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Celebrating Progress, Possibilities, and Partnerships:

Proceedings of the 2019 Forest Inventory and Analysis (FIA) Science Stakeholder Meeting

November 19–21, 2019
Knoxville, Tennessee

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Cover photo: Pisgah National Forest following heavy rains, McDowell County, North Carolina. (photo courtesy of Warren Reed)

Celebrating Progress, Possibilities, and Partnerships
The 2019 FIA Stakeholders Science Meeting

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ABSTRACT

The USDA Forest Service's Forest Inventory and Analysis Program (FIA) is the primary source of information about our Nation's forests' status and trends. Built on a statistically robust sampling network of permanent forest inventory and monitoring plots, the program has created a framework upon which a diverse variety of scientific studies have been built. An FIA Science Stakeholder Meeting was held November 19–21st, 2019 in Knoxville, TN, to bring together FIA personnel, researchers from peer organizations, academia, policymakers, and members of the international scientific community under the theme "Celebrating progress, possibilities and partnerships". Presentations given at this meeting showed the evolution of FIA over time, innovative uses of the data collected by the program now, and looked to future applications in the fields of vegetation monitoring, land use and land cover change, and methods for delivering this information to stakeholders. These biennial meetings serve to maintain and expand the community of FIA data users by providing them with a forum in which to share and explore their ideas on how to make use of this ever growing body of data and information. This proceedings document includes abstracts of the presentation given and expanded details from selected papers presented at the meeting.

Keywords: Cover estimation, data integrity, environmental monitoring, estimation, forest health, forest inventory, international forest monitoring, modeling, remote sensing, sampling.

FOREWORD

During 3 days in late November, Knoxville, TN, the USDA Forest Service Southern Research Station (SRS) Forest Inventory and Analysis (FIA) Program and the National Council of Air and Stream Improvement (NCASI) became hosts to nearly 300 forest scientists, managers, and policymakers from across the globe. Over 20 countries and more than 60 different organizations participated in the 2019 FIA Stakeholders Science Meeting. Meeting attendees met under the theme of "Celebrating Progress, Possibilities, and Partnerships."

This biennial meeting draws a world-class group of partners, practitioners, and scientists with regional, national, and international inventory and monitoring missions. Maintaining the Forest Service's leadership in this area requires both regular consultation with FIA's users, as well as periodic technical exchange among scientists cooperating with FIA in fields such as data visualization, statistical inference, and remote sensing inventory techniques.

The meeting included over 190 oral presentations, 12 plenary speakers, and hands-on sharing of nearly 30 digital products from scientists and partners like ESRI, Texas A&M Forest Service, and Tableau (just to name a few). The plenary was headlined by Jim Hubbard, the current USDA Under Secretary of Natural Resources and the Environment where he shared that FIA is one of the "crown jewels" of our great Agency. Other plenary speakers included Alex Friend (Deputy Chief for R&D, USDA Forest Service), Ken Arney (Regional Forester, Region 8, USDA Forest Service), Rob Doudrick (Station Director, Southern Research Station, USDA Forest Service), David Arnold (State Forester, Tennessee), Tom Martin (CEO, American Forest Foundation), Healey Hamilton (Chief Scientist, NatureServe), Andrew Hait (U.S. Census Bureau), and Songlin Fei (Professor, Purdue University).

The following document is full of abstracts (brief and extended) from each of the presentations that were part of the 2019 FIA Stakeholders Science Meeting. The myriad of projects presented here is a true testament to the impact the USDA Forest Service FIA Program has and the contributions that continue to be made to forest resource research.

ACKNOWLEDGMENTS

The Steering and Planning Committees wishes to thank the National Council for Air and Stream Improvement (NCASI) for co-hosting the 2019 Stakeholder Meeting. We also thank the Southern Research Station Technical Publications Team for excellent work in producing this proceedings document.

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FIA & Ecology Research: Shifting Ranges, Forest Management and Stand Development

ASSESSING TREE MORTALITY PROBABILITY IN HARVESTED HARDWOOD STANDS USING LONG-TERM FOREST INVENTORY DATA

Thomas J. Brandeis, Consuelo Brandeis
USDA Forest Service, Southern Research Station

Partial harvesting (here defined as removal of ≤50 percent of pre-harvest volume) is the predominant silvicultural scheme applied to hardwood forest types in the Eastern United States. Future stand conditions are largely reliant on trees retained after harvest so ensuring the survival of good quality trees can be essential to meeting long-term management goals. Retained tree mortality due to damage caused by harvesting activity should be minimized or taken into account when planning. We quantify partially harvested stand characteristics and post-harvest mortality using data from 27,671 forested conditions, 276,883 trees with a diameter at breast height (DBH) ≥5 inches of which 15,061 trees were cut and utilized. On average 23.3 percent of stand volume was harvested with an additional 2.5 percent of volume lost to harvesting-caused mortality. The likelihood of mortality was 1.35 times higher (95 percent CI of 1.29 to 1.42) for trees retained in stands that had undergone partial harvesting than for trees growing in unharvested stands. There were 83.7 percent of post-harvest mortality trees under 11 inches DBH. The increased odds of mortality were similar for both commercial and non-commercial species, and for trees on both privately and publicly-owned lands.

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ASSESSING LONG-TERM IMPLICATIONS OF FOREST MANAGEMENT ON WILDLIFE HABITAT IN MINNESOTA

John Zobel, Alan Ek
University of Minnesota

As part of the comprehensive evaluation of alternative harvesting scenarios, the Minnesota Generic Environmental Impact Statement (GEIS) used or created several methods to assess specific environmental conditions, including forest wildlife habitat. Over 25 wildlife professionals were involved in the development of the habitat models based on Forest Inventory and Analysis (FIA) data, and results were incorporated into the final GEIS report. Subsequently, the original models were updated and refined into the Wildlife Habitat Indicator for Native Genera and Species (WHINGS), a forest habitat model that allows for rapid assessment of habitat based on forest inventory data and projected forest conditions. The model uses Habitat Suitability Index (HSI) methodology for native, forest dependent wildlife species, including 138 birds, 22 small and medium mammals, 4 large mammals, and 8 herptofauna. This talk will demonstrate the use of WHINGS across 40 years of statewide inventory data from the FIA program. Results will address long-term statewide forest management trends and their direct impact on wildlife habitat in Minnesota.

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UPDATING THE FOREST VEGETATION SIMULATOR WITH CLIMATE RESPONSE RECORDED IN TREE RINGS

**Courtney L. Giebink, R. Justin DeRose,
John D. Shaw, Margaret E.K. Evans**
University of Arizona, Utah State University

The Forest Vegetation Simulator (FVS) is a widely used growth and yield model that uses tree and plot data to simulate growth, mortality, and response to treatments for forest stands to inform management decisions. Although a climate extension of FVS modifies forest development based on spatial species distribution models, FVS lacks the direct effect of climate variation on diameter growth. We plan to use the climate response recorded in tree rings, complemented by inventory data from the ecologically unbiased Interior West-Forest Inventory and Analysis (IW-FIA) program to parameterize the diameter growth for several species in the Utah variant of FVS. Current models predict a 10-year growth increment using a multiple linear regression. Updated models will predict an annual growth increment with climate as a predictor using a mixed effects model. All focal species show positive sensitivity to precipitation variability and negative sensitivity to temperature variability, with differing strengths in response. The inclusion of climate in the diameter growth models will provide more accurate projections, allowing foresters to anticipate stand vulnerability to climate change and adaptively manage to increase stand resiliency.

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MANGROVE INVENTORY COMPARISONS, FINDINGS FROM MULTI-AGENCY TESTS IN FLORIDA

**Mark J. Brown, Jarek Nowak, Karen Cummins,
Todd Schroeder, Bruce Cook**
USDA Forest Service, Southern Research Station; Florida Forest Service

Traditional ground based inventory of mangrove forests can be difficult and time consuming. Tides, mud flats, prop roots, and tree densities impede foot travel. To mitigate these issues and improve data collection, the Southern Research Station (SRS) initiated a collaborative study with the Florida Forest Service (FFS) and the National Aeronautics and Space Administration (NASA) to test alternative methods for mangrove inventory. Consultation with Mexico's National Forestry Commission (CONAFOR) mangrove inventory provided the diameter method studied. This presentation describes study parameters and findings from methods compared. First, inventory a one point plot design to reduce extensive traverse involved with current 4 subplot design. Second, measure tree diameter at 1.0 feet above highest prop root when encountered at or above normal diameter at breast height (dbh), to alleviate difficult measurement at 3.5 feet above that point under current methods. Third, synchronize NASA flyovers of mangrove plot locations using global positioning system (GPS) coordinates and Goddard LiDAR Hyperspectral Thermal (G-LiHT) airborne imaging to test viability of remotely-sensed data to represent inaccessible mangrove plot locations in Florida.

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ARE CURRENT SEEDLING DEMOGRAPHICS POISED TO REGENERATE NORTHERN U.S. FORESTS?

Lance A. Vickers, William H. McWilliams, Benjamin O. Knapp, Anthony W. D'Amato, Daniel C. Dey, Yvette Dickinson, John Kabrick, Laura Kenefic, Christel Kern, David Larsen, Alejandro Royo, Michael Saunders, Stephen Shifley, James Westfall
University of Missouri, USDA Forest Service NRS-FIA

Securing desirable regeneration is essential to sustainable forest management, yet failures are common. Detailed seedling measurements from a new NRS-FIA regeneration indicator inventory across 24 northern U.S. States were examined for plausible regeneration outcomes following overstory removal. The examination included two fundamental regeneration objectives: (1) stand replacement-securing future forest, and (2) species maintenance-securing upper canopy species. Almost half the plots lacked adequate seedlings to regenerate a stand after canopy removal and over half risked compositional shifts. Based on those advance reproduction demographics, regeneration difficulties could occur on two-thirds of the plots examined. The remaining one-third were regeneration-ready. However, compared to historical norms, increased small-tree mortality rates reduces that proportion. Not all forest types rely on advance reproduction and results varied among the forest types examined. Some variability was associated with browsing intensity, as areas of high deer browsing had a lower proportion of regeneration-ready plots.

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LEVERAGING THE FOREST INVENTORY AND ANALYSIS DESIGN IN A NATIONAL, SPATIALLY EXPLICIT ASSESSMENT OF FOREST TREE GENETIC DEGRADATION RISK

Kevin M. Potter, Kurt H. Riitters
North Carolina State University

Genetic diversity is essential for forest tree species because it provides a basis for adaptation and resilience to environmental stress and change. The Montréal Process, which the U.S. Department of Agriculture Forest Service uses as a forest sustainability assessment framework, incorporates genetic variation among its indicators of biological diversity, including the following: “Number and Geographic Distribution of Forest-Associated Species at Risk of Losing Genetic Variation and Locally Adapted Genotypes.” To address this indicator, we intersect Forest Inventory and Analysis data with climatically and edaphically defined provisional seed zones, which encompass areas with similar geology, climate, vegetation, and soils. These zones are proxies for among-population adaptive variation in tree species under the assumption that their adaptive genetic variation is associated with the environmental conditions that define the seed zones. We determine, for each species, the ratio of mature trees to saplings within each seed zone as an indicator of insufficient regeneration that could lead to the loss of genetic variation. The results offer insights into which species and which areas of the country may be experiencing degradation of genetic diversity.

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TREES OUTSIDE FORESTS: WHERE ARE THEY AND WHAT ARE THEY DOING?

Dacia Meneguzzo, Todd Kellerman
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Forests in the agriculturally-dominant Great Plains region are not like traditional forests. Their placement is often intended to provide a specific ecological service, such as conserving soil, protecting crops, livestock, and humans, or improving water quality. While these tree features often fail to meet the definition of "forest" employed by the Forest Inventory and Analysis Program, they are viewed as such by the region's land managers. Windbreaks are a prime example; they are critically important yet little information describing their extent and location is available in formats (e.g., maps) that are useful for resource professionals and decisionmakers. Collaborative research with the U.S. Department of Agricultural National Agroforestry Center has led to the development of high-resolution tree cover maps as well as value-added map products depicting ecological services provided by trees outside forests (TOF). Mapping methodologies, output products, and data describing the TOF resource for multiple States in the Central United States are presented. This endeavor is the first of its kind in the region and provides information at a new scale that is appropriate for inventory, monitoring, and decisionmaking related to nontraditional forests.

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ESTIMATING WILDFIRE EFFECTS WITH PROPENSITY SCORE AND SPATIAL MATCHING

Hyeyoung Woo, Bianca N.I. Eskelson, Vicente J. Monleon
University of British Columbia

Wildfire effects on standing tree carbon are often estimated based on observational studies of wildfires. Many of these studies focus on extreme, large wildfires that gained public interest and research support. Using Forest Inventory and Analysis (FIA) data in Oregon and Washington, we identified plots (n = 611) that burned in large forest wildfires within the Pacific Northwest between 2001 and 2016. We matched them with unburned FIA plots using three approaches: (1) propensity score matching based on topography, climate, and land cover variables, (2) spatial matching, and (3) distance-adjusted propensity score matching. With these matched plots we estimated wildfire effects with a quasi-experimental approach for the entire area that burned during that period. Therefore, our results provide estimates of wildfire effects that are representative of all wildfires across Oregon and Washington. We discuss (1) the performance of the three different propensity score matching approaches for estimating wildfire effects from matched inventory plots, and (2) how this regional approach to wildfire effect estimation provides complementary information to that from detailed fire effects studies conducted as case studies in individual fires.

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Forests of Interior Alaska—Insights from the Tanana Unit

USE OF HIGH-RESOLUTION, MULTI-SENSOR AIRBORNE REMOTE SENSING TO SUPPORT FOREST INVENTORY IN INTERIOR ALASKA

Hans E. Andersen, Jacob Strunk, Kate Legner, Bruce Cook, Doug Morton, Chad Babcock, Mike Alonzo, Andrew Finley

USDA Forest Service, Pacific Northwest Research Station

Given the rapid development of several complementary advanced geospatial technologies (e.g., laser scanning, hyperspectral imaging, direct georeferencing) the role of airborne remote sensing in forest inventory is also continually changing. In this presentation, we describe how advanced, high-resolution, and multi-sensor airborne remote sensing data [airborne laser scanning, hyperspectral imaging, ultra-high resolution (3 cm pixels) stereo imagery] collected by NASA-Goddard are being used to support the FIA inventory in interior Alaska, with particular emphasis on the development of tools to make these technologies more accessible to end users. First, we describe how stereo imagery from a high-resolution mapping camera can be used to support field operations in the Susitna-Copper inventory unit, including detailed forest condition class mapping. Second, we describe how a combination of airborne lidar and hyperspectral imagery can be used to increase the reliability of inventory reporting for the Tanana inventory unit through the use of model-assisted survey regression estimators, including the development of an R package to facilitate calculations and presentation of tabular results.

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ASSESSING POTENTIAL CHRONOLOGY BIAS IN THE FIA INCREMENT CORE RECORD WITH INCREMENT CORE DATA FROM DENSELY SAMPLED FOREST PLOTS ACROSS NORTH AMERICA

Robert G. Jespersen, Patrick F. Sullivan,
Sean M.P. Cahoon, Hans-Erik Andersen
University of Alaska-Anchorage

Increment cores collected through the United States Forest Inventory and Analysis (FIA) Program offer the potential for unique insights into forest growth and its sensitivity to climate. While FIA plots are randomly located, trees selected for coring on FIA plots are generally a small number (n ~ 5 trees) of dominant or co-dominant individuals whose growth patterns may or may not reflect the broader population. We took advantage of tree-ring data from densely sampled plots (n ~ 30–60 trees) to examine the potential for chronology bias emerging from sampling primarily dominant and co-dominant trees. Data from densely sampled plots were acquired for the Tanana Valley of interior Alaska and from forested sites throughout North America. Preliminary results suggest the potential for chronology bias might vary strongly by species. Further analyses will examine the relative chronology quality from dominant and codominant trees across forest types, tree functional groups, and sampling designs. Our findings of bias, or lack thereof, may help inform the use and interpretation of FIA tree-ring chronologies.

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HIGH-RESOLUTION DATA FROM NASA'S G-LIHT AIRBORNE IMAGER FOR REMOTE INVENTORY AND SCIENCE APPLICATIONS

Bruce Cook, Douglas Morton, Larry Corp,
Mike Alonzo, Hans-Erik Andersen
National Aeronautics and Space Administration,
Goddard Space Flight Center

Interior Alaska accounts for 15 percent of U.S. forest lands, yet the remoteness of interior Alaska presents a range of challenges for inventorying forest resources. Beginning in 2014, the U.S. Department of Agriculute Forest Service partnered with NASA's Goddard Space Flight Center to pilot a lidar-assisted forest inventory. This approach leverages the unique, multi-sensor, high-resolution data from NASA Goddard's Lidar, Hyperspectral, and Thermal (G-LiHT) Airborne Imager (www.gliht.gsfc.nasa.gov). During 2014–19, G-LiHT flights have collected strip samples of data spaced every 9 km across three inventory units (Tanana Valley, Susitna-Copper River, and Southwest). Within these strips, the Forest Service implemented a ⅕th intensity grid of FIA plots. Here, we discuss the role of 1 m resolution airborne lidar, hyperspectral, thermal, and fine-resolution (< 4 cm) stereo photographs for connecting the dots between inventory plot locations, including analyses of forest biomass, species composition, and trajectories of vegetation succession following stand-replacing wildfires. G-LiHT data also sample gradients in elevation, soils, and disturbance history needed to evaluate changing permafrost, insect outbreaks, expanding shrub biomass, and wildlife habitat.

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TOWARD ESTIMATING LITTER AND SOIL CARBON STOCKS ON FOREST LAND IN ALASKA

Grant M. Domke, Brian F. Walters, Andrew Gray, Brendt Mueller, Charles Perry, Lucas Nave, Stephen Ogle
USDA Forest Service

Soil organic carbon (SOC) is the largest terrestrial carbon (C) sink on earth and management of this pool is a critical component of global efforts to mitigate atmospheric C concentrations. SOC is also a key indicator of soil quality as it affects essential biological, chemical, and physical soil functions such as nutrient cycling, water retention, and soil structure and maintenance. Much of the SOC on earth is found in forest ecosystems and is thought to be relatively stable. That said, several studies have documented the sensitivity of SOC to global change drivers, particularly in the northern circumpolar region where approximately 50 percent of the global SOC is stored. The Forest Inventory and Analysis (FIA) Program within the U.S. Department of Agriculture, Forest Service has been measuring litter and soil attributes in forests of the U.S. since 2001. These data have recently been harmonized with auxiliary biophysical and geospatial data to develop models for predicting litter and soil carbon stocks on forest land in the conterminous United States. In this study, we expand that work to estimate litter and soil carbon stocks and associated uncertainties for managed forest land in Alaska.

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Advances in Modeling Distributions, Structure, and Sustainability

FIA USE IN DEVELOPING THE FOREST SUSTAINABLE AND ECONOMIC ANALYSIS MODEL (FORSEAM)

Lixia H. Lambert, Burton C. English, Bryce Stokes, Matthew H. Langholtz, Tim Rials, Nicolas O. André
Oklahoma State University, The University of Tennessee

The Forest Sustainable and Economic Analysis Model (ForSEAM) is a dynamic linear optimization model developed to determine where conventional wood and energy feedstocks could be acquired from timberland. The model is compartmentalized into three sections including supply, demand, and sustainability. The supply component includes timber-sector production activities for 305 production regions in the lower 48 U.S. States. Each region is composed of a set of production activities including sawlog, pulpwood, and energy feedstock (woody biomass). The model currently considers two sources of energy feedstock: (1) logging residue, and (2) removal of whole pulpwood and nonmerchantable trees as energy feedstock. The growth rates and yields of different size and types of timber were calculated based on information from the Forest Inventory and Analysis (FIA) database. The conventional timber demand component is based on U.S. Forest Service scenarios determined by the U.S. Forest Products Module. The sustainability component insures that harvest in each region does not exceed annual timber growth, forest tracts are located within reasonable distance of the roads, and current year forest attributes reflect previous period harvests and removals.

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SPECIES DISTRIBUTION MODELS PREDICT SHIFTING CLIMATIC SUITABILITY FOR IMPORTANT SUBSISTENCE SPECIES IN INTERIOR ALASKAN FORESTS

Kathryn C. Baer, Andrew N. Gray
USDA Forest Service,
Oak Ridge Institute for Science and Education

Rapidly changing climatic conditions in subarctic forests have the potential to drive dramatic shifts in the distribution and abundance of their component vegetation. Of particular concern in Alaska is the potential for changes in the distribution and productivity of berry-producing understory species, which represent an important cultural and subsistence resource. FIA inventory data for interior Alaska offer a unique dataset from which models can be constructed to estimate current berry species distributions and project how these distributions may shift under future climate change. In this study, we utilized records of berry species presence and absence paired with current climate data to estimate the current extent of berry species distributions. We then applied these models to three global circulation models for future climate to predict how these distributions might shift in the study area under future climatic conditions. Models predicted a decrease in the incidence of highly suitable habitat along with shifts towards higher elevations and away from population centers. These results indicate that subsistence berry species may become less abundant in interior Alaska and suggest areas for intensified future monitoring.

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USING FOREST INVENTORY DATA TO BUILD DEMOGRAPHY-DRIVEN MODELS OF THE GEOGRAPHIC DISTRIBUTION: A CASE STUDY OF *PINUS EDULIS* (TWO-NEEDLE PIÑON)

Margaret E. K. Evans, Emily L. Schultz, Lisa Huelsmann, Michiel D. Pillet, Pieter Zuidema, Dave D. Breshears, Sydne Record, Florian Hartig, John D. Shaw, R. Justin DeRose
University of Arizona

Climate change is expected to affect species' distributions. Species distribution models based on occurrence data using bioclimatic predictors alone, are widely criticized as phenomenological. Here we view the FIA database as the world's largest repository of demographic data on trees, and use these data to parameterize a demographic model, an integral projection model, for a species whose entire geographic distribution is contained within the FIA domain, *Pinus edulis* (two-needle piñon). We evaluate competing hypotheses for piñon's distribution: climate alone limits this species vs. climate and competition are both important limiting factors. We find support for the importance of both, with respect to the response of vital rates (growth, mortality, and regeneration) to variation in climatic and competitive conditions, and in terms of the fit between projected population growth rate and observed occurrences of *Pinus edulis*. Drawing on both disturbance ecology and a deep time perspective on the importance of fire in shaping the evolution of pines, we further suggest that fire may a missing factor that leads to a mismatch between occurrence data and predicted population growth rate above a mean annual precipitation of ~750 mm.

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DATA SOLUTIONS FOR LARGE-SCALE MODELING AND PLANNING: USING FIA-BASED SILVIATERRA DATA FOR RESILIENCE PLANNING IN THE CENTRAL SIERRA NEVADA

Patricia Manley, Rodd Kelsey, Brian Clough, Charles Maxwell, Robert Scheller, Henry Rodman, Zack Parisa
USDA Forest Service, Pacific Southwest Research Station;
The Nature Conservancy

Western coniferous forests are exhibiting substantial stress from lack of fire, drought, and changing climates. Large-scale mortality events have been increasing in extent and frequency, and they are raising concerns that the opportunity to restore forest resilience may be slipping away. A common barrier to increasing the pace and scale of restoration is the availability of vegetation data that is consistent across large areas and multiple ownerships, and that describes forest conditions with sufficient detail, accuracy, and precision to support management actions. The Tahoe Central Sierra Initiative, a collaborative of Federal, State and non-profit organizations in California was formed to restore forest resilience across 2.4 M acres of mixed land ownership in some of the most ecologically and socially important watersheds in California. SilviaTerra data was identified as a singular, high quality data source for vegetation data across the entire landscape that provided spatially explicit, high resolution data on forest structure and composition. We conducted a detailed assessment of forest structure and composition, wildlife habitat, and timber supply, and then modeled changes in these parameters over 100 years using the Landis II dynamic growth model to inform restoration options.

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AN APPLICATION OF GENERALIZED JOINT ATTRIBUTE MODELING FOR MODELING FOREST STRUCTURE AND COMPOSITION

David M. Bell, Matthew J. Gregory
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Wall-to-wall maps of forest structure and composition are needed for landscape monitoring and planning. Any such mapping strategy should generate statistically rigorous estimates of multiple response variables (e.g., species-level abundances) that are consistent with emergent properties (e.g., total abundance and species richness). In this study, we will apply the generalized joint attribute modeling (GJAM) approach, a hierarchical Bayesian modeling method for complex, multivariate ecological data, to predict multivariate Forest Inventory and Analysis structure and composition data based on environmental gradients and multispectral remote sensing. We will compare GJAM with an existing multivariate approach (gradient nearest neighbor imputation) in terms of (1) individual species basal area, (2) total tree basal area, and (3) total species richness. Comparisons will include plot-level accuracy assessments as well as comparisons of resulting map products, including both mean predictions and prediction precision (e.g., standard deviations). By comparing GJAM with existing nearest neighbor imputation methods, we will provide new guidance regarding the mapping of complex, multivariate forest attribute datasets.

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COMBINING FIA DATA WITH THE LANDIS FOREST SIMULATION MODEL TO IMPROVE PROJECTIONS

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Forest simulation models allow users to project potential forest conditions into the future under different conditions and scenarios. Forest inventory and analysis (FIA) data provides rigorous information about past forest conditions. When used in combination, FIA data and forest simulations models, such as LANDIS, can utilize the information from the recent past to inform the projections of future conditions. FIA data has been used widely in LANDIS simulation studies to provide information about current forest conditions and to calibrate and validate model initialization and growth parameters. The USDA Forest Service Northern Research Station is now pursuing improved integration between the LANDIS modeling community and the FIA research program to draw on the strengths of these two lines of research. FIA data can be used to develop seamless forest condition maps meeting the specific model requirements for the simulation starting conditions and statistically rigorous evaluation of model behavior at different spatial scales utilizing the FIA data structure. In turn, the LANDIS model has the potential to inform aspects of the FIA carbon accounting by modeling growth and disturbance processed between plot measurement years.

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Damage, Disease, Disturbance: Forest Health Research with FIA

HISTORICAL ACTIVITY OF MAJOR PESTS IN THE LAKE STATES

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Our goal is to create a series of technical reports and story maps that summarize the historical patterns of major pests in the Lake States. Since the 1950s, detailed information on insect activity has been collected by State agencies (Forest Health Highlights) and the U.S. Department of Agriculture Forest Service (Forest Health Monitoring, Forest Inventory and Analysis). Although these data and observations have been carefully documented in annual and periodic reports, the existing format is not easy to use. Historical patterns in insect activity and concurrent forest conditions can be a useful predictive tool for future forest conditions. We will synthesize this information and present it in a visually intuitive format that forest managers can readily use. Each installment in the series will include a different major pest, with brief sections on basic biology and ecology, historical activity, forest conditions, and management implications. The series will focus most on patterns of insect activity over time in relation to changing forest conditions. The first installment is spruce budworm, (*Choristoneura fumiferana*), a native insect with a well-documented history of outbreaks affecting balsam fir and white spruce in the Lake States.

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LICHEN AND MOSS METRICS FOR MONITORING AIR QUALITY IN WILDERNESS AND URBAN AREAS

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It's widely acknowledged that monitoring mandates under the Clean Air Act (CAA) aren't well met using existing instrument-based networks. Federal land managers (FLMs) in the West often supplement with bio-indicator datasets to gain smaller-scale perspectives on air quality, including the 9,000+ lichen community surveys collected by FIA and NFS since 1989. Stakeholder priorities, however, increasingly focus on air quality in high elevation ecosystems and urban forests. Both environments are hostile to most lichens, making our typical community-based metrics unreliable. Three studies are underway to develop the use of low cost chemical assays of lichen and moss tissue as an alternative: (1) The CAA tasks FLMs with monitoring air quality in Wilderness, many acres of which lie above the elevation limit for epiphytic lichens. We collaborate with R6 NFS to establish an N mapping protocol for their Wilderness Monitoring Plan. (2) We work with air regulators, State, city, and municipal organizations in Portland, OR, to map air toxics regulated under the CAA using a hardy moss. Results guide placement of limited air instruments. (3) A 1-year urban study comparing pollutants in moss to PM10 and precipitation is underway.

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THE RISE AND FALL OF INDIVIDUAL AND MULTIFACTOR DAMAGE AGENTS IN FORESTS OF THE UNITED STATES: A RETROSPECTIVE LOOK AT FIA DAMAGE COLLECTION PROTOCOLS

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The Forest Inventory and Analysis (FIA) Program of the U.S. Department of Agriculture, Forest Service, has included damage collection protocols in its inventory since the initiation of forest surveys in the 1930s. These protocols have naturally undergone revisions over time as information needs and technologies for data collection, storage, and analysis have evolved. Although changes in the damage collection protocols may impede long-term trend analyses, an examination of the protocols utilized at various points in history highlights shifts in the agents considered to be most important. Many agents such as dwarf mistletoe and fusiform rust have persisted in importance over the years whereas other agents (e.g., turpentining) are no longer of great concern. Agents on the rise include declines, diebacks, and wilts resulting from multiple interacting factors and individual agents introduced into the U.S. or moved outside their native ranges within the United States.

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USING EVALIDATOR TO REPORT ON NATIONAL SCALE MORTALITY TRENDS FOR THE FOREST HEALTH MONITORING ANNUAL REPORT

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Since 2001, the national Forest Health Monitoring (FHM) Program has produced an annual report on the forest health status and trends across the United States using monitoring data from a variety of sources. The method of analyzing mortality has changed several times since the first FHM report. Most recently, EVALIDator has been used to produce growth and mortality estimates by ecoregion section for the most recent cycle of measurements for each State and to identify regions with unusually high mortality. EVALIDator output also has been used to identify the forest types suffering the greatest mortality and major mortality-causing agents. Limitations on the use of EVALIDator for national-scale analyses are failures when the system times-out waiting for a response. In this talk, examples of analyses from the most recent FHM national report will be presented, as well as other uses of EVALIDator that may provide greater insight into tree mortality trends.

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USING CLIMATE AND BIOPHYSICAL ATTRIBUTES TO PREDICT THE DISTRIBUTION OF ROOT DISEASE ACROSS THE U.S. NORTHERN ROCKY MOUNTAINS

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We used a database of more than 15,000 root disease measurements at FIA plots collected across the U.S. Northern Rocky mountains coupled with high resolution (30 m) gridded climate and soil water balance datasets to examine the climatic and biophysical factors associated with presence and severity of root disease. Root disease occurrence was moderately well explained by dewpoint temperature, evapotranspiration and climatic water deficit (AUC = 0.77) with higher root disease prevalence at moist, humid sites with low or moderate soil water balance deficits. Root disease severity was not well explained by climatic and biophysical factors alone (R^2 = 0.19). Variogram analysis indicated little spatial autocorrelation beyond a 5 km range, suggesting that the distribution of FIA plot samples may not be well suited for capturing the spatial processes governing root disease spread. We used the fitted models to estimate root disease probability of occurrence and severity across the U.S. Forest Service Northern region and to produce spatially explicit maps that will be used to help identify and quantify potential impacts and help prioritize areas for broad scale planning and analysis.

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THE RELATIONSHIP OF 19TH CENTURY VEGETATION TO 21ST CENTURY OAK DECLINE AND MORTALITY IN MISSOURI OZARK HIGHLANDS

Sunil Nepal, Zhaofei Fan, Martin Spetich
Auburn University

To examine the role of historical vegetation condition change in current oak decline and mortality, we investigated annual FIA data and early 19th-century public land survey (PLS) in the Missouri Ozark Highlands. Historical tree data revealed that white oaks were the most frequent species (50 percent), followed by red oaks (30 percent), shortleaf pine (8 percent), hickories (5 percent), and other species (7 percent). At present, white oaks, red oaks, and pine decreased to 34, 25, and 6 percent respectively, but hickories and other species increased to 10 and 25 percent, respectively. Changes in species composition varied among historical vegetation conditions. Hickory and other species increased in all conditions. In contrast, oaks decreased in oak closed woodland, oak forest, oak open woodland and oak savanna, and increased in oak/pine closed woodland, oak/pine forest, and oak/pine open woodland. Red oaks mortality reached up to 2.6 percent per year which was significantly higher than other species. The highest red oak mortality was found in the oak/pine closed woodland. In the future, we plan to develop a modeling system that includes all factors contributing to oak mortality at different spatial scales to aid in the development of applicable mitigation methods of oak decline.

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Integration of Forest Health Data Sources: Leveraging Big Data Tools to Shape the Future

COMBINING NOVEL REMOTE SENSING METHODS WITH FIA DATA TO EVALUATE EFFECTS OF DROUGHT AND GYPSY MOTH DEFOLIATION ON TREE MORTALITY AT LANDSCAPE SCALES

Valerie J. Pasquarella, Kyle Haynes, Andrew Liebhold, Randall Morin, Nathan Siegert
Boston University, University of Virginia

Gypsy moth (*Lymantria dispar*) defoliation is contributing to the declining abundance of oaks in Eastern North America. Stand-level observations suggest drought predisposes trees defoliated by gypsy moths to mortality, however the extent to which drought and defoliation have joint effects on tree mortality and growth at regional scales is less understood. We combine Landsat-based estimates of defoliation severity with FIA plot data to examine relationships between defoliation, drought, mortality, and the net growth of trees. In order to provide consistent, repeatable assessments of changes in forest condition over time, we utilize a new remote sensing approach to map and monitor the intensity of gypsy moth defoliation based on new and historic Landsat imagery. Because this approach is data-intensive, it has previously been applied to only parts of New England. To assess changes in forest condition over larger areas, we have implemented in Google Earth Engine, and this presentation will focus on this new toolset and our evaluation of regional-scale defoliation products. We also highlight challenges in combining plot remeasurements with the Landsat record, as well as preliminary analysis of defoliation and tree mortality.

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ESTIMATING BASELINE MORTALITY FOR WHITE PINE IN THE CENTRAL APPALACHIANS TO ASSESS THE IMPACT OF A NOVEL SCALE INSECT/PATHOGEN COMPLEX

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In the Central and Southern Appalachians, a novel and poorly understood die-back phenomenon in white pine (*Pinus strobus* L.) has been attributed to a scale insect and a weak fungal pathogen. Monitoring plots established in 2012 show considerable mortality, primarily in younger age cohorts in mixed pine-hardwood stands. While overall decline in white pine volume has been minimal thus far, baseline mortality analysis indicated that five (2 cm) diameter classes (4–6, 6–8, 8–10, 14–16, 24–26) observed mortality that was significantly greater that the established baseline mortality after only 5 years of monitoring. Initially, only one of these diameter classes (4–6) had observed mortality significantly greater than the baseline. Baseline mortality across all white pine cohorts was estimated to be approximately 12 percent based on study plot data and 13–14 percent based on FIA data. Observed mortality on study plots was over 30 percent for the smallest diameter classes (4–6, 6–8), and over 20 percent for the other three diameter classes. If these trends continue, white pine abundance or sustainability in these mixed stands could eventually be compromised as mature trees gradually die and fewer cohorts of younger trees are available to replace them.

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RATING FIA PLOTS FOR SOUTHERN PINE BEETLE HAZARD AND APPLICATIONS FOR THE NATIONAL INSECT AND DISEASE RISK MAP

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and Applied Sciences Team

The National Insect and Disease Risk Map (NIDRM) estimates areas and magnitudes of tree mortality due to major insect and disease (pest) outbreaks, over a 15 year future time horizon. There is a need for annual assessments of hazard. Many NIDRM models are based on metrics that can be solely derived from FIA plot measurements. We applied southern pine beetle (SPB) models to FIA data. Outputs for each FIA plot location were relative hazard rating (0–10, unitless), and total predicted percent basal area loss over the next 15 years. Because of the importance of geographic representation of model outputs for making adjustments and coordination with State and regional entomologists and pathologists, we compared two scales for spatially-averaging plot hazard: counties, and 6,000-acre hexagonal lattices which included the 3–4 nearest plot locations for each hexagon using a buffer of 2600 m outside the edge. We compare results to the most recent (2018) NIDRM model for SPB and explore opportunities for including additional FIA measurements that would allow us to develop more complex models of insect and disease hazard. A possible future outcome of this work is a risk rating system for plots that can be added as a supporting table in FIADB.

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INSECT AND DISEASE THREATS TO UNITED STATES TREE SPECIES AND GEOGRAPHIC PATTERNS OF THEIR POTENTIAL IMPACTS: COMBINING FIA DATA WITH AGENT-SPECIFIC DISTRIBUTIONS AND SEVERITIES

Kevin M. Potter, Maria E. Escanferla, Robert M. Jetton
North Carolina State University

Diseases and insects arguably pose the most destructive threat to North American forests. As part of an effort to identify U.S. tree species and forests most vulnerable to these epidemics, we compiled a list of the most serious insect and disease threats for 419 native tree species and assigned a severity rating for each of the 1378 combinations between mature tree hosts and 339 distinct insect and disease agents. We then joined this list with Forest Inventory and Analysis data to assess the potential ecological impacts of insect and disease infestations. Specifically, we used the potential host species mortality for each host/agent combination to weight species importance values on approximately 132,000 FIA plots. When summed on each plot, these weighted importance values represent an estimate of the proportion of the plot's existing importance value at risk of being lost. In general, the potential impacts of insects and diseases were greater in the West, where there are both fewer agents and less diverse forests. However, the impact of nonnative invasive agents was potentially greater in the East.

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USING FOREST INVENTORIES TO ASSESS LONG-TERM CHANGE IN THE STRUCTURE AND COMPOSITION OF THE NORTHEASTERN ASH RESOURCE IN RELATION TO THE EAB INVASION

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USDA Forest Service, Forest Health Protection

While insects are natural disturbance agents that help regulate forest ecosystem processes, the introduction of nonnative insects can significantly alter forest structure and composition, and in turn, stand productivity and biodiversity. Originating in Asia, emerald ash borer (EAB), *Agrilus planipennis*, Coleoptera: Buprestidae, was introduced to southeastern Michigan in the early to mid-1990s, though it was not detected until 2002. In this study, the long-term structural and compositional response of Northeastern United States ash forests to the invasion of EAB was examined. Using a measure of EAB presence based on county-level detections and tree-ring records, we evaluated changes in ash density, basal area, and regeneration in States that were first affected by EAB (Michigan, Indiana, and Ohio) to determine impact trajectories in recently invaded States. Results are based on analysis of 12,363 FIA plots that were measured three times between 2001 and 2017. Quantifying the cumulative changes to ash forests in the Northeastern United States since the arrival of EAB will help inform land management practices designed to minimize the impacts of this insect.

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CARBON LOSSES RESULTING FROM INSECT AND DISEASE INVASIONS IN U.S. FORESTS

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Worldwide, forests are increasingly affected by nonnative insects and diseases, many of which cause substantial tree mortality across large regions. North America has been invaded by a particularly large number of such species; over 400 forest insect and pathogen species are known to be established and damage has been recorded from about 70 of these. While information exists about ecological impacts of certain individual species, a comprehensive analysis assessing the composite ecosystem impacts of these species is lacking. Here we analyze >120,000 forest inventory plots distributed across the United States to estimate the composite impact of the 15 most damaging forest insects and diseases on total tree biomass and carbon loss. We determine that the most damaging agents, in terms of biomass and carbon loss, are Dutch elm disease, emerald ash borer, beech bark disease, and hemlock woolly adelgid. From 2009–2015, all nonnative forest pest species combined induced an average annual mortality rate (above background mortality) of 4.7 percent of living tree biomass. These results indicate that forest pest invasions, driven primarily by globalization, are contributing to the accumulation of atmospheric greenhouse gases.

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ASSESSMENT OF LANDSCAPE-LEVEL MICROBIAL COMMUNITY DIVERSITY THROUGHOUT FIA MONITORING PLOTS

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Soil microbes are primary drivers of forest ecosystem processes and play important roles in nutrient cycling, soil structure formation, decomposition, detoxification, regulating plant productivity, influencing plant diversity, and suppression of root diseases. Soil microbial communities are critical to the forest health components of sustainability, productivity, and resilience. However, our understanding of their synergistic interactions tends to be localized and difficult to apply to the landscape or ecoregion level. Soil samples were collected during the 2018 field season in conjunction with 49 FIA plots located within Colorado and Wyoming (125 samples). Using molecular approaches, we can determine taxonomic diversity of microbial communities directly from DNA extracted from environmental soil samples. The identification of microbial communities will increase our understanding of landscape level microbial diversity in forested ecosystems. Additionally, documenting potential drivers of microbial communities (i.e., changes in silvicultural treatments, forest types, land use, and regional climate change) across landscapes and over time is a valuable resource for modeling/predicting and managing western forests.

