FOREST LAND AREA ESTIMATES FROM VEGETATION CONTINUOUS FIELDS

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ABSTRACT

The USDA Forest Service's Forest Inventory and Analysis (FIA) program provides data, information, and knowledge about our Nation's forest resources. FIA regional units collect data from field plots and remotely sensed imagery to produce statistical estimates of forest extent (area); volume, growth, and removals; and health and condition. There is increasing need to analyze and display FIA estimates within a geospatial context. A nationwide map of forest land would provide the basis for mapping additional FIA attributes. Forest land maps derived from existing satellite image-based land cover products are inconsistent with FIA estimates of forest land area, especially within smaller geographic areas. We describe an image stratification approach for calibrating MODIS Vegetation Continuous Fields (VCF) data to produce maps of forest land that provide unbiased estimates of forest land area compared to FIA estimates across multiple spatial scales.

INTRODUCTION

The Forest Inventory and Analysis (FIA) program of the United States Department of Agriculture (USDA) Forest Service conducts detailed inventories of the Nation's forests across all ownerships. Satellite image-derived land cover data and related geospatial data layers provide an alternative to inventory data for obtaining estimates of forest land area. Conversely, inventory data provide a reference for assessing the accuracy of satellite image-derived data.

Nelson et al. (In Press) compared estimates of forest land area derived from inventory data and four satellite image-derived land cover datasets, including Moderate Resolution Imaging Spectroradiometer (MODIS) Vegetation Continuous Fields (VCF) data (Fig. 1a,b). In their study, a threshold of 25 percent VCF tree canopy cover produced estimates of forest land area similar to inventory estimates for the entire United States (U.S.) and for the conterminous U.S. (CONUS). However, they observed that for most individual states, forest land area estimates derived from a 25 percent VCF tree canopy cover threshold differed considerably from inventory estimates. Although state specific thresholds of VCF percent tree canopy cover result in estimates of statewide forestland area that are comparable with inventory estimates (Nelson et al., In Press), the resulting maps show spatial discontinuities at state borders (Fig. 1c,d). As an alternative, this paper investigates the stratification of VCF using land cover classes in an attempt to identify thresholds of percent tree canopy cover resulting in estimates of forestland area similar to inventory estimates for the U.S., CONUS, and individual states, but without the undesirable spatial discontinuities noted above.

