IMPROVING FIA TREND ANALYSIS THROUGH MODEL-BASED ESTIMATION USING LANDSAT DISTURBANCE MAPS AND THE FOREST VEGETATION SIMULATOR

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Abstract.—The Forest Inventory and Analysis (FIA) Program's panel system, in which 10-20 percent of the sample is measured in any given year, is designed to increase the currency of FIA reporting and its sensitivity to factors operating at relatively fine temporal scales. Now that much of the country has completed at least one measurement cycle over all panels, there is an immediate need for estimation strategies which make the best use of this sampling schedule. A primary obstacle is that only a fraction of plots can be considered current in any particular year. This leaves the analyst with a choice of ignoring annual trends or creating estimates one panel at a time and suffering precision losses which may render apparent year-to-year differences uninterpretable.

One option for increasing the temporal specificity of estimates is to update plot conditions for every year in a time series using the Forest Vegetation Simulator (FVS) and to use model-based estimation to create annual estimates using "observations" from every plot. The variance estimators used in such an approach would incorporate both sample and model uncertainty, the latter of which could be assessed at remeasured FIA plots. Disturbance maps created from time series of Landsat (or similar sensor) satellite imagery could be used to identify and appropriately alter FVS simulations for those plots which have been disturbed. Use of disturbance maps would allow sensitivity to year-to-year variation in the disturbance rate. FIA has recent experience in all of the components of the proposed approach including FVS, Landsat disturbance mapping, and model-based estimation. Further study to integrate these components into a production estimation system is warranted.

THE CHALLENGE OF FIA ANNUAL ESTIMATION

The Forest Service's FIA (Forest Inventory and Analysis) Program does not survey each of its plots every year. The sample is divided into random subsamples called panels, and each panel is remeasured once every 5 to 10 years (Patterson and Reams 2005). Measuring a fraction of the plots in a particular sample unit (e.g., a state) every year provides some sensitivity to forest changes as they occur throughout a measurement cycle. However, since the plot data for any cycle are collected uniformly over a 5-10 year period, one is left with the dilemma of using all plots to estimate conditions over a long and undifferentiated period, or making panel-wise estimates that provide high temporal specificity but low precision due to a low sample size. Once all plots have been surveyed, one can calculate a new moving average estimate every year (Roesch et al. 2002), but the period for such estimation is still an undifferentiated 5- or 10-year span, which can obscure the effects of discrete large-scale events such as fires, droughts, or insect outbreaks.

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Research is ongoing regarding the possibility of enhancing FIA trend analysis through use of the Kalman filter, a sequential application of composite estimators (Czaplewski and Thompson 2009), and mixed estimators (Van Deusen 2008). Building on concepts developed during the formative years of FIA's annual inventory (eg., Czaplewski 1999, McRoberts and Hansen 1999), this paper suggests an approach for identifying within-cycle trends by growing all plots (regardless of panel) forward in time with the Forest Vegetation Simulator (FVS) growth model (Crookston and Dixon 2005) so that there is an observed or modeled value for each plot in every year. As discussed below, this option would take advantage of a number of tools with which FIA has recent experience, including FVS, forest change detection using Landsat imagery, and model-based estimation.

USE OF FVS AND LANDSAT TO UPDATE PLOT VALUES

The FVS is maintained by the Forest Service's Forest Management Service Center and is delivered with executable code which automatically converts FIA data into an FVS-ready format. It is a distance-independent growth model that can project a wide range of stand characteristics over a 100-year time frame while simulating an equally wide range of disturbance/management scenarios. FVS is widely used by the Forest Service for forest planning in conjunction with FIA and other stand monitoring data. Because of its importance in the management community, FVS benefits from ongoing active calibration.

