A New FIA-Type Strategic Inventory (NFI)

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Abstract—*New remote sensing technologies are now available to lower the cost of doing strategic surveys. A new sampling approach for the Forest Inventory and Analysis program (FIA) of the U.S.D.A. Forest Service is discussed involving a bi-sampling unit (BSU) that is composed of a field sample unit (FSU) centered within a large scale (1:1,000 to 1:3,000) photo sample unit (PSU) of the same size and shape. Within the PSU, a circular plot size is used for timber inventory and a strip plot for riparian buffer assessment and down woody material. On PSUs in previous studies in Alaska and Washington we counted or measured individual trees, tree height, crown area by digitizing the perimeter, plot crown closure, tree crown closure, tree branch density, plot area, and tree type (species and decay class). FSUs provide ground truth for PSUs as well as permanent and forest health plot information. Data for core FIA variables such as species, diameter, crown class, rotten/missing cull, and decay class may also be furnished by FSUs. National gross board foot volume per hectare estimates will be made from PSUs. Then permanent FSUs will provide growth, mortality, and defect factor information that are combined with the PSU estimates. Integration of PSUs with simultaneously collected Lidar data is used to improve tree height measurement accuracy in dense forest stands by providing local digital elevation models. Annual national estimates of stocking, mortality, and growth by tree species or forest type are obtained on a random sample chosen from a grid. Strata will be superimposed over this grid. The FSUs collected in the past will be incorporated in the new design which has the potential to result in a 50 percent reduction in cost relative to current FIA.*

Introduction

Why Forest Inventory is Needed

Throughout the development of the United States, forests that cover about one-third of the land base have been seen as a provider of goods and services (i.e., scenic, subsistence, industrial, and spiritual or cultural) (Haynes, 2003). This forest land supplies wood products, range land, recreation, and wildlife habitat. About 45 percent is public and 55 percent is privately owned (Haynes, 2003), (Wright and others, 2002), (USDA, 2002b). Because of the substantial interest in the economic, ecological, and sustainable basis of these forest resources, government agencies, industry, and others need a current and accurate inventory of their extent and condition (AF&PA, 1998). This inventory is used for substantive discussion and planning of forest land issues, such as "sustainability, national forest policy, carbon sequestration, changes in growth and productivity, changes in land use and demographics, ecosystem health, and economic opportunities in the forest sector" (Van Deusen and others, 1999). The Forest Inventory and Analysis program (FIA) of the U.S.D.A. Forest Service provides the only inventories broad enough in scope to serve these varying needs (Van Deusen, 1998).

The FIA Inventory Background, Current Approach, and Drawbacks

The statistical technique of double sampling became the foundation of the FIA forest inventory design in the 1950s. This technique uses remote sensing and ground sampling in conjunction with permanent sample plots for estimating forest area and volumes, growth, removals, and mortality (Birdsey and Schreuder, 1992). Currently there are 3 phases in the double sampling scheme: Phase 1, a relatively inexpensive land cover classification by Landsat Thematic Mapper or aerial photo plots; Phase 2, collection of detailed forest composition and condition by permanent and non-permanent field plots; and Phase 3, collection of expensive field plots from a subsample of Phase 2 plots that monitor indicators of forest health (Czaplewski, 1999); (USDA, 2003). These plots are located on an interpenetrating design of hexagonal cells with each representing 6,000 acres and sample locations that are distributed systematically about every 3 miles (5 km) (McWilliams and others, 2002). Limitations of the Phase 2 and 3 field plots are that private landowners may deny access and consequently information (Czaplewski, 1998a) or plots may be inaccessible.

The program mission of the FIA is to meet "the nation's needs for high quality information on the extent and condition of forests and forest resources in the U.S." (AF&PA, 1998). The operation of FIA conflicts with this national mission by operating in five regional offices (Cost, 1996) and as of 1998 resulted in "limited consistency for drawing conclusions at the national level" (Gillespie, 1998). As of 2002 one-fourth of the country was delayed or excluded from the implementation strategy of the Forest Service Strategic Plan (FSSP) (Willits and others, 2002), (USDA, 1999). The continuation of this condition was favored by a majority of those present at a 2002 FIA joint band meeting in Arizona (Willits and others, 2002), evidently favoring regional over national interests. This has contributed to the inability to completely sample all U.S. forest land. In addition FIA's role in data collection has significantly expanded to include forest health assessment and a vast array of non-timber resources, but all states are not included due to a 2002 and 2003 fiscal year funding shortfall (Willits and others, 2002).

