

The Role of Pre-Field Operations at Four Forest Inventory Units: We can see the trees, not just the forest

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Abstract:

The Forest Inventory and Analysis (FIA) program attempts to inventory all forested lands throughout the United States. Each of the four FIA units has developed a process to minimize inventory costs by refraining from visiting those plots in the national inventory grid that are undoubtedly nonforest. We refer to this process as pre-field operations. Until recently, the pre-field process of differentiating forest from nonforest plots received very little attention or scrutiny. No national pre-field manual currently exists, nor does any other form of formal documentation of the pre-field process. Pre-field specialists from all four FIA units gathered in December 2007 to discuss the role of pre-field operations, to identify national commonalities, to share techniques and technologies, and to explore opportunities to increase efficiency and expand functionality. The meeting revealed that each of the four FIA pre-field teams serves the same two fundamental roles: 1) identifying plot locations that are potentially forested and therefore require visitation by a field crew, and 2) subsequently preparing field materials. Each pre-field team currently practices some form of quality assurance, yet no common procedures exist regarding pre-field quality assessment and quality control. Participants agreed that additional information could be derived from the photo-interpretive aspect of this process via the collection of land use and crown cover data from all FIA plots, including those that are not visited by field crews. Such information might facilitate estimates of nonforest conditions with trees, e.g., urban forest, and land-use changes, e.g., the development of formerly forested lands. This paper documents the current status of pre-field operations, suggests areas for future process improvements and collaboration among the four FIA units, and evaluates the potential of the pre-field process to provide additional information to the inventory.

Keywords: pre-field, forest canopy, canopy cover, crown cover, nonforest land use, aerial photography, National Agriculture Imagery Program, image segmentation

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Introduction

The Forest Inventory and Analysis (FIA) program attempts to inventory all forested lands throughout the United States. The national FIA sampling grid includes a nontrivial proportion of nonforest plots, so a major means of increasing the program's efficiency has been to minimize unnecessary field visits to nonforest plots. Each of the four FIA units has developed a process to reduce inventory costs by refraining from visiting plots that are undoubtedly nonforest (Reams et al. 2005). We refer to these processes as pre-field operations.

Pre-field specialists distinguish potentially forested plots from plots that are undoubtedly nonforest by examining aerial photographs, maps, and previous inventory data, if any exist. They observe individual trees, patches of trees, and entire forest areas as they examine each plot, and their interpretation focuses on whether each plot meets the FIA definition of forest. Therefore, the pre-field process involves evaluating the land use and tree cover of every plot in the national FIA grid. Plots that are deemed to be nonforest by pre-field specialists are then omitted from the field inventory.

Two aspects of this process are particularly remarkable. First, pre-field operations have the ability to affect estimates of total forest area by constraining the sample of potentially forested plots. For this reason, the pre-field process should be examined for consistency, repeatability, and efficiency. Currently no national pre-field manual exists, nor does any other formal documentation or consistent quality assurance of pre-field protocols. Second, pre-field specialists are in a unique position to quantify and document variables pertaining to land use and tree cover at all FIA plots, including nonforest plots that are not visited by field crews.

Thus, pre-field operations not only have a major impact on the overall forest inventory, but as Reams et al. (2005) suggested, they may also be currently under-utilized. The purpose of this paper is to document the current state of FIA pre-field operations nationwide, and to suggest potential process improvements that increase efficiency while also providing additional information for the inventory.

The Current Status of Pre-field Operations

Pre-field specialists from each of the four FIA units (Interior West, Northern Research Station, Pacific Northwest, and Southern Research Station, hereafter referred to as IW, NRS, PNW, and SRS, respectively) met in Salt Lake City on December 4-5, 2007, to discuss the current state of pre-field operations. The objectives of this meeting were to discuss the role of pre-field operations, identify national commonalities, share techniques and technologies, and explore opportunities to increase efficiency and expand functionality. Participants in this meeting ascertained that pre-field operations are remarkably similar at each of the

four FIA units, and they were thus able to summarize the status of pre-field nationwide.