While FVS projections typically function at 5- or 10-year intervals, stand changes can also be produced in 1-year increments. In the approach we propose, each plot would be updated with FVS from the time of its last measurement to each subsequent point in time until it is re-measured (Fig. 1). Scenarios of undisturbed growth in FVS should provide a reasonable model for updating the majority of plots (i.e., growing forward all trees in the tree list, plus any changes due to mortality and recruitment functions), particularly since the maximum length of projection would be only 9 years and as few as 4 years in some states. However, a method of identifying disturbed (including managed) plots would be needed for two reasons: FVS projections for such plots using undisturbed dynamics could introduce significant error; and, more importantly, the value and point of producing within-cycle trend estimates would be greatly diminished if the monitoring system were insensitive to disturbance.

The Forest Service and FIA have extensive experience using the Landsat series of satellites to characterize the timing, type, and magnitude of forest disturbance (Nelson et al. 2009). Much of this experience has been gained through FIA's association with the NASA-funded North American Forest Dynamics project (NAFD). The NAFD project is currently producing a national wall-to-wall map of disturbance timing and type, and the Forest Carbon Management Framework (ForCaMF) project is currently producing disturbance timing, type, and magnitude maps for the entire National Forest System (approximately 75 million hectares). Furthermore, a follow-on to the Monitoring Trends in Burn Severity (MTBS) project called the Landscape Change Monitoring System is in development, targeting operational national-scale disturbance mapping. Results of these or other efforts could be used to direct disturbed plots into specialized scenarios to increase model accuracy and to introduce intra-cycle sensitivity to disturbance.

MODEL-BASED ESTIMATION

Model-based inference depends upon fundamentally different assumptions than the design-based methods used by most field-based inventories, including FIA's. (For a detailed description of the difference between model- and design-based inference, see Gregoire 1998.) Unlike design-based estimation, model-based methods treat observations as realizations of a random process (model). Model-based methods are appropriate for forest inventory situations where there is one

