# Estimating County level Timber Volume in Virginia Using Small Area Estimation

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## Abstract

Accurate estimates of forest components such as, biomass, composition, or health are important for forest management and policy decisions. The USDA Forest Service Forest Inventory and Analysis (FIA) program serves as a national survey system to assess such forest characteristics within the United States (US). When making estimates at the county level or smaller spatial scale with FIA plot data, the accuracy in estimation of forest components drops. Here we use NAIP data in conjunction with FIA data in order to improve upon county level timber volume estimation precision in Virginia using Small area estimation (SAE).

## Introduction

Accurate estimates of forest components such as, biomass, composition, or health are important for forest management and policy decisions. To this end the USDA Forest Service Forest Inventory and Analysis (FIA) program serves as a national survey system to asses such forest characteristics within the United States (US). The FIA program does this by using a network of sampling plots with an intensity of one sampling plot per 6000 ac for the eastern US which are resampled on a 5-year cycle. Due to the 5-year cycle, this means that only 20% of these plots are resampled within a given year. With this sampling intensity and procedure, the FIA program is able to get a good picture of the current state of the forests within the US and within each state. However, when making estimates at the county level or smaller spatial scale with FIA plot data, the accuracy in estimation of forest components drops. This is where the use of remote sensed data can be used in conjunction with field-based measurements in order to improve forest component estimation. Small area estimation (SAE) can serve as a basis for combining this auxiliary information (remote sensed data), with field measurements in order to improve the accuracy of our forest attribute estimation (Goerndt, Wilson, and Aguilar 2019).

Research shows that Light detection and ranging (lidar) data is correlated with forest attributes. (McRoberts et al. 2010) By using lidar in a SAE framework as auxiliary data in conjunction with field measurements such as FIA plot data, improvements can be made on estimation of forest attributes (Ver Planck et al. 2018). Other spatial variables have also served to improve forest biomass estimates within an SAE framework including Landsat imagery, land coverage, seasonal phenology, and ecoregions (Goerndt, Wilson, and Aguilar 2019). We seek to build upon the spatial auxiliary data available for forest attribute estimation by using National Agriculture Imagery Program (NAIP) aerial imagery. NAIP serves as a yearly acquisition of "leaf-on" digital ortho photography. This imagery is collected in natural color (Red, Green and Blue, or RGB) and can provide a remote sensed surface of forest canopies. This could be quite useful within the SAE framework with FIA data due to its coverage, color photography which can assist with species composition attributes, and depiction of the forest canopy surface. This forest canopy surface can be used in conjunction with a digital elevation model (DEM) to easily produce forest height, which could provide as a great auxiliary variable in improving the accuracy of timber volume estimation on smaller landscapes. Here we seek to reduce the error in county level estimates of timber volume within Virginia counties by using SAE with a canopy height model (CHM) generated from NAIP data as auxiliary data with FIA plot level data.

## Methodology

The most recent 5-year panel plot level data is collected from the FIA program for the state of Virginia (US Forest Service 2018). This five-year (2013-2018) full panel selection was done to ensure that each forest plot had information from just the most recent time in which it was sampled. This plot level data was processed to produce timber volume estimates and standard errors for each county within Virginia. These estimates and errors serve as the basis for which this study seeks to improve upon using SAE.

The NAIP data for Virginia was obtained as the DSM tiles which were generated by the contractors who collected the NAIP data. These DSM tiles were then mosaic together to cover the entire state and clipped to the extent of Virginia. The National Elevation Database 10m DEM was then subjected from the NAIP DSM to generate a CHM. To help remove outliers from the CHM, the National Land Cover Database (NLCD) canopy coverage was used to identify any areas with 0 percent canopy cover, and were initialized to 0 for canopy height within the CHM. Additionally, extreme values such as those below 0 and above 100 meters were initialized to 0. This filtered CHM raster was then clipped to each county of Virginia to produce average estimates for each county to be used as auxiliary information. From this CHM, 5m increment bins were created. These bins were then summed for each county in Virginia. Each of these bin totals were then were used to fit a Fay-Herriot model using FIA net cubic volume per county as the left hand side and the binned areas of canopy height used as the right hand side of the model. The bins totaling 0-5m and 5-10m canopy height in acres were rejected in our used model using backward selection with AIC.