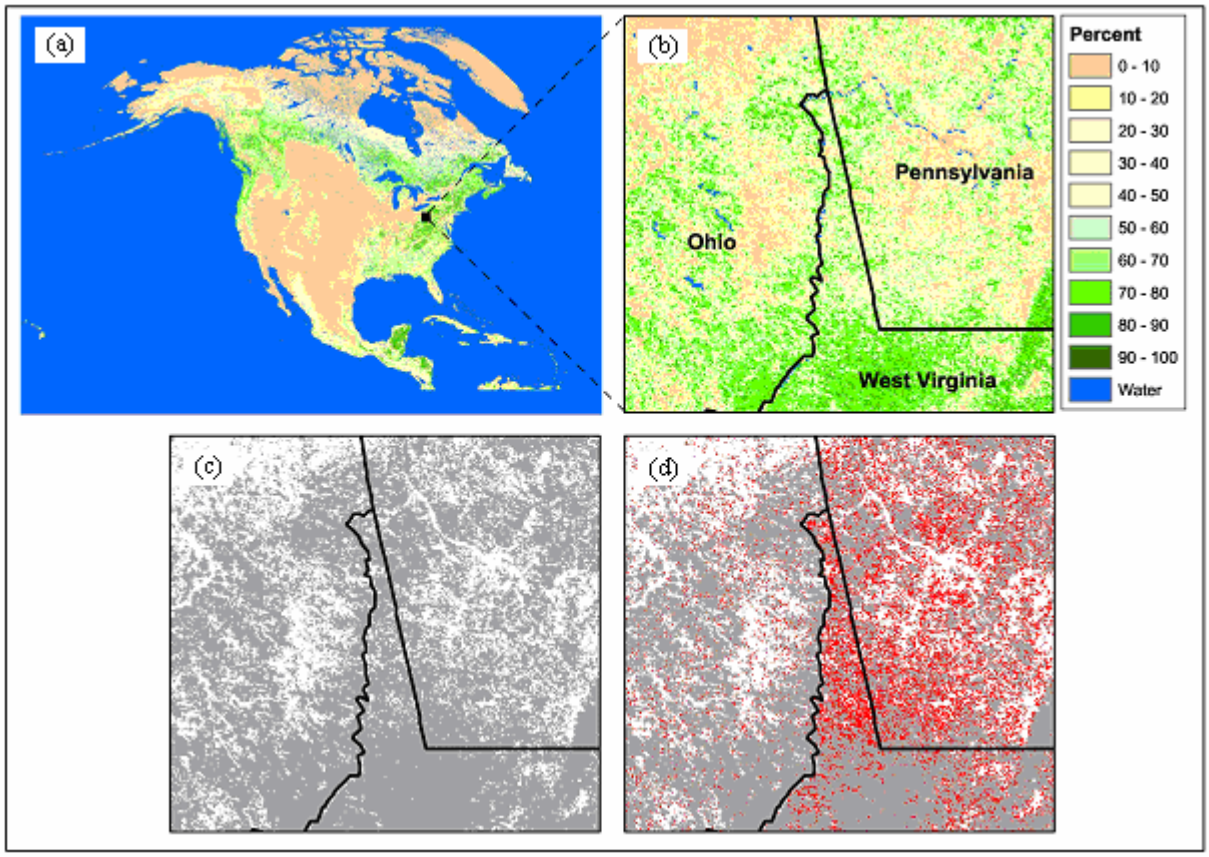

Figure 1. (a) VCF percent tree canopy cover within North America and (b) for a subset of Ohio, Pennsylvania, and West Virginia, USA. (c) Forest land cover (gray) based on a CONUS threshold (25%) and (d) per-state thresholds (Ohio, 30%; Pennsylvania, 45%; and West Virginia, 55%) of VCF percent tree canopy cover, with areas in red representing forest land based on the CONUS threshold that is not classified as forest land when using per-state thresholds.

DATA & METHODS

Inventory estimates

Reports on the forest resources of the U.S. result from the Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA), P.L. 93-378, 99 Stat. 4765 (U.S. Department of Agriculture, 2003). RPA Forest Resource Assessments are derived from FIA data, except for portions of some western states where National Forest System (NFS) lands were inventoried independently (Smith et al., 2001; U.S. Department of Agriculture, 2003). Estimates used in this study are from RPA 2002 draft tables, with source dates ranging between 1983-2000 and an average measurement year of 1994. Sampling errors for the estimates were obtained from a compilation of published statewide FIA reports (Mark Hansen, unpublished data) or by updating published data from previous FIA inventories using a formula from Hansen (2001). Because no sampling errors of forest land area were available for Alaska or Hawaii, sampling errors for these two states were estimated based on a conservative assumption that their forest area estimates met the FIA national precision standard (±3-5 percent per million acres).

VCF

VCF data provide per-pixel estimates of percent bare, percent herbaceous, and percent tree canopy cover (Fig. 1a,b). Water pixels are labeled with a separate thematic code and were excluded from analyses. VCF percent tree canopy cover data used in this study are derived from year 2001 MODIS imagery at 500-m spatial resolution and were obtained from the Global Land Cover Facility, University of Maryland.

Land cover

A 1-km spatial resolution land cover product, MOD12Q1 was used to stratify the U.S. into 16 land cover classes (plus one water class), following the International Geosphere-Biosphere Programme (IGBP) classification scheme (Belward et al., 1999; Running et al., 1994). The MOD12Q1 data used in this study (2000289 V003) were produced from MODIS imagery from the period 15 October 2000 – 15 October 2001 and were obtained from the Department of Geography, Boston University. Because MOD12Q1 excludes data for Hawaii and because RPA estimates for Hawaii and Alaska have unknown precision, comparisons derived from IGBP were restricted to CONUS.

Geospatial processing

Geospatial data were analyzed in Interrupted Goode's Homolosine projection (a global equal area projection with units in meters) using ArcGIS™ and ArcInfo™ software. State FIPS codes and IGBP land cover classes were assigned to VCF pixels by combining raster datasets of detailed state boundaries (ESRI Data & Maps, 2001), MOD12Q1, and VCF.