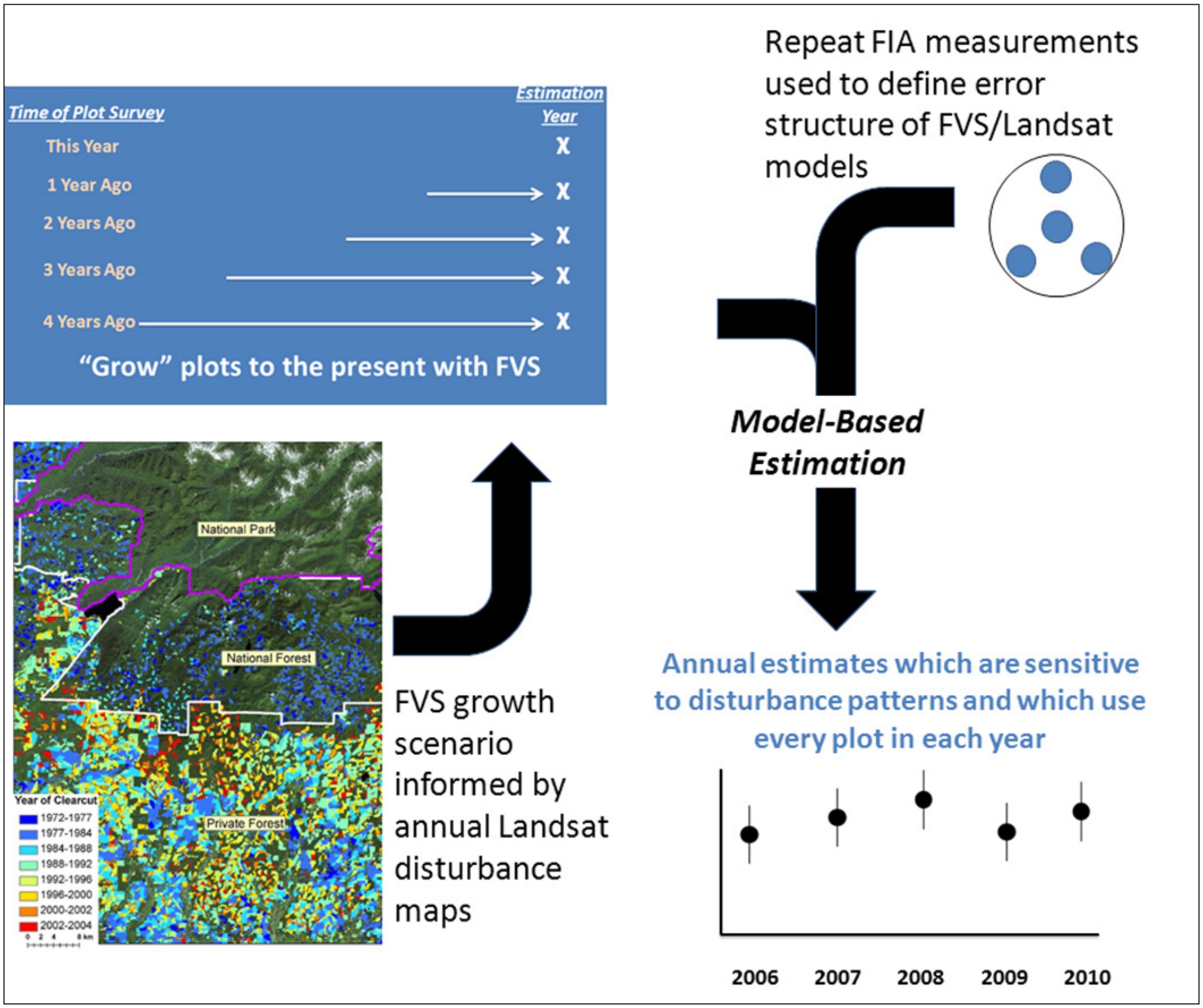

Figure 1.— Schematic of the estimation approach.

sample of plots where both the variable of interest and one or more predictors are known, and there is another, generally larger, sample in which only the predictors are known. Models built over the first sample are applied to the second sample, which is used to make a population estimate. Variance estimators incorporate elements of both sample uncertainty and model uncertainty. The authors have used this approach with FIA biomass measurements and predictor data from spaceborne lidar to predict biomass in California (Healey et al., in press).

In the idea we present, the entire FIA grid (all panels) constitutes the second type of sample; the current tree list is not known (or is known only for the most recent panel), but a tree list from some point in the past is known. This predictor tree list is used with FVS to model the forest condition to be estimated at each point in time (Fig. 1). Ongoing validation activities associated with the ForCaMF project mentioned above are comparing FVS predictions for incremental tree list changes with plot remeasurement occurring at intervals from 2 to 12 years. This work could be the basis for a larger validation effort, functioning as the first type of sample mentioned above by supplying model error rates to be used in variance estimates (Fig. 1). Model-based estimation should allow FVS-modeled updates which allow each plot to be used in estimating the forest condition of interest in every year.

ANTICIPATED BENEFITS

In general, using modeled observations in model-based estimation will tend to increase variance estimates relative to observations based on field measurements. However, in this case, use of model-based estimates would increase the sample number for any given year by a factor of 5 or 10. Tests are needed to determine the interaction of these two factors as they impact precision of annual estimates. One significant advantage of this approach is that repeated "observations" for each plot (through FVS models) will allow direct estimation of annual change (e.g., change in biomass per hectare). Currently, since each year's panel is independent of the previous year's, change must be inferred from differences in sequential estimates of a variable's "state." Addressing change directly, as illustrated in Figure 2, may lead to a better ability to compare inventory estimates to ancillary drivers such as housing starts or drought patterns. It would also allow more timely identification and reporting of forest change than would be possible from trend-based alternatives, some of which require several years of continued data collection before changes are confirmed.