State, federal, native, public, private, and international FIA data users have been demanding improved and more timely information on five politically sensitive issues: (1) timber supply, demand, and availability; (2) maintenance of biodiversity; (3) forest sustainability; (4) forest health; and (5) global climate change (AF&PA, 2001). They formed a panel of experts that felt that the usefulness of FIA was threatened by increasing inventory cycle length, lack of an accountable, responsive organization, and lack of funding. These demands for change were reflected in the Agriculture Research, Extension, and Education Reform Act of 1998 (16 USC 1642 (3)) or the Farm Bill of 1998 (USDA, 2001), (Smith, 2002) which specified a national, annual inventory and resulted in the merger of FIA with the USFS and EPA's Forest Health Monitoring program in 1999.

The new geo-positioning systems (i.e., global positioning systems (GPS), inertial navigation systems (INS), and inertial measurement units (IMU)) that have made light detection and ranging (Lidar) (Carson and others, 2004) and large scale photography (LSP) (Schwarz and others, 1993) practical have largely been overlooked by FIA. They have the potential to offer assistance in meeting the demands of FIA stakeholders and enabling all U.S. forest land to be sampled. LSP provides detailed, 3D-views of forests that can be interpreted and measured with accuracies comparable to field visits (Titus and Morgan, 1985), (Megown and others, 2003). Past research has indicated that LSP and Lidar may replace and/or supplement field data collection of timber inventory and ecosystem data (Grotefendt and others, 1996), (Andersen and others, 2001).

A New FIA-Type Strategic Inventory (NFI)

We think change in an inventory setup in the USFS is desirable. The new LSP and Lidar technologies are available and not being used. Although there is significant pride in what has been done and in what they are doing within the FIA organization an entirely new strategic inventory may enable the national mandate to be realized within budget.

Our proposed New FIA-Type Strategic Inventory (NFI) would incorporate large scale photography (LSP) as the primary sample unit with field subsampling for some variables, validation, and trend data. There are many remote sensing sources, but only LSP provides 3D vision and measurement comparable to field plot visits at less cost. Many of the FIA problems, such as excessive costs, landowner-imposed or dangerous access restrictions, inconsistent classification of conditions especially on or near boundaries, insufficient ecosystem sampling, and lack of timeliness, will be eliminated or reduced through LSP use. A grid that is one hundred times the current FIA grid will be superimposed over all national lands and territories. Available funds will determine the sample size collected from this grid. The current core and extended core FIA variables will be reduced to only those absolutely requisite for reporting. Generalized regression estimation will be used to analyze photo-field relationships. Annually, sampling costs have the potential to be reduced by 37 to 78 percent over the proposed U.S.D.A. Forest Service Strategic Plan (FSSP) (USDA, 1999). Because of the dramatically improved flexibility, suddenly emerging issues can be addressed much more rapidly and cheaply so that an increase in demand for data and an expanded clientele can be expected and should be planned for.

Methods

The components necessary to sample the entire U.S. forest land area with available funds are presented in the methods section. The sampling locations, units, and size are detailed as well as examples of the variables to collect. Point and change estimation and analysis are addressed.

Sample Locations

A fine grid with distances between plots of 0.5 km that overlays the entire U.S. land base and the current FIA sample locations will increase the potential sample location number by one hundredfold. This allows past FIA permanent plots to be re-sampled for change estimation, concentrated sampling for sudden changes such as storm or insect damage, change in sample plot design for key variables, and an increase in sample size if needed.

Sample Units

A primary, large scale photo sample unit (PSU) and a secondary field sample unit (FSU) will be used to collect timber and non-timber information. Both sample units have the same shape and the FSU is centered in the PSU. A circular plot is used for timber inventory and a strip plot for riparian buffer assessment and down woody material. Different ecological type surveys may have different plot shapes, but the photo and field plot shape will usually be the same to ensure that there is a one to one correspondence between visible photo and field measured variables.