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Linking Forest Disturbance and Forest Dynamics to Water Quality

COMBINING FIA AND LAND COVER DATA FOR ASSESSING WATERSHED CONDITIONS FOR COLDWATER FISH WITHIN GREAT LAKES BASINS

William J. Severud[1], Patrick Landisch[1], Mark D. Nelson[2], Lisa H. Elliott[1], Jody C. Vogeler[3], Trevor K. Host[1], and Joseph F. Knight[1]

Landscape characteristics of watersheds can be important determinants of water quality and consequently influence fish ecology (Albertson and others 2018, Seilheimer and others 2013). Brook trout (*Salvelinus fontinalis*), a species of charr native to Eastern United States and Canada, is sensitive to landscape-level and local disturbances and human activity (Hudy and others 2008). Water quality, temperature, barriers to fish passage, non-native salmonids (e.g., rainbow [*Oncorhynchus mykiss*] and brown trout [*Salmo trutta*]), angling pressure, and other factors can all influence populations of brook trout (Haxton and others 2019, Hudy and others 2008,). The Great Lakes Restoration Initiative (GLRI) strategically targets the biggest threats to the Great Lakes ecosystems through the use of science-based adaptive management. Our GLRI-funded project aims to describe spatiotemporal patterns of land use, land cover, and forest disturbance at multiple watershed scales [hydrologic unit codes (HUC)] within the Great Lakes basins (fig. 1), and then relate those patterns to coldwater stream fish distribution and abundance. Ultimately, we will use our results to prioritize restoration sites to maximize impact. Here, we address the first of these objectives by describing spatial patterns of land cover, land use, and multiple disturbance agents inside and outside riparian areas at multiple HUC levels.

Attributes of land use were obtained from the Forest Inventory and Analysis (FIA) database (Burrill and others 2018), using data from approximately 2012–2018. We obtained land cover attributes from the 2016 National Land Cover Database (NLCD) (Jin and others 2019) and Landsat time series-based forest canopy disturbance data for Minnesota (Vogeler 2019). Disturbance classification maps were created by examining summer composites of tasseled cap spectral indices from Landsat imagery (1974–2018) (Vogeler and others 2018) and then applying the LandTrendr segmentation algorithm (Kennedy and others 2010) to identify patches of abrupt change in forest cover. This process identified the most recent fast disturbances (MRFDs) (fig. 1) in the forested landscape. Training data then informed change agent attribution into 6 categories: conversion, fire, flood, harvest, wind, and other.

We used the national Riparian Areas Base Map for regional assessments, and the Riparian Buffer Delineation Model (RBDM) https://www.riparian.solutions/ (Abood and others 2012) for finer scale analyses of differences in disturbance, and land cover between riparian and non-riparian areas. RBDM model inputs included streamlines, watershed boundaries, elevation, 50-year flood heights, wetlands data, lakes, hydric soils, and land cover.

Forest land cover characteristics varied by hydrologic scale and whether within or outside of riparian areas; results from smaller geographic areas (e.g., HUC 8) ranged more widely. At a broad scale, the entire Great Lakes Region is comprised of FIA land uses of forest (51 percent), agriculture/range (29 percent), developed (14 percent), open water (3 percent), and other classes (wetlands, undeveloped areas; 3 percent). Composition varied among five Great Lakes basins: 20–84 percent forested, 8–52 percent agricultural, 5–26 percent developed, and 1–4 percent water. Riparian areas constitute 9.4 percent of the total land area. HUC 4 watersheds ranged from 79.8 percent to

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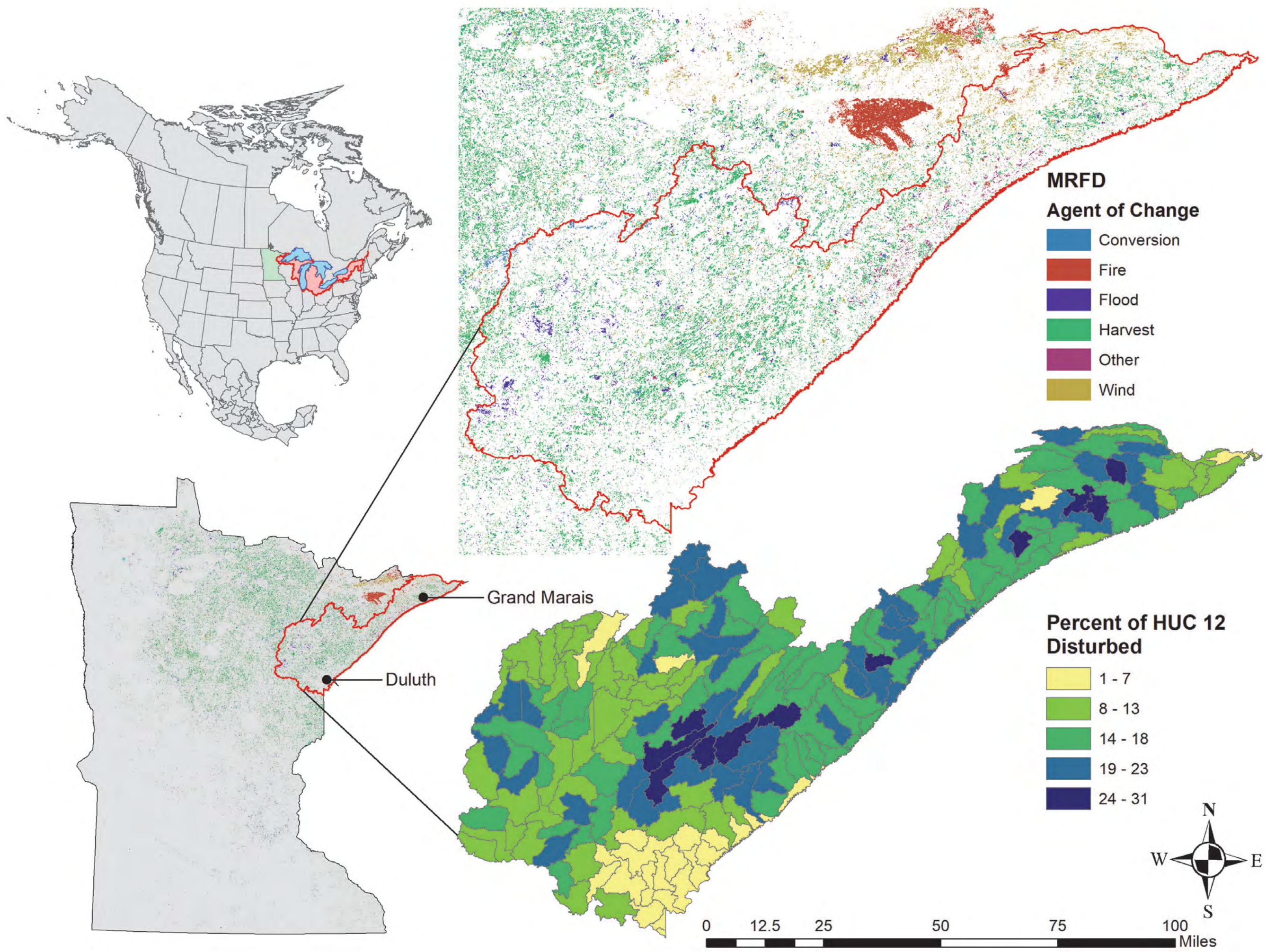

Figure 1—United States portion of the Great Lakes Basin (upper left), and Minnesota's portion of the Lake Superior Basin (hydrologic unit code [HUC] 4; bottom left), the agents of most recent fast disturbance (MRFD; upper right), and the percentage of each HUC 12 that has experienced disturbance at least once during 1974–2018 (lower right).

91.3 percent non-riparian area and 8.7 percent to 20.2 percent riparian, whereas at the HUC 8 scale non-riparian area ranged from 62.2 percent to 96.8 percent and riparian area ranged 0 percent to 37.8 percent. NLCD forest land cover made up 53 percent of the region; forest cover comprised 68.5 percent of riparian areas and 50.5 percent of non-riparian areas.

At a fine scale, we examined land cover patterns within Minnesota's portion of Lake Superior's basin from 1974–2018 across 189 HUC 12 watersheds (fig. 1). Overall, lands are 82 percent forest cover and 15 percent of forested lands have experienced disturbance at least once during 1974–2018. About 17 percent of the total land area was within riparian buffers, and 89.9 percent of the buffers are forested. Within forested riparian buffers, 9.7 percent have experienced disturbance. In contrast, the percentage of disturbance in non-riparian forested lands (16 percent) was considerably larger than in riparian forested lands. Overall, 57 percent of disturbance was timber harvest. The remaining agents were flood (33 percent), wind (8 percent), conversion (1 percent), fire (1 percent), and other (<1 percent). Timber harvest was the most frequent disturbance agent over all land ownerships, with State-owned forested land being most likely to have been harvested. Conversion occurred most frequently on private lands, whereas fire and wind were most likely on federal lands. At the HUC 12 scale, we observed some clustering of watersheds by degree of disturbance. For example, the greater Duluth area experienced some of the lowest amounts of disturbance, while a cluster of the most highly disturbed watersheds occurred directly north of Duluth (fig. 1).

Our work thus far provides a baseline to explore relationships between remotely sensed and field measured landscape variables and brook trout distribution data. We acknowledge uncertainties in FIA estimates and map classifications can influence results and we will address and incorporate uncertainty in future work. At present, we have partnered with the Minnesota Pollution Control Agency to incorporate their stream fish monitoring data (1984–2017) across Minnesota's portion of the Lake Superior basin. We anticipate modeling brook trout distribution as a function of land use, land cover, canopy cover, and other factors at several HUC levels. We aim to partner with other agencies across the Great Lakes to leverage existing data and target areas where data are lacking.

Our future work includes expanding these analyses to additional focal areas within the Great Lakes Region as well as to the full region extent. We plan to apply the RBDM to National forests and other focal areas with available inputs. The MRFD data will soon be available for the entire Great Lakes basin, plus the Allegheny and Green Mountain National Forests. In addition, annual disturbance maps, currently under construction, will allow finer scale temporal pattern analysis. We will also examine the effects of land use category aggregation on modeling results. We have partnered with Trout Unlimited to collect eDNA and stream temperature to address data gaps in brook trout distribution and potential habitat. We will examine the effect of culverts and other potential barriers to fish movement on brook trout distribution as well.

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FORESTS AND WATER YIELD: A REVIEW OF RECENT DISTURBANCE EFFECTS ON STREAMFLOW AND SNOWPACK IN WESTERN FORESTS

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A long-held theory in forest hydrology is that forest cover loss leads to increased water yield. We reviewed 78 studies of hydrologic response to recent widespread tree mortality in western coniferous forests and reassessed this theory. Results included increases, no change, or even decreases in streamflow or snow accumulation. Studies that found unexpected hydrologic responses help to improve the predictability of when water yield or snowpack may actually decrease the following disturbance: (1) when increased sub-canopy radiation results in increases in sublimation and evaporation from snowpack and soil that overcompensate for reduced canopy interception losses, and (2) when post-disturbance understory transpiration overcompensates for reduced canopy transpiration. However, most studies did not quantitatively characterize pre- or post-disturbance conditions. New hypotheses continue to be formulated and tested in this rapidly evolving discipline, and the U.S. Forest Service's Forest Inventory and Analysis Program is poised to provide better information on forest cover than is currently available for hydrologic modeling and analysis.

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AN ENHANCED REPRESENTATION OF FOREST COVER FOR DISTRIBUTED HYDROLOGIC MODELING BASED ON FOREST INVENTORY DATA

S.A. Goeking[1] and D.G. Tarboton[2]

Tree canopies exert stronger controls than understory vegetation on hydrologic processes. Forest type, density, and dynamics (i.e., disturbance) affect the relative magnitudes of hydrologic fluxes such as interception, transpiration, evaporation, infiltration, and runoff. Although many distributed, physically based hydrologic models are capable of distinguishing overstory vs. understory influences on water resources, most assessments lack stratified canopy data and thus rely on remote sensing-based estimates of total leaf area index (LAI) (Goeking and Tarboton 2020).

The Forest Inventory and Analysis (FIA) Program collects detailed information on forest characteristics that affect hydrologic processes. Although FIA does not collect LAI observations, FIA data can be used to estimate LAI based on empirical or physical relationships. The objectives of this study are: (1) to compare methods of estimating plot-scale LAI from FIA data, and (2) to combine plot-scale LAI estimates with remote sensing, climatic, and topographic variables in a machine-learning algorithm to produce maps of LAI. We addressed our objectives using 421 forested FIA plots measured between 2008 and 2017 within the South Fork Flathead watershed, Montana, and surrounding area (fig. 1).

To address our first objective, LAI was estimated using five different methods (table 1) at each FIA plot. Three methods were presented in previous studies and only estimate overstory LAI (table 1). Two methods are novel and are described here. Method LAI4 relies on tree and understory vegetation data (USDA 2019) to estimate proportional canopy volumes by stratum (overstory vs. understory) and then uses those proportions to partition total LAI from Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data (Xiao and others 2014) into separate overstory and understory LAI values. Overstory canopy volume is calculated as percent tree cover multiplied by tree height and compacted crown ratio. Understory canopy volume is calculated as percent cover in each vegetation layer (USDA 2019) multiplied by half of the depth of that layer. Method LAI5 uses percent cover of vegetation as inputs to Beer's law, where clumping indices (Chen and others 2005) are applied to specific life forms for understory LAI and forest types for overstory LAI (Burrill and others 2018).

We compared the five plot-scale overstory LAI estimates with a 30-m Landsat-based map of total LAI (Ganguly and others 2012). Caveats of using remote sensing-based LAI for validation are: (1) it requires a single time period of imagery, and (2) estimates based on remote sensing are known to underestimate LAI when overstory vegetation is sufficiently dense that no additional understory or lower-canopy leaf area can be detected from the air (Nemani and other 1993). We computed four performance metrics (table 1) based on the difference between plot-level and Landsat-based LAI pixel values: Pearson's correlation coefficient (Zar 1996); mean absolute error (MAE), which assesses the mean magnitude of differences independent of their direction (positive or negative); root mean square error (RMSE), which does not reflect over- vs. under-estimation and includes a squared term that weights larger errors more heavily than small ones; and mean bias error (MBE), which indicates the mean magnitude while accounting for over- vs. under-estimation.

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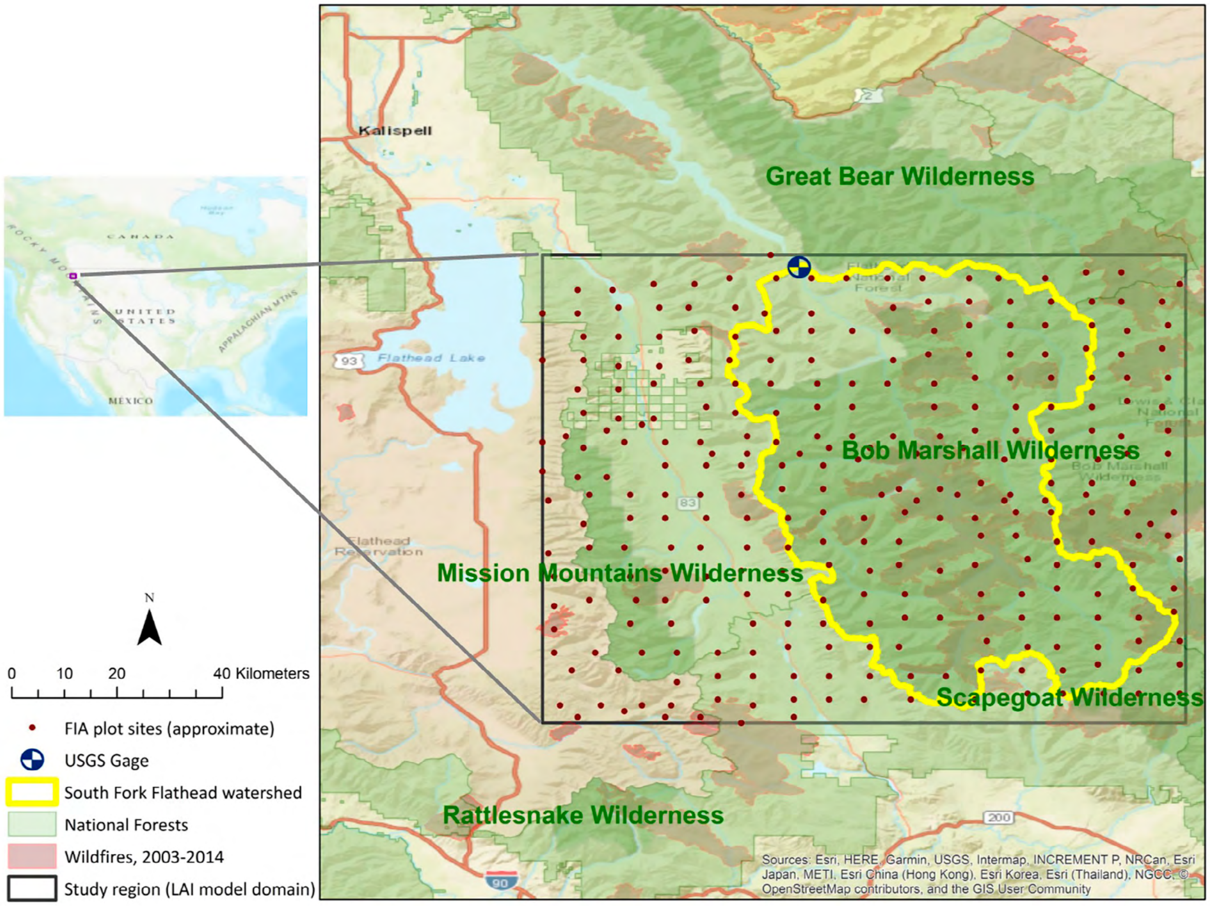

Figure 1—The South Fork Flathead watershed (yellow outline), the surrounding area which served to calibrate interpolated leaf area index (LAI) models (black outline), and FIA plot locations where LAI was estimated using five alternative methods (see table 1).

All five methods were moderately correlated with Landsat-based total LAI, and no single method performed appreciably better than the others (table 1). Given the five methods' similar performance, we considered the practical utility of the five alternative LAI methods. Although method LAI3 produced the lowest error rates (table 1), its disadvantage is the use of species-specific allometric equations (Kaufman and others 1982) that are not reliably transferable to other tree species. Methods LAI1, LAI2, and LAI3 all performed similarly (table 1), but all have the disadvantage of not estimating understory LAI. Although method LAI4 allows estimation of both overstory and understory LAI, a disadvantage is its reliance on MODIS-based total LAI. Method LAI5 has two main advantages: it produces both overstory and understory LAI estimates, and it does not require any additional data inputs. Thus, we concluded that method LAI5 is optimal for using FIA data to produce spatially and temporally explicit datasets of overstory and understory LAI.

Our second objective was to develop LAI maps using a combination of plot-level LAI estimates, spectral reflectance data, and climatic and topographic variables. Watershed-scale LAI maps were produced using random forests (Breiman 2001) models, where predictor variables included Landsat-based normalized difference vegetation index (Robinson and others 2017), topographic variables (slope, aspect, elevation, topographic wetness index or distance up/down), climatic variables (Daly and others 2001), and wildfire data from the Monitoring Trends in Burn Severity

Table 1—Five methods used to estimate leaf area index (LAI) from FIA plot data, Pearson's correlation coefficient (r), and four error metrics; error metrics are unitless as LAI is measured in square meters of leaf area per square meter of ground surface (m^2/m^2)

				Comparison of plot-level vs. Landsat LAI				
Method	Description	Outputs	Source	Pearson's r	RMSE	MAE	MBE	Random forests model r^2
LAI1	Linear scaling of tree canopy cover with local max LAI	Overstory LAI	Method from Broxton and others (2015); Local max LAI from Pierce and Running (1988)	0.550	0.93	0.38	0.25	0.54
LAI2	Empirical equation based on tree canopy cover	Overstory LAI	Varhola and others (2010)	0.505	0.78	0.35	0.01	0.37
LAI3	Species-specific allometric equations based on diameter or basal area	Overstory LAI	Kaufmann and others (1982)	0.521	0.82	0.27	0.04	0.35
LAI4	Partition total MODIS LAI based on overstory and understory percent cover, height, and depth	Overstory & understory LAI	Novel method	0.517	0.91	0.72	-0.27	0.64
LAI5	Apply Beer's law, where clumping index is specific to vegetative cover type	Overstory and understory LAI	Novel method; Chen and others (2005) for clumping indices	0.535	0.92	0.34	0.17	0.38

Pearson's correlation coefficient (r) indicates correlations between plot-based overstory LAI estimates and Landsat-based total LAI.
MAE=mean absolute error; RMSE=root mean squared error; MBE=mean bias error. Negative values of MBE indicate plot-level LAI estimates greater than Landsat-based total LAI; positive values indicate plot-level LAI smaller than Landsat-based LAI.
Model r^2 is calculated from out-of-bag samples (Breiman 2001; Liaw and Wiener 2002) of random forests models with 500 trees.

(MTBS) program (Eidenshink and others 2007). The performance of the random forests model for each LAI estimation method was assessed via cross-validation using out-of-bag samples from 500 trees (Breiman 2001). All analyses were conducted in the R statistical computing software (R Core Team 2018), and random forests models were built and assessed within package randomForests (Liaw and Wiener 2002).

Based on method LAI5, we produced maps of overstory and understory LAI for two time periods in our study area. Between these two time periods, total and overstory LAI decreased, understory LAI increased, and runoff ratio (i.e., basin-scale annual streamflow divided by basin-scale annual precipitation) increased from 0.49 to 0.55. These shifts in basin-scale LAI and runoff ratio coincide with tree mortality caused by drought, insects, and wildfire.

Future work will collect field observations of LAI from FIA plots to further validate LAI estimation methods, and also demonstrate the utility of gridded LAI datasets derived from FIA plot data for hydrologic modeling purposes. Using FIA data as demonstrated in this paper will enable an enhanced understanding of hydrologic responses to forest disturbance as well as projections of future water availability under alternative climate and land cover scenarios.

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FLEXIBLE MODEL APPROACH TO MODELING OF SOLUBLE AND TOTAL NUTRIENT TRANSPORT FROM WILDFIRES

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A new model for Nutrient Loss Modelling (NLM) has been developed as the latest iteration version of the BURN (wildfire burn nutrient transport simulation model). This is a user-friendly, model, which has a potential for increased applications and use for various scenarios. The new NLM uses output data from WEPP (Water Erosion Prediction Project—WEPP Cloud version), including the soil hillslope detachment, the soil hillslope deposition, and the soil stream channel yield for each soil texture to calculate particulate carbon, nitrogen, and phosphorus. Following this, the new NLM model calculates soluble carbon, nitrogen, and phosphorus using three different approaches. The same approach, with the exception of using baseflow, has been also formulated for GeoWEPP (ArcGIS based application). The model uses particulate and soluble concentrations to calculate total carbon, nitrogen, and phosphorus. Three different models that calculate the soluble nutrient losses were included in the model to increase its versatility and to allow applications in relatively simple cases as well as in more complex scenarios. We compare results of modeling using these three different approaches for various types of watersheds and soil types.

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MODELING OF CARBON, NITROGEN, AND PHOSPHORUS FLUXES FROM WILDFIRES

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In order to evaluate the influence of forest disturbances, including wildfires, on water quality, we have been developing computer models which simulate fluxes of carbon, nitrogen, and phosphorus at the watershed scale. Our approach assumed that both, particulate and dissolved forms of these nutrients, are controlled by soil erosion and water flow. We utilized the existing Water Erosion Prediction Project (WEPP) model as a starting point and the main source of the input data to our nutrient transport model. We have built our nutrient transport model, BURN, and coupled it with WEPP algorithms integrated with spatial analysis and geographic information systems at the watershed scale (GeoWEPP program). We have utilized hillslope sediment detachment and deposition for each erosion event in the GeoWEPP simulation, and we separated it into the five soil classes. The soil classes for detachment and deposition at each hillslope were then transformed into soil textures. All of these processes have been maintained for the new Nutrient Loss Model. Our latest attempt uses a more intuitive approach of using soil concentrations of nutrients in sands, silts, and clays and flows of water as surface runoff, subsurface water, and the baseflow.

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Pushing Timber Products in New Directions

TPO-PLUS: A WESTERN VALUE-ADDED PERSPECTIVE

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The FIA's Timber Product Output (TPO) program characterizes timber removals. For the Western States, the University of Montana's Bureau of Business and Economic Research (BBER) conducts mill surveys, forest industry analyses and logging utilization studies. In addition to collecting the base data for the national FIA-TPO database, BBER maintains broader information on the forest products industry. This "TPO-Plus" approach adds value by providing a more complete accounting of harvested wood and enabling clients and data users to answer a variety of questions about timber flow and utilization. Western data are used by public land managers to guide strategic decisionmaking and meet National Forest System (NFS) planning needs. The TPO-Plus approach has helped define economic impact areas; informed NFS transaction evidence appraisal systems; parameterized harvested wood products (HWP) carbon models; and linked mill infrastructure to forest restoration planning at various scales. TPO-Plus allows for applied research beyond tracking harvest volume and the product mix of utilized wood fiber, thus providing important information for forest-related policy and management decisions across the Western United States.

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MILL DYNAMICS: EXPLORING MILL ENTRY AND EXIT PATTERNS IN THE SOUTHERN UNITED STATES

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Timber is the most valuable commercial commodity taken from most forests. The U.S. South produces approximately 60 percent of the Nation's timber products, where the majority is obtained from private forests. U.S. mills were studied using information from the U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis (FIA) Timber Products Output (TPO) program survey of primary wood-using mills. Surveys were conducted biennially from 2005 to 2015 in 12 Southern States and participants included all primary mills varying from sawmills, veneer mills, poles, and post production mills. This historical TPO mill information was analyzed using a time to event analysis (survival analysis), controlling for size and other internal and external factors likely affecting its survival. Variables included plant size, plant structure (single-firm or multi-firm), mill consumption capacity, county demographics, etc. In terms of size and structure, studies have shown that larger plants are less likely to close while multi-firm plants are more likely to close. Competition is also another factor which has shown a positive influence on plant closure. We also studied how the changes in mill numbers and distribution affect wood procurement patterns. Studies indicate that plan.

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WOOD SUPPLY ASSESSMENT USING FIA PLOT AND LANDOWNER SURVEY DATA

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Although timber supply is a common topic of many studies, there is a surprising lack of information on exactly where the timber is coming from. We know, based on FIA plot data, that there are nearly 13 billion cubic feet of wood annually harvested across the United States with 3 percent of this wood coming from National forests, 8 percent from other public forests, and the remaining 89 percent coming from private forests. But we do not know much more about the private ownerships from where this wood is originating. By combining data from the FIA plot and landowner survey programs, we will provide new insights to the origins of timber supplied in the United States including detailed information on ownership types, size of forest holdings, and other topics. For example, preliminary results from this analysis show that 47 percent of the total timber supply comes from family forest lands. This work will also be able to quantify the timber being supplied from lands owned by timber investment management organizations (TIMOs) and real estate investment trusts (REITs). Information such as this is important to those who rely on this timber supply and those designing policies that influence it.

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USE OF FIA DATASETS TO ANALYZE EFFECTS OF WOOD-BASED BIOENERGY PRODUCTION

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FIA datasets gathered from 1978-2017 were used to estimate changes in two forested landscapes supplying biomass to Southeastern United States pellet mills. These “fuelsheds” supply over half of U.S. industrial wood pellet exports to an established bioenergy market. The Chesapeake fuelshed supplies the port of Norfolk, VA with biomass from Virginia and North Carolina timberlands, and the Savannah fuelshed supplies the port of Savannah, GA with biomass from Georgia and South Carolina timberlands. We analyzed trends in total forest land and timberland area, growth and removal ratios, proportion of planted versus naturally regenerating area, proportion of softwood versus hardwood area, number of snags per hectare, stand size distributions, and tons of carbon stored in three different biomass pools. Because TPO data indicate that roundwood procurement distances for pellet production have increased over time, the analyses were conducted for three spatial extents: fuelsheds delineated with 35-mile, 50-mile, and 75-mile procurement distances around each major pellet mill operating as of April 2018. Results of the analyses indicate little sensitivity of the indicators to fuelshed size and no significant impacts of export bioenergy wood pellet production on Southeastern United States timberland health as of 2017.

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ASSESSMENT OF FOREST BIODIVERSITY IN PROVIDING NONTIMBER FOREST PRODUCTS AND EFFECTS OF ENVIRONMENTAL FACTORS ON TREE SPECIES IN DECIDUOUS FORESTS FOR COMMUNITY FOREST MANAGEMENT IN NORTHERN THAILAND

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This study aims to assess the potential of forest biodiversity in providing nontimber forest products (NTFP) as well as investigate the relationship between tree species and environmental factors in the Ban Mae Chiang Rai Lum Community Forest, Northern Thailand. 0.1 percent of the total forest inventory was sampled using the stratified systematic sampling method. Twenty-five 40 m × 40 m (0.16 ha) square plots were established in an area of 3925 ha. Species IVI values and environmental factors evaluated the ecological gradient of vegetation using a Canonical Correspondence Analysis (CCA). The inventory of the subject forest area yielded a total of 18,555 stems encompassing 197 species, 144 genera, and 60 plant families. The Shannon diversity index was 2.486. As NTFP, 160 of these species have been classified as having medicinal uses, 89 species are used as food, 37 species as extractives, 32 species as fuelwoods, and 12 species as fibers. The CCA analysis clearly showed that environmental factors had significant effects on 129 tree species in the community forest ($p < 0.05$). Organic matter, soil moisture, elevation, distance to streams, and distance to communities were the most important factors explaining the species composition and distribution.

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Advances in Timber Products Monitoring

OVERVIEW OF TIMBER PRODUCTS MONITORING: RECENT CHANGES AND APPLICATIONS

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The Advances in Timber Products Monitoring session aims to highlight key technical changes to how the estimates of roundwood consumption and production are constructed. The annual timber products design is based on an innovative stratified simple random sample approach that approximates probability proportional to size design. We will review this design to provide context for subsequent presentations in the session. Given the programmatic thrust to shift to an annual sample based design, we will also provide examples of some assessment applications that can be enhanced with annual timber products estimates. Our examples will focus on application in the Western United States.

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ESTIMATING CHANGE IN ANNUAL TIMBER PRODUCTS OUTPUT USING A STRATIFIED SAMPLING WITH CERTAINTY DESIGN

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The national timber products output (TPO) monitoring program in the United States is adopting a stratified sampling approach to be conducted annually. Estimation of change from year-to-year is necessary, but is complicated due to shifts in the population as well as changing strata over time. In this study, various approaches to estimating the covariance between successive samples were evaluated. A primary challenge was that often only a single sample unit occurred in both samples within a given stratum. The result that none of the covariance estimation approaches performed adequately, was largely overshadowed by the outcome that treating the samples as being independent provided an overall variance estimate that was very consistent with the Monte Carlo variance obtained via simulation. It is proposed that this outcome was a derivative of the sampling design, which included some strata that were sampled with certainty. Due to the complexities introduced through changes in populations and strata over time, being able to treat the samples as independent is very beneficial because it avoids the need to introduce complex covariance calculations into the estimation process.

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ALTERNATIVE MEASURES OF SIZE AND SAMPLE-WITH-CERTAINTY THRESHOLDS IN MONITORING OF TIMBER PRODUCTION IN THE LAKE STATES

Christopher Edgar, John Young
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The Forest Inventory and Analysis program is implementing a new sample design for annual monitoring of timber production in the Lake States and other regions of the United States. We examine two key areas of the new design: (1) the selection of an effective measure of size used in constructing strata, and (2) the identification of a threshold value for allocating mills into sample-with-certainty strata. Precision of estimates can be increased by using measures of size that are more highly correlated with the variable of interest. We review the availability of mill profile information in Minnesota, Michigan, and Wisconsin and discuss the strength of relationships of candidate measures of size and timber production. When sampling skewed populations, a few large units may account for a large portion of the total. We examine different approaches to allocating mills to sample-with-certainty strata and the impacts on precision of the estimates. We conclude the presentation with general discussion of the efficiency of the new design, implementation considerations, and potential areas for further research.

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WESTERN REGION TPO ANNUAL SAMPLING–FIRST YEAR EXPERIENCE

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Annual mill sampling has been added to the suite of FIA TPO services, such as the periodic censuses of facilities, to provide stakeholders timely estimates of received roundwood and mill residue volumes. To help guide future sampling plans the University of Montana (UM) staff developed non-replicated simulations of sampling protocols for 11 western States. Our goal was to identify protocols which minimized differences in State-level received timber volumes between the most recent UM censuses (assumed to represent “true” volumes, including nonresponse) and annual sampling estimates, and which also produced standard errors of the mean of < 5 percent. The national TPO R program was used to select active mills to sample; we tailored program sampling percent, certainty volumes and product type mixes for each State. Program outputs were post-processed to adjust for nonresponse. Differences in censused and program-predicted State-level roundwood volumes varied from 0.44 to 4.73 percent and standard errors varied from 0.10 to 4.77 percent. Accounting for anticipated nonresponse was the most critical component of this work. These efforts have helped prepare UM staff to conduct informative annual samples.

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IMPROVING RESIDENTIAL FUELWOOD ESTIMATES FOR TPO

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Timber Products Output (TPO) studies report estimates of forest removals by county. The majority of data for the TPO program are collected by surveying primary wood processors, such as sawmills. This survey methodology largely omits fuelwood for residential use as many users of residential fuelwood obtain the product themselves or through a path not captured by the industrial surveys. Previously, data from the U.S. Energy Information Administration (EIA) was used for the residential fuelwood component of TPO reporting, however EIA data are not available on the same spatial scale as other TPO estimates nor do they provide geographic sourcing information. FIA is developing, testing, and implementing a new methodology to estimate residential fuelwood use that will better align with other TPO estimates. Using data from the EIA's Residential Energy Consumption Survey, Census' American Community Survey, the National Climatic Data Center, and EIA's home heating fuel prices, volumetric data for annual residential fuelwood usage in TPO will be modeled to the county level as well as species distribution and county-of-origin information using ancillary TPO and FIA data.

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TIMBER PRODUCTS OUTPUT FIELD DATA COLLECTION METHODS: PAST, PRESENT, AND FUTURE

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The Forest Inventory and Analysis Timber Products Output program has been collecting data from primary wood processing facilities across the United States for decades. The TPO program has recently switched to a sample-based data collection protocol and it is time to thoroughly review the field data collection methods. Traditional techniques often involved visits to mill locations and working with mill managers to complete the questionnaires. More recent efforts have started to rely more on self-administered, mail-back questionnaires. This presentation will summarize the past and current methods used to collect TPO data. Potential future data collection protocols based on the current science of survey design and implementation will be discussed along with methods for testing these new approaches. Specific components to be considered include questionnaire design, the use of incentives, and data collection modes.

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SOUTHERN TIMBER SUPPLY ANALYSIS: FOREST INVENTORY DATA FOR ALL

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The Southern Timber Supply Analysis web application summarizes U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis (FIA) data for a user-defined supply area. The application produces estimates of the amount of timberland and standing timber, growth, and removals within a user-specified distance (50, 75, or 100 miles) or trucking time (1, 1.5, or 2 hours) of the user's site of interest in the U.S. South. The analysis can be filtered by State and ownership, and timber quantities can be displayed by volume or by green weight. The results can be downloaded in a PDF report. The application also contains pre-made statewide reports available for download. Designed specifically for ease of use, Southern Timber Supply Analysis simplifies the process of examining forest inventory levels and sustainability within a custom area. It presents the results—equivalent to running numerous EVALIDator queries—in a matter of seconds, with very little effort required by the user. The information available through Southern Timber Supply Analysis will support economic development, conservation and sustainability efforts, and State forestry agencies and associations.

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Development and Implementation of New Volume/Biomass/Carbon Models for FIA

DATA NEEDS AND AVAILABILITY FOR DEVELOPING AND TESTING NATIONAL SCALE BIOMASS ESTIMATORS

David Walker, Philip Radtke
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A two-track approach involving legacy data compilation and new data collection was pursued to provide sufficient data for developing and testing models to use in FIA's national-scale biomass estimation. Legacy data sources included agency, university, and industry studies from the United States, as well as government studies from both provincial and national agencies in Canada. The main data type involved stem taper and volume measurements, mainly from felled-tree studies conducted over the past 120 years in the United States and Canada. Weight and biomass data including wood properties such as specific gravity comprised the second largest type of data, almost exclusively from felled-tree studies conducted in North America over the past 60 years. Major gaps in legacy data tree species, size, and geographic location were addressed by conducting field campaigns at strategic locations in the United States over a period of about 8 years since 2011. In total, data from nearly a quarter-million trees were compiled, about one-tenth of which include biomass measurements. Despite existing needs to be addressed in ongoing model development, the database is among the largest known collections of felled-tree records ever compiled for national-scale model development.

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ALTERNATIVE MODELING STRATEGIES FOR ESTIMATING TREE BIOMASS ACROSS A NATIONWIDE SYSTEM OF INVENTORY PLOTS

David Affleck, Aaron Weiskittel, Philip Radtke, David MacFarlane, Dehai Zhao, Andrew Sanchez-Meador, David Auty, Temesgen Hailemarium, James Westfall, Andrew Gray, John Shaw, John Coulston, Krishna Poudel
University of Montana, University of Maine

We review the advantages and limitations of alternative model systems for estimating tree volume and biomass over the Forest Inventory and Analysis (FIA) plot network. Systems proposed under FIA's National Biomass Estimators Project have been structured according to biological and dimensional principles. Yet user needs and FIA protocols have also figured prominently in development and evaluation. Chief among the former are demands for being data-driven, for additivity among biomass components, and for smoothness across administrative boundaries, as well as the desirability of compatibility between stem volume and mass estimates. Considerations related to inventory protocols include retrospective applicability and the economics associated with the collection of alternative variables. Similarly, the form, quantity, and distribution of tree data, as well as inherent data dependence structures, have motivated alternative statistical specifications. We thus describe the biological, practical, and statistical strengths of systems that model; (1) total tree mass directly or indirectly; (2) mass as a function of, or independently of, volume; and (3) trans-species or individual species trends. Instances of these are explored further in this session.

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EVALUATING MODELING SYSTEMS FOR NATIONAL-SCALE BIOMASS ESTIMATORS: A SCORECARD APPROACH WITH PRELIMINARY RESULTS

Philip Radtke
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Numerous approaches will be evaluated to ensure desirable modeling properties in live tree aboveground biomass (AGB) estimators for national forest and carbon inventories, including: (1) component additivity for stem and branch wood or bark, branches, and foliage; (2) compatibility of volume, taper, biomass, and specific gravity predictions; (3) accuracy in predicting AGB for species well-represented in model fitting datasets and for those lacking data; (4) performance of models used to predict for species lacking adequate data; (5) well-behaved prediction patterns in models when used to extrapolate beyond the range of observed data; and (6) the effectiveness of incorporating stand and site-level predictors to reduce prediction uncertainty. A “scorecard” approach has been developed for delivering concise yet complete information to aid in the model evaluation process. The scorecard approach enumerates categorically which properties proposed modeling systems are designed to achieve and provides a means for reporting quantitative measures of models’ performance. Examination of both the intended design and measured performance of proposed models will lead to a transparent modeling solution with highly favorable predictive abilities.

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FUNCTIONAL, SPECIES-SPECIFIC OR HYBRID GROUPS FOR NEW TREE MODES FOR FIA PLOTS?

David W. MacFarlane
Michigan State University

The Forest Inventory and Analysis (FIA) program of the U.S. Department of Agriculture, Forest Service is compiling continent-wide data to create new mass and volume models to be applied to trees on FIA inventory plots. FIA will need to consider how these models should be constructed to capture variation in tree attributes across the vast array of tree species, forest ecosystems, climatic regions, and forest disturbance regimes that comprise the scope of FIA's inventory. In practical terms, this means allowing model coefficients and model forms to vary and, traditionally, this would mean allowing model coefficients to vary by species or groups of species. Here, ideas, data and models are presented from several studies to examine alternative, tree-functional approaches to species-specific models, along with hybrid approaches that use both species and functional types to better characterize tree to tree variation, both within and between species, across the large spatial domain of FIA. A new species—form type volume modeling approach, developed for the Michigan State forest inventory system, is presented, as case study of the potential utility of a species-functional group approach for both volume and mass estimation for trees on FIA plots.

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APPROACHES TO ESTIMATE INDIVIDUAL TREE ABOVEGROUND BIOMASS

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Philip J. Radtke, Andrew N. Gray
Mississippi State University, Oregon State University

Forest ecosystems contribute substantially to global climate change mitigation by sequestering and storing carbon. Forest carbon inventories are obtained by using tree and area measurements along with biomass equations. Therefore, large-scale forest biomass estimation is important to assess the role of forestry sector in mitigating climate change impacts. Methods to estimate total aboveground biomass as well biomass of different tree components (stem, bark, branch, and foliage) were developed using a large dataset compiled from studies over the years. Missing components in the dataset were imputed using species-specific or combined-species Dirichlet imputation. Alternative model formulations and fitting techniques for obtaining biomass estimates were tested. Specifically, the independent estimation of biomass is compared with the biomass estimates derived from volume estimates that are obtained using volume equations fitted in this study. Error produced by the methods developed in this study are compared with the error produced by the Component Ratio Method currently being used for official U.S. forest carbon inventories.