Mean VCF percent tree canopy cover was calculated for CONUS and for each MOD12Q1 IGBP land cover class. We derived a calibration factor, C (Eq. 1),

$$C = \frac{T_{VCF}}{\mu_{VCF}} \tag{1}$$

where T_{VCF} is the VCF percent tree canopy cover threshold resulting in a thematic map having forest land area approximately equivalent to the RPA inventory estimate of forest land area, e.g., 25 percent threshold for CONUS, and μ_{VCF} is the mean VCF percent tree canopy cover across the geographic area of interest. This calibration factor was applied to each IGBP land cover class to obtain per-class thresholds of VCF percent tree canopy cover, (Eq. 2),

$$T_{VCF,l} = C\,\mu_{VCF,l} \tag{2}$$

where *l* is the IGBP land cover class. Thresholds derived from Eq. (2) are truncated to whole percents for subsequent data processing. Statewide proportion forest land area was estimated as $\hat{p}_i$, (Eq. 3),

$$\hat{p}_i = \frac{\left(\sum_l a_{il}\right)}{a_i}$$

where a_i is the total area of the ith state; and a_{il} is the area of the ith state, land class *l* having VCF percent tree canopy cover pixel values exceeding the threshold $T_{VCF,l}$.

Comparisons of estimates

No estimate of uncertainty was available for the VCF-based estimates of forest land area. Therefore, differences in estimates of forest land area between VCF- and RPA-based estimates are conservatively reported as significantly different if VCF-based estimates fell outside the 95 percent confidence intervals for RPA.

State-wise differences between VCF- and RPA-based estimates of forest land area were computed using area-weighted Root Mean Square Deviation (RMSD), modified from Häme et al. (1997), Eq. (4).

$$RMSD_{rv} = \sqrt{\sum_i \frac{a_i}{A}\left(\hat{p}_{ir} - \hat{p}_{iv}\right)^2} \tag{4}$$

where a_i is the area of the i[th] state, $A = \sum a_i$ is the total area, and $\hat{p}_{ir}$ and $\hat{p}_{iv}$ denote the estimated proportion of forest land area in the i[th] state obtained from RPA (*r*) and VCF (*v*), respectively. Least squares linear regression analyses were performed to test relationships between VCF- and RPA-based estimates of statewide forest land area.

RESULTS

VCF 25 percent threshold

Based on a minimum VCF tree canopy cover threshold of 25 percent (VCF25), estimates of forest land area for CONUS and the U.S. were 623.4 and 742.4 million acres, respectively. Ninety five percent confidence intervals surrounding RPA 2002 estimates included VCF25 estimates of forest land area for CONUS (620.3 ± 6.5 million acres) and for the entire U.S. (748.9 ± 7.2 million acres). For all but one state (Illinois), VCF25 statewide estimates of forest land area were significantly larger than (n=35) or significantly smaller (n=14) than the upper and lower limits respectively, of 95 percent confidence intervals surrounding the corresponding RPA-based estimates. Comparisons of VCF25 and RPA statewide estimates of forest land area show RMSD values of 10.7 percent for CONUS and 9.9 percent for the entire U.S. RPA statewide percent forest land area estimates were strongly positively correlated with statewide mean VCF percent forest canopy estimates ($\hat{y} = 11.7 + 0.484x$, Adjusted $R^2 = 0.87$, $P < 0.001$, $n = 48$; Fig. 2).

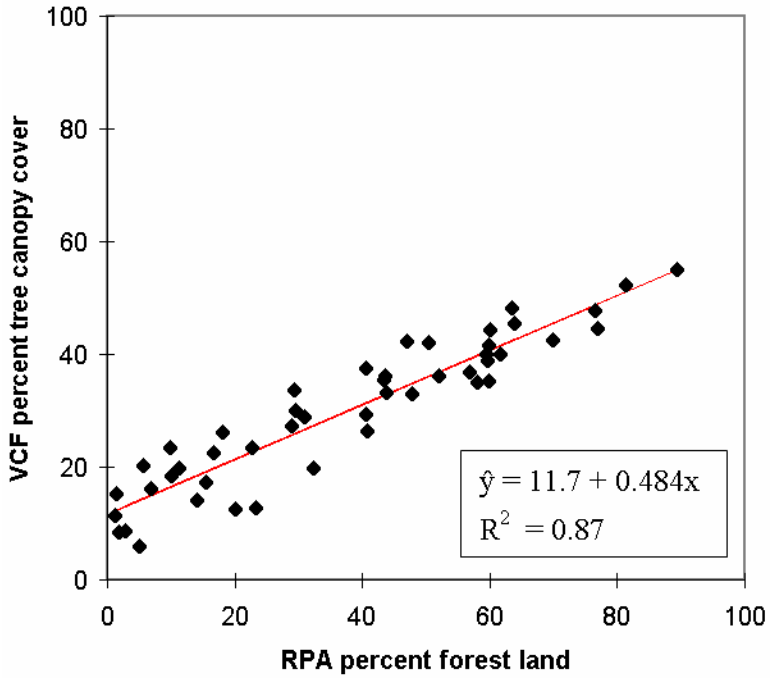

Figure 2. Comparison of statewide estimates of RPA percent forest land area and VCF percent tree canopy cover within CONUS.

