MAINTAINING A PERMANENT PLOT DATA BASE FOR GROWTH AND YIELD RESEARCH: SOLUTIONS TO SOME RECURRING PROBLEMS

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ABSTRACT

Methods for solving some recurring problems of maintaining a permanent plot data base for growth and yield research are described. These methods include documenting data from diverse sources in a common data base, documenting diverse sampling designs, changing sampling designs, changing field procedures, and coordinating activities in the plots with the land management agency. Managing a permanent plot data base (including plot recruitment, maintenance, and replacement) over a long time frame for northern Rocky Mountain ecosystems has been the impetus for developing these methodologies. We have assembled a permanent plot data base by accepting responsibility for maintenance of plots initially installed for silvicultural experiments of a limited duration. This approach contrasts with the ideal one, in which plots would be installed and maintained to randomly sample different treatments and site types. Unfortunately, the ideal approach has the great disadvantage of requiring a long wait before data are available for analysis. Older plots allow immediate use of some growth and mortality data, a detailed description of treatment history, and the opportunity to select only those plots needed to fill data gaps. Concerns related to sample stand selection are discussed. These methods may provide guidance for others who are initially installing plots for growth and yield research.

Keywords: sampling, experimental plots, experimental design

INTRODUCTION

Managing a network of permanent plots, which includes recruiting, maintaining, and replacing plots, and their data is a vital component of growth and yield research. A permanent plot is defined here as a long-term plot where numbered trees are measured at successive time intervals to monitor growth and development. Though it is possible to obtain growth data from increment cores or stem analysis from trees on temporary plots (plots on which trees are only measured once), permanent plots are needed to obtain reliable mortality data. The mortality component typically comprises a major portion of the error in growth and yield model predictions (as much as 80% in the Prognosis model; Stage and Renner 1988). Permanent plots are also needed for forest inventories, although this paper discusses their use in growth and yield research.

Building a permanent plot data base that adequately represents the range of forest stand types, conditions, and treatments requires forethought and diligence; that of a predecessor, or your own if you install the plots (see Curtis (1983) and Vanclay (1991)). Only rarely are permanent plot data bases established in such a thorough, systematic manner because of the large expense (in money, personnel, and time) associated with permanent plots. Alternatively, we built our permanent plot data base by adopting plots initially installed as part of short-term silvicultural studies. Others have brought diverse permanent plot data together for growth and yield research (Arney and Curtis 1977; Johnson and Dixon 1985), but they have not typically dealt with the management of these plots into the future.

Our approach of building a permanent plot data base provides immediate access to growth and mortality data (see Hamilton 1986) and detailed descriptions of treatment history. In addition, it

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is possible to select only those plots that fill data gaps for specific treatments or site types. Some of the problems with our approach include: data from diverse sources, different sampling designs, inefficient sampling designs, inefficient field procedures, and lack of coordination with the land management agency. This paper describes the methods we use in dealing with each of these problem areas. Also, I discuss concerns related to sample stand selection using this approach. This paper is based on my work in accumulating old silviculture plots, and subsequently managing them, as part of a growth and yield research unit in the northern Rocky Mountains of the United States; however, most of the methods would apply to forested areas anywhere in the world.

METHODS

In the next five sections, I describe methods for documenting data from diverse sources in a common data base, documenting diverse sampling designs, changing sampling designs, changing field procedures, and coordinating activities in the plots with the land management agency.

Documenting Data from Diverse Sources in a Common Data Base

Invariably, data from different studies will be stored in different file formats. So, for ease in collectively managing and analyzing data from the different sources, Sweet and Byrne (1990) developed a common data structure as part of a project to exchange permanent plot data within the Inland Northwest Growth and Yield Cooperative (INGY). This data structure supplements the older COSMADS format (Arney and Curtis 1977) by adding the capability to fully describe sampling designs, measurement methodologies, individual tree characteristics, and treatment histories. Using this data structure, data from permanent plots are organized into records in four general categories: (1) basic information (records of sampling design, administrative descriptors, location descriptors, plot descriptors, plot summary descriptors, measurement dates, treatment descriptors, and site descriptors), (2) supplemental information (records of administrative units, fertilization treatments, soil descriptors, climatic descriptors, and height from dbh regression), (3) individual tree information (records of individual tree descriptors and individual tree measurements), and (4) comments (records of general comments and individual tree comments). Each installation, stand, plot, and tree is referenced by a unique identifier. Common codes (e.g., species, tree status) are described for use with the various data attributes.

