# ALGORITMIC DECISION RULES FOR ESTIMATING GROWTH, REMOVALS, AND MORTALITY WITHIN A NATIONAL-SCALE FOREST INVENTORY (USA)

William H. McWilliams, Carol L. Alerich, William A. Bechtold, Mark Hansen, Christopher M. Oswalt, Mike Thompson, and Jeff Turner

## ABSTRACT

The U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis (FIA) program maintains the National Information Management System (NIMS) that provides the computational framework for the annual forest inventory of the United States. Questions regarding the impact of key elements of programming logic, processing criteria, and estimation procedures were raised by national FIA Information Management Band (IMB the review of the estimation procedures for forest "inventory" change, i.e. growth, removals, and mortality (GRM). The goal of the study was to review these questions and develop Decision rules to provide transparency to otherwise undocumented algorithmic pathways. These questions are important because they are the basis of FIA's timber volume, tree biomass, and carbon stock GRM estimates for the United States. This study highlighted an incremental benefit of the annual system—the benefits of consistent rules, transparent methods, and reliable trend estimates for tracking forests in time and space accrue with each new panel.

## INTRODUCTION

The U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis (FIA) program maintains the National Information Management System (NIMS) that provides the computational framework for the annual inventory of the United States. (NIMS version 4.0 was used for this study.) The NIMS algorithms process all FIA field and other base measurements and provide all classified and estimated data for the national web service (Woudenberg and others 2011). NIMS is continually being revised to incorporate new field protocols and variable definitions, eliminate regional differences, and improve estimation procedures. The algorithms contained in NIMS follow the work of Patterson (2005). Although NIMS is a national system, it still uses regional procedures for estimating volumetric variables: timber volume, tree biomass, and carbon. Some key stem measurements are diameter, height, and rotten or missing portion. Questions concerning the estimation procedures for forest "inventory" change; or growth, removals, and mortality (GRM) from the national FIA Information Management Band (IMB) have resulted questions regarding the impact of key elements of the programming logic, processing criteria, as well as estimation procedures. The IMB submitted these questions to the Techniques and Remote Sensing Band (TRSB) for decision rules. The TRSB convened the national Review Team. This paper represents the Review Team's findings.

The goal of the study was to review these questions and develop Decision rules to provide transparency to otherwise undocumented algorithmic paths. More specific objectives include: compare of regional approaches, evaluate the impact of implementation options on the estimates, recommend implementation options for questions that significantly impact the results, and provide procedural recommendations for processing current and past GRM estimates. These questions are important because they are the basis of timber volume, tree biomass, and carbon GRM estimates for the United States. A national team was chartered to address these needs and to report findings.

## METHODS

This national Review Team was comprised of representatives of all FIA Bands with direct experience with repeated FIA measurements, specifically field protocols, information technology, estimation, and quantitative analysis.

William H. McWilliams, Research Forester, U.S. Department of Agriculture, Forest Service, Northern Research Station, Forest Inventory and Analysis program, Newtown Square, PA 19073, USA.
Carol L. Alerich, Forester, NRS.
William A. Bechtold, Research Forester, Southern Research Station, Asheville, NC, 28804, USA, Retired.
Mark Hansen, Research Forester, NRS, Retired.
Christopher M. Oswalt, Research Forester, Southern Research Station, Forest Inventory and Analysis program, Knoxville, NC, 37919, USA.
Michael Thompson, Forester, Rocky Mountain Research Station, Forest Inventory and Analysis program, Ogden, UT, 84401, USA.
Jeff Turner, Research Forester, SRS, Asheville, NC, 28804, USA.

A series of criteria were used for sensitivity analysis of the impact that decision rules have on NIMS GRM estimates. The decision criteria included the level and degree of impact on estimates, and the degree of concurrence among the reviewers. The level of impact includes frequency and scale of occurrence (state, regional, or national) and whether the algorithm is for periodic inventories or annual inventories. The degree of impact was estimated by running simulations under various scenarios.

The NIMS algorithms contain many "pathways" for tree variables as they flow from input to output as volumetric estimates of average annual change. The complete NIMS system contains hundreds of thousands of program code and continues to expand. The pathways for "growing-stock" trees are particularly intricate. NIMS includes major pathways for periodic-to-annual (P2A) and annual-to-annual (A2A) change components. The P2A pathways are much more complicated because of changes in measurement protocols, methods, and procedures both in time and space. The A2A algorithms center on measurements that have been common since their inception around 2000. The team focused on A2A for context in providing transparent decision rules for current and future needs.

## RESULTS

The national Review Team addressed nine questions. Some of these questions have been discussed for decades in various forms within FIA regions and national teams. The questions are listed below along with the Review Team's final decision rules.

