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Cost-effective Forest Inventory Designs: Field Data Collection

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Background

The cost and the difficulty of securing financial support for forest inventories is substantial. Thus, it may take many years to complete an inventory. That time frame and the rapidity of forest change are also why inventory data is often out of date and of low utility. Here we address field data collection approaches to make such efforts more timely and cost-effective.

Key words: Forest inventory, databases, imputation.

Introduction

The Cooperative Stand Assessment (CSA) used by the Minnesota Department of Natural Resources (MNDNR) is a typical forest vegetation inventory design. The CSA manual is available on the IIC website at: http://iic.umn.edu/catalog/land-cover-land-use/detailed-forest-inventory/state

This design details a stand-focused inventory used for over 200,000 stands across nearly 5 million acres of state land. In execution, the intent is to map forest stands (polygons), assign a forest covertype, measure each stand with a sample of field plots and make the data available for the agency's Forest Information System (FIM). The field visit and associated field plots observe the number, species, size, timber volume and condition of trees present. Additionally, field crews typically describe the stand by physiographic class, soils, and ecological classifications, among others.

Most Minnesota counties with substantial forested land use similar designs and systems for inventory. In fact, National federal, state and industry ownerships across the U.S. also use similar designs.

For this research note, we consider the overall design to have two parts: (1) mapping and (2) field data collection. In fact, the cost of these inventories is substantial. Typical costs in Minnesota are $6 per acre, with the cost split equally between the two parts. With the task of assessing MNDNR lands, the overall cost could reach $6 x 5 million acres = $30 million!

Approach and Objectives

Fundamental to designing an inventory is an understanding of your objectives. A first step is a simple listing and prioritizing of objectives for use of the resulting data. Some commonly stated objectives include:

(1) Finding and evaluating certain types of stands, e.g. for treatment including regeneration, protection, harvesting, road building, etc.
(2) Planning/harvest scheduling, i.e., for age class management, revenue generation,

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opportunity and threat analysis and long term planning.
(3) <u>Timber sale appraisal</u>, e.g., annual timber sales.

In brief, your ownership may have numerous uses and perspectives on management, but our view is that all of these can fit under this set of three objectives.

The usual approach for addressing these objectives is to visit each mapped stand. Typically a tentative type map of the stand has been establish through remote sensing image interpretation; the field visit is to check, refine and/or correct that interpretation by observing actual stand and tree conditions. Further, per the CSA manual, the stand and tree tally sheet (paper or electronic) is populated with stand description and field plot data. The usual sample size is 1-10 plots per stand, with the sample size determined by stand size in acres. The plots are then distributed randomly or systematically across the stand—to ensure a representative sample. Unfortunately, this approach is costly, time-consuming and can fail to meet the objective of timely and truly useful data. In fact, it often emulates rather than avoids the *ten-plots-per-stand syndrome* described by Ek et al. (1984).

Alternatives

Cost-effective alternatives in inventory design do not necessarily involve replacing your tally sheet. Instead, we seek to diminish your field efforts, i.e., travel expenses, time on the ground in subject stands and data entry by using (imputing[2]) data from other sources. Realistically, this requires a rethinking of objectives (and use of the information) plus stand level precision and alternative sources of data. An important tradeoff is that cost-savings here can enable more frequent inventories and achieve more up-to-date and useful data. Below we treat the set of three primary objectives in order.

(1) <u>Finding and evaluating</u>
This objective seemingly requires frequent inventories. Supporting that view, the authors have found that USDA Forest Service Forest Inventory and Analysis (FIA) plots (Bechtold and Patterson 2005; O'Connell et al. 2017) in Minnesota change rapidly—on average, 14% change covertype in 5 years! This implies a need for frequent visitation of existing maps, especially for updating the **<u>key data</u>:** <u>covertype, stand age/or size class, stand density class and site index</u>. With these data plus spatial location information, other variables may be imputed from thematic maps or by prior linking such information to the key data.

To be cost-effective, the solution implies frequent remote sensing analyses and/or prioritizing field visits. Here we stress the key data as sufficient to impute estimates of on-the-ground conditions from your existing stand or other data. For example, given a covertype, stand age and/or stand size class, one can impute the average for that set of conditions from your existing old or new database. Simply put, such relationships do not change much over time, even though they may appear in different places and at different times in the history of your forest.[3] One can also intensify field visits according to the importance of particular forest conditions; say the economically important aspen type.
This discussion highlights the role of the key data. One can often update or otherwise determine the key data sufficiently by brief visual inspection. Given that, subsequent classification and/or imputation can proceed such that additional observations in terms of field plots in that stand are unnecessary. Photo or other classification guides can also be helpful in estimating key data and have been widely used for terrestrial and aerial photo interpretation in forestry practice. Note these suggestions highlight the importance of well-trained and experienced field personnel and guiding materials. Importantly, these steps can dramatically reduce the time spent collecting field plot data as well as time traveling to and visiting stands. At a minimum this can reduce time spent on the inventory of low priority forest types while retaining a useful level of statistical and practical utility for these stand characterizations.

These alternatives also raise the question of whether or not we need to visit all of the stands in the forest. Briefly, the answer is <u>no</u>! For cover types of low priority or those unlikely to change much, or those known to be very similar to those already visited, they can be mapped, but only a fraction of them might be visited. This saves

[2] Imputation in terms of statistics is the process of replacing missing data with substituted values. In this case, we are replacing missing data with values from similar or nearby conditions or the average overall of data in that stratum.