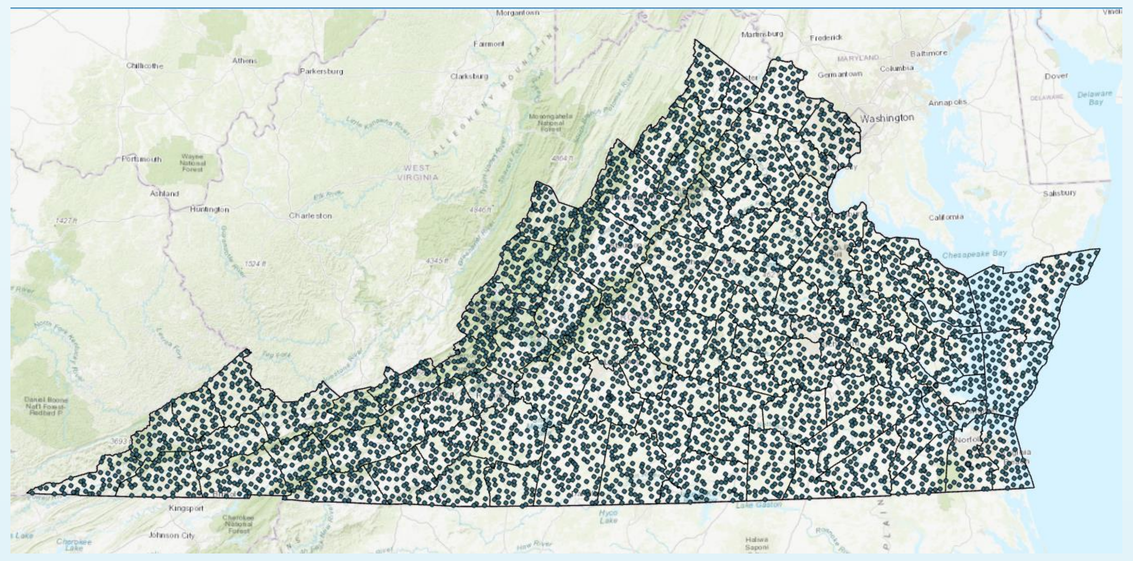

*Figure 1: "Fuzzed" plot locations of FIA plots.*

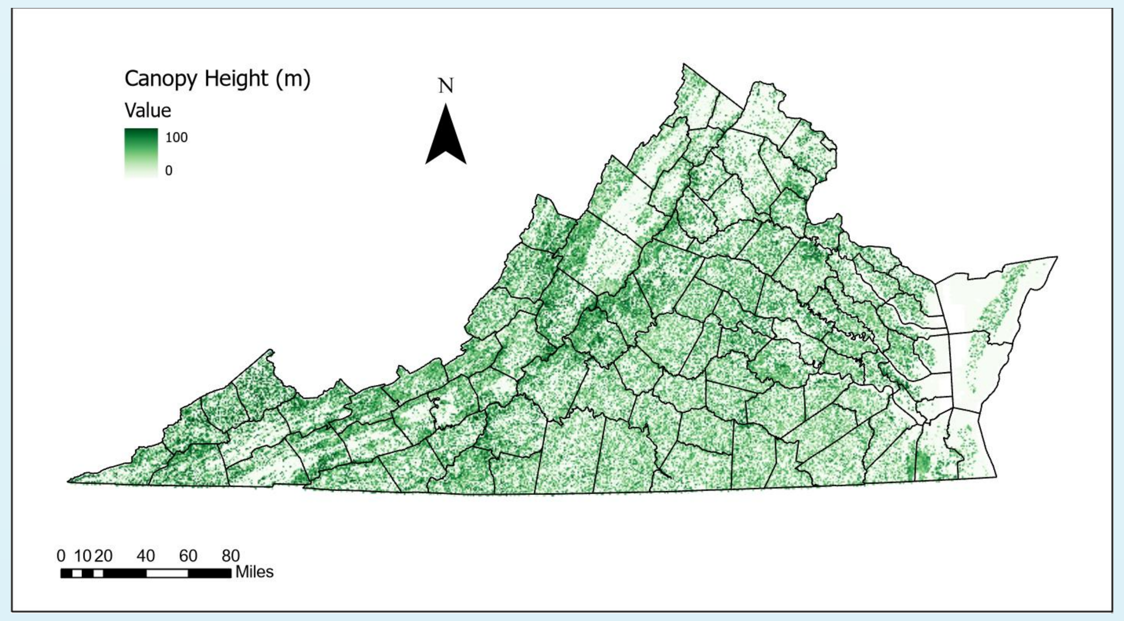


*Figure 2. Estimation of canopy height using NAIP DSM minus NED DEM, with areas of 0% canopy cover from the 2016 NLCD canopy cover, and extreme values filtered out across the state of Virginia.*

