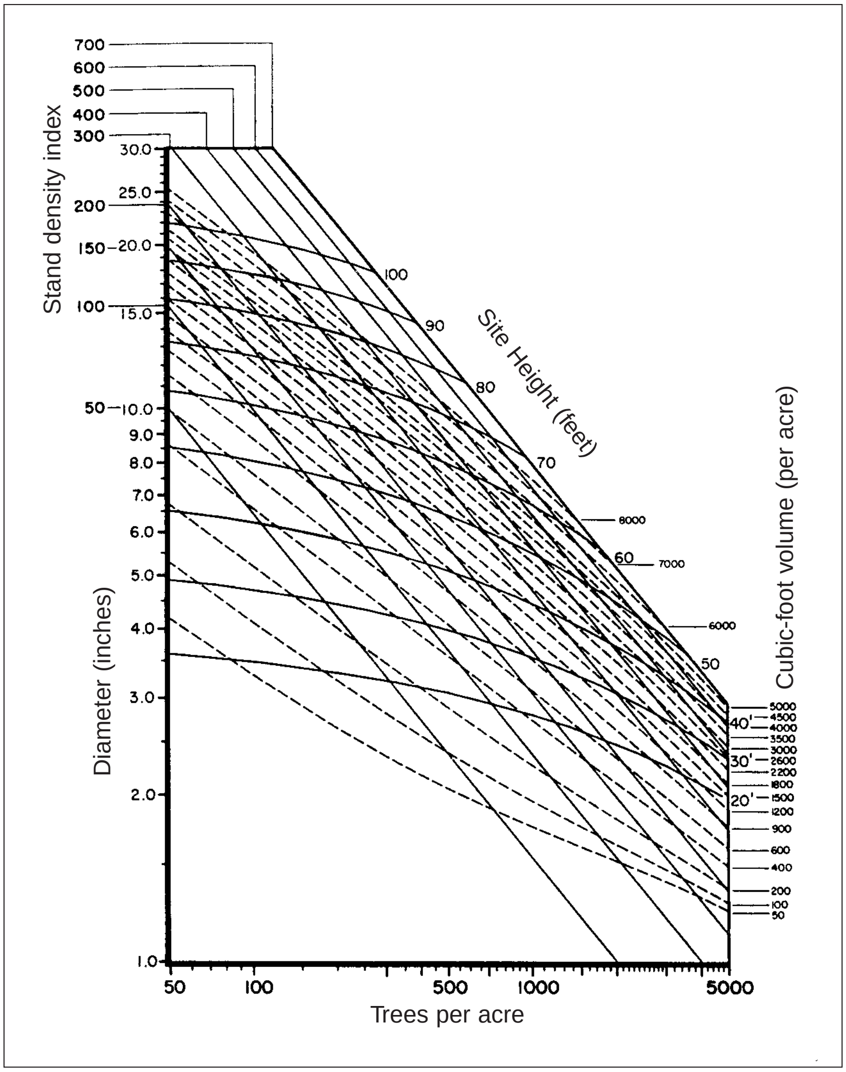

Figure 1—McCarter and Long's (1986) modification of Reineke's (1933) stand density index for lodgepole pine.

Timber Volume and Forest Structure

Trees Per Acre and Mean Diameter Model

The joint distribution of TPA and mean diameter provided a basis for developing a quantitative model describing differences in forest condition across the Tongass. There is strong precedent in forest mensuration for using TPA and mean diameter to quantify forest conditions. Reineke (1933) used these two measures (log-transformed) to explain patterns of change in stand density and stocking. McCarter and Long (1986) later modified Reineke's work by using TPA and mean diameter to describe differences in stand volume and height (fig. 1). Although McCarter and Long's diagram was generated for stands of lodgepole pine (*Pinus contorta* Dougl. ex Loud.) and may not apply directly to the Tongass, the complexity of their diagram indicates a potential for using these two measures to simultaneously model and relate several forest attributes. More recently, Acker et al. (1998) found TPA and mean diameter useful for quantifying structural differences in Douglas-fir (*Psuedostsuga menziesii* (Mirb.) Franco) forests in the Pacific Northwest of the United States.

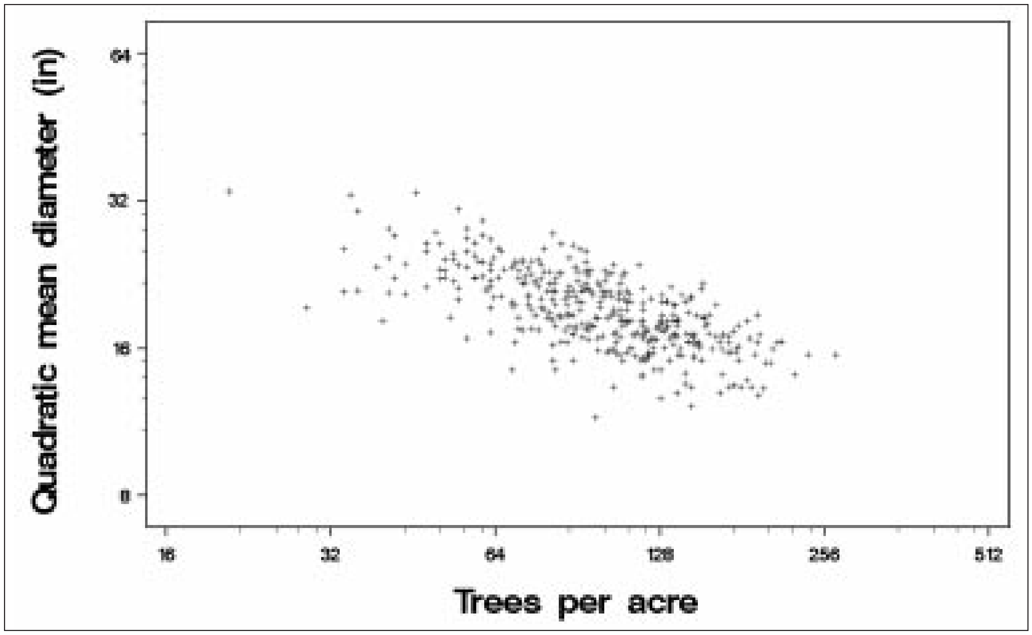

Figure 2—The trees per acre and quadratic mean diameter scattergram, displayed on a log scale, for 390 forest inventory plots.

We applied a TPA and mean diameter model to the Tongass by using the 1980s forest inventory data. The mean TPA and QMD (diameter of a tree having mean basal area) were calculated for each of the 390 forest inventory plots. Inventory plots were displayed on a log-transformed two-dimensional scattergram with TPA along the x-axis and QMD along the y-axis (fig. 2), hereafter referred to as the “TPA-QMD data cluster.”