The completed records can be moved with relative ease into any of the commonly available data base management software systems (e.g., dBase or Paradox for the IBM PC). Most such software packages have an associated programming language for developing routines that summarize the data and write reports or field measurement tally sheets. Byrne and Sweet (1992) summarize the essential features of data base management systems for permanent plot data.

Moving the original data into this common data structure is far more time consuming than one might think. This conversion of existing data typically involves an extensive process of editing, correcting, and screening for quality. The necessity for such a time consuming process is a result of past inconsistencies in measurement procedures, recording and coding among people and among organizations, and the lack, until recently, of effective editing programs. Therefore, conversion is an ongoing process, with the most needed information (e.g., individual tree measurements) moved first, and other information moved as time allows. Computer routines for processing the data are developed as the need arises. Managing the data, in general, is a task often assigned little time or priority; yet, without it, data are of little value now or in the future.

Documenting Diverse Sampling Designs

Different studies, from which the plots are obtained, necessarily have different sampling designs. A common method of describing sampling designs, and changes in the designs, eases compiling tree measurements on a per unit area basis (per acre or per hectare). Byrne and Stage (1988) define a data structure for sampling design description, which facilitates compilation of data with a simple algorithm applicable to a very diverse mix of designs. Their data structure defines three basic elements of a sampling design: spatial relations, definition and sampling of subpopulations of interest, and sampled tree measurement accuracy. They demonstrated the usefulness of this structure in describing a variety of designs ranging from the simple to the complex. The rest of this section briefly describes this sampling design data structure.

Spatial relations are documented by standardizing definitions of the hierarchical levels of a sampling design. These levels and their definitions are as follows:

Stand = a uniquely treated, biologically uniform area,
Plot = a collection of trees included within a single sample, and
Subplot = a cluster of trees nested within the plot.

Defining a stand in this manner makes it synonymous with the plot in many silvicultural studies and with the stand in operational research studies. It was necessary to agree on one term for a biologically uniform, uniquely treated area so all studies can be related at the proper level. This data structure only deals with levels of spatial hierarchy at the stand level and below, but the authors realized that an installation numbering scheme would be necessary to categorize stands within an experimental design and stands in an operational monitoring scheme (see Sweet and Byrne 1990).

To allow for a variety of sampling designs, the sample is defined by a rule for selecting a group of trees from all possible trees in a stand instead of a plot drawn from many possible plots. In this context, then, it is important to define the subpopulations of trees sampled by each sample and the rules that determine which trees are sampled.

Subpopulations of interest have traditionally been defined by a minimum diameter limit (e.g., 13 cm dbh for large tree samples) or height limit (e.g., 0.5 m for small tree plots), above which all trees are sampled. For nested designs it is often necessary to have both a minimum and maximum size limit (e.g., one part of a nested design might sample trees from 7 to 13 cm dbh). Other designs define subpopulations by species or some specific characteristic of the tree (e.g., alive or dead, infected by a particular pathogen or not). The sampling design structure can incorporate all of these subpopulation definitions by using these four variables (or multiples of them):

1. subpopulation number,
2. the variable for delimiting a subpopulation (e.g., continuous variables such as diameter or height, or codes for categorical variables),
3. minimum value or first code for the variable, and
4. maximum value or second code for the variable.