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NATIONAL SCALE BIOMASS ESTIMATOR (NSBE) PROJECT: NEXT STEPS, IMPLICATIONS, AND FUTURE TIMELINE

Aaron Weiskittel, Phillip Radtke, James Westfall, David Walker, David Affleck, John Coulston, David W. MacFarlane
University of Maine, Center for Research on Sustainable Forest

The National Scale Biomass Estimator (NSBE) has been a joint collaborative project between several universities and the U.S. Forest Service, Forest Inventory and Analysis (FIA) program. The overall goal is to refine FIA's approach to estimating aboveground tree biomass and carbon for the primary species in the United States using existing and newly collected data. Acquiring and strategically collecting biomass data was an initial focus of the project, while current efforts have shifted to evaluating alternative modeling approaches based on this available data. A current target for the project is to deliver a revised methodology to FIA for estimating tree biomass in 2020. Implementation and testing of this revised methodology by FIA will then occur with particular focus on communicating the revisions to FIA's broad array of key stakeholders. However, preliminary results indicate rather significant shifts in total biomass for certain species and regions, which have important implications for U.S. biomass and carbon estimates. This presentation will review past accomplishments, current plans for next steps in the coming year, and the broader implications of revising FIA's approach to estimating biomass nationally.

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How Do You Do That, Again? Exploring Methods in Inventory

INTERPRETING EFFECTS OF MULTIPLE, LARGE-SCALE DISTURBANCES WITH DIFFERENT APPROACHES TO TEMPORAL AGGREGATION OF FOREST INVENTORY AND ANALYSIS DATA

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University of Minnesota, USDA Forest Service

Large-scale disturbances can greatly alter the composition and structure of forests and thereby impact the economic and ecological character of a region. Forest Inventory and Analysis (FIA) is a key information source in the assessment of regional forest conditions. Here we compare how temporal aggregation of annual FIA data (i.e., panels) affects population estimates of standing dead trees as these respond to extreme disturbance events. East Texas was selected as a case study owing to the occurrence of three significant disturbance events: Hurricane Rita in 2005, Hurricane Ike in 2008, and a historic drought in 2011. Using the standard FIA estimation approach, we computed population estimates using data from the full set of panels (FSP), multiple sets of panels (MSP), and single set of panels (SSP). We found that interpretations of disturbance event impacts varied depending on which sets of estimates were considered. In the case of the drought, FSP estimates showed clear lag bias and smoothing of trends relative to the SSP estimates. Given the potential for lag bias and smoothing, we recommend that SSP and MSP estimates be considered along with FSP estimates in assessments of large-scale disturbance impacts on forest conditions.

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REAL-TIME MONITORING OF DOWNED DEAD WOOD MOISTURE: DO MICRO-SENSORS HOLD PROMISE FOR FOREST INVENTORIES?

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The attributes of downed dead wood (DDW) in forests such as quantity, arrangement, and condition is a driver of numerous ecosystem processes such as wildfire behavior, tree regeneration, and carbon cycling. Forest inventories typically monitor the amount, condition, and arrangement of DDW across large spatial scales at multi-year time intervals. However, numerous attributes of DDW of interest to managers and/or communities vary at diurnal or even sub-diurnal time steps such as wildfire risk. Technological advances in efficient micro-sensors and associated communication networks may afford an opportunity to leverage DDW inventories such as those conducted by FIA to inform daily assessments of forest attributes such as wildfire risks. In order to explore potential applicability of sensor arrays to FIA's DDW inventory, moisture sensors and communication technology was developed and applied to a series of logs in varying stand conditions in a northern hardwood forest to record/transmit moisture at 15-minute intervals. Results suggest that the moisture of DDW is highly dynamic with significant soil interactions while the recording and transmittal of streaming data was achieved if cell service was within reach of a plot.

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A NEW, BIOME-SPECIFIC FRAMEWORK FOR DISTINGUISHING PRIMARY FORESTS FROM OTHER NATURALLY-REGENERATED FORESTS USING REMOTE SENSING AND DESIGN-BASED FOREST INVENTORY

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Primary forests are forests where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed. Their loss, either through deforestation or through conversion to managed forests or tree plantations, is a concern with respect to at least three identified planetary boundaries: loss of biosphere integrity, land system change, and climate change. There is broad consensus on the importance of primary forest inventory and monitoring, but no standard or common approach exists for distinguishing these forests from other naturally regenerated forests. Development of a globally standard approach may be desirable, but biome-specific standard approaches are more likely to yield ecologically relevant information. Forest dynamics, including natural disturbance regimes and successional pathways, differ markedly between tropical, temperate and boreal forests. Using North America as a case study, we propose a biome-specific framework for primary forest inventory and monitoring using existing remote sensing technologies in combination with the design-based national forest inventories of the United States, Mexico, and Canada.

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PHOTOGRAMMETRIC MEASUREMENT OF HARDWOOD SPECIES AT A STAND LEVEL USING RGB IMAGES FROM UNMANNED AERIAL VEHICLE (UAV)

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Nowadays, for many remote sensing applications, drones are employed for gathering data, as it provides low cost image acquisition with minimal human intervention. Drone remote sensing has an extensive use in forestry for maintaining inventories, mapping canopies structure, measuring canopy height and monitoring forest fires. Maintaining a forest inventory database is a crucial task as it is the only means of keeping a record of the forests. This study aims to explore unmanned aerial vehicle (UAV) based image acquisition (consumer-grade sensor) and analysis for forest studies. The main objective is to derive a methodology for computing tree parameters such as tree height, diameter at breast height, and crown width from drone images. We also aim to classify each tree with its species. This study as a whole aims to create a database that will contain information on the physical attributes of trees that is necessary for an inventory. This work will have high significance in urban forestry as time can be saved from measuring trees manually for maintaining inventories.

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SATELLITE-BASED ESTIMATES REVEAL WIDESPREAD FOREST DEGRADATION IN THE AMAZON

Eric L. Bullock[1], Curtis E. Woodcock[1], Carlos Souza, Jr.[2], and Pontus Olofsson[1]

Anthropogenic and natural forest disturbance cause ecological damage and carbon emissions. Forest disturbance in the Amazon occurs in the form of deforestation (conversion of forest to nonforest land covers), degradation from the extraction of forest resources, and destruction from natural events. The crucial role of the Amazon rainforest in the hydrologic cycle has even led to the speculation of a disturbance "tipping point' leading to a collapse of the tropical ecosystem. While reaching a peak in 2004, the regional deforestation rate was reduced by over 50 percent in subsequent years, but the extent of forest degradation and natural disturbance has yet to be reliably quantified, and thus the total area affected by disturbance remains uncertain. Here we show that degradation and natural disturbance, largely during periods of severe drought, have affected as much of the forest area in the Amazon Ecoregion as deforestation from 1995 to 2017. Consequently, an estimated 17 percent (1,036,800 ± 24,800 km^2, 95 percent confidence interval) of the original forest area has been disturbed as of 2017. Our results suggest that the area of disturbed forest in the Amazon is 44–60 percent more than previously realized, indicating an unaccounted for source of carbon emissions and pervasive damage to forest ecosystems. If the increasing trend in the frequency and severity of droughts continues, degradation and natural disturbance will continue to intensify, further affecting the global carbon cycle and pushing the Amazon towards a "tipping point" before hydrologic collapse.

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NICKELS AND DIMES: END-DIGIT PREFERENCE IN FOREST INVENTORY DATA

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The affinity for numbers that end in zero or five or that are associated with even quantities (e.g., 4 weeks), has been observed in a variety of situations, including consumer spending, athletic events, and activity recollections, (e.g., number of cigarettes smoked). This phenomenon, termed end-digit or terminal-digit preference, rounding, or heaping, is a form of bias, and depending on the circumstance may have serious consequences. An examination of data collected by the Forest Inventory and Analysis Program suggests a preference for values ending in zero and five among visually estimated variables such as live crown ratio, cull volume, and canopy cover, as well as heights and diameters of irregular trees. Heaping also appears when values are estimated above a certain threshold (e.g., seedling counts). The degree to which this phenomenon occurs varies across variables and FIA regions. The costs and consequences associated with this practice depend upon the variable under consideration.

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GLOBAL FOREST MONITORING: HOW NORDIC COUNTRIES PERFORM THEIR FOREST INVENTORIES

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In May of 2019, the Norwegian Institute of Bioeconomy Research (NIBIO) celebrated its 100th birthday. To commemorate this event, they held a conference to celebrate their discoveries as well as learn from other countries who perform large scale forest monitoring. Part of the curriculum was a session and field trip that allowed the five Nordic countries (Norway, Denmark, Finland, Iceland, and Sweden) the opportunity to demonstrate how they carry out their mission. This presentation encapsulates these presentations and discuses similarities, differences and various methods used to conduct their national forest inventories. This includes plot grids and intensities, plot descriptions, tree and plot variables collected, field composition, and instruments used to collect the data.

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SMALL AREA ESTIMATION OF POST-FIRE TREE REGENERATION USING THE FOREST INVENTORY & ANALYSIS PLOT NETWORK

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In the Western United States, wildfire activity is expanding and many forests are struggling to regenerate post-fire under increasingly warm, dry climatic conditions (Stevens-Rumann and others 2017). Effective forest planning necessitates accurate estimates of seedling densities and proportions of area reforested within burned areas, and in some cases federal legislation requires it.

The U.S. Department of Agriculture Forest Service Forest Inventory & Analysis (FIA) plot network (Bechtold and Patterson 2005) provides substantial ground sample data on tree regeneration at the national level. However, the network's spatial and temporal coverage is too sparse for traditional direct estimation (*sensu* Rao and Molina 2015, chapter 2) of regeneration attributes within finer-scale spatiotemporal domains required for effective regeneration management, planning, or reporting. As an example, figure 1 shows the areas burned in 2007 across four National forests in western Montana. Although this domain (collection of burns) spans approximately 104,000 ha, it includes only four FIA plots providing information on regeneration

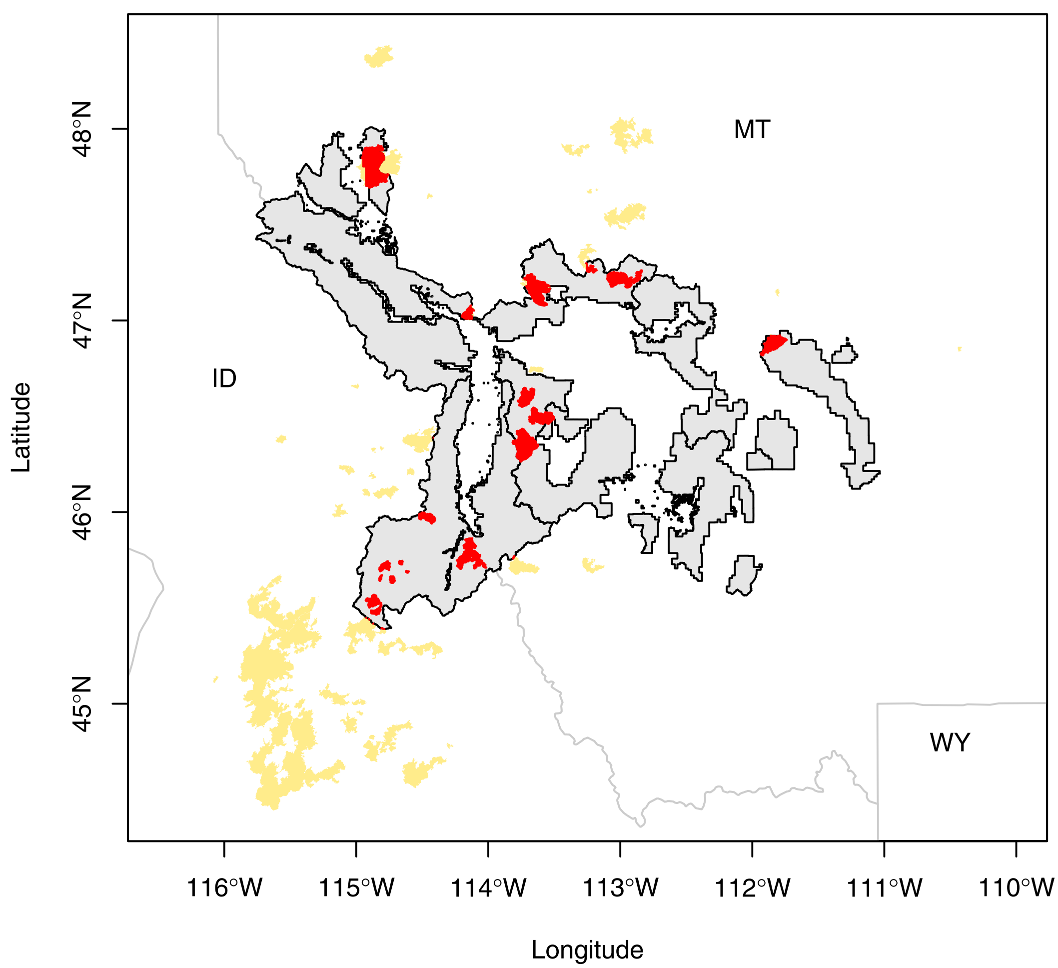

Figure 1—Area burned in 2007 (red) falling within the Bitterroot, Deerlodge, Helena, and Lolo National Forests (grey). Also shown are 2007 fires occurring within 100 km (orange) of these four National Forests.

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levels 5 years post-burn (i.e., only four plots that were measured in 2012). More generally, there will be an average of only one FIA plot measurement per year for every 24,000 ha of forest land burned in the Western United States. Thus, short of estimating regeneration at the level of entire National Forest regions, the number of FIA plot measurements from within a given domain and available in a given year post-fire will provide insufficient data for direct estimation.

This research evaluates alternative small area estimators that leverage data from outside spatiotemporal domains of interest while providing domain-specific estimates. For example, to estimate 2012 regeneration levels over the domain identified in figure 1, additional 2012 FIA plot data could be drawn from other 2007 burns within a 100 km buffer of the domain of interest. In this case, that would increase the number of FIA plot measurements from 4 to 23. Alternatively, the geographic footprint of the domain could be respected, but additional data could be drawn from FIA plots measured between 2010 and 2014 (±2 years of 2012). For this particular domain, that would increase the number of available FIA plot measurements from 4 to 36. More generally, one could borrow data for domain estimation from a broader geographic extent and a broader temporal extent. The results of doing so for the domain identified in figure 1 are summarized in table 1. The number of FIA plot measurements increases with the scope of borrowing, though at different rates over space and time. Similar results would be expected for other spatiotemporal domains, though the absolute numbers would vary as a function of the domains' geographic extents and configurations.

Table 1 also provides direct expansion estimates of 2012 tree densities (live trees per ha) for the domain of figure 1 based on alternative data-borrowing strategies. Estimates vary widely throughout the table. This reflects the consequences of having low bias but low precision when sample sizes are low (upper left corner of table 1) and potentially large bias but high precision where sample sizes are augmented with extra-domain data (lower right corner). Evaluation of these data-borrowing strategies must then involve an investigation of trade-offs in mean squared error (MSE). This is a non-trivial undertaking owing to the fact that reliable estimators of MSE must be derived for decisionmaking in real applications. As such, this research will involve an evaluation of both

Table 1—Estimates of 2012 tree density (number of FIA plots in parentheses) for the 2007 burned area domain of figure 1 drawing on data from different geographic or temporal extents. The estimate in the upper right is based only on within-domain FIA plot measurements made in 2012

Geographic buffer (km)	Temporal buffer (years)				
	0	1	2	3	4
			live trees per ha		
0	20,559 (4)	6,622 (23)	4,768 (36)	4,050 (51)	6,178 (55)
50	6,320 (15)	3,407 (56)	2,595 (93)	2,335 (134)	3,311 (148)
100	4,819 (23)	3,240 (83)	2,494 (138)	2,322 (196)	2,915 (218)
150	4,654 (26)	3,419 (98)	2,611 (159)	2,296 (230)	2,782 (257)
200	4,757 (28)	3,250 (107)	2,525 (170)	2,188 (248)	2,636 (278)

empirical and simulated estimation results. In particular, we envision using simulation to assess (1) the bias and variability of alternative domain-level estimators of tree density, and (2) the bias of the corresponding estimators of MSE.

Model-based or model-assisted small area estimators can also be derived to take advantage of auxiliary variables related to regeneration levels or success. We identify several promising sources of auxiliary data and the means by which they can support estimation of regeneration in small spatiotemporal domains. Chief among these are burn severity metrics from the Monitoring Trends in Burn Severity (MTBS) program (Eidenshink and others 2007) and remotely sensed vegetation indices, but static terrain variables such as elevation, aspect, and ecoregion could also be informative. In the context of informative auxiliary variables, the objectives become how to identify effective data-borrowing strategies for model calibration and how to best estimate the MSE of the corresponding regeneration estimators. We again envision using simulation to evaluate MSE estimators and to permit empirical comparison of alternative regeneration estimates across domains.

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USING PHOTO-BASED LAND USE OBSERVATIONS TO ADDRESS SURVEY NONRESPONSE IN SOUTH TEXAS

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Abstract

The U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis (FIA) Program uses a probability-based sample of field plots to derive design-based estimates of forest attributes, which are used to monitor the status and condition of America's forests. For various reasons plots can go unsampled, such as when field crews are denied access or hazardous conditions are encountered. When these situations arise, the unmeasured plots are essentially dropped from the estimation process, which results in lower estimate precision and higher sampling errors. In certain areas of the country, nonresponse rates are so high that FIA estimates are seriously compromised. In south Texas, nonresponse rates approach 30 percent for the unit as a whole. One possible solution is to fill in missing plots with photo-based observations, such as those collected by FIA's Image-based Change Estimation (ICE) project. In this paper, we demonstrated how FIA and ICE tend to agree at a higher level than FIA and the National Land Cover Database (NLCD) map, which is typically used for post-stratification. We compared plot-level estimates derived from FIA, ICE, and FIA and ICE blended together to discuss potential opportunity to use ICE to address other FIA nonresponse issues.

Keywords: Forest Inventory and Analysis (FIA), Image-based Change Estimation (ICE), land use, nonresponse.

INTRODUCTION

The Lower Rio Grande Valley is called "The Magic Valley" (Jordan 1978). The 4th survey unit of Texas for the U.S. Department of Agriculture (USDA) Forest Service, Forest Inventory and Analysis (FIA) Program extends beyond the Magic Valley, north from the mouth of the Rio Grande past the Coastal Bend then trending east to Galveston County, thence westward through Brush Country and the Winter Garden to Maverick County in the west, thence southward along the Rio Grande to the point of beginning. It is a diverse survey unit, ranging from ocean, wetlands, urban, and cropland in the east, to pasture, rangeland, and scrub forest (with just a bit of cropland in the Winter Garden) in the west (fig. 1). This region has the highest rate of nonresponse in FIA data in the Forest Service Southern Research Station. Nonresponse clearly increases from east to west, in most cases due to the landowner not allowing the field crew on the property. The unmeasured plots are essentially dropped from the estimation process, which results in lower estimate precision, higher sampling errors, and FIA estimates that are seriously compromised. One possible solution is to fill in missing plots with photo-based observations, such as those collected by FIA's Image-based Change Estimation (ICE) project.

In FIA, plots are reviewed by photo interpreters. If a plot is obviously Nonforest, the land use at plot center is recorded and that plot is not sent to the field to be visited. If the plot might be forested, it is sent to the field and will be visited, unless the landowner denies access or the topography is hazardous. If the plot is accessible, field crews will assign it one or more conditions. For each condition on the plot, the percentage of the plot in that condition and the status of that condition as Forest, Nonforest, Noncensus Water, Census Water, or Nonresponse is recorded. In general terms, recognized Nonforest conditions are Agricultural, Rangeland, Developed, or Other, although the actual codes are more detailed (Burrill and others 2018). In the first seven panels (set of plots intended to be collected in a given

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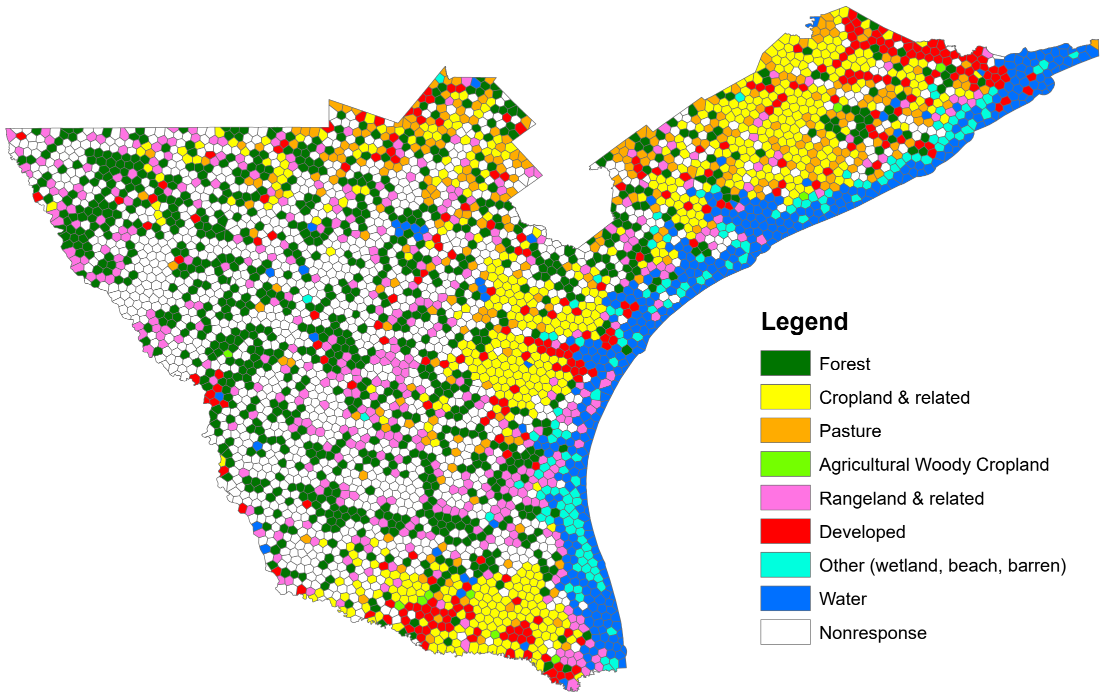

Figure 1—Forest Inventory and Analysis (FIA) land use map of south Texas.

year) of the first cycle (set of all plots in the unit), plots that were determined to be between 5- and 10-percent canopy were called "Other Wooded Land" (Burrill and others 2018). Here these plots are counted as Rangeland. The Other category includes non-vegetated land, wetlands, beach, and plots not better described by one of the existing categories.

Meanwhile, Image-based Change Estimation (ICE) is a relatively new photo-interpretation project used by FIA. ICE plots are collocated with FIA plots, but the plot footprint is different. The FIA plot consists of four circular subplots 120 feet apart arranged in an inverted wye pattern (Shepherdson 1924), with each having a radius of 24 feet. A plot footprint may be found in Bechtold and Patterson (2005). ICE plots are on the same 144-foot circle. If the ICE interpreter detects no difference between the two dates of imagery, five dots are recorded; if difference change is detected, 45 dots are recorded. The 45 dots are 12 meters (39.37 feet) apart in a 7- × 7-square pattern with the corners cut off; the five no-change dots are located in the center and near the edge of the 144-foot circle 90 degrees apart. The two footprints are shown in figure 2. Due to issues with magnetic declination, an outer ICE dot matching an outer FIA subplot is not guaranteed.

In this paper, we compare plot-level estimates derived from FIA, ICE, and FIA and ICE blended together and discuss potential opportunity to use ICE to address other FIA nonresponse issues.

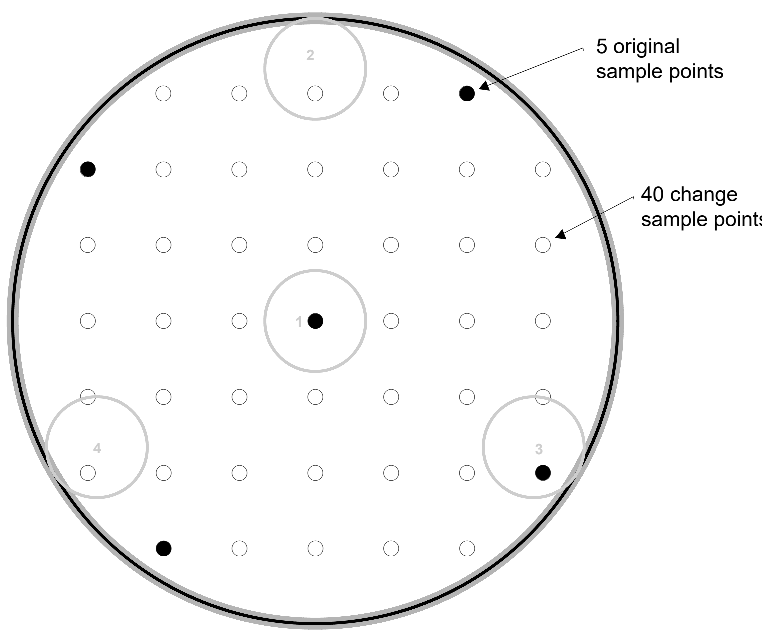

Figure 2—Forest Inventory and Analysis (FIA) and Image-based Change Estimation (ICE) plot footprint (from Bakken 2018).

METHODS AND RESULTS

Two dates of National Agriculture Imagery Program (NAIP) imagery were used to collect ICE data for Texas: 2010 and 2014. For each dot, land use is recorded. The general land use categories are similar to those in standard FIA, although detailed ones are not. For instance, plots are called "Agricultural Woody Cropland" in ICE, but "Orchard" or "Christmas Tree Plantation" in the FIA Database (FIADB). There is an "Uninterpretable" category in ICE, but it is rarely used. On five plots (0.1 percent), one or more dots (but not the entire plot) were uninterpretable. Further details on ICE design and methodology can be found in Webb and others (2012).

Table 1 shows the FIA official estimates of land use in number of plots and acres (EXPALL and EXPCURR, Burrill and others 2018) for the 4th unit of Texas for inventory year 2015, as well as the number of plots in each land use as determined by ICE in 2010 and 2014. EXPCURR is the number of acres in a stratum divided by the number of observed plots in that stratum. EXPALL is the number of acres in the stratum divided by the number of plots, observed and unobserved, in that stratum.

Estimates using EXPCURR apportion the acres assigned to nonresponse plots based on post-stratification. Tables using EXPCURR may be accessed from USDA Forest Service FIA Program (2019); raw data may be accessed from the FIADB (FIADB 2019). For post-stratification, FIA used a combination of the 2011 National Land Cover Database (NLCD) Tree Canopy Cover layer and a public/private ownership map. There were 4,490 plots collected between June 2004 and January 2018.

If we assign the FIA measurement date (consisting of MEASMON and MEASYEAR from FIADB—the month and year of data collection, respectively) to the nearest ICE date (whether 2010 or 2014), there is no more than a 6-year difference between ICE and FIA measurements. The cross-tabulation comparing ICE and FIA is shown in table 2. Fractional values arise due to condition classes that are explicitly defined on FIA plots, and they indirectly arise on ICE plots when two or more land uses are observed on one plot. The "condition" size for an ICE plot is determined by the number of dots in the land use of interest divided by the total number of observed dots for the plot. Under the assumption that conditions are independent, a confusion matrix, M, is generated by:

$$M[x,y] = \sum_{p=1}^{P} \sum_{i=1}^{K(p)} \sum_{j=1}^{K(p)} a[p,i,x] \cdot b[p,j,y] \quad (1)$$

where

$a[p,i,x]$ = the condition proportion for ICE condition i on plot p in land use x

$b[p,j,y]$ = the condition proportion for FIA condition j on plot p in land use y

P = the number of plots in the area of interest

$K(p)$ = the number of conditions on plot p.

Table 1—Number of plots and estimate of land use in south Texas for Forest Inventory and Analysis (FIA) 2015[a] Image-based Change Estimation (ICE) 2010, and ICE 2014

Land use	FIA plots	EXPALL (*acres*)	EXPCURR (*acres*)	ICE 2010	ICE 2014
Forest	946.06	5,607,320	8,246,650	2,170.57	2,145.53
Agricultural	947.79	5,617,036	7,940,076	1,089.62	1084.56
Rangeland	437.35	2,592,314	3,658,407	379.01	358.27
Developed	294.62	1,748,706	2,492,987	340.02	394.18
Other	133.49	797,070	1,076,776	108.09	104.84
Water	386.96	2,293,436	3,218,555	402.69	402.62
Nonresponse	1,343.73	7,977,569			
Total	4,490.00	26,633,451	26,633,451	4,490.00	4,490.00

EXPALL = number of acres in each category (Nonresponse included); EXPCURR = number of acres in each category (Nonresponse excluded).

[a] FIA data were collected 2004–2018.

Table 2—Cross tabulation of land use in south Texas by Forest Inventory and Analysis (FIA) and Image-based Change Estimation (ICE) (all plots)

Land use	Forest	Agricultural	Rangeland	Developed	Other	Water	Nonresponse	ICE total
Forest	806.18	43.48	220.35	38.49	4.56	5.93	1,035.88	2,154.87
Agricultural	51.34	808.65	62.88	46.22	7.30	3.71	103.92	1,084.02
Rangeland	43.62	54.68	127.49	5.43	32.14	2.67	108.00	374.04
Developed	37.15	34.65	15.35	201.24	0.40	3.90	75.95	368.71
Other	4.69	1.80	9.61	0.93	61.51	18.48	9.47	106.49
Water	3.08	4.53	1.68	2.30	27.58	352.18	10.52	401.87
FIA total	946.06	947.79	437.35	294.62	133.49	386.96	1,343.73	4,490.00

We see that a very large proportion (77 percent) of nonresponse plots were called Forest in ICE. According to current estimates of EXPALL and EXPCURR, FIA believes that only 33 percent of nonresponse plots are Forest.

Now we consider how the data were collected, shown in table 3. The first batch of 1,206 plots was photo interpreted in the office and determined to be obviously Nonforest. Thus, values in the Forest column are all zero. While the plot footprints of FIA and ICE are different, FIA photo interpreters are supposed to consider the entire neighborhood of the plot when deciding whether or not to send it to the field. Even so, ICE interpreters thought about 60 plots out of 1,206 (5 percent) were forest.

Overall agreement was 83 percent with Cohen's Kappa κ = 0.75 (Kappa value, κ, was calculated based on Cohen [1960]). Additionally, agreement for each land use was further computed by Teufel's *F*-measure (Teufel and Moens 2002)

$$F(i) = 2m_{ii}/(\Sigma m_{i.} + \Sigma m_{.i}) \qquad (2)$$

where

$F(i)$ = the agreement for class i

m_{ij} = the plot count for FIA class i and ICE class j (Note that m_{ii} is a special case of m_{ij}.)

$\sum m_{i.}$ = the sum of FIA class i

$\sum m_{.i}$ = the sum of ICE class i.

For instance, m_{12} = 10.09 (the number of plots believed to be Forest in ICE and Agricultural in FIA) and m_{22} = 523 (the number of plots believed to be agricultural in both datasets). Consequently, $F(2) = 2 \times 523/(576 + 571.2)$ = 91.2 percent.

The agreement percentages for Agricultural (91 percent), Developed (79.5 percent), and Water (95 percent) are very similar to the

Table 3—Cross tabulation of land use in south Texas by Forest Inventory and Analysis (FIA) and Image-based Change Estimation (ICE) (FIA photo-interpreted plots only)

Land use	Forest	Agricultural	Rangeland	Developed	Other	Water	ICE total	Agreement
Forest	0	10.1	47.1	2.3	1.4	1.1	62.02	0.000
Agricultural	0	523.0	21.4	23.0	1.8	2.0	571.20	0.912
Rangeland	0	22.1	19.8	2.5	13.6	0.2	58.20	0.259
Developed	0	17.4	4.7	103.1	0.4	1.7	127.37	0.795
Other	0	0.4	1.9	0.4	27.0	13.7	43.42	0.543
Water	0	3.0	0.0	0.7	11.8	328.3	343.78	0.950
FIA total	0	576.0	95.0	132.0	56.0	347.0	1,206.00	0.830

results reported in Pengra and others (2019) for the conterminous United States. The Other category is among the hardest to interpret, having 54 percent agreement in this study. Pengra cites interpreter agreement of 74 percent for Wetland and 56 percent for Barren. Figure 1 shows that most of the Other category is near the coast. This result would suggest Wetland rather than Barren. In many areas, "non-vegetated" will mean either mud flats (causing confusion with Water) or dry barren (causing confusion with Rangeland), but in south Texas, both these situations occur. Agreement for Rangeland (26 percent) is quite a bit worse than any of Pengra's results. Another concern is that 62 plots were called Forest by ICE interpreters that were called obvious Nonforest by prefield FIA interpreters. While it is only 5 percent of the subtotal (1,206 plots), it may be a good idea to require that more than one set of eyes agree that a plot is obviously Nonforest before it is not sent to the field. Another possibility would be to adjust results based on quality assurance checks.

Next we analyzed the plots that went to the field but consisted of a single condition class. Results are shown in table 4. Overall agreement was 72 percent, and Cohen's κ was 0.60. We see that ICE overestimates Forest by 108 plots and underestimates Rangeland by 127 plots. Meanwhile, ICE overestimates Agricultural by 16 plots, Developed by 15 plots, and Water by 10 plots, but underestimates Other by 23 plots. Clearly the greatest source of confusion is between Forest and Rangeland.

The likelihood matrix is formed from table 4 by dividing the first six rows and six columns by their row total. It may be desirable to multiply this matrix by the number of acres each plot represents in the sample (EXPALL) before dividing by the row total. Then, weight the nonresponse plots by EXPALL (this is the prior distribution), and then multiply this vector by the likelihood matrix to get the posterior distribution. These results are shown in table 5. Traditionally, the field visit is assumed to be correct (Frayer 1978). In Frayer's notation, the prior is $\{N_i/N\}$, the raw dot count, while the posterior is $\{\sum(N_i\, p_i)/N\}$, the dot count adjusted for the plot count.

Lastly, we analyzed the plots sent to the field which had more than one condition class. Overall agreement (58 percent) and Cohen's κ (0.20) was much lower for these plots than the single condition field plots. In the interest of brevity, results are not shown, but may be obtained from the corresponding author. They may also be obtained by subtracting the values in tables 3 and 4 from the values in table 2. Partial nonresponse affects < 60,000 acres, and the posterior for these plots is nearly equal to the prior.

A summary of all the estimates derived in our analysis is shown in figure 3. First, there is the traditional FIA estimate for 2015. Second is the ICE estimate (2014 estimate with plots weighted equally). Third, is the FIA estimate, with nonresponse filled in with ICE without error correction? Last of all, there is the FIA estimate,

Table 4—Cross tabulation of land use in south Texas by Forest Inventory and Analysis (FIA) and Image-based Change Estimation (ICE) (single-condition field-visited plots only)

Land use	Forest	Agricultural	Rangeland	Developed	Other	Water	ICE total	Agreement
Forest	645.4	19.3	159.0	6.7	2.0	1.0	833.4	0.828
Agricultural	23.1	270.2	39.1	18.6	3.6	1.5	356.1	0.776
Rangeland	35.4	31.6	103.6	1.4	18.1	2.0	192.1	0.405
Developed	16.5	15.9	9.3	86.0	0.0	2.1	129.9	0.706
Other	3.2	1.4	7.7	0.0	34.5	3.8	50.6	0.554
Water	1.4	1.5	1.4	1.2	15.8	22.6	43.9	0.588
FIA total	725.0	340.0	320.0	114.0	74.0	33.0	1,606.0	0.724

Table 5—Likelihood matrix, prior, and posterior for whole Nonresponse plots, south Texas

Land use	Forest	Agriculture	Rangeland	Developed	Other	Water	Plots	Prior	Posterior
Forest	0.774	0.065	0.184	0.127	0.063	0.032	1,028.84	6,111,359	4,951,505
Agricultural	0.023	0.759	0.164	0.123	0.028	0.034	103.62	614,327	770,315
Rangeland	0.191	0.110	0.539	0.071	0.152	0.031	108.00	639,471	1,619,833
Developed	0.008	0.052	0.007	0.663	0.000	0.028	73.60	436,915	376,922
Other	0.002	0.010	0.094	0.000	0.682	0.359	9.47	55,535	141,463
Water	0.001	0.004	0.010	0.016	0.075	0.514	10.47	62,398	59,966
ICE total	1.000	1.000	1.000	1.000	1.000	1.000	1,334.00	7,920,004	7,920,004

with nonresponse filled in with ICE observations that have been adjusted for error based on comparison with FIA measurements. For instance, the estimate of Forest is just over 8 million acres with FIA's current methods but would be over 12 million acres if FIA relied solely on ICE measurements and 10.6 million acres if it used the FIA call (if available) and the ICE call corrected by FIA calls. Agriculture is almost 8 million acres with current FIA methods, but would be just over 6 million acres if FIA used ICE. Developed at almost 2.5 million acres and Other at just over 1 million acres would be relatively unchanged. Finally, Water at 3.2 million acres under current methods appears to be an overestimate compared to any ICE-related estimate.

CONCLUSIONS

The largest differences with respect to the raw ICE and adjusted ICE estimates are in Forest and Rangeland. That is, ICE interpreters were too eager to call a plot Forest and not eager enough to call one Rangeland. Thus, we cannot rely solely on photo interpretation to fill in Nonresponse. The largest differences with respect to the FIA estimate and the adjusted ICE estimate were in Forest, Agriculture, and Water. In south Texas, nearly all of the area is in the low percent-canopy NLCD class, including Forest. However, the nonresponse for Agriculture is much lower than it is for Forest, and the nonresponse for Water is very low. Consequently the plot count gives a false impression of what the land use really is.

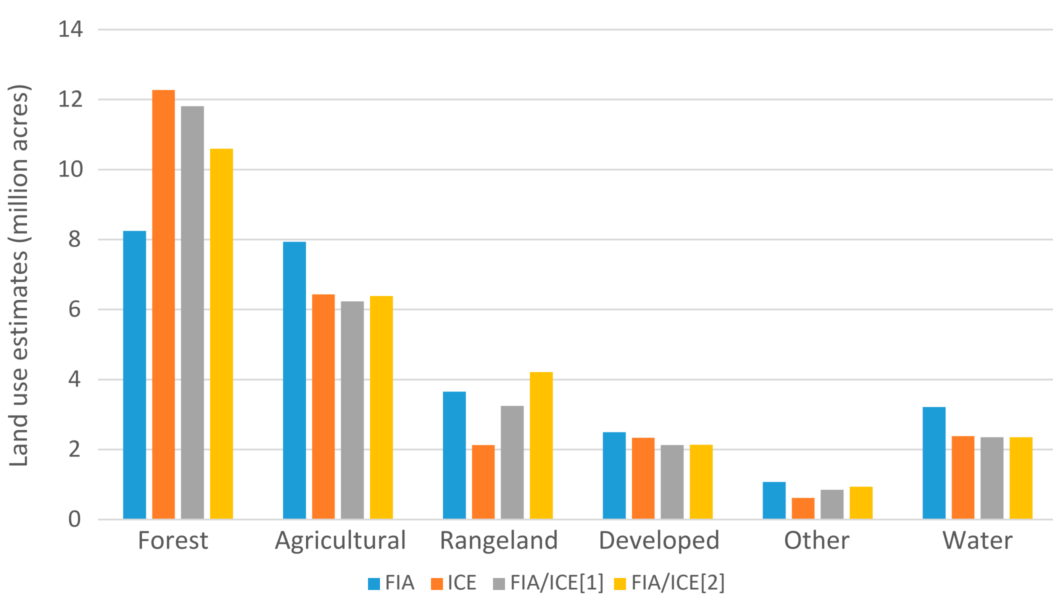

Figure 3—Comparison of land use estimates in south Texas, 2015. FIA = estimates with only FIA plots (using EXPCURR); ICE = estimates with only ICE plots; FIA/ICE[1] = estimates with FIA plots using ICE plots to fill in Nonresponse; FIA/ICE[2] = estimates with FIA plots, using ICE plots to fill in Nonresponse, but adjusted.

Second, it has long been suspected that nonresponse plots have a higher-than-base-rate chance of being Forest; consequently the estimate of Forest in this paper is higher than the one in McCollum and Jacobs (2017). ICE was intended to estimate change rather than fill in Nonresponse; however, it does appear to be more accurate than NLCD.

Third, the distinction between Rangeland and Forest is fuzzy; there are fewer trees per acre and lower percent canopy in this part of the State than there are in eastern Texas (home to the State's commercial and recreational forest). The call might hinge on whether field crews see evidence of cattle grazing.

Last of all, ICE interpreters thought 62 out of 1,206 plots were Forest which prefield interpreters thought were obvious Nonforest. These plots represent over 360,000 acres. It may be advisable to require that more than one set of eyes agree that a plot is obviously Nonforest before not sending it to the field. Another possibility would be to adjust estimates based on quality control plots. FIA might also consider having photo interpreter review plots where field and interpreter or two different interpreters disagree.