Forest Structure

The word “structure” often is used broadly in discussions of forest character. Foresters and ecologists intuitively recognize differences in forest structure, but such differences are difficult to quantify because structure consists of a multitude of features, including tree sizes and shapes, tree densities, canopy structure, and stand vigor. Kershaw (1973) considers vegetation structure to have three major components: vertical structure, horizontal structure, and species abundance. Forest ecologists tend to describe structure in terms of stages of stand development (Alaback 1982, Bormann and Likens 1979). Oliver and Larson (1996) recognize four forest developmental stages: (1) stand initiation, (2) stem exclusion, (3) understory reinitiation, and (4) old growth. A conceptual timeline for these developmental stages has been constructed for the temperate rain forests of southeast Alaska (Nowacki and Kramer 1998; see fig. 3). O’Hara et al. (1996) use Oliver and Larson’s developmental stages as a basis for a broad-scale structural classification system for inland Northwest forests. Although such work has helped define forest structure, quantification of structure still proves difficult (Hastings 1997, O’Hara et al. 1996). Acker et al. (1998) have had some success quantifying structure by using some combination of four forest measures: (1) trees per acre, (2) mean tree diameter, (3) standard deviation of diameters, and (4) density of large trees.

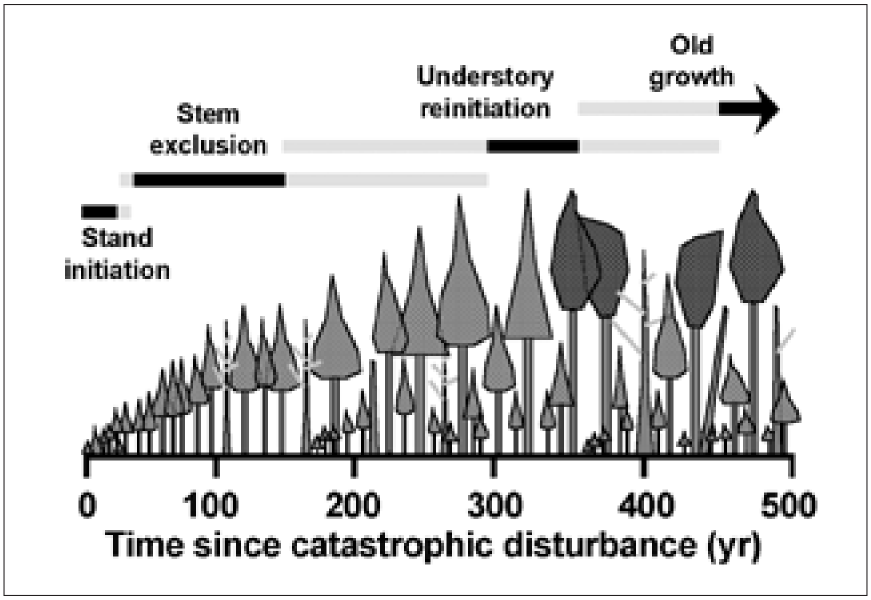

Figure 3—Conceptual timeline portraying developmental stages for temperate rain forests of southeast Alaska. Shaded bars represent temporal overlap among developmental stages (Nowacki and Kramer 1998).

Although the bivariate distribution of Ln(TPA) and Ln(QMD), hereafter referred to as “TPA” and “QMD,” may not capture the full range of structural attributes in the Tongass, these two measures can serve as rough indicators of forest structure. In figure 2, inventory plots in the lower right portion of the TPA-QMD data cluster are expected to differ considerably in forest structure from plots in the upper left portion. Inventory plots in the lower right portion of the data cluster, shown in figure 2, are expected to be from forests with high tree density and more uniform size distribution, similar to forests in the stem exclusion development stage (fig. 3); plots in the upper left portion of the TPA-QMD data cluster (fig. 2) are expected to be from forests with moderate tree density and more heterogenous size distribution, similar to forests in the old-growth development stage (fig. 3).

Stand visualization system (SVS; McGaughey 1997) profile illustrations were generated for six inventory plots selected randomly from various areas of the TPA-QMD data cluster (fig. 3). Each SVS illustration is a simulated view of trees on a given plot, produced by using measured attributes (species, diameters, and heights) from plot trees. The appendix further explains the SVS process and assumptions. Differences among the six SVS inventory plot illustrations (fig. 4) demonstrate that the TPA-QMD data distribution captures some basic differences in forest structure. In figure 4, inventory plots 1 and 2 have homogeneous forest structures typical of early stages of stand development. In contrast, plots 3 and 4 have heterogeneous forests structures typical of older, more developed stands. Plots 5 and 6 (fig. 4) appear to be less productive stands, with smaller, more widely spaced trees. These plot illustrations support the notion that differences in forest structure can be captured by differences in TPA and QMD. In general, we see a gradient in forest structure coinciding with the long axis of the TPA-QMD data cluster (fig. 4). This structural gradient is defined by differences in tree density, average tree size, and the variation of tree sizes.