[3] Readers familiar with inventory design will recognize that the key data provide a form of stratification.

both travel and plot taking time. In addition, the small fraction of actual stand visits can provide the data for imputation of detail to those not visited. **<u>Not visiting all stands</u>** is likely to be the largest time and cost savings in an inventory.

Finally, there are diverse sources for data for imputation beyond your current inventory. Your past inventory records and inventory data from nearby forests (say other public ownerships, e.g., nearby counties). One can also use other surveys, e.g., FIA plot data. The FIA data is readily available and together with supporting software (Miles 2014; 2018) may be used online or from a personal computer.

(2) <u>Planning/harvest scheduling</u>. Harvest scheduling methods have progressed over more than a century from simple area control to mathematical programming solutions as evidenced by the Remsoft, Inc. linear programming (LP) based package (and supporting software) employed recently by the MNDNR. Such models use aggregated stand and plot data for each forest covertype, typically with further breakdowns of data for more detailed stand and landscape conditions and administrative constraints. To allow more detail, decomposition models help simply analysis by allowing the large problem to be subdivided into many small problems that are linked. Examples of decomposition models are Dualplan (Hoganson and Rose 1984; Hoganson and Reese 2010); DTRAN (Hoganson and Kapple 1991; Hauer and Hoganson 1996) and DPspace (Hoganson and Borges 1998) allow individual stands and their locations to be considered directly. Examples of using that detail are for examination of adjacency constraints and economic impacts depending upon stand and mill locations.

In practice, for LP models, one needs to provide a volume x age class distribution for each forest type, typically aggregated across the ownership for each age class for each year (or period of years) in the harvest scheduling analysis. With nonlinear models, individual stand level rather than aggregated stand data may be employed. Importantly, these stand level data come from your inventory.

Where does the growth and yield information come from? It can come from your own inventory if that involved permanent plot remeasurements. Alternatively, you may assume the average volume change from one age class to the next represents the change in yield. Another and more common alternative is to assume growth and yield as described by various published models for your area and cover types (e.g., Walters and Ek 1993; Zobel et al 2014; Dixon 2017). The choice depends on what is available, how well it describes your situation, and how easy it is to use.

The major factor in choice of growth and yield models is whether they work from stand level or individual tree data, i.e., tree lists on plots. In the latter case, say with the Forest Vegetation Simulator (Dixon 2017) you will need to collect and include individual tree level records as part of your inventory database. However, one could also impute individual tree data for each covertype and age class from the FIA plot and tree data for Minnesota for your ownership or a larger area. That is an approximation, but may be sufficient.

A caveat here is not to expect that a detailed database and complicated scheduling and yield models will necessarily guarantee better planning results than simpler choices. Experience and common sense still matter. Also, with Minnesota county data, we have found that there is a tradeoff between inventory cost and net returns suggested from harvest scheduling (e.g., when using aggregated stand level data and an LP scheduling model). In other words, when the inventory costs effectively reduce net returns, few cases suggested the need for more than 1-2 field plots per stand. Further, in related trials, there was little loss in net returns if only half of the stands were actually visited and field plots taken. Why? If the acres x age x site class are well known for a covertype (say from your mapping) and the yield model is already specified, then the results of the harvest scheduling trial are HEAVILY dependent on the acres by age class distribution--not how many plots you had in each stand. Clearly stand age is a key inventory variable. Hence the suggestion again that thousands of plots and visits to each and every stand may not be necessary for effective CSA inventories--with respect to the harvest scheduling objective.

(3) <u>Timber sale appraisal</u>

Unless you are operating with a very generous inventory budget, that database is unlikely to provide specific timber sale appraisal precision and accuracy. However, with little effort, the inventory can provide helpful prior information on what to expect with timber sales for the noted forest type, age class and site conditions. See an example of this approach for the aspen forest type from Burk and Ek (1987).

Inventory Design Examples

1. Assume a forest ownership of 100,000 acres with 4,000 stands averaging 25 acres in size. Assuming you visit each stand and observe four field plots in each on average; that totals 16,000 plots. Assume an inventory contract where visiting a stand for the key data would cost $15 each. This would be the first plot. And each additional field plot in the stand would cost an additional $15 each. Data collection for stands would then average $60 each. The total field data collection cost would be $240,000 or $2.40 per acre.

2. As an alternative, consider the cost if you decided to visit and observe the key data for each stand at say $15 per stand, and actually take 4 field plots on average in only half of those stands. This amounts to three additional plots. The cost would then be:

$30,000 for key data (2,000 stands x $15)
$120,000 for key data plot plus three additional plots (2,000 stands x $60)

The result is a savings of $90,000 compared to Example 1. The total field data collection cost would be $150,000 or $1.50 per acre. Additionally, per acre values for stands without field plots can be imputed from the data provided by stands with field plots. Note that remote sensing costs are assumed the same for the two examples.

Of course, there is a wide range of options in inventory design planning. For example, one might assume a higher cost for the first plot or assessment step in a stand as compared to subsequent plots…thereby reducing the travel cost of the remaining plots. Clearly, these examples are but a start. However, to the extent that key data observation and additional plot costs differ, there can be very significant savings, thus allowing for inventories to be conducted faster and more often. One might assume Example 2 would be conducted in a short time frame, say 1-3 years. Subsequent on-going costs would depend very much on the frequency of follow-up efforts.

There can also be advantages where some of the key data are already known and essentially constant, say site index for example. Then they need not be remeasured. Remote sensing may also provide for cost effective observation and field plot measurement supplementation.

Following up on this note, we anticipate reader suggestions and research will lead to more and more effective options and alternatives.

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