Pre-field operations at all four FIA units encompass two basic functions. First is identification of plot locations that are potentially forested and therefore require visitation by a field crew. The second function is preparation of field materials such as old and new data sheets, and maps and imagery for documentation and navigational purposes.

The basic decision rule for distinguishing potentially forested plots from nonforest plots is the same at all units. If there is any evidence that a plot might meet the FIA definition of forest, it is scheduled for field visitation. The difficulties of identifying “field visit” plots vary due to some units being several cycles into the inventory, and some being in their first cycle. NRS and SRS have previous inventory data to inform their interpretation of aerial imagery, whereas IW and PNW are trying to determine whether a plot that has never been visited might be forested. The portion of the entire sample grid that is scheduled for sampling in any given year is referred to as that year’s panel (Bechtold and Patterson 2005, Reams et al. 2005).

Digital imagery provides the basis for classification of each panel’s plots into visit and non-visit plots, where non-visit plots are then assumed to be synonymous with nonforest. After the December 2007 meeting, all units began using the Image Server provided by the Remote Sensing Applications Center, except in states where National Agriculture Imagery Program (NAIP) imagery was recently made available and was not yet updated in the Image Server. Pre-field specialists in Alaska are at a distinct disadvantage due to the spatially and temporally variable availability of high-quality aerial imagery in that state.

Most of the developmental effort for the pre-field process has been directed at the development of technological tools and file structures to support pre-field operations. All units have a user interface that is linked to aerial imagery and previous inventory data (where it exists), and is also used for pre-field data entry. These tools and file structures are parallel in function but different in practice. Each interface was built with a different programming language and uses a different database structure. Therefore, the effort required to develop graphical user interfaces and pre-field database has been replicated at each of the four FIA units.

All units include, or are about to implement, quality assurance programs as part of the pre-field process. Some units assess repeatability of visit/non-visit determinations based on aerial imagery, while others assess the accuracy of equating non-visits with nonforest, i.e., “non-visit” plots are field-visited and checked to make sure they are nonforest. The quality assurance processes at SRS, NRS, and PNW assess the repeatability of visit/non-visit determinations. SRS and NRS also field-verify a portion of both visit and non-visit plots. PNW plans

to begin field verification in the upcoming season, and IW plans to implement a quality assurance process that assesses the repeatability of visit/non-visit determinations and field-verifies a portion of both visit and non-visit plots.

Each pre-field team assembles some type of plot packet (or jacket, folder, etc.) for use by field crews. The packets may contain imagery (stereo photo pairs or printed digital imagery), travel maps, and field reference sheets. Much of this work is done manually by pre-field specialists and field staff.

Recommendations for Future Collaboration and Process Improvement

Participants at the December 2007 meeting developed a list of three major areas for improvement and collaboration: development of pre-field user interface tools, automated preparation of field materials, and standardization of the quality assurance process. The first two areas would involve collaboration among specialized programmers and database managers, or creating a pre-field programming group. The third area would require initiating a focused quality assurance protocol that could evaluate the repeatability of visit/non-visit determinations, evaluate the uncertainty associated with these determinations, and include documentation of the pre-field process.

User interface tools

The development of pre-field user interfaces requires specific programming expertise. Each unit currently uses its own user interface, yet the basic requirements of each pre-field team are very similar. As FIA migrates to new databases and data centers, old tools will likely become obsolete. The development of a template, which could then be adapted to each unit's specific requirements, would make more efficient use of programmers' resources.

The ideal interface for pre-field operations would include the following characteristics: (1) it would permit on-screen inspection of each plot, including links to georeferenced aerial imagery, maps and other ancillary spatial data, and previous inventory data, (2) the link to aerial imagery and spatial data must be flexible enough to integrate new data sources as they become available, (3) the interface would also permit pre-field data entry and connect directly to the relevant data tables, and (4) data entry portions of the interface must also be sufficiently flexible to incorporate each unit's regional pre-field variables, e.g., in IW, distance from a maintained road to the plot center.