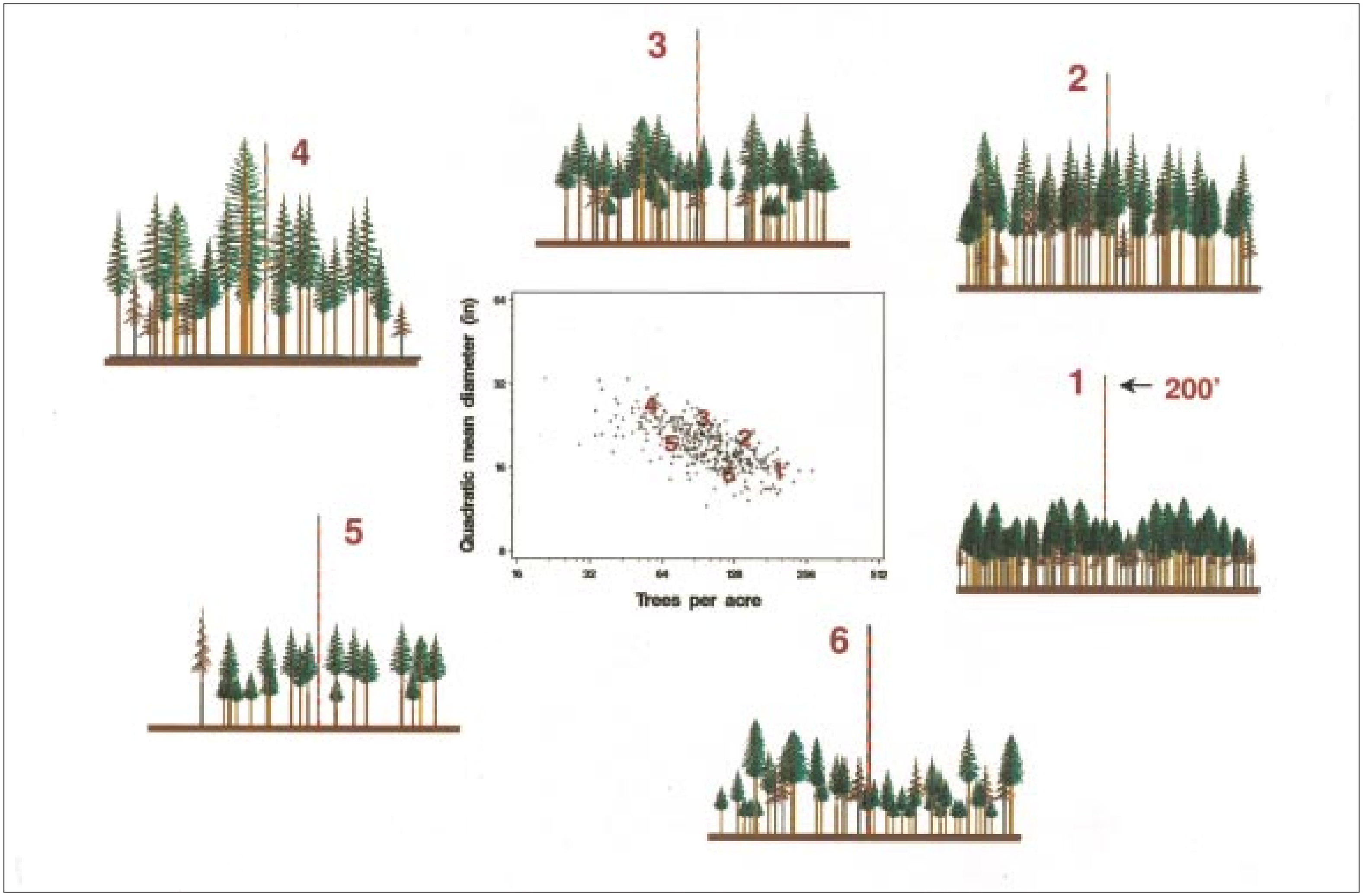

Figure 4—Six forest inventory plots illlustrated by using stand visualisation system software (McGaughey 1997). Each plot was selected at random to represent various parts of the scattergram in figure 2.

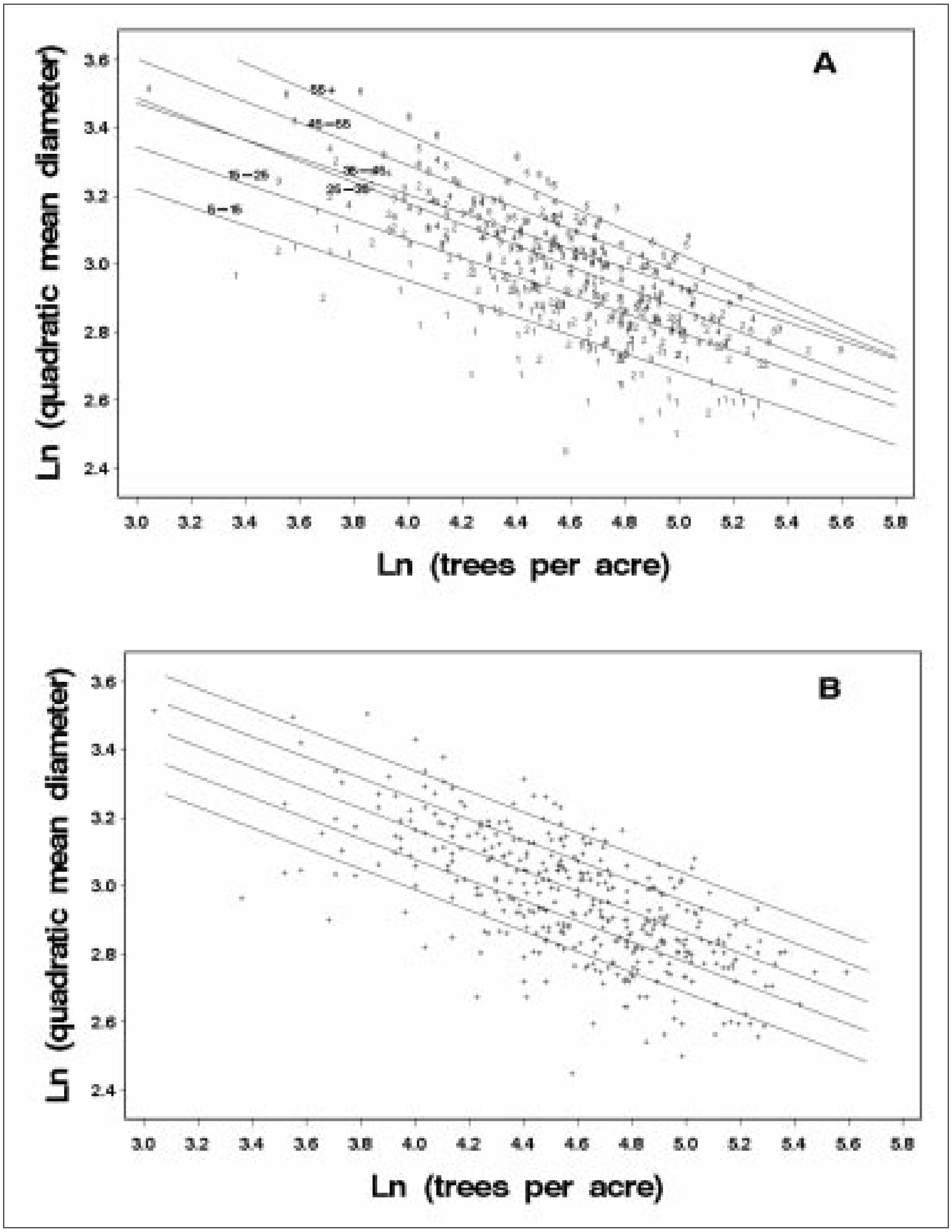

Figure 5—(**A**) Least-squares regression lines for net board-foot volume ranges. Forest inventory plots are labeled with a number representing the associated volume range (0=0-5,000; 1=5-15,000; 2=15-25,000; 3=25-35,000; 4=35-45,000; 5=45-55,000; 6=>55,000). (**B**) Isoclines represent net board-foot volume in relation to the joint distribution of trees per acre and quadratic mean diameter.