Sampling rules used to select trees in each subpopulation define the probability of a tree being sampled. Four variables are used to define the rules for sampling each subpopulation:

1. sampling rule number,
2. variable (i.e., tree characteristic) for defining geometric sampling probability (constant for fixed area plot, basal area for horizontal point sample, etc.),
3. expansion constant, i.e., that number for compiling to a unit-area basis (1/plot area for fixed area plots, BAF for horizontal point samples, etc.), and
4. number of subplots.

The third aspect of the sampling design is the way tree characteristics are measured on each sample tree; whether or not they are directly observed, and, if they are directly observed, the accuracy of that measurement. For example, was tree height obtained by direct observation using a telescoping height pole or a clinometer, was it estimated in the field to the nearest 10 feet, or was it estimated from a height-dbh regression estimator? A simple set of codes associated with each tree characteristic is usually all that is required to address this aspect of the sampling design.

To tie all aspects of each design together for ease in compilation procedures, each subpopulation (subpopulation number) must be linked with the rule used to sample it (sampling rule number) and the date this design was initiated. The example at the end of the next section shows how we did this.

Changing Sampling Designs

Sampling designs sometimes must be changed because of stand structure changes that were not anticipated when the study was originally designed or because the original design was inadequate in some way. Previous studies may have concentrated on larger trees, those that are at or near a size of commercial interest, and may have inefficient or nonexistent sampling schemes for trees in smaller size classes. There may be other instances where a subpopulation of interest was not sampled sufficiently. It may be better to modify the sampling criteria of an existing plot than to start over with a new plot installation with a comprehensive sampling design. The existing plots have an invaluable mortality and growth record that would not be available for many years from new plots.

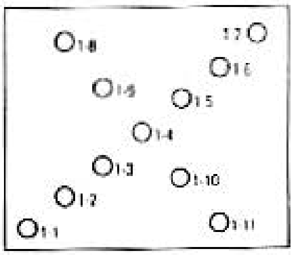
The most common deficiency in the many sample designs we've encountered is the failure to efficiently sample smaller size classes. The solution is to introduce subplots specifically for these smaller size classes. Several examples may be illustrative. In the first case, the original design required measuring all trees greater than 2.5 cm dbh on a 0.1 ha plot. In the second case, the design called for sampling only those trees greater than 13 cm dbh, with no sampling of smaller trees. In either case, as the stand matures and opens up due to the death of some large trees, smaller trees may begin to fill in the gaps in the stand. The original sample designs would no longer be suitable for the stand. Measuring all trees greater than 2.5 cm dbh would take too much time, and measuring only those trees over 13 cm dbh would totally ignore the larger number of small trees now found in the stand.

Another instance where the sampling may need to be modified is where only a subset of species of a particular size class are sampled, often because only those species anticipated to be of commercial value were of interest. However, other species that may be present in the stand for a short time period may provide significant competition for species of commercial interest, as hardwood species do for conifers in young plantations. Even understory plants may be of interest as the Forest Service moves to a management strategy that stresses ecosystem management rather than timber extraction. For all sampling designs, especially those for new permanent plots, we recommend including all species present in each size class and also including some observations of all vegetative life-forms.

Design changes may be needed to modify present permanent plots for a greater assessment of tree mortality. One such proposal calls for delineating a larger mortality plot around existing permanent plots. In this additional outer plot, only the size and species of the dead trees are recorded.

Adding a new set of linking variables (i.e., subpopulation number, sampling number, and date design was initiated) to the original design description allows the changes in sampling design to be described. A simple example is shown on the next page. See Byrne and Stage (1988) for other examples.

Sampling Design Example (including a change in design)



1-0

From 1933 to 1974, all trees ≥ 2.5 cm dbh were measured on a 0.1 ha plot (subplot 0). We changed the sampling scheme in 1984 because of a large increase in small trees. All trees ≥ 7.5 cm dbh were measured on the 0.1 ha plot (subplot 0), but trees 2.5 to 7.4 cm dbh were subsampled using 11 plots of 0.001 ha each (subplots 1-11), distributed systematically within the 0.1 ha plot.