Photo sample unit (PSU)—Navigation to PSU grid points will be by a camera equipped helicopter. Large scale photography (1:1,000 to 1:3,000) provides a large enough image size for measurement and interpretation of key field collected variables such as tree height and species. Metric film cameras will be used to eliminate the error that is introduced with non-metric cameras that can reach 5 percent (Reutebuch and Ahmed, 1997). Camera lens position and orientation provided by global positioning system/inertial navigation system (GPS/INS) (Schwarz and others, 1993) or a fixed-base camera system (Bradatsch, 1980), (Veress, 1980) will provide scale to enable photo measurement. Analytical stereoplotters or softcopy systems will be used for PSU interpretation and measurement. Improvement in ergonomic viewing and interpretation will be made. Regression estimation using relationships between PSU and FSU variables will permit efficient reporting of key parameters such as volume and forest type. Primary sampling by PSU will eliminate the majority of owner access restrictions or inaccessibility, avoid misclassification of condition classes, allow sampling of remote wilderness areas, and enable complete national coverage. Tree heights may be impossible to measure from PSU when stand densities preclude formation of a digital elevation model (DEM) due to an insufficient number of visible ground points. In this case extra field sample units (FSU) will be collected or light detection and ranging (Lidar) will be used to form a DEM. Circular or strip plot area will range from 0.2 to 30.0 ha for the given overlaps, scales, and camera formats (for example, 70 mm, 5x5 in, and 9x9 in). The use of smaller format metric cameras (in other words, 70mm or 5x5 in), that have significant cost savings over 9x9 in format cameras, will be encouraged.

Field sample unit (FSU)—The field sample unit (FSU) is a subsample that provides: information for developing relationships with PSU measured variables; validation of photo measurements or interpretation; information obtainable only by field visits; and change information through repeat measurements. Change information provides growth, mortality, removal, and defect. PSU orthophoto prints overlaid with photo interpreted stem maps, GPS receivers, and smaller scale resource photography will facilitate navigation to the FSU and verification of the plot center location. The collection of FSU data may still be limited but less frequently due to landowner restrictions. Portable stereo cameras will collect field plot stereo views (in other words, a terrestrial photo sample unit) from 3 angles to enable future data capture of new variables without a field visit.

Selection of Sample Size

The total survey cost depends on the overhead, sample unit cost, and sample size. Optimum sample size is determined by either fixing the total cost or the standard error (Schreuder and others, 2004). Even though there has been a dramatic recent increase in FIA funding above the FY99 funding level of $37 million (pers. comm. [Rhoads, 2003], [Schreuder, 2003]) the $82 million required by the U.S.D.A. Forest Service Strategic Plan still has not been reached (USDA, 1999). "It is unlikely there will be an increase in the Forest Service budget for the next 3 to 5 years" (remark [Rey, 2003])." Therefore, the number of samples taken in our new FIA-Type Strategic Inventory (NFI) will be limited to the available funding. The current United States land base that is delineated as forested will be used until a validated stratification method is employed.

The method of PSU and FSU sample location selection is as follows. Two coarse grids, each with different variable cell sizes, will be superimposed over the fine grid each year to ensure systematic and complete coverage (figure 1). Two cell sizes will be used that provide the number of PSU and FSU samples funded. The FSU grid will always be more coarse than the PSU grid.

NFINE = population size of fine grid points = 36,000,000

nPSU = current annual number of PSU funded

nFSU = current annual number of FSU funded (assumed 10 percent of nPSU)

The proportion of PSU that are field sampled could vary due to experience (for example, even-aged