Table 1—Statistics for best-fit regression lines shown in figure 5A

Net board-foot volume range	Plot label	No.	Best-fit regression line Ln(qmd)=a+b*ln(tpa)	Slope	R^2
0 - 5K	0	1	NA	NA	NA
5 - 15K	1	77	Ln(qmd) = 4.03 - 0.27*Ln(tpa)	-0.27	0.62
15 - 25K	2	113	Ln(qmd) = 4.16 - 0.27*Ln(tpa)	-0.27	0.58
25 - 35K	3	94	Ln(qmd) = 4.42 - 0.31*Ln(tpa)	-0.31	0.74
35 - 45K	4	64	Ln(qmd) = 4.28 - 0.27*Ln(tpa)	-0.27	0.73
45 - 55K	5	29	Ln(qmd) = 4.54 - 0.31*Ln(tpa)	-0.31	0.70
> 55K	6	12	Ln(qmd) = 4.78 - 0.35*Ln(tpa)	-0.35	0.86

Timber Volume

To understand the relation between timber volume and the TPA-QMD data cluster, we overlaid timber volume information for each inventory plot onto the cluster (fig. 5A). Each inventory plot was assigned a number corresponding to its volume range; for example, if an inventory plot had a ground-measured volume of 32,000 NBFT, it would fall within the 25,000-35,000 NBFT volume range and be labeled with a "3." The assigned volume range numbers for all inventory plots were graphed from their respective TPA and QMD values, and each NBFT volume range was fitted with a best-fit regression line (fig. 5A, table 1).

The slopes of the best-fit regression lines shown in figure 5A were tested for significant differences by using analysis of covariance (SAS 1994).[7] The slopes did not differ significantly (p=0.51). The slopes of best-fit regression lines (fig. 5A) were averaged, and the weighted average slope of 0.29 was used to generate a series of equidistant lines or isoclines across the TPA-QMD data cluster shown in figure 5B. The isoclines summarize the relation between timber volume and the TPA-QMD data cluster. Forest inventory plots falling near the same isocline are likely to have similar timber volumes. Inventory plots falling near an isocline farther from the origin are likely to have higher timber volume than plots falling near an isocline closer to the origin.

Comparing Timber Volume and Forest Structure

There seems to be no direct correlation between timber volume and forest structure. In figure 5A, inventory plots with similar timber volumes are well distributed across the long axis of the TPA-QMD data cluster (i.e., the structural gradient). Plots with similar timber volumes can be related to many different combinations of TPA and QMD. The randomly selected plots illustrated in figure 4 provide a more specific demonstration of the lack of correlation between timber volume and forest structure. Consider plots 2, 3,

[7] To meet the assumptions of analysis of covariance, the TPA and QMD distributions for each volume range were assumed to have a normal distribution and homogenous variances among volume ranges.

Table 2—Information for the 6 inventory plots illustrated in figure 4

Plot illustration (shown in figure 4)	Trees per acre	Quadratic mean diameter	Net board-foot volume per acre
1	192	15.6	21, 500
2	135	21.4	67,600
3	94	24.1	44,300
4	57	26.9	58,200
5	69	19.6	18,100
6	121	15.2	17,800

and 4 in figure 4; although these plots have similar timber volumes (table 2), plot 2 is densely stocked with many medium-sized trees forming a closed, single-storied canopy, whereas plot 4 is more moderately stocked with trees differing in diameter and height and forming an open, multilayered canopy. The structural attributes of plot 3 seem to fall somewhere in between plots 2 and 4. Plots 1, 5, and 6 (fig. 4) also have similar timber volumes (table 2), yet these plots have large differences in structure (i.e., tree density and variation of tree sizes).

Analysis of Photointerpreted Information

1977 Timber Volume Strata

Do the original timber volume strata (4-7) accurately capture volume differences in the Tongass or are they more oriented toward differences in forest structure? To address this question, we graphed each forest inventory plot on TPA-QMD coordinate axes and labeled each plot with its photointerpreted timber volume stratum (fig. 6A). That is, an inventory plot located in a polygon designated volume stratum 6 was labeled with a "6" and graphed according to its ground-measured TPA and QMD values. Because

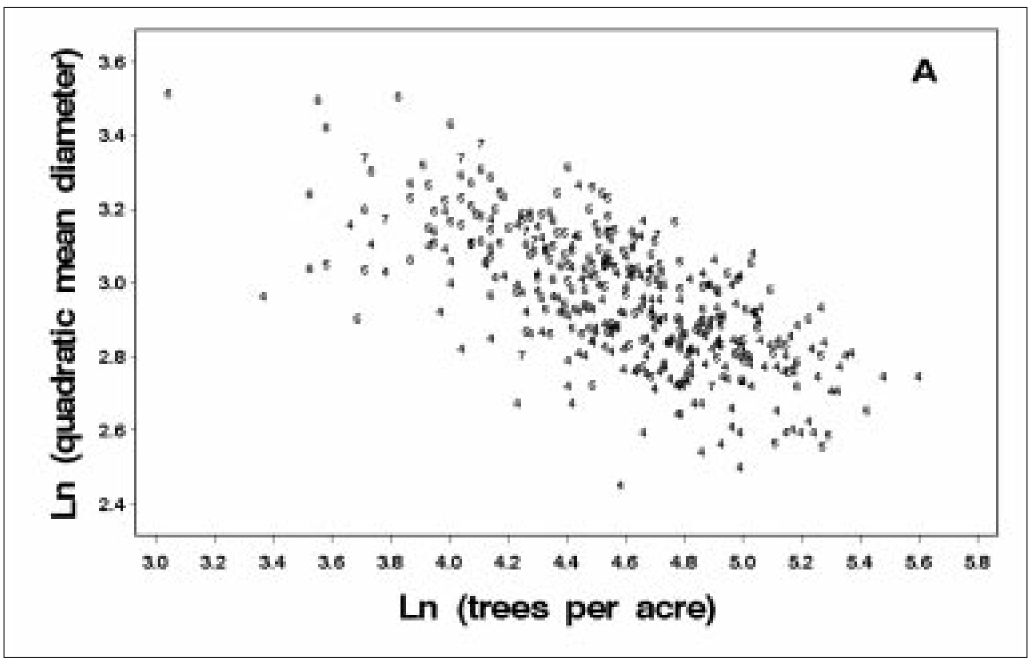

Figure 6—(**A**) The trees per acre and quadratic mean diameter scattergram for 390 forest inventory plots. Numbers 4 through 7 represent the volume stratum designated for the timber type polygon surrounding the inventory plot.