IGBP per-class VCF thresholds

The CONUS mean VCF tree canopy cover was 20.98 percent; the IGBP per-class means are illustrated in Figure 3. Using this CONUS mean and the 25 percent VCF threshold discussed above, a CONUS calibration factor of 1.19 was obtained (Eq. 1). The estimate of CONUS forest land area based on this calibration factor and resulting IGBP per-class VCF truncated thresholds (Eq. 2, VCF_IGBP) was 623.3 million acres, an estimate falling within the 95 percent confidence intervals surrounding the RPA draft 2002 estimate of CONUS forest land area (620.3 ± 6.5 million acres). An RMSD of 13.2 percent was obtained when comparing VCF_IGBP and RPA CONUS estimates of statewide forest land.

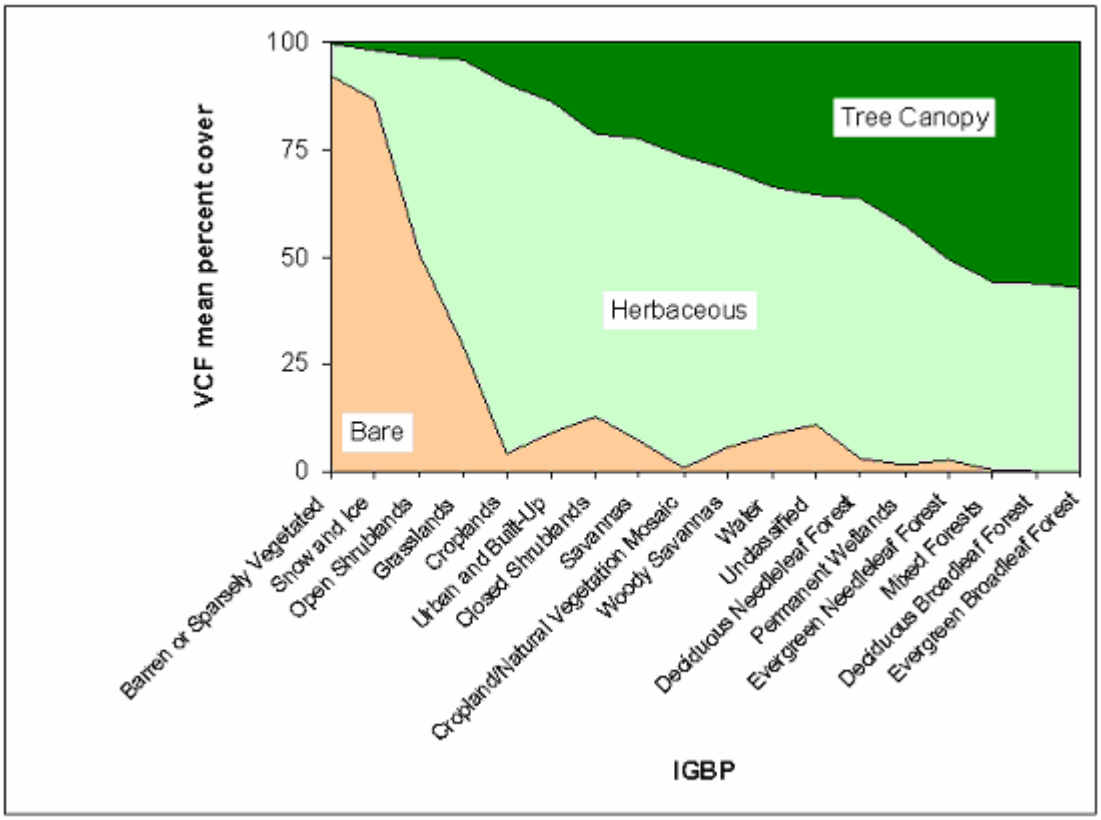

Figure 3. CONUS mean VCF percent tree canopy, herbaceous, and bare cover by IGBP land cover class.

