Design Tool for Inventory and Monitoring

Charles T. Scott [1]
Renate Bush[2]
Ken Brewer[3]

***Abstract**: Forest survey planning typically begins by determining the area to be sampled and the attributes to be measured. All too often the data are collected but underutilized because they did not address the critical management questions. The Design Tool for Inventory and Monitoring (DTIM) is being developed by the National Inventory and Monitoring Applications Center in collaboration with the National Forest System (NFS) and the Remote Sensing Applications Center. DTIM will assist inventory planners by stepping them through the monitoring process: 1) identifying key customers and broad objectives, 2) identifying monitoring questions, 3) identifying attributes needed to answer the questions, 4) evaluating existing data; then if additional data are needed, 5) setting precision and cost constraints, 6) selecting the sampling and plot designs and sample sizes; and, 7) selecting the sample locations. A prototype was successfully used on the Mark Twain National Forest and is being applied on several other National Forests. A team of NFS representatives is identifying the requirements for developing DTIM to help establish monitoring plans on National Forests as well as for use by other Forest Inventory and Analysis partners.*

Keywords: FIA, sampling design, plot design, software.

Introduction

Information on natural resources is important to any land management organization. The U.S. Forest Service spends at least $200 million annually on resource monitoring, and the expenditure could be more than $500 million. There are concerns that some of the monitoring is not statistically sound, defensible in court, efficient, consistent over time and space, well integrated across resources, or well utilized once data are collected. The 2008 National Forest Management Act Planning Rule requires that forest plans have an associated monitoring program to ensure that each national forest is progressing toward its desired

[1] United States Forest Service Northern Research Station, FIA, 11 Campus Blvd., Suite 200, Newtown Square, PA 19073 USA; ctscott@fs.fed.us; http://nrs.fs.fed.us/people/Scott

[2] United States Forest Service, Northern Region, 200 E Broadway, P.O. Box 7669, Missoula, MT 59807

[3] United States Forest Service, Remote Sensing Applications Center, 2222 W 2300 S, Salt Lake City, UT 84119

In: McWilliams, Will; Moisen, Gretchen; Czaplewski, Ray, comps. 2009. 2008 Forest Inventory and Analysis (FIA) Symposium; October 21-23, 2008: Park City, UT. Proc. RMRS-P-56CD. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 1 CD.

conditions and objectives. An inventory and monitoring toolkit is being developed to address these needs. A brief overview of the toolkit is presented followed by a more detailed description of the Design Tool for Inventory and Monitoring (DTIM).

Overview of Toolkit

Inventory and monitoring of natural resources is an involved and expensive process. The National Inventory and Monitoring Applications Center (NIMAC), part of Forest Inventory and Analysis (FIA) Program within the U.S. Forest Service, is focused on this issue. NIMAC has identified 15 inventory and monitoring steps from the initial identification of the information needs through the analysis and decision process. While the data collection process is familiar to many, most of the steps are not. Initial steps to identify measurable objectives and questions that can be answered are often overlooked or given little attention. Existing inventories are often used to answer questions after the fact without consideration for changes or managing costs in inventories. While analysis and reporting steps will be repeated after each remeasurement, the planning (design) steps are done once, thus land managers have little or no experience at initiating an inventory and monitoring system. Based upon experience gained with FIA, NIMAC provides technical assistance to others so that they can develop inventory and monitoring systems that are compatible with FIA data which are collected on all lands across the United States.

An inventory and monitoring toolkit is being built to help with most of the 15 steps. The toolkit has four main tools. The Design Tool for Inventory and Monitoring (DTIM) is used to identify monitoring needs, to evaluate existing data, and, if necessary, to specify the sampling design to balance cost and precision in order to address the monitoring questions. The Portable Data Recorder (PDR) Tool is software on PDRs and personal computers to collect, validate, and transfer field data. The Database and Compilation Tool is used to store the data and to compute calculated fields, such as tree volumes, biomass, and species richness. NIMAC and FIA are developing several spatial and tabular Analytical Tools for Inventory and Monitoring (ATIM) to estimate tables and produce maps. The tabular tools produce estimates with associated sampling errors based on the data. The spatial tool selects subsets of the data for estimation based on spatial layers, such as ownership, cover-type maps, and ecological classification maps. The vision for the completed set of tools, the relationships between the tools, and their roles are shown in Figure 1.