Automated preparation of field materials

The pre-field function of preparing field materials could be made much more efficient by automating some of the basic tasks. Field materials include new data forms (referred to as plot sheets, reference sheets, drawsheets, etc., at different

units); previous inventory data forms; printed imagery and/or aerial photographs; and topographic maps. Streamlining this process could be accomplished by developing programs or scripts that generate printable maps including topographic maps and imagery, and also retrieve scanned and archived versions of previous inventory data. The ideal tool would print these materials, along with new field data sheets, as one bundle per plot.

The ideal tool proposed here could eventually lead to the creation of virtual plot packets, which would not only streamline the pre-field process but would also enable remote access by field crews anywhere. This ideal field preparation tool would require that previous inventory data be available digitally, and that old field data sheets exist as scanned, digital copies. Most FIA units have already scanned, or are in the process of scanning, their previous inventory data sheets. However, distribution of virtual plot packets to remote duty stations could be constrained by the availability of hardware and intranet connections.

Since the December 2007 meeting, Doug Shipley of SRS has developed a prototype tool that addresses one function of our hypothetical ideal tool. This tool relies on attributes of a point shape file to designate the plots of interest, and then produces print imagery using either NAIP imagery or the RSAC Image Server (Doug Shipley, pers. comm.). At least two FIA pre-field teams are currently using this tool to prepare imagery for inclusion in field packets.

Quality assurance

Due to the potential impact of visit/non-visit determinations on the overall forest inventory, it is important to know whether those determinations are both accurate and repeatable. An effective quality assurance program would include both quality control to evaluate the repeatability of visit/non-visit determinations, and quality assurance to evaluate the uncertainty associated with these determinations. It would also include documentation of the pre-field process, and why a particular plot was, or was not, sent to the field.

A quality control program would involve setting standards and processes to control the data acquisition process. This would include standards for training of pre-field specialists, as well as hot and/or cold checks to evaluate the need for more training. Hot and cold checks involve making a determination with a priori knowledge of the initial determination. There are two possible types of pre-field hot or cold checks: 1) a field visit to determine whether the pre-field determination was correct, and 2) a comparison of the determination made by a pre-field expert using the same imagery and materials the original specialist used. This type of quality control is similar to the method that is currently used for quality control in the field.

A quality assessment program would assess whether the error in pre-field visit/non-visit determinations is within a range of acceptable errors. The smaller

the acceptable error rate is, the larger the sample of plots must be in order to be confident that the actual error rate is below the acceptable error. This process would be similar to the blind checks performed in the field, where repeatability is assessed using a large number of blind checks that compare two sets of independent observations. In the case of pre-field quality assurance, the blind checks could be based on two remote, image-based determinations, or on a field visit as compared to a pre-field determination.

Another aspect of quality assurance is documentation of the overall process. At the December 2007 meeting, all participants agreed that the pre-field process should include documentation of the data and source of the imagery that was used to exclude nonforest plots from the field inventory. Documentation should include enough information to indicate why each plot was designated as either a visit or non-visit plot.

Region-Specific Quality Issues: It is clear that although pre-field operations are similar at the four FIA units, unique challenges exist at each unit. Three of these issues are briefly summarized here: GPS coordinate quality, ownership data quality, and packet tracking and accountability.

Most plots within NRS and SRS have been visited multiple times due to the shorter five-year inventory cycle in those regions (Reams et al. 2005). As a result, pre-field specialists at those two units exert substantial effort examining multiple sets of GPS coordinates to identify the one that appears to be the most accurate. Their main objective is to provide field crews with the most accurate coordinates possible to enable easier re-location of the plot center. In addition, accurate plot coordinates enable better linkages between plots and other geospatial datasets. This is not yet a problem at IW or PNW because they are still in their first inventory cycle in most states.