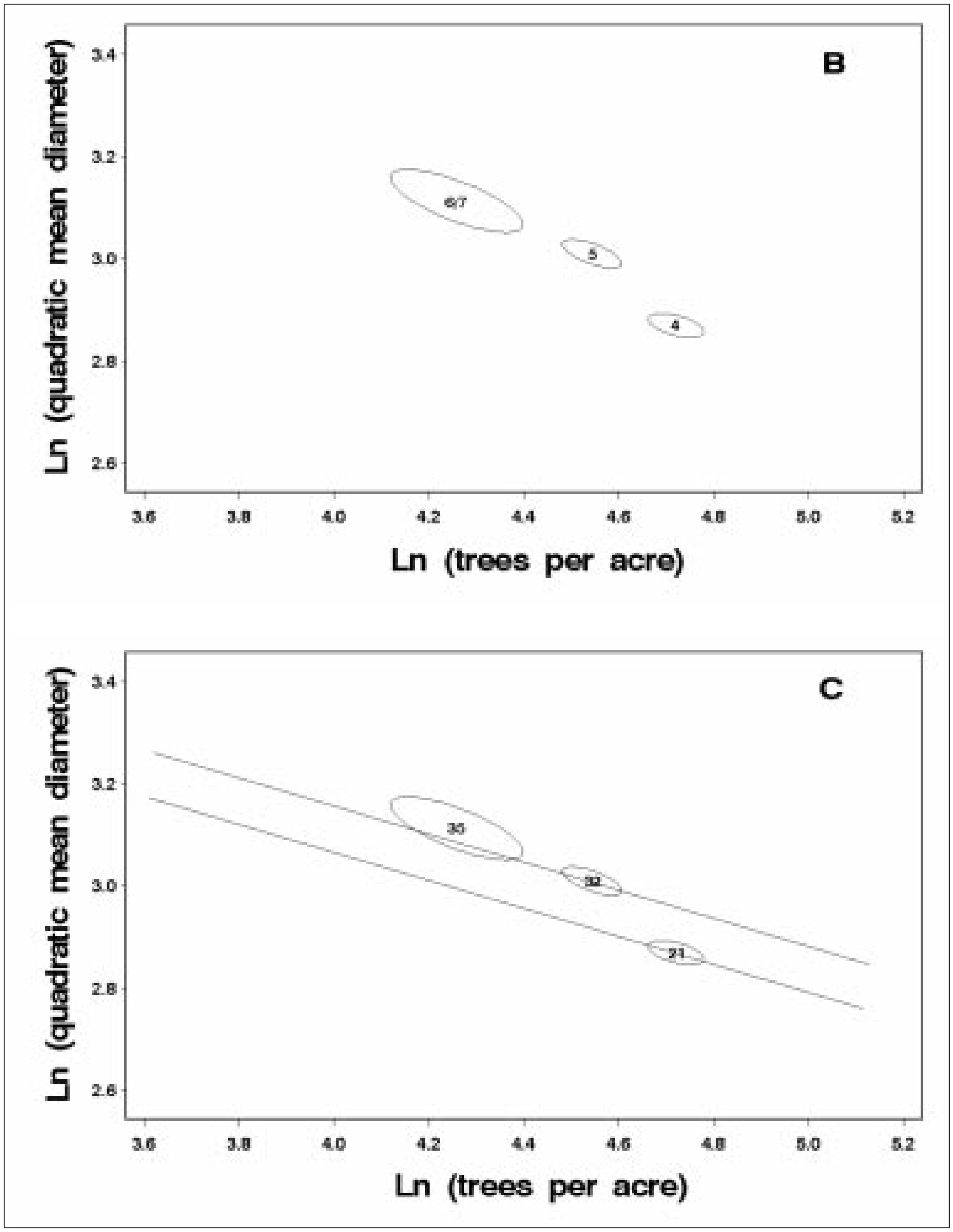

Figure 6—(**B)** Mean trees per acre, quadratic mean diameter (log-transformed), and 90-percent confidence ellipses for inventory plots located within timber type volume strata 4 (n=186), 5 (n=155), and 6/7 (n=49). (**C**) Mean trees per acre, quadratic mean diameter (log-transformed), and 90-percent confidence ellipses for inventory plots located within timber type volume strata 4, 5, and 6/7. The number in the center of each ellipse is the mean net board-foot volume for inventory plots within each timber type volume stratum. Net board-foot isoclines are added for reference.

high-volume stands are distributed along the top, outer portion of the TPA-QMD data cluster (fig. 5A), we would expect plots designated as timber volume strata 6 or 7 (high-volume, >30,000 NBFT) to be distributed along the top, outer portion of the TPA-QMD data cluster as well. Instead, the 6s and 7s appear to be more frequently distributed in the upper left portion of the TPA-QMD data cluster (fig. 6A). This distribution indicates that stands photointerpreted as high volume may have been selected on the basis of forest structural attributes related to TPA and QMD.

Although the scattergram in figure 6A is instructive, the statistical analysis most appropriate to the design of 1980s forest inventory involves the computation of Forest-wide means and confidence intervals for those means (see Brickell 1989 for a detailed explanation). We calculated the Forest-wide means and confidence intervals for TPA and QMD for all ground-measured plots falling within each photointerpreted timber volume stratum.[8] These means are displayed in figure 6, B and C, with 90-percent confidence ellipses. Each ellipse encompasses the range of mean TPA and mean QMD values in which we expect 90 percent of all sample means of the same size to fall. Non-overlapping ellipses indicate that differences between timber volume strata are likely significant ($\alpha = 0.10$) for mean TPA or mean QMD (or both). Data were analyzed by using a one-way ANOVA[9] (PROC GLM; SAS 1994). Scheffe multiple comparisons contrasts were calculated ($\alpha = 0.10$) to test the hypothesis of no difference between mean TPA and mean QMD for all possible pairwise contrasts among timber volume strata 4, 5, and 6/7. Results showed significant differences in all possible pairwise contrasts for both mean TPA and mean QMD ($p < 0.10$).

Most relevant in this analysis are the differences between mean TPA and QMD for timber volume strata 5 and 6/7. The separation between strata 5 and 6/7, along the long axis of the TPA-QMD data cluster, indicates differences in forest structures. However, the mean timber volumes for strata 5 and 6/7 are similar (fig. 6C). Thus, it seems that differences between timber volume strata 5 and 6/7 tend to reflect structural differences more than differences in timber volume.

1997 Revised Timber Volume Strata

We conducted the same TPA-QMD analysis described above by using the revised timber volume strata, low, medium, and high (Julin and Caouette 1997). The low, medium, and high timber volume stratification was created by combining the original timber volume strata with soil and slope information from CLU. By using the CLU database, two soil and slope strata, hydric (H) and nonhydric (NH), were intersected with the original timber volume strata (4-7). The intersection resulted in the formation of five groups (fig. 7A).

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[8] Timber volume strata 6 and 7 were combined for this analysis. There were too few samples in timber volume stratum 7 polygons (12), and the TPA and QMD means for volume strata 6 and 7 were similar.

[9] To meet the assumptions of ANOVA, the TPA and QMD distributions for each volume stratum were assumed to have a normal distribution and homogenous variances among strata.