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SMALL AREA ESTIMATION OF ZERO-INFLATED, SPATIALLY CORRELATED FOREST VARIABLES USING COPULA MODELS

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Modeling forest inventory variables present a number of challenges, including accounting for spatial correlation, excess zeros, and non-standard distributions. Gaussian copulas can be used to flexibly model the spatial dependence between random variables with very different marginal distributions. They may provide a useful tool to model the complex variables measured in forest inventories and could be used for spatial prediction and estimation for small areas. We apply copula models to predict inventory variables for increasingly narrower domains and, therefore, greater proportion of zero values (total volume, volume of douglas-fir and volume of western hemlock in northwest Oregon). In general, after including covariates derived from geographic and remote sensing data, the spatial correlation was relatively weak, indicating that synthetic prediction based on zero-inflated models may suffice for most applications. We thus compare the performance of copulas with or without spatial dependency in the context of small area estimation.

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UNCERTAINTY IN MEASUREMENTS OF STANDING TREES AND DOWNED COARSE WOODY DEBRIS IN THE U.S. FOREST SERVICE FOREST INVENTORY AND ANALYSIS (FIA) PROGRAM

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As knowledge of the uncertainty in estimates of forest live and dead biomass is important for interpreting forest inventory data used in applications such as national greenhouse gas inventories and biodiversity assessments, we used blind remeasurement data from the FIA quality assurance program to assess measurement uncertainty in trees and downed coarse woody debris (DCWD). For trees, diameter measurements had better agreement between the two crews (0.14 ± 0.53 cm or 1 percent of diameter) than did height (0.96 ± 1.1 m), with hardwoods, being more difficult to identify than conifers. Tree status (live, dead, or cut), crown class, crown ratio, grade, and decay class were also subject to error. However, aggregated at larger scales, differences between estimates of volume or biomass based on production or QA crew measurement were negligible. In contrast, estimates of DCWD volume, averaging 31.2 m^3 ha^{-1} across the 79 plots evaluated, were highly uncertain (with a 95 percent confidence interval of 15.9 m^3 ha^{-1}). Estimates of carbon storage were more uncertain, due to poorly constrained estimates of wood density. This study demonstrates how uncertainty analysis can be used to quantify confidence in estimates and to help identify where best to allocate resources to improve monitoring designs.

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UPDATING ANNUAL STATE- AND COUNTY-LEVEL FOREST INVENTORIES WITH DATA ASSIMILATION AND FIA DATA

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The national report on sustainable forests provides a new opportunity to produce and distribute annual updates for Montréal Process Criteria and Indicators. An annual update for forest land area is particularly important because of its association with other indicators such as forest biomass and carbon. As a result, the National Greenhouse Gas Inventory Reporting program has similar needs for forest land area, both in a timely fashion and at flexible geographical scales. The Forest Survey handbook advises that the sampling error (SE) shall not exceed 3 percent error per 1 million acres for estimating area, a target that is achievable by pooling FIA panel observations inventoried from respective years of an inventory cycle. Consequently, the objectives of this study were to propose and illustrate an updating procedure using data assimilation that integrates design-based estimates with a model-based (mixed) estimator for updating the annual estimates of forest land area at both the State- and county-level. This procedure effectively reduced the SE of annual estimation at both population levels and achieved annual estimates with SEs comparable with those based on using pooled observations.

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Evolving Approaches for Impact Assessment to Forests After Hurricanes

MONITORING POST-DISTURBANCE FOREST RECOVERY: IMPROVING CAPACITY FOR LARGE-AREA ASSESSMENTS

Joanne C. White, Michael A. Wulder, Txomin Hermosilla, Nicholas C. Coops
Canadian Forest Service

With some rare exceptions, plot-based studies of post-disturbance forest recovery are limited by sample size, and spatial and temporal extent, precluding a comprehensive analysis of recovery across a range of site types, forest types, and disturbance magnitudes. Spectral recovery, as measured using a time series of optical satellite data, provide quantitative insights on the return of vegetation following disturbance. Satellite-derived spectral recovery assessments are therefore useful as they provide a consistent, large-area spatially explicit framework for assessing recovery that can be integrated with field plots and other sources of reference data such as airborne laser scanning (ALS) data. Our research generated a national assessment of recovery following wildfire and harvest using Landsat time series for Canada's forested ecosystems. Subsequent research has used measures of forest height and cover derived from ALS data as well as field plot data. Results corroborate the use of spectral recovery metrics to provide a spatially exhaustive and retrospective assessment of recovery, and to provide baseline data on the potential for natural regeneration at a given location.

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WOOD SALVAGE EFFORTS IN PUERTO RICO AFTER HURRICANES IRMA AND MARIA

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Hurricanes Irma and María made landfall in Puerto Rico (PR) on September 2017, leaving hundreds of thousands of logs along the roads. Although this fallen material included wood of high value, the initial response was to dispose of it in landfills or burn it after removal. To explore beneficial alternatives for a growing industry of wood products in PR, a post-hurricane wood salvage project was initiated by the Caribbean Climate Hub. This initiative included assembling a team of specialists to assess and characterize woods recovered from debris management operations, and collected at 17 sites around PR. Various methods were employed including procedures used by the FIA program to sample residue piles, transects to characterize the size of logs, and collection of samples for species identification. The mean volume of the piles was 51,323 ft^3 from a total of 1,180,429 ft^3 of wood. More than ⅔ of the logs were < 6.5 feet in length as most were cut into short pieces, but 58 percent had more than 8 inches of diameter. Logs of mahogany and other valuable tropical species were found with a mean decay class close to 3 after 18 months of the storms. Pre-approved plans and procedures for post-storm hardwood recovery are recommended.

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RAPID PROJECTIONS OF THE EFFECTS ON THE FOREST RESOURCE IMPACTED BY A MAJOR HURRICANE

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With hurricanes being a common occurrence along the Gulf and Atlantic coasts, the 12-year absence of major hurricane landfalls (Category 3 or greater) came to an end in 2017 with Hurricanes Harvey and Irma. FIA conducts a preliminary assessment within a few days after landfall for major hurricanes in order to provide early projections for immediate and direct impacts to the forest resource, as determined from forest inventory data available as of the day of the storm. The initial product generated is GIS polygon data—a draft map developed from iso-lines of wind speed provided by the National Hurricane Center, which may then be improved via aerial reconnaissance and possible ground visits performed by State personnel to determine percentage impact within forest areas. Percentages of forest damage are applied to forest inventory data to provide tabular output for forest acreage along with cubic-foot volume of hardwoods, softwoods and baldcypress for all live trees on forest land. Only through more intensive aerial and ground surveys can more precise timber volume losses be determined.

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MODERNIZATION AND STANDARDIZATION OF FOREST DISTURBANCE ASSESSMENT AND VALUATION METHODOLOGIES FOR SOUTHERN STATE FORESTRY AGENCIES

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Mississippi Forestry Commission

The Southern Group of State Foresters (SGSF) is working to modernize and standardize forest damage assessment and valuation methodologies. This is a multidisciplinary, collaborative effort led by the SGSF Forest Management committee and involving members from the GIS, Forest Health and Ecosystem Services Utilization and Marking committees as well as key USDA, Forest Service (USFS) partners from FIA and Remote Sensing analysts from the Southern Research Station (SRS). Fine resolution forest disturbance mapping techniques developed by the USFS SRS have proven very useful for assessing both small and large scale forest disturbances. We will present examples of these forest disturbance maps and provide an update on this SGSF effort.

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ASSESSING POST-HURRICANE DAMAGE IN MANGROVE FORESTS OF SOUTH FLORIDA USING REPEAT LIDAR, LANDSAT AND U.S. FOREST INVENTORY AND ANALYSIS (FIA) DATA

Todd A. Schroeder, Mark Brown, Karen Cummins,
Jarek Nowak, Bruce Cook, Chandra Giri
USDA Forest Service

With hurricane frequency, intensity and duration on the rise, the economic and ecological benefits of mangrove forests are becoming more valued across the globe. To facilitate better management and protection there is an urgent need for more accurate information regarding the distribution, abundance and health of mangrove forests. To date, airborne laser scanning (ALS) data has been widely used to map changes in mangrove canopy height, however most previous studies have focused on limited geographic areas. In this study, a large collection of ALS strips collected before and after Hurricane Irma are combined with Landsat imagery and other predictors to map mangrove canopy height and cover change across all of southwest Florida. Prior to mapping, tree heights measured on U.S. Department of Agriculture, Forest Service FIA plots are used to adjust the LiDAR data to account for the fact FIA measures total height, including length of leaning crowns. The maps are used to analyze distributions and spatial patterns of mangrove canopy height and cover change in five sub-regions with different orientations from the eye wall of the storm. Results are used to evaluate potential for broad scale mapping of mangrove species and other structure-related LiDAR variables.

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A MONITORING FRAMEWORK FOR TRACKING FLOOD IMPACTS TO FORESTS

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The Coastal Plain bottomlands of the Southeastern United States are occupied by relatively uncommon forest community types. These bottomlands support tree species adapted to edaphic conditions and seasonal hydroperiods that are beyond the tolerance threshold of many other tree species. Trends in the frequency and intensity of weather extremes (e.g., climate change and hurricanes) may spell out significant changes for the occurrence and distribution of vulnerable species. The Coastal Plain is a characteristically low gradient landscape that grades from swamp to upland transition zone. Flood inundation could pose important threats to tree species that are already poised near their water and anaerobic tolerances. This paper describes our efforts to combine U.S. Geological Survey water data with spaceborne imaging radar [Sentinel-1 Synthetic Aperture Radar (SAR)] to address challenges in estimating the impacts and extent of flooding caused by Hurricane Michael (2018) as it made landfall in Florida's Panhandle and surged northeast. We describe the methodology of our approach to tree species vulnerability assessment, how it can be informed by Forest Inventory and Analysis, as well as SAR techniques used to quantify impacts.

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SESSION REVIEW—EVOLVING APPROACHES FOR IMPACT ASSESSMENT TO FORESTS AFTER HURRICANES

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Remote sensing technology and tools for efficient processing are changing rapidly. When clouds permit, it is now possible to map inferred damage from hurricanes and other disturbances in just a few days of their occurrence at 10m resolution using the twin Sentinel 2 satellites of the European Space Community and cloud computing. Initial assessments can be efficiently conducted over large regions using indexed measures of change such as the normalized difference vegetation index (NDVI) and other indices at 20 m. As with remote sensing efforts at any resolution, these maps are no panacea, as interpretation is the critical second half of assessment. Observations include false positives from atmospheric issues and standing water, along with confounding issues such as seasonal phenology, leaf abscission, and difficulties isolating structural damage from ephemeral change in ways that lends itself to field calibration or validation. Pre-event conifer/deciduous forest type masks can be readily generated annually to compare with the damage observed, and this provides a means to rigorously associate levels of damage to different forest types for near-real-time assessments for owners, counties, or the affected region in ways that can be quantified with FIA and other field data.

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Urban FIA Update and Latest Results

URBAN FIA: INTEGRATING ALL LANDS INVENTORIES INTO THE NATIONAL WORK FLOW

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The Forest Inventory and Analysis (FIA) Program of the U.S. Department of Agriculture, Forest Service reports on the status and trends in forest land health, growth, area, location, and ownership. The 2014 Farm Bill instructs FIA to “Implement an annualized inventory of trees in urban settings, including the status and trends of trees and forests, and assessments of their ecosystem services, values, health, and risk to pests and diseases.” Urban areas implementation started in Baltimore, MD, and Austin, TX, during the 2014 field season and expanded into 35 cities in 24 States; 15 of which have both their proposed cities and all their urban areas active as of the 2019 field season. Installing plots in urban areas is just the first step in FIA's vision of an “All trees, All lands, All the time” approach to the long-term monitoring of the nation's trees. This session will cover the status of the program as well as the efforts being made, and challenges encountered, while folding FIA’s plots in urban areas into the existing national work flow from prefield, field, data processing, analysis, and on to data delivery while taking an approach of thinking regionally while acting nationally as a unified national program representing four regional units.

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ADVANCES IN UURBAN FIA PROCESSING, DATA AVAILABILITY, TOOLS, AND PRODUCTS

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Forest Inventory and Analysis (FIA) initiated an annualized urban inventory in 2014 and the program has grown to include urban forest monitoring in 35 cities, across 24 states, with new cities added each year. During this period of implementation, there has been limited published urban data available. However, a number of cities now have nearly complete cycles of baseline data and data distribution frequency will soon be annual. In this presentation, we describe advances in the processing of urban FIA data including database development, the implementation of a data review process, data publication, the development of analytical tools, and automated 5-year reporting. An overview of the data release schedule and reporting timeline are also presented. We conclude with a discussion of future directions in urban data delivery, analysis, and reporting.

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MY CITY'S TREES: DELIVERING INFORMATION FROM URBAN FIA DATA

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Texas A&M Forest Service

My City's Trees delivers Urban FIA data to a broad audience in a user-friendly interface, making the complex database accessible to average users. The use of themes to break down city-wide estimates into selected areas of the city remains a main feature of My City's Trees. Themes, such as ecoregions, watersheds, or income level, are selected independently for each city to reflect local resource issues. Available estimates include tree counts, carbon storage, energy savings, and more. The web application received some major updates in 2019, including improved functionality and additional features as well as data for more cities. Information on the status of Urban FIA in participating cities is available on the map. The revamped app has better reporting capability—users are now able to produce a full report or one-page summary for their area in PDF format and share it directly from the application. Estimates now include breakdowns by diameter class and land use in addition to ownership. Data for San Diego and San Antonio are now available along with Austin and Houston data. The 2019 release of My City's Trees is designed to work seamlessly across devices of all sizes, from smart phones to desktops.

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AN INVENTORY OF SAN DIEGO'S FOREST RESOURCES: URBAN FIA IN THE WILD WEST

Kathryn C. Baer[1] and Kurt G. Hellman[2],
Tonya Lister, Nancy F. Sonti

In 2017, San Diego, CA became the first urban area in FIA's Pacific Northwest Region to be inventoried as part of the Urban FIA (UFIA) initiative outlined in the 2014 Farm Bill. A full complement of 200 plots were selected in San Diego, of which 190 were sampled by UFIA crews from September to November of 2017. The results of this inventory will be released in 2020 in what is anticipated to be the first standardized UFIA report. This presentation will describe novel techniques utilized in the San Diego urban inventory, including methods for the consistent measurement of the city's many palm trees. We will highlight key findings of the San Diego UFIA analysis and report, including descriptions of the species composition and distribution of the city's urban forest and the ecosystem services it provides. Attributes of San Diego's urban forest will be compared to those of two urban areas within FIA's Southern Region that were previously inventoried as part of the UFIA initiative: Houston and Austin, TX. These comparisons will include a discussion of differences in tree cover and regeneration among urban areas within different ecoregions, and unique threats to the sustainability of San Diego's urban forest.

[1] Oak Ridge Institute for Science and Education.
[2] USDA Forest Service.

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GOING WITH THE FLOW: TRACKING URBAN WOOD FLOWS TO TEST AN URBAN TPO APPROACH

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Urban wood waste is a plentiful, underutilized resource. The National Renewable Energy Laboratory estimates that over 41,000,000 tons of urban wood waste are generated annually in the United States, and tree care crews generate ~1,000 tons of urban wood waste per crew per year. Reports indicate that most of it is chipped or used for firewood. We examined three models of various levels of intensity for an urban analog to the FIA TPO, which we subsequently refer to as Urban TPO. We found that the most basic level of Urban TPO, focusing on wood waste generators and volumes, would be most appropriate for a national program. With an inventory of urban trees, of those that generate urban wood waste (tree care companies), and of those that process urban wood, we can understand the scope and potential of an urban wood waste system. We apply this model to Baltimore and share our results and their limitations. We also discuss potential approaches for intensification by including urban wood processors, producers, and customers.

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IMPLEMENTING URBAN FIA IN THE U.S. VIRGIN ISLANDS

Thomas J. Brandeis
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Forest cover is of particular importance on Caribbean islands. Trees capture rainfall and stabilize soils, improving aquifer recharge and protecting fringing coral reefs vital to fisheries and tourism. It preserves endemic plant and animal species and mitigates ambient temperatures on these subtropical islands. The Forest Inventory and Analysis (FIA) Program began inventorying forests in the U.S. Virgin Islands (USVI) in 2004 with an intensified sample (6–12 times for a total of 106 sampling points), remeasured these plots in 2009 and 2014, and will again in late 2019. While the islands of St. Croix (53,870 acres total area; 56 percent forested, 50,601 people), St. Thomas (20,480 acres, 44 percent forested, 51,634 people) and St. John (12,800 acres, 81 percent forested, 4,170 people) vary in size and population, they share similar dispersed, low density development. 46 percent of FIA sampling points on St. Croix fall within the Christiansted urban cluster (UC) and 70 percent of points on St. Thomas fall within the Charlotte Amalie UC. Trees on the islands' developed lands also contribute ecosystem services and the goal of the urban FIA program is to quantify them. In this latest cycle, all USVI sampling points will be treated as falling within an UC and have the full suite of urban FIA data collection.

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Urban Forest Research and Advances in Urban Inventory and Monitoring

URBAN NATIONAL LANDOWNER SURVEY: RESULTS AND APPLICATION FROM PILOT CITIES

Nancy F. Sonti, Dexter H. Locke, Brett J. Butler, Katy Thostenson, Andy Stoltman, Amanda Robillard, Emma Sass
USDA Forest Service, Northern Research Station

The Urban FIA program was created to inventory the nation's urban trees and forests, expanding the FIA sampling frame beyond the FIA definition of forest land. Alongside the plot-based Urban FIA data collection, development of an Urban National Landowner Survey (analogous to FIA's National Woodland Owner Survey) captures the attitudes and behaviors of urban residential landowners regarding their neighborhood and community, as well as their property's trees and other green spaces. A more complete understanding of private residential land management both within and across cities can help policymakers, natural resource managers, and private industry in their efforts to create, sustain, and make productive use of urban trees and other vegetation. This talk will discuss some of the challenges and opportunities encountered in the process of developing and implementing the Urban National Landowner Survey in pilot cities, as well as the application of this data to inform targeted outreach to community stakeholders in urban forestry. Pilot cities include Austin, Texas and the cities of Green Bay, Madison, Milwaukee, and Wasau, WI.

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URBAN TREE SPECIFIC GRAVITY AND ASH CONTENT: A CASE STUDY FROM BALTIMORE, MARYLAND

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Interest in conducting urban tree inventories and quantifying the associated wood resource has accelerated at a pace faster than supporting research needs can be identified and accomplished. To examine potential differences in wood properties between trees grown in forest and urban settings, wood samples were collected from various tree species in the city of Baltimore, MD. The samples were analyzed for basic specific gravity (SG) and ash content (AC). The results from urban trees were compared with published values from studies based on forest-grown trees. There was no general trend in the results for SG; however, urban *Acer rubrum* L. and *Fraxinus* spp. appeared to have higher SG and *Quercus palustris* Münchh. lower SG than their forested counterparts. Based on these results, the use of existing forest-based SG data may produce weight estimates of urban woody biomass that are 5–10 percent too low. Conversely, most of the species studied had higher AC than their forested counterparts. Further work is needed on a wider range of species and geographic locations to refine the results and better support the analysis of urban tree inventories.

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NEW APPROACHES AND CONSIDERATIONS FOR DEVELOPING TREE MEASUREMENTS AND MODELS FOR URBAN FIA PLOTS

David W. MacFarlane, Georgios Arseniou, James A. Westfall
Michigan State University

As the Forest Inventory and Analysis (FIA) program enhances its national plot network to include comprehensive annual forestry inventory and monitoring data for trees growing in urban areas, it will facilitate analyses of tree resources along an urban to rural gradient. While a tree is a tree, at some level, FIA may need new measurements and/or models unique to some urban environments to allow for unbiased comparisons of plots in urban versus rural areas, in terms of tree merchantability and quality, risk assessment, and ecosystem services provided. Here, we present results from initial investigations in the northern FIA region that show some important differences in urban (open-grown) versus rural (forest-grown) trees, which should be considered when developing urban tree measurement protocols and models. Also discussed are data needs for developing urban-tree-specific models, including nondestructive methods based on terrestrial LiDAR and photography.

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EVALUATION OF SIMPLIFIED CROWN MEASURES FOR URBAN FIA

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Davey Tree Expert Comapany and
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The incorporation of i-Tree methods in Urban FIA inventories has added several new field measurements. Many of these new measurements are associated with assessing crown volume, a key driver of leaf surface area and ecosystem service models within the i-Tree tools. These new variables include perpendicular crown widths, crown base heights, and the foliage absent within the silhouette of the live crown. These additional variables can be challenging to collect, especially in closed canopy settings where overlapping crown boundaries can be difficult to discern from the ground. We suggest a method to replace the new percent foliage absent measure with an adaptation of the existing compacted crown ratio measure. Initial evaluation shows that this approach leads to underestimates of individual tree leaf surface area by an average of 2 percent and underestimates of leaf surface area at the plot level by an average of 7 percent. Eliminating the need to assess percent absent has the potential to save time in the field while relying on the established compacted crown ratio measurement. The modest underestimates of leaf surface area will lead to conservative estimates of ecosystem services from the i-Tree models.

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CROWN WIDTH MODELS FOR TREE SPECIES GROWING IN URBAN AREAS OF THE UNITED STATES

James A. Westfall, David J. Nowak, Jason Henning, Christopher B. Edgar, Tonya W. Lister, Mark Majewsky, Nancy F. Sonti, Robert Hoehn
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Crown widths of trees growing in urban areas are of considerable importance as an overall indicator of tree health and also serve as an important factor when assessing ecosystem services such as carbon sequestration, air quality, energy efficiency, and aesthetic values. Unfortunately, assessing tree crown width in urban environments is often challenging, which compromises the accuracy and consistency of measurements for this key variable. To circumvent this issue, models to predict crown widths for urban trees were developed using data from 49 cities across the United States. The effort consisted of fitting mixed models for 29 species groups that encompassed 964 species. Cities were considered as random effects and were statistically significant for 22 of the 29 groups. The presentation will also include assessments of using crown width predictions instead of observed values for leaf area index calculations within the iTree software suite, as well as comparisons with other published crown width models for both forested and urban environments.

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THE USE OF FRACTAL DIMENSION TO STUDY ECOLOGICAL TRAITS OF TREES IN U.S. CITIES

Georgios Arseniou, David W. MacFarlane
Michigan State University

There is growing interest in understanding the nature of urban trees, because they provide multiple social and ecological services (e.g., temperature regulation, carbon storage). Functional traits of urban trees may be very different from trees growing in rural forests, because urban environments can be very stressful, due to conditions like excessive moisture and heat, barriers to root growth and pruning, but also more favorable, because trees in cities may receive additional watering, fertilization, and other care. Here, we studied the fractal dimension of urban tree crowns, a metric related to tree form and function. We analyzed a national urban tree database (McPherson and others 2016) and found that urban-tree fractal dimensions are significantly correlated with drought and shade tolerance and leaf mass per unit area and sensitive to local- (e.g., distance from buildings) and regional-scale factors (e.g., mean annual temperature). The results suggest that urban forest monitoring programs (like urban FIA) may benefit from measuring fractal dimension, which helps to enhance understanding of urban tree physiology and may provide important information for managing urban trees under different local and regional environmental conditions.

McPherson, E.G., Van Doorn, N.S. & Peper, P.J. (2016) Urban tree database. Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2016-0005. [Date accessed: November 4, 2019].

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I-TREE WILDLIFE: A TOOL FOR EVALUATING BIRD HABITAT POTENTIAL IN THE URBAN FOREST

Susannah B. Lerman, Keith H. Nislow, David J. Nowak, David I. King, Stephen DeStefano, Todd Farrand-Jones
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As more land becomes slated for urban development, identifying effective urban forest management tools becomes paramount to ensure the urban forest provides habitat to sustain bird and other wildlife populations. To address this need, we developed a wildlife tool for i-Tree to (1) provide detailed information on habitat requirements for a variety of songbirds, (2) to evaluate the bird habitat potential at ecoregional scales, and (3) to guide habitat improvement plans. The tool quantifies and qualifies available habitat based on data, and summarizes bird habitat relationships for variables that directly relate to these datasets. These data served as the basis for generating habitat suitability equations for predicting the probability of a species occurrence for the selected habitat variables. The bird habitat models calculate specific targets (e.g., canopy percent or dead wood density) geared towards urban foresters and planners when determining how to manage the urban forest for wildlife. Further, because of the flexibility of the tool and associated habitat models, the i-Tree wildlife module has the potential to integrate the habitat outputs in urban Forest Inventory and Analysis reports.

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Use of Photogrammetrically-Derived 3D Point Clouds to Support Large-Area Forest Inventory and Monitoring

OVERVIEW OF DIGITAL AERIAL PHOTOGRAMMETRY

Robert J. McGaughey
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Digital aerial photogrammetry (DAP) is a technique that derives 3D information from overlapping aerial images. The required overlap can be obtained using a series of images captured with frame-based cameras or from the multiple look angles captured by continuous scanners (push-broom sensors). DAP products include digital surface models and 3D point clouds. DAP-derived data is often compared to LiDAR. However, DAP can only produce measurements for areas in an image that are well illuminated and contain enough contrast to allow image matching to work. This means that DAP-derived data products can contain gaps and only represent the ground surface in open areas. Combined with U.S. Geological Survey 3DEP elevation data, DAP-derived data products offer the ability to characterize vegetation height and canopy cover over large areas for relatively low cost. Such information has many applications in the FIA context including pre-field conditions assessment, improving the precision of county-level estimates, and reducing bias associated with non-sampled plots. This presentation will present an overview of DAP technology, describe the basic data products, and compare the technology to LiDAR.

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THE POTENTIAL FOR AUGMENTING STATEWIDE FOREST ESTIMATIONS WITH CANOPY HEIGHT FROM REMOTELY-SENSED PRODUCTS–THE STATUS OF NATIONAL PROGRAMS

James Ellenwood
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Since the initial development of LiDAR and digital aerial photogrammetric technologies, their use has been limited to local project assessments and analysis. In recent years, a number of developments have increased the potential for the use of these datasets for larger-area assessments. The National 3D Elevation Program (3DEP) allows for the cooperation among federal agencies and partners to join forces in funding common and adjacent areas to improve project costs and gather more usable data. The National Agriculture Imagery Program (NAIP) allows for the optional purchase of the digital aerial photogrammetric point clouds, as of 2018. The University of Minnesota Polar Geospatial Center is conducting a large-area digital photogrammetric project based upon all available U.S. Government purchased imagery from Digitalglobe for global coverage. It is possible to produce a nationwide Canopy Height Model (CHM) at a 1-m resolution. Benefits to the Forest Inventory and Analysis program include the potential to improve Image-based Change Estimation (ICE) and pre-field efficiencies; the potential to incorporate better measurements in nonforest areas such as agriculture and urban forest areas; and improved small area estimation and modeling.

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COMPARING THE RELATIONSHIP BETWEEN TREE CANOPY HEIGHT INFORMATION FROM LIDAR, PHODAR AND FOREST INVENTORY DATA IN NORTHEASTERN FORESTS

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Detailed tree canopy height information is valuable to natural resource monitoring, science and management specialists. Canopy height is commonly measured from the ground on forest inventory plots, but this information is expensive and prone to error. Alternatively, 3D models of canopy height and structure can be made using aerial LiDAR or stereo pairs of digital aerial photographs, sometimes referred to as phodar. The operational use of phodar over large areas is relatively recent, and there is thus a gap in the understanding of how phodar compares to LiDAR or ground measurements with respect to producing useful canopy height products. The current study seeks to fill this gap by comparing data from wall-to-wall LiDAR and phodar-based height products with height information from U.S. Department of Agriculture Forest Service Forest Inventory and Analysis (FIA) plots in the northeastern States of Connecticut and Maryland. Bivariate correlation between the data types and other metrics will be compared with the goal of assessing the utility of phodar for various FIA business processes. The goal of this pilot analysis is to assess the potential for this new technology to provide useful 3-d vegetation structure information in northeastern forests.

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EVALUATING THE POTENTIAL OF NATIONAL AGRICULTURE IMAGERY PROGRAM (NAIP) POINT CLOUDS TO SUPPORT OPERATIONAL FOREST INVENTORY APPLICATIONS IN THE SOUTHEASTERN UNITED STATES

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The U.S. Department of Agriculture, Forest Service Forest Inventory and Analysis (FIA) program regularly collects tree and stand-level data to produce statistical estimates which are used to analyze the current status and condition of America's forests. Land cover data from the National Land Cover Database (NLCD) are typically used to post-stratify these estimates but the information in these maps is often more related to forest area than tree density or size, thus there is a need for alternative products that can help operationally improve estimates of forest structure-related variables like volume and biomass. In this presentation, we evaluate the quality of 3D point clouds developed through photogrammetric processing of high resolution stereo imagery collected by the National Agriculture Imagery Program (NAIP). NAIP canopy height surfaces developed for the States of Tennessee and Virginia are compared with measured tree heights collected in the field by FIA, as well as with canopy height products developed with airborne LiDAR data. Issues affecting data quality such as image acquisition date, post-processing techniques, and precision of field GPS locations are evaluated and used to recommend standards needed for broader use of 3D point clouds within the FIA program.

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AN EXAMINATION OF DAP, LANDSAT, AND ENVIRONMENTAL VARIABLES FOR MODELING VOLUME, BIOMASS, AND CARBON ON FIA PLOTS

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Digital Aerial Photogrammetry (DAP) has recently received increased interest for forest inventory augmentation due to its low cost and availability over large areas including the entire conterminous United States every 2–3 years. There are additional opportunities for large area inventory augmentation, such as the integration of DAP with satellite imagery (e.g., Landsat multispectral data) and environmental gradients (e.g., slope, aspect, elevation, and temperature and precipitation attributes). This study explores the relationships between DAP, Landsat, and environmental gradients and contrasts their abilities to independently and jointly explain variation in measured tree volume, aboveground live biomass, and live carbon on Forest Inventory and Analysis plots. For 570 plots in Washington State, we looked at associations between principal components for the three auxiliary datasets, fit linear models for volume, biomass, and carbon to principal components, and performed a variable selection exercise with all subsets' regressions. Initial results indicate that integration of multiple sources of auxiliary information in forest mapping efforts enables superior products to support forest monitoring, management, and planning efforts.

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ESTIMATION OF TREE DIAMETER AT BREAST HEIGHT USING CLOSE RANGE STEREO PHOTOGRAMMETRY

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Purdue University

Forestry inventory analysis is time-consuming and expensive. Contemporary solutions such as terrestrial laser scanning are not convenient for small-scale landowners due to their cost. State of the art solutions involving the use of stereo photogrammetry have the advantage of being mobile, relatively low-cost, and do not require training to use. Our method captures the mobility and low-cost benefits of stereo photogrammetry, while surpassing diameter at breast height accuracy compared to similar groups. Our improvement is an algorithm that is used with stereo footage to report diameter at breast height. Two types of video footage were recorded for use in our algorithm (1) video captured standing still, and (2) video captured in motion walking through a plot. The best diameter at breast height root mean square error reported for video standing still was 1.32 cm over 40 trees. Our algorithm produced a root mean square error of 1.11 cm on the video captured in motion, which included 18 trees. Footage taken standing still over 20 trees took 5 minutes to record, but only 28.7 seconds for our algorithm to report diameters for each tree.

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EVALUATING THE UTILITY OF PUSHBROOM PHOTOGRAMMETRY-DERIVED POINT CLOUDS FOR ESTIMATING TREE CANOPY COVER

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Tree canopy cover is an important biological and ecological parameter often used as a criterion for land classification and other purposes. Definitions of forest land, a critical parameter in assessing rates of forest gain, loss and degradation, are based on a minimum cover threshold (e.g., 10 percent). Because it is time consuming and challenging to measure with acceptable accuracy and precision during field visits of inventory plots, canopy cover is often estimated via remote sensing. LiDAR data arguably yield the best estimates, but their acquisition cost often leads to sporadic availability. Manual, photointerpretation-based estimates from airborne imagery, such as the one acquired periodically by the National Agriculture Imagery Program (NAIP) for the continental United States, require substantial analyst involvement and are susceptible to overestimation owing to the wide field of view and minimal overlap between image swaths. Limitations to photo-interpretation can be potentially overcome by Digital Aerial Photogrammetry (DAP) for NAIP stereo imagery, with tree canopy cover estimates obtained by processing the point clouds generated by DAP. We evaluate this potential with dense LiDAR point clouds co-temporal to the NAIP imagery in the State of Washington.

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Large-Scale Computing Applications in FIA

CAN I GET FRIES WITH THAT? SUCCESSES AND CONTINUED CHALLENGES FOR BIGMAP

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The Forest Inventory and Analysis (FIA) Program entered into a public:private partnership with the U.S. Department of Agriculture Forest Service CIO Geospatial Services Branch and Esri, Inc. to configure the Big Data Mapping and Analytics Platform (BIGMAP). We are entering the final year of our 4-year agreement to deliver a prototype cloud-based system for scalable production, analysis, and on-the-fly delivery of massive, integrated, geospatial products. This solution is notable for its use of a commercial off-the-shelf (COTS) software solutions in a secure cloud environment. The resulting authoritative science-based products are designed to support decisionmaking for private and public land management planning, resource allocation, and landscape sustainability assessments. BIGMAP is designed to address several agency priorities, and this presentation will highlight several applications available for hands-on exploration during the digital engagement session. We will also review several persisting challenges associated with this type of partnership and IT applications in a rapidly evolving political environment.

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DEVELOPMENT OF BIGMAP: A CLOUD-BASED NATIONAL SCALE MODELING, MAPPING, AND ANALYSIS ENVIRONMENT USING ESRI RASTER ANALYTICS

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With the burgeoning remote sensing sector and the growing volume of imagery available at finer resolutions, new approaches are needed to support FIA's techniques research and national scale applications. Cloud-based solutions provide the flexibility to marshal the computing resources needed, and place algorithms and data together in a common environment. This presentation summarizes efforts to configure the Big Data Mapping and Analytics Platform (BIGMAP) environment, built upon Esri software utilizing Amazon Web Services (AWS). A pilot project was designed to test this environment with a set of use cases intended to cover much of the range of functionality required. This presentation focuses on two of these use cases: (1) support for national carbon reporting, and (2) small area estimation. The presenters will provide a brief overview of Esri Raster Analytics. They will discuss the process of architecting the AWS infrastructure and subsequent software configuration and performance testing of environment. They will address the technical challenges of taking use case workflows that were originally developed under different programming paradigms and adapting them to fit within BIGMAP. Finally, they will present some of the outputs produced to date and lessons learned.

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CLOUD COMPUTING SUPPORTING LAND COVER CHANGE MAPPING

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IW FIA

Since the beginning of the Landsat program in the 1970s, scientists have been using the platform's imagery to map land cover and land cover change. When the Landsat archive became free in 2008, algorithms using annual or even all acquisitions began to proliferate, with demonstrable benefits in sensitivity and accuracy. However, these algorithms have only begun to reach their potential as cloud computing has become more accessible. Several developments have driven the entire remote sensing field toward cloud platforms: (1) emerging evidence of the effectiveness of new, computationally intensive algorithms; (2) the sheer number of images now available; (3) the need to share ideas and code across increasingly diverse teams, and (4) the need for on-the-fly access to imagery for new user engagement applications.We highlight uses of a cloud platform for: detecting forest disturbances in the United States; mapping land cover and use change across East Africa; and, merging a global sample of LiDAR data with wall-to-wall image data from Landsat to make statistical estimates of biomass over user-requested areas. We're learning lessons about forest cover and land use change that would have been inconceivable without a huge expense just 5 years ago.

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USE OF MULTI-OBJECTIVE MACHINE LEARNING AND HIGH PERFORMANCE COMPUTING TO REDUCE PREDICTION BIAS IN FOREST MAPS

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Erin Simons-Legaard, Aaron Weiskittel
University of Maine, Center for Research on Sustainable Forests and
School of Forest Resources; University of Maine, Advanced Computing Group

Methods used to produce maps from satellite imagery and forest inventory plot data generally result in patterns of error that are detrimental to many applications. We have developed machine learning techniques that reduce systematic error when mapping forest attributes from multispectral satellite imagery and geospatial data. Our approach is based on the optimization of support vector machines using a multi-objective genetic algorithm designed to simultaneously minimize total and systematic error. Using Forest Inventory and Analysis plot data we have mapped tree species occurrence and relative abundance across Maine and obtained outcomes that compare well against other approaches. Our methods are highly generalizable and automatable, but also computationally demanding. Large-scale applications require use of high performance computing resources. We have developed efficient software for use on University of Maine cyberinfrastructure, including modular image processing and data handling workflows implemented on the cloud, and highly parallelized model training and map production code executed on a computing cluster. Our intention is to support a broad set of research and management applications through the production of high-quality spatial data at low cost.

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UTILIZING CLOUD-COMPUTING FOR IMPLEMENTING A DEEP CONVOLUTIONAL NEURAL NETWORK BASED FOREST STRUCTURE AND CLASSIFICATION MODEL

Tony Chang, Brandon P. Rasmussen, Luke J. Zachmann, Brett G. Dickson
Conservation Science Partners

In recent years, the increased availability of high-resolution (< 30 m) imagery and advancements in machine learning algorithms have opened up a new opportunity to fuse multiple datasets of varying spatial, spectral, and temporal resolutions. Here, we present a new model, based on a deep learning architecture, that performs both classification and regression concurrently, thereby consolidating what was previously several independent tasks and models into one stream. The model, a multi-task recurrent convolutional neural network that we call the Chimera, integrates varying resolution, freely available aerial and satellite imagery, as well as relevant environmental factors (e.g., climate, terrain) to simultaneously classify five forest cover types (“conifer”, “deciduous”, “mixed”, “dead”, “none” [nonforest]) and to estimate four continuous forest structure metrics (aboveground biomass, quadratic mean diameter, basal area, canopy cover). We demonstrate the model’s ability and performance on the Azure cloud-computing platform for model training on 9,967 georeferenced FIA field plots within California and Nevada, and then implement a large scale prediction for the Sierra Nevada region to understand the viability of this new approach.

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AN INTEGRATED DISTURBANCE AND VEGETATION MAPPING FRAMEWORK HIGHLIGHTS LANDSCAPE LEVEL CHANGES IN FOREST DYNAMICS DURING A MULTI-YEAR DROUGHT

David M. Bell, Matthew J. Gregory, Robert Kennedy, John J. Battles, Brandon Collins, David Saah, and Robert York
USDA Forest Service, Pacific Northwest Research Station

Future increases in the prevalence of drought may alter forested landscapes globally. In recent decades, forest disturbances associated with multiple, consecutive drought years have become increasingly common. However, the consequences of these multi-year droughts for forest landscape biomass stocks are not yet fully appreciated. In this research, our objectives were to (1) assess regional changes in disturbance rates and aboveground live forest biomass during the 2011–2016 drought in California and Oregon, and (2) examine whether changes were associated with aridity (climatic water deficit [CWD] 1990–2010) and drought magnitude (CWD 2016–2011—CWD 1990–2010). We leveraged an integrated disturbance and vegetation mapping approach to map annual live tree aboveground biomass (AGB) across all forest lands in California and western Oregon from 1990–2016. We describe how cloud-computing based image processing and disturbance mapping advances facilitate forest attribute mapping based on FIA plot data, Landsat imagery, and other geospatial predictors. Our results indicate that changes from historical (1990–2010) to drought (2011–2016) periods in disturbance rates (% forest area disturbed) and disturbance magnitude (AGB losses) increased with aridity and drought magnitude (R^2 = 0.32 and 0.16, respectively). Thus, our results indicated that multi-year drought, especially in semi-arid forest landscapes, contributed to increased disturbance rates and elevated AGB losses. This study highlights the capacity of cloud computing frameworks to facilitate ecological research into and monitoring of emerging drivers of forest landscape change.

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Advances in Estimating Carbon Stocks and Fluxes on Forest Land, Woodlands, and Urban Trees Across Space and Through Time

REMOTE SENSING-ASSISTED MULTIVARIATE HIERARCHICAL SPATIAL MODELS FOR SIMULTANEOUS PREDICTION OF MULTIPLE FOREST CARBON POOLS

Chad Babcock, Andrew O. Finley,
Grant M. Domke, Hans-Erik Andersen
University of Minnesota, Michigan State University

The Forest Inventory and Analysis (FIA) monitors six forest carbon pools by taking repeat measurements on plots, including (1) live tree, (2) understory, (3) standing dead, (4) downed dead wood, (5) litter, and (6) soil organic carbon. Some pools, such as live tree and standing dead, can be highly correlated with remote sensing data. However, other pools, such as litter and soil organic carbon, can be very weakly correlated with remote sensing products. All six forest carbon pools themselves typically are highly related (i.e., cross-correlated). These cross-correlations are useful information that, if appropriately modeled, can improve remote sensing-assisted prediction for all six pools. We demonstrate how a multivariate hierarchical spatial model can be paired with remote sensing data to predict multiple forest carbon pools simultaneously. Because we are using a unified multivariate framework for spatial prediction, we can explicitly model the cross-correlations between the six carbon pools. Our model is informed by FIA forest carbon pool plot data as response variables and Landsat-derived metrics as explanatory variables. Using this model framework, we make 30 meter spatial predictions for all NLCD-classified forest areas in the continental United States.