The issue of plot ownership is somewhat problematic for IW and PNW, where permission-to-access requests are sent to private landowners and public land management agencies prior to the field season. Thus it is critical to identify plot ownership during preparation of field materials. Map servers are available online for some counties, but where they are not available field crews must visit county courthouses to identify the owners of privately owned plots. ALP (the Forest Service's Automated Lands Program) may eventually help resolve issues on national forest lands, but other lands such as BLM and state may still prove problematic and thus require a new process for accurately identifying land ownership. Specific units are examining different protocols of updating plot ownership data prior to field data collection, but no standard protocol exists.

Within all units, field plot packets tend to travel more widely than nearly any FIA staff member, as the packets are sent from pre-field teams to field supervisors to field crews to quality control crews and back to the office. Therefore, it may be useful to create systems to track plot packet locations and thus maintain

accountability for field materials. Currently, SRS has a fairly extensive tracking and accountability system, and IW has a packet database and check-in/out system for office use.

Expanding the Utility of Pre-field Operations

Pre-field specialists from each unit agreed that additional information could be derived from the photo-interpretive aspect of making forest/nonforest determinations. Specifically, they were confident that it is possible to document crown cover and land use at all FIA plots; they just need a formal protocol to guide the process. The pre-field process involves assessing whether each plot meets the current FIA definition of forest, which is defined as land that is $\geq 10\%$ stocked by forest trees of any size (or $\geq 5\%$ cover in IW), or land formerly having such cover, and is not currently developed for a nonforest land use (USDA 2007). Thus, the process involves making judgments about the land use and tree cover of each plot, but documentation of these variables is not standard protocol.

Although nonforest land use is not part of the national protocol, all units currently record a land use code for nonforest plots as part of the pre-field process. Pre-field observers use the national FIA land use categories and interpret the land use at the plot center.

Recording land use and crown cover variables would meet several objectives. First, it would document why a plot was, or was not, scheduled for field visitation. Second, it would facilitate categorization of nonforest plots for adjunct vegetation inventories, such as urban forests or rangelands (Figure 1). Third, recording land use would enable tracking of land use changes over time, such as conversion of forest to agriculture or developed areas. Finally, the variables would allow for a flexible future definition of forest. At least within IW, a historically inconsistent definition of “forest land,” as well as procedural changes in forest inventory, have

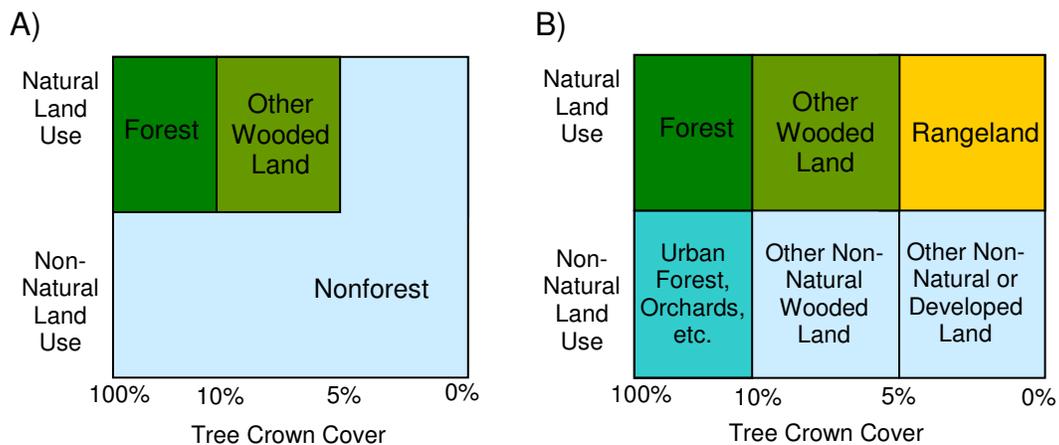


Figure 1: The relationship between land use and crown cover. A) The current ability to categorize FIA plots according to land use and crown cover. B) The ability to categorize FIA plots if land use and crown cover are recorded for all FIA plots.

led to difficulties in comparing forested area over time. Knowing the history of land use and crown cover at each plot would enable analysis of long-term dynamics as inventory definitions and procedures change.