The Design Tool will play a major role in linking the tools. DTIM will provide the analytical tool, ATIM, with a list of tables to estimate. If existing data are insufficient, it also will provide metadata to the protocol sample design on data collection methods, the attributes to measure and variables to compute. DTIM computes the sample size and can create a list of plots which is then input to the data recorder software. DTIM also could be used to create portions of forest plan monitoring guides for national forests.

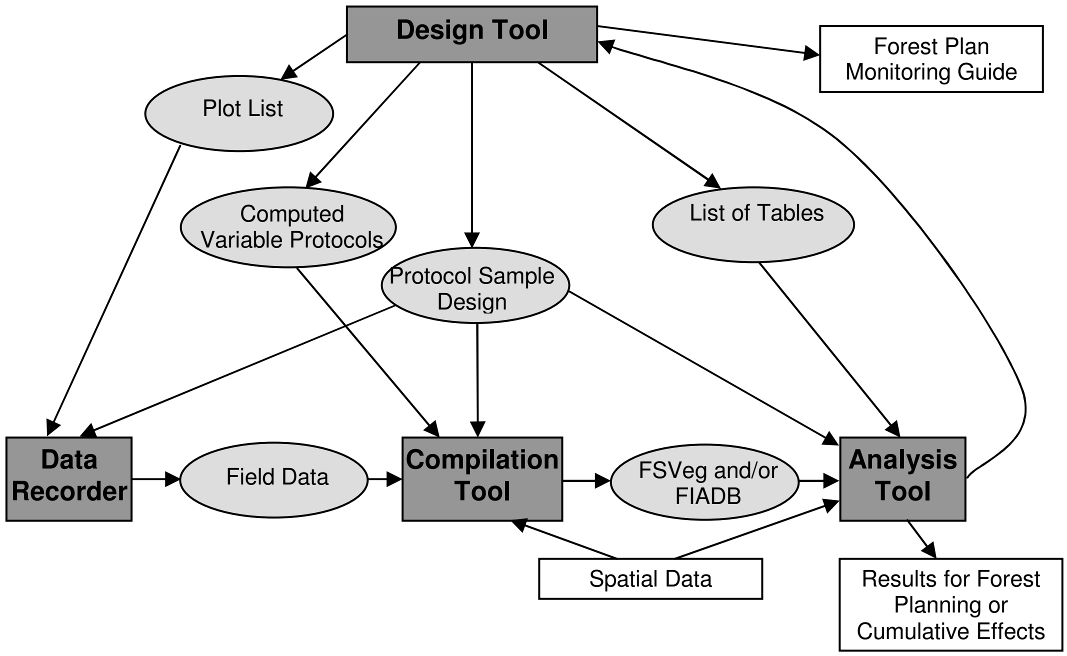

Figure 1: Diagram of the inventory and monitoring toolkit, its linkages, and its outputs.

Design Tool for Inventory and Monitoring (DTIM)

The Design Tool for Inventory and Monitoring is being developed to assist with the first 9 of the 15 monitoring steps. Using a knowledge base from monitoring experts, users will be presented with lists of choices to guide the development of the monitoring system that best suits their needs. These steps are done largely within a Microsoft Excel spreadsheet.

1. Identify customers and set broad objectives. – Pick from a list of broad objectives based on desired conditions or outcomes. Examples of broad objectives are: forest production, biodiversity, and ecosystem restoration.
2. Select monitoring questions. – Pick from list of generic questions based on the chosen objectives. Many of the questions relate to more than one broad objective.
3. Select attributes. – Pick from list of metrics for the questions chosen, then select from list of categorical attributes used to make tables to answer the questions. For example, to answer the question, “Are forests replacing themselves?”, the chosen metric could be the number of seedlings and saplings by species (rows) and forest type (columns). Once the list of all attributes needed for tables is developed, then the attributes that were not selected should be evaluated to see if any should be included.
4. Assess existing data. – Use the Analytical Tool on FIA or other existing data to determine whether they are sufficient to answer the questions, in terms of precision of the estimates or whether the attributes have been

collected (data gaps). If so, then stop. If not, then use the ATIM to assess their variability for the next steps.