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EFFECTS OF DISTURBANCES AND LAND USE CHANGE ON CARBON STOCKS IN SIX U.S. STATES

Lucia A. Fitts, Matthew B. Russell,
Grant M. Domke, Joseph F. Knight
University of Minnesota

Forests serve as a large terrestrial carbon sink. Land use change is a major threat to forested areas, but the likelihood of change in forested areas is unknown. This research focuses on forest as a land use, and how forest conditions and population growth affect the carbon stocks in six U.S. States. The goals of the study are (1) to quantify the impacts of forest disturbances on the probability of forest becoming nonforest, and (2) to quantify the resiliency of forest carbon stocks when faced with forest disturbances. FIA data was used to generate models with two approaches: a machine learning algorithm (random forest), and generalized mixed effects models. Predictions from these models were used to create a regression with spectral information from Landsat imagery and produce a wall-to-wall probability map of land use change. Results indicate that land use change from forests is more likely with increasing population and housing growth rates, and non-public areas have a higher probability of forest change. Furthermore, disturbances were not a major predictor of land use change. This study provides information for decision-makers and land managers for designing policies and practices aimed at mitigating climate change.

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A USER PROTOCOL FOR GREENHOUSE GAS INVENTORIES OF FORESTS AND TREES AT COMMUNITY SCALE: COMBINING FOREST INVENTORY AND REMOTE SENSING

Richard Birdsey, Nancy Harris, Donna Lee, Stephen Ogle
Woods Hole Research Center, World Resources Institute

A new greenhouse gas (GHG) protocol is designed to support forestry-related decisions by communities (i.e., municipalities, counties, land-based cooperatives, large ownerships, States) for the purpose of achieving net reductions in GHG emissions. Land management decisions are typically made at relatively small scales such as U.S. counties; yet, barriers to accessing and using data and models has resulted in a lack of consideration of land management options in the hundreds of city and county climate action plans across the country. Working closely with city, county and municipal stakeholders, we have designed and tested a protocol that can be used by local planners to access publicly available data and compile estimates of GHG emissions and removals for forests and trees outside forests. Foundational data include the National Land Cover Data (NLCD) and Forest Inventory and Analysis (FIA) data, both readily accessible for all areas of the conterminous United States. The results of three case studies demonstrate how the protocol works. This protocol is associated with ICLEI—Local Governments for Sustainability, whose ClearPath™ is the online software platform used by U.S. communities to report greenhouse gas inventories.

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MAPPING GLOBAL CLIMATE MITIGATION POTENTIAL FROM REFORESTATION

Nancy L. Harris, David Gibbs, Kristine Lister,
Sassan S. Saatchi, Susan Cook Patton
World Resources Institute

Recent research suggests that reforestation is the single largest natural climate solution for mitigating climate change, and many countries have prioritized forest activities in their Nationally Determined Contributions (NDC) to the Paris Agreement. However, the magnitude and geographic distribution of reforestation's sequestration opportunity remains poorly characterized. One contributing factor is limited data on rates of biomass accumulation, which are spatially highly variable and influenced by numerous biophysical and management factors. By combining existing georeferenced field plot networks from around the globe (including FIA plots), biophysical predictor variables, and machine learning, we mapped current and potential future carbon sequestration potential of natural forest regeneration over the next 20–30 years with more geographic specificity than the regional estimates that currently exist. This type of information can help improve existing greenhouse gas (GHG) inventories at subnational scales where management decisions often take place, and enable local decisionmakers to evaluate the feasibility, timeframe, magnitude, and extent to which reforestation could contribute to and enhance NDCs and local Climate Action Plans.

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U.S. WEST COAST FOREST CARBON STOCKS AND FLUX: RESULTS FROM RECENT ANALYSIS AND USING FIA DATA AS BASIS INFORMING STATE-LED FOREST CARBON EMISSION MITIGATION POLICIES

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Forest Inventory and Analysis

Following California's lead, Oregon and Washington along the U.S. West Coast has increasingly sought to adopt climate goals through specific strategies to reduce carbon (C) emissions. Understanding the role forests play in each State's overall C stocks and flux is critical to developing, implementing, and monitoring these strategies. Similar to the role FIA continues to play in California and our partnership with the California Department of Forestry and Fire Protection (CAL FIRE), the Pacific Northwest Research Station has developed new partnerships with the Oregon Department of Forestry and Washington State Department of Natural Resources to assess current C stocks and flux on forest land in order to estimate a statewide rate of carbon dioxide (CO_2) sequestration. We present the latest findings from California, Oregon, and Washington including notable differences in growth and mortality in the tree C pool. The future direction of this work are discussed including State-led efforts improving the reporting and confidence of FIA's forest C stock and flux estimates.

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LEVERAGING TPO DATA FOR HWP CARBON STORAGE IN THE PACIFIC NORTHWEST

Todd A. Morgan, Glenn Christensen
University of Montana, Bureau of Business and Economic Research

Stakeholders in Forest Inventory and Analysis (FIA) Pacific Northwest (PNW) region have interest in quantifying carbon (C) stored in harvested wood products (HWP) because of State climate goals regarding carbon emissions. The FIA's Timber Product Output (TPO) program quantifies and characterizes timber used for products and disposition of mill residue, using mill surveys and logging utilization studies. In the PNW Region, this survey work is conducted by the University of Montana's Bureau of Business and Economic Research (BBER). Working with PNW-FIA, BBER researchers are using the Intergovernmental Panel on Climate Change (IPCC) production accounting approach to estimate HWP-C storage in California, Oregon, and Washington with a model developed by the U.S. Department of Agriculture, Forest Service as well as timber harvest, primary products and residue generated by timber-processing facilities. Results from California and Oregon indicate HWP-C storage is a fraction of ecosystem C storage. However, being able to consistently quantify C stored in HWP through time and across political boundaries will allow stakeholders and policymakers to better understand the role that timber harvested and used for wood products plays in total forest carbon storage and flux.

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PROPENSITY SCORE MATCHING ANALYSIS OF FIA REMEASUREMENT ACROSS DIVERSE WEST COAST FORESTS YIELDS INSIGHTS ON DRIVERS OF IN-FOREST CARBON SEQUESTRATION

Jeremy S. Fried, Olaf Kuegler, Bill Stewart, Van Butsic
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To estimate stand structure, management and disturbance influence on aboveground net carbon increment on timberland, we developed matched subsets totaling 3,920, not recently harvested, remeasured, U.S. Department of Agriculture, Forest Service and private Forest Inventory and Analysis plots in Washington, Oregon, and California. Grouping plots into four regions (Pacific Northwest (PNW) coast/inland and Pacific Southwest coast/inland), we applied propensity score matching (PSM) to generate comparable plot subsets for a better "apples to apples" evaluation of the marginal influence of those drivers on aboveground live tree carbon increment. As expected, carbon increment associated positively with site quality and initial inventory everywhere. Even-aged stand structure associated with higher increment only in PNW coastal. Negative impacts of fire, insect, and disease were evident in only inland regions. Higher quadratic mean diameter of trees reduced carbon increment in all regions. The more active forest management common on private timberlands elevated carbon increment in all regions, all else equal. PSM presents a promising approach for creating datasets amenable to evaluating the effect of discrete variables that aren't randomly distributed across the forested landscape but are key to testing policy relevant forest management hypotheses.

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Building Strong Partnerships: NFS and FIA

INTENSIFIED FIA GRID FOR BLM AND NFS; PARTNERSHIP SUCCESS IN THE PACIFIC NORTHWEST

Marin Palmer, Kevin Ford
USDA Forest Service, Pacific Northwest Region

Forest Inventory and Analysis (FIA) is a key data source for monitoring late-successional old growth and associated wildlife habitat components in the Pacific Northwest. Through a strong partnership with the Pacific Northwest Research Station FIA program (PNW-FIA), NFS R6 implemented a 3× spatial intensification of FIA plots across all nonwilderness National Forest System (NFS) R6 lands beginning in 2001, providing more detailed information about the status and trends of forest resources on NFS lands. Prior to FIA annual inventory, both NFS R6 and OR BLM had a similar inventory known as current vegetation survey (CVS). In 2018, OR BLM adopted the FIA sampling design as their strategic vegetation inventory. This expanded the partnership between PNW-FIA and NFS Region 6 to include OR BLM, integrating the vegetation inventories of both agencies. The FIA infrastructure enables both agencies to make inventory data available to the public and capitalize on FIA's national estimation tools, and is an example of the all lands approach to shared stewardship.

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A NEW SOURCE FOR FIA DATA SUITABLE FOR USE IN THE FOREST VEGETATION SIMULATOR

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Not since the retirement of the Forest Inventory Mapmaker in 2008 has the FIA program provided users with FIA data prepared for direct use with the Forest Vegetation Simulator (FVS). The Forest Management Service Center, developers of FVS, provided a translator for several years, but upkeep was difficult in light of frequent changes to FIADB and regional variation in data. Other FIA-based tools, such as BioSum and DATIM, extract FIA data into FVS-usable format, but these translations are not readily usable to users of FVS as a stand-alone tool. The new process pre-translates all plots present in FIADB into FVS-ready format and stores the FVS-ready data in a separate schema. The tables are then added to FIADB tables in a single, State-level SQLite database and delivered through the FIA Datamart. Having FIADB and FVS-ready tables in a common database provides FVS users with capabilities not previously available. With a simple Group selection in the current FVS interface tools, Suppose and FVS Online/Onlocal, users can project FIA data by condition, whole plot, or subplot. A series of user guides will cover topics such as properties and manipulation of the FVS-ready tables, and guidance on FVS projections for use in forest planning.

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LANDSCAPE CHANGE MONITORING SYSTEM—DELIVERY AND USE FOR FOREST SERVICE (NFS)

Kevin Megown, Mark Finco, Ian Housman, Leah Campbell, Jennifer Lecker, Nathan Pugh, Seth Bogle
USDA Forest Service, Red Castle Resources

The Landscape Change Monitoring System (LCMS) is a U.S. Deparment of Agriculture, (USDA) Forest Service (FS), Landsat based, annual national geospatial data product describing land cover change for every year from 1984 to the present. The LCMS product used together with other Forest Service enterprise data can support multiple business needs across FS Deputy areas, including Research and Development, National Forest System (NFS) and State and Private. This talk will briefly describe the LCMS outputs, the delivery of LCMS data and applications identified within the NFS Deputy area.

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INNOVATIONS IN ADDRESSING CARBON IN NEPA AND NATIONAL FOREST PLANNING

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There is a growing demand for forest carbon information to support National Forest System (NFS) planning and National Environmental Policy Act disclosures. The U.S. Department of Agriculture (USDA) Forest Service produced two carbon reports for all NFS units using Forest Inventory and Analysis (FIA) data and several empirical modeling tools to evaluate forest carbon trends and influences. Because these reports are nationally-consistent, we were able to develop a template-based approach to address carbon in decisionmaking documents that align with current policy. This approach has improved understanding of forest carbon dynamics by managers and stakeholders. These templates have also greatly increased efficiency, while improving the quality and legal defensibility of information used for decisionmaking. The templates work synergistically with one another and embody a number of innovations, creating an effective information delivery system that staff with even little training in carbon can use accurately. The data on which these templates are based are becoming dated and information needs and estimation methods have evolved, so we are looking to support the development of new FIA-based carbon reports to continue to serve NFS needs.

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COLLABORATIVE GOVERNANCE LEADERSHIP COMPETENCIES IN FEDERAL NATURAL RESOURCE MANAGEMENT PARTNERSHIPS

Melissa Hamid
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and Applications Center (GTAC)

Effective leadership is important to collaborative governance outcomes in Federal natural resource management partnerships. Within the natural resource field, there is a growing call in the literature to continue to explore interpersonal and other leadership competencies that could be leveraged by government to facilitate more effective collaborative partnership outcomes. It is not known how Federal Government and natural resource management partner organization executives perceive the influence of leadership competencies on the formation and maintenance of effective collaborative governance processes and partnerships. There is a paucity of empirical information relating to leadership competencies that would benefit intended public outcomes involving collaborative governance partnerships. A qualitative descriptive study is planned to explore leadership competency perceptions from participants in natural resource management partnerships to study the phenomenon of collaborative governance.

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INTEGRATING FIA DATA INTO NATIONAL FOREST MANAGEMENT THROUGH THE FOREST PLAN REVISION PROCESS: WORK IN PROGRESS ON THE SALMON-CHALLIS NATIONAL FOREST

Kristen A. Pelz
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Forest Inventory and Analysis (FIA)

National forests, under the current “planning rule” are required to use “best available scientific information” (BASI) for assessing forest conditions, developing a forest plan, and monitoring conditions as they relate to the plan. FIA data can be one source of BASI, but because of the scale of data and lack of familiarity with it, the data can be difficult to integrate with other data sources. On the Salmon-Challis National Forest, FIA data were used in their assessment, and an interdisciplinary team analysis is being used to help with the development of plan components and identify potential uses of data for monitoring. This presentation will outline what has worked, challenges of working with FIA data in the plan revision context, and potential monitoring plans for the future.

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EVALUATING EXISTING LONGLEAF PINE ECOSYSTEM CONDITION WITH FOREST INVENTORY AND ANALYSIS (FIA)

Emrys Treasure, Joanne Baggs, Ray Sheffield, Amy Nathanson, Rickie White, Carl Nordman
USDA Forest Service

The Range-Wide Conservation Plan for Longleaf Pine established condition-based restoration goals to meet by 2025. The initial 2009 estimate of 3.4 million existing acres was based on a combination of FIA and local inventory data (i.e., FSVeg) for NFS lands. The split between “maintain” and “improve/restore” was based on professional judgement with limited sampling. Since then, NatureServe led an interagency effort to better define condition classes for longleaf pine ecosystems. These Open Pine Metrics score various criteria, which are combined to produce an overall condition class. There are 13 Open Pine Metrics, though FIA protocol only collects sufficient data to score 7 of them. We selected all FIA plots that contained at least one longleaf pine, and used the relevant FIA plot measurements to assign a condition. Preliminary results estimate considerably more longleaf pine area than previous estimates based on FIA forest-type, though this likely is an overestimate from including plots where longleaf ecosystems are not desired. Despite the need for further refinement, this approach shows promise in characterizing existing condition based on the best available science using the most robust data available.

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Supporting the USFS WUI Research Agenda

SUPPORTING THE U.S. FOREST SERVICE WILDLAND-URBAN INTERFACE (WUI) RESEARCH AGENDA: FRAMING THE SESSION

Miranda Mockrin, Kurt Riitters
USDA Forest Service

The wildland-urban interface (WUI), that area where houses meet or mix with undeveloped natural areas, is widespread and growing rapidly. As of 2010 the WUI covered 9.5 percent of the conterminous United States and included 33 percent of all homes. From 1990 to 2010, the WUI expanded by more than 189,000 km^2, an area larger than Washington State. We know that WUI expansion in the United States occurs overwhelmingly as a result of housing growth, but we lack a comprehensive understanding of ecological and social conditions within the WUI. Much of the current research and management focuses on wildfire risk, but the WUI is widespread, including in areas that are not fire-prone, and the ramifications of residential development on natural resources extend far beyond implications for wildfire management. As the national inventory of forest extent and conditions, the FIA Program is well positioned to provide additional insight into forest conditions, invasive species distribution, carbon sequestration benefits, and family forest owners within the WUI. This broad perspective on datasets, WUI conditions, and management issues will contribute to a national assessment of WUI research being conducted by the Washington office of Forest Service Research and Development.

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WILDLAND-URBAN INTERFACE (WUI) ANALYSIS USING DATASETS RELATED TO URBANIZATION AND FRAGMENTATION OF FOREST LAND

Rachel Riemann, Miranda Mockrin, Kurt Riitters
USDA Forest Service, Northern Research Station—
Forest Inventory and Analysis (FIA)

Urbanization and fragmentation are dominant forest stressors with substantial ecological, economic, cultural, and human health implications and they are particularly relevant in the wildland-urban interface (WUI). They reduce forest ecosystem resilience in the face of stresses associated with climate change, and in the face of increasing human demand for processing (air/water pollution), use (recreation), and extractive ecosystem services (timber, nontimber and wildlife forest products). Measuring and monitoring the status and change in forest fragmentation, urbanization, and landscape conditions has become an invaluable tool in both understanding the impacts of these stressors and characterizing their nature and extent. This information has become vital for planning, management decisions, predicting future impacts, and policy development at all scales. Much work has gone into selecting and fine-tuning a series of geospatial datasets to characterize the fragmentation, urbanization, and landscape context associated with forest land in the United States. We describe these datasets, how they fit together, and report on what they have been able to tell us about the WUI.

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USING FIA PLOT DATA TO CHARACTERIZE FOREST IN THE WILDLAND-URBAN INTERFACE (WUI)

Nancy F. Sonti, Rachel Riemann, Miranda H. Mockrin
USDA Forest Service, Northern Research Station

The wildland-urban interface (WUI) is rapidly expanding into forested areas across the United States, leading to widespread forest fragmentation. Forest Inventory and Analysis (FIA) data can be used to characterize forest in the WUI, and to examine whether WUI forest conditions are different from wildland forest that remains outside the WUI. Based on FIA data circa 2013, 16 percent of total forest land area in the conterminous United States was in the WUI, of which one-third became WUI since 1990. In this presentation, we explore differences in forest structure and species composition between areas that are outside the WUI (wildland forest), that have been in the WUI since 1990 (persistent WUI), or that have more recently been characterized as WUI (since 1990). Is the WUI associated with certain forest types or stand size and how might that relationship vary by region? We also look at patterns in forest ownership among these WUI classes, finding that WUI is more likely to develop on private or local public lands rather than State or federal lands. Finally, we highlight regional differences in these trends across the Northern Research Station geographic footprint impacted by a combination of ecological and social drivers.

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DOES THE WILDLAND-URBAN INTERFACE (WUI) PREDICT INVASIVE PLANT OCCURRENCE ON FIA PLOTS?

Cassandra M. Kurtz, Kurt H. Riitters, Rachel Riemann
USDA Forest Service

Invasive plants are spreading across ecosystems causing concern and threatening the future environment. We explored the occurrence of invasive forest plants on FIA plots in the Eastern United States in relation to the wildland-urban interface (WUI) class which contained the plots, with and without adjusting for site and landscape variables known to influence invasion rates. "Invasion" was defined as the presence of at least one individual of any invasive plant species. Compared to an overall invasion rate of 58 percent, a smaller rate (38 percent) was observed only for plots in WUIs that were uninhabited and dominated by natural vegetation, and the highest rates (~85 percent) were observed in the WUI classes with low- to medium-housing density that were not dominated by natural vegetation. To account for potentially confounding effects of ecological province, site quality, forest cover fragmentation, and distance from road, we used logistic regression to estimate adjusted odds of invasion among four housing density classes and two classes of natural vegetation dominance. The results indicated that both housing density and natural vegetation dominance are strong predictors of the occurrence of invasive forest plants on FIA plots.

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FAMILY FOREST OWNERS ALONG THE URBAN-RURAL SPECTRUM

Jacqueline S. Dias, Emma M. Sass, Brett J. Butler
University of Massachusetts

Family Forest Owners (FFOs) hold a plurality of forest land in the United States. Much of this land falls within the Wildland-Urban Interface (WUI), the intersection of housing density and wild vegetation. FFOs living in areas of high housing density (i.e., urban areas) face different pressures and decisions compared to those living in rural areas, and the WUI classifications allow for comparison of dynamics along a gradient within this critical area. As land continues to be developed and the WUI expands to new areas, it is important to understand who the landowners are in these areas and how they plan for and manage their land. Using data from the U.S. Department of Agriculture, Forest Service National Woodland Owner Survey, we can contextualize landowner responses within the WUI landscape. We analyze a range of FFO characteristics and behaviors to quantify how they vary across the WUI, including recreational use, forest management, and demographics.

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TOWARD ESTIMATING CARBON STOCKS AND STOCK CHANGES ACROSS THE WILDLAND-URBAN INTERFACE

Grant M. Domke, Rachel Riemann, Brian F. Walters
USDA Forest Service

This is for an organized session on WUI coordinated by Rachel Reimann and others.

Carbon sequestration from live trees in forests, woodlands, and settlements in the United States offsets more than 7 percent of total greenhouse gas emissions each year. How much of this carbon is sequestered and stored in the wildland urban interface (WUI)? How are total carbon stocks distributed across the ecosystem pools within the WUI and on the margins of these landscapes? How are carbon stocks and stock changes within the WUI quantified in national reports? This study combines Forest Inventory and Analysis (FIA) data with auxiliary information to estimate ecosystem carbon stocks and stock changes within and beyond the WUI with particular emphasis on carbon dynamics associated with land change. We will describe how FIA data and auxiliary information were used to classify the WUI and estimate carbon stocks on forest land, woodlands, and settlements. We will also point to future research needs to better characterize carbon stock changes in these dynamic landscapes.

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Understanding Landscape Change Using FIA Data

ICE—LAND USE, LAND COVER AND AGENT OF CHANGE DATA FOR NATIONAL FOREST SYSTEM (NFS)

Jack Triepke, Kevin Megown
USDA Forest Service

The U.S. Department of Agriculture, Forest Service has invested in measuring land use, land cover and agent of change using the National Agricultural Imagery Program (NAIP) imagery source—the Image Change Estimation (ICE) project. The information provided from the ICE project is unique to supporting multiscale monitoring designs. The ICE project provides information to Forest Service Research and Development, State and Private, and National Forest System (NFS) Deputy Areas. Key support and reliance comes from the Forest Inventory and Analysis (FIA) program; using the FIA plot locations allows for design based estimators, LU/LC/AC data to be estimated on all lands, supports consistent/unbiased intensification across all lands, allows for monitoring change on permanent plots, and is nationally implemented. The NFS uses of ICE measures allows for temporal measures forward through time. As the Forest Service scans its historical aerial photos, the ability to measure land use, land cover, and change agent estimates back through time supports tracking supporting a historical context through multiple decades. This talk discusses a project utilizing historical scans of the NFS Region 3, Lincoln National Forest, implications for NFS, and practical methods used to support ICE measurements of the Forest Service scanning their historical imagery.

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USING BIANNUAL CHANGE DETECTION MAPS FOR PRESTRATIFICATION OF PHOTOINTERPRETED SURVEY SAMPLES FOR AREA CHANGE ESTIMATION

Andrew J. Lister, Sean Healey, Zhiqiang Yang, Thomas Weber, Mark Finco, Gretchen Moisen, Todd Schroeder, James Westfall
USDA Forest Service, Forest Inventory and Analysis Unit

Monitoring land use and land cover change with ground plots or remote sensing is important to environmental managers and policymakers. With estimates directly from maps, traditional uncertainty indices are difficult to interpret through the lens of sampling theory. Estimates from design-based ground plot samples are interpretable using sampling theory, however they can be more expensive and are not wall-to-wall. The current study seeks to leverage the strengths of remote sensing- and plot-based area change estimation. For a forest inventory survey unit in Georgia, Landsat-based biannual change maps derived through time series analysis were used to prestratify plot data on cover change class derived from Landsat temporal signature graphics assembled using the TimeSync software. The goal of the project was to assess the accuracy of the biannual change product, produce corrected area estimates of change from that product, and assess the feasibility and costs of using this method for operationally producing biannual change estimates. Results will be presented and implications for the U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis business practices will be discussed.

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A COMPARISON OF LAND USE OBSERVATIONS FROM IMAGE-BASED CHANGE ESTIMATION AND FOREST INVENTORY AND ANALYSIS

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Abstract

Image-based Change Estimation (ICE), which involves visual interpretation of high-resolution imagery at U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis (FIA) plot locations, is a relatively new photointerpretation project created by the FIA program. Land use class is among the variables collected as part of ICE, and it is also collected on the FIA plots. In the current paper, I compare results from both FIA and ICE. The major result is that the area estimates by use class are very similar at the State level. Overall agreement ranges from 66 percent of all plots common to both datasets in Connecticut to 96 percent of such plots in the U.S. Virgin Islands. Agreement is higher among plots that were photo interpreted (such as large surface water and cropland belts) and in homogeneous areas (such as dense forest). Agreement for plots with multiple use conditions is improved when looking at only plot centers. The length of time between the FIA measurement date and ICE photography date explained relatively few disagreements.

Keywords: forest inventory, Image-based Change Estimation, land use, monitoring, photo interpretation.

INTRODUCTION

Anderson and others (1976) famously suggested a land use classification system consisting of Urban or Built-up Land, Agricultural Land, Rangeland, Forest Land, Water, Wetland, Barren Land, Tundra, and Perennial Snow or Ice. In so doing, they cited the work of Frey (1973) to show how much of each type there was, which is what policymakers and interest groups want to know. Frey himself cites land use data compiled as early as 1900. By 2001, Vogelmann and others (2001) had completed the National Land Cover Data Set for the Conterminous United States using Landsat data. Morgan and others (2010) point out the strengths and weaknesses of manual interpretation of land use versus pixel-based classifiers.

Image-based Change Estimation (ICE), which involves visual interpretation of high-resolution imagery at U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis (FIA) plot locations, is a relatively new photointerpretation project created by the FIA program. Land use class is among the variables collected as part of ICE, and it is also collected on the FIA plots.

The intended cycle length of FIA is 7 years in the Eastern United States (which may be brought down to 5 years) and 10 years in the Western United States. However, the cycle can take longer; for example, this paper uses an 8-year cycle length in North Carolina and a 14-year cycle length in Texas. ICE is based on National Agriculture Imagery Program (NAIP) photography, which has had a 2–3-year cycle length since 2008.

It is not clear how differences in interpretation quality or definitions might affect land use estimates derived from ICE. Therefore, it is important to address this problem by doing an assessment of differences. The objective of this study is to match plots in ICE with the same plots in FIA and see how good the agreement is.

For the purposes of this paper, there are five major land uses: Forest, Agriculture, Developed, Other, and Water. Agriculture includes Rangeland, a very rare type in the Eastern United States, as

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well as Other Treed Land, a designation formerly used in western Texas (Burrill and others 2018). Other includes Wetland, Barren, and Tundra, as well as Chaparral (which might well have been considered Rangeland under Anderson and others [1976]). Water includes Perennial Snow or Ice.

Data

The comparison data were assembled from the FIA Database (FIADB) and ICE data. See Burrill and others (2018) for details on FIADB. FIADB is a mixture of photo-interpreted images and field visits, while ICE is purely photointerpretation. ICE (Bakken 2018) and FIADB have similar categories for land use, but FIADB is more detailed. For instance, “Agricultural Woody Cropland” is one category in ICE, but in FIADB it is reported as “Orchard” and “Christmas Tree Plantation.” The ICE equivalent of Nonresponse is Uninterpretable; however, this code is very rarely used.

ICE plots were matched to FIA plots. The intention is that plot centers are the same, but there is some error in collecting plot coordinates. ICE was intended to estimate change, so there are two dates of photography. FIA plots were matched to the nearest ICE date. An overview of the data is shown in table 1. In Texas, most of the commercial and recreational forest is in the eastern part of the State; those plots are on a 7-year cycle. The western part of the State has mostly scrub forest; those plots are on a 10-year cycle but it took 14 years to complete them. ICE dates for both parts of the State were 2010 and 2014. FIA plots collected before July 2012 were matched to the 2010 date; those collected after June 2012 were matched to the 2014 date. In eastern Texas, there was no more than a 2-year difference between the FIA measurement date and the ICE date, with an average of 1.6 years. In western Texas, there was no more than a 6.1-year difference between the FIA measurement date and the ICE date, with an average of 1.9 years. The States listed in table 1 are the first States in the ICE program to be processed. Other States have had ICE data collected but not yet processed.

Plot footprints differ between ICE and FIA. The FIA plot footprint consists of four 24-foot subplots

Table 1—Dates and time differences of Forest Inventory and Analysis (FIA) and Image-based Change Estimation (ICE) data collection

State	MEASYEAR	ICE1	ICE2	Average difference *(years)*	Maximum difference *(years)*
California	2006–2017	2005	2014	2.2	4.5
Connecticut	2011–2018	2014	2016	1.0	3.3
Georgia	2004–2011	2005	2010	1.3	2.5
New Hampshire	2010–2015	2012	2014	0.8	2.4
North Carolina	2008–2016	2012	2014	1.2	3.5
Rhode Island	2011–2018	2014	2016	1.0	3.0
Texas	2004–2018	2010	2014	1.9	6.1
Eastern Texas	2009–2016	2010	2014	1.6	2.0
Western Texas	2004–2018	2010	2014	1.9	6.1
Utah	2008–2017	2011	2014	1.5	3.5
Vermont	2010–2015	2012	2014	0.8	2.3
Wisconsin	2010–2016	2013	2015	0.9	2.8
Puerto Rico	2011–2015	2017	2018	4.0	6.4
U.S. Virgin Islands	2014–2014	2017	2018	3.0	3.0

MEASYEAR = years during FIA measurement cycle; ICE1 = first date of ICE photography; ICE 2 = second date of ICE photography.

120 feet apart laid on a wye (Shepherdson 1924) pattern. A plot footprint may be found in Bechtold and Patterson (2005). The ICE footprint consists of 1, 5, or 45 dots. The one-dot configuration was used in Georgia for a plot with no change. Elsewhere the five-dot configuration was used for plots with no change. One dot is at the center, and the other four are near the edge of the plot, 90 degrees apart. The 45-dot configuration is a 7×7 square with the corners cut off. Depictions of the plot footprints may be found in Bakken (2018). Due to magnetic declination and chaining issues, an outer FIA subplot cannot be guaranteed to line up with an outer ICE dot.

Another difference is that in ICE reports, plots are weighted equally. In FIADB, plots are weighted according to the stratum size divided by the number of plots in the stratum; usually, strata are derived from the National Land Cover Database (NLCD) Canopy Cover layer, but there may be other layers involved in constructing strata.

The number of plots in FIADB and ICE are not necessarily the same. There may be Water plots in FIADB not done in ICE, on the theory that those plots are not going to change. There may be intensifications in FIADB not done in ICE. Nonresponse in FIADB is much more common than Uninterpretable photography in ICE.

FIA plots are reviewed in the office by prefield photo interpreters. If a plot is obviously nonforest, a land use call is made and the photo interpreter goes on to the next plot. If a plot might be forested, it is sent to the field crews for a ground check. Plots sent to the field consist of one or more conditions. A condition is a fraction of a plot. For instance, if three subplots are Forest and one is Developed, the condition proportions (CONDPROP_UNADJ) are 0.75 and 0.25. Each dot in ICE gets a land use call: for instance, Forest, Farmland (for the purposes of this paper that category has been generalized to "Agriculture"), or Developed. Different land use calls on the same plot give rise to "conditions" on ICE plots. An ICE plot with three dots in Forest and two in Developed would have condition proportions of 0.6 and 0.4. Plots not sent to the field are assumed to have one condition, and consequently one generalized land use. A summary of the differences between ICE and FIA is shown in table 2.

METHODS AND RESULTS

Statistical independence is assumed for conditions on the same plot. The Forest-Forest agreement for the hypothetical plot just mentioned would be 0.45, and the Developed-Developed agreement would be 0.10. The actual agreement is likely higher (due to the results) but could be lower.

Table 2—Summary of methodological differences between Forest Inventory and Analysis (FIA) and Image-based Change Estimation (ICE)

Attribute	FIA	ICE
Data	Mixture of photointerpretation and field visits	Photo interpretation
Land use	More detailed (Cropland, Pasture, etc.)	Less detailed (Farmland, etc.)
Conditions	Condition boundaries are drawn by field crews Photo interpreters generalize to one condition	Percentage of dots in each land use by plot forms a condition
Plot footprint	Four 24-foot circles inside a 1.5-acre circle	1, 5, or 45 dots inside a 1.5-acre circle
Weight	Stratum size divided by number of plots in the stratum	Systematic sample treated as simple random

A confusion matrix is computed from the data by equation (1). Matrices A and B can be, and usually will be, sparse. Plots do not have every land use on them.

$$m[x,y] = \sum_{p=1}^{P} \sum_{i=1}^{K(p)} \sum_{j=1}^{K(p)} a[p,i,x] \times b[p,j,y] \quad (1)$$

where

$m[x,y]$ = the number of plot-equivalents in ICE land use x and FIA land use y

$a[p,i,x]$ = the condition proportion for ICE condition i on plot p in land use x

$b[p,j,y]$ = the condition proportion for FIA condition j on plot p in land use y

P = the number of plots in the area of interest

$K(p)$ = the number of conditions on plot p

$\times$ = ordinary multiplication, not matrix multiplication.

The major finding was that for every State and every land use, the marginal distributions came very close to matching. That is, the row totals of the confusion matrix nearly equal the column totals of the confusion matrix; this implies that even in the face of misclassification within a land use class, the population-level estimates of class proportions from both methods are very similar. Marginal distributions are depicted in a scatterplot in figure 1. The largest disagreement is Forest in Utah, with 36 percent of the plots

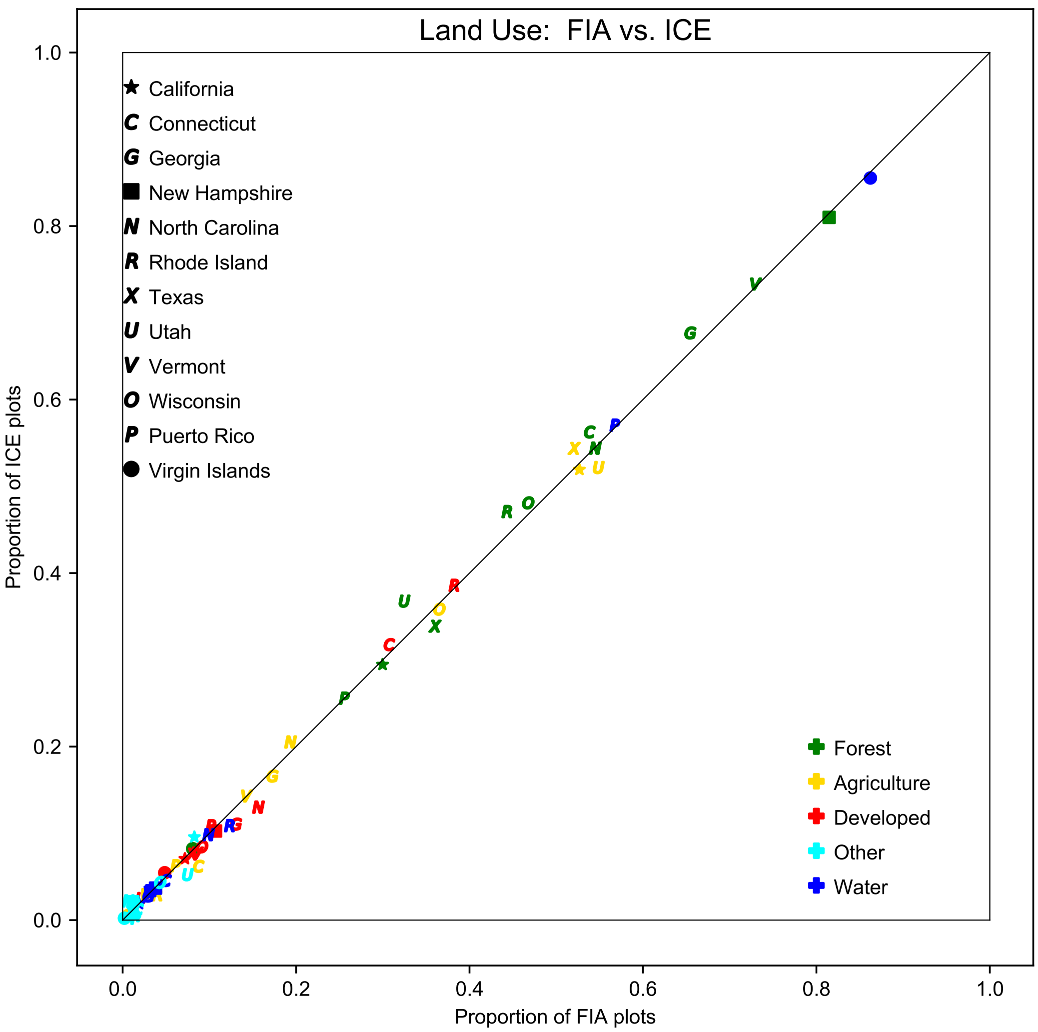

Figure 1—Marginal proportions of land use: proportions of Forest Inventory and Analysis (FIA) plots vs. Image-based Change Estimation (ICE) plots (all data).

common to both datasets being Forest in ICE but only 32 percent of them being Forest in FIADB. There are many States with land uses comprising <13 percent of the landscape, so figure 2 shows the land uses for those cases. We see that in a relative sense, the agreement for the Other type is poor; however, it forms a very small portion of the overall landscape.

A sample matrix *M* (for North Carolina) is shown in table 3. The on-diagonal observations in table 3 represent perfect agreement, and the off-diagonal entries represent misclassification.

I used Teufel's F-statistic (Teufel and Moens 2002) to define agreement for a land use:

$$A = \frac{2m_{ii}}{\sum m_{i\cdot} \sum m_{\cdot i}} \tag{2}$$

where

A = the agreement

m_{ij} = the component of the confusion matrix in the ith row and jth column (Note that m_{ii} is a special case of m_{ij}; $m_{i\cdot}$ and $m_{\cdot i}$ imply j.)

For instance, agreement on Forest in North Carolina was 2 × (2703.94) / (3113.46 + 3121.70) = 87 percent.

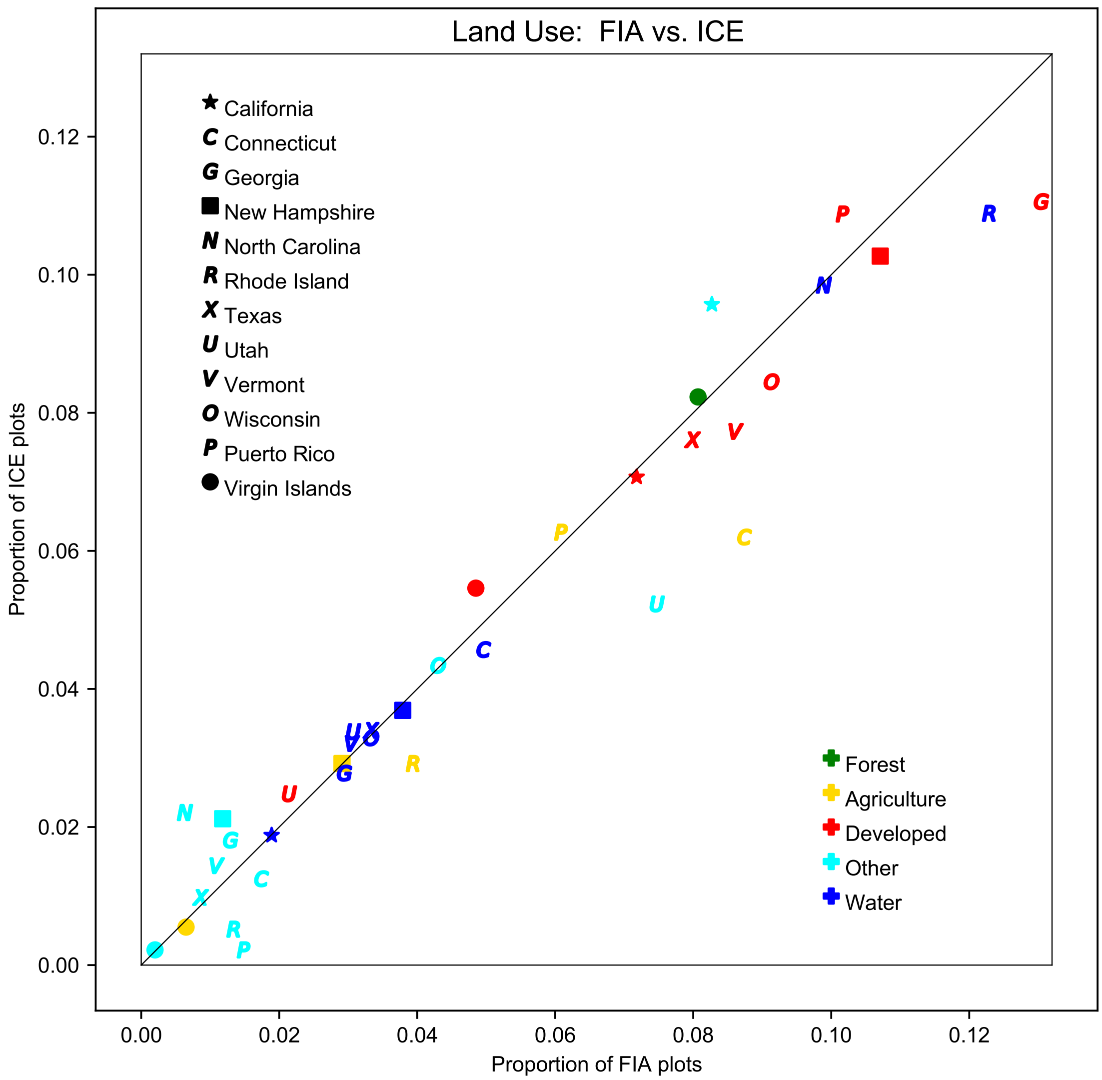

Figure 2—Marginal proportions of land use: proportions of Forest Inventory and Analysis (FIA) vs. Image-based Change Estimation (ICE) (small land uses).