Methods of remotely estimating crown cover

As mentioned above, pre-field specialists at the December 2007 meeting agreed that it is possible to classify the land use and quantify the crown cover of each FIA plot as part of the pre-field process. At this meeting, a few potential methods were discussed, but none was selected as the group agreed that more study was needed before selecting a preferred technique.

The Interior West Pilot Study: We recently completed a pilot study to identify a method of remotely estimating crown cover that produces accurate, efficient, and repeatable estimates for any given plot. The analysis for this pilot study is in progress (Goeking et al., in prep.) but preliminary results are presented here.

The Interior West (IW) FIA area was selected for the pilot study because crown cover is a regional field variable in IW. This variable provided us with ground-truth data against which we could compare various methods for remotely estimating crown cover.

We compared three methods of remotely estimating crown cover: ocular estimates, dot-count samples, and image segmentation. These three methods were applied at 100 plots that were sampled from the population of all single-condition plots that were visited in five IW-FIA states (Arizona, Colorado, Idaho, Montana, and Utah) during the 2007 field season. Each method of estimating cover was applied to the area inside a 1-acre circle around the plot location center. All estimates were based on 1-m resolution NAIP imagery.

Ocular estimates were made by three observers aided by a visual crown coverage scale. Dot counts consisted of 50 random points within each plot's 1-acre sample circle, with a minimum distance of 2 m between points (Figure 2). Image segmentation was accomplished using the Feature Analyst tool provided by the Forest Service's Remote Sensing Applications Center (Figure 3).



Figure 2: Examples of three plots showing the distribution of dots used for dot counts.

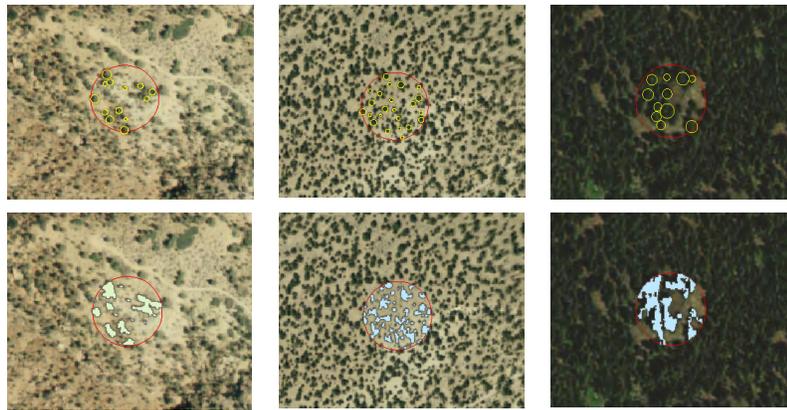


Figure 3: Examples of three plots showing the polygons digitized for use in image segmentation (top) and the output classification of crown cover (bottom).

We assessed the accuracy of the three methods by comparing our estimates against field-recorded crown cover. Korhonen et al. (2006) found line intersect sampling to be an accurate and unbiased method of estimating canopy cover as compared to other ground-based methods, although their sample intercepts were denser than those used by IW. Field transects in IW consist of four 25-ft transects, one in each of the cardinal directions, on each subplot (Figure 4). Intercepts were recorded in 1-ft increments. Intercepts are defined as points within the crown perimeter of tally tree species of any size. Each subplot has a total of 100 possible “hits” of tree cover; an entire plot has 400 possible hits (USDA 2007).