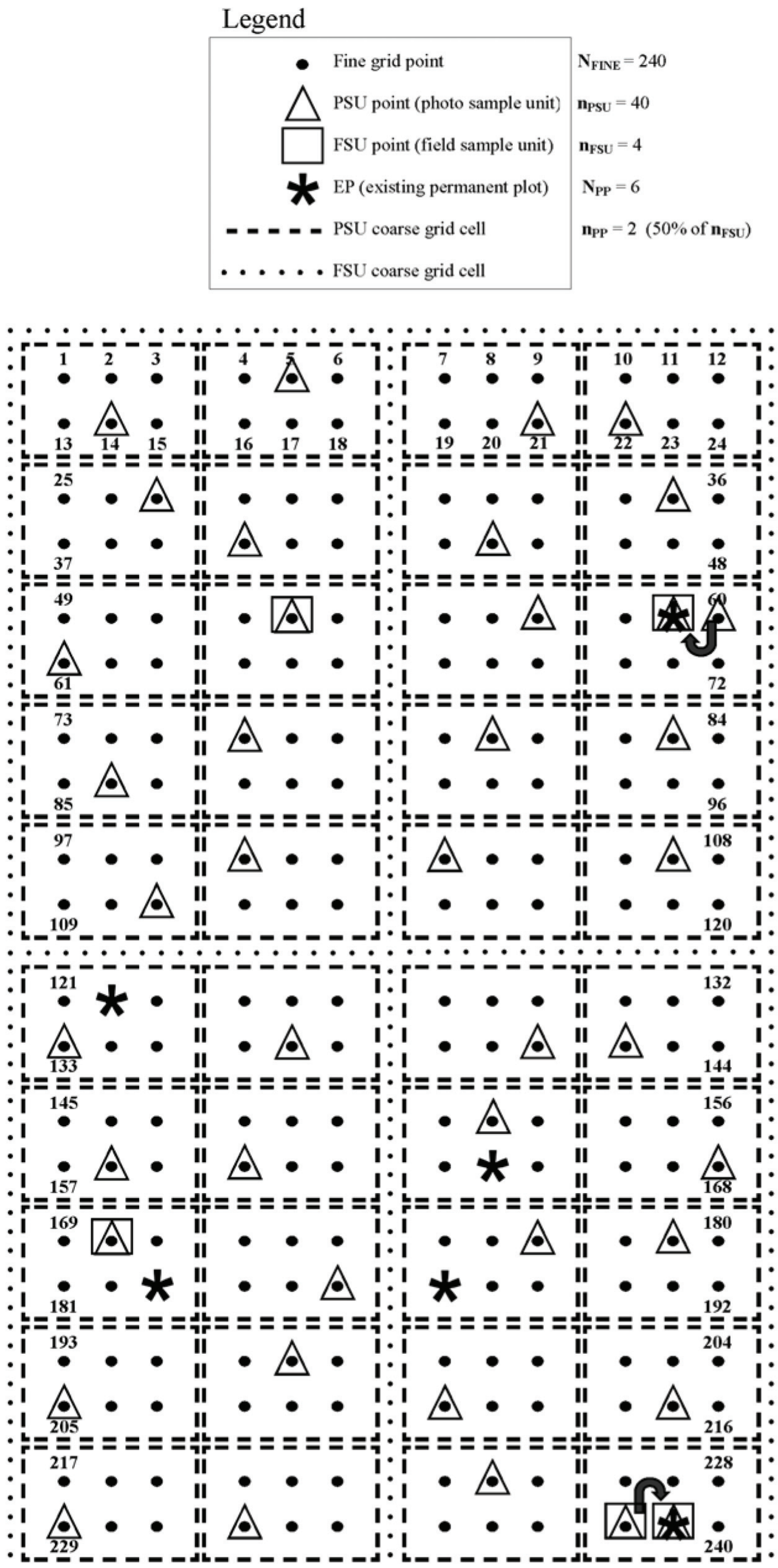

Figure 1. Example NFI sample size selection process.

conifer stands may require fewer samples than old-growth stands).

NPP = population of existing permanent FIA field plots (EP) = 121,993 (USDA, 1999)

nPP = current annual number of EP plots to re-sample

Within each PSU coarse grid cell simple random sampling without replacement (SRS) will be used to form a list of the NFINE that fall within it. The first unsampled fine grid point in each list will become a PSU location and part of the nPSU. SRS without replacement will be used for each FSU coarse grid cell to form a list of the nPSU that fall within it. The first unsampled PSU location of each list becomes the FSU. If additional funding is provided by a stakeholder or a special event occurs requiring additional sampling the next unsampled points from the random list are chosen.

The NFI has no previous FSU for change estimation. Therefore a transition sample selection method will be followed for the first five years. Under this transition plan, the nFSU will be sorted into a random list. The first 50 percent of the FSU sample that have at least one EP plot in its cell will be used to select the sample nPP for re-measurement. A geographic information system (GIS) program will be used to locate the EP plot that is closest to each FSU. The FSU will be shifted to the EP position, a transition method of field measurement will be developed and used, and the PSU that was associated with that FSU will also be shifted to the EP plot location.

After the first five years, re-measured FSU plots will include NFI FSU plots as well as NPP. In the subsequent annual surveys half of the FSU are re-measured plots and half are newly located. This provides a constantly increasing field sample size for improvement in FSU prediction from PSU. Annual surveys are frequent and standard error of estimates will indicate survey reliability. If it is too low for concerned stakeholders this will provide justification for increasing the budget. Sampling PSU without replacement will allow more accurate area verification and adjustments over time; increase the probability of encountering small area ecotypes; and sample more riparian habitat. After other remote sensing methods

Table 1. Example U.S.D.A. Forest Service Strategic Plan (FSSP) core and extend core variables [USDA, 1999 #295], [USDA, 2002 #402] forming the basis for the new FIA-Type Strategic Inventory (NFI) variables with their priority and sampling combinations.

