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Procedures for Establishing and Maintaining Permanent Plots for Silvicultural and Yield Research

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Abstract

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This paper reviews procedures for establishing and maintaining permanent plots for silvicultural and yield research; discusses purposes, sampling, and plot design; points out common errors; and makes recommendations for research plot designs and procedures for measuring and recording data.

Keywords: Plot analysis, permanent sample plots, tree measurement, sample plot design.

Contents

2	Introduction
2	Background
3	Purpose
4	Data Sources
5	Plot Classification
5	Temporary Plots
5	Temporary Plots, With Supplementary Growth Information
5	Permanent (Remeasured) Plots
6	Some Sampling Considerations
8	Plot Installation
8	Plot Configuration
12	Plot Size
17	Plot Buffers
17	Surveying and Marking Plots
18	Plot Protection
18	Plot Measurement
19	Record of Initial Conditions
19	Tree Numbering
21	Determination of Breast Height
22	Determination of Stand Age
24	Tree Dimensions
34	Site Index Estimates
35	Stem Maps
35	Photographs
36	Remeasurement Schedule
36	Control of Treatments
38	Timing of Measurements in Relation to Treatment
39	Data Management
41	Literature Cited
46	Appendix
46	Checklist of Needed Plot and Tree Measurement Information
47	Standard USDA Forest Service Species Codes for Western Species
48	PDMS Tree Classification Codes
50	Field Tree Measurement Forms and Height Measurement Procedures
53	Equipment Checklist for Field Plot Work
54	Plot Dimensions and Conversion Tables

Introduction

Background

Rational forest management requires information on production and patterns of development of forest stands under current and future stand conditions and management regimes, as a basis for managerial choices, economic decisions, and field application of chosen regimes. This information comes from observation of forest stand development and from silvicultural experiments.

Estimates of present stand volumes and growth rates usually come from forest inventories. The planned forest of the future will, however, often be quite different from the present forest. Present average growth rates do not tell us what we can expect from the future forest, nor do they provide guides to desirable management regimes or a basis for choice among possible management regimes. These require estimates of the behavior of managed stands, including response to such management measures as spacing control, thinning, and fertilization. Such estimates are provided by silvicultural experiments designed to determine the relationships between growth, stand conditions, and stand treatments; and by various types of yield tables and stand simulators which attempt to combine these relationships into generally applicable systems for estimating behavior and production of future stands.

From about 1920 to the 1940's, normal yield tables were developed for many major species. Procedures for constructing normal yield tables from temporary plot measurements in well-stocked wild stands were worked out and fairly well standardized. During the next two decades, relatively little new work was done on yield tables, but many silvicultural field experiments were established.

Since the early 1960's, there has been renewed interest and activity in yield research. This was stimulated by the advent of the computer, the availability of increasing amounts of data from thinning and fertilization experiments, and an urgent need for silvicultural guides and yield estimates applicable to the growing area of young stands and to increasingly intensive management. The former distinction between yield research and silvicultural research is no longer clear, and the new yield tables are various types of simulation models that estimate growth rates and yields for a range of possible management regimes, using the results of silvicultural research.

Estimates of growth rates and treatment responses are wanted for stand conditions and stand treatments that do not yet exist on large operationally developed forest areas. These estimates must therefore be based on silvicultural experiments and small experimentally treated areas. Most of the present information on thinning and fertilization has been so developed. There have been many studies showing response at particular locations, usually reported as case studies. But until recently, there have been relatively few attempts to combine such information into regionally applicable quantitative generalizations.

Such generalized estimates are badly needed. Few individuals or organizations possess a data base adequate for the purpose, and there is much to be gained by pooling data in cooperative efforts among research workers and research organizations. This requires compatibility of and comparable reliability in data collected by different individuals and organizations.

Certain defects that are repeatedly encountered severely limit or destroy the usefulness of much data obtained at high cost in time and money.

1. Documentation is often inadequate. Records of procedures, stand measurements, and stand treatments are incomplete, poorly organized, or contradictory.
2. Plots are often excessively small or are installed without buffers between adjacent treatments, or both.
3. Height measurements are frequently inadequate in number, distribution, or accuracy, and have sometimes been omitted altogether.
4. Measurements are often omitted for trees below some arbitrary "merchantable" size, which results in truncated diameter distributions and statistics that cannot be compared with other data.
5. Estimates of tree and stand ages are often inaccurate. Sampling is frequently inadequate, definitions are ambiguous or inconsistent, and procedures have not been documented.
6. Initial stand conditions, prior to treatment, are often not recorded.
7. Plot areas are often unreliable because of poor plot surveys and poor records.
8. Changes are sometimes made in treatments, plot sizes, or measurement procedures for reasons of immediate expediency in fieldwork, without consideration of effects on later analyses.
9. Data codes and measurement standards are often inconsistent or incompatible. This prevents use of a common set of computer programs or pooling of data among organizations or individuals, without costly and time-consuming conversions and loss of information.

Purpose

This paper discusses items that should be considered by anyone planning or undertaking establishment and measurement of field plots in silvicultural experimentation, or for construction of yield tables. It is concerned primarily with design and measurement of individual plots. The larger questions of experimental design in general, and of overall sampling design, are touched on only as they relate to plot procedure.

Procedures for establishing and maintaining such research plots have been discussed in a number of past publications, including Decourt (1973), Forestry Commission (1979), Hummel and others (1959), Robertson and Mulloy (1944, 1946), Synnott (1979), and USDA Forest Service (1935). There are also various in-house manuals that are not generally available. These contain much information of value; however, some procedures discussed are now out of date, and many manuals are oriented specifically to the needs and procedures of individual organizations and projects.

Installation and maintenance of permanent plots are not simple tasks. This paper is not intended to be a complete, detailed manual of field procedure. Rather, it is intended as an aid for those preparing procedural specifications. It should help them to avoid repetition of past mistakes by calling attention to decisions needed in the planning stage of a research study. It should help them to provide some standardization and compatibility between data sets. It may give field personnel insight into the reasons behind procedures, and possible alternatives.

Portions of the discussion may appear to be mere repetition of the obvious. Experience, however, shows that many obvious points become obvious only in the analysis stage, when it is too late to correct mistakes made in establishing and measuring plots.

The discussion is generally in terms of fixed area remeasured plots and even-aged stands with one principal species. Historically, these are the plot type and stand condition most often used in silvicultural experiments and in construction of managed stand yield tables; however, many of the same ideas and principles apply to studies using point sampling and to other stand conditions. Although aimed at research applications, they may also suggest possible modifications in inventory and stand examination procedures to make them more compatible with information developed from research.

Necessarily, recommendations made in this paper often represent informed opinion and the author's best judgment rather than established fact.

Data Sources

Approaches to silvicultural and yield estimation problems are influenced by (1) specific objectives, (2) nature of the forest (even aged vs. uneven aged, pure vs. mixed species), (3) data already available, and (4) feasibility of acquiring new data.

Data may come from research plots installed to secure information on a particular relationship, from research plots designed to sample specified stand conditions over a region, from existing research plots originally installed for these or other purposes, from management inventories, or from some combination of these.

Inventory data are often available in large quantity, and they provide a representative sample of the existing forest. They are usually the best basis for short-term projections; they have not generally proved satisfactory for other purposes, for several reasons.

The small plots used in many inventories are subject to unknown edge effects. Usual procedures provide only rough estimates of such attributes as age and height for the individual plot and frequently omit or inadequately sample stems below some arbitrary and fairly large diameter. Such data are well suited to estimation of stratum means (their designed objective) but are poorly suited to estimation of treatment responses or the regression relationships used in stand simulation.

When estimating treatment effects, comparing potential treatment regimes, and making long-term estimates for future managed stands, one is commonly dealing with conditions that as yet exist only on small areas and very restricted experimental installations. These are not sampled adequately, if at all, by management inventories. If sampled, the uncontrolled variation present usually prevents satisfactory evaluation of treatment response.

For these and similar reasons, most silvicultural research and much yield research are based on plots established independent of management inventories.

Plot Classification

Field plots used in silvicultural and yield research can be classified into three groups:

1. Temporary (single-measurement) plots.
2. Temporary plots, with supplementary growth information.
3. Permanent (remeasured) plots.

Temporary Plots

The normal yield tables of the 1930's were generally based on temporary plots. Ages, diameters, and heights were measured, but no direct information was obtained on current growth rates and mortality rates.

Such plots still have their uses, but they will not be further considered here. They do not provide the information on growth and mortality required for most modern yield tables.

Temporary Plots, With Supplementary Growth Information

Additional measurements obtained from increment cores and stem analyses can provide information on growth rates of trees on temporary plots. This information can be extrapolated for short periods to provide the periodic growth values or estimates of current growth rates needed for some types of analyses. This is a common procedure in inventories in which such procedures provide some growth information at less cost and without the delay involved when permanent plots are used. Similar methods can be used to obtain growth data for construction of yield tables and stand simulators, by procedures such as those discussed by Curtis (1967b), Myers (1966, 1971), and Vuokila (1965).

Although information may be obtained quickly by such methods, precision comparable to that of permanent plot methods is not cheap, if attainable at all. The accurate determination of diameter growth required in research studies is not easy. Except in young stands of species with annual internodes which can be directly measured from the ground, height growth estimates can be obtained only by laborious and destructive stem analyses; or by assuming (perhaps incorrectly) that preexisting site index curves are a correct representation of height growth. Information on mortality is obtainable only in the form of subjective estimates of year of death of dead trees on the plot. Stand treatment information is usually confined to measurement of visible stumps and rough estimates of date of cutting. No information can be obtained for stand conditions and treatments not present in the existing forest.

It is possible, however, to construct yield estimates from this type of data, and such data are often useful as a means of supplementing existing permanent plot data.

Permanent (Remeasured) Plots

Much past and present research uses "permanent" plots, which are established and measured at the start of an investigation and subsequently remeasured at intervals over a period of a few to many years. Such plots are expensive and represent a long-term commitment of resources which is unpopular with many administrators. Permanent plots can provide data of superior accuracy and information obtainable in no other way, however.

For the period of observation, permanent plots provide points in a real growth series, as opposed to artificial growth series constructed from single measurements of stands thought to represent successive stages in development. Over an extended period of years, the record of actual development of individual stands provides a standard against which estimates can be compared. Characteristics and development of individual trees can be followed over time. Such plots provide a complete history of stand development and stand treatment, response to treatment, and actual stand damage and mortality information not obtainable from other types of plots. When observations are continued over many years, variations in growth caused by short-term climatic fluctuations should be compensating. And, for demonstration purposes, the on-the-ground examples and historical record of treatment and response which they provide are more convincing to field foresters than any amount of statistical analyses and projections of temporary plot values.

This paper is primarily concerned with permanent plots, although many of the principles and recommendations given also apply to temporary plots with supplementary growth information.

Some Sampling Considerations

A first step in any sampling scheme is to define the population about which inferences are to be made, in terms of such associated characteristics as physical location, site quality, stand origin, age class, species composition, management treatment, and freedom from destructive agents. For many research studies, there is no need to sample conditions that will be excluded from the forest under anticipated future management. Thus, silvicultural experiments and yield studies rarely include very old and decadent age classes. Stands severely injured by disease, insects, or climatic agents are usually excluded on grounds that, under management, such stands will be terminated.

Sample selection is relatively straightforward in management inventories, where the population consists of all presently existing stands and the primary objective is to estimate stratum means. It is less straightforward in silvicultural studies intended to develop estimates of growth of future managed stands. In the latter case, one often seeks inferences about some largely hypothetical population of future managed stands, which may differ considerably from the present forest. The primary objective is often not to determine means of volume or basal area for some category of stands, but to estimate coefficients of functions relating growth to current stand values and possible treatments. The conditions of most interest for this purpose may exist only on certain small areas. Some conditions and treatments must be created on newly established experimental plots. Some combinations of stand condition and treatment can be produced only by an extended period of management; these cannot be sampled directly, and estimates must be based on extrapolations from the most nearly analogous conditions available.

Yield studies often use regression analyses of unreplicated plots, established in the portions of the existing forest that meet stated specifications of age, species composition, health, density or treatment category, and relative uniformity in stand and site conditions. Plot location within suitable areas is often done subjectively; the observer attempts to select a plot representing either an average condition for the stand or the observer's conception of conditions likely under future management. An alternative, more objective, and statistically more defensible approach in such studies is to select and delineate stands that meet the required specifications and then to locate the plots) within them by some random or systematic sampling procedure.

Such stands should be deliberately selected to obtain as wide a distribution of the predictor variables as possible, consistent with study objectives and expected application of the model. As an example, many predictors of growth are regression models that involve age and some measure of density. A statistically desirable selection would insure that the plots include a wide range of densities for each age class. As sample selection proceeds, the distribution of age and density can be indicated in a two-way table and an effort made to fill all cells as equally as feasible. Such a selected sample yields a rectangular distribution of age and density; in subsequent regression analyses, it will provide a better assessment of effects of the predictor variables, and better predictions near the margins of the range of data.

In silvicultural experiments, treatments are usually replicated at a given location in accordance with some specified experimental design. This provides an estimate of experimental error and allows statistical analysis of results at that location. Often, the experimenter's primary interest is in defining some specific relationship, such as response to fertilizer dosage or to density level. To minimize the experimental error, the experimenter will then impose stringent requirements on initial homogeneity and comparability of plots within that installation. Meeting this requirement of close comparability of initial conditions among plots generally requires that the plots be subjectively located, with subsequent random assignment of treatments.

Many yield studies use regression analyses of plots selected in chosen strata of the existing population, supplemented with plots from silvicultural experiments. The latter furnish information on conditions and treatments not available in the existing forest and may provide guides to the form and nature of certain relationships. Considerations of time, cost, and availability of data often force the analyst to use data that are not completely comparable or compatible in method of plot selection and standards of measurement, and treatments may or may not be replicated at a particular location. Stringent stand uniformity requirements and close control of treatments, which are necessary for identification and measurement of treatment effects in silvicultural experiments, may lead to estimates that require adjustment for operational use (Bruce 1977).

Valid conclusions applicable on a regional basis also require that additional installations be distributed over a range of site conditions, initial stand conditions, and geographic locations that include various unmeasured and possibly unrecognized factors affecting growth.

Most silvicultural experiments and yield studies recognize the need for replication at a given location if conclusions are to be drawn for that location and the need to sample the range of stand and site conditions if conclusions are to be drawn on a regional basis. The need to include a range over time is less generally recognized, however.

Growth of forests varies from year to year and decade to decade because of variation in climatic conditions and sporadic occurrence of widespread stand injuries and cone crops. In some instances, these fluctuations can be extreme (Keen 1937, Reukema 1964). Mortality tends to be clustered in both time and space because it is associated with climatic extremes and with the occurrence of windstorms and insect and disease outbreaks.

It is therefore risky to base estimates of expected growth on observations of growth, mortality, and treatment response made in a single short time period. Although little can be done to allow for possible long-term trends, short-term variations will average out when the basic data represent a series of time periods rather than a single short period. This is one major value of long-term permanent plot observations and of the accumulation over time of compatible data collected by consistent procedures.

Plot Installation

Well-designed permanent plots maintained and repeatedly remeasured over time become more valuable with increasing length of record. Many times they are valuable for purposes other than the study for which they were installed, and for purposes not anticipated by the person who installed them.

Long-term permanent plot data are often analyzed by someone other than the original investigator. Analytical techniques and objectives change over time, and there can be no certainty that the computational procedures and analyses foreseen at the time the plots were established will be those judged most suitable at the time of later analyses.

Therefore, procedures and data should be as complete and general as possible. Shortcuts that will later limit analyses to specific summarization and analysis procedures should be avoided. Experience shows that such shortcuts usually result in later costs and loss of information far more important than small immediate savings in field time. It should be anticipated that details of site classification, volume computation, and similar procedures will change, and the data should be adequate to permit summarization and analysis by any generally applicable procedure.