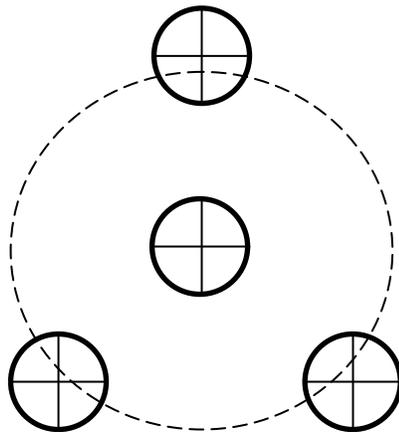


Figure 4: Configuration of transects used for measuring crown cover on IW FIA plots. Dashed circle represents an area one acre in size. Transects are shown by four solid lines per subplot. Each transect includes 25 transects that are spaced 1 ft. apart.

Results from the Interior West Pilot Study: Initial results are depicted in Figure 5. Dunnett’s nonparametric test for multiple comparisons against a control indicated that only image segmentation produced estimates that were not

significantly different from field transects ($\alpha=0.05$), although dot-count estimates were only marginally statistically different from the field transects ($p=0.06$). All methods tended to over-estimate crown cover (Figure 6). Ocular estimates were the most biased, followed by dot-counts and image segmentation, in that order. A more rigorous statistical analysis of these data appears in Goeking et al. (in prep.).

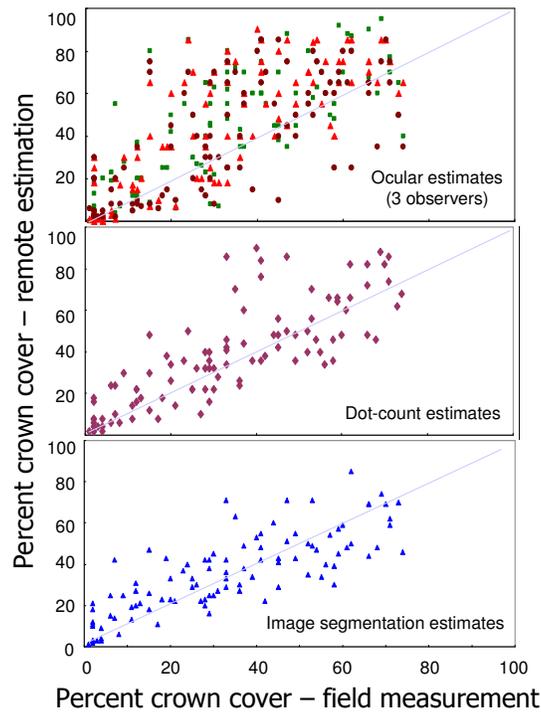


Figure 5: Relationship between field-measured crown cover and remotely estimated crown cover using ocular estimation, dot counts, and image segmentation methods (n=100).

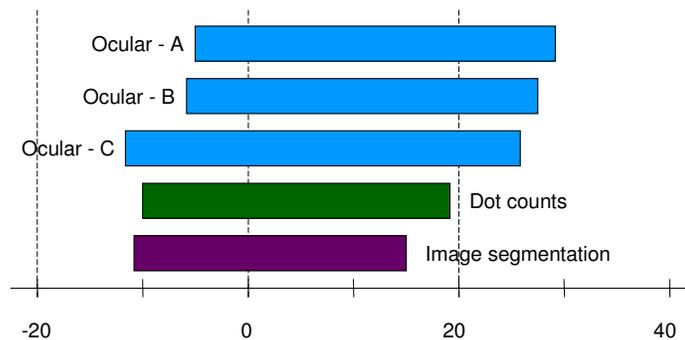


Figure 6: Differences between the crown cover estimates produced ocular estimates (three observers), dot counts, and image segmentation methods compared to field-measured crown cover. The center of each bar represents the mean difference between the estimates and the field-measured values. The width of each bar represents one standard deviation around the mean of these differences. The position of each bar relative to zero indicates the bias of that method of remotely estimating crown cover, relative to field measurements.