## Results

On average, the volume of timber calculated from the SAE method was close in agreement with that calculated natively from just FIA plot data. Despite the close agreement of volume estimates, we see that in counties with a greater volume of timber saw a decrease of estimate variance in the estimate from the SAE methodology. Additionally, when looking at the coefficient of variation we also see that the SAE methodology tends to have a lower coefficient of variation across the board. This is a promising result as the intent for using SAE is to provide estimates of values with reduced error. Taking this these results into account demonstrates a solid base for moving forward with using SAE for timber volume estimation.

| County | FIA Plots | Net Volume (Direct) | Net Volume Variance (Direct) | Net Volume (F-H) | Net Volume MSE (F-H) |
|---|---|---|---|---|---|
| ACCOMACK | 22 | 3.61E+08 | 2.54E+15 | 3.3E+08 | 1.84E+15 |
| ALBEMARLE | 58 | 7.39E+08 | 3.63E+15 | 7.5E+08 | 2.55E+15 |
| ALLEGHANY | 63 | 5.67E+08 | 2.42E+15 | 5.67E+08 | 1.78E+15 |
| AMELIA | 29 | 3.59E+08 | 2.9E+15 | 3.74E+08 | 2E+15 |
| AMHERST | 52 | 5.89E+08 | 2.69E+15 | 5.89E+08 | 1.96E+15 |
| APPOMATTOX | 27 | 2.77E+08 | 1.82E+15 | 2.9E+08 | 1.43E+15 |
| ... | ... | ... | ... | ... | ... |
| MONTGOMERY | 33 | 3.34E+08 | 7.95E+14 | 3.44E+08 | 7.1E+14 |
| ... | ... | ... | ... | ... | ... |

*Table 1. Timber volume estimates for a select few the counties of Virginia using two methods, Fay-Harriot SAE, and direct estimation.*