5. Set time/cost and precision constraints. – If existing data are imprecise or have gaps, then identify the costs of each component of monitoring. Specify the upper limit of funding. Specify precision requirements and the scale of analysis (e.g., forest or ecoregions) for key metrics, such as forest area, volume, or carbon.
6. Select sampling and plot designs. – Based on the selected attributes, specify which portions of the FIA plot need to be measured, or what components need to be added. DTIM can then be used to evaluate plot design options: FIA's Phase 2 (trees only), Phase 3 (forest health), or simplifications of them, including 1, 2 or 3 subplots or eliminating some of the components such as lichens, soils, downed woody material, or crowns. Based on the plot design chosen, determine sample size.
7. Select plots. – Based on the sample size chosen, select plot locations in a spatially balanced manner across the population.
8. Plan field work. – Since most attributes are chosen from the list provided in DTIM (so that they are compatible across the landscape), existing FIA field guides could supply the text for a field guide for the selected attributes.
9. Train field crews. – Since most attributes are chosen from the list provided in DTIM, existing FIA training materials could be accessed to provide training materials for the selected attributes.

This provides a quick overview of the nine steps that precede data collection, processing, analysis, and decisionmaking. The sample selection steps (steps 6 and 7) merit additional discussion.

Sampling Design Alternatives

Considerable research on forest inventory has resulted in a wealth of efficient alternatives for one-time surveys. However, when monitoring over time, many of these alternatives result in changing probabilities of selection over time, which can be difficult to handle. Hence, the standard sampling design alternative that DTIM evaluates is an intensification of FIA Phase 2 and/or Phase 3 plots (e.g., 2X for Phase 2 and 7X for Phase 3). This makes maximum use of the existing FIA plots which are permanent, fixed-area plots. If a higher intensity is required for certain areas, such as rare habitat, old growth, or other key management areas, then additional samples can be located within them. It is strongly recommended that this two-step process be used rather than partitioning the target areas first, then allocating the samples to each. This could create estimation problems for the whole population over time as those boundaries change. For this reason, pre-stratification with other than proportional allocation should only be used if it is a one-time inventory or when the strata boundaries are "permanent" (e.g., political boundaries rather than forest cover).

In general, NIMAC recommends intensifying using the standard FIA plot design (Bechtold and Patterson 2005). However, when high levels of intensification are used, then other plot designs may prove more efficient (e.g., using fewer or larger subplots). This is because the FIA design was chosen to be efficient when travel to and from the plot requires about half a day, thus the on-plot time should take much of the other half. If plots are located close to one another (within a mile or so), then sampling smaller plots allows the crew to sample more than one per day. However, smaller plots are more variable, so there is a tradeoff. Scott (1993) describes these tradeoffs by first identifying the different subplot types: overstory, understory, soils, etc. For each type of subplot, the survey planner can specify the size, the number of subplots, and their spatial arrangement (distance). By knowing the time it takes to do each and the resulting precision of the key metrics, an optimal plot design can be chosen. For FIA, the optimal design chosen has four subplots (Fig. 2) but for the much higher sampling intensities (less than 1 km apart), a single set of nested subplots can be more efficient (i.e., using only the center set of subplots).