Logistical Considerations: Ocular estimates differed widely among the three observers, indicating that they are not very repeatable. The one consistency among the three interpreters was an overall bias toward overestimation. In general, ocular estimation is by far the fastest method of estimating crown cover, but these estimates are also the most biased, least accurate, and least precise.

Dot counts were less efficient than ocular estimates, but slightly more efficient than image segmentation. They also produced the most consistent and precise estimates, being slightly more precise than image segmentation. However, this method tends to overestimate crown cover at all levels, although the bias is less than that shown by ocular estimates.

Image segmentation is the most time-intensive due to the image pre-processing and on-screen digitizing that it requires, but it is also the least biased and most accurate overall. This method has the unique advantage of producing polygon output, which could be useful for estimating landscape-level parameters such as patch size, perimeter to area ratios, and other landscape metrics. However, image segmentation tends to overestimate crown cover at plots with very low crown cover (<20%). In woodland areas of the Mojave and Sonoran deserts, tally and non-tally species appear very similar in NAIP imagery, and thus lead to over-classification of crown cover. Analyses in progress are investigating whether it is possible to reduce the bias of image segmentation at low crown cover by reducing over-classification of shadows and non-tally species.

Summary

The four FIA pre-field teams fulfill the same fundamental functions within their respective units, so their parallel roles present several opportunities to increase efficiency by reducing duplication of effort. The primary recommendation of the pre-field workshop participants was to create a programming group that could assist pre-field teams in developing new tools for plot inspection, photo-interpretation, and data entry; and for automating the preparation of field materials. The pre-field process could also be made more robust by developing a standard quality assurance protocol that would document the pre-field process, provide guidelines for training and quality control, and assess the error rate of visit/non-visit determinations.

As pre-field specialists determine whether each plot should be visited or not, they evaluate the land use and tree cover of every plot in the national FIA grid. They already record a land use variable, even on nonforest plots. Since objective methods exist for remotely quantifying crown cover, the utility of pre-field operations could be expanded by recording both land use and crown cover for all FIA plots. Doing so would not only provide clear documentation of pre-field protocols, but would also enable analysts to estimate the magnitude of other vegetation inventories, track land use changes at all FIA plots, and estimate the impact of changing the definition of forest. There are tradeoffs among the various

potential methods of estimating crown cover, including expediency vs. cost; accuracy, bias, and precision; and potential ability to assess landscape-level parameters.

In summary, pre-field operations may have a major impact on the overall forest inventory by potentially constraining the field sample, and may also be currently under-utilized. Collaboration among pre-field teams may lead to increased efficiency and accuracy, and simultaneously contribute additional information to the inventory.

Acknowledgments

Pre-field staff from each of the four FIA units contributed to this paper through their participation in the national pre-field workshop on December 4, 2007. Participants included Jennifer Bakken and Jason Toombs of IW-FIA; Perry Colclasure, Melissa Patterson, and Gerry Bednarczyk of PNW-FIA; Doug Shipley of SRS-FIA; and Dale Gormanson, Jeff Wazenegger, and Rich McCullough of NRS-FIA. Phyllis Adams of PNW-FIA and Paul Patterson of IW-FIA also provided valuable guidance regarding quality assurance of the pre-field process. Thanks also to Ken Brewer, Kevin Megown, and Mark Finco of the Remote Sensing Applications Center for graciously hosting the workshop.

IW analysts John Shaw and Larry Deblander helped focus the purpose and need for estimating crown cover at all FIA plots. Jennifer Bakken and Jason Toombs assisted with the evaluation of various methods of remotely estimating crown cover. Doug Shipley of SRS, Chris Toney of RMRS, and other reviewers at Rocky Mountain Research Station provided valuable editorial comments.

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