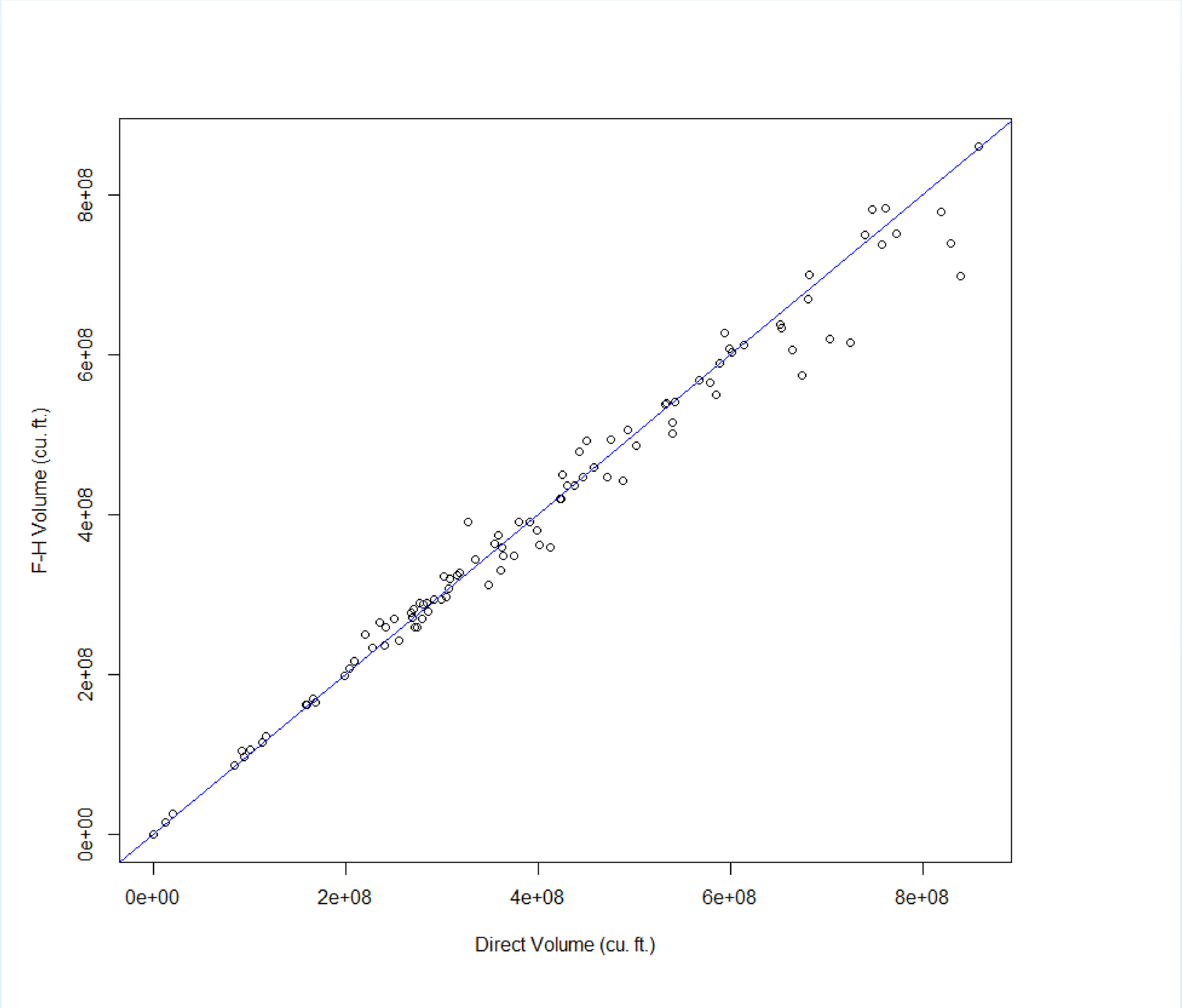


*Figure 3. Forest timber volume estimates in cubic feet calculated from a direct method compared to estimates generated from a Fey-Harriot SAE model using canopy height bins per county.*

## Conclusion

Here the model used to produce SAE estimates of timber volume was quite simple. However, despite this, we still see a reduction of variance in estimates. This suggests a promising basis for moving forward with more complex methodologies, and additional auxiliary information to produce even more accurate variable estimates. Such methodology could also be employed to produce estimates of other variables of interest, such as biomass or forest species composition for FIA, or other stakeholders on small areas such as counties. Additionally the methodology used here could be easily expanded beyond just the state of Virginia due to the availability of FIA plots and NAIP imagery across the country.