Sampling description using data structure:

Subpopulation number	1	2	3
1st var. for subpop. definition	dbh	dbh	dbh
Minimum or 1st code	2.5	7.5	2.5
Maximum or 2nd code	200.0	200.0	7.4

Sampling rule number	1	2
Variable defining probability	Constant	Constant
Expansion constant	10	1000
Number of subplots	1	11

Linkages between design descriptors:

Identifiers		Linking variables		
Plot #	Subplot #	Subpop #	Rule #	Date
1	0	1	1	1933
1	0	2	1	1984
1	1	3	2	1984
1	2	3	2	1984
1	3	3	2	1984
1	4	3	2	1984
1	5	3	2	1984
1	6	3	2	1984
1	7	3	2	1984
1	8	3	2	1984
1	9	3	2	1984
1	10	3	2	1984
1	11	3	2	1984

Changing Field Procedures

Many of the same tree measurements (such as dbh, total height, crown measures, damage, etc.) are taken as when the plots were used for silvicultural studies. However, measurement techniques may change over time. A plot initially consisting of smaller trees may have had every tree height measured because of the ease of using a telescoping height pole or similar device for measurement. But as trees grow larger and require the time-consuming use of a clinometer to measure height, subsampling heights may be necessary. The same may be true for crown measurements. See Curtis (1983) for procedures to select a representative subsample. Subsample trees may have to be added as old ones are damaged (e.g., broken top) or die.

Plot maintenance varies greatly depending on whether plots are viewed as short term or long term. Maintenance includes marking of measurement points, such as dbh, with nails, paint marks, etc., plot center or corner markers, and sample tree identification and location. Short-term plots are typically measured more frequently than long-term plots (for example, every 2-5 years rather than every 5-10 years). The same personnel may make all of the measurements. Trees and other identification points may be marked well when the plot is established but not be maintained when measurements are made later. When plots are used over the long term, tree identifiers and measurement points must be continually maintained because of degradation over time and the probability that completely different personnel will be measuring the trees. Nails and attached number tags are overgrown, paint marks fade or are lost by sloughing of bark, corner markers rot away or fall over, and smaller trees may become difficult to locate as stand vegetation changes. For permanent plots, tree identifiers and plot corners must be maintained at least at every measurement. Locations of trees should be documented with location from plot centers or corners or another similar way. To maintain our plots' visibility and to assure adequate tree identification at time of measurement, we visit plots that are on a 10-year measurement cycle at the 5th year to do a maintenance check.

Coordinating Activities with the Land Management Agency

In many forestry operations, the forest research branch operates independently of the forest management branch. The U.S. Department of Agriculture Forest Service is a prime example, with National Forests in charge of forest management and Research Stations in charge of research. The two branches are typically housed at different locations. Because permanent plots are usually installed on National Forest lands, coordination between research and management staffs is crucial if long-term research is to be sustained. Lapses in communication can easily result in damage to the plots, with subsequent abandonment or modification of the plots becoming necessary. Types of activities that have damaged our plots include both partial and clearcuttings, burning, and road building.

Communicating research activities to management personnel would seem to be a straightforward task. However, in our situation, it is plagued by several problems. The first problem is that the personnel who manage the land and the researchers often do not stay in the same location with the same duties very long. Another problem is the difficulty of communicating exact locations of plots. Our National Forests divide similar forest or landscape types into manageable stand units, which are subsequently aggregated to a compartment level. These stand boundaries can often change because of management activities, damage, etc. The forests maintain their own maps at their locations. On the other hand, our research staff locates plots on general forest maps and topographic maps, usually by documenting distances of plot markers from easily seen land or man-made features, such as road intersections, stream crossings, etc. Obviously, the way to alleviate this problem is to maintain a common geographical standard that both management and research personnel can use. This is slowly happening with the movement toward computerized mapping using Geographic Information Systems (GIS) and the availability of Global Positioning Systems (GPS) for obtaining exact latitude, longitude, and elevation coordinates of plot locations (Luepke 1991; Evans and others 1992). Most forests can use latitude-longitude-elevation coordinates to either place research plot locations on their GIS, if available, or on stand maps. Then, notes can be attached that encourage managers to contact research personnel if activities are proposed for the plot locations. We have started using this process in the last year with good success in communicating plot locations.