Table 3—Confusion matrix showing agreement between Image-based Change Estimation (ICE) and Forest Inventory and Analysis (FIA) for North Carolina (number of plots)

Land use	Forest	Agriculture	Developed	Other	Water	FIA total
Forest	2,703.94	131.72	257.63	3.43	16.75	3,113.46
Agriculture	213.56	881.44	82.68	1.08	2.08	1,180.84
Developed	109.60	87.29	549.17	0.16	2.86	749.07
Other	83.53	2.69	4.84	25.68	10.53	127.26
Water	11.08	4.90	6.62	7.03	535.61	565.24
ICE total	3,121.70	1,108.04	900.94	37.37	567.83	5,735.89

Conventions on box plots vary. Figures 3 and 4 were made with the R statistical computing language (R Core Team 2018). The line in the middle of the box is the median. The top of the box is the third quartile. The bottom of the box is the first quartile. The top whisker is the highest data point less than or equal to the third quartile plus 1.5 times the interquartile range. Similarly the bottom whisker is the lowest data point greater than or equal to the first quartile minus 1.5 times the interquartile range. If there are no data points between the quartile and the whisker, the whisker is not shown, as in the Agriculture box in figure 3. If there are any data points outside the whiskers, they are shown with small circles.

Figure 3 gives an insight on the joint distribution by land use. Agreement on Forest was near 90 percent, ranging from 95 percent in the U.S. Virgin Islands to 75 percent in Connecticut. Agreement on Agriculture was closer to 80 percent, ranging from 88 percent in Wisconsin to 25 percent in Rhode Island, with the U.S. Virgin Islands and Connecticut showing poor agreement as well. Agreement on Developed was about 70 percent, ranging from 84 percent in the U.S. Virgin Islands to 60 percent in Utah. Agreement on Other was about 40 percent with a wide range from 79 percent in Georgia to 0 percent in the U.S. Virgin Islands. We can see that Other is usually a small class, comprising no

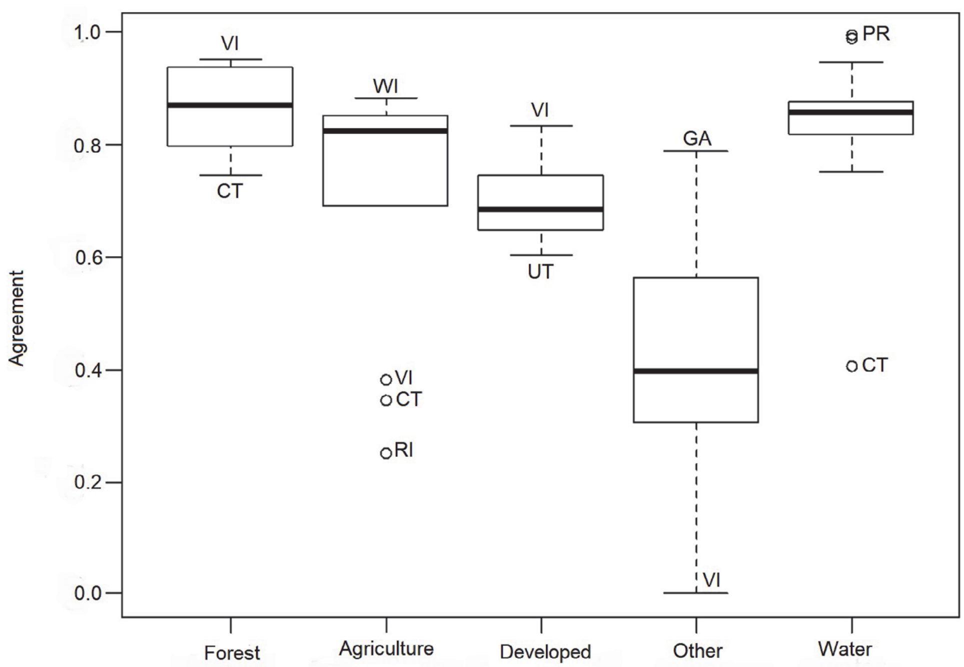

Figure 3—Forest Inventory and Analysis (FIA) vs. Image-based Change Estimation (ICE) agreement, by land use.

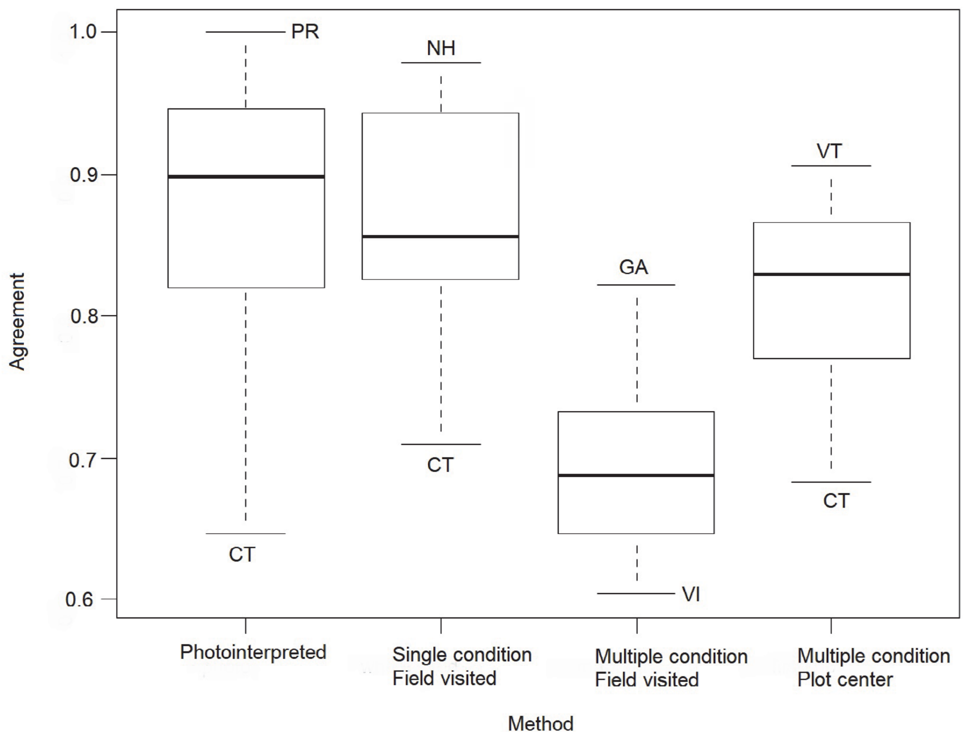

Figure 4—Forest Inventory and Analysis (FIA) vs. Image-based Change Estimation (ICE) agreement, by method of data collection.

more than 10 percent of the landscape (California had 8.3 percent in FIADB and 9.6 percent in ICE) but usually much less. Finally, agreement on Water was about 90 percent, ranging from 99 percent in Puerto Rico to 40 percent in Connecticut. Ocean plots were done in the Forest Service Southern Research Station but not in the Northern Research Station. We further see from figure 1 that Water consists of nearly 60 percent of the landscape in Puerto Rico. Meanwhile, Water in Connecticut consists of only lakes and streams.

Figure 4 shows agreement by the method of data collection. The first box plot shows agreement for plots that were photo interpreted by FIA in the office and not sent to the field. Here there is about 90 percent agreement, ranging from 100 percent in ocean-dominated Puerto Rico to 65 percent in highly fragmented Connecticut. There is only one condition on an FIA plot called in the office, so all the fragmentation is due to multiple land uses on ICE plots. The next box plot shows agreement for plots that were sent to the field but consisted of a single condition. Here there is 85 percent agreement, ranging from 98 percent in heavily forested New Hampshire to 71 percent in fragmented Connecticut. Once again, all the fragmentation is due to multiple land uses on ICE plots. The next box plot shows the agreement for plots that were sent to the field but consisted of more than one condition. Here the agreement was about 70 percent, ranging from 82 percent in Georgia to 60 percent in Rhode Island. There could be multiple land uses on the ICE plot, the FIA plot, or both. The final box plot shows agreement for plot center for the FIA plots with multiple conditions. Results were comparable to those for single-condition plots, ranging from 91 percent in Vermont to 68 percent in Connecticut.

Table 4 shows that the time difference between the FIA measurement date and the ICE date makes little difference. Plots collected in the same year as the ICE photography had about the same level of agreement as the entire cycle. The only area in which there was a significant difference was in Texas, and that was due to the large number of plots and the difficulties in interpreting western Texas. Utah had a similar absolute difference but with half as many plots, the result

Table 4—Effect of time on overall agreement between the Forest Inventory and Analysis (FIA) measurement date and the Image-based Change Estimation (ICE) date

State	Plots[a]	Agreement (t < 1 year)	p-value	Agreement (*cycle*)
California	1,602.66	0.8085	0.5446	0.8096
Connecticut	167.00	0.6541	0.5476	0.6585
Georgia	1,393.75	0.8978	0.6163	0.9002
North Carolina	1,542.00	0.8165	0.5922	0.8188
New Hampshire	320.50	0.9076	0.4630	0.9061
Rhode Island	32.75	0.7334	0.5249	0.7382
Texas	4,277.86	0.8302	0.0011	0.8127
Eastern Texas	1,066.50	0.8824	0.3026	0.8773
Western Texas	3,211.36	0.8129	0.0369	0.8006
Utah	1,720.95	0.8248	0.1047	0.8133
Vermont	337.00	0.8840	0.7109	0.8937
Wisconsin	1,906.39	0.8534	0.7233	0.8582

[a] Plots = number of plot equivalents completed within a year of the ICE date; fractions are due to nonresponse.
No plots were completed in the same year as ICE photography in Puerto Rico or the U.S. Virgin Islands.

was not significant. There were no plots in Puerto Rico or the U.S. Virgin Islands collected within 1 year of the ICE measurement date.

CONCLUSIONS

At the State level, marginal proportions of major land uses in ICE and FIA are nearly equal. This result may not hold true at the survey unit or county level. For instance, in table 3, 83 plots in North Carolina were called Other in ICE which had been called Forest in FIA. Most of these plots were herbaceous wetland, in the eastern part of the State. These plots were balanced out by plots that were called Forest in ICE which had been called Developed in FIA. Most of these plots appear to be low-density residential plots in the central and western part of the State. However, each State tells its own story. Georgia had an 80 percent agreement in the Other category while North Carolina's agreement in this category was only 31 percent. It appears photo interpreters in Georgia were much better at distinguishing forest from herbaceous wetland than they were in North Carolina.

ICE photo interpreters agreed with FIA photo interpreters better than they agreed with FIA field crews. It might be useful for photo interpreters to have feedback sessions, with each other and with field crews, to discuss why they made the calls that they did.

This study does show the difference in business rules from one station to the next. The Southern Research Station does ocean plots; the Northern Research Station does not do ocean or Great Lakes plots. In the interest of completeness, the Pacific Northwest Research Station did ocean plots in FIA but not in ICE; the Rocky Mountain Research Station did plots in the Great Salt Lake in both FIA and ICE.

Marginal proportions of land uses in a State change slowly. However, since it took 14 years to complete one cycle of western Texas and 11 years in California, and NAIP takes new photography every 2 to 3 years, ICE could be an effective way of updating estimates in the Western United States.

Matching multiple conditions on an FIA plot with ICE dots is problematic. Possibly conditions could be drawn on the 144-foot circle instead of each subplot; possibly all plots could be oriented to true north rather than magnetic north.

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TESTING FOR TEMPORAL CHANGE IN FOREST INVENTORY AND ANALYSIS PROGRAM (FIA) DATA USING THE DIFFERENCE TESTER ON THE WEB

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Online analytical tools from Forest Inventory and Analysis (FIA) provide current inventory and change estimates that guide management and policy decisions for our Nation's forest resources. A broad range of temporal comparisons are of interest to analysts. For example, an increase in the number of standing dead trees can indicate a forest health issue. Often, these comparisons have covariance because the estimates are derived from observations on the same plots over time (not independent). Hypothesis testing for statistically significant differences should account for covariance but FIA tools to date have not offered this benefit. A new online tool called Difference Tester (https://apps.fs.usda.gov/Evalidator/diftester.jsp and https://apps.fs.usda.gov/Evalidator/diftesterratio.jsp) accounts for covariance when comparing total and per acre estimates of a chosen attribute between two consecutive inventory cycles. A calculated z-score and p-value indicate the likelihood that a difference is different from 0 (no difference). Failure to include covariance in statistical tests can foster incorrect conclusions and poor management decisions.

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PROXIMATE CAUSES OF FOREST LOSS 2001–2011 IN A LANDSCAPE MOSAIC CONTEXT

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USDA Forest Service, Southern Research Station

The areas of forest loss are of concern for many Earth System applications. Equally important are changes in the spatial arrangement of forest. To really understand these dynamics and their proximate causes and landscape context is invaluable. Here we use two dates of the new epoch of National Land Cover Database (NLCD) land cover change maps, 2001 and 2011, to analyze changes in gross and interior forest. We combine these metrics with signals, measured in 4.41-ha neighborhood, of proximate causal processes. NLCD maps provide land cover change classes and North American Forest Dynamics (NAFD) attribution maps provide classification of fire, harvest, and insect/stress for forest canopy cover loss events nationally (CONUS). Annual NAFD attribution data are subset to the same 2001–2011 period for analysis. An advantage of this neighborhood approach is that it alleviates many of the issues related to per-pixel map comparisons. We discuss variations in changing forest patterns and proximate causes across the Resources Planning Act (RPA) regions and Landscape Mosaic categories, which locates and measures dominant land cover and the degree of land cover heterogeneity at a specified scale.

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CLASSIFICATION OF SATELLITE TIME SERIES PARAMETERS INSTEAD OF INDIVIDUAL IMAGES SUPPORTS TEMPORALLY COHERENT MODEL-ASSISTED ESTIMATION AT ANNUAL TIME STEPS

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IW FIA

There are mature methods for using maps to support design-based estimation of forest characteristics. An obstacle to applying these model-assisted methods every year is the lack of temporally coherent maps. When land cover models are applied to individual images from a series of years, image noise makes it likely that cover class will fluctuate implausibly through time. This causes big problems for model-assisted change estimates.We produced the first national time series analysis of the Landsat satellite record (1985–2018), using the continuous change detection and classification (CCDC) algorithm. This analysis fits harmonic functions to all cloud-free acquisitions for each pixel (1000+ images), allowing us to see beyond image-specific noise. Parameters of these functions remain the same until a land cover change is detected. Applying models to time series parameter makes map calls both more accurate by accounting for the entire growing year and more stable between detected changes.We demonstrate the use of time series analysis to support design-based inference by estimating the area of tree cover over time for major regions of the United States, combing CCDC-based maps of tree cover with a national-scale random sample of tree cover history collected using the TimeSync tool.

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MONITORING CHANGE IN THE PACIFIC ISLANDS: NONTRADITIONAL ESTIMATES OF CHANGE

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Pacific Northwest Station (PNW) Forest Inventory and Analysis (FIA) has measured the forest in the U.S. affiliated Pacific Islands [American Samoa, Guam, Republic of Palau, Commonwealth of Northern Mariana Islands (CNMI), Federated States of Micronesia (FSM), and Republic of the Marshall Islands (RMI)] since 2001 and recently completed a full remeasurement of these surveys. Apart from changes in food crops (e.g., change in number of Coconut trees), interest in traditional FIA components of changes (growth, removals, and mortality) is very limited. However, monitoring changes in forest structure and biodiversity as well as any increases of invasive species are of paramount interest. The Micronesia Challenge (www.miconesiachallenge.org) is a commitment by Palau, FSM, RMI, Guam and CNMI "to conserve at least 30 percent of the near-shore marine resources and 20 percent of the terrestrial resources across Micronesia by 2020". In 2013, the Micronesia Conservation Trust started to fund the collection of additional plots in order to monitor the progress of conservation efforts.While the FIA database structure is designed to allow the estimation of the traditional components of change, it can also be used to estimate change in forest structure, biodiversity, as well as changes in invasive species.

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COSTA RICA'S LAND USE, LAND COVER, AND ECOSYSTEMS MONITORING SYSTEM (SIMOCUTE)

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Costa Rica implemented a National Forestry Inventory (NFI) in 2014 as part of its MRV processes. This inventory was implemented by the Costa Rica's forest office. Among others products, the NFI generated a systematic grid (SG) of points. Field plots were established on a subset of these. The SG has formed the basis of the country's National Land Use, Land Cover, and Ecosystems Monitoring System (SIMOCUTE). SIMOCUTE aims to be the country's official platform for coordination and institutional and sectoral integration, to facilitate the management and distribution of information and data related to the country's land use, land cover, and ecosystems. In addition to the NFI, SIMOCUTE includes a mapping subsystem and a land use and land cover monitoring system based on photo-interpreting these attributes from the grid of points. The latter subsystem generates tabular estimates of the areas of the country's different land uses and land covers, and changes in them through time. This work presents the state of progress of SIMOCUTE in Costa Rica, emphasizing the use of tools such as Collect Earth Online, the image-based change estimation tool and Forest Inventory ESTimation and Analysis, an R package developed by the U.S. Forest Service.

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DEVELOPING COUNTY-LEVEL HARVEST AND CONVERSION RATES FOR SOUTHEASTERN FORESTS USING LANDSAT TIME SERIES AND U.S. FOREST INVENTORY AND ANALYSIS (FIA) PLOTS

Todd A. Schroeder, Nicholas N. Nagle, Brooke Rose, Karen Schleeweis, Gretchen G. Moisen, Andrew J. Lister
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Known as the Nation's "wood basket", the Southeastern United States contains some of the most biologically diverse and dynamic landscapes in the country. In order to help sustainably manage the effects of forest management reliable estimates of harvest area and volume are needed at spatial and temporal resolutions that are typically smaller than what FIA's plot sample alone can reliably address. Remote sensing techniques, particularly the use of Landsat time series algorithms, have surfaced as an effective way to map the location, extent, and timing of forest harvest activities and other types of disturbance. In this study Landsat disturbance maps and time series metrics are used to develop Fay-Herriot small-area estimation models to predict annual harvest and conversion (i.e., loss of forest to nonforest use) rates for 67 counties in Georgia from 1986 to 2010. Results are used to discuss the advantages of using agent specific predictor variables, as well as the benefits of combining remote observations with FIA plots to improve annual estimation of rare events. The potential for using county-level harvest estimates in timber products studies, FIA reporting, and other applications are also discussed.

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PHOTO-BASED OR PIXEL-BASED CHANGE ESTIMATION?

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Interior West—Forest Inventory and Analysis

Aerial photography may be used to estimate change within a landscape. This involves establishing a base sample of photo-plots and interpreting the characteristics of a grid of points within each of the photo-plots. The points within the photo-plot give an estimate of the proportion of the change categories on photo-plot; which are combined for the overall estimate. In many situations (REDD+) when using the base sample, the precision estimates of the change categories are not sufficient. Another method to estimate change is to create a disturbance map (e.g., from the Landsat stack), then using a probability sample of the pixels evaluate the pixel level accuracy of the map, and finally using the accuracy assessment output construct an estimate of the proportion of each change category. A sample size based method for increasing the precision of the photo-based estimates will be presented. This will be followed by a discussion of the statistical and technical properties of the photo-based and pixel based methods.

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DEVELOPING FIA SURVEY WEIGHTS WITH HIGH SPATIAL AND TEMPORAL RESOLUTION BY CALIBRATION TO LANDSAT TIME SERIES

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FIA's plot sample is not designed for the spatial and temporal resolution of annual, wall-to-wall maps or small area estimates. While many auxiliary data are available for calibrating FIA survey weights to small domains, many of these auxiliary data are collinear or noisy, making it difficult to use standard survey weighting approaches. A penalized maximum entropy approach is presented for survey weight generation. Like least absolute shrinkage and selection operator (LASSO), this approach allows the efficient use of collinear and noisy auxiliary variables. Compared to LASSO, the penalized maximum entropy has the desirable property of producing non-negative survey weights, but does not possess the same desirable sparseness properties as LASSO. We demonstrate the application of this method to produce a time series of survey weights for 67 counties in Georgia that are calibrated to Landsat time series that have been categorized using a recently published non-linear, trajectory fitting algorithm. Although entropy-based design weights are slightly less precise than LASSO, they can be used with multiple forest attributes to produce estimates which are internally consistent such that sub-populations sum to larger regions, and tabular estimates match spatial estimates.

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COMPARING AND COMBINING OBSERVATION SYSTEMS FOR LAND USE AND LAND COVER CHANGE IN GEORGIA

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FIA has access to a variety of observation systems for understanding land use and land cover change in the United States. There is the network of ground plots, photo-based observations collected through Image-based Change Estimation (ICE) methodology, Landsat-based observations collected through Timesync, as well as a variety of change map products. Using data collected in the north central section of Georgia, we compare how four sources of land use and land cover change information differ in terms of the “story” they tell about land use and land cover dynamics. That is, for each of the observation systems we assess the ability to detect net and transitional change estimates through time that are statistically different than zero, as well as trends that are significantly increasing or decreasing. We also explore ways in which these four sources can be combined through model-assisted estimation methods, as well as through logistically harmonized systems, to produce the best information with an eye toward cost.

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DISTRIBUTIONAL SHIFTS OF REGIONAL FOREST COMMUNITIES IN THE EASTERN UNITED STATES

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The impact of climate change on forests is often measured by species-level changes, but much less is known about community-level responses. Here, we identified 12 regional forest communities of the Eastern United States using data from the Forest Inventory and Analysis Program and the Latent Dirichlet Allocation topic model. In addition, we detected distributional shifts by evaluating movement in community centroid and changes in community area over the last three decades. We found 11 of 12 communities had significant shifts in centroid (eight in longitude, seven in latitude), and 5 of 12 communities had significant changes in area (three expansions, two contractions). Mixed-effects models revealed significant forest-related (fire frequency, basal area, and nitrogen deposition) and climate-related (temperature, precipitation, and precipitation change) predictors of changes in community distribution, but the model performed poorly (marginal $R^2 = 0.07$). This may reflect resilience of forest communities to climate change, but may also indicate a lag between climate change and community-level responses. By identifying changes in forest communities, our results can provide useful information for managers of vulnerable forest communities.

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USING NONFOREST CONDITIONS TO IDENTIFY FOREST FRAGMENTS AND QUANTIFY TREE GROWTH ACROSS A CHANGING LANDSCAPE

Luca L. Morreale, Lucy R. Hutyra, Jonathan R. Thompson
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Forest fragmentation is a ubiquitous land cover change phenomenon with important implications for the health and function of forested ecosystems worldwide. Designing studies that capture both the variability of regional land use regimes, as well as accurately quantifying ecosystem responses on the level of individual trees presents a distinct challenge. The U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis (FIA) database is uniquely suited to address this multiscale research challenge due to the density, spatial range and detailed, on-the-ground measurements. The purpose of this study is to quantify the magnitude and spatial variability of tree growth and mortality responses to forest fragmentation in the Northeastern United States. Our research leverages the spatially explicit FIA measurements of forest and nonforest subplot conditions and the locations of individual trees. The condition-boundary dataset allows us to compare trees near the forest edge to those in the interior to understand both organismal and community responses to edge stimuli, such as increased sunlight. This study characterizes ecosystem responses to fragmentation across a range of forest types and land cover adjacencies.

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Uncharted Outcomes: Delivering Geospatial Products With FIA

THE 3D ELEVATION PROGRAM—USEFUL FOR FIA?

Jason Stoker
U.S. Geological Survey

The 3D Elevation Program(3DEP) is a national program managed by the U.S. Geological Survey (USGS) on behalf of federal and other partners to acquire high-quality three-dimensional elevation data with a goal to complete nationwide coverage by 2023 (LiDAR for the conterminous United States, Hawaii, and the U.S. territories; and IfSAR for Alaska). 3DEP is a cooperatively-funded program that provides a systematic approach for aligning federal, State and local investments to provide publicly available, high resolution elevation data to support a broad range of applications, including for U.S. Department of Agriculture, Forest Service. Today, over 50 percent of the Nation has 3DEP-quality data available or in progress. This presentation will give an overview of 3DEP, introduce new data access and tools, and open discussion as to the utility of these data to help meet FIA's mission.

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HIGH-RESOLUTION DATA FROM NASA'S G-LIHT AIRBORNE IMAGER FOR REMOTE INVENTORY AND SCIENCE APPLICATIONS

Bruce Cook, Douglas Morton
NASA Goddard Space Flight Center

The remoteness of interior Alaska presents a range of challenges for inventorying forest resources. Beginning in 2014, the U.S. Department of Agriculture, Forest Service partnered with scientists at NASA's Goddard Space Flight Center to pilot a LiDAR-assisted forest inventory. This approach leverages the unique, high-resolution data from NASA Goddard's LiDAR, Hyperspectral, and Thermal (G-LiHT) Airborne Imager (www.gliht.gsfc.nasa.gov). In July 2014, we acquired 1 million has of G-LiHT data in strip samples spaced every 9 km across the Tanana Inventory Unit, an area the size of Arkansas (138,000 km^2) that stretches west from the Canadian border past Denali National Park. Within these strips, the Forest Service implemented a ⅕th intensity grid of FIA plots. Here, we discuss the role of 1 m resolution airborne LiDAR and hyperspectral data for connecting the dots between inventory plot locations, including analyses of forest biomass, species composition, and trajectories of vegetation succession following stand-replacing wildfires. G-LiHT data also sample gradients in elevation, soils, and disturbance history needed to evaluate changing permafrost, insect outbreaks, expanding shrub biomass, and wildlife habitat.

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FOREST SERVICE NATIONAL LAND COVER DATA (NLCD) TREE CANOPY COVER—SCIENCE FOR FUTURE PRODUCTS

Karen Schleeweis, Stacie Bender, Kevin Megown
USDA Forest Service

The U.S. Department of Agriculture, Forest Service has supported a National Tree Canopy Cover for almost a decade. The data is a Landsat based, CONUS, Coastal Alaska, Hawaii, American Virgin Islands and Puerto Rico of tree canopy cover data and map products for epochs 2011 and 2016. Science and Research has always been a key foundation of the Forest Service National tree canopy cover team. These science efforts have supported the advancement, given prescriptive and perspectives for a production team. The information shared during this talk will describe the key science efforts, focus areas and applied science as the Forest Service plans to support a 2019 mid-cycle tree canopy cover change and the 5-year cycle 2021 product.

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FOREST SERVICE NATIONAL LAND COVER DATA (NLCD) TREE CANOPY COVER— 2016 DATA AND FUTURE TREE CANOPY COVER PRODUCTS

Stacie Bender, Greg Likness, Kevin Megown
USDA Forest Service

The U.S. Department of Agriculture, Forest Service is a founding member of the Multi-Resoluttion Land Characteristics (MRLC) and supports the development and maintenance of the National Land Cover Data (NLCD) Tree Canopy Cover (TCC) data. As the NLCD TCC data steward, the Forest Service has recently delivered the 2016 NLCD Tree Canopy Cover suite to the MRLC. The TCC data is one of many NLCD data that is core to multiple users and applications, demonstrated by the thousands of annual downloads. The making of the NLCD 2016 TCCover data required the use of many key and valued geospatial processes. These processes included efforts from the 2016 science team and innovations from the production team. This talk describes the key innovations used, the 2016 NLCD TCC data, and outlines the future goals for supporting a 2019 mid-cycle as well as the future 2021 NLCD TCC data.

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MAPPING FOREST LAND USE

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Land use, land cover, and tree canopy cover all provide valuable insights into conditions and changes in forests. A variety of definitions and minimum canopy cover thresholds have been developed and applied to forest inventory estimates and map products. Estimates of forest land area from the Forest Inventory and Analysis (FIA) program show net gains over the past few decades, while estimates based on land cover maps show net losses. Gains in forest cover that occur gradually are more difficult to detect from image-based change analyses than from field observations, resulting under representation of gross gains and overestimation of net loss than is actually occurring. To better understand these differences we modelled a 30-m spatial resolution geospatial dataset of FIA forest land use from geospatial datasets of forest land cover, tree canopy cover, forest disturbance, roads, and developed areas. We modelled forest site productivity to further stratify forest land use pixels into FIA classes of timberland, reserved-productive, reserved-unproductive, and other forest. We compare maps of forest use versus forest cover and discuss definitional effects on area estimates.

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PREDICTIVE MAPPING OF TREES PER ACRE (TPA) USING A NON-PARAMETRIC APPROACH

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Stand level forest attributes such as trees per acre (TPA), biomass, volume and basal area are increasingly important for a large-scale forest management planning. Traditional field-based timber cruising is costly and time consuming, and requires high sampling intensity to capture the spatial heterogeneity in sample population. We hypothesized that variables derived from remote sensing data could be important predictors while estimating stand level attributes from pixel to landscape level. Landsat TM satellite imageries and their derivatives, national land cover dataset (NLCD), and digital elevation model were paired with Forest Inventory and Analysis (FIA) data from 2007 to 2011. We evaluated the use of non-parametric approach—random forests to build a predictive model of TPA for each 68 U.S. Geological Survey zones in R statistical computing environment to generate a continuous gridded raster map across the conterminous United States. The models explained over 30 percent variability, with RMSE < 110 TPA. Among many other variables, NLCD canopy cover percent was the most important predictor variable while predicting TPA. This approach can be replicated for mapping various goods and services that forests provide to the society.

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Marketing FIA—Engaging New Tools for Traditional and Nontraditional Users

FIA 101: A TRAINING MODULE FOR FIA STAFF AND ASPIRING DATA USERS—THE PROCESS, THE PRODUCT, AND FUTURE DEVELOPMENTS

Sara A. Goeking, Whitney Burgess, Jeremy Morrone, Drew Narduzzi, Rachel Simons, Tracey Frescino, Jim Menlove, Maryfaith Snyder
USDA Forest Service, Rocky Mountain Research Station,
Forest Inventory and Analysis

In 2018, staff at the Interior West unit of the Forest Inventory and Analysis (FIA) program began developing “The FIA Academy.” This series of four self-guided training modules begins with basic information about FIA’s purpose and sample design and progresses to advanced data analysis. Module 1 was completed in early 2019, with the title “FIA 101: A self-study course and reference guide for FIA staff and aspiring data users.” The development team was composed of highly motivated and experienced field staff, who wrote, organized, and presented content in Portable Document Format (PDF) with internal links to cross-referenced concepts and terminology. They worked with a steering team of analysis, information management, and data collection specialists under the principles of consensus and constructive feedback. Future work includes development of Modules 2, 3, and 4; revision of Module 1 based on 2019 feedback; and engagement with digital communication specialists for conversion of existing content to an interactive web-based platform. The purpose of this presentation is to increase awareness of this resource and to solicit input on future development or revision with a more nationally-consistent perspective.

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FORESTRY WEB TOOLS PROMOTE STAKEHOLDER ACCESS

Robert J. Smith, Andrew N. Gray
Oregon State University

Streamlining the estimation of forest attributes can benefit FIA data consumers and data-contributing partners alike, while reducing demands on analysts. We deployed a free and open-source web application (https://ecol.shinyapps.io/grlyr/) that lets users quickly and accurately estimate biomass, carbon, and nitrogen in ecologically important "ground-layers" (moss and lichen mats that carpet the forest floor). Users simply upload a CSV file of on- or off-frame observations to obtain accurate, quality-checked, downloadable plot estimates within seconds. Measures of uncertainty are provided. Because calculations are internal, users need not bother with burdensome allometric equations, nor worry about how to handle complicated sampling statuses or condition codes. We illustrate three real scenarios in which interagency stakeholders used the ground-layer app to describe: (1) fire effects in Pacific Northwest prairies, (2) functional diversity in Montana rangelands, and (3) nutrient status in interior Alaska forests. Freely accessible web applications are a democratizing force that can broaden participation in forestry.

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NEW DEVELOPMENTS IN THE DESIGN AND ANALYSIS TOOLKIT FOR INVENTORY AND MONITORING (DATIM)

John R. Bertini
Forest Inventory and Analysis (UNLV partner)

The Design and Analysis Toolkit for Inventory and Monitoring (DATIM) is an application in collaborative development by the National Forest System (NFS), Forest Inventory and Analysis (FIA), the University of Nevada, Las Vegas, and Southern Utah University. DATIM is a comprehensive suite of applications and tools useful for forest management, inventory, and planning. As DATIM matures, improvements are added on a quarterly basis. Recent features include: close integration with the FIA EVALIDator application, improved appearance and functionality for the Spatial Intersection Tool (SIT), data export tools, and report management functionality. DATIM's EVALIDator integration provides access to new estimates and allows users to run reports using the latest FIADB data. The SIT tool provides a streamlined user interface to allow users to generate new attributes using their own spatial data and will soon allow authorized users to securely intersect against real plot coordinates. DATIM's data export tool provides forest inventory datasets to users in an easy-to-use format. DATIM's report management tool allows users to edit and share their existing reports. This talk will demonstrate and discuss some of these new features and developments.

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RFIA: UNLOCKING THE POTENTIAL OF THE FIADB IN R

Hunter Stanke, Andrew O. Finley, Aaron Weed
Michigan State University

rFIA is an R package designed to simplify the estimation of forest variables using the Forest Inventory and Analysis (FIA) database and unlock the flexibility inherent to the Enhanced FIA design. rFIA was designed to improve accessibility to the spatio-temporal estimation capacity of the FIA Database via space-time indexed summaries of forest variables within user-defined population boundaries, in a widely used, open-source programming language. With direct integration with other popular R packages (e.g., dplyr, sp, and sf), rFIA facilitates efficient space-time query and data summary, and supports common data representations and API design. The package implements design-based estimation procedures outlined by Bechtold and Patterson (2005), and has been validated against estimates and sampling errors produced by EVALIDator. Current development is focused on the implementation of spatially-enabled model-assisted estimators to improve population, change, and ratio estimates. We will demonstrate the flexibility and ease of implementation of rFIA by sharing our assessment of the status and trends in forest resources along the Appalachian National Scenic Trail corridor.

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FOREST SERVICE HISTORICAL FILM SCANNING PROJECT—MUCH MORE THAN AN AERIAL PHOTO HISTORICAL ARCHIVE

Gary Nebeker
USDA Forest Service

The 3.5 million frames of historical U.S. Department of Agriculture, Forest Service film span 60+ years, but are currently not available in digital format to readily support information needs. However, recent developments in film scanning and digital photogrammetry processing technologies has provided new ways to use aerial film. State of the art photogrammetric scanners can convert the film to high-resolution digital copies for processing to produce orthomosaics, 3D point clouds, and digital elevation models (DEMs). These products provide valuable spectral and elevation data for a host of projects supporting Forest Service uses. Consequently, the digital imagery compiled from historical Forest Service film holdings perhaps have even more value than contemporary digital airborne imagery since they provide a rare view into the past that allows land managers to better understand natural and anthropogenic impacts on the National forests. It is crucial that this collection of Forest Service film be preserved and made accessible for mapping and analysis in support of various Agency and department initiatives and information needs that require data and trends information that can be elicited from the imagery.

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DEMONSTRATING A PROGRESSIVE FIA THROUGH FIESTA: A BRIDGE BETWEEN SCIENCE AND PRODUCTION

Tracey S. Frescino[1], Gretchen G. Moisen[1], Paul L. Patterson[2], Chris Toney[3], and Elizabeth A. Freeman[1]

Abstract

FIESTA (Forest Inventory ESTimation and Analysis) is an open-source, R estimation package designed for analysts who work with sample-based vegetation inventory data from the USDA Forest Service, Forest Inventory and Analysis (FIA) Program. With today's complex questions and fast-evolving technologies, an adaptive tool is needed to efficiently process and translate multi-scale resource data into information. FIESTA was developed to augment currently available FIA tools by providing a flexible platform to accommodate unique research questions, including on-the-fly estimations from user-defined polygons as well as enabling the use of auxiliary data from a wide variety of remote sensing instruments. It also incorporates statistical advances in areas such as model-assisted, model-based, and small area estimation. FIESTA's flexible, open-source strategy allows for accessibility, adaptability, and integration with other R packages and other software platforms—helping bridge the gap between science and FIA's production-level operations.

The Forest Inventory and Analysis (FIA) Program of the U.S. Department of Agriculture, Forest Service was established in 1928, with primary responsibility to collect, analyze, and report on the status and trends of America's forests (https://www.fia.fs.fed.us/). Through the years, a publicly available national database of forest resources was developed to house a comprehensive collection of field inventory data, along with auxiliary information needed to generate State-wide population estimates in support of a standard FIA estimation procedure (Bechtold and Patterson, 2005). Publicly available tools have been created to access this database and compile, analyze, and report estimates of forest resources by State and inventory cycle (https://apps.fs.usda.gov/fia/datamart/datamart.html).

While these standard estimates continue to serve an important function, information needs continue to evolve, including estimates to accommodate unique geographic areas and time scales, non-forested lands, and small areas having minimal inventory data. FIA scientists have been taking advantage of advancements in computing capacity, statistical techniques, and availability of remotely-sensed data to develop new estimation strategies for meeting these needs. Unfortunately, no national FIA tools are available for scientists to access customized datasets to facilitate development and testing of new estimation and analysis strategies, nor are there national FIA tools available for implementing new estimation techniques or non-standard analysis routines. FIESTA emerged to "bridge" this gap between science and production for FIA, demonstrating a progressive solution for using FIA data.

FIESTA is an open-source, R estimation package designed for scientists who work with sample-based vegetation inventory data, like that from the FIA Program. FIESTA was developed to augment the capabilities of currently available FIA estimation tools, such as DATIM or EVALIDator (https://www.fia.fs.fed.us/tools-data/index.php). It provides a flexible platform to accommodate unique research questions such as on-the-fly estimations from user-defined polygons, and enables the use of auxiliary data from a wide variety of remote sensing instruments. It also allows FIA to make use of statistical advances in areas such as model-assisted, model-based, and small area estimation. The package contains a collection of functions that can access publicly available FIA databases, summarize and explore inventory data, compile spatial data, generate

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estimates with associated sampling errors, and automate reports and analyses. FIESTA's flexible, open-source strategy allows for accessibility, adaptability, and integration with other R packages and software platforms.

FIESTA's functions are organized into three categories: (1) Core functions; (2) Estimation modules; and (3) Analysis functions. The Core functions provide assistance for data compilation, including: database functions (DB*) for querying FIA databases; data functions (dat*) for data summarizing; and spatial functions (sp*) for spatial data manipulation. FIESTA's Estimation modules use compiled data and either programmed estimators or estimators from other R packages to generate population estimates of inventory attributes. FIESTA's current estimation modules include: Green-Book (GB*), Photo-Based (PB), Model-assisted (MA), and Small-Area (SA). The Green-Book module contains FIA's standard estimators from Bechtold and Patterson (2005) for semi-systematic annual sample design, with capability for on-the-fly estimation for a given area of interest. The Photo-Based module contains estimators from Patterson (2012), using the infinite sampling paradigm with a support region for image-based, point sample designs. The Model-Assisted module reaches out to the *mase* R package (McConville and others 2018) for use of alternative model-assisted survey estimators, such as post-stratification and generalized regression estimators. The Small-Area module also integrates other R packages including *JoSAE* (Breidenbach 2018) and *sae* (Molina and Marhuenda 2015) for generating estimates using different area- and unit-level small area estimation techniques. FIESTA's Analysis functions are wrapper functions, or subroutines, to streamline customized estimation routines.

FIESTA can serve as a "bridge" from FIA database production to FIA data users. Acquiring and compiling FIA inventory and auxiliary data for development and analysis purposes requires an extensive amount of knowledge, preparation, and time. FIESTA's *Core functions* provide a mechanism or "bridge" for securing data in appropriate formats, thereby empowering FIA data users to extract and explore different datasets, allowing more time for analysis, research, and development. FIESTA's open-source R-based design provides a platform for users to share and improve methods, while also having access to an extensive library of other open-source tools. FIESTA can also "bridge" FIA research and development to production-level operations. FIA's current operational estimation strategy was designed for mandated State-level reporting. This strategy is fast, efficient, and easy to use and includes reproducible web-based functionality. Unfortunately, the strategy was not designed to handle special studies with unique populations, customized attributes, or different auxiliary information. FIESTA's *Estimation modules* provide a mechanism or "bridge" for implementing new, on-the-fly estimation strategies developed for situations not standard to FIA, such as unique populations, small areas, and supplementary photo-based inventories. In addition, FIESTA's *Analysis functions* provide a venue for investigators to develop analytical templates that can be quickly applied to any geographic region or timeframe. FIESTA's single-platform strategy allows interaction with other software platforms, thus allowing FIESTA interoperability with FIA's current estimation production-level system.