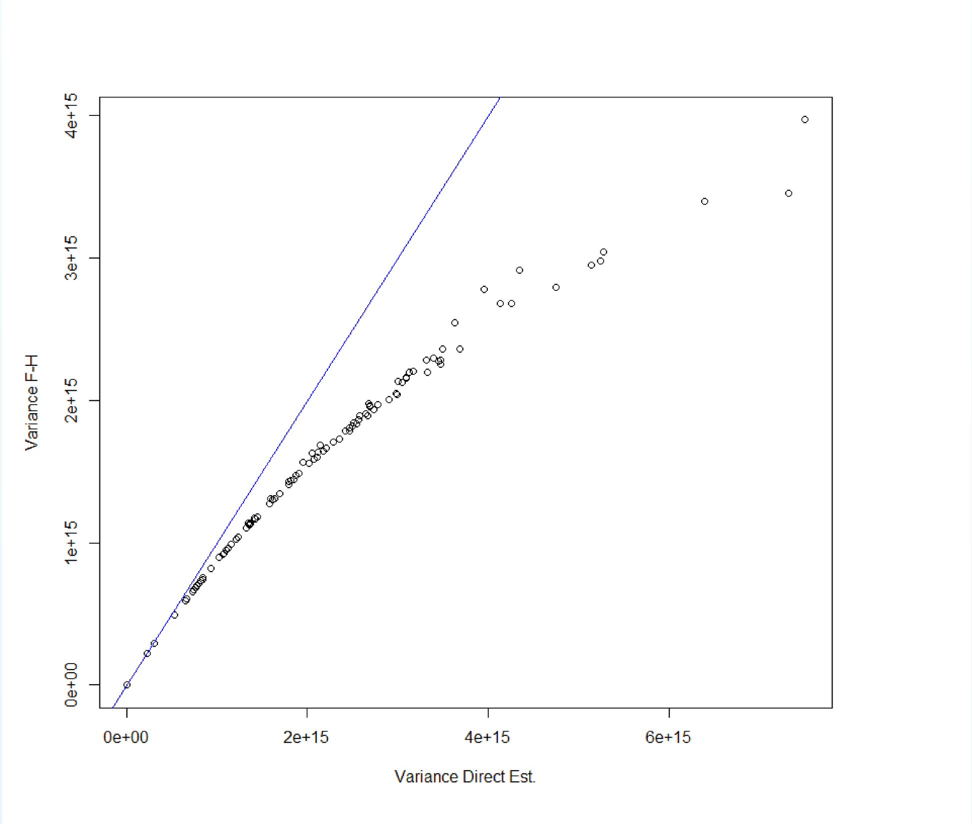


*Figure 4. Forest timber volume variance estimates calculated from a direct method compared to estimates generated from a Fey-Harriot SAE model using canopy height bins per county.*

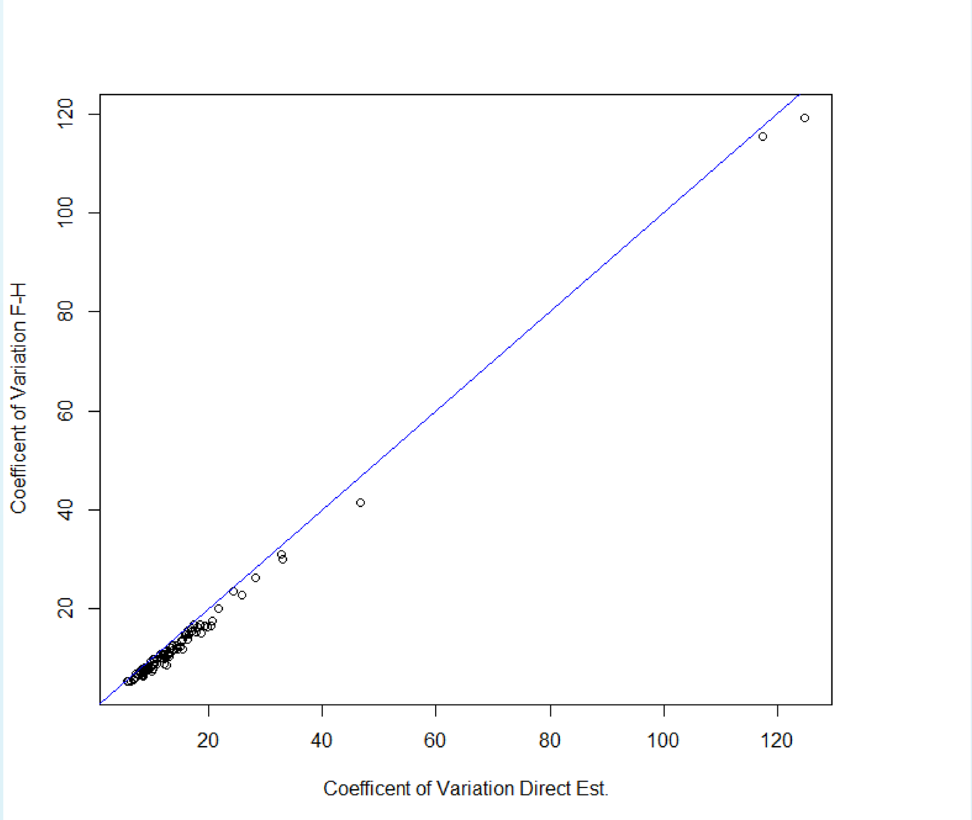


*Figure 5. Forest timber volume estimates of coefficient of variance calculated from a direct method compared to estimates generated from a Fey-Harriot SAE model using canopy height bins per county.*

## Citations

Goerndt, Michael E., Barry T. Wilson, and Francisco X. Aguilar. 2019. "Comparison of Small Area Estimation Methods Applied to Biopower Feedstock Supply in the Northern U.S. Region." *Biomass and Bioenergy* 121 (February): 64–77. https://doi.org/10.1016/j.biombioe.2018.12.008.

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