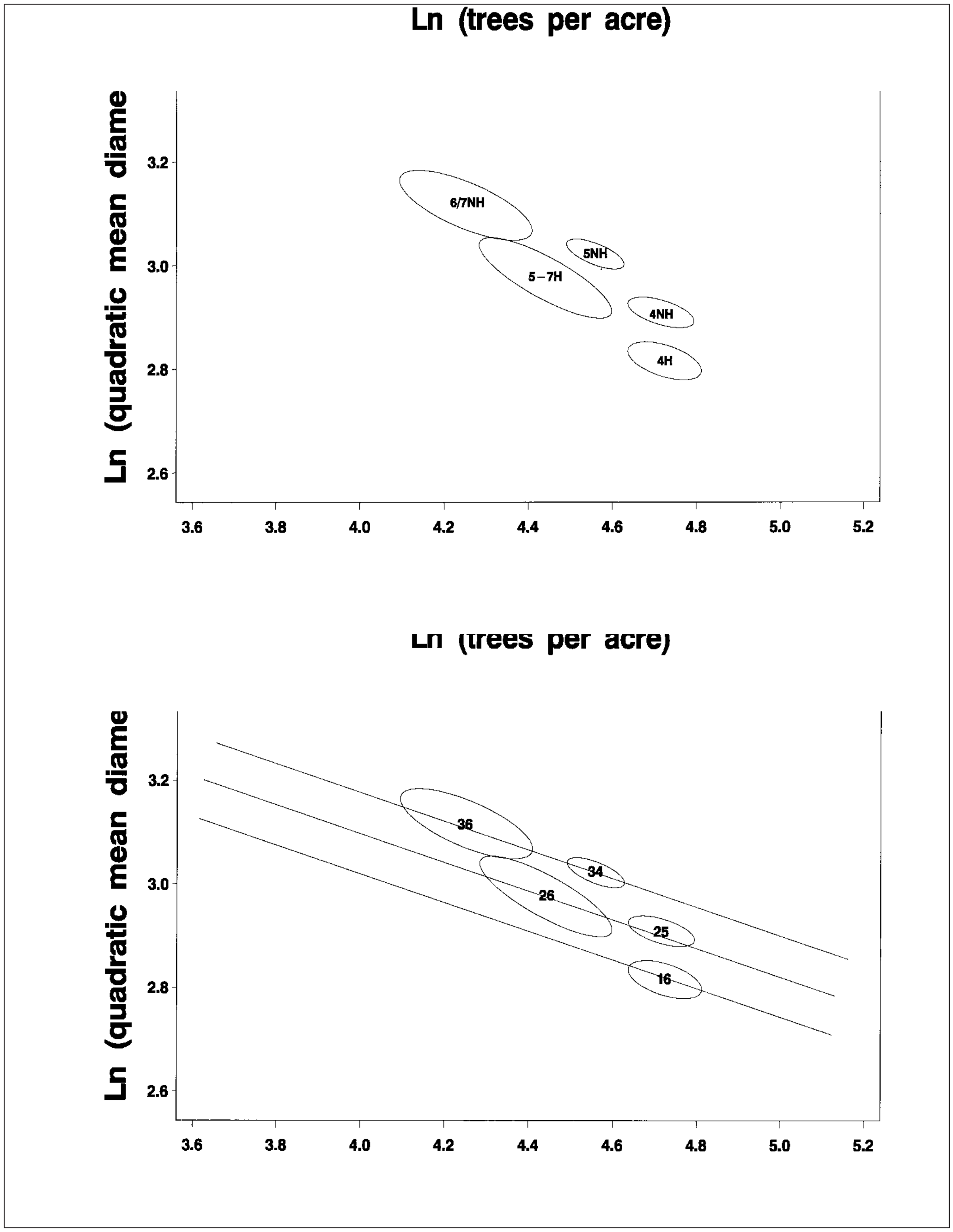

Figure 7—(**A**) Mean trees per acre, quadratic mean diameter, and 90-percent confidence ellipses (log-transformed) for inventory plots located within the intersection of timber type volume strata and common land unit (CLU) hydric soils strata. The numbers shown in the center of each ellipse represent the timber type volume strata (4, 5, or 6/7), and the letters represent CLU hydric soils strata (hydric soils [H] and nonhydric soils [NH]). The timber type and CLU merger creates five groups 4H (n =77), 4NH (n=106), 5-7H (n=34), 5NH (n=125), and 6/7NH (n=41). (**B**) Mean trees per acre, quadratic mean diameter (log-transformed), and 90-percent confidence ellipses for timber type volume strata intersected with CLU hydric soils stratification. The number in the center of each ellipse is the mean net board-foot volume for inventory plots within each of the timber type-CLU groupings shown in figure 7A. Net board-foot isoclines are added for reference.

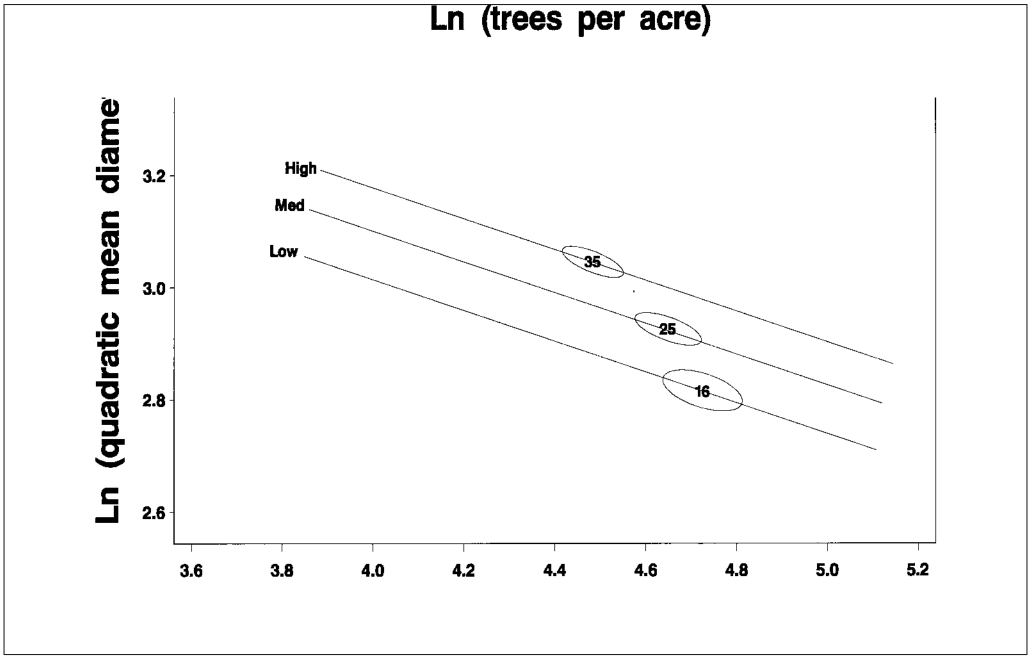

Figure 7—(**C**) Mean trees per acre, quadratic mean diameter (log-transformed), and 90-percent confidence ellipses for inventory plots located within new volume timber type-CLU volume strata. The number in the center of each ellipse is the mean net board-foot volume for inventory plots within each volume strata (low, medium, and high). Net board-foot isoclines are added for reference.