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BUGS, FEATURES, OR WHAT? SOME POTENTIAL OPPORTUNITIES TO TIDY UP PARTS OF FIADB (AND BE KIND TO OUR USERS)

John D. Shaw
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In the process of writing programming specifications for a new data translation process from FIADB to the Forest Vegetation Simulator, a number of situations were encountered where programming logic according to available documentation, and sometimes reasonable assumptions about data properties, did not produce the desired results. This resulted in numerous programming and evaluation hours being used, perhaps unnecessarily, to ensure data integrity. In some cases the issues could be diagnosed by reviewing all values existing in a field, such as unusually long values or leading blanks. In other cases, unexpected situations appear to be by design—for the purpose of producing commonly used estimates—but with potential unintended consequences for users who use FIA data for other purposes and take the current documentation at face value. For some issues, resolution of the issues may can be addressed by clarification of documentation. However, there are some situations where the inconsistency between what database documentation appears to say and what it stored in FIADB raises questions about the purpose and use of certain variables. Several examples and possible solutions will be shown and discussed.

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Spatial Dynamics of Forest Invasion

SPATIAL PATTERNS AND DYNAMICS OF FOREST INVASION

Songlin Fei
Purdue University

Invasion of exotic organisms is a major threat to global forested ecosystems. The ecological dynamics of forest invasions often vary across spatial scales making it challenging to provide recommendations for local to national management. The use of forest inventory data, computational and statistical advances, and remote sensing technologies are providing an enhanced ability to understand how invasion dynamics vary across spatial scales. Recent advances in the understanding of forest invasion across scales will be covered, including support for common hypotheses of invasive success and the modelling of the drivers of spatial patterns of invasion. Finally, remaining gaps in knowledge that are needed to improve invasive management in U.S. forests will be identified.

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USING FIA DATA TO DETECT DRIVERS OF SPATIAL HETEROGENEITY IN PHYLOGENETIC-INVASION RELATIONSHIPS

Basil V. Iannone, III[1, 2], Kevin M. Potter[3], Qinfeng Guo[4], Insu Jo[2], Christopher M. Oswalt[4], and Songlin Fei[2]

Forests having less evolutionarily related trees tend to be more resistant to plant invasion, although this resistance varies geographically. Here we use Forest Inventory and Analysis (FIA) data to identify drivers of this heterogeneity for the forests of the Eastern United States. Using data from 42,626 FIA plots, we quantified spatial variability among the 91 ecological sections of the Eastern United States in relationships between plant invasion (species richness and cover) and the degree to which forests trees are evolutionarily related. We then modeled this variability in response to three variables known to affect invasions: environmental harshness (as estimated via tree height), relative tree density, and environmental variability. Invasive plant species richness and cover declined in forests having less evolutionarily related native trees; the size of this effect varied considerably across ecological sections. An ecological section's mean maximum tree height (MTH) and, to a lesser degree, standard deviationin MTH explained from 47 percent to 63 percent of this variability. Therefore, we found that less evolutionarily related native tree communities better resist plant invasions in less harsh forests. These findings can guide investigations into the precise environmental variables that affect the degree to which evolutionary relatedness limits plant invasions.

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FOREST STRUCTURAL DIVERSITY AND PLANT INVASION DYNAMICS ACROSS NORTH AMERICA

Elizabeth A. LaRue, Jon Knott,
Kevin Potter, Songlin Fei
Purdue University

Biotic resistance has been hypothesized to allow exotic species to invade ecosystems that have many unfilled niches, but species richness, a proxy of the number of niches filled, has often been found to facilitate invasion at large scales. Structural diversity is the arrangement of biotic structural elements within ecosystems and provides a direct measure of ecosystem niche space. Structurally diverse forest canopies have high realized niche space and may therefore contribute to the biotic resistance of recipient forest systems. We tested the hypothesis that structural diversity, as a direct measure of niche space, would promote biotic resistance across spatial scales versus species richness which would result in facilitation of invasion. We use over 45,000 Forest Inventory and Analysis plots to show that intermediate levels of forest structural diversity across the Eastern United States promote resistance to plant invasion. Ongoing analyses are examining whether these relationships between structural diversity and invasion are sensitive to spatial scale.

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UNDERSTANDING THE IMPACTS OF EMERALD ASH BORER AND FOREST STRUCTURE ON UNDERSTORY PLANT INVASION

Jessica M. Elliott, Elizabeth A. LaRue,
Joey Gallion, Songlin Fei
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Emerald ash borer (*Agrilus planipennis*) (EAB) is a significant threat to hardwood forests and can cause extensive ash tree (*Fraxinus* spp.) mortality in North America. Mortality of ash trees by EAB and its subsequent effects on forest structure are expected to influence the community composition and invasion of understory plants, but has been rarely investigated. Light Detection and Ranging (LiDAR) is a critical tool for visualizing and quantifying forest structure at large spatial scales. The goal of this project is to use LiDAR and field inventory to examine the impacts of EAB on canopy structure and ash tree mortality, and the subsequent invasion of understory nonnative plants. First, we identified 537 established plots from the Indiana DNR Continuous Forest Inventory that contain ash trees. We then used aerial LiDAR collected from 2011–2013 across the State of Indiana to measure a suite of 15 metrics that describe different aspects of canopy structure. We further tested how forest canopy structure, time since EAB invasion, and ash tree mortality are correlated to understory plant species richness of native and invasive plants. Results of this research could be used for informing management of forests following EAB invasion.

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THE MOST INVADED STATE IN THE NATION: APPLYING FIA DATA TO ASSESS FOREST IMPACTS OF NONNATIVE PLANTS AND PATHOGENS IN HAWAII

Kevin M. Potter, Julie C. Canavin
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Hawaii is unique in the United States both in the extent to which its native forests contain rare and endemic tree species, and in the degree to which they are imperiled by nonnative invasive species. We used the most recent Forest Inventory and Analysis (FIA) forest plot data from the State to quantify the uniqueness and invadedness of Hawaiian forests. Nearly 75 percent of the 238 forested plots contained at least one tree species endemic to Hawaii, and plots on average had 2.2 endemics (maximum: 10). Meanwhile, 54 percent of plots had at least one nonnative tree species (maximum: 8). Low-elevation wet forests were the most invaded, with higher elevation wet and mesic forests dominated by native endemic species. Elevation was, in fact, strongly positively related with native species importance value and negatively related with nonnative importance value on the Big Island. The most important tree species in the upland native forests (and the most commonly inventoried in the State) was ‘ōhi‘a (*Metrosideros polymorpha*), which is being decimated on the Big Island by rapid ‘ōhi‘a death, a wilt disease caused by exotic fungal pathogens. ‘Ōhi‘a is a highly important tree species in Hawaii, both ecologically and culturally.

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TREE DIVERSITY REGULATES FOREST PEST INVASION THROUGH BOTH FACILITATION AND DILUTION

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Nonnative pests often cause cascading ecological impacts, leading to detrimental socio-economic consequences. However, it is still unclear how plant diversity may influence insect and disease invasions. Most studies to date have been on small scales, and large-scale studies especially in natural ecosystems are extremely rare. Using subcontinental-level data, we examined the role of tree diversity on pest invasion across the conterminous United States. We find that the tree-pest diversity relationships is hump-shaped. Pest diversity increases with tree diversity at low tree diversity (facilitation or amplification), and is reduced at higher tree diversity (dilution). Thus, both facilitation and dilution operate simultaneously, but their relative strengths vary with overall diversity. Our findings demonstrate the role of native species diversity in regulating nonnative pest invasions.

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FIA Contributions to Monitoring Biological Diversity

FIA CONTRIBUTIONS TO MONTRÉAL PROCESS CRITERIA AND INDICATORS FOR MONITORING BIOLOGICAL DIVERSITY

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Conservation of biological diversity is critical for maintaining many ecological services. Biological diversity includes diversity within species, between species, and of ecosystems, as defined by the Convention on Biological Diversity. Many countries have implemented programs for monitoring biological diversity across these scales. The Montréal Process (MP) was developed to provide a standard, international framework for assessing the sustainability of temperate and boreal forest ecosystems across 12 countries, including the United States. The first of seven MP criteria is Conservation of Biological Diversity, containing nine indicators, three each for ecosystem, species, and genetic diversity. Data, information, and knowledge produced by the U.S. Forest Service, Forest Inventory and Analysis (FIA) program contribute to MP monitoring at national, regional, and State scales. We present the MP, other regional and State variations of indicators, and corresponding applications of FIA for monitoring biological diversity. This presentation provides introduction and context for subsequent presentations in this session.

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USE OF FOREST INVENTORY TO ASSESS TRENDS IN HABITAT ABUNDANCE FOR THE INDIANA BAT ACROSS FORESTS OF THE NORTHERN UNITED STATES

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Forest Inventory and Analysis (FIA) data has long been used to address broad classes of forest habitat types and address global, national, and regional biodiversity assessments. For example, forest inventory data can be used to estimate the current status and trends in early-successional forest. In cases where specific habitat requirements related to trees are well documented for forest-associated species it becomes possible to make habitat estimates for specific wildlife species. The Indiana bat (*Myotis sodalis*) was listed as endangered by the U.S. Fish and Wildlife Service in 1967. Indiana bats live in hardwood and hardwood-pine forests across much of the midwestern, southern, and mid-Atlantic regions of the United States. They have specific requirements for the number of live and standing dead trees per acre that are necessary to provide suitable and optimal habitat for roosting and nesting. Here we analyze forest inventory data distributed across the Eastern United States to estimate the current distribution and trends of suitable and optimal forest habitat for the Indiana bat and demonstrate a digital tool for sharing this information at multiple spatial scales.

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JOINING U.S. GEOLOGICAL SURVEY (GAP) SPECIES-HABITAT RELATIONSHIPS TO FIA VIA USNVC MACROGROUPS

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U.S. Geological Survey Science Analytics and Synthesis, Gap Analysis Project (GAP);
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Forest Inventory and Analysis (FIA) data provide opportunities for monitoring biological diversity by creating linkages between forest characteristics and wildlife habitat. Tree species data recorded during FIA field visits provide direct estimates of tree species distribution, abundance, and change. Some forest-associated terrestrial vertebrate species also have nationally consistent population trend data (e.g., Breeding Bird Survey), but many do not. For those species, diversity can be monitored indirectly via species-specific estimates of habitat abundance and change. Most forest species-habitat relationships include detailed attributes of forest composition and structure, which FIA data can provide—if species habitat data can be efficiently linked to FIA via common attributes. We joined USGS Gap Analysis Program (GAP) species-habitat relationships at the macrogroup level to FIA using the recently added U.S. National Vegetation Classification (USNVC) macrogroups in the FIA condition attributes across the Eastern United States. GAP species-habitat relationships data were recently completed for birds, mammals, reptiles, and amphibians. To further refine GAP-USNVC-FIA linkages we incorporated vertebrate species range maps.

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ESTIMATING POTENTIAL ABUNDANCE OF WOOD DUCK NEST CAVITIES

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Tree cavities provide nesting substrate for Wood duck (*Aix sponsa*) hens. Habitats used by wood ducks in Minnesota have changed in recent decades. We initiated a study to explain the variation in suitable cavity presence in the broader Laurentian Mixed Forest Province of north central Minnesota between 1990 and 2014–2018, and used these results with Forest Inventory and Analysis data to make inferences about temporal changes of cavity abundance in northern Minnesota. We measured 7,869 trees >22 cm diameter at breast height (DBH) in Cass County, MN. We classified 223 cavities as suitable and 111 as marginally suitable for nesting. Data were sparse for large DBH trees of all species, so we surveyed additional plots to obtain sufficient data on large-DBH stems (>40 cm for early and mid-successional species, >50 cm for late successional species). Logistic regression models fit to these data explained the variation of cavity presence in seven common tree species for which there was adequate cavity data. The estimated number of these trees increased between 1990 and 1999–2003, then decreased during subsequent periods. We will discuss our projections of the temporal change in cavity abundance.

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THE IMPACTS OF VARYING SPATIAL SCALE IN DETERMINING PREDICTORS OF TREE SPECIES DIVERSITY USING NESTED WATERSHEDS AND FOREST INVENTORY DATA IN THE SOUTHEASTERN UNITED STATES

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The relationship between tree species diversity and various climatic, environmental, and anthropogenic factors in the Southeastern United States is multifaceted and complex. Key among these is the impact of plantation forestry, agricultural establishment, and urban development on three measures of tree species diversity: species richness, Shannon-Wiener index, and Simpson's index. Forest Inventory and Analysis data as the source of tree species data and nested watersheds from the Watershed Boundary Dataset (WBD) were used as spatial boundaries. The measures of diversity were calculated for the differing watershed scales. Multivariate analysis and spatial analysis techniques were incorporated to understand how possible predictors and covariates of tree species diversity vary with spatial scale. Multivariate analysis techniques such as multi-response permutation procedures (MRPP), non-metric multidimensional scaling (NMS), and regression trees were used to assess relationships within the data. A species-area curves was created to determine appropriate spatial scales. Getis-Ord Gi* hot-spot analysis was utilized to determine if diversity hot and cold spots clustered, as well as if clustering patterns changed in regards to changes in area. Finally, ordinary least squares, spatial lag, and spatial error models were developed to explore how scale dependencies exist and interact within these relationships. The results revealed that anthropogenic and local factors were more important in smaller scales, and climate and global factors increased in significance as spatial scale increased. Additionally, variables relating to plantation forestry were found to be positively related to species richness, and negatively related to diversity measures that included species evenness.

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VARIATION IN INDIVIDUAL-TREE GROWTH ACROSS SPECIES MIXTURES PROVIDES EVIDENCE OF COMPLEMENTARITY EFFECTS IN INTERIOR WEST FORESTS

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A central challenge to contemporary forest management is maintaining forest productivity in the face of climate change. Research suggests species diversity could be used to enhance both stand productivity and resilience through complementarity effects (e.g. facilitation) However, this research has focused on European forests, with limited North American examples. To fill this knowledge gap, we investigated the relative influence of complementarity, stand structure, and tree characteristics on the growth of four major species in the Interior West: ponderosa pine, Douglas-fir, quaking aspen, and Engelmann spruce. Using 10 year FIA remeasurements, we created individual-tree (>4.9 inches DBH) models and examined the growth of each of the four species along community gradients. Our preliminary results indicate that only shade-tolerant Engelmann spruce (*Picea engelmannii*) and Douglas-fir (*Pseudotsuga menziesii*) increase in growth with decreasing stand purity. Light partitioning between shade-tolerant and intolerant species, modified by stand structure, may drive mixture effects on growth. These implications of species mixtures for individual-tree growth and vigor will help guide future efforts to sustain function across the Adaptive Silviculture for Climate Change network.

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The Small Area Estimation Conundrum

OVERVIEW OF SMALL AREA ESTIMATION CONCEPTS AND APPLICATIONS

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Small area estimation techniques have recently gained attention in forest inventory applications. Pursuant to the 2014 Farm Bill initiative on improving sub-state estimates, the Forest Inventory and Analysis program invested in research on small area techniques. However, there is substantial variation in what partners, and FIA staff themselves, consider as small areas. Further, there is lack of a common understanding of what small area techniques offer and how they may differ from other approaches. In an effort to understand the variation in what partners and stakeholders are after with respect to “small area”, we conducted a survey to highlight the various user needs. In this presentation we will provide an overview of small area estimation concepts and applications, and summarize the results of a recent user community survey about small area estimation needs, applications, and perceptions.

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STATE PERSPECTIVES ON SMALL AREA ESTIMATION

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Texas A&M Forest Service

The Forest Inventory and Analysis (FIA) program collects data on forest ecosystems across the United States and its territories at an intensity of approximately one plot every 6,000 acres. While FIA data have traditionally been used to produce population estimates over large geographic areas, there is considerable interest in using modeling approaches that combine remotely sensed data with FIA plot data to estimate forest attributes in small areas. In this presentation we will share the perspectives of multiple States to clarify the range of needs to help guide future work in small area estimation.

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AN OVERVIEW OF SMALL AREA ESTIMATION RESEARCH OUTSIDE THE UNITED STATES: THE INTERNATIONAL PERSPECTIVE

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Small area estimation (SAE) research outside of the United States has been centered in Europe—both in transnational organizations, such as the European Union, and in the national statistics offices of individual countries. Support for SAE research is driven by government policymakers responsible for core national statistics across domains. Examples include demographic information for political jurisdictions (domain) or business data for an economic sector (domain). SAE research on forest statistics is typically a subset of core environmental statistics, defined by a geography domain. Whatever the domain—geography, economic sector, political jurisdiction—the same principles and basic statistical research are driving ongoing SAE research activities in other countries. Policymakers who seek better estimates of conditions and trends for smaller areas in a domain than can be provided at acceptable levels of precision from contemporary sampling frames are often the impetus behind ongoing SAE research activities. This is but another example of how researchers at the science-policy interface seek to build better bridges to inform policymakers' decisions.

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A PERSPECTIVE ON SMALL AREA ESTIMATION FROM THE COMMERCIAL FORESTRY SECTOR

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National Council for Air and Stream Improvement

Obtaining reliable forest inventory data for smaller geographic areas and with finer grain is of increasing interest in the commercial forestry sector. Commercial forestry entities need inventory data to estimate potential wood supply for facilities, to develop strategic responses to supply disruptions by hurricanes or wildfires, and to anticipate markets for forest products to inform investment decisions. A wealth of relevant resource data at fine spatial grain is readily available—including high-resolution aerial imagery at increasing temporal frequencies, detailed soils maps, ownership parcel boundaries, transportation networks, topography and derivative layers, and many others. It is apparent that we have not yet realized the potential to use inventory data from sparse samples (like the Forest Inventory and Analysis plot network) to inform estimates for finer geographic and categorical domains. Numerous approaches have been tested ("classical" small area estimation, downscaling, imputation, and interpolation, among others), but there is little consensus on a best way forward. This presentation will make the case for focused research and operational testing of scientifically sound approaches to small area estimation to meet information needs.

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NEEDS FOR FINE-SCALE VEGETATION DATA ON NATIONAL FOREST SYSTEM LANDS

Priya C. Shahani, Jamie Barbour, Emrys Treasure, Amy Nathanson
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The U.S. Department of Agriculture Forest Service has numerous needs for fine-scale vegetation data on National Forest lands that are difficult to address, given limited staff time available for conducting field surveys. These data needs relate to land management and monitoring to support both condition-based management and adaptive management decision making. We will provide an overview of some of these needs in different parts of the country.

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Global View of National Forest Inventories (NFIs): How They Have Progressed, Ways They Have Utilized Partnerships, and Possibilities for the Future.

THE IMPORTANCE OF NFIS IN THE INTERNATIONAL CONTEXT

Rebecca A. Tavani
United Nations Food and Agriculture Organization

For more than 50 years, Food and Agriculture Organization (FAO) has been supporting countries to collect forest information through national forest inventories (NFI) that meet national and international information needs—operating on the premise that better information leads to improved decisions, which leads to more effective action in the forest sector and beyond. Today, FAO is supporting multipurpose NFIs in over 20 countries. The data collected has supported countries in both national and international reporting, particularly in meeting the reporting requirements of the Paris Agreement. NFI data has been critical to the construction of national and sub-national forest reference levels as well as in providing improved biomass estimates for updating IPCC default emission factors. In this presentation, current FAO support to global NFI efforts will be presented focusing on the application of the data to REDD+ processes and related challenges.

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STATE OF THE NATIONAL FOREST INVENTORIES IN CAMEROON: CHALLENGES AND PERSPECTIVES

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Cameroon carried out a national inventory of its forest resources with the technical support of the Canadian International Development Agency (CIDA) between 1982 and 1990 on about 14 million hectares, or 29.47 percent of the territory. From 2002 to 2004, Food and Agricultural Organization (FAO) decided to support a second national forest inventory (NFI), which covered 45 percent of the country's area this time around. The methodology used in these inventories was based on stratified sampling. As part of the work, partnerships were established with academic and research institutions, as well as the national herbarium. As the main results, the FAO NFI helped for development of volume rates for the estimation of standing tree volumes as well as updating the phytogeographic map of Cameroon. In addition to these inventories, others are carried out on a regular basis on smaller areas, including management inventories, as well as exploitation inventories, in each parcel of forest to be logged. Unfortunately, most of the data are out of date and qualified personnel are retired. As prospects, it is envisaged to the realization of a new forest inventory to update the volume rates, and estimate the the biomass, as well as carbon stocks in connection with the REDD+ mechanism.

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FOREST RESOURCES OF THE UNITED STATES, 2017: INFORMING THE NATION, THE CONTINENT, AND THE GLOBE

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The Forest Inventory and Analysis (FIA) program contributes statistics to the federally mandated Resources Planning Act every 10 years, with 5 year updates. These statistics contribute not only to domestic policy action, but have international implications, as well. Currently, through the work of the North American Forest Commission, forestry agencies in the United States, Canada, and Mexico have worked to align data definitions from their respective forest inventories in a manner sufficient for combination in a continent-wide database. Additionally, FIA statistics continue to feed into the United Nations Food and Agriculture Organization (UN FAO) report on global forest resources. This presentation shares the outcome of the 2017 U.S. Forest Resources Report, progress on the North American Forest Database as well as lessons learned, and the process by which the United States participates in the global Forest Resources Report.

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THE CHALLENGE OF THE PERUVIAN STATE IN LEADING THE CONSERVATION OF RELICT FORESTS OF POLYLEPIS THROUGH THE NATIONAL FORESTRY AND WILDLIFE INVENTORY: CHALLENGES AND OPPORTUNITIES TO MAKE DECISIONS

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Department of Inventory and Valuation

In recent years, communities around the world have had a central role in local forest management and ecosystem conservation. In the Andes of Peru, peasant communities have a long tradition of forest management based on a particular world view. The information generated by the National Forestry and Wildlife Inventory (Inventario Nacional Forestal y de Fauna Silvestre-INFFS in Spanish) provides information on the current situation of the relict forests of Polylepis "Queuña." In this context, the Government of Peru, through SERFOR, implements the INFFS in all forests. Through 1855 sample units, of which 489 are in the Andes' ecozone, mountain forests containing "queñuales" (local name for Polylepis trees) are examined. The challenge is to characterize the composition, structure, state of conservation and benefits that the Polylepis forests generate for rural communities. The methodology consists in organizing permanent sample units in "L" shaped conglomerates of 10 circular sampling subunits of 500 m^2 each, where trees larger than 10 cm dap are measured. Currently, 67 Sample Units (SU) have been evaluated, of which Polylepis trees are found in 13 SU. Additionally, it should be noted that in Peru there are approximately 21 Polylepis.

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Biomass and Carbon: New Techniques, Big Potential, and Novel Equations

USING FIA VOLUME AND BIOMASS EQUATIONS THROUGH NATIONAL VOLUME ESTIMATOR LIBRARY

Yingfang Wang
USDA Forest Service

Forest Inventory and Analysis (FIA) volume and biomass equations were programmed in the National Information Management System (NIMS) Oracle database and were not accessible outside of NIMS. The National Volume Estimator Library (NVEL) has been expanded to incorporate all FIA volume and biomass equations. The NVEL was programmed in FORTRAN and compiled into a dynamic link library (DLL) and a shared library. The library is available to use in Windows, Linux, and Android applications. The NVEL Excel Addins functions can be easily configured to calculate total cubic foot volume from the stump to the tip, merchantable cubic foot volume from the stump to a specified top diameter, boardfoot volume, and topwood volume for tree data stored in Excel spreadsheets. For profile model equations, there are also functions to calculate diameters at a given height, the height to a given diameter on the stem, and log diameters and volumes. The NVEL has built-in interface functions for use with C#, VB, C/C++, Python, and R program. The NVEL also has the National Biomass Estimator Library (NBEL) combined with it. It contains published biomass equations to calculate tree component biomass. The FIA existing volume and biomass equation number could be used in NVEL.

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SOUTH CAROLINA FORESTS POTENTIAL TO CONTRIBUTE TO THE CALIFORNIA CARBON MARKET

Lucas Clay, Marzieh Motallebi, Bo Song
Clemson University

South Carolina has a variety of different forest types, and they all have potential to sequester a certain amount of carbon. Private forest landowners control a significant portion of the overall forest land in South Carolina, and their management efforts can maintain or improve forest carbon stocks. Currently, the California Carbon Market gives a monetary value to sequestered carbon. One carbon credit is equal to one metric ton of carbon, and is currently worth around $15. This study aims to educate forest landowners about various forest management practices that contribute to increasing carbon stocks by looking at various forest types in South Carolina and their current and projected carbon stocks. Forest Inventory and Analysis data was used in the Forest Vegetation Simulator to project carbon sequestration for 100 years for 130 forested plots in South Carolina. Ten different management practices were employed to see the variance in carbon sequestration. Results showed that carbon sequestration would increase for certain management practices such as thinning and prescribed fire. This data will be beneficial for forest landowners interested in a carbon project and those interested in seeing how different management practices affect carbon sequestration.

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DEVELOPING NEW TAPER, VOLUME AND BIOMASS MODEL SYSTEMS FOR FIA TO MEET THE NEEDS OF DIVERSE CLIENTS

Dehai Zhao, James Westfall, John W. Coulston
University of Georgia, USDA Forest Service

Forest Inventory and Analysis (is striving to develop/update estimators of volume, biomass, and carbon contents of trees and tree components for the major tree species of the United States. In addition to total volume and total biomass, some clients need to accurately estimate biomass of each component for improving stand carbon/biomass estimates or nutrient accounting due to the variation of carbon and nutrient concentrations among different components, and some industrial partners are more interested in estimating volumes or weights of various portions of tree boles with changing utilization standards. It is desirable and possible to develop taper, volume and biomass model systems to meet such a variety of needs. Here, we present the structures, conditions, and estimation methods that are required to achieve the compatibility and additivity of the model systems. The main subtopics include (1) new variable-top merchantable volume and weight equations; (2) how to develop and estimate the completely compatible taper and volume equations; and (3) strategies for developing additive biomass component and biomass allocation equations.

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DEVELOPMENT OF DOWNED WOODY DEBRIS DIAMETER AND LENGTH MODELS FOR APPLICATION IN FOREST BIOMASS AND CARBON ESTIMATION

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An accurate assessment of the dimensions of downed woody debris (DWD) are required to obtain reliable estimates of the volume, biomass, and carbon attributes of forest dead wood. Measurement protocols in Forest Inventory and Analysis (FIA)'s downed and dead wood inventory have changed tremendously over the past two decades, with current procedures forgoing detailed measurements on DWD pieces such as large- and small-end diameters and length. Despite this, over 400,000 observations of DWD pieces have been collected by the FIA program across the United States that contain these detailed measurements. These historical data were used to develop new models of DWD end-point diameters and length using simpler measurements such as the decay class, species, and diameter at transect. Models were fit with linear quantile mixed models and were subsequently used to determine plot-level volume, biomass, and carbon stocks in the DWD pool. Results indicate important differences in plot-level attributes depending on whether direct measurements or modeled estimates were used to determine DWD diameter and length. These findings have important implications in quantifying carbon attributes, estimating fuel loads, and determining wildlife habitat.

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DISENTANGLING DIRECT DISTURBANCE IMPACTS FROM OTHER CARBON FLUXES ON REMEASURED PLOTS ON THE WEST COAST

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Forest Inventory and Analysis

The impacts of disturbance on forest carbon (C) stores are a common concern among managers, policymakers, and the public, especially after a large fire event or insect outbreak. However, estimates of impacts often vary wildly, confuse short- and long-term impacts, or don't consider all C pools. Our objectives were to explore alternative approaches to estimating immediate and longer-term (e.g., 10 years) impacts of disturbance, with a focus on fire on the West Coast, USA (i.e., California, Oregon, and Washington). We compiled remeasured tree, dead wood, and forest floor estimates from 11,892 inventory plots distributed across 33.4 million ha of forest land and assessed changes in forest C pools by disturbance severity. The mechanistic approach estimated pre- and post-disturbance growth of live trees, decay of dead wood, combustion of live and dead vegetation parts, and combustion and accumulation of forest floor. The plot-matching approach compares trajectories of C pools on disturbed and undisturbed plots that share the same starting conditions. We discuss the strengths and limitations of each approach in terms of assumptions and data availability.

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EXTENDING BIOSUM TO OPTIMIZE MULTI-DECADE FOREST RESTORATION AND EVALUATE BIOCHAR FACILITY FEASIBILITY IN THE UPPER KLAMATH BASIN

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Capacity of the dry National forests of southern Oregon and northern California to generate a sustainable and economically feasible supply of biochar feedstock under restoration management regimes designed to enhance fire resistance was analyzed using Forest Inventory and Analysis data. The BioSum analysis framework, combined with recently developed effectiveness metrics, offered a compelling foundation for this analysis, which, thanks to BioSum's modular design, could be extended with custom scripting to more accurately represent wood value recovered and to encompass landscape scale optimization of the treatment program over time. This case illustrates the value of inventory-linked, open analytic tools adaptable to problems not originally envisioned at the onset of tool development, and the mutual benefits that flow from collaborating with users with different analytic perspectives. Implemented with tethered harvest systems, modeled treatments elevated fire resistance on most forested area; the most effective ones usually more than covered treatment cost with sales of wood. At current, 100-year management intervals, biochar feedstock is sufficient to supply at least one large-scale facility over the next 20 years.

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EVALUATION OF ESTIMATES OF BIOMASS FROM INITIAL ON-ORBIT DATA OF THE GLOBAL ECOSYSTEM DYNAMICS INVESTIGATION LIDAR MISSION

Paul L. Patterson, Sean P. Healey, Ralph O. Dubayah, Laura Duncanson, John Armston, Steven Hancock, James R. Kellner, Zhiqiang Yang
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In December 2018, the National Aeronautics and Space Administration (NASA) Global Ecosystem Dynamics Investigation (GEDI) mission installed a full-waveform LiDAR instrument on the International Space Station for the purpose of measuring global forest structure. The waveforms are collected in "footprints" that are spatially discontinuous; the waveform data is expected to be strongly correlated with aboveground forest biomass density (AGBD in Mg/ha). Using simulated GEDI waveforms, models of AGBD have been constructed for the footprints by plant functional types within the six continental regions. The estimates for the discontinuous footprint level AGBD will be combined to estimate the mean AGBD within geographical regions (e.g., 1 km grid cell, administrative unit, national park, etc.) using a hybrid estimator. Using a diverse set of global sites a simulation study was conducted to empirically assess the statistical properties of hybrid estimator and the proposed estimated variance. In this talk we present an overview of the first 6 months of on-orbit GEDI science data. Based on the on-orbit GEDI science data a post-launch evaluation of the GEDI footprint level AGBD biomass estimators and hybrid estimate of the mean AGBD with geographical regions will be presented.

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EVALUATING FOREST BIOMASS INVENTORY MODELS BASED ON INTEGRATION OF FIXED-RADIUS AND VARIABLE-RADIUS PLOT DATA WITH DIFFERENT MODES OF LIDAR AND PHOTOGRAMMETRIC METRICS

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LiDAR and digital aerial photogrammetry (DAP) data have become an integral part in enhanced forest inventories (EFI). However, the sensor characteristics, season of data acquisition and field sampling techniques (e.g., plot size, fixed radius vs. variable radius plots) can affect the accuracy of spatial inventory models. This study was implemented in Lake County, MN where an overlap area (~20,000 acres) had DAP and three types of LiDAR data: high density linear LiDAR (55 points/m^2), Single Photon LiDAR (33 points/m^2) and low density linear LiDAR (1.5 points/m^2). We evaluated aboveground forest biomass (AGB) models developed using DAP-derived predictors and grid metrics derived from the three types of LiDAR. The spatial predictors were integrated with field sampling data based on fixed and variable radius plots that were measured in summer 2018 by Minnesota Department of Natural Resources at 51 locations using concentric 1⁄10 acre, 1⁄24 acre (i.e., the size of Forest Inventory and Analysis subplot) and BAF 5 prism plots. AGB was calculated for the three plot sizes and the three types of AGBs were separately related to the three types of LiDAR and DAP metrics in Random Forest modeling framework to obtain the inventory models. The modeling and analyses are underway.

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The Complex Dynamics of Collecting and Reporting Forest Ownership

THE MANY FLAVORS OF THE FIA LANDOWNER SURVEYS

Brett J. Butler
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This session will highlight the increasingly multi-faceted nature of Forest Inventory and Analysis (FIA) landowner surveys. The base, or rural, National Woodland Owner Survey (NWOS) has been conducted at the national-level since the late 1970s with more recent cycles completed in 2006, 2013, and 2018. The base NWOS survey is most applicable for family forest owners. To help collect data more applicable to corporate forest owners, FIA is initiating the Corporate NWOS to look at large corporate forest ownerships, those with 45,000 acres or more, across the United States. As the rest of the FIA program has expanded into urban areas, so too has the landowner survey with the Urban National Landowner Survey now being administered to residential urban landowners in select cities. The U.S. territories and protectorates represent unique opportunities and challenges for both biophysical inventories and social surveys; as the landowner surveys are expanding into these areas, they are being adapted to address these unique environments. A future effort will focus on working with Tribal entities and allied organizations to establish a framework for implementing a survey covering this population.

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ENCOURAGING LANDOWNER PARTICIPATION IN THE INVENTORY: BARRIERS AND POSSIBLE SOLUTIONS

Yuling Gao, Lynn Huntsinger, Eric M. White, Jeremy S. Fried
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Forests owned by noncorporate entities are a substantial share of forest area on the west coast. Their management differs from, and is more variable than, public and corporate ownerships, elevating the importance of obtaining a complete Forest Inventory and Analysis sample. Unfortunately, denied access rates to FIA plots that include non-corporate forest sometimes exceed 50 percent, most likely owing to (1) distrust of the Federal Government, (2) a general unwillingness to participate in surveys, (3) the difficulty of identifying all landowners controlling portions of a plot and/or access thereto, (4) confusion among woodland landowners about whether forested land occurs on their parcels, and (5) a disinclination to open impersonal mail. To better understand individual reasons for denying access and explore changes in landowner recruitment and contact protocols that could promote granting of access, PNW-FIA initiated some immediate protocol changes and partnerships with social scientists at Pacific Northwest Research Station and the University of California. We share insights from interviews with natural resource professionals about reasons for nonresponse, and from our attempt to correlate property characteristics with the tendency to respond and grant access.

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RESULTS FROM THE CORPORATE FOREST LANDOWNER SURVEY PILOT STUDY

Emma M. Sass, Brett J. Butler, Andrew Hartsell, Marla Markowski-Lindsay, Jesse Caputo
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Large, corporate landowners own a substantial portion of forest land in the United States; who these owners are, how they manage their land, and their plans for the future will impact the forested landscape across the country. As an extension of the National Woodland Owner Survey, we conducted a pilot survey of large, corporate forest owners across the country. The primary objectives reported by large, corporate forest owners are for timber, investment, and water protection. All companies reported road construction or maintenance and cutting trees for sale in the past 5 years. More than three quarters of companies also reported improving wildlife habitat, using herbicides, and eliminating or reducing invasive plants in the past 5 years. The primary concerns that companies reported were regarding regulations and changes to taxes and markets. While this study reveals interesting trends and themes, the small sample size and complicated corporate structures prevent extrapolation to the entire population of large, corporate forest owners.

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LINKING THE URBAN NATIONAL LANDOWNER SURVEY TO AUXILIARY DATA: THE CASE OF BALTIMORE, MD

Dexter H. Locke, Nancy F. Sonti, Amanda Robillard, Brett J. Butler, Morgan J. Grove
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The Urban Forest Inventory and Analysis program was created to inventory the nation's urban trees and forests, expanding the FIA sampling frame beyond the FIA definition of forest land. Alongside the plot-based Urban FIA data collection, development of an Urban National Landowner Survey (UNLS) (analogous to FIA's National Woodland Owner Survey) captures the attitudes and behaviors of urban residential landowners regarding their neighborhood and community, as well as their property's trees and other green spaces. Baltimore is home to the Baltimore Ecosystem Study (BES), a Long-Term Ecological Research (LTER) site, which has collected social and ecological data since 1997. We link UNLS survey responses to a BES telephone survey, U.S. Census data, and high-resolution tree canopy maps. Here we show how attitudes of urban land owners and managers compare to telephone survey respondents and how UNLS respondents compare to the demographic composition of the regional population. Understanding the relationships between measurable tree canopy cover and perceptions of urban trees can better inform land management decisions. Joining UNLS to other locally-relevant datasets extends the value of the inputs, making them greater than the sum of their parts.

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FOREST OWNERSHIP DYNAMICS IN THE UNITED STATES: ACCOUNTING FOR RECENT, SIGNIFICANT HISTORICAL CHANGES

Marla Markowski-Lindsay, Brett J. Butler, Daowei Zhang, David Newman, Dave Wear, Jesse Caputo
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Forest ownership patterns across the United States are diverse, and while the Forest Inventory and Analysis (FIA) data on privately owned forests encompass a variety of classes, our project addresses the significant historical changes in private forest ownership across the United States. Recent changes include the large-scale divestiture of vertically integrated forestry companies and the ascendency of timber investment management organizations (TIMOs) and real estate investment trusts (REITs), as well as the parcellation of family forest lands. These private forest owners make decisions about the land cover, resource production, and access. This project contributes new data to existing FIA plot data to reflect these historical changes and describes the distribution of public and private forest ownerships across the United States in greater detail than ever before. We add to current FIA plot data by identifying forest land owned by TIMOs, REITs, and other large corporate ownerships. Using these new data, we summarize ownership trends and ownership transitions over 5-year increments. These results are based on data gathered from FIA plots and supplemented with additional ownership detail gathered from a collaborative effort involving scientists from multiple institutions.

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A COLLABORATIVE APPROACH TO DEVELOP A TRIBAL FOREST OWNER SURVEY

John Schelhas
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The Forest Service aims to implement programs and activities in a manner that honors Indian Tribes' treaty rights, fulfills the Agency's trust responsibilities, and respects each independent tribal nation and their cultures. This requires working with Tribes on a nation-to-nation basis, supporting and collaborating with tribal natural resource management agencies. It also requires new efforts for adequate representation of Native American family forest owners in the National Woodland Owners Survey. Tribal forests face many of the management issues of other forests in the United States, but also have unique cultural issues and land tenure systems. Addressing these complex and unique attributes of forest values, forest ownership, and forest management requires a collaborative approach from top to bottom. Collaboration early in planning and development of a Tribal Forest Owner Survey is required for shared ownership and implementation with Tribes. Tribal colleges and natural resource agencies must be involved in survey design and implementation. Initial steps are underway to work with Tribes in developing a mutually beneficial and collaborative approach that will encompass lands owned by Tribes and tribal communities.

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SURVEYING MINORITY FAMILY FOREST OWNERS

Amanda Robillard, Jesse Caputo, Cassandra Johnson,
Emma Sass, John Schelhas, Brett J. Butler
University of Massachusetts-Amherst

Understanding minority groups of family forest owners is important, as their attitudes and behaviors about their forest land are potentially different than non-minority family forest owners, and different programs and policies focused on minority groups might be necessary to reach these more underserved populations. The National Woodland Owner Survey (NWOS) asks demographic questions, but these questions have a relatively high item nonresponse rate and sample sizes for respondents indicating minority status are small. We do not know if the low numbers of minority respondents are a result of high nonresponse rates among these groups or low numbers of minority landowners. To investigate this population we have conducted an intensified version of the NWOS in six counties in the U.S. South with high percentages of African Americans. This presentation will discuss preliminary results from this study including response rates, comparisons between minority and non-minority owners, and implications for future survey efforts.

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NONRESPONSE ASSESSMENT AND IMPUTATION FOR THE NATIONAL WOODLAND OWNER SURVEY

Brett J. Butler, Jesse Caputo, Emma Sass
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Nonresponse, be it unit or item level, is a major issue facing most surveys. Unit nonresponse occurs when there are no data recorded for a survey respondent and item nonresponse occurs when there is only partial data recorded for a respondent. The National Woodland Owner Survey (NWOS) has relatively low unit and item nonresponse rates compared to comparable surveys, but both issues are still very present and need to be assessed and, as appropriate, mitigated. The first step in the item nonresponse assessment is to quantify the missingness in terms of respondents and questions. Most respondents had relatively low levels of item missingness and a threshold of 25 percent missingness was selected (i.e., respondents with a missingness of > 25 percent were classified as a special category of nonrespondent). This reduced the NWOS sample size by 4.8 percent. Most questions had missingness rates of < 5 percent and those variables with higher nonresponse rates will need to be assessed for potential measurement errors and interpreted accordingly. Multiple imputation using chained equations is being used to impute missing values for respondents and variables that were retained. Unit nonresponse is being addressed in a separate presentation.