*Question One*: What should be done with trees that were recorded at T1 but missing at T2 with no explanation, or "non-reconciled" trees?

*Decision rule:* The occurrence of this situation is low and the degree of impact on estimates is very low. All trees loaded into the national database at T1 (Woudenberg and others 2011) must be reconciled and corrected at the regional level.

Regional estimation methods for reconciling parameters are a common theme in many of the questions. Each of four regional systems was built with specific models to predict volume for species or species groups. Independent variables typically include diameter, rotten portion, and other related variables, e.g. tree class. Approaches use modeled and measured independent variables and some use combinations of both. To illustrate one approach, NRS-FIA computes gross volume (cubic and board foot) using equations by Scott (1979 and 1981). The independent variables are diameter and merchantable length. Length is estimated using a taper model (Westfall and Scott In Press). Percent rotten cull is also modeled and subtracted to provide "net" volume. It is important to note that precision requirements are the same for regions.

Tree biomass, and hence carbon, is estimated using a national approach termed Component Ratio Method (Heath and others 2009), which provides national harmonization for these variables.

The national annual inventory GRM algorithm has introduced many improvements to existing systems. For example, a method for "growing" trees to the midpoint of the inventory cycle (2.5 years for a five-year cycle) replaced previously disparate methods. The overall net change is equivalent under the new and previous theories, but individual components of change will vary. Not all regions had fully developed approaches for these calculations when the approach was implemented.

*Question Two*: What should be done about trees that are measured at T2 and found to be too large to be considered ingrowth, e.g., missed at T1?

*Decision rule*: The degree of impact is low. It is recommended to follow current NIMS procedures with some added details. First, it is recommended to assign T1 tree status to "live." Then use regional-scale growth estimators to calculate T1 tree diameter. This Rule is subject to two sub-rules: if a tree is alive at T2, set T1 and T2 tree status to live; if tree status is "dead" at T2, set T1 tree class to "rotten cull." The Team determined it was not possible for a tree to be considered alive at T1 then missed and removed at T2 due to data recorder edit procedures.

*Question Three*: What should be done about species mismatches between T1 and T2?

*Decision rule*: The impact is low and occurrence is relatively rare. The NIMS procedures for current estimates do not consider species code at T1. No suggested change is recommended. The Team did note that this will introduce some minor discrepancies for "net change" estimates. This is because NIMS estimates volumetric variables in both the GRM and the inventory estimation modules. With- in the GRM context, net change is defined as gross growth minus mortality and removals. Net change can also be computed using inventory estimates by subtracting volume at T1 from T2. With no discrepancies, the GRM and inventory modules would provide identical estimates of net change. Discrepancies should not be significant for population totals,

such as the total volume of loblolly pine in Georgia. The discrepancy would be apparent for data cells or summaries with small sample size, e.g., loblolly pine in southern Georgia, on National Forest Land for growing-stock trees 18 inches and larger only.

*Question Four*: What should be done about trees with very large positive values or negative growth values?

*Decision rule*: The impact on estimates for trees with growth that is outside a normal range is considered low. Currently, if the diameter measurements at T1 and T2 are not taken at the same height, NIMS recalculates T1 diameter and associated T1 attributes. It was decided that other valid negative values for change in these attributes should be allowed to flow normally, as is the case with height discrepancies.

*Question Five*: What should be done about trees that change tree class between T1 and T2 (growing stock to rough or rotten and rough or rotten to growing stock)?

*Decision rule*: This question required simulations of the various combinations of tree class for T1 and T2, as well as related implications for all the various sub-components of GRM, e.g. growth on mortality of growing-stock trees on land that changed from forest to non-forest.

After evaluation of simulated results of the pathways that such a growing-stock tree could follow, the decision rules included in Table 1 are recommended.

The purpose of changing T1 attributes is to ensure variables used for volumetric estimates are as consistent as possible across the Nation and that the approach is transparent. The reason for changing T1 variables when a tree class changes from rough or rotten to growing stock is that these are often due to inconsistent methods and have significant impact on GRM estimates for growing-stock trees. Changes from growing stock to rough or rotten occur naturally and often, and hence, should not be changed. Any changes are made at T2 to integrate with estimates that are calculated separately in the inventory and GRM algorithms.

Monitoring real change in tree class is challenging because of objectivity in the classification. Suggestions for improved control include asking field staff to verify T1 tree class for all re-measured trees. Procedures used at the Southern Research Station provide a model for national implementation. Some trees may need to be added to the national database prior to implementing the rules. For these trees, it is recommended that if the tree is alive at T2, tree class at T1 should be set equal to tree class at T2; it the tree is dead at T2, set tree class at T1 to "rotten cull." In the highly unlikely event that a tree was live and missed at T1 and removed at T2, set tree class to "growing stock." It should be noted that pathways for estimating growing-stock GRM's could be the most complicated programming component of NIMS.