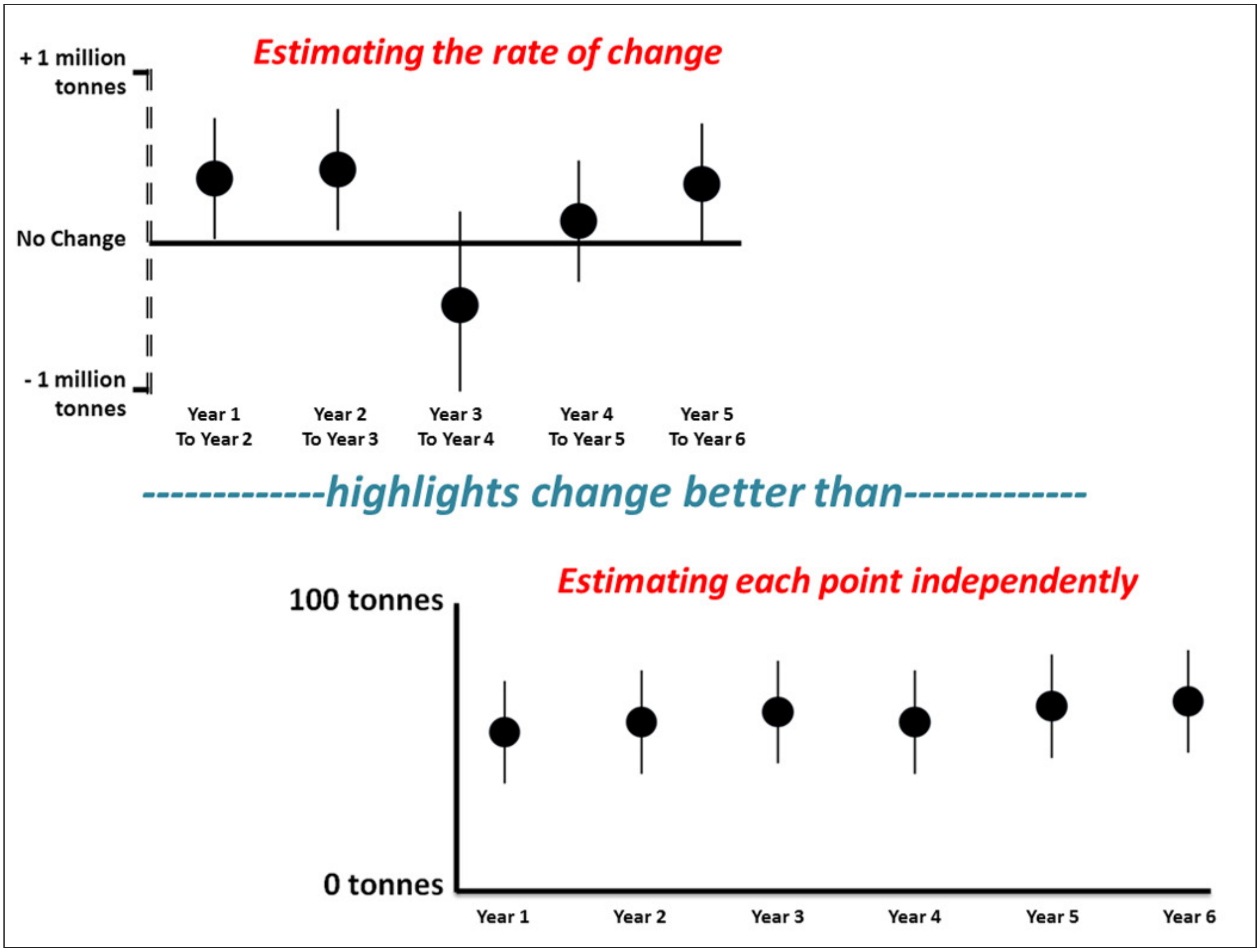

Figure 2.—Hypothetical illustration of possible benefits of estimating change directly. Estimating the difference between a forest attribute at two points in time allows ecosystem change to be assessed more directly than comparison of sequential state estimates. The incremental observations shown would only be possible because the Forest Vegetation Simulator (FVS) provides modeled observations of each plot annually.

CONCLUSIONS

1. Model-based estimation of FVS-derived intra-panel change may provide greater temporal specificity than other estimation methods.
2. Ongoing FIA work with FVS, Landsat disturbance mapping, and model-based estimation form a foundation from which future research may proceed.

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