Well-marked plots help to communicate research activities to management personnel in the field. We wish to be actively involved in any management activities that would affect our long-term plots. In contrast, inventory-type plots are often minimally marked so management activities can occur without bias and thus be monitored. When management activities are necessary near or in our research plots we use the guidance of Curtis (1983) for measurements both immediately before and after the activity. Also, if at all possible, we try to reserve an untreated control sample along with the treated sample.

No matter how diligent our coordination with the land management agency, damage occasionally occurs. Then, the question is whether to abandon the plot or not. The decision has to be based on the extent of the damage and the importance of the plot to your research. One recent example might be illustrative. We maintained a cluster of plots in an older, partially cut stand for 15 years, with measurements at 0, 5, and 15 years from establishment. At year 16 we discovered that the stand had been nearly clearcut (due to a failure of communication). The stand was to be planted the following year with disease-resistant white pine (Pinus strobus). Because we had marked the plot centers with tall, painted wooden stakes and with short iron stakes, we felt confident that we could relocate plot centers, possibly with the help of a metal detector. Because we had measured the stand the previous year, we had a good precutting inventory. We decided to continue measuring the plots because of the need for information about the development of planted and natural regeneration after a cutting. Our plot design was adequate for small trees, so no modification of the sampling criteria was necessary.

CONCERNS RELATED TO SAMPLE STAND SELECTION

A permanent plot data base for building growth and yield estimators would ideally consist of a combination of two types of plots: (1) controlled silvicultural studies that provide data for new treatments and/or stand density effects and (2) permanent plots that describe stand growth and mortality across the variety of present stand types and treatments represented in the operational forest (Stage 1976). Silvicultural studies are often subjectively placed in stands with uniform characteristics that meet a predetermined set of specifications of stand density, size class, ecological type, etc. Within these stands, a variety of replicated treatments are established and randomly sampled with plots. Such controlled experiments permit hypotheses of treatment effects to be tested statistically and provide information on response to treatments not now present in the operational forest. By contrast, to assure a representative sample of data across the operational forest, a table of forest type, condition, and treatment classes may be built. A complete listing of candidate stands for each class is obtained, and a random sample of stands is selected from each class for establishment of plots. Curtis (1983) and Curtis and Hyink (1985) provide detailed summaries of the procedures for building permanent plot data bases for growth and yield estimation. These rigorous procedures were used for some, but not all, of our plots.

In building a permanent plot data base using existing plots as described, we sacrifice some control over the location of plot installations and are less likely to obtain a truly representative sample than if we were able to better randomize the selections. Realistically, the ideal method is rarely feasible for reasons of cost, time, and practicality. Costs would be very high for large sets of newly installed plots, long waits would be necessary to obtain sufficient data, and inefficiencies would result because of poor access to some of the plots. Some compromise is necessary.

To identify data gaps, we first classified the existing forest land base and designed a matrix defined by ecological type, elevation, slope, aspect, and geographic region. We then distributed our plots into the appropriate matrix cells, with additional categorization by silvicultural treatment types (Byrne and others 1988). Comparison of the forest area in each cell with the number of plots in that cell showed the importance of filling gaps. Stage and Renner (1988) have discussed the difficulty of maintaining an ideal distribution of representative data over a long time frame because of random occurrences of damaging effects caused by weather (e.g., high winds, ice storms, flooding) or pest effects (e.g., insects or pathogens). Any new plots we might establish will be selected randomly from listings of suitable stands. We feel our method, though by no means ideal, attempts to use the limited resources available to us on a scientifically sound basis.

CONCLUSION

Maintaining a set of permanent plots and their data has been greatly aided by using the methods described in this paper. Although we have used these methods in the context of a data base built by accepting responsibility for the maintenance of plots from existing silvicultural studies, these methods may provide guidance for others who are initially installing plots for growth and yield research.

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