Plot Configuration

The plot is the basic unit of observation. It is usually a single area delineated on the ground. It may consist of a cluster of subplots (or points, if variable radius plots are used) arranged randomly or systematically within the treatment area or stand, with cluster totals treated as the basic values for analysis. In clumped or irregular stands, such clustered subplots may be preferable to single larger plots and more consistent with later management application of results.

Fixed area plots can be any shape but are usually circles or squares, which minimize perimeter per unit area and, hence, edge effects and required area of buffer. Circles are convenient for very small plots, but accurate location of the perimeter becomes difficult for larger plots. The straight borders of squares and rectangles lend themselves to accurate location and marking of corners and borders: Corners of squares are easily located with compass and tape by measuring diagonals from an initial plot center (fig. 1); subsequent measurement of boundaries provides a check on errors. Rectangles are sometimes advantageous where there is a pronounced site gradient (as on steep slopes) and the long axis of the rectangle can be oriented at right angles to the gradient to reduce variation within the plot. Fieldwork is simplified and blunders are reduced if a standard plot shape and layout procedure are adopted and used whenever the situation permits.

RECOMMENDATION: The square plot is generally the most useful and convenient for research studies.

Some special considerations arise in regularly spaced plantations, which sometimes influence positioning, orientation, and exact size of plots.

In some research plantations established with very close control of spacing, it is feasible to use a square or rectangular plot positioned so that its sides lie midway between rows, thereby insuring that plot area is identical with the growing space available to the trees on the plot. This is desirable when feasible and will produce plots with areas that differ slightly from the simple fractional acres or fractional hectares generally used (fig. 2).

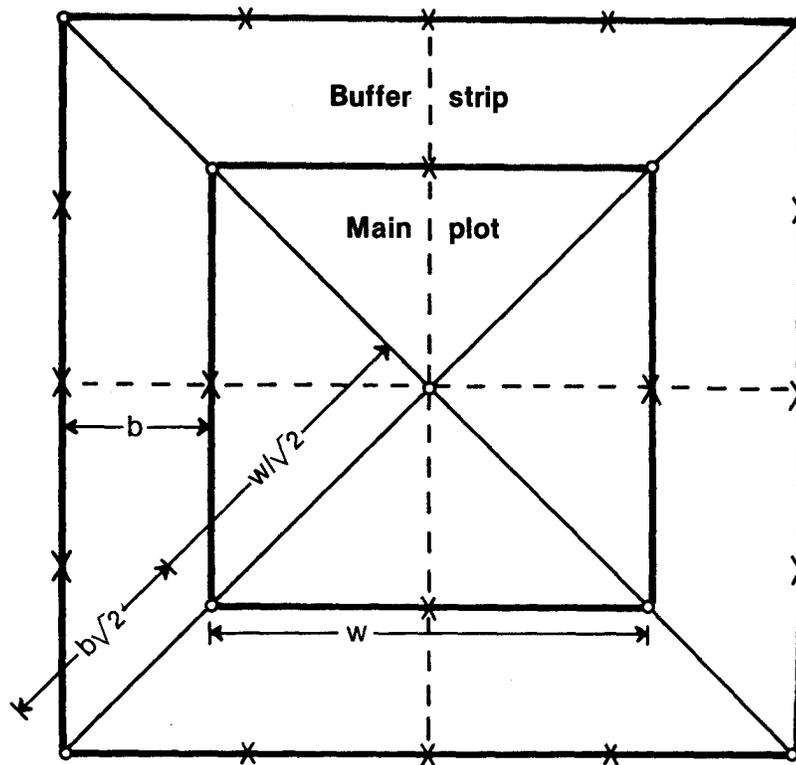
A more common situation is that in which an existing plantation has spacing not sufficiently regular to allow positioning the plot with sides midway between rows, but still sufficiently regular that position and orientation of the plot can result in a plot area that differs appreciably from the total growing space available to the trees on the plot. This in turn will bias all growth computations. One means of reducing such bias is to orient the plot so that its sides intersect the planting rows at an angle of 20° to 30° (fig. 3).

Variable radius plots (points) may also be used for permanent plots. Single points are not a usable sampling unit for research purposes, since they include too few trees to provide satisfactory estimates either of growth rate or of the stand attributes used as predictors of growth. A systematic arrangement of 5 to 10 points within a stand can be used, however.¹ Variable radius plots are more consistent with commonly used inventory procedures than are fixed area plots, and they have the well-known advantage that sampling proportional to basal area concentrates the measurements on the trees of larger size and (usually) higher growth rates.

Because variable radius plots include few trees from the smaller diameter classes and information is generally also needed for these, it is usually necessary to combine the variable radius plot with a concentric fixed area plot on which all trees below a specified limiting diameter are recorded. The fixed area plot size should equal the size of the variable radius plot for the specified limiting diameter.

The fact that trees initially outside the variable radius plot grow "onto" the plot as they increase in size ("ongrowth" trees) complicates computations and introduces irregularities in growth estimates for successive periods, which are not present with fixed area plots (Martin 1982, Myers and Beers 1968).

¹ Hann, David. Development of growth and yield information for the mixed conifer zone of southwest Oregon. Study plan on file at Oregon State University, Corvallis, Oregon. 1981.



- o = permanent stakes at corners
- x = temporary stakes (optional) aid in locating lines and in subdividing plot for tagging trees and measurement and selection of site trees
- w = length of side of main plot
- $w/\sqrt{2}$ = length of semidiagonal of main plot
- b = width of buffer strip
- $b\sqrt{2}$ = extension of semidiagonal to corner of buffer

Figure 1.—Typical layout of a square plot.

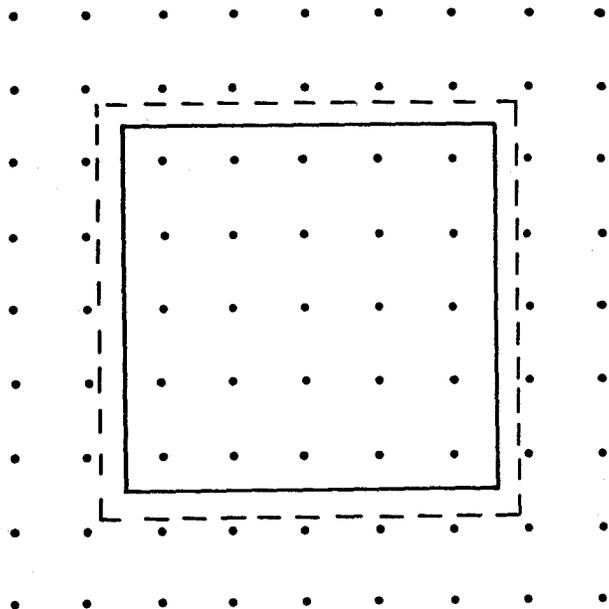


Figure 2.-Position of plot borders in a plantation. Correct position (solid line) gives unbiased estimates of growth per unit area. Incorrect position (dashed line) gives biased estimates of growth per unit area.

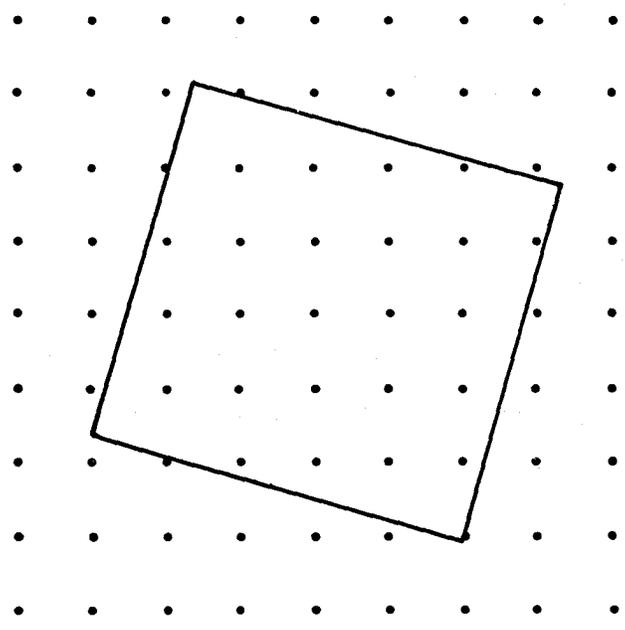


Figure 3.-Orienting plot at an angle to rows in plantation reduces bias in estimates of growth per unit area associated with position of plot borders.

Such a cluster of points usually extends over more physical area than atypical fixed area plot serving a similar purpose. This may be an advantage or a disadvantage, depending on the nature and purpose of the study. It may be difficult to provide the buffers and replication needed when several treatments are to be applied within a limited area in a silvicultural experiment. Over an extended observation period, an initially reasonable spacing of points can lead to variable plots that overlap or extend into adjacent dissimilar treated areas. Because the point cluster extends over a greater area, however, it may be more representative of conditions existing on a stand basis and may be more consistent with data arising from typical stand examination procedures.

Variable radius plot (point) clusters are best suited to studies that sample preexisting stand conditions, or where treatments are applied to relatively large areas, rather than to typical silvicultural treatment experiments.

Plot Size

Plot size is influenced by intended purpose, by stand conditions, by expected duration of the study, and by cost considerations.

The criteria for suitable plot size in a research study are not the same as in an inventory. Frequently, an inventory aims to determine average values of certain variables (such as volume) for given strata, as means of plots falling in those strata. Within limits, increased plot numbers can compensate for increased variability associated with smaller plots, and estimated means are unbiased regardless of plot size.

Many research studies, however, use regression equations to estimate individual tree or plot growth as functions of current stand values of individual plots. Very small plots will produce highly variable estimates and can lead to biased estimates of regression coefficients as a result of edge effects and bias in subjective location of plots.

Variability increases with decreasing plot size, and plots that are excessively small relative to the pattern of within-stand variation will produce a considerable range of values for variables such as density and volume (Smith, 1975). If field plots are then subjectively located for apparent uniformity and full stocking (a common procedure in field experiments), the resulting values may be higher than are realistically attainable on a stand basis. If plots are systematically located, observed growth on the plot will represent in part an effect of adjacent, unmeasured, differing stand conditions. High density plots will grow well because they are using adjacent growing space. Low density plots will grow relatively poorly because of the competition of adjacent dense groups of trees.

Small plots are also likely to bias mortality estimates. In many studies, plots which lose a substantial part of their stocking to mortality between two successive measurements are assumed to represent instances of "catastrophic mortality" and are discarded. On small plots, however, death of even a few trees in a given period will result in large negative increments. The analyst cannot tell whether this represents merely a few trees whose loss is insignificant in overall stand development, or a major disaster; the variation introduced can totally obscure any relationship between growth response and stand treatment. The plot must therefore be discarded. The result is not merely highly variable estimates of mortality, but estimates of mortality and of the relation of mortality to stand conditions and treatment which are biased by the plot selection process.

Excessively small plots can be expected to give erratic values for stand statistics and poor correlations of increment with site and stand attributes; they may also give biased estimates of the increment-stand density relationship (Jaakola 1967). Such effects will generally be more serious in mechanically located plots without buffers (as in inventories) than in research plots established in selected stand conditions (usually chosen for homogeneity) and provided with suitable buffers, so that edge effects are reduced.

Although the effects of plot size on yield analyses have not been thoroughly investigated, a number of rules of thumb for desirable size of fixed area plots are given in the literature.

Early U.S. investigators commonly recommended plot sizes that would include at least 100 stems exclusive of understory at the end of the experiment (Bruce 1926; Osborne and Schumacher 1935; USDA Forest Service 1935-still an excellent reference on many aspects of plot installation and measurement; Marckworth and others 1950). Since much of this work was in untreated stands, presumably a somewhat lesser number would be acceptable in the more uniform stand conditions expected in plantations and consistently thinned stands.

Fabricius and others (1936) recommended plots of at least 0.6 acre (0.25 ha), larger in irregular stands. Robertson and Mulloy (1944, 1946) recommended 0.5- to 1.0- acre (0.2- to 0.4-ha) plots. Jeffers (1959) recommended 0.25 to 1.2 acres (0.1 to 0.5 ha) for even-aged pure stands, depending on spacing. Hummel and others (1959) recommended plot sizes of 0.3 to 0.5 acre (0.12 to 0.20 ha) for pure conifers, 0.5 to 1.0 acre (0.2 to 0.4 ha) for mixed stands. The Forestry Commission (1979) recommended plot sizes of 0.25 to 0.5 acre (0.1 to 0.2 ha) for general use, with a minimum of 0.2 acre (0.08 ha) for single plots in conifer plantations, 0.3 acre (0.125 ha) for hardwoods, and 0.1 acre (0.04 ha) in replicated treatment experiments (excluding buffers).

Vuokila (1965) compared coefficients of variation for alternate plot sizes and recommended a size in hectares equal to $0.01 \times$ (dominant height in meters), which corresponds to a plot size in acres of $0.0075 \times$ (dominant height in feet). Decourt (1973) recommended the same standard, with the restrictions that minimum plot size should not be less than 0.25 acre (0.1 ha) and that the plot should contain 100 to 200 stems. Hegyi (1973) made a somewhat similar analysis of plot size in three untreated jack pine (*Pinus banksiana* Lamb.) stands. His coefficient of variation curves suggest minimums of 50. to 75 stems per plot and areas of about 0.1 acre (0.05 ha) for these small-diameter stands. Note that these comparisons of coefficients of variation all deal with live stand volumes and basal areas, rather than with increment rates-which are frequently the values of primary interest.

Plot sizes in the general range of 0.25 to 0.5 acre (0.1 to 0.2 ha) have been used in several U.S. and foreign thinning and fertilization studies (Carbonnier and Fries 1976, Clutter and Jones 1980, Hamilton 1976, McEwen 1979).

In 1969, the University of Washington Regional Forest Nutrition Program adopted a minimum plot size of not less than 0.1 acre (0.05 ha), to contain at least 50 stems, plus buffer.² The British Columbia Forest Productivity Committee specified a minimum of 0.12 to 0.25 acre (0.05 to 0.1 ha) according to number of stems, but not less than 60 stems, plus buffer.³

Recent studies in the Pacific Northwest have frequently used quite small plots-sometimes as small as one-twentieth acre (0.02 ha)-because of difficulty in finding fully comparable stand conditions over an area large enough to allow replication of a series of treatments at a single location.

Our experience (Curtis and others 1981) leads to the conclusion that the very small plot sizes used in some thinning and fertilization experiments are undesirable, and sometimes unusable, as a basis for increment regressions and for estimates of mortality and diameter distributions.

Note that all the rules of thumb given above lead to plot sizes considerably larger than those used in many inventories, even though stands are selected for uniformity. Plots smaller than those used in the University of Washington and British Columbia Forest Service studies cited are clearly undesirable as sources of growth and yield data, and even these have severe limitations for study of diameter distributions and mortality.

² University of Washington. Forest fertilization research in the Douglas-fir region of the Pacific Northwest: research proposal and project description. College of Forest Resources, Seattle. 1969.

³ British Columbia Forest Service, Forest Productivity Committee. Field manual, balanced installation field programme. Victoria, B.C. 1974.

Consistency among plot sizes in different stand conditions may be obtained by relating a standard number of stems to average diameter or to stand height. Figure 4 gives an example of such a guide, indicating the plot sizes required to include 50 stems in Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) stands of a given average diameter and percentage of normal stand density. (Many thinned stands, for example, would fall between the 50- and 75-percent curves indicated in early thinnings, and near the 75-percent curve at older ages.) Similar guides can also be derived from the relation of number of trees and dominant height, or from the crown area-diameter relationship of open-grown trees. Such guides should be qualified by a minimum number of trees acceptable in the most open stands (minimum of 50 suggested). Generally, a single plot size determined by the most extreme treatment should be used for all plots within an installation.