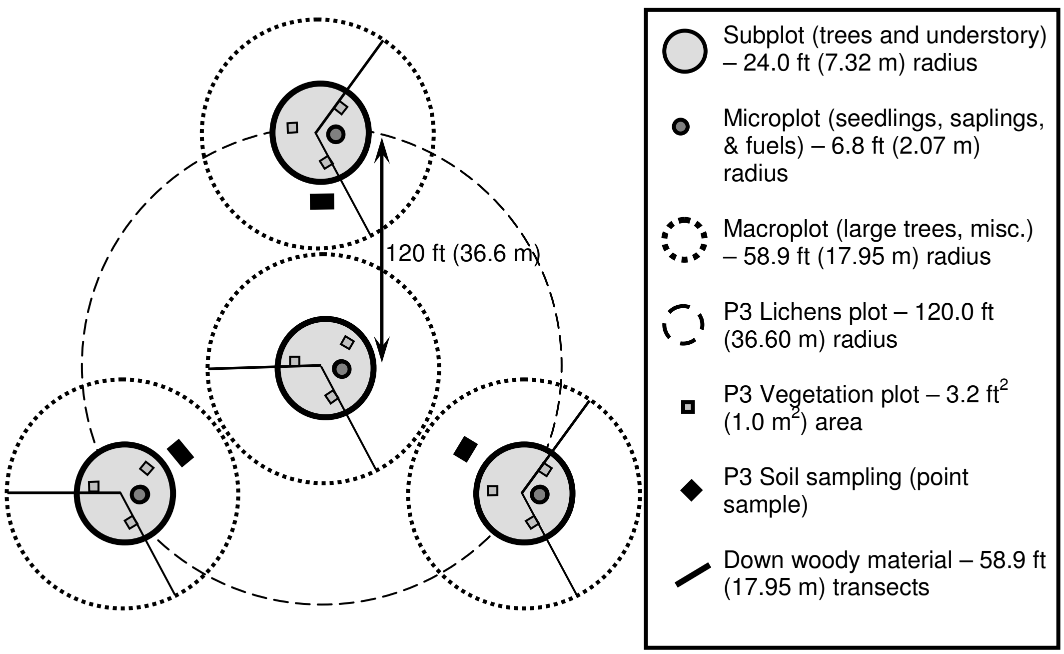

Figure 2: FIA plot design including both Phase 2 and Phase 3 subplots.

Optimization of the plot design features attempts to avoid over-sampling one attribute while under-sampling another. For example, if the regeneration sample is too variable relative to the overstory sample, then the regeneration subplot size or the number of regeneration subplots could be increased. Since the time required to sample the plot would thus increase, it might be necessary to decrease the overstory subplot size. DTIM will allow the user to evaluate these alternatives. Another alternative is to consider using a subsample for precise, expensive, or seasonal attributes, such as Phase 3 plots. In this case, not all attributes are measured on all plots, thus two (or more) plot kinds could be identified. DTIM helps evaluate tradeoffs between time on plot versus traveling (increasing plot size versus increasing sample size). DTIM also attempts to efficiently use the available time in a day (no partial plots that require a second visit). Once the cost and precision relationships are developed, then the optimization can be performed in one of two ways: optimize precision for fixed cost, or minimize cost for fixed precision.

Select Plot Locations

FIA uses a hexagonal grid across the nation to spatially balance the plot locations (Bechtold and Patterson 2005). While this meets FIA's needs, it is difficult to achieve a fixed sample size when intensifying for a given area. NIMAC developed an alternative method which also is spatially balanced but results in the desired sample size (n) for the target population (Lister and Scott 2008). The approach is to use a geographic information system (GIS) to divide the population area into pixels, and use the GIS to aggregate the pixels into n equal area groups (clumps). Then randomly sample a point (or pixel) within each clump (Fig. 3).