*Question Six:* What should be done with trees that were classified as dead at T1 and found to be alive at T2?

*Decision rule*: The impact on estimates and frequency are both very low. This question addresses the same phenomena as Question Two and so, the decision rule for missing trees should be followed, i.e., compute missing variables using regional approaches.

*Question Seven*: How should NIMS accommodate storage of adjusted tree-level variables?

*Decision rule*: A fundamental paradigm of FIA has been that continuous improvement processes should address systematic differences in any field measurement or algorithm that is used to assign or estimate variable values, e.g., tree class, height, or rotten portion. This issue is very important because of the very large size and temporal nature of FIA data sets. It was decided that corrections to erroneous data should be replaced with corrected data; however, it is imperative that all original data is permanently archived and documented. The NIMS structure allows for this kind of archival and has more than one option that can be used.

*Question Eight*: Should trees with diameter measurements taken at different locations at T1 and T2 be used in GRM computations?

*Decision rule*: The degree of impact was considered low and the resolution follows other rules. These trees are used in the NIMS GRM calculations, so they are given T1 diameters and other variables needed to re-calculate volumes. As before, this assures consistent trend information to the extent possible.

*Question Nine*: Are denied/hazardous (DH) plots included in GRM calculations?

*Decision rule*: Access to the FIA samples can be denied by the landowner or have conditions too hazardous to conduct measurements (DH). The impact is considered to be non-existent because Bechtold and Patterson (2005) reviewed this issue in forming the theoretical constructs for the national FIA program. The existing rules are:

• if a sample is DH at T1 and visited at T2, do not include in GRM calculations,

• if visited at T1 and DH at T2, do not include in GRM calculations,

• if a part of the sample is DH at T1 and fully measured at T2, the portion included at both occasions is used in the GRM calculations,

• if fully measured at T1 and partially DH at T2, the portion included at both occasions is used in the GRM calculations,

• if partially DH at T1 and T2, the portion included at both occasions is used in the GRM calculation.

## DISCUSSION AND CONCLUSIONS

As part of the review process, the Team developed a set of tenets to guide the sensitivity analyses, e.g. future questions. The tenets include: maintain temporal consistency; provide balance between regional and national needs; emphasize the need for field-level checks for temporal consistency; allow for correction of variables with inconsistent temporal measures, recognize the need to re-process delinquent data sets to current standards by allowing as much field checking of previous measurements as possible; and archive all existing raw and computed data sets. These may be useful to others grappling with similar questions.

Many of the questions considered conditions with low occurrence and impact, however, trees with the conditions described can be problematic if they do not have a specific pathway to follow, e.g., contribute to the wrong change component/sub-component or follow a terminal pathway incorrectly. Growing-stock computations account for the majority of the GRM algorithmic pathways of NIMS and are quite complicated due to the number of pathways and junctures.

Efforts to develop nationally consistent and harmonized estimates of volume, wood and carbon weight should continue. Currently, modeled and measured independent variables are used in estimation and vary by region, e.g., height and rotten portion. As harmonization continues, the national system will continue to use models appropriate for the biomes that span FIA regions and become more seamless in application.

During the discussion of tracking trees and attributes over time, a related issue was noted that may need addressed in the future. It was clear that approaches and protocols for re-measuring trees with diameter measurement at the root collar are needed. All four regions of the country utilize root-collar diameter measurements and are challenged by the task of reconciling data and producing meaningful trend estimates.

It was very clear from this experience that the entire NIMS program code lacks the kind of documentation needed to understand the critical estimation components. The little information that is available publicly does not begin to address the need for transparency for details; although there is considerable documentation housed within regional FIA units. This report highlights the major incremental benefit of the annual system: the benefits of consistent rules, transparent methods, and reliable trend estimates for tracking forests in time and space accrue with each time step.

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**Table 1—After evaluation of simulated results of the pathways that such a growing-stock tree could follow, the following decision rules are recommended**

| Tree Class at T1 | Tree Class at T2 | Rule |
|---|---|---|
| growing stock | growing stock | no change to the variable |
| growing stock | rough | no change to the variable |
| growing stock | rotten | no change to the variable |
| rough | growing stock | change T1 value of tree class and percent cull to T2 values |
| rough | rough | no change to the variable |
| rough | rotten | no change to the variable |
| rotten | growing stock | change T1 value of tree class and percent cull to T2 values |
| rotten | rough | change T1 value of tree class and percent cull to T2 values |
| rotten | rotten | no change to the data |
| | | |