The preceding discussion applies to relatively uniform even-aged stands of a single species; in many cases cited, to plantations. Mixed species stands and uneven-aged stands will be inherently more variable and will require larger plots-sometimes much larger-to characterize stand structure and growth. (For example, Synnott (1979) recommends 2.47-acre (1 .0-ha) plots for mixed tropical forest.)

Although the above discussion applies directly only to fixed area plots, similar considerations apply to variable radius plots. The basal area factor, number of points, and limiting diameter and radius of the concentric fixed area plot should be chosen to include a sufficient number of trees to provide a reasonably smooth diameter distribution and the ability to distinguish "catastrophic" from "regular" mortality. The decision on arrangement and spacing of points should take into account future growth, so that with increase in tree size the variable radius plots will not overlap each other or adjacent dissimilar treatments or conditions, within the anticipated life of the study.

Plots composed of single trees or small groups of trees have their uses for such purposes as determining presence or absence of response, relation of response to individual tree characteristics, pruning studies. Fully satisfactory and generally accepted techniques for expanding such results to a unit area basis are not now available, however.

RECOMMENDATIONS: Experimental designs that require large numbers of plots within a single homogeneous stand condition-forcing use of small plots because of the limited size of suitable areas-are not generally feasible for silvicultural and yield research and should be avoided.

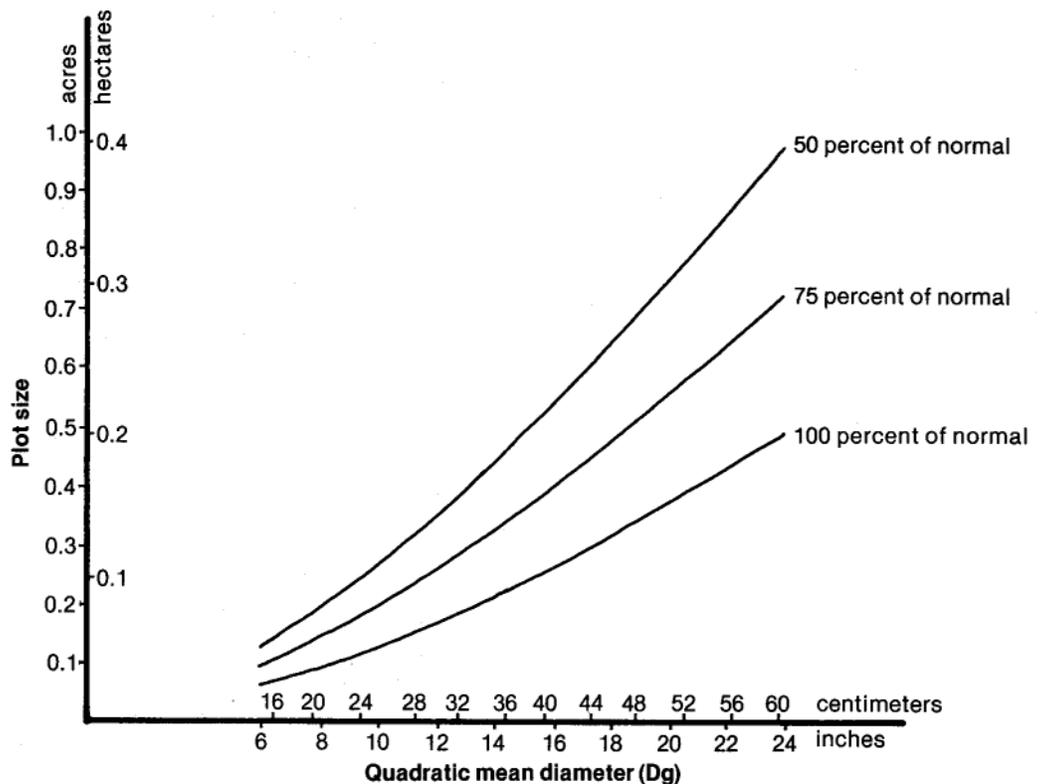


Figure 4.—Plot sizes required to include 50 trees in Douglas-fir stands of given quadratic mean diameter and density expressed as percent of normal. (Percent of normal is here defined as number of trees relative to that in the long-used table 25 in McArdle and others (1961).)

Although no fixed universal standards can be given, required size of plot (or plot cluster) will increase with (1) average tree size and (2) within-stand heterogeneity. Plot size should be selected in relation to the stand conditions expected at the end of the planned period of observation, rather than to initial conditions only. Plot size should be large enough in relation to stem size, number of stems, and pattern of stem distribution that:

- (1) the plot can be regarded as representative of a condition that exists, or could exist, on a stand basis (that is, minor shifts in plot location would not materially alter the plot statistics);
- (2) growth of trees on most of the plot area is little affected by surrounding, possibly unlike, stand conditions;
- (3) sufficient stems are included to provide a reasonably smooth diameter distribution; and
- (4) “catastrophic” mortality can be distinguished from “regular” mortality composed of suppression losses plus occasional death of scattered larger trees.

Plot Buffers

Research plots should be surrounded by a buffer strip of comparable initial conditions, which receives identical treatment. This insures that growth of the plot is not influenced by adjacent, unlike stand conditions and treatments. It also provides for the possibility of future destructive sampling of individual trees for such purposes as determination of past height growth patterns and wood quality studies, without destruction of the plot proper.

Adjacent stand density differences have an effect on microclimate on the plot. It is well known that root systems extend for considerable distances and that root grafting and physiological linkage with nearby trees are common. Root systems of onplot trees will exploit water and nutrients available adjacent to the plot, and vice versa. Therefore, onplot growth is likely to be influenced by adjacent changes in site conditions and stand density. Adjacent fertilizer treatments may affect growth of unfertilized plots through root systems that extend across plot boundaries, through downslope movement of soil water, and through litter fall from fertilized trees onto unfertilized areas.

Failure to provide adequate buffers will tend to produce underestimates of differences in response to treatment. Provision of adequate buffers is most critical on small plots, because small plots have a greater proportion of edge to total area than do large plots.

A frequently quoted rule of thumb is that width of buffer should equal stand height (Fabricius and others 1936, USDA Forest Service 1935). In the tall stands of the Pacific Northwest, however, this rule often gives values that seem unreasonable and impractical in application. Buffer size is sometimes specified as a proportion of plot area, but any single fixed proportion will give unreasonable values when applied to extremes of plot size.

If future destructive sampling of individual trees in the buffer is anticipated, width of the buffer may need to be increased to allow for this and to insure that the sample trees can be considered representative of conditions on the measured plot proper.

An additional isolation strip outside the treated buffer may be needed if there is an adjacent drastically different stand condition (for example, a clearcut), an abrupt site change, or concern over possible movement of fertilizer.

RECOMMENDATIONS: A rule that is probably adequate for most situations, provided adjacent conditions are not drastically different, is that width of the buffer should be at least equal to the expected crown width of dominant trees at the end of the planned period of observation. The Forestry Commission (1979) recommendation of 33 feet (10 m) seems reasonable as a general guide.

Surveying and Marking Plots

Much time is lost relocating inadequately monumented plots. Lost corners and carelessly surveyed plots are frequent sources of error in plot areas and in corresponding values of stand statistics.

The plot center or a plot corner should be referenced to some easily relocatable point along a road or other access route, by compass bearing and measured distances. Other plots in the installation should be referenced to this by bearings and distances, and a careful sketch map prepared adequate for relocation of the plots by someone unfamiliar with them. The map should include approximate location in relation to the public lands survey system.

Plot centers and corners must be marked by stakes of some permanent material, such as metal, or substantial stakes of preservative-treated wood. Stakes should be marked in a way that positively identifies the plot and the particular corner and should be witnessed by appropriate paint blazes or scribe marks on adjacent trees. Declination used should be recorded. Bearings and horizontal distances between corners or centers must be carefully measured and recorded. The sketch map should show all bearings and distances needed to relocate plot centers and corners.

Large plots, elaborate installations, or difficult terrain may warrant use of transit surveys, including computation of error of closure to a preassigned standard. Smaller plots and simpler situations can be adequately handled with staff compass and tape, provided care is used. To insure against blunders, boundaries should be run twice in opposite directions, or error of closure calculated. Errors should not exceed one-half degree in angles and 1:100 in horizontal distances, or 1 percent error of closure.

Plot borders should be marked with paint blazes or signs (except where public attention is undesirable) or standard scribe marks on adjacent trees facing the plot border. In dense stands they should be carefully delimited with string before the trees are initially tagged and measured.

A standard record form should be used and checked to insure that all specified items are recorded.

Plot Protection

There must be an agreement with the organization administratively responsible for the area to protect the installation from disturbance for the planned period of observation. The land manager must be informed of the exact location and nature of research plots. Organizations should have a standard procedure for insuring that managers have an up-to-date record of research installations on their lands, and that these are not disrupted by forest operations without prior consultation and agreement with the research organization.

Common hazards include road construction, thinning operations, and aerial application of fertilizers or herbicides. Any of these can quickly destroy the usefulness of a research installation.

Plot Measurement

All measurements and records on a given installation should be either in metric or in English units. The two should not be mixed. Tapes and instruments graduated in both systems invite errors and should be avoided where possible. In general, metric units are preferable for new installations. Measurement of old installations should continue in English units until the entire system of records is converted to metric.

Record of Initial Conditions

General characteristics and past history of the site and stand, so far as these are known, should be recorded at the time of the initial measurement using a standard procedure and specifications. This includes such items as location (public land survey, map coordinates, political subdivision); ownership; administrative responsibility for the area; elevation; aspect; slope percent; stand origin (natural, planted, seeded, planted with natural fill-in); forest type; age at time of first measurement (even-aged stands); known past treatment or injury; estimated site index (specify system); soils classification and habitat type, when available. Quantitative items such as elevation, aspect, and age should be recorded as numerical values rather than classes, to provide flexibility in later use. For example, the practice of recording aspect as cardinal direction only-instead of azimuth-prevents use of the trigonometric functions in later analyses to describe the location of maximum and minimum growth.

There must be a complete record of stand conditions at the time of plot establishment and immediately before any treatment. All stems removed should be recorded by species and diameter at breast height (d.b.h.) and any treatment should be completely described. If d.b.h. is not directly available for cut trees, it should be estimated from measured stump diameters and stump heights (Alemdag and Honer 1973, Beck and others 1966, Chambers 1978, Curtis and Arney 1977, McClure 1968). When plots are established in stands which have had cutting prior to plot establishment, date of cut should be ascertained and the dimensions of trees removed from the plot should be estimated by stump measurements or otherwise.

Although diameters can be estimated from stump measurements with reasonable accuracy under favorable conditions, the procedure becomes unreliable when trees are small, if stumps are not recent, or if portions of the plot are covered with slash or brush or have been disturbed by logging equipment. Direct measurement before trees are cut is preferable.

Tree Numbering

Each five tree of measurable size within the plot should be assigned a permanent identification number. This is necessary for later separation and summarization of the components of forest growth; namely, survivor growth, mortality, cut, and ingrowth (Beers 1962).

Live trees that are below minimum measurable size at the time of initial plot establishment but appear likely to grow to measurable size later may also be assigned numbers and tagged at the time of establishment, even though d.b.h. is not measured. Though initially time consuming, this insures that numbers will be in sequence-thereby simplifying relocation of trees and handling of record sheets at subsequent measurements. This practice is desirable in plantations and similar situations where the number of such stems is limited and most will later reach measurable size.

As an alternative procedure for insuring that ingrowth trees will be numbered in sequence with adjacent trees, tree numbers assigned at time of plot establishment can be multiples of 10. When an ingrowth tree is later found, it is then assigned the number of the nearest initially numbered tree, plus 1, 2 . . . 9 as the case may be. For example, if a tree was initially assigned the number 1120, numbers 1121 through 1129 are then available for subsequent assignment to nearby ingrowth trees. This system can be used when the number of very small trees makes initial tagging of all trees impractical.

A consistent procedure should be used with "line trees" in determining whether or not to consider them on the plot and tag them. The decision is best based on location of the center of the tree at stump height. Trees exactly on line by this standard can be classified as "in" or "out" according to the direction of lean, if any. Borderline cases can be classified as "in" or "out" alternately or by coin toss. "Out" trees should be identified by paint blaze or standard scribe mark facing the plot, to prevent later confusion.

Depending on stand conditions and stage of development, dead limbs may be pruned to a height of 6 or 7 feet to facilitate numbering and later remeasurements.

At each remeasurement, a search should be made for additional unnumbered trees and new numbers assigned to any found. If this is neglected, impossibly large "ingrowth" trees will later appear in the record. Such impossible "ingrowth" introduces abrupt changes in calculated periodic growth values, and the missing values must then be supplied by borings or by estimating past unmeasured diameters of these trees.

Note that when tagging such new trees in the field, one should not transfer to them numbers previously used on trees that have died or been cut. This practice, though convenient in the field, causes endless confusion. A label maker should be carried and tags made as needed for newly assigned numbers. The number of the nearest previously numbered tree should be noted on the field sheet as an aid to later relocation.

Determination of Breast Height

For consistency in successive d.b.h. measurements on the same tree, all measurements must be made at the same point on the tree bole. The system used *must* include a mark at the b.h. point on all numbered trees. This mark may be a painted band or the location of the tag nail. There are, however, some unresolved inconsistencies in definition of b.h. which require a choice.

In the United States, breast height has been defined both as 4.5 feet above mean ground level (common practice in many past research studies) and as 4.5 feet above ground level on the high side (common inventory practice). The former definition sometimes gives unreasonably low points for large trees on steep slopes; the latter definition gives a point that, for trees on steep slopes, rises as the tree increases in size (Bruce 1980). A further source of uncertainty is that in many cases the standard used in collecting the data used to construct existing volume tables is unknown.

On gentle slopes, the difference between the two procedures is slight.

A second inconsistency arises in the shift from English to metric measurements. Traditionally, b.h. has been defined in the United States as 4.5 feet above ground, however "ground" is defined. Some people in the United States and other English-speaking countries have used the equivalent metric value of 1.37 meters; however, the international standard is 1.3 meters and this will probably eventually become standard in the United States, as it is now in Canada (Bruce 1976, Demaerschalk and Kozak 1982).

RECOMMENDATIONS: When new plots are installed, it is best to establish and mark the b.h. point measured from ground level on the high side, thereby at least partially avoiding the unreasonable heights that sometimes arise from use of average ground level on steep slopes. All subsequent measurements should be made at this same marked point on the tree. In new studies, measured in metric units from the start, b.h. height should be the international standard 1.3 meters.

A consistent procedure should be used for forked trees and trees with abnormal swellings at the b.h. point. Suggested conventions are (fig. 6):

1. If a tree forks above b. h., treat it as a single tree, with the tag and diameter measurement below the swelling caused by the fork but as close to normal b.h. height as feasible.
2. If a tree forks below b.h., treat it as two trees, with the tag and diameter measurement located at (1) 2.0 feet (0.6 m) above fork at the initial measurement or (2) 4.5 feet (1.3 m) above ground, whichever is higher.
3. If the tree has an abnormal swelling at the normal b.h. point, tag and measure it immediately above the irregularity at the point where it ceases to affect stem form.

Determination of Stand Age

Stand age must be determined for all even-aged stands. This is best done at the time of first plot measurement.

Tree ages are normally determined by boring at b.h., by counting rings on stumps, or from known planting dates. Some estimate of intervening years is necessary to convert age to corresponding total age from seed. The record may show age as either total age from seed or age at b.h. but must clearly specify which and should indicate the basis for conversion from actual measurements to the ages given.