DISCUSSION

We suggest that 25 percent VCF tree canopy cover provides an optimal minimum threshold for calculating forest land area estimates for both CONUS and the entire U.S. that equal the corresponding draft 2002 RPA estimates. Our threshold differs from the 35 percent threshold reported in Hansen et al. (2002) as being equivalent to a 1992 CONUS Forest Service estimate (Powell et al., 1993). Applied to the 2001 VCF data used in this study, a 35 percent threshold results in an estimate of 580.7 million acres of CONUS forest land, which is smaller than the 605.8 million acre estimate reported in Powell et al. (1993) and is significantly different from the 620.3 million acre estimate reported in RPA 2002 draft tables. Although our 25 percent threshold resulted in CONUS and U.S. estimates of forest land area that were not statistically different from RPA estimates, statewide estimates based on this threshold differed from RPA estimates for 49 of 50 states. Thus, it is inappropriate to use a nationwide or CONUS VCF threshold for estimating forest land area for individual states.

Although statewide mean VCF percent tree canopy cover and statewide RPA percent forest land use are strongly positively correlated (Adjusted $R^2 = 0.87$), the slope (0.484x) and intercept (11.7) differ from the expected slope (1.0) and intercept (0.0) under a null hypothesis of no differences between the respective state forest land area estimates. Three states (North Dakota, South Dakota, Nebraska) having less than 2 percent forest land use (according to RPA 2002) had mean VCF tree canopy cover estimates exceeding 8 percent, and the state with the most forest land use (Maine: 89 percent according to RPA 2002) had only 55 percent mean VCF tree canopy cover. Thus, VCF percent tree canopy cover data are strongly positively correlated with inventory estimates of forest land area (fig. 2), but the two measures are not equivalent. These differences may be attributed to uncertainty in either of the estimates, to definitional differences between land use and land cover, or to temporal differences in the two datasets.

The calibration approach employed in this study allowed us to quickly and systematically calculate per-class thresholds of VCF percent tree canopy cover. Although CONUS estimates of forest land area derived from per-class

thresholds were approximately equivalent to both RPA and VCF25 estimates, the area-weighted RMSD from per-class thresholds (VCF_IGBP, 13.2 percent) was actually larger than for the CONUS threshold (VCF25, 10.7 percent). Much of this difference in RMSD can be attributed to the large, sparsely forested state of Texas, where VCF25 overestimated forest land area by 6.5 million acres relative to the RPA estimate (23.6 vs. 17.1 million acres) but VCF_IGBP overestimated forest land area by 47.2 million acres relative to the RPA estimate (64.3 vs. 17.1 million acres). Because Texas alone comprises almost 9 percent of CONUS land area, the large discrepancy in Texas forest land area estimates accounts for much of the increase in area-weighted RMSD. When Texas was removed from the analysis of area-weighted RMSD for both VCF_IGBP and VCF25, RMSD of VCF_IGBP actually improved from 13.2 to 10.2 percent, a value slightly smaller than the RMSD for VCF25 (10.7 percent), which did not change after removing Texas data from the analysis. Furthermore, deletion of two large, sparsely forested neighboring states, Oklahoma and Kansas, both of which also have relatively large discrepancies in forest land area estimates, resulted in further improvement of VCF_IGBP area-weighted RMSD (8.5 percent), even though RMSD did not change for VCF25 (10.7 percent) following the deletion of these states from analyses.

All four 500-m VCF pixels contained within each 1-km MOD12Q1 pixel were assigned the single IGBP land cover class associated with that MOD12Q1 pixel. However, MOD12Q1 pixels often encompass multiple land cover features, e.g., a mixture of water and forest land cover along lake shorelines. When such MOD12Q1 pixels were classified as water, all four 500-m VCF pixels contained within were assigned to the water stratum, even though some of the VCF pixels fell within a forested portion of the 1-km pixel and had substantial percent tree canopy cover (Fig. 3). This mismatch in spatial resolution results in some incorrect assignments of land cover class to VCF pixels, adding uncertainty to our stratified thresholds of VCF percent tree canopy cover required to match inventory estimates of forest land area. The pending release of two new 500-m VCF data elements, leaf type and leaf longevity, will provide further opportunity to stratify and calibrate VCF pixels for estimating and mapping forest land area. Further investigation is recommended to determine the influence of VCF data, land cover stratification data, and RPA inventory data on these discrepancies in state and CONUS estimates of forest land area.

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