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RELATIONSHIPS AMONG SIZE OF FOREST HOLDINGS AND PRIVATE FOREST OWNERSHIP ATTITUDES AND BEHAVIORS

Brett J. Butler, Jesse Caputo, Emma Sass
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There are an estimated 11.5 million private forest ownerships in the United States with holdings that range in size from a single acre to millions of acres. This presentation will share results from the 2018 National Woodland Owner Survey that will explore the distribution of private forest ownerships in terms of size of forest holdings and how size is correlated with selected attitudes and behaviors. Break point analysis will be used to identify specific acreage thresholds. Preliminary analyses show that size of forest holdings is highly correlated with some attributes, such as forest management behaviors and timber production objectives, but there are no apparent correlations with other attributes, including many of the landowner demographics. We are proposing size of forest holdings as an alternative classification for private forest ownerships. This approach has some advantages over other classifications that focus on, for example, legal structure or ownership objectives. The size approach is simpler and more transparent, but the demarcation of the acreage thresholds needs to be carefully considered.

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EXPANDING THE NATIONAL WOODLAND OWNER SURVEY TO THE U.S. TERRITORIES AND PROTECTORATES: CHALLENGES AND OPPORTUNITIES

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The Forest Inventory and Analysis (FIA) program now collects and reports biophysical data on forests across most U.S. protectorates and territories throughout the Caribbean and Pacific. These data collection and reporting efforts are a critical source of information for forest-related decisions, practices, and policies. Nevertheless, specifics on forest ownership within and across the islands are limited, and very little is known about forest landowners, particularly in terms of how they view and use their forested lands, what motivates and moderates their land use decisions, and what role they play in forest conservation and recovery. The island territories and protectorates of the United States represent unique opportunities and challenges for both biophysical inventories and social surveys, particularly in terms of their relative remoteness, small size, social-ecological diversity, and limited land ownership records, among other factors. To fill the gap, the FIA landowner surveys are expanding into the Islands. We discuss how the National Woodland Owner Survey is being adapted to address these unique environments, beginning with the U.S. Virgin Islands, and the associated challenges and opportunities for implementation and interpretation.

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FACTORS ASSOCIATED WITH FAMILY FOREST LANDOWNER ENROLLMENT IN STATE PREFERENTIAL FOREST PROPERTY TAX PROGRAMS IN THE UNITED STATES

Gregory E. Frey[1], Justin T. Meier[2], Michael A. Kilgore[2], Stephanie A. Snyder[3], and Charles R. Blinn[2]

All 50 States in the United States offer preferential forest property tax programs (PFPTPs) that defer, reduce, or eliminate property taxes on enrolled private forest lands, to foster ecosystem services. Among individual programs, there is wide variability in enrollment levels, as well as program structure and administration. Past research has explored patterns of enrollment in individual States, but to our knowledge has never been conducted at the national level. We used binary logistic regression with multiple imputation for missing data to explore the landowner, land, and program characteristics that correlate with the likelihood of enrollment in a PFPTP. We found that most landowner objectives and concerns, including those that would appear to be linked to program enrollment, such as concern about the level of taxes, were generally not correlated with likelihood of enrollment. Owning more forest area was correlated with higher likelihood of enrollment. The link of enrollment to population density suggested that enrollment is higher in moderate densities, with higher and lower densities having lower enrollment, possibly due to conflicting incentives for enrollment as land values increase. Program characteristics were negatively correlated with likelihood of enrollment, especially those that restrict uses or management. The owner's desire for wooded land to stay wooded and higher levels of penalty for program withdrawal were positively correlated with likelihood of enrollment and average rates of tax reductions were not significantly correlated, suggesting that landowners may see programs as a method of conserving and protecting their forest land in the future more than as simply a way to save money.

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Digital Engagement Session

CREATING HOMOGENOUS LANDFIRE VEGETATION CLASSES FOR FOREST INVENTORY APPLICATIONS IN THE INTERIOR WEST

Madelon R.K. Basil[1], Salma Huque[2], Kelly S. McConville[3], Gretchen G. Moisen[4], and Tracey S. Frescino[5]

Abstract

This project involved collapsing the existing vegetation type (EVT) classes created by the LANDFIRE Program into a smaller set of structure metrics based on four key forest attributes: (1) aboveground biomass, (2) net volume of trees, (3) count of trees per acre, and (4) basal area. Our goal was to create categories that were internally homogenous with respect to these four variables and heterogeneous between categories so that the resulting categories could be effectively used in estimation, mapping, and analysis applications for forest inventory. We used k-means clustering as the main classification method and made refinements to the algorithm in order to make the final categories as intuitive and useful as possible. The result was two classification schemes (1) one with five categories, and (2) one with 10 categories. We used data from one cycle of the Interior West region of the Forest Inventory and Analysis Program (FIA) but intend our method to be applicable for all FIA administered regions.

Keywords: Classification algorithm, FIA, k-means clustering, LANDFIRE, U.S. Geological Survey (USGS).

INTRODUCTION

The U.S. Department of Agriculture (USDA), Forest Service, Forest Inventory and Analysis Program (FIA) estimates numerous forest attributes at a variety of domains across the United States. Supplementing the data from ground plots with remote imagery, FIA uses auxiliary remotely sensed data to increase precision in estimates (Bechtold and Patterson 2005), build predictive models for mapping forest attributes (Moisen and Frescino 2002), and serve as a backdrop for analyses (Shaw and others 2017). Often, however, remotely-sensed data comes in the form of classified maps with an unwieldy number of classes such that collapsing is necessary to make a workable dataset for estimation, mapping, and analytical applications. This project illustrates an objective collapsing process applied to classified remotely sensed data to determine how these data could be transformed to support FIA's varied uses of remotely sensed data.

LANDFIRE (Landscape Fire and Resource Management Planning Tools) is a joint program between the USDA, Forest Service and U.S. Department of the Interior that provides geographic information to assist with wildland fire management (Rollins 2009). The LANDFIRE data products include categories such as disturbance, fuel, and vegetation. The vegetation type products include existing vegetation layers and potential vegetation layers. LANDFIRE offers three existing vegetation layers: (1) Existing Vegetation Type (EVT), (2) Existing Vegetation Canopy Cover, and (3) Existing Vegetation Height (USGS 2013, 2016). The layers were created using satellite imagery and classification and regression trees.

An EVT Class depicts the vegetation and land cover type, based on a classification of NatureServe's terrestrial ecological systems for the western Hemisphere. These types are groups of plant communities that tend to occur together (NatureServe 2018). Each class is further represented by a more generic physiognomic

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class describing the overall characteristic of the community, such as Conifer, Shrubland, and Grassland. The EVT classification also aligns with the upper physiognomic levels of the National Vegetation Classification (NVC) System, which provides standards for vegetation classifications (http://usnvc.org/). The NVC upper physiognomic levels include three variables representing general physiognomic features (*order*), such as Tree-dominated and Shrub-dominated; and more detailed physiognomic characteristics (*class*), such as Open tree canopy and Closed tree canopy; and subclasses (*subclass*), such as Evergreen closed tree canopy and Deciduous closed tree canopy. The mapped values of EVT used in these analyses are predicted values from an empirical model that naturally has a classification error.

Our primary task was the re-categorization of LANDFIRE's EVT variable. The EVT variable currently encompasses over 635 distinct classes such as "Western Cool Temperate Undeveloped Ruderal Grassland", "Western Great Plains Shortgrass Prairie", and "Madrean Pinyon-Juniper Woodland; 182 of these classes can be found in the Interior West. LANDFIRE releases the data at this level of detail to accommodate all users and their potential analysis. LANDFIRE provides users with examples and tutorials on how land managers can collapse classes to suite their analysis questions and to conduct a related assessment of class agreements. We illustrate an alternative solution by collapsing the current EVT classes into a smaller set of categories based on four forest structure attributes (live trees only) that form the foundation of many FIA analyses: aboveground biomass (pounds), net volume (cubic feet) of trees, count of trees per acre, and basal area (square feet). Understanding that EVT classes are based on species composition and the target variables are based on forest structure, our goal is to create new structure metric categories that are internally homogenous with respect to these four variables and heterogeneous between categories.

This report explains the methodology used to create the structure metrics for collapsing the EVT variable. In the Data section, we discuss the data used to build the new classification and in the Methods section, we explain the techniques used to create the classification scheme. In the Results section, we present our refined process, final schemes, and visualizations. In the Discussion section, we review the effectiveness of our final schemes, offer limitations of our work, and outline potential uses of the final schemes.

DATA

The data used include the most current 10-year measurement cycle for each Interior-West State, downloaded from the FIA database on February 6, 2019 from version FIADB_1.8.9.99 (last updated December 3, 2018). The data were collected between 2007 and 2017 and represent 86,085 ground plots. All States included a complete 10-year cycle of data except Wyoming, which had only 7 of 10 years of data collected at the time of download. These data were collected using a quasi-systematic sampling design (Bechtold and Patterson 2005) wherein the observational unit is a single ground plot. We merged a dataset containing the four FIA collected variables. These variables were extrapolated and summed to an acre-plot size for live trees only (aboveground biomass, net volume of trees, count of trees per acre, and basal area) with a dataset containing the EVT variable that was identified by the center point of each plot location. A clustering algorithm was applied to the data at (1) the plot level, wherein each row of the dataset represented one of the 86,085 ground plots, and (2) at the EVT level, wherein each row of the dataset represented one of the 182 EVT classes found in the Interior West. To create the EVT level dataset, we recorded the mean of each of the four forest attribute variables (mean biomass, mean net volume, mean tree count, and mean basal area) across all the observations within a specific EVT class.

METHODS

Defining Observations

The overarching objective of this analysis was to collapse the EVT classes into a meaningful number of larger classes for our analysis purposes by assigning EVT classes to clusters identified through the k-means process. The process was run in two distinctly different ways. First, the individual plots were treated as the observations and run through the clustering process, referred to as "plot-level analyses" in the RESULTS. Second, the EVT classes themselves were treated as the observations, referred to as "EVT class level analysis" in the RESULTS.

K-Means Clustering

For much of our research, we utilized the k-means clustering algorithm. K-means clustering is an unsupervised learning algorithm that helps to reveal distinct structures in a dataset by partitioning the observations into non-hierarchical groups called clusters (James et al. 2013). To create the clusters, the algorithm requires the user to specify the number of groups they want to obtain from the data; this value is denoted as *k*. In step one, the algorithm randomly assigns each observation to one of the *k* groups. Then, for each of these groups, a mean point known as a centroid is computed. In step two, each observation is reassigned a cluster based on its Euclidean distance to the closest centroid. The mean of each new cluster is found and the centroid is repositioned to once again represent the mean. Step two is iterated repeatedly until the centroids no longer shift. To implement this method, we used the R function *kmeans()* (R Core Team 2019), which implements the Hartigan and Wong (1979) algorithm. When used appropriately, k-means clustering results in observations neatly separated into clusters that are internally similar with respect to the response variables of interest, yet dissimilar from other clusters.

Elbow Method

In conjunction with our use of k-means, we consulted the elbow method, a process used to verify that a user of the k-means clustering algorithm has selected a suitable value for *k*. To determine the optimal number for *k*, the elbow method uses the within sum of squares measure, which is given by

$$WSS = \sum_{j=1}^{k}\sum_{i=1}^{nj}(\boldsymbol{x}_{j,i} - \mathbf{c}_j)^t(\boldsymbol{x}_{j,i} - \mathbf{c}_j)$$

where $\boldsymbol{x}_{j,i} = (x_{j,i,1}, x_{j,i,2}, x_{j,i,3}, x_{j,i,4})^t$ is the vector containing the four forest attribute values for the ith observation in cluster j, $\mathbf{c}_j = (c_{j,1}, c_{j,2}, c_{j,3}, c_{j,4})^t$ is the vector containing the forest attribute values for the centroid of cluster *j*, and *nj* is the number of observations in cluster *j* (James and others 2013). This measure is the sum of the squared distances between each observation and its respective centroid. When calculated for various k-means trials, all with different *k* values, it demonstrates how tightly clustered the resulting k-means groupings are, as *k* grows. In this sense, the elbow method allowed us to determine the smallest *k* value in which the resulting clusters are still very tightly grouped and name this our optimal *k* value. We produced an elbow curve that displays the relationship between k-means trials with a different *k* and the calculated corresponding WSS. This visualization indicated that beginning with four clusters ($k = 4$), the WSS only exhibits small decreases as *k* increases for both the plot level dataset and the EVT class level dataset and therefore $k = 4$ would be the best starting option for our analyses.

RESULTS

Zero Response Cluster

Seventy-two percent of the plots contained a zero for biomass, net volume, count of trees, and basal area. The vast majority of these plots, 96 percent, belonged to the Interior West non-forest stratum. When the k-means algorithm was applied to the dataset that included the zero observations, it resulted in the creation of a very large cluster that represented plots having small values for the four response variables. In our 5-cluster scheme, this "Low" cluster was composed of over 72,000 of the 86,085 observations and combined different EVT classes that were not to be conflated with one another. For example, sparsely vegetated and shrub-like classes were grouped together with observations labeled "Snow-Ice", "Barren", and "Water". Because we aimed to create clusters guided by ecological principles (as well as being homogenous in terms of our responses), the zero observations were automatically placed into their own cluster, denoted *Cluster 0*, and excluded from further analyses.

Increasing the Number of Categories

Another technique we used to further refine our k-means clusters involved increasing our k value and evaluating whether any new patterns were drawn out from our cloud of observations. Altering the number of clusters we wanted to obtain from our data helped us identify layering effects we were not able to see when there were only five clusters. The $k = 10$ appeared to bring out subtle patterns that may prove beneficial to some applications. Therefore, we decided our final product should consist of two schemes for condensing EVT: one coarser scheme where $k = 5$ and one finer scheme where $k = 10$.

Mapping EVT Classes to Clusters

***Plot level analysis*—**Once each ground plot had a cluster assignment, the final task was to assign each EVT class to a particular cluster. This proved difficult because in many cases, a given EVT class had membership in more than one of our clusters. For example, we would anticipate that most "Northern Rocky Mountain Mesic Montane Mixed Conifer Forest" observations would be sorted into the one of our four k-means clusters that ensured the most within-cluster homogeneity and between-cluster heterogeneity in terms of our four responses of interest. However, what we found when we plotted the division of the four clusters within "Northern Rocky Mountain Mesic Montane Mixed Conifer Forest", as shown in figure 1, was that this EVT class was included in all four of our distinct k-means clusters. This phenomenon was not exclusive to only one or two

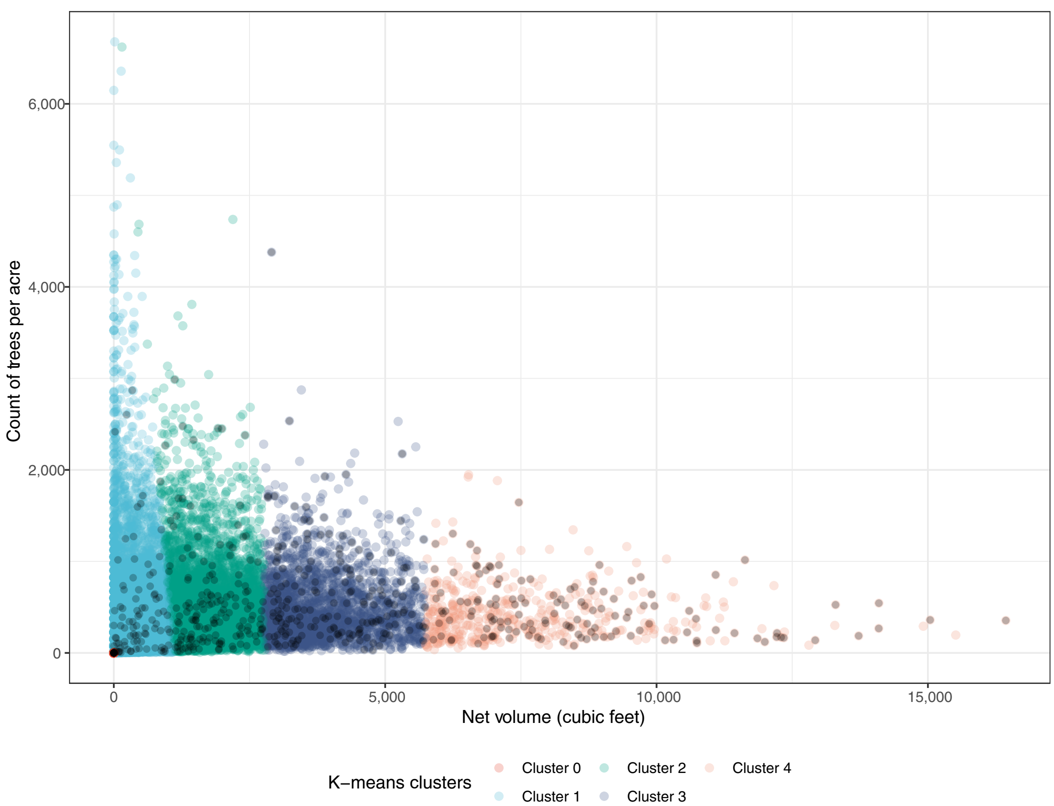

Figure 1—A scatterplot of volume and tree count, colored by the 5 k-means clusters. Although only two response variables are graphed, the clusters do account for all four response variables. Each dot represents a single ground plot and the black dots are those in the existing vegetation type (EVT) class "Northern Rocky Mountain Mesic Montane Mixed Conifer Forest".

EVT classes, but also appeared in many instances across the data. It was seen most commonly with observations marked “Conifer”, “Hardwood”, or “Riparian” in terms of plant physiognomy.

One possible explanation for the presence of these physiognomic classes in multiple clusters could be that certain types of vegetation are sorted into different clusters at different points in their growth. In the case of conifers, the trees included in this category grow very large across their lifespan. While conifer saplings may fall into a cluster characterized by low biomass and low net volume, fully grown trees will likely be clustered in a different group. On the other hand, this is less of an issue with EVTs generally composed of smaller trees and shrubs because they typically remain the same size (with limited aboveground biomass, net volume, etc.) over their lifespan relative to the conifers. Another possible explanation could be due to the natural variations in the vegetation communities within the EVT classes themselves. For example, plant communities at the fringes of membership in EVT classes can look very different in terms of canopy closure.

We attempted to resolve this issue by implementing our unique version of a classification algorithm. The process unfolded as follows: we first created a dataset with all observations grouped by *order*, with one row per cluster per order. We then determined which of the k-means clusters contained the majority of the data within each order and assigned all observations of that order to that majority cluster. In cases where there was no cluster that encompassed a clear majority, we divided the order into the finer category of *class* and repeated; for classes with no clear majority cluster, we went down to the *subclass* level and repeated. If a particular subclass did not have a clear majority cluster, we divided the subclass into EVT classes and repeated the process a final time. Note the “nested” nature of these categorical variables; all of the EVT classes in our data had membership in exactly one subclass, all subclasses had membership in exactly one class, and all classes has membership in exactly one order.

Ultimately, many of the EVT classes had no clear majority cluster, so we determined EVT class-level analyses to be most appropriate for this application. Exhausting this classification algorithm allowed us to return to the k-means algorithm with new knowledge about where our clusters intersected well with EVT classes and where the majority of observations within a particular EVT class refused to be sorted into a singular k-means cluster.

***EVT class level analysis*—**We solved the multiple class problem by clustering at the EVT class level, instead of at the plot level. With only one observation per EVT class, it could only be placed into one cluster. As outlined in the Data section, we created the EVT level dataset by computing the mean response values (mean biomass, mean net volume, mean tree count, and mean basal area) across all observations within a specific EVT class. Then, instead of running k-means on all 86,085 ground plots, we were able to cluster each of the 182 EVT classes based on their mean response values. This eliminated the possibility of one EVT class inappropriately falling into multiple clusters. As with the schemes above, we included a *Cluster 0* composed of EVT classes in which the mean values for each forest structure attribute were all zero.

Final Results

Our final result was two classifications at the EVT level—one with five clusters and one with ten clusters. We used k-means to create the clusters and used the elbow method to determine that four clusters (plus a zero cluster) were the optimal number. As discussed in the Methods section, the decision to also increase the k value was made with the hope that doing so could reveal distinctions between different vegetation classes (particularly those with low volume and high-count values). Both of the resulting classifications were created using the mean values of the four response variables across all EVT observations. The result for $k = 5$ is shown in figure 2 and $k = 10$ in figure 3. A summary of each scheme is given in table 1 and table 2 and the entire look-up table can be found in the appendix table.

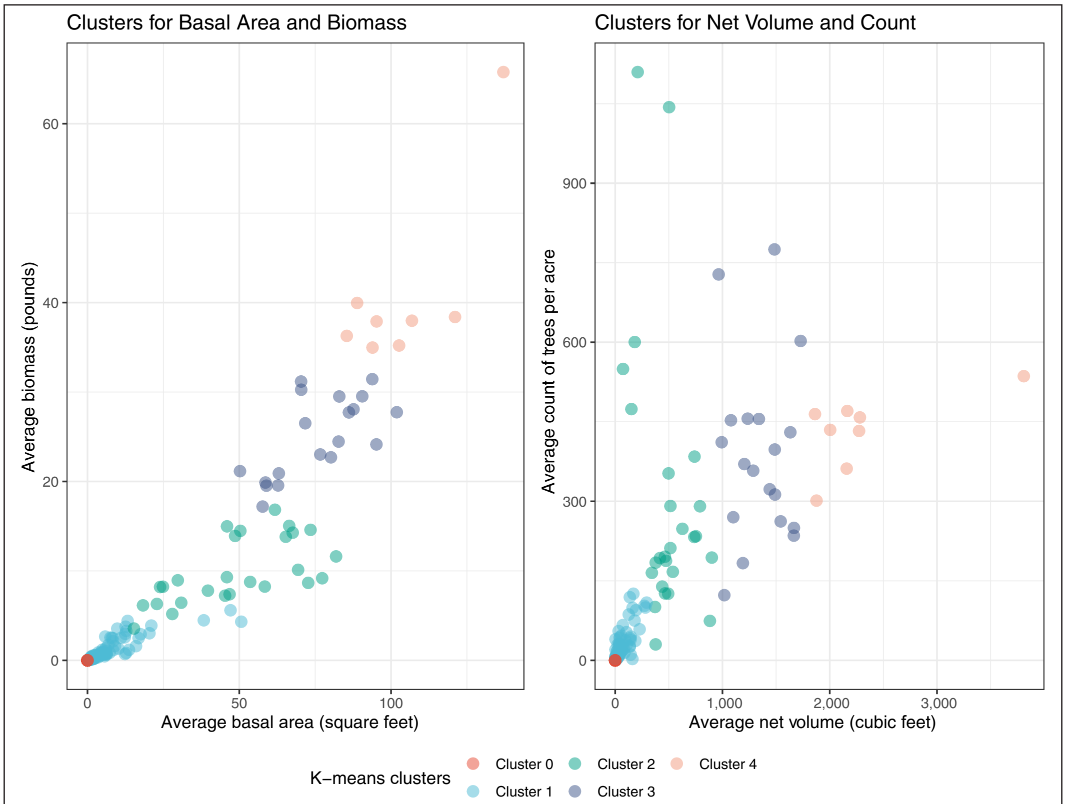

Figure 2—Scatterplots of the response variables, colored by the 5 k-means clusters at the existing vegetation type (EVT) classification level.

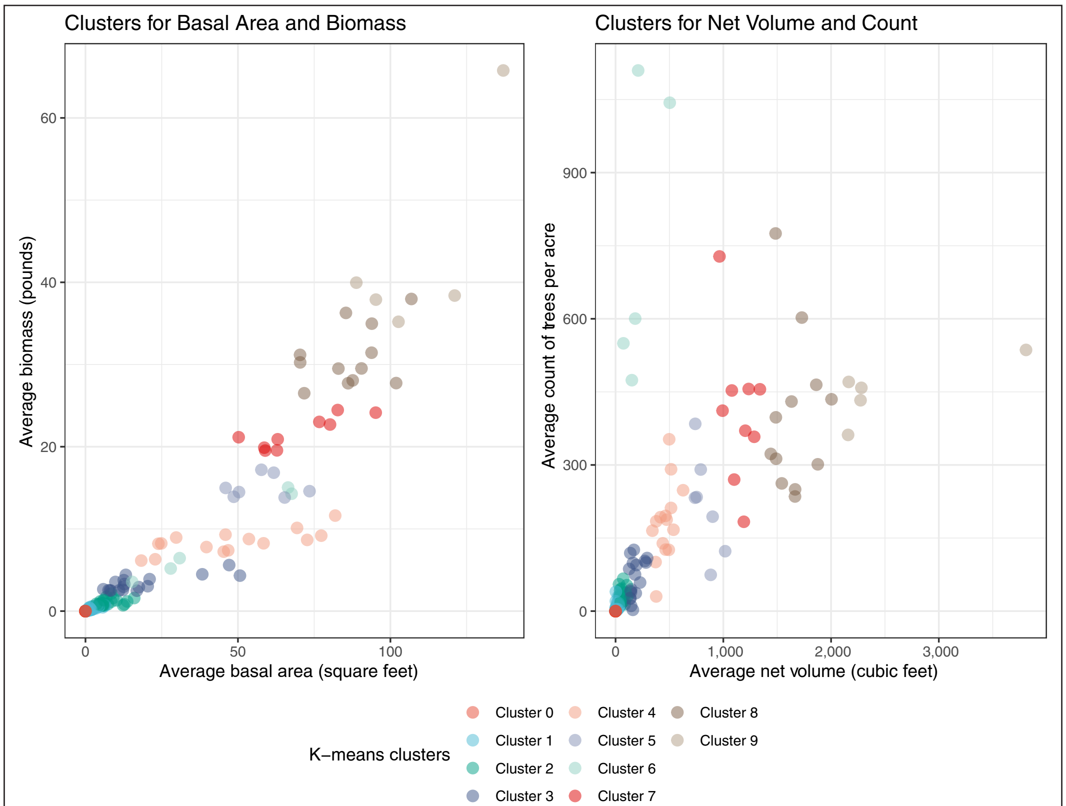

Figure 3—Scatterplots of the response variables, colored by the 10 k-means clusters at the existing vegetation type (EVT) classification level.

Table 1—Final existing vegetation type (EVT) cluster descriptions (*k* = 5)

Cluster	Cluster description	Most common EVT class names (count)
0	All response variables equal zero	• Western Cool Temperate Wheat (1,922) • Sonoran Desert Sparsely Vegetated (140) • Western Cool Temperate Undeveloped Ruderal Grassland (136)
1	Tends to be shrubland and prairie	• Inter-Mountain Basins Big Sagebrush Shrubland (7,323) • Northwestern Great Plains Mixedgrass Prairie (4,836) • Western Great Plains Shortgrass Prairie (4,519)
2	Tends to be Pinyon-Juniper Woodland	• Colorado Plateau Pinyon-Juniper Woodland (3,419) • Great Basin Pinyon-Juniper Woodland (1,911) • Madrean Pinyon-Juniper Woodland (681)
3	Tends to be conifers with moderately high levels of biomass, basal area, and net volume	• Southern Rocky Mountain Ponderosa Pine Woodland (1,462) • Rocky Mountain Aspen Forest and Woodland (1,039) • Rocky Mountain Lodgepole Pine Forest (1,024)
4	Tends to be conifers with moderately high levels of biomass, basal area, and net volume	• Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest (1,627) • Rocky Mountain Subalpine Mesic-Wet Spruce-Fir Forest (1,012) • Northern Rocky Mountain Dry-Mesic Montane Mixed-Conifer Forest (918)

Final results are also illustrated in figures 2 and 3. They are the result of clustering on the EVT class level with the inclusion of a *Cluster 0* group. The coarser scheme (where $k = 5$) is more collapsed, but it is less representative of subtle patterning in the dataset, especially regarding observations with low volume values but higher tree count values. The finer scheme (where $k = 10$) is less collapsed but may be more appropriate for use in situations where it is important for the EVT variable to be able to distinguish between different types of vegetation with low volumes and high counts. Each cluster name is our attempt to broadly describe the EVT classes typically found in that cluster. However, these names don't perfectly define all the EVT classes represented.

Each scheme and the clusters included within them are outlined further in tables 1 and 2. They display a more extensive name for each cluster based on the various EVT classes that appear within it. Additionally, the tables list the top three most common, in terms of number of ground plots, EVT classes within each cluster.

DISCUSSION

The goal of this project was to demonstrate an objective process for using classified remotely sensed data to support FIA. We used FIA's commonly reported attributes for describing structure characteristics of forest land, with the understanding that the classified EVT map characterizes plant community types across all land. The difficulties in defining discrete clusters can be attributed to both how the map classification scheme was designed as well as with the prediction error of the map product. The alignment was naturally challenging because we were trying to coerce species composition-based classes into classes that specifically reflected forest structure. Also, prediction error is always an issue when trying to apply any classification scheme across large geographic extents. These are common issues FIA faces when trying to build relationships with ground data to classified map products. We are hoping this objective process can shed some light on this issue.

Table 2—Final existing vegetation type (EVT) cluster descriptions (*k* = 10)

Cluster	Cluster description	Most common EVT class names (count)
0	All response variables equal zero	• Western Cool Temperate Wheat (1,922) • Sonoran Desert Sparsely Vegetated (140) • Western Cool Temperate Undeveloped Ruderal Grassland (136)
1	Tends to be shrubland and prairie	• Inter-Mountain Basins Big Sagebrush Shrubland (7,323) • Northwestern Great Plains Mixedgrass Prairie (4,836) • Western Great Plains Shortgrass Prairie (4,519)
2	Tends to be grassland and shrubland	• Inter-Mountain Basins Semi-Desert Grassland (1,417) • Artemisia Tridentata ssp. Vasenya Shrubland Alliance (1.413) • Inter-Mountain Basins Montane Sagebrush Steppe (889)
3	Tends to be grassland	• Northern Rocky Mountain Lower Montane-Foothill-Valley Grassland (811) • Rocky Mountain Subalpine-Montane Mesic Meadow (582) • Introduced Upland Vegetation-Perennial Grassland and Forbland (473)
4	Tends to be Pinyon-Juniper Woodland	• Colorado Plateau Pinyon-Juniper Woodland (3,419) • Great Basin Pinyon-Juniper Woodland (1,911) • Madrean Pinyon-Juniper Woodland (681)
5	Tends to be conifer woodlands	• Northwestern Great Plains-Black Hills Ponderosa Pine Woodland and Savanna (267) • North American Warm Desert Riparian Forest and Woodland (105) • Southern Rocky Mountain Ponderosa Pine Savanna (99)
6	Tends to be shrubland with a high tree count	• *Quercus Gambelii* Shrubland Alliance (419) • Rocky Mountain Gambel Oak-Mixed Montane Shrubland (169) • Rocky Mountain Bigtooth Maple Ravine Woodland (76)
7	Tends to be conifers with moderately high levels of biomass, basal area, and net volume	• Southern Rocky Mountain Ponderosa Pine Woodland (1,462) • Rocky Mountain Aspen Forest and Woodland (1,039) • Northern Rocky Mountain Subalpine Woodland and Parkland (605)
8	Tends to be conifers with high levels of biomass, basal area, and net volume	• Rocky Mountain Lodgepole Pine Forest (1,024) • Dry-Mesic Montane Douglas-Fir Forest (894) • Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland (782)
9	Tends to be Spruce-Fir Forest with high levels of biomass, basal area, and net volume	• Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest (1,627) • Rocky Mountain Subalpine Mesic-Wet Spruce-Fir Forest (1,012) • Northern Rocky Mountain Dry-Mesic Montane Mixed-Conifer Forest (918)

Our hope is that these schemes will allow for a more convenient use of the EVT variable by FIA. Rather than having to deal with an overwhelming 182 EVT classes in the Interior West, researchers will now be able to utilize the new classes we created in order to incorporate information from the EVT class into estimation, mapping, and analysis applications. Of course, caution must be exercised when using collapsed classes in model-assisted estimators to ensure the data used to create new clusters are not the same data used in estimation equations. Similarly when building predictive models for mapping, care should be taken not to use the same data in cluster creation as is used in map validation.

The biggest difficulty we faced when collapsing the EVT variable revolved around trying to generate clusters which made sense from both a mathematical and an ecological standpoint. Our priority throughout the research process was to create groupings that were internally homogenous for our forest structure attributes, but fairly dissimilar from the other clusters created. However, it was also important for us to consider that our clusters were able to reconcile these statistically driven criteria with ecological distinctions. For example, we thought it was inappropriate for our clusters to group things like "Snow-Ice", "Barren", and "Water" observations with sparsely vegetated plant communities. In the same way, it was not useful to have Pinyon-Juniper type trees in different clusters. However, we were able to strike this balance between the ecological and the statistical through our various refinements of the k-means process. These refinements included constructing the *Cluster 0*, increasing the k value to expose patterns that were otherwise obscured, and clustering on the EVT class level rather than the plot level.

Researchers looking to continue refining the re-categorization of the EVT variable may want to turn to hierarchical clustering. Running a complete hierarchical clustering algorithm on the multitude of EVT classes may yield interesting results. It would be compelling to see if our proposed k-means schemes would be enhanced, corroborated, or contradicted by a procedure that arranges the EVT classes hierarchically. Another avenue for further inquiry may be to explore the geography of our clusters. Since many of the original EVT classes seemed to be geographically informed (especially with class names like "Colorado Plateau Pinyon-Juniper Woodland" and "Southern Rocky Mountain Ponderosa Pine Woodland"), it would be valuable to investigate if our suggested clusters are concentrated in particular regions of the Interior West or if they follow any notable geographic patterns.

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APPENDIX

Look-up table for Interior West existing vegetation type (EVT) classification

evtLF	Class name	Coarse clusters	Fine clusters	Count
3968	Western Cool Temperate Wheat	Cluster 0	Cluster 0	1922
3223	Sonoran Desert Sparsely Vegetated	Cluster 0	Cluster 0	140
3944	Western Cool Temperate Undeveloped Ruderal Grassland	Cluster 0	Cluster 0	136
3985	Western Warm Temperate Close Grown Crop	Cluster 0	Cluster 0	81
3298	Developed-High Intensity	Cluster 0	Cluster 0	44
3004	North American Warm Desert Sparsely Vegetated Systems	Cluster 0	Cluster 0	35
3913	Western Warm Temperate Urban Herbaceous	Cluster 0	Cluster 0	26
3504	Chihuahuan-Sonoran Desert Bottomland and Swale Grassland	Cluster 0	Cluster 0	22
3077	Chihuahuan Succulent Desert Scrub	Cluster 0	Cluster 0	21
3088	Sonora-Mojave Mixed Salt Desert Scrub	Cluster 0	Cluster 0	21
3094	Western Great Plains Sandhill Shrubland	Cluster 0	Cluster 0	21
3963	Western Cool Temperate Row Crop - Close Grown Crop	Cluster 0	Cluster 0	20
3988	Western Warm Temperate Wheat	Cluster 0	Cluster 0	20
3943	Western Cool Temperate Undeveloped Ruderal Shrubland	Cluster 0	Cluster 0	19
3980	Western Warm Temperate Orchard	Cluster 0	Cluster 0	13
3255	Inter-Mountain Basins Montane Riparian Shrubland	Cluster 0	Cluster 0	11
3987	Western Warm Temperate Pasture and Hayland	Cluster 0	Cluster 0	11
3211	*Grayia spinosa* Shrubland Alliance	Cluster 0	Cluster 0	10
3983	Western Warm Temperate Row Crop - Close Grown Crop	Cluster 0	Cluster 0	10
3134	Columbia Basin Foothill and Canyon Dry Grassland	Cluster 0	Cluster 0	7
3090	Sonoran Granite Outcrop Desert Scrub	Cluster 0	Cluster 0	4
3065	Columbia Plateau Scabland Shrubland	Cluster 0	Cluster 0	3
3925	Western Warm Temperate Developed Ruderal Deciduous Forest	Cluster 0	Cluster 0	2

Note: The first and second column represent the original EVT code and classification name. Column three is based on $k = 5$ and column 4 is based on $k = 10$. The last column represents the number of Interior West ground plots in that EVT class.

(continued)

Look-up table for Interior West existing vegetation type (EVT) classification (continued)

evtLF	Class name	Coarse clusters	Fine clusters	Count
3027	Mediterranean California Dry-Mesic Mixed Conifer Forest and Woodland	Cluster 0	Cluster 0	1
3138	North Pacific Montane Grassland	Cluster 0	Cluster 0	1
3926	Western Warm Temperate Developed Ruderal Evergreen Forest	Cluster 0	Cluster 0	1
3948	Western Warm Temperate Undeveloped Ruderal Shrubland	Cluster 0	Cluster 0	1
3911	Western Warm Temperate Urban Evergreen Forest	Cluster 0	Cluster 0	1
3080	Inter-Mountain Basins Big Sagebrush Shrubland	Cluster 1	Cluster 1	7323
3141	Northwestern Great Plains Mixedgrass Prairie	Cluster 1	Cluster 1	4836
3149	Western Great Plains Shortgrass Prairie	Cluster 1	Cluster 1	4519
3125	Inter-Mountain Basins Big Sagebrush Steppe	Cluster 1	Cluster 1	3100
3081	Inter-Mountain Basins Mixed Salt Desert Scrub	Cluster 1	Cluster 1	3006
3109	Sonoran Paloverde-Mixed Cacti Desert Scrub	Cluster 1	Cluster 1	2072
3294	Barren	Cluster 1	Cluster 1	2039
3181	Introduced Upland Vegetation-Annual Grassland	Cluster 1	Cluster 1	1949
3153	Inter-Mountain Basins Greasewood Flat	Cluster 1	Cluster 1	1910
3256	Apacherian-Chihuahuan Semi-Desert Grassland	Cluster 1	Cluster 1	1480
3079	Great Basin Xeric Mixed Sagebrush Shrubland	Cluster 1	Cluster 1	1458
3135	Inter-Mountain Basins Semi-Desert Grassland	Cluster 1	Cluster 2	1417
3220	Artemisia tridentata ssp. vaseyana Shrubland Alliance	Cluster 1	Cluster 2	1413
3087	Sonora-Mojave Creosotebush-White Bursage Desert Scrub	Cluster 1	Cluster 1	1253
3095	Apacherian-Chihuahuan Mesquite Upland Scrub	Cluster 1	Cluster 1	1124
3924	Western Cool Temperate Developed Ruderal Grassland	Cluster 1	Cluster 1	1094
3965	Western Cool Temperate Close Grown Crop	Cluster 1	Cluster 1	1064
3966	Western Cool Temperate Fallow/Idle Cropland	Cluster 1	Cluster 1	1060
3082	Mojave Mid-Elevation Mixed Desert Scrub	Cluster 1	Cluster 1	989
3126	Inter-Mountain Basins Montane Sagebrush Steppe	Cluster 1	Cluster 2	889
3139	Northern Rocky Mountain Lower Montane-Foothill-Valley Grassland	Cluster 1	Cluster 3	811
3292	Open Water	Cluster 1	Cluster 1	782
3210	Coleogyne ramosissima Shrubland Alliance	Cluster 1	Cluster 1	731
3074	Chihuahuan Creosotebush Desert Scrub	Cluster 1	Cluster 1	706
3964	Western Cool Temperate Row Crop	Cluster 1	Cluster 1	696
3299	Developed-Roads	Cluster 1	Cluster 1	692
3219	Inter-Mountain Basins Sparsely Vegetated Systems II	Cluster 1	Cluster 2	673
3093	Southern Colorado Plateau Sand Shrubland	Cluster 1	Cluster 1	622
3145	Rocky Mountain Subalpine-Montane Mesic Meadow	Cluster 1	Cluster 3	582
3148	Western Great Plains Sand Prairie Grassland	Cluster 1	Cluster 1	548
3967	Western Cool Temperate Pasture and Hayland	Cluster 1	Cluster 1	515
3212	Western Great Plains Sandhill Grassland	Cluster 1	Cluster 1	498
3100	Chihuahuan Mixed Desert and Thornscrub	Cluster 1	Cluster 1	497
3182	Introduced Upland Vegetation-Perennial Grassland and Forbland	Cluster 1	Cluster 3	473
3127	Inter-Mountain Basins Semi-Desert Shrub-Steppe	Cluster 1	Cluster 2	464

Note: The first and second column represent the original EVT code and classification name. Column three is based on *k* = 5 and column 4 is based on *k* = 10. The last column represents the number of Interior West ground plots in that EVT class.

(continued)

Look-up table for Interior West existing vegetation type (EVT) classification (continued)

evtLF	Class name	Coarse clusters	Fine clusters	Count
3104	Mogollon Chaparral	Cluster 1	Cluster 2	441
3183	Introduced Upland Vegetation-Annual and Biennial Forbland	Cluster 1	Cluster 1	404
3066	Inter-Mountain Basins Mat Saltbush Shrubland	Cluster 1	Cluster 1	394
3086	Rocky Mountain Lower Montane-Foothill Shrubland	Cluster 1	Cluster 2	376
3923	Western Cool Temperate Developed Ruderal Shrubland	Cluster 1	Cluster 1	373
3218	North American Warm Desert Sparsely Vegetated