A stand age based on borings at b.h. is highly desirable in plantations as well as in natural stands, even though year of planting may be known. Time required to grow to the b.h. point varies with weather, site preparation, brush control, and other factors and is often considerably shorter in plantations than in natural stands. Hence, inconsistencies in method of determining age can introduce apparent differences among stands that have little meaning for long-term development. Use of measured age at b.h. in site estimation and growth relationships avoids at least part of this variation.

Stand age is meaningful only for even-aged stands. It should be defined as average age of dominant or crop trees or of trees selected by some nearly equivalent numerical rule, such as the 40 largest per acre (100/ha). Occasional large residuals, lower crown classes, and trees unlikely to reach rotation age should be excluded. The sample should normally include designated site trees, if any, plus additional trees selected from the stand tally on the basis of dominant or crop tree classification or the 40 largest trees per acre.

The sample should be large enough to determine the mean age of dominant (crop) trees on the plot to a prespecified standard of precision. Staebler (1954) suggests a standard error of the mean of 1.0 year or less, after elimination of obvious outliers.

Individual tree ages used in calculating the plot mean should be retained in the record, with identifying tree numbers. The plot age carried in the record should be the mean calculated to the nearest year, not a broad age class category.

In mixed species stands, sufficient samples of each major species should be taken to determine whether or not age differences exist among species.

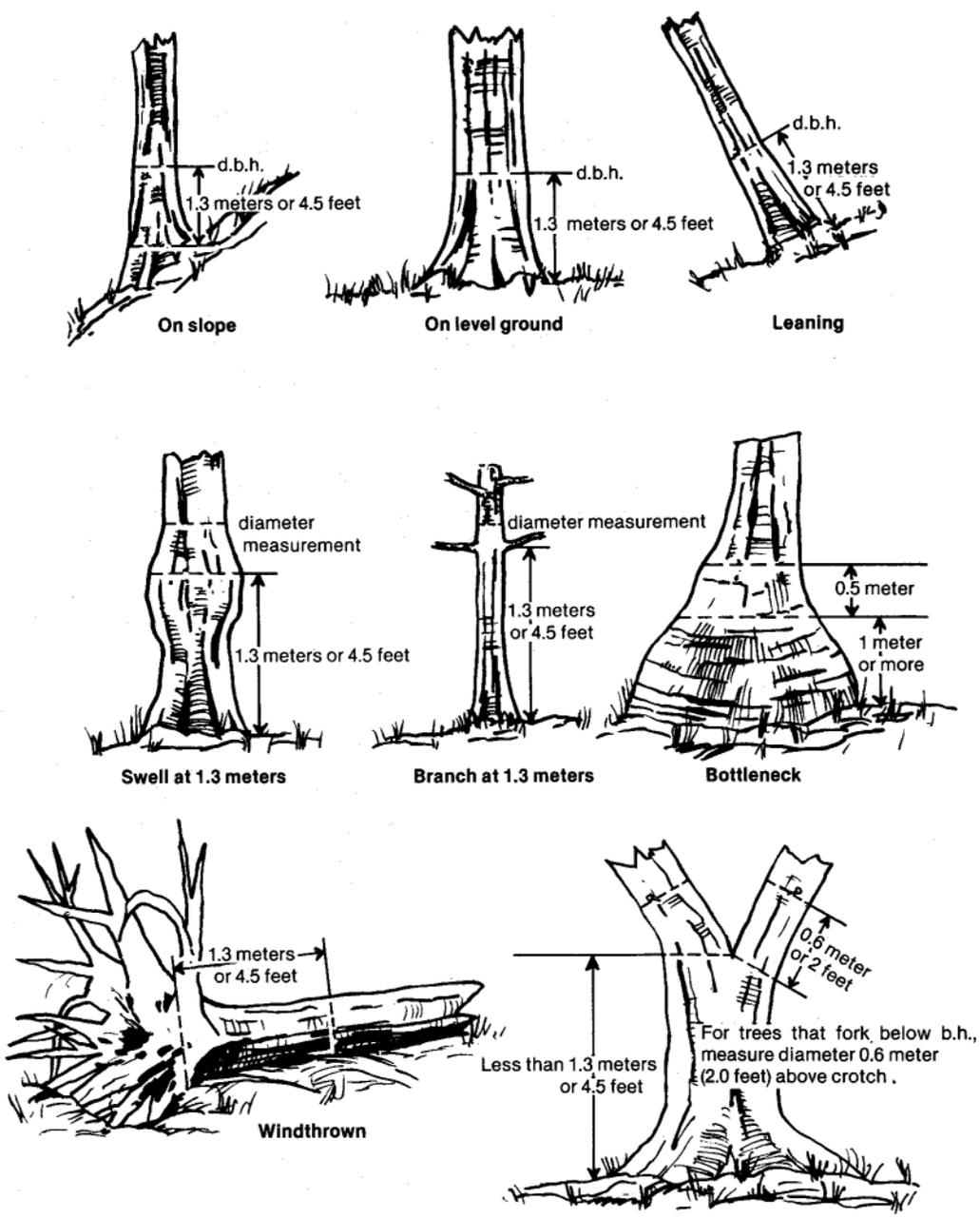


Figure 6.—Measuring diameter at breast height of trees in various situations.

Tree Dimensions

Standard procedure at each scheduled plot measurement must provide for:

1. D.b.h. measurement of all trees above the lower limit of measurement.
2. Classification of measured stems by crown class, tree status, condition, cause of injury or death, in accordance with a standard coding system. This must recognize the categories:
 - a. Survivors.
 - b. Ingrowth.
 - c. Mortality.
 - d. Cut.
 - e. Intentionally killed trees.

Where variable radius plots are used, there will be the additional category "ongrowth". In even-aged stands, understory stems (those clearly of a younger age class than the main stand) should be recognized as a separate crown class.

3. Measurement of heights of a sample of trees sufficient to provide a reliable height-diameter curve and estimates of stand average height, top or dominant height, and site index. (Measurement of heights to live crown is a highly desirable addition.)
4. An estimate of tree form. This is most commonly made indirectly by means of standard volume tables or taper functions based on diameter and height but may be done by direct measurement of a sample of trees.

When plots are remeasured, it is advantageous to use a standard tally sheet (fig. 7) or recording device containing the previous measurements on each tree. New and old measurements should be checked for reasonable agreement, and major discrepancies checked by remeasurement of the tree. This will frequently avoid gross blunders and recording errors, which are easily corrected in the field but which become a major nuisance if not caught until the compilation stage.

The initial measurement is particularly prone to blunders and recording errors, since no check is available. One method of avoiding troublesome errors in the initial measurement is to make two successive measurements at the time of plot establishment, exchanging the measurement and tally roles among the crew. Measurements that do not agree within reasonable limits are repeated and corrected on the spot. The time required for such a second measurement, although considerable, is usually a relatively small fraction of the total time required for initial plot installation and measurement.

Diameter measurements. -D.b.h. of each tagged tree should be measured at the marked b.h. point at each plot remeasurement, normally to the nearest 0.1 inch or 1.0 millimeter. Except in stands with many very small stems, this is best done with a diameter tape.

When a tree that died since the last measurement is encountered, its diameter is recorded, together with a mortality code indicating that it was found dead at this measurement. It will save time in future remeasurements if such trees are blazed and the tag nails driven into the wood so that the tag does not fall off as the bark decays, making the trees easily identifiable as previously recorded mortality.

Location Trout Creek Study # Q31
 Inst # 527 Plot area 0.20 A; _____ Ha
 Plot # 1 Initial year 1969
 Subplot # 0 English X or Metric _____

Date			Measured by	Tallied by
M	D	Y		
<u>9</u>	<u>26</u>	<u>80</u>	<u>Rutherford</u>	<u>Lewington</u>

TREE #	SP	AGE BH	DIAMETER			H	CC	STAT	DAMAGE					HLC	Tree coordinates		NOTES				
			74	76	80				76	80	76	80	Sev		Loc	Sev		Cause	Spec	X	Y
10	205		52	61	77	47	1	1	0							10					
20	205		44	50	66	44	1	1	0								9				
30	205		39	45	59	33	2	2	0								12				
40	205		35	42	60		2	2	0												
50	205		18	21	30		4	3	0	2	3	1	3	8	2						
60	205		24	28	39		3	2	0												
70	205		49	58	75		2	1	0												
80	205		21	26	38		4	3	0												
90	205		47	56	78	44	1	1	0								11				
100	205	11	57	68	99	47	1	1	0								14				
81	205				29		4	3												ingrowth	

Figure 7.—Plot measurement record form.

It has been a common practice in the past to measure only trees above an arbitrary d.b.h. limit, more or less corresponding to some merchantability standard. This was usually done to simplify fieldwork, but it has been the source of numerous difficulties in analysis. Such truncation of diameters distorts the statistics of stand average diameter and number of trees, hampers or prevents fitting of diameter distribution functions, and often makes different data sets completely incompatible. It should be avoided.

In principle, it is desirable to tally all stems taller than b.h.; however, very small stems are difficult to tag and measure and may be numerous. As a practical matter, it is usually necessary to adopt some lower limit of measurement such as 0.5 inch or 1.5 inches or 2.5 centimeters. Higher limits should not be used. Where it is not feasible to measure all trees on the plot above such a limit, a subsampling scheme can be adopted.

When fixed area plots are established in very young stands and are to be observed over an extended time period, a plot size adequate for the initial condition is much too small for the stand condition expected at the end of the observation period. Conversely, a plot size suitable for the final stand condition may initially involve tagging and measuring a prohibitive number of small stems.

A procedure sometimes used in this situation is to tag and measure all stems on subplots within the main plot, but only stems over a specified larger d.b.h. (no larger than absolutely necessary) on the remainder of the plot. The sample of small trees must be large enough to provide stable estimates and must be representative of trees on the main plot area. Since small stems are frequently clumped, several systematically located subplots within the main plot may be preferable to the single concentric plot often used. A common mistake is insufficient sampling of the small stems. Particular care must be taken that the ingrowth over the larger d.b.h. limit is tagged, numbered, and measured at each remeasurement.

Note that increment values for each successive period will be based on a slightly different tree sample (because of ingrowth into the main plot), that this design complicates computation of plot summaries, and that it involves a continuing need to search for and tag numerous new ingrowth stems at each subsequent measurement. Therefore, such subsampling should be used only when absolutely necessary.

When variable radius plot (point) sampling is used, the tree population must be subdivided by a limiting d.b.h., below which trees are recorded on a circular fixed area plot and above which trees are recorded if their diameter subtends an angle larger than the critical angle for the basal area factor selected for the larger trees. Size of the fixed area plot for small trees should match the size of the variable radius plot at the limiting d.b.h. A suitable choice of limiting d.b.h. and associated size of the fixed area plot can reduce the problem of measuring very large numbers of small trees, while including enough such trees to define the diameter distribution.

Height measurements.-Stand height is (with age, number of trees, and average diameter) one of the basic descriptors of a stand. It is essential to most analyses of growth and yield. Heights are necessary for computation of volume and volume increment, for estimation of site index, and for characterization of stand conditions and stand development. Because measurement of heights is time consuming and frequently inaccurate, height sampling and measurement are the weakest points in much existing data.

For species in which the limit of merchantability is generally determined by bole diameter, as in most conifers, only total height need be measured. Merchantable heights, if wanted, are better determined from taper curves. In species where the limit of merchantability is frequently determined by "breakup" of the main stem rather than by diameter (for example, many hardwoods), it may be desirable to measure merchantable height in addition to (but *not* instead of) total height.

In most situations, it is impractical to measure heights of all trees on the plot, and one must resort to subsampling. A suitable sample of trees should be measured for heights when the plot is established and at each remeasurement.⁴ This requires (1) adequate sample size, (2) efficient distribution of the sample, and (3) careful height measurement. Measurement of only a few heights at a given date, insufficient for construction of a height-diameter or volume-diameter curve, serves no useful purpose.

RECOMMENDATIONS:

1. Each plot or cluster of subplots should be sampled independently. Samples generally cannot be combined across plots without biasing analyses.
2. Height sample trees are best drawn initially from the plot tally, rather than selected visually. After the initial sample is drawn, trees with broken tops, pronounced lean (over 10°), severe malformations, or disease should be rejected. Sample trees should be reasonably well distributed across the plot area.
3. The sample should include trees from the full range of diameters present. A common and serious mistake is omission of small d.b.h. classes, which leaves the curve shape undefined; the sample should *not* be confined to only dominants and codominants.
4. Large d.b.h. classes should be sampled more heavily than small d.b.h. classes, since they contribute more to volume, volume growth, and value.
5. When designated site trees are used (discussed on p. 34), these should routinely be included in the height sample, with additional sample trees selected as needed to provide a satisfactory distribution across the range of diameters.

⁴ Given several well-distributed height samples, satisfactory curves for intermediate dates can often be obtained by interpolation or by fitting a system of height-diameter-age curves (Curtis 1967a). This, however, is computationally bothersome, may obscure real differences in growth among periods, and is usually a makeshift solution made necessary by past omissions. It is better to avoid the need.

6. Normally, except where new trees are needed replace trees lost by cutting, mortality, or severe top breakage, the same height sample trees should be used at each successive measurement. This provides better estimates of height increment than independent sampling at each measurement (even though it may perpetuate peculiarities of the initial sample). It may be convenient to mark trees with paint for easy subsequent recognition. Lost trees should be replaced by other trees of similar diameter and crown position. Over long periods or in plots established at an early stage of stand development, it will become necessary to delete some trees and add others to maintain a satisfactory distribution across the range of diameters.

A rule of thumb used at the Forestry Sciences Laboratory in Olympia, Washington, calls for height measurement of at least 15 trees per plot, with two-thirds distributed across the d.b.h. classes larger than average stand d.b.h., and one-third distributed across the smaller d.b.h. classes. This is a *minimum* applicable to relatively small homogeneous plots of a single species with well-established crown differentiation. More trees will be required in large plots and mixed species stands and in young plantations where crown differentiation is only beginning.

Height estimates should be compared with previous measurements before the field crew leaves the plot. If obvious discrepancies are found, the measurement should be repeated to determine whether the present or previous measurement is in error. Where conditions allow, height growth since the previous measurement can also be estimated from internodal distance, as a check in doubtful cases.

If more than one species are present, a decision must be made on sampling the associated species. Options are:

1. If the secondary species represents a minor component of the plot, and particularly if it is not greatly different in characteristics from the primary species, then the simplest course may be to ignore height differences and sample the primary species only-accepting any error in volume computations that arises from use of heights of the primary species in computing volumes for the secondary species.
2. If the secondary species is small in numbers but includes a few large trees with a substantial contribution to plot volume, the best course will be to measure heights of all such trees and use these heights in computation of their volumes.
3. If the secondary species represents a substantial portion of both plot volume and numbers of trees, then a height sample should be drawn and measured the same as for the primary species.

Choice of instruments and procedures for measurement of heights is influenced by expected tree size, terrain, and brush and understory conditions.

In young stands height poles are fast and accurate. Commercially available telescoping poles provide measurements to 30-45 feet in height, depending on the model. Certain sectional poles can be used, with difficulty, for heights up to 50-60 feet or more. Care must be taken that the pole is kept close to the tree and that the pole tip is at the same distance from the observer as the tree bole. The observer should stand as far away as possible.