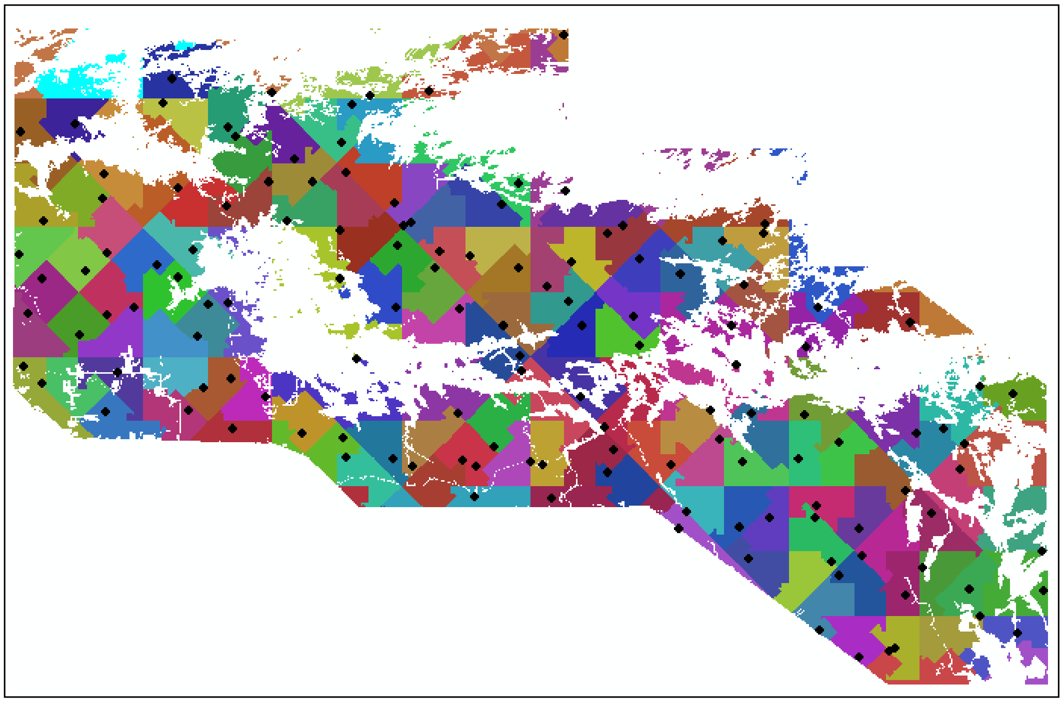

Figure 3: Example of spatially balanced sample using pixel groups from Lister and Scott (2008).

Space-filling curves are a mathematical means of creating a string of plots by connecting adjoining plots until all sample plots are included. A systematic sample of this string (e.g., every fifth plot) also is spatially balanced, thus the sample can be divided into annual panels (one for each measurement year) or into subsamples, such as Phase 3. Another approach to creating annual panels is to first group plots within compartments or other subpopulation of interest for which it would be helpful to have all plots completed in a single year. These groups can then be formed into a space-filling curve and then divided into annual panels. This approach was used to monitor state forests in Indiana. It also could be applied to wilderness areas or other remote areas. The groups would be sized so that a crew could do an entire group during a single entry into the area (e.g., a 2-week sampling trip). For estimation purposes, the groups become the primary sampling units, thus variances would be computed using the group means.

Current Status and Path Forward

Early versions of DTIM were applied on the Mark Twain, Cherokee, Mississippi, Superior, Texas and Humboldt-Toiyabe National Forests, as well as to state forests in Wisconsin and Indiana. The Mark Twain collected the first season of data based on the intensified design in 2008. The other forests are in various stages of planning based on DTIM results.

The current version of this spreadsheet tool assists with steps 1-3, 5, and part of 6 (only evaluates sample size based on one to four subplots). A team of National Forest System (NFS) representatives is identifying the requirements for developing the Design Tool to help establish monitoring plans on National Forests as well as for use by other Forest Inventory and Analysis partners. Iterative use of DTIM has assisted in developing desired condition and objectives statements that are both meaningful and measurable. We will refine and complete DTIM so that it handles all 9 steps (with the help of ATIM). We also will include more questions and attributes with hope of extending beyond vegetation sampling to other resources that can be sampled with plots. We plan to expand DTIM's ability to evaluate sampling design alternatives and to optimize plot designs for customers who need to do so. DTIM will include a module to generate a spatially balanced list of plot locations. While designed to meet the needs of NFS, many of the new features also will be applicable to other NIMAC customers, such as states. NIMAC's goal is to make more efficient and comparable estimates across the landscape resulting in the sustainable use of our forest resources.

Literature Cited

Bechtold, W.A.; Patterson, P.L. 2005. The enhanced Forest Inventory and Analysis program--national sampling design and estimation procedures. Gen. Tech. Rep. SRS-80. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 85 p. http://www.srs.fs.usda.gov/pubs/20371

Lister, A.J.; Scott, C.T. 2008. Use of space-filling curves to select sample locations in natural resource monitoring studies. Environmental Monitoring and Assessment. http://www.nrs.fs.fed.us/pubs/3672

Scott, C.T. 1993. Optimal design of a plot cluster for monitoring. In: Rennolls, K.; Gertner. G., eds. The optimal design of forest experiments and forest surveys; Proceedings, IUFRO S.4.11 conference. London, UK: University of Greenwich: 233-242.