Variable Name	Core (C) or Extended Core (EC)	Sampling Unit Combination	Priority Code	Reliability Code
Plot Number	C	PSU	1	1
Forest Type	C	PSU	1	2
Owner Group	C	PSU	1	OFC
Stand Structure	C	PSU&FSUi	1	2
Slope	C	PSU	2	CG
Ground Cover	C	FSUi	2	1
Crown Cover	C	PSU	1	1
Soil Erosion	C	FSUi	2	1
Species	C	PSU	1	2
Diameter at Breast Height	C	PSU&FSUi	1	2
Percent Rotten/Missing Cull	C	FSUi	1	2
Uncompacted Crown Ratio	C	FSUi	2	2
Site Tree Diameter	C	FSUi	1	1
Site Tree Total Height	C	FSUi	1	1
Lichen Species	EC	FSUi	1	2
Lichen Relative Abundance	EC	FSUi	1	2
Crown Diameter - Wide	EC	PSU	1	1
Foliage Transparency	EC	PSU&FSUi	2	2

NFI Priority Codes: 1 = required for annual reporting, 2 = collected if funding provided;
Method Codes: OFC = office work, CG = compute from GIS; and
Reliability Codes: 1 = certainty, 2 = very good likelihood, 3 = maybe as shown from research.
Note: FSUi is the ith type of field plot used.

have been validated, strata may be superimposed over this grid.

Variables

The PSU and FSU variables collected must relate to the required annual reporting items such as land area, number of trees, and growth and the required classifications, such as forest type and diameter class (USDA, 1999). These variables will be chosen from the current core and extended core variables in the U.S.D.A. Forest Service Strategic Plan (FSSP) (USDA, 1999), (USDA, 2002a) and will be collected by three sampling unit combinations: PSU only; PSU and FSU combined with generalized regression estimators (Schreuder and others, 2004); and FSU only. The final list of variables will be broken down by priority of collection and which sampling unit combination will be employed to collect them. Companies or environmental groups interested in priority 2 variables could supply funding to collect them. Examples of priority 1 variables are tree height from PSU only, photo predicted volume from PSU and FSU combined, and tree age from FSU only. Table 1 provides additional examples.

Point and Change Estimation

The variables will be used for point and change estimation, such as current volume and volume removed, respectively. Point estimation is made from the annual PSU and FSU. Change estimation is made from the subsample of FSU points that are randomly selected for re-sampling. Permanent plot information from FSU that were established prior to this new strategic design will be incorporated in these estimates so that their valuable change information is used.

Data Analysis

Quality control, data transformation, American Standard Code for Information Interchange (ASCII) file production and geographic information system (GIS) layers formation are data processing tasks that will be performed on PSU and FSU data. All the raw data will be stored in a national, common format and maintained on FTP sites for accessibility. User friendly programs written in 'R' will be provided that combine raw data into summary datasets to facilitate public user analyses (R, 2004). FIA staff will develop equations from PSU and FSU variables that estimate tree conditions, such as gross volume (Aldred and Sayn-Wittgenstein, 1972), (Grotefendt and Pickford, 1998), (Timberline, 1993). PSU measurements will be used to compute direct estimates (for example, crown closure equals sum of plot tree crown areas divided by fixed plot area). Change or trends will be computed from FSU plot re-measurement differences. Adjustment factors (AF) will be developed from FSU only variables for application to PSU estimates for items that are hidden such as understory shrub composition and fine woody debris. Spatial data will be derived from GIS algorithms (for example, distance and azimuth of trees from the plot center or to the nearest stream bank). Standard analyses and reports that are mandated, such as change detection, by the Farm Bill of 1998 will be major products of NFI (USDA, 2001). Extrapolation of the PSU and FSU data and plot characteristics (for example, volume) to national estimates will be based on PSU classification and the number of acres each sample represents until a validated method of stratification is proven. The use of PSU to validate the stratification tools of small scale aerial photos and satellite imagery will be studied.

Costs

The cost savings that PSU collection provides is one of NFI's main advantages. An indication of this is illustrated by using known costs for PSU collection (Grotefendt and Light, 2004), (Grotefendt and Fairbanks, 1996), (Grotefendt and Martin, 2003) and Forest Service FSU cost estimates by Czaplewski (Czaplewski, 1998b). The cost estimate to collect, measure, interpret, and produce raw data files nationally is $349 per PSU. The cost estimates for the collection of one FIA plot ranged from $600 to $1,240 per plot. This was dependent on whether it was a one day plot (One-Day), a wilderness plot (WP), or a forest health monitoring plot (FHM). The Forest Service Strategic Plan (FSSP) (Gillespie, 1998) specifies a total of 15,124 field plots in the southern Pacific Northwest Region (i.e., Oregon, Washington, California, and Hawaii). If 7 percent, 10 percent, and 83 percent of these were FHM, WP, and One-Day plots, respectively with 10 percent of the total being subsampled as FSU, the NFI would save 37 percent over the USDA Forest Service strategic plan (FSSP) when overhead cost differences are not included in the comparison.