The most common procedure has been to measure slope distance from observer to the tree with tape, and angles to tip and base of tree with an Abney level or similar instrument graduated in percent slope. Then (1) calculate corresponding horizontal distance using slope correction factors given in table 4 in the appendix (=cosine of angle in degrees), and (2) calculate tree height as:

$$H = (\text{horizontal distance}) (\text{slope percent, tip}) \\ - (\text{horizontal distance}) (\text{slope percent, base});$$

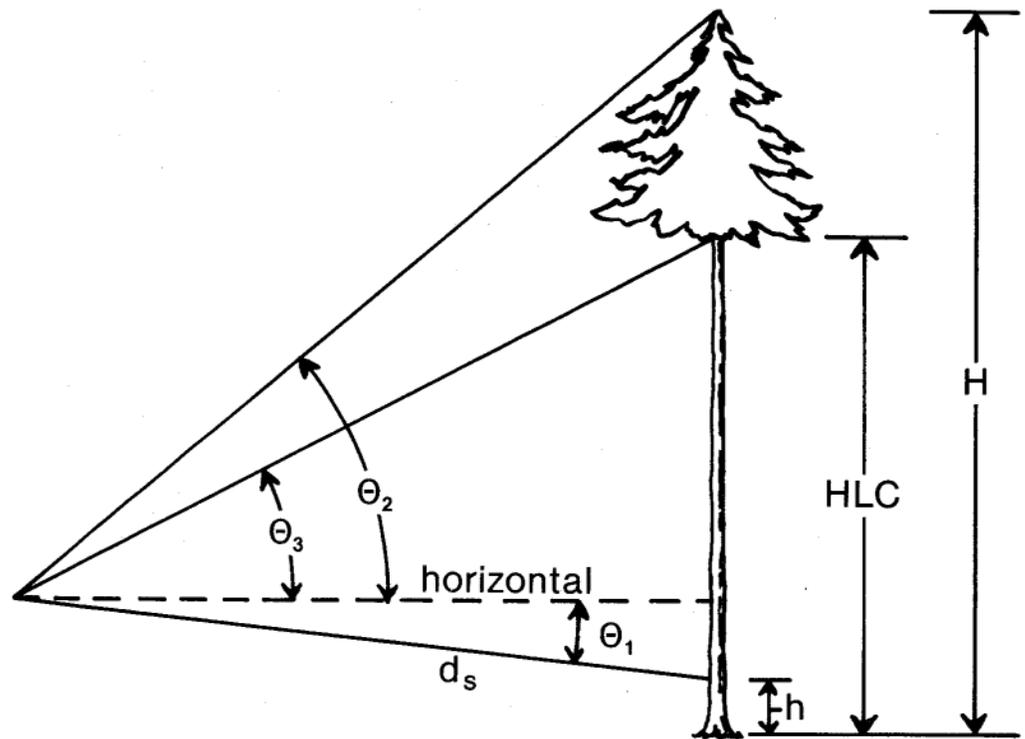
where, slope to base is negative if below horizontal, positive if above.

This procedure is adequate for moderate size trees on moderate slopes, without heavy brush. Special circular slide rules (Haig 1925, Stage 1959) simplify field computation of heights, but these are being replaced by the programable pocket calculator. With such a calculator and a clinometer graduated in degrees, cumbersome tables and calculation of horizontal distance as a separate step can be eliminated, using the procedure shown in figure 8. Angles should be read to the nearest one-fourth degree (or 1 percent).

It is often convenient to adopt a standard procedure of sighting on the b.h. mark rather than the base of the tree (often obscured by brush), and then adding the value of b.h. (4.5 ft or 1.3 m) to the calculated height. A flashlight is useful to provide a sighting point in heavy brush or shade.

On steep terrain or if heavy brush is present, distance measurement by tape becomes laborious and inaccurate, resulting in poor height measurements. Procedures not requiring tape measurement of distance are advantageous.

Several optical rangefinders are on the market. In general, the simpler types lack the precision needed for research work. Some limit the user to a fixed distance, which is impractical in dense stands where trees are often visible from only a few points. The more precise instruments are expensive, and some are cumbersome and difficult to use with poor lighting and visibility.



Formulas (alternate forms):

$$(1) \quad H = d_s * \cos \theta_1 * (\tan \theta_2 - \tan \theta_1) + h;$$

$$(2) \quad H = d_s * \frac{\sin(\theta_2 - \theta_1)}{\sin(90^\circ - \theta_2)} + h;$$

$$(3) \quad d = d_s * \cos \theta_1, \text{ and}$$

$$H = d * \frac{(\text{slope } \theta_2 - \text{slope } \theta_1)}{100} + h;$$

since slope θ in percent = $\tan \theta * 100$.

Figure 8.-Estimation of tree height using clinometer and tape measurement of slope distance.

θ_i is angle in degrees.

H is total tree height.

HLC is height to live crown.

h is height to lower aim point (usually, b.h.).

d_s is slope distance, measured parallel to line of sight from observer to center of tree at lower aim point.

Angles should be measured to nearest one-fourth degree or 1 percent. Formulas for HLC are as shown, but with θ_3 replacing θ_2 .

A useful procedure, requiring only a height pole and a clinometer, which provides satisfactory precision for moderate size trees while eliminating tape measurement of distance, is illustrated in figure 9 (Curtis and Bruce 1968, Bell and Gourley 1980).

Tall trees (over 100 feet or 30 meters) tax the accuracy of the Abney level and similar instruments. Sighting angles over 45° should be avoided. Precision of hand-held instruments can often be improved by resting the instrument hand on a staff as support. This reduces hand tremor and provides a constant instrument height for all angles measured from a given point. It is often advisable to make two height estimates from different positions and average the results, since errors are the combined result of errors in clinometer reading and in measurement of distance, and of any lean in the tree. An alternative procedure, sometimes useful in improving height growth estimates in relatively open stands in which the tree tip is easily visible, is to record bearing and slope distance from tree to observer at the initial measurement and then take subsequent height measurements from the same position.

A tripod-mounted optical instrument such as the Bitterlich Telerelaskop or the British "Enbeenco" clinometer will improve accuracy.⁵ Special studies requiring accurate height values for individual trees require measurement of angles by transit. For tall trees in stands with reasonable visibility at rod height, the transit with stadia measurement of distances may be not only the most accurate method but also relatively rapid.

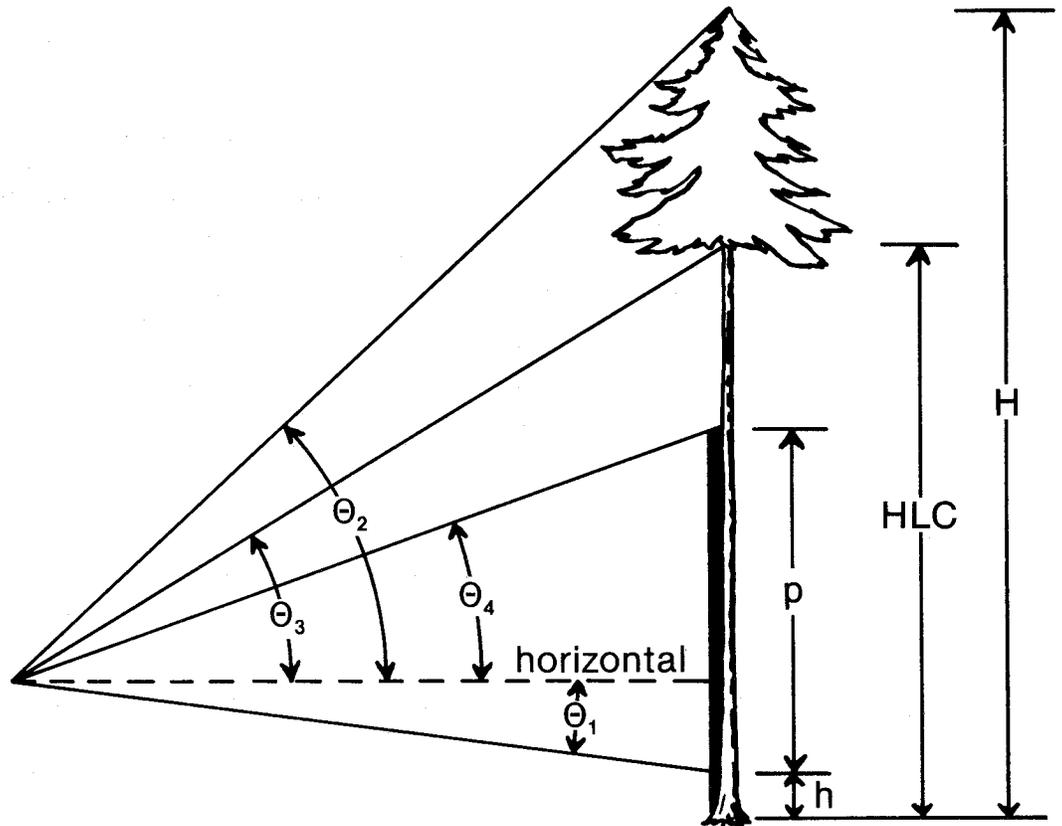
Crown measurements.-Crown dimensions have only rarely been measured in the past. Yet, crown development reflects the past history of trees and stands and is related to competitive status and growth rate and to future growth potential.

Live crown length is the most easily determined crown dimension. It is associated with tree competitive status and potential response to treatment and has been a useful predictor of growth in recent yield research (Hahn and Leary 1979, Holdaway and others 1979, Krumland and Wensel 1980, Stage 1973). In combination with total height, live crown length is equivalent to height to live crown or live crown ratio. These can be obtained by including measurement of height to live crown for the trees in the height sample.

Some care is needed in defining base of live crown for consistency among different installations and measurements made by different individuals. A suggested definition is "lowest whorl with live branches in at least three quadrants, exclusive of epicormic branches and whorls not continuous with the main crown." Irregular and one-sided crowns must be ocularly "adjusted" to estimate the corresponding position of the base of a normally formed crown of the same volume.

Crown widths are also frequently of interest in studies of tree and stand growth and response to treatment.

⁵The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.



Formulas:

$$H = \frac{p * (\tan \theta_2 - \tan \theta_1)}{(\tan \theta_4 - \tan \theta_1)} + h;$$

$$HLC = \frac{p * (\tan \theta_3 - \tan \theta_1)}{(\tan \theta_4 - \tan \theta_1)} + h.$$

Figure 9.-Estimation of tree height by the pole and clinometer method. θ_i is angle, in either degrees or percent.

Since $\tan \theta = 0.01 * \text{slope } \theta$ in percent, and the factor 0.01 cancels, the computational formulas are the same for either unit.

H is total tree height.

HLC is height to base of live crown.

h is height of lower aim point (usually b.h.).

p is length of portion of pole above lower aim point. Length of pole should be at least one-fourth of total tree height, more when feasible.

Care must be taken that base and tip of pole are against the tree bole, or beside the tree at the same distance from the observer as the tree bole.

Measurements should be taken perpendicular to direction of any tree lean.

Under favorable conditions, crown widths can be measured on large-scale aerial photographs. Ground measurements require vertical projection of crown margins and can be made with such simple instruments as the Suunto clinometer, or with any of a variety of instruments constructed especially for the purpose (Montana and Ezcurra 1980, Shepperd 1973).

Ground measurements of crown width are easily obtained for short trees with crowns extending nearly to the ground but become difficult and inaccurate with increasing height to live crown, particularly when crowns are in contact with adjacent trees. Ground measurement of crown widths is considerably more difficult and time consuming than measurement of height to live crown.

RECOMMENDATIONS: Height to live crown should be measured on new research installations and at least some of the more valuable older installations.

Crown width should be measured only on selected installations where there is a clear and specific purpose for such measurements.

Upper-stem diameters and tree form measurements.-There may be need to measure upper stem diameters on a sample of trees for either of two reasons:

1. The form estimate implicit in conventional double-entry volume equations may not adequately account for a change after treatment; hence, estimates may be needed for individual plots or treatments.
2. Information on stem taper and size assortments may be needed as a basis for subdivision of tree and stand volume into size, product, or value classes.

The question of possible effects of stand treatment on standard volume equation and taper function estimates has not been entirely resolved. Direct estimation of individual tree and plot volumes is laborious and expensive. Most researchers have preferred-in the absence of clear evidence that individual plot volume and taper equations are needed-to assume that treatment effects on form beyond those incorporated in standard volume equations can be ignored; hence, that upper stem measurements specifically for this purpose are probably not needed. This is assumption rather than clearly demonstrated fact.

There is generally a need for estimates of volume to different merchantability limits, and by size, product, or value classes. Some information is easily obtainable from the tariff system (Brackett 1973, Turnbull and others 1980); more complete information is given by stem taper curves.

Suitable taper curves are often available from other sources. If not, it may be desirable to include upper stem measurements on a sample of trees to provide the basis for developing such curves and associated assortment tables. Needs for such information and existing sources should be considered as part of the study planning process.

If there is need for upper stem measurements, these can be obtained either by measurement of felled trees on the plot or on the adjacent buffer strip, or by dendrometry. Commercially produced instruments suitable for measuring upper stem diameters in the standing tree include the Barr & Stroud dendrometer, the Wheeler penta prism caliper (Wheeler 1962), the Bitterlich Telerelaskop, and the transit dendrometer (Robinson 1962).

Required measurements are stump height; stump diameter; d.b.h.; diameters outside bark at height intervals of 0.05, 0.10, 0.20... 1.0 fractions of total height (or more or less equivalent absolute height intervals); bark thickness at point of diameter measurement; total height; and merchantable height, in species where this is determined by factors other than diameter. Height to base of live crown is a desirable additional measurement. Detailed procedures and various taper and volume equations are given by Bennett and Swindel (1972), Bitterlich (1981), Bruce (1972), Bruce and others (1968), Cao and others (1980), Demaerschalk and Kozak (1977), Grosenbaugh (1963), Gray (1956), Kozak and others (1969), Martin (1981), Max and Burkhart (1979), and Ormerod (1973).

The time and cost of such data collection and analyses are substantial and should be carefully evaluated in relation to needs before such work is undertaken.

Site Index Estimates

Even-aged stands are commonly classified by site index, the expected height of a specified portion of the stand at a specified reference age, as an index of productivity. Details of definition of the stand component used and the estimation techniques differ among species and regions because of the evolution of techniques over time and the vagaries of different authors. Normally, classification is based on the principal species present, although approximate conversions are possible for species having similar site requirements.

Established procedures often involve subjective choice of site trees on the basis of crown class or other descriptive criteria. Newer procedures define site trees by position within the diameter frequency distribution. Where a procedure is well established, plot measurement procedures should provide for its use. Procedures continue to evolve, however, and a procedure in general use at the start of an experiment is not necessarily that which will be used at its conclusion.

Trees with damage affecting height and height growth should be excluded. Height estimates for the specified stand component may be obtained as values read from the height-diameter curve for the mean diameter of the specified component, or as a mean of measured heights of sample trees drawn from that component. If the latter procedure is followed, guidelines will be needed for the required number of sample trees, based on the variability of site index estimates. In general, the required number will increase as plot size increases and also as the difference between plot age and index age increases, but the number cannot exceed the number of qualifying trees present on the plot and, if necessary, its buffer strip. A site index estimate should not be based on fewer than four trees per plot, and more are desirable when allowed by plot size and component specifications. Site trees should be identified on the plot record and remeasured at successive plot remeasurements as long as they remain qualified site trees. Age of all site trees should be determined by boring at b.h.

Site index estimates will improve as stand age approaches the reference age. Therefore, a new estimate should be made for each measurement date. Actual shape of the height growth curve varies among stands. As young stands develop, later estimates of site index will more accurately represent the growth potential of the site. Site index estimates often change over time, and the record should be updated as this occurs.

RECOMMENDATIONS: In general, it is best to base site index estimates on a stand component defined in terms of the d.b.h. frequency distribution rather than subjective crown classes. The preferred basis is a specified number of the largest diameter stems per unit area (Curtis and others 1974), such as the 40 largest per acre (100 largest per hectare).

Application of any selection rule should include a "well-distributed stems" requirement to insure that the average represents the entire plot area and is not materially influenced by any site gradient across the plot. (For example, on steep slopes the tallest trees are often found along the lower edge of the plot.) One means of insuring this is to divide the plot into subplots or strips parallel to the contour and of approximately equal area, and then apply the site tree selection rule separately within each subplot.