The five groups created from the intersection of original timber volume strata and CLU soil and slope strata are shown again in figure 7B with their respective mean timber volumes (NBFT) and timber volume isoclines. The differences in means and the non-overlapping ellipses in figure 7B indicate that each group may have significant differences in TPA and QMD and, hence, significant information regarding forest structure. If the goal is strictly to provide efficient timber volume stratification, structural information is superfluous, and one would naturally collapse the five groups into three by merging groups located along similar NBFT volume isoclines (fig. 7B). The revised 1997 timber volume strata (low, medium, and high) did just that, as shown in figure 7C. The collapsing of five groups into three demonstrates the problems of having a strict timber volume-based mapping objective. Although the revised timber volume strata provide significant differences in timber volume (Julin and Caouette 1997), available information, which could be useful in modeling differences in forest structure, has been sacrificed.

Photointerpretation of Canopy Texture

Canopy texture is generally an obvious and intuitive attribute to recognize and delineate in aerial photographs. Canopy texture, as viewed from aerial photographs, seems to correspond to differences in forest structure on the ground. To test this theory, we compared photointerpreted texture classes with ground-measured structural attributes (TPA and QDM).

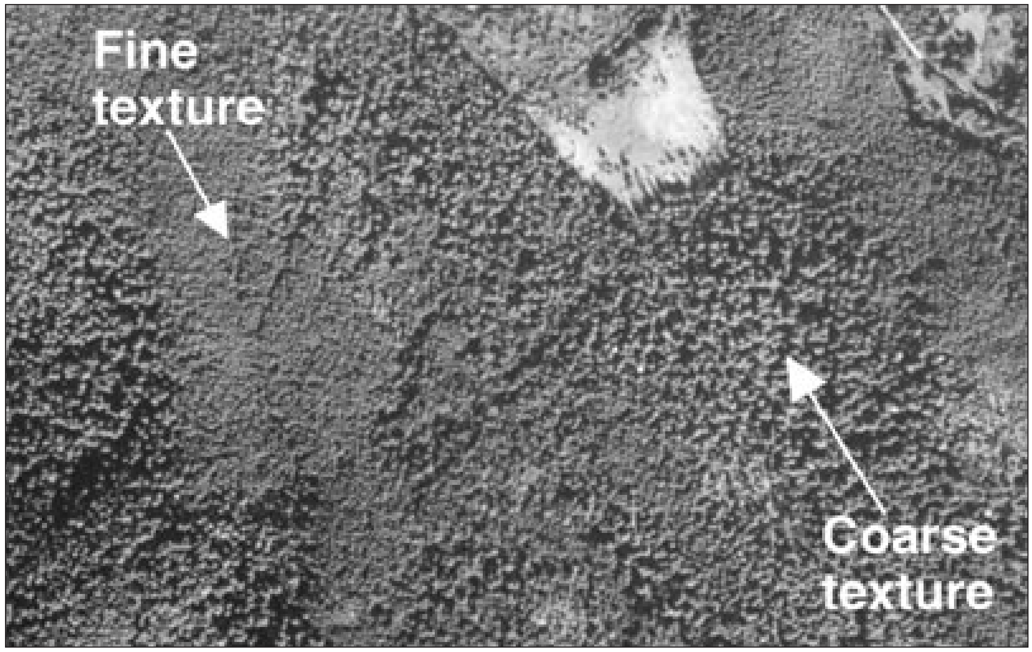

Figure 8—Forested area south of Eagle Beach, Juneau, Alaska. Canopy textures ranging from fine to coarse are shown.

We had an experienced Tongass photointerpreter assign canopy texture designations to each of the 390 land and timber type polygons sampled in the 1980s forest inventory. The photointerpreter had no prior knowledge of the polygon location or any previously assigned attributes. Four texture designations ranging from fine to coarse were defined by forest characteristics visible on aerial photographs (crown density, uniformity of canopy, crown size, and frequency and size of canopy gaps) (Paine 1981). Fine-textured forests have high crown density, uniform crown sizes and heights, small crowns, and few canopy gaps. In contrast, coarse-textured forests have lower crown density, nonuniform crown sizes and heights, large crowns, and many canopy gaps. The middle texture designations, medium-fine and medium-coarse, fall along a gradient between the endpoints. Figure 8 shows the range of canopy textures.

Mean TPA and QMD and 90-percent confidence ellipses for inventory plots within polygons having the same texture designation are shown in figure 9. Polygons designated as fine or medium-fine had a higher mean TPA and smaller QMD than polygons with medium-coarse or coarse designations. The differences among means coincide with the long axis of the TPA-QMD data cluster. Earlier analysis showed that differences along the long axis of the TPA-QMD data cluster appear to be good indicators of structural differences on the ground. This exercise suggests that canopy texture corresponds to differences in forest structure on the ground as measured by TPA and QMD.

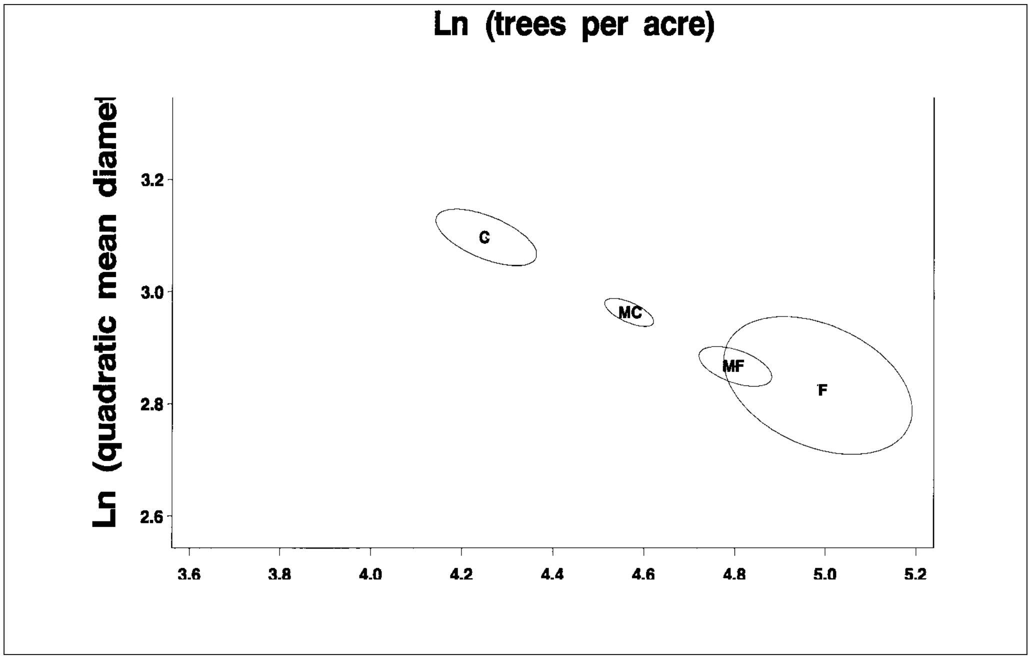

Figure 9—Mean trees per acre, quadratic mean diameter (log-transformed), and 90-percent confidence ellipses for inventory plots located within timber type polygons that have been photointerpreted and classified by canopy texture: fine (F) (n=11), medium-fine (MF) (n=91), medium-coarse (MC) (n=222), and coarse (C) (n=56).