The NFI national annual total plot cost is $10,132,334 using our PSU and Czaplewski's FSU cost estimates with the same ratio of field plot types given in the southern Pacific Northwest Region example above. The FSSP national annual total plot cost is $45,252,000 (see tables 3 and 4 in (USDA, 1999)). Using these two annual plot cost estimates without overhead NFI would save 78 percent. The average savings of the NFI may be over 50 percent based on these southern Pacific Northwest Region and national annual estimates.

A NFI overhead item not borne by the FSSP would be the additional cost of one to two million dollars for a research proposal to fine-tune its sampling approach. This research would determine: the number of FSU needed to calibrate PSU in different forest types; the amount of PSU interpretation and measurement training required; methods to reduce photo interpretation fatigue; and what kind of plots are best for calibration.

Results

These NFI methods have been partially implemented in Alaska and Washington for forest inventory and riparian buffer monitoring. Remote areas of rough topography were accessed and photographed even under adverse weather conditions. For forest inventory, fixed area PSU were collected from a random list chosen from a superimposed systematic grid overlaid upon 80,000 acres. PSUs of riparian buffers along streams were collected from the western half of Washington state and southeast Alaska extending from Juneau to Ketchikan. Photo measurements were comparable to field measurements (Grotefendt and others, 1996), (Grotefendt and Pickford, 1998). The correlation of photo measurements of individual tree dimensions to tree volume in old growth forest predicted average plot volume to within 10.9 percent of actual volume as determined from ground plots (Grotefendt and others, 1996). The absolute average tree height difference between photo and field clinometer measurements was 6.1 ft (s.d. = 4.7 ft, n=214). The absolute average difference between photo predicted and field measured diameter at breast height (DBH) was 2.3 in (s.d. = 2.2, n=109) (Grotefendt and Pickford, 1998). These and other applications provided cost information and an indication of the potential of the NFI (Grotefendt and Light, 2004).

Discussion

The proposed new FIA-Type Strategic Inventory (NFI) is designed to reduce costs, increase amount and timeliness of information, and will promote an increased user base. New ecological sampling needs, such as riparian, are met by NFI as well as timber inventory requirements. Flexibility in plot size and shape ensure adaptability to specific variables and plot locations are known. Flexibility in intensity of sample size from the fine grid improves detection of small area ecotypes. Timely annual results are achievable with reduced field effort.

NFI is untested in a national inventory and will require a major change in current techniques. Nonetheless, it has been applied across large areas which indicate its potential. Exploratory research will be required to better understand relationships between PSU variables and desired FSU variables across a broader geographic extent.

There also are conditions, such as dense forest stands, where currently a PSU may be unable to collect the needed information and a FSU will still be required.

The potential 50 percent field sampling cost savings that NFI may provide over the USDA Forest Service Strategic Plan (FSSP) costs make its proven methodology an attractive alternative and can be readily adapted to changes in funding. It is less dependent on owner goodwill, weather conditions, budgeting, and it has been applied in wilderness and remote Alaska sites. If catastrophic storms or suspected environmental concerns arise, a sample can be quickly collected and analyzed for the problem area. Interpretation and measurement of PSU can employ FSU field staff in the winter when field work is inefficient. This can increase employee retention and continuity of skilled data collectors.

Larger quantities of data, such as tree heights, can be collected more cost effectively. Information from PSU are more directly comparable to that from other remote sensing techniques, such as Lidar, small scale aerial photography, and satellite visible-infrared remote sensing, and can be used as validation for these techniques. This will improve reliability of area estimates. The PSU may be re-evaluated without field work if new questions arise, which is not possible with FSSP field plots.

Further research in the use of LSP with other techniques could provide potential enhancements such as development of Lidar or interferometric synthetic aperture radar (IFSAR) relationships; automation of individual tree assessment using LSP by Gong (Gong and others, 2002); and incorporation of small scale photography to automate facets of individual tree and crown assessments (ITC) (Gougeon and Leckie, 2003).

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