Stem Maps

Consideration should be given to stem mapping selected installations expected to be major sources of long-term growth data. Stem maps can provide:

1. Easy relocation of missing trees and of sample trees drawn from the plot record.
2. Description of spatial distribution of stems.
3. Description of spatial distribution of mortality and injury.
4. Information needed for development of distance-dependent simulation models, which use measures of intertree competition based on individual tree dimensions and distances.

Stem mapping can be done rapidly in stands with moderate numbers of stems, good visibility, and easy terrain. It becomes laborious, expensive, and error prone when there are large numbers of small stems, difficult terrain, or dense brush; it should not be undertaken lightly under such conditions.

One procedure determines coordinates by reference to two tapes stretched at right angles, using right-angle prisms. Other procedures use angles and distances from plot center (best for circular plots) or aerial photography (open stands).

Stem mapping need be done only once on an installation. Once coordinates for each tree are available, actual stem maps for the first or any subsequent measurement can be produced by computer.

Photographs

A sequence of photographs showing stand development over time is useful for both oral presentation of research results and illustration of publications. The need for photographs should be considered and procedures specified at the time a study is established. Usually, a sequence of photographs beginning with the initial plot measurement date should be obtained for at least a sample of plots, sufficient to illustrate the stand conditions and treatments involved.

Photos are most useful when they show the same scene at successive points in time. So far as is feasible with changing stand conditions, photos should be taken in the same direction from the same points at successive dates. Photo points can be identified either by distinctively marked stakes or by distance and bearing from plot corners or plot center. A person or some object of easily recognized dimensions should be included in photos to provide a size scale meaningful to the viewer.

For oral presentations, 35 mm transparencies are most useful, but they are generally unsatisfactory for reproduction; black and white photographs in larger film sizes (for example, 4 by 5 inches) are preferred for publication.

Photos are worthless unless they are carefully and completely identified by study, installation, plot, location, direction, date, photographer, and any special points illustrated. A systematic procedure must be used for identifying and filing photographs to insure that the needed information is recorded; that each photo can be associated with other records for a particular study, installation, and plot; and that negatives and transparencies are protected from damage.

Remeasurement Schedule

A plot remeasurement schedule should be specified and adhered to as closely as possible. A standard planning procedure should be provided to insure that scheduled remeasurements are not missed.

The interval between measurements depends on stand conditions and on the purpose of the installation. In general, measurements at relatively short intervals are needed for rapidly growing stands (young stands, good sites) or where there is major interest in short-term changes in growth in response to treatment. Longer intervals suffice in slower growing stands. Except where there is a specific need for measurements at short intervals to define the shape of a response function, measurements at very short intervals (say, under 3 years) are not generally useful because of the irregularities introduced by year-to-year variations in growth and the measurement errors involved in attempting to measure small changes.⁶ With longer intervals and slower growing stands, limited deviations from the planned measurement schedule *may* be allowable, depending on the nature of the study; but measurements must not be missed or postponed when an associated treatment is applied. A complete stand measurement should be made whenever a thinning, fertilization, or other stand treatment is applied.

Research studies generally use a fixed interval for all plots in a given installation or study. This is usually specified in calendar years but *may* be defined by amount of height growth or other measure of stand development, as a means of allowing for differences from expected growth rates and obtaining closer comparability among installations.

Measurements should be made during the dormant season if possible. Although fractional years arising from measurement during the growing season can be used in analyses, they are a complication and a source of errors, which may be large for short growth periods. Changes in bole moisture content and the attendant shrinkage and swelling have measurable effects on diameters and estimated diameter increments; to a considerable degree, these effects are associated with season and are reduced by dormant season measurement.

Control of Treatments

Thinning.-Type, severity, and frequency of thinning in silvicultural research studies are normally specified in the study plan. Procedures for applying and controlling thinning on the ground to meet these specifications and needs for prethinning information will vary with study objectives and the required degree of control over the thinning operations.

⁶A first remeasurement soon after establishment will, however, serve to correct measurement and recording errors made at the time of establishment.

In precommercial thinning, the objective is generally some specified number of well-spaced best trees, compatible with some target diameter for first commercial thinning. Detailed knowledge of present stand statistics is usually not necessary to apply the initial thinning, although knowledge of initial stand statistics may be needed in later analyses. For subsequent thinnings, knowledge of pretreatment stand statistics and growth may or may not be necessary to carry out the thinning, depending on study objectives and specifications.

In stands that have been previously spaced, the objective may also be to leave a specified number of well-spaced best trees. This can often be achieved without prior knowledge of stand statistics and growth. In some studies, however, knowledge of individual tree growth obtained by measurement may be the primary basis for deciding which trees to remove.

If study specifications call for retention or removal of some specified fraction of growth or growing stock, then the stand must be remeasured and stand statistics calculated before the marking is done, since the approximate volume and size distribution of trees are necessary as a guide to the marking operation.

The close control of residual numbers, size, and spatial distribution of trees needed in many silvicultural studies often requires subdivision of the plot and plot record into subplots or other subdivisions for marking purposes. Where very close control of residual spacing is wanted, the area may be gridded with string or otherwise at the desired spacing and the nearest suitable tree to each grid point designated as a leave tree. More commonly, it will suffice if the required number of reasonably well-spaced best trees is left on each subplot or other subdivision of the plot.

Fertilization.-Although operational forest fertilization is generally done by aerial application, most research studies use carefully controlled hand application. The plot is subdivided with string or paint into relatively small segments or squares, and measured amounts of fertilizer are applied to each subdivision. Although this uniformity of application is not consistent with the variability encountered in operational fertilization, it is necessary if the objective is to relate growth response to fertilizer dosage.

Plots are sometimes installed in operationally fertilized areas for monitoring purposes, in an attempt to estimate the gain in yield from fertilization. For meaningful results, one or both of two procedures must be followed: (1) the fertilizer dosage actually reaching each plot must be estimated by sampling with an adequate number of fertilizer traps on each plot or (2) clustered subplots may be distributed within portions of the treated area which are comparable in other respects, in a manner that insures that the average amount of fertilizer received by the cluster will approximate the nominal area dosage.

The gain in yield from fertilization is estimated by comparing growth on the fertilized plots with that on comparable unfertilized plots, or with some other estimate of expected untreated growth. Because of the relatively large treatment areas necessary with aerial application, it is difficult to provide comparable control plots and adequate replication. This fact, plus the high variability in actual dosage and in stand conditions within operational areas, makes direct quantitative measurement of treatment response difficult, inaccurate, and often impossible; hence the researcher's preference for uniform ground application in fertilizer studies (Bruce 1977).

Timing of Measurements in Relation to Treatment

Main plot.-A complete stand measurement is needed whenever a thinning or fertilization treatment is applied to an installation. For plots that are fertilized only, a single measurement suffices. For plots that are thinned, information is needed for the live stand before thinning and after thinning, for trees cut, and for damage occurring during the thinning operation. Prethinning statistics may or may not be used as a basis for controlling the thinning operation, but they are always needed in analyses to describe the initial conditions. Associated control plots are rarely sufficiently comparable to provide satisfactory information. Postthinning stump measurements, though possible, are often inaccurate and are an undesirable substitute for adequate prethinning measurements.

When possible, the prethinning measurement and the actual thinning should be done during the same dormant season. Diameters of all trees should be measured before thinning. A postthinning check is then made to identify trees cut, destroyed, or damaged during the thinning operation. If there is substantial delay-one or more growing seasons-between initial measurement and the actual thinning, a complete remeasurement of the installation is necessary after thinning; this situation should be avoided.

When thinning is done at the time of plot establishment, alternative procedures may be used, depending on stand conditions and the expected numbers of cut and leave trees:

1. Permanently number all trees at the start. Tag or paint all trees with tree number and a clear identification of the height at which d.b.h. is to be measured. Measure all trees for exact d.b.h. (nearest 0.1 inch or 0.1 cm). Then make a postthinning check to identify trees that were cut, destroyed, or damaged.
2. Temporarily tag all trees. To avoid permanent tagging of trees that are measured only once and then cut, temporary numbered cards can be stapled to the trees. Numbers should be in the sequence in which trees are encountered and positioned so that the top edge of the tag denotes the height at measurement. Measure all trees and make the postthinning check as in (1). Permanently number the leave trees with tags or paint at the time of the postthinning check.
3. Preidentify leave trees. If leave trees can be identified before measurements are made, it may suffice to measure and record other (cut) trees by 1-inch or 2-cm classes only.
 - a. If numbers are assigned to these trees, they can be recorded in the order encountered which provides an indication of spatial position.
 - b. An alternative, sometimes necessary when large numbers of small trees are cut, is a dot tally only of trees to be cut by size classes.

In either (a) or (b), all designated leave trees must be measured to 0.1 inch or 0.1 cm, numbered, and tagged or painted. The postthinning check is made as in (1).

4. Preliminary dot tally to guide treatment.

If pretreatment stand statistics are needed to guide treatment and methods (1) or (2) are not feasible, a dot tally of all trees by size classes may provide all that is needed. Leave trees are then marked, numbered, and measured before thinning. A postthinning check is made as in the other methods. (Numbering and accurate measurement of the leave trees can be deferred until the postthinning check but may be severely hampered by slash, and there is no opportunity to correct errors.)

When thinning is done at the time of plot establishment, it may be desirable to measure heights at the time of the postthinning check, rather than at the prethinning measurement. This avoids one-time height measurements on trees that are then immediately cut, and confines the sample to trees likely to be present at the next measurement. If, however, prethinning heights or volumes are needed as a basis for controlling treatment, heights must be measured before thinning. Substitutes for any trees cut can be remeasured at the postthinning check, which is often not made until the next growing season. In such cases, recorded height should be the height at the end of the previous growing season.

On previously measured plots, trees having prior height measurements should be remeasured at the time of the prethinning measurement. If any of these trees are cut or if additional trees are needed to maintain a desirable distribution of the height sample, the additional trees should be added at the time of the postthinning check. Growth estimates for the subsequent period can then be based on the same sample trees.

Buffer strip.—Although all residual trees on the main plot must be assigned permanent numbers, tagged, and measured at the time of plot establishment, the procedure to be followed with trees on the buffer strip may vary with the nature of the study and the treatments applied.

There is normally no need to tag or measure trees on the buffer strip surrounding an untreated control plot or any plot that is not thinned. There may or may not be need to measure buffer strip trees on plots to be thinned, as a basis for controlling thinning. If needed, a dot tally by diameter classes usually suffices.

Studies of individual tree competition that require information on diameter and location of competing trees may require numbering, measurement, and stem mapping of trees in the buffer strip, in the same manner as on the main plot. This situation arises when very small plots are used for such studies, in which it is not possible to designate a central subplot that is not influenced by trees in the buffer strip.

Data Management

In many instances plot procedures, measurement standards, data recording codes and formats, and computational procedures have been developed more or less independently for each study by the individual or organizational unit concerned. These have been shaped by the investigator's immediate interests, experience, and limitations, and are often inadequately documented.

There is an urgent need to draw together accumulated data from different sources, to develop generally applicable estimates of treatment responses and potential yields. There is also a need to secure new data to supplement those now existing and to extend work to other species little studied as yet. The magnitude and costs of the plot establishment, plot measurement, and data management tasks lead to the conclusion that cooperative efforts involving several organizations are necessary. Cooperation and exchange of data are severely hampered by the general absence of uniform procedures for collecting, coding, recording, and summarizing data.

It is often a major task merely to discover what information exists. Much information is lost in attempting to reconcile inconsistent measurements and coding systems. Individual data sets frequently require their own tailor-made computer programs. Conversion to a common format and codes, essential for analysis by a single set of programs, is costly and prone to error.

Standardization is clearly needed. It is probably impractical to write detailed specifications for nationwide use. Research workers and cooperating organizations concerned with particular species or types of major importance should jointly prepare and adopt specifications for collecting and recording permanent plot data. These should provide for a minimum set of required measurements and information codes and a common basic record format.

The elements involved are:

1. Establishment and maintenance of an index of plot data relevant to specified objectives which can be continuously updated. This would provide specified information on the nature of the installation and treatment and status of existing data.
2. Agreement on and specifications for the basic design standards and measurements to be made on all permanent plots.
3. Adoption of a standard data format and coding system. It is impossible to anticipate the special interests and objectives of individual studies and investigators, and these should therefore be designed so that the user has latitude to subdivide codes or add additional special purpose codes, while retaining certain mandatory lower category codes common to all data in the system and necessary for compatibility with the associated computational package.
4. A package of computer programs designed to operate on data in the standard format and codes. These should include programs for:
 - a. Maintaining and updating index information describing plot status.
 - b. Editing and correcting plot and tree data.
 - c. Updating plot and tree records.
 - d. Calculating standard summaries of plot and tree data.

Portions of such systems already exist in some organizations, although most either are not publicly available or are incomplete or inadequately documented.

Western Forestry and Conservation Association (1977) gave a list of recommended items to be included in plot records. Arney and Curtis (1977) gave specifications for a plot index system and a detailed tree record format and coding system used in a large regional yield study in Douglas-fir. These codes and formats are being revised at the Forestry Sciences Laboratory, Olympia, Washington, and an associated package of computer programs is in preparation.⁷

This system is now in trial use in one large study in coastal Douglas-fir in Oregon and another in the hemlock-spruce type in Alaska. In its present form, the system is applicable only to fixed-area plots. Current expectations are that the specifications, programs, and documentation will be available by 1984.

Some examples of codes and types of information are given in "PDMS Tree Classification Codes" in the appendix. These are subject to change, and there is no implication intended that others should adopt these as given. They do, however, illustrate the types of information that must be provided in such a system.

⁷ Curtis, Robert O.; Clendenen, Gary W. Plot data management system (PDMS). Study plan on file at the Forestry Sciences Laboratory, Olympia, Washington. 1981.

Literature Cited

- Alemdag, I. S.; Honer, T. G. Relationships between breast-height and stump diameters for eleven tree species from eastern and central Canada. Inf. Rep. FMR-X-49. Ottawa, ON: Forest Management Institute, Canadian Forestry Service, Department of the Environment; 1973. 14 p. plus tables.
- Arney, James D.; Curtis, Robert O. Code legend for standardized permanent plot records. In: Reimer, D. R., chairman. Standards of measure and data sharing: report of the Committee of Standards of Measure and Data Sharing (COSMADS). Portland, OR: Western Forestry and Conservation Association; 1977. 18 p.
- Beck, James A., Jr.; Teegarden, Dennis E.; Hall, Dale O. Stump diameter-d.b.h. relationships for young-growth mixed conifer species. Calif. For. and For. Prod. 44. Berkeley, CA: University of California, School of Forestry; 1966. 6 p.
- Beers, Thomas W. Components of forest growth. J. For. 60(4): 245-248; 1962.
- Bell, John F.; Gourley, Robert. Assessing the accuracy of a sectional pole, Haga altimeter, and alti-level for determining total height of young coniferous stands. South. J. Appl. For. 4(3):136-138; 1980.
- Bennett, F. A.; Swindel, B. F. Taper curves for planted slash pine. Res. Note SE-179. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1972. 4 p.
- Bitterlich, Walter. Telerelaskop techniques. In: Proceedings 17th world congress of the International Union of Forestry Research Organizations, Div. 4; [Date of meeting unknown]; Japan. [Place of publication unknown]; [Publisher name unknown]; 1981: 155-162.
- Brackett, Michael. Notes on tariff tree volume computation. Resour. Manage. Rep. 24. Olympia, WA: State of Washington, Department of Natural Resources; 1973. 26 p.
- Bruce, David. Metrication-what's next? J. For. 74(11): 737-738; 1976.
- Bruce, David. Yield differences between research plots and managed forests. J. For. 75(1): 14-17; 1977.
- Bruce, David. Where is the ground? In: Growth of single trees and development of stands: Proceedings, joint meeting of working parties S4.01-02 and S4.02-03, International Union of Forestry Research Organizations; 1979 September 14-15; Vienna. [Place of publication unknown]; [Publisher name unknown]; 1980: 49-50.
- Bruce, David; Curtis, Robert O.; Vancoevering, Caryanne. Development of a system of taper and volume tables for red alder. For. Sci. 14(3): 339-350; 1968.
- Bruce, Donald. A method of preparing timber-yield tables. J. Agric. Res. 32(6): 543-557; 1926.
- Bruce, Donald. Some transformations of the Behre equation of tree form. For. Sci. 18(2): 164-166; 1972.
- Cao, Quang V.; Burkhart, Harold E.; Max, Timothy A. Evaluation of two methods for cubic-volume prediction of loblolly pine to any merchantable limit. For. Sci. 26(1): 71-80; 1980.

- Carbonnier, Charles; Fries, Joran. Permanent plots in Swedish growth and yield research. In: Fries, J., ed. Permanent plots in forestry growth and yield research. Subject Group S4.01. Research Notes 43. Stockholm: International Union of Forestry Research Organizations, Royal College of Forestry, Department of Forest Yield Research; 1976: 50-56.
- Chambers, Charles J., Jr. Predicting dbh from stump dib and stump height for second growth Douglas-fir. DNR Note 25. Olympia, WA: State of Washington, Department of Natural Resources; 1978. 2 p.
- Clutter, Jerome L.; Jones, Earle P., Jr. Prediction of growth afterthinning in old-field slash pine plantations. Res. Pap. SE-217. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1980. 14 p.
- Curtis, Robert O. Height-diameter and height-diameter-age equations for second-growth Douglas-fir. *For. Sci.* 13(4): 365-375; 1967a.
- Curtis, Robert O. A method of estimation of gross yield of Douglas-fir. *For. Sci. Monogr.* 13; 1967b. 24 p.
- Curtis, Robert O.; Arney, James D. Estimating d.b.h. from stump diameters in second-growth Douglas-fir. Res. Note PNW-297. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1977. 7 p.
- Curtis, Robert O.; Bruce, David. Tree heights without a tape. *J. For.* 66(1): 60-61; 1968.
- Curtis, Robert O.; Clendenen, Gary W.; DeMars, Donald J. A new stand simulator for coast Douglas-fir: DFSIM user's guide. Gen. Tech. Rep. PNW-128. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1981. 79 p.
- Curtis, Robert O.; DeMars, Donald J.; Herman, Francis R. Which dependent variable in site index-height-age regressions? *For. Sci.* 20(1): 74-87; 1974.
- Decourt, N. Protocole d'installation et de mesure des placettes de production semi-permanentes: Procedures for installation and measurement of semi-permanent yield plots. [Place of publication unknown], France: Centre National de Recherches Forestieres (INRA); 1973. 25 p.
- Demaerschalk, J. P.; Kozak, A. The whole-bole system: a conditioned dual-equation system for precise prediction of tree profiles. *Can. J. For. Res.* 7(4): 488-497; 1977.
- Demaerschalk, Julien P.; Kozak, Antal. Dbh measurements and conversions in the metric system. *For. Chron.* 58(4): 173-175; 1982.
- Fabricius, L.; Oudin, A.; Guillebaud, W. H. Outlines for permanent sample plot investigations. [Place of publication unknown]: International Union of Forest Research Organizations; 1936. 33 p.
- Forestry Commission. Sample plot code. London: (British) Forestry Commission; 1979. Unpaged.
- Gray, H. R. The form and taper of forest-tree stems. Inst. Pap. 32. Oxford: Oxford University, Imperial Forestry Institute; 1956. 79 p.

- Grosenbaugh, L. R. Optical dendrometers for out-of-reach diameters; a conspectus and some new theory. *For. Sci. Monogr.* 4;1963. 47 p.
- Hahn, Jerold H.; Leary, Rolfe A. Potential diameter growth functions. In: A generalized forest growth projection system applied to the Lake States region. Gen. Tech. Rep. NC-49. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1979: 22-26.
- Haig, I. T. Short cuts in measuring tree heights. *J. For.* 23(11): 941-944; 1925.
- Hamilton, G. J. Permanent sample plots in Britain. In: Fries, J., ed. Permanent plots in forestry growth and yield research. Subject Group S4.01. Research Notes 43. Stockholm: International Union of Forestry Research Organizations, Royal College of Forestry, Department of Forest Yield Research; 1976: 75-81.
- Hegyí, F. Optimum plot dimensions for experimental designs in jack pine stands. Sault Ste. Marie, ON: Canadian Forestry Service, Department of the Environment, Great Lakes Forest Research Centre; 1973. 13 p.
- Holdaway, Margaret R.; Leary, Rolfe A.; Thompson, Jerrilyn LaVarre. Estimating mean stand crown ratio from stand variables. In: A generalized forest growth projection system applied to the Lake States region. Gen. Tech. Rep. NC-49. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1979: 27-30.
- Hummel, F. C.; Locke, G. M. L.; Jeffers, J. N. R.; Christie, J. M. Code of sample plot procedure. *For. Comm. (G. B.) Bull.* 31; 1959. 113 p.
- Jaakola, Sipi. On the use of variable size plots for increment research. In: Proceedings 14th world congress of the International Union of Forestry Research Organizations. Div. 6, Sect. 25; [Date of meeting unknown]. [Place of publication unknown]; [Publisher name unknown]; 1967: 370-378.
- Jeffers, J. N. R. Experimental design and analysis in forestry research. [Place of publication unknown]; International Union of Forest Research Organizations; 1959. 172 p.
- Keen, F. P. Climatic cycles in eastern Oregon as indicated by tree rings. *Mon. Weather Rev.* 65(5): 175-188; 1937.
- Kozak, A.; Munro, D. D.; Smith, J. H. G. Taper functions and their application in forest inventory. *For. Chron.* 45(4): 458-463; 1969.
- Krumland, Bruce; Wensel, Lee C. Concepts, design, and uses of coastal growth models. Res. Note 14. Berkeley, CA: University of California, College of Natural Resources; 1980. 7 p.
- McArdle, R. E.; Meyer, W. H.; Bruce, D. The yield of Douglas-fir in the Pacific Northwest. *Tech. Bull.* 201 (rev.). Washington, DC: U.S. Department of Agriculture; 1961. 24 p.
- McClure, Joe P. Predicting tree d.b.h. from stump measurements in the Southeast. Res. Note SE-99. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1968. 4 p.
- McEwen, A. D. Yield research plots of the Forest Research Institute. In: D. A. Elliot, ed. Mensuration for management planning of exotic forest plantations. Symp. 20. Rotorua, New Zealand: New Zealand Forest Service, Forest Research Institute; 1979: 253-301.

- Marckworth, Gordon D.; McKay, Donald; Gross, W. C. Report No. VIII. Techniques for establishing permanent growth plots in the Douglas-fir region. In: Reports of the West Coast Forestry Procedures Committee on Various Recommended Forest Practices and Techniques. Portland, OR: Western Forestry and Conservation Association; 1950: 59-67.
- Martin, A. Jeff. Taper and volume equations for selected Appalachian hardwood species. Res. Pap. NE-490. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1981. 22 p.
- Martin, George L. A method for estimating ingrowth on permanent horizontal sample points. *For. Sci.* 28(1): 110-114; 1982.
- Max, T. A.; Burkhart, H. E. Segmented polynomial regression applied to taper equations. *For. Sci.* 22(3): 283-289; 1979.
- Montana, Carlos; Ezcurra, Exequiel. Simple instrument for quick measurement of crown projections. *J. For.* 78(11): 699; 1980.
- Myers, C. C.; Beers, T. W. Point sampling for forest growth estimation. *J. For.* 66(12): 927-929; 1968.
- Myers, Clifford A. Yield tables for managed stands with special reference to the Black Hills. Res. Pap. RM-21. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1966. 20 p.
- Myers, Clifford A. Field and computer procedures for managed-stand yield tables. Res. Pap. RM-79. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1971. 24 p.
- Ormerod, D. W. A simple bole model. *For. Chron.* 49(2): 136-138; 1973.
- Osborne, James G.; Schumacher, Francis X. The construction of normal-yield and stand tables for even-aged timber stands. *J. Agric. Res.* 51(6): 547-564; 1935.
- Reukema, Donald L. Some effects of freeze injury on development of Douglas-fir. *Northwest Sci.* 38(1): 14-17; 1964.
- Robertson, W. M.; Mulloy, G. A. Sample plot manual. Misc. Ser. 4. Ottawa, ON: Dominion Forest Service, Canadian Department of Mines and Resources; 1944. 60 p. plus tables.
- Robertson, W. M.; Mulloy, G. A. Sample plot methods. Ottawa, ON: Dominion Forest Service, Canada Department of Mines and Resources, Ottawa; 1946. 69 p.
- Robinson, D.W. A special forestry transit. *J. For.* 60(3): 202-204; 1962.
- Shepperd, Wayne D. An instrument for measuring tree crown width. Res. Note RM-229. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1973. 3 p.
- Smith, J. Harry G. Use of small plots can overestimate upper limits to basal area and biomass. *Can. J. For. Res.* 5(3): 503-505; 1975.
- Staebler, George R. Standard computations for permanent sample plots. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1954. 14 p.

- Stage, Albert R. A cruising computer for variable plots, tree heights, and slope corrections. *J. For.* 57(11): 835-836; 1959.
- Stage, Albert R. Prognosis model for stand development. Res. Pap. INT-137. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1973. 32 p.
- Synnott, T. J. A manual of permanent plot procedures for tropical rain forests. Trop. For. Pap. 14. Oxford: University of Oxford, Commonwealth Forestry Institute; 1979. 67 p.
- Turnbull, K. J.; Little, Gene Roy; Hoyer, Gerald E. Comprehensive tree-volume tariff tables. 3d ed. Olympia, WA: State of Washington, Department of Natural Resources; 1980. 13 p. plus tables. 3d edition written by Charles J. Chambers and Bruce W. Foltz; edited by Julie A. McLaughlin.
- U.S. Department of Agriculture, Forest Service. Sample plots in silvicultural research. Circ. 333. Washington, DC; 1935. 88 p.
- Vuokila, Yrjo. Functions for variable density yield tables of pine based on temporary sample plots. Helsinki: Communicationes Instituti Forestalis Fenniae 60.4; 1965. 86 p.
- Western Forestry and Conservation Association. A set of recommended parameters and measurement instructions for field records of permanent growth plots. In: Reimer, D. R., chairman. Standards of measure and data sharing: report of the Committee of Standards of Measure and Data Sharing (COSMADS). Portland, OR: Western Forestry and Conservation Association; 1977. 7 p.
- Wheeler, P. R. Penta prism caliper for upper-stem diameter measurements. *J. For.* 60(12): 877-878; 1962.

Appendix

Checklist of Needed Plot and Tree Measurement Information

The following list is taken from the current version of the Plot Data Management System (PDMS). This is still under development and is subject to change; readers may not wish to follow the details. It does, however, indicate items that should be recorded in some comparable manner.

Header (index) information.-

Installation number
Plot number
Status: active, abandoned, destroyed
Plot age b.h., at first measurement
Site index
Site index system used
Plot area
Plot shape
Stem mapped: yes or no
Stand origin: natural, planted, seeded (if known, note spacing, seed source, etc., under general comments)
Primary species
Secondary species
Location: forty, section, township, range, State
Elevation
Aspect, azimuth (N=360)
Slope percent
Slope position
Local name of installation
Measurement units: English vs. metric
Organization responsible
Project identification

Date of first measurement: month, day, year



Date of last measurement: month, day, year

Date of first thinning, if any: month, day, year



Date of last thinning, if any: month, day, year

Date of first fertilization, of any: month, day, year



Date of last fertilization, if any: month, day, year

Fertilization treatments: (enter successively for repeated treatments)

Method of fertilizer application (hand, fixed wing, helicopter)

Nutrient element, application rate per unit area

Physical soil description (if available)

Analytical soil characteristics (if available)

Area environmental characteristics (if available)

General comments: (Provides for descriptive notations on any special characteristics of the area, plot, or treatment history not adequately described by the above)

Individual tree records.-

- Installation number
- Plot number
- Tree number
- Species Age b.h. as of first plot measurement (sample trees only)
- Stem map coordinates (stem-mapped plots only)
- Number of measurements on plot
- Tree measurement information to be recorded for each successive measurement:

- D.b.h.
- Height (height sample trees only)
- Height to live crown (height sample trees only, optional)
- Crown class code
- Tree status code
- Tree damage, location (optional)
- Tree damage, cause, general (optional)
- Tree damage, cause, specific (optional)



See "PDMS Tree Classification Codes," page 48, for code definitions as used in the 1982 version of PDMS.

Standard USDA Forest Service Species Codes for Western Species¹

1 Unclassified Softwoods	93 Engel mann Spruce	201 Big cone Douglas-fir	542 Oregon Ash
4 Unclassified Hardwoods	94 White Spruce	202 Inland Douglas-fir	631 Tan Oak
11 Pacific Silver Fir	95 Black Spruce	204 Eastslope Rocky Mtn Douglas-fir	740 Cottonwood Species
15 White Fir	96 Blue Spruce	205 Coastal Douglas-fir	741 Balsam Poplar
17 Grand Fir	98 Sitka Spruce	211 Coast Redwood	746 Quaking Aspen
18 Corkbark Fir	101 Whitebark Pine	212 Giant Sequoia	747 Black Cottonwood
19 Subalpine Fir	102 Bristlecone Pine	231 Pacific Yew	760 Cherry Species
20 California Red Fir	103 Knobcone Pine	242 Western Red Cedar	800 Oak Species
21 Shasta Red Fir	104 Foxtail Pine	251 California Torreya	803 Arizona White Oak
22 Noble Fir	106 Pinyon Pine	263 Western Hemlock	805 Canyon Live Oak
41 Port-Orford Cedar	108 Lodgepole Pine	264 Mountain Hemlock	807 Blue Oak
42 Alaska Yellow Cedar	109 Coulter Pine	310 Maple Species	810 Emory Oak
51 Arizona Cypress	112 Apache Pine	312 Big Leaf Maple	814 Gambel Oak
60 Juniper Species	113 Limber Pine	313 Box Elder	815 Oregon White Oak
62 California Juniper	114 Mexican White Pine	350 Alder Species	818 California Black Oak
63 Alligator Juniper	116 Jeff rey Pine	351 Red Alder	821 California White Oak
64 Western Juniper	117 Sugar Pine	361 Pacific Madrona	829 Mexican Blue Oak
65 Utah Juniper	118 Chihuahua Pine	376 W. Paper Birch	839 Interior Live Oak
66 Rocky Mtn Juniper	119 Western White Pine	377 Alaska Paper Birch	920 Willow Species
71 Tamarack	120 Bishop Pine	378 NW Paper Birch	981 Oregon Myrtle
72 Subalpine Larch	122 Ponderosa Pine	431 Golden Chinkapin	999 Noncommercial Species Not Coded in other Specific Codes
73 Western Larch	124 Monterey Pine	492 Pacific Dogwood	Such as Vine Maple, Cascara, Etc.
81 Incense Cedar	127 Digger Pine	540 Ash Species	

¹ Quoted from Forest Survey Handbook. Forest Service Handbook SH 4813.1. March 1967.

PDMS Tree Classification Codes

The following system of tree classification codes is that used in the 1982 version of the PDMS system.

Note that although the system provides for six digits of information, including very detailed information on tree condition and cause of damage, only the first two digits are necessary for operation of summary programs and are mandatory for all tree measurements.

This system may not meet all needs, but it does illustrate characteristics needed in any system. It is sufficiently general that with minor modifications it should meet most needs.

For all classifications, programs will assign code "0" if no other entry is present.

1. Crown class
 - 0 No estimate
 - 1 Dominant
 - 2 Codominant
 - 3 Intermediate
 - 4 Suppressed
 - 5 Understory
 - 6 Overstory
 - 7 Off-plot tree

Codes 5, 6, and 7 are necessary for operation of PDMS and **must** be entered when applicable. Code 7 has priority over all other crown class designations (that is, if both 7 and another code apply, record 7). Code 5 is a tree in an even-aged stand which is clearly of a younger age class than the main canopy. Code 6 is a tree in an even-aged stand that is recognized as substantially older than the average age of the main canopy. Code 7 is a site tree or buffer strip tree located off the plot proper; these trees may be measured for site estimates or included in stem maps but are excluded from plot summaries.

2. Tree status
 - 0 Live
 - 1 Live cut
 - 2 Dead
 - 3 Ingrowth
 - 4 New tree (that is, a tree missed in previous measurement)
 - 5 Dead cut, salvable

- 6 Live tree with measured height, not suitable for height-diameter curves or site estimates
- 7 Both site and crop tree
- 8 Site tree
- 9 Crop tree

Codes 1 through 6 are essential to PDMS and **must** be entered when applicable. Codes 7, 8, and 9 are not essential to the system but should be recorded when applicable and override code 0. Codes 1 through 6 have priority over codes 7, 8, and 9. (Dead or cut trees are identified as site or crop trees by a summary program check on classification at the previous measurement.) Codes 7, 8, and 9 are treated as code 0 by PDMS in summary computations. Programs will treat a code 5 tree as code 2 and include it in mortality if the tree was alive at the immediately preceding measurement; if coded 2 at the immediately preceding measurement, the tree will be excluded from mortality totals for the current measurement.

3. Location and nature of damage or cause of death (code only the most serious damage)
 - 0 No damage or no information
 - 1 Damage present, location and nature unspecified
 - 2 Tip
 - 3 Foliage
 - 4 Limbs
 - 5 Bole, other than 2 or 6
 - 6 Basal
 - 7 Roots
 - 8 Leaning or bent tree
 - 9 Down tree

These codes and those for severity and cause of damage (classifications 4, 5, and 6 below) are not essential to operation of standard PDMS programs. It is desirable to include the classifications for location and severity (3 and 4) at least for the conditions that render a tree unsuitable for use as a height-diameter sample or as a site tree. Otherwise, one may use all, some, or none of those codes as desired.

4. Severity of damage
 0 Unspecified
 1 Minor
 2 Moderate
 3 Severe

Where more than one type or location, of damage is present, rate "severity" as the combined effect of all damage-minor if damage is noticeable but judged unlikely to have a significant long-term effect; moderate if the tree is judged likely to survive but with substantially reduced growth rate or value; severe if the tree is judged likely to die or become unmerchantable.

5. Cause and nature of damage-general
 0 Unknown or unspecified
 1 Human activities

6. Cause and nature of damage-specific
 0 Unknown or unspecified
 0 Unknown or unspecified
 1 Logging
 2 Foliage sprays
 3 Bole treatments
 4 Root and soil treatments
 5 Pruning²
 6-9 User defined

- 2 Crown diseases and abnormalities

- 0 Unknown or unspecified
 1 Unhealthy appearance
 2 Foliage diseases
 3 Mistletoe
 4-9 User defined

- 3 Bole diseases and abnormalities

- 0 Unknown or unspecified
 1 Bole rots
 2 Multiple stems and forks
 3 Stem cankers and mistletoe
 4 Sweep and crook
 5 Dead or broken top
 6 Epicormic branching
 7 Fluting
 8-9 User defined

- 4 Root diseases

- 5 Insects

- 6 Mammals and birds

- 7 Fire

- 8 Weather

- 9 Miscellaneous

- 0 Unknown or unspecified
 1-9 User defined
 0 Unknown or unspecified
 1 Defoliators
 2 Bark beetles
 3 Sucking insects
 4-9 User defined
 0 Unknown or unspecified
 1 Deer, elk
 2 Bear
 3 Livestock
 4 Porcupine
 5 Mountain beaver
 6 Other small mamr
 7 Birds
 8-9 User defined
 0 Unspecified
 1-9 User defined
 0 Unspecified
 1 Wind
 2 Snow, ice
 3 Freeze
 4 Drought
 5-9 User defined
 0 Unspecified
 1-9 User defined

² Note: Code 5 is recorded at initial measurement of any pruned tree. If subsequently coded as damaged by other causes, it is still identifiable by a summary program check for code 5 at previous measurements.

Field Tree Measurement Forms and Height Measurement Procedures

Plot measurement record form.-A standard form, which can also serve as a data entry document, should be used for field measurements. For remeasurements, the information needed for tree identification plus previous measurement values needed to provide a check against measurement errors must be entered before fieldwork.

Several organizations are now using computer-produced forms for this information.

Figure 7 is based on one of these forms, modified to conform to the standards and coding system used in the 1982 version of PDMS. (Although this particular variation has not yet been implemented at the Forestry Sciences Laboratory at Olympia, an earlier version has been in use for several years.)

The successive fields represent:

TREE #: tree identification number, preprinted for all trees recorded at the previous measurement. Final digit is "0" for trees present at initial measurement (can be left blank on field form, if preferred); subsequent ingrowth trees are assigned a number determined as that of the nearest initial tree + a nonzero integer from 1 to 9.

SP: tree species, coded by standard USDA Forest Service three-digit species code (see p. 47). Preprinted.

AGE BH: tree age at breast height, as of the year of plot establishment. Preprinted if determined at the date of a previous measurement.

DIAMETER:

"74"- previous measurement, 1974 in this case. 1974 diameters preprinted on forms.

"76"- previous measurement, 1976 in this case. Preprinted. Blank columns: used for entry of new field measurements of d.b.h. as illustrated. Enter measurements to 0.1 unit (inches or centimeters). Enter year of measurement in column heading.

H: total height of height sample trees. When heights are determined by one of the clinometer methods, this value is transcribed from the height measurement field sheet (fig. 10), after completion of field measurement and before data are entered into the computer system. If heights are measured with a height pole, heights are entered directly on this form. Last column to be used only if height is measured to nearest 0.1 unit.

CC: crown class.

"76"- value recorded at previous measurement, 1976 in this case. Preprinted. Blank column-used for entry of new field measurement, as shown.

STAT: tree status (see tree classification codes, p. 48).

"76"- status code from previous measurement, 1976 in this case. Blank column-used for entry of new field measurement as illustrated. Enter year in heading.

DAMAGE: Damage classification codes (see p. 48-49).

"76" -severity code from previous measurement, 1976 in this case. Preprinted. Blank columns-used for entry of new field observations. "Loc" = location; "Sev" = severity; "Cause" = cause, general; "Spec" = cause, specific.

HLC: height to base of live crown. When determined by one of the clinometer methods, this value is transcribed from the height measurement field sheet (fig. 10), after field measurements are completed and before data are entered into the computer system. It can be entered directly when measured with a height pole.

Last column to be used only if measured to 0.1 unit.

Tree coordinates: X and Y coordinates of tree. Preprinted if plot has previously been stem mapped. Left blank and available for "Notes" if plot is not stem mapped.

NOTES: Blank space for any miscellaneous information not covered by specified items, or for reference to explanatory notes elsewhere, if any.

Height measurement form and measurement procedures.-Sample tree height measurements are normally obtained as a separate operation after measurement of diameters of all trees on the plot. The diameter record is used as the basis for selecting or modifying the sample of trees to be measured for heights.

A form for recording height measurements in the field is given in figure 10. The form is designed for use of either of two common height measurement procedures described in figures 8 and 9. (If heights are measured with a height pole, values are entered directly on the plot measurement form (fig. 7).)

Numbered columns on the form (fig. 10) represent the following:

1. Tree identification number for each tree in the height sample.
2. D.b.h. of each tree.
3. Recorded height (H) at last measurement, if any.
4. Recorded height to live crown (HLC) at last measurement, if any. (Note: 1, 2, 3, and 4 may be either preprinted on the form or transcribed from a computer-generated list of trees measured for heights at the last measurement. This initial list must then be modified by any deletions and additions needed to obtain a satisfactory height sample for the current measurement.)
5. Slope distance from instrument to tree.
6. Angle to tip of tree.
7. Blank column, provided to allow for measurements to some other point, if wanted; for example, if height of the nth node from tip is wanted to provide an estimate of height growth in the last n years.
8. Angle to base of live crown.
9. Angle to tip of measurement pole (when using pole and clinometer method).
10. Length of portion of pole used in item 9.
11. Angle to lower aim point.
12. Height of lower aim point above ground.
13. Blank column provided for miscellaneous notes.
14. Total height of tree calculated from the above values.
15. Height to base of live crown calculated from the above values.

Values of H and HLC should be calculated in the field and compared with previous values (if any) recorded in columns 3 and 4. If differences appear unreasonable for the time involved and apparent lengths of leader and internodes, the heights in question should be remeasured to be sure that current measurements and calculation are correct. Any abnormal leader and internode lengths or other characteristics that would account for an apparently inconsistent previous value should be noted, as an aid to later data editing.

After field measurements are complete, the calculations in columns 14 and 15 should be checked for arithmetical errors and the values of H and HCL transcribed to the plot measurement record form. This serves as the data entry document.

Equipment Checklist for Field Plot Work

Modify this checklist as needed for specific jobs:

Tatum holder
 Pocket calculator (preferably programmable)
 Extra battery pack for above
 Field tally sheets (or recording device), with previous measurements, if any
 Coordinate paper or standard form for sketch maps
 Protractor Engineer's pocket scale
 Copy of study plan or establishment report
 Manual or specifications with applicable measurement instructions and recording codes
 Maps
 Aerial photos
 Pocket stereoscope
 String, large cones (for delimiting plot boundaries and strips within plot)
 Paint gun or pressurized paint cans; tube paint for marking boundaries, numbering trees, marking b.h. point
 Lumber crayons, yellow
 Lumber crayon holders
 Nails, aluminum (for tags)
 Prenumbered metal tags, in sequence (if tagging new plot)
 Label maker with metal tape
 Claw hammer
 Aluminum wire (for tagging small trees, corner stakes)
 Flagging, assorted colors

Bark scribe
 Hatchet
 Machete
 Small maul (for driving stakes)
 Stakes (metal or other permanent material, for marking plot corners and centers)
 Pruning saw
 Staple gun, staples, cards (if there may be a need to tag trees temporarily)
 Pocket compass
 Staff compass with staff
 Steel tape, 150 ft or 60 m, with reel (for laying out plot boundaries and measuring base lines)
 Tape repair sleeves or spare tape
 Pocket cloth tape, 75 ft or 30 m
 Range poles
 Height pole
 Clinometers of type appropriate for expected tree size
 Tripod if required by above
 Diameter tapes
 Increment borers (two sizes) with extra bits
 Increment core holders (plastic drinking straws or the equivalent)
 Bark gage
 Hand lens
 Flashlight with extra batteries
 Transit with tripod (initial plot layout)
 Stakes, tacks (initial plot layout)
 Plumb bobs (initial plot layout)
 First aid kit
 Packs for carrying equipment

Plot Dimensions and Conversion Tables (Tables 1-4)

Table 1-Dimensions of square plots of specified area

English units				Metric units			
Area	Side	Diagonal	Semidiagonal	Area	Side	Diagonal	Semidiagonal
<u>Acre</u>	- - - - Feet - - - - -			<u>Hectare</u>	- - - - - Meters - - - - -		
0.001	6.60	9.33	4.67	0.001	3.16	4.47	2.24
.01	20.87	29.52	14.76	.01	10.00	14.14	7.07
.05	46.67	66.00	33.00	.05	22.36	31.62	15.81
.10	66.00	93.34	46.67	.10	31.62	44.72	22.36
.15	80.83	114.32	57.16	.15	38.73	54.77	27.39
.20	93.34	132.00	66.00	.20	44.72	63.25	31.62
.25	104.36	147.58	73.79	.25	50.00	70.71	35.36
.30	114.32	161.67	80.83	.30	54.77	77.46	38.73
.40	132.00	186.68	93.34	.40	63.25	89.44	44.72
.50	147.58	208.71	104.36	.50	70.71	100.00	50.00
.75	180.75	255.62	127.81	.75	86.60	122.47	61.24
1.00	208.71	295.16	147.58	1.00	100.00	141.42	70.71

Table 2-Dimensions of circular plots of specified area

English units		Metric units	
Area	Radius	Area	Radius
<u>Acre</u>	<u>Feet</u>	<u>Hectare</u>	<u>Meters</u>
0.001	3.72	0.001	1.784
.01	11.78	.01	5.64
.05	26.33	.05	12.62
.10	37.24	.10	17.84
.15	45.60	.15	21.85
.20	52.66	.20	25.23
.25	58.88	.25	28.21
.3	64.50		
.4	74.47		
.5	83.26		

Table 3-Multipliers to convert slope distance to horizontal distance and horizontal distance to slope distance ¹

Slope percent	cos θ (ds to d)	1/cos θ (d to ds)	Slope percent	cos θ (ds to d)	1/cos θ (d to ds)
5	0.999	1.001	60	0.857	1.166
10	.995	1.005	62	.850	1.177
15	.989	1.011	64	.842	1.187
20	.981	1.020	66	.835	1.198
22	.977	1.024	68	.827	1.209
24	.972	1.028	70	.819	1.221
26	.968	1.033	72	.812	1.232
28	.963	1.038	74	.804	1.244
30	.958	1.044	76	.796	1.256
32	.952	1.050	78	.788	1.268
34	.947	1.056	80	.781	1.281
36	.941	1.063	82	.773	1.293
38	.935	1.070	84	.766	1.306
40	.928	1.077	86	.758	1.319
42	.922	1.085	88	.751	1.332
44	.915	1.092	90	.743	1.345
46	.908	1.101	92	.736	1.359
48	.902	1.109	94	.729	1.372
50	.894	1.118	96	.721	1.386
52	.887	1.127	98	.714	1.400
54	.880	1.136	100	.707	1.414
56	.872	1.146			
58	.865	1.156			

^{1/}(1) Slope distances to horizontal distance: $d = ds \cdot \cos\theta$, for θ in degrees. (2) horizontal to slope distance: $ds = d/\cos\theta$, for θ in degrees.

Table 4-English and metric equivalents

English or metric	=	Equivalent
1 inch	=	2.540 centimeters
1 meter	=	39.37 inches
1 mile	=	1.609 kilometers
1 kilometer	=	0.6214 mile
1 square foot	=	929.0 square centimeters
1 square foot	=	0.0929 square meter
1 square meter	=	10.76 square feet
1 acre	=	0.4047 hectare
1 hectare	=	2.471 acres
1 cubic foot	=	28.32 cubic decimeters
1 cubic foot	=	28.32 liters
1 ounce liquid	=	29.57 cubic centimeters
1 quart	=	0.9463 liter
1 liter	=	1.0567 quarts
1 cubic foot	=	0.02832 cubic meter
1 cubic meter	=	35.31 cubic feet
1 cubic foot/hectare	=	0.06997 cubic meter/hectare
1 cubic meter/hectare	=	14.29 cubic feet/acre
1 pound avoirdupois	=	453.6 grams
1 kilogram	=	2.205 pounds
1 short ton	=	0.9072 tonne
1 long ton	=	1.016 tonne
1 tonne	=	2.205 pounds

Curtis, Robert O. Procedures for establishing and maintaining permanent plots for silvicultural and yield research. Gen. Tech. Rep. PNW-155. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1983. 56 p.

This paper reviews procedures for establishing and maintaining permanent plots for silvicultural and yield research; discusses purposes, sampling, and plot design; points out common errors; and makes recommendations for research plot designs and procedures for measuring and recording data.

Keywords: Plot analysis, permanent sample plots, tree measurement, sample plot design.

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.

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