Discussion

Timber Volume Strata Revisited

Throughout the 1980s and early 1990s, the original timber volume stratification map (4-7) was a standard tool for land-use planning and managing timber and wildlife resources. With increased reliance on timber volume stratum information, concerns about its accuracy began to emerge. To address these concerns, a statistical analysis of the original timber volume strata was conducted by Brickell (1989). He compared timber volume strata to ground-truthed forest inventory data and concluded that polygons designated as timber volume strata 5, 6, and 7 (the three highest) did not actually differ significantly in average volume. He stated that strata 5, 6, and 7 could be combined “without any appreciable loss of precision in the overall volume estimate.” Furthermore, continued use of strata 5, 6, and 7 to represent distinct volume categories could not be justified statistically. Brickell’s conclusions, along with corroborating evidence from the Kelp Bay timber sale, formed the basis of a lawsuit on using timber volume strata to administer proportionality (U.S. District Court for the District of Alaska 1994). The Wilderness Society argued that because there were no statistical differences in ground-measured timber volume among timber volume strata 5, 6, and 7, the use of timber volume strata for determining proportionality was “arbitrary and capricious.” The court agreed and the Forest Service was ordered to devise a more accurate means of determining proportionality than the existing timber volume stratum map.

Our analysis suggested that timber type photointerpreters may have delineated the Forest by using structural attributes and translated structural information into timber volume classes—perhaps under the assumption that structure and timber volume are closely correlated. Our analyses demonstrated that forest structure and timber volume are not directly correlated. It is therefore not surprising that timber volume strata, often based on differences in forest structure, did not correspond to differences in timber volume. Further analysis indicated that aerial photointerpreters may recognize differences in forest structure by focusing on canopy texture. Differences among texture classes coincide with the long axis of the TPA-QMD data cluster similar to differences observed among timber volume strata.

As land managers were revising TLMP during the mid 1990s, many felt it was imperative to address the problems associated with the original timber volume stratum map. This goal was achieved when Julin and Caouette (1997) revised the timber volume strata from additional photointerpreted information. Revised timber volume stratum (low, medium, and high) provided statistically defensible differences in Forest-wide volume averages. Although the revised timber volume strata provide more reliable volume data, many interested parties remain unsatisfied. One scientist stated that "the richest old growth and the less valuable stands are classified into a single category [high volume]" (Schlickeisen 1998). An appeal of the recently revised TLMP argues that the revised timber volume strata are unsatisfactory because they do not differentiate the "characteristics found in the structure of ancient old growth, often extremely high-volume stands" (USDA 1997). Some have even advocated for the Forest Service to return to using the original timber volume strata.

It seems that many people are dissatisfied with the revised timber volume strata because they want to see forest structure delineated and mapped for the Tongass. Yet, most people do not appear to question the role that timber volume goals play in preventing this from happening. Any forest stratification that has timber volume as its primary objective will necessarily group together stands of similar timber volume regardless of differences in forest structure. Our analysis showed that this is what happened in the timber stratum revision process (Julin and Caouette 1997). During this process, differences in forest structure were collapsed into a single category because they showed no significant difference in mean timber volume.

Conclusion

Many people associate differences in timber volume with differences in forest structure; perhaps this is because people naturally associate big trees with high timber volume without accounting for the sparse stocking that generally characterizes stands of big trees. Stands of medium-sized trees often have as much or more timber volume than stands of large trees owing to differences in number of trees. Consider two forest stands: one is densely stocked with smaller trees and has a uniform canopy, few rotting or dead trees, and a sparse understory; the other is moderately stocked with many larger, older trees and has many openings in the canopy, standing and down dead trees, and a large amount of understory vegetation. In many cases, the timber volume of such stands will reveal nothing of their differences. Stands similar in timber volume can have a wide range of forest structures.

Although timber volume information is critical for many management objectives, such as calculating forestwide harvest rates or the allowable sale quantity and planning timber sales, there are limits to what timber volume can tell us about a forest. To manage a forest for quality wildlife habitat, timber values, alternative harvest prescriptions, biodiversity, and recreational opportunities, we must develop a system of forest measures that capture differences in forest structure as well as volume. Such a system can provide managers, scientists, and forest users with richer and more diverse information to help them understand ecological processes and plan for a healthy and sustainable forest.

Acknowledgments

We thank the following USDA Forest Service personnel: Gene Degayner, Jim Russell, Bill Pawuk, Bill Wilson, Don Golnick, and Bob Smith for their quest to understand and solve the problems associated with forest stratification on the Tongass. Many of the ideas and concepts presented in this paper were built upon their ideas and work. We thank our peer reviewers, Robert Deal (USDA Forest Service, Juneau, AK), Tim Max (USDA Forest Service, Portland, OR), Robert Curtis (USDA Forest Service, Olympia, WA), William Wykoff (USDA Forest Service, Moscow, ID), and Michael Marsden (USDA Forest Service, Coeur d'Alene, ID). We thank Charles (Terry) Shaw, Kent Julin (then with USDA Forest Service, Juneau, AK, now with County of Marin, Woodacre, CA), and Karen Esterholdt (USDA Forest Service, Portland, OR) for providing important and helpful reviews and comments. Rebecca Braun for her many editorial comments, insights, and support; and Kim Hastings and Richard Carstensen for their attempts to understand and interpret the evolving concepts that led to the development of this paper.

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Appendix

Plot Illustrations, Stand Visualization System

The following protocol was used to select and develop the six SVS plot illustrations. Plots were selected from different regions of the TPA-QMD data cluster without prior knowledge of their location or contents. The only known attribute of each plot was its location in the TPA-QMD data cluster. Each plot illustration randomly displays tree measurement data from the plot over a single square acre. Plot profiles represent a 237- by 20-foot (one-tenth of an acre) cross section across the diagonal of the square acre. Crown types and trunk colors were assigned to individual trees according to their species (spruce, hemlock, cedar). Crown size for each individual tree was calculated by using two-thirds of the theoretical maximum crown radius for a tree of any given diameter. The maximum crown radius was calculated by using a regression equation (derived from measures of open-grown trees in southeast Alaska [Farr et al. 1989]). Crowns were shown only in the upper one-half of the tree height. Dead trees less than 50 feet tall were deleted. Dead trees taller than 50 feet were assigned an SVS snag crown type with an 8-foot radius. A 200-foot reference pole, marked in 20-foot increments, was added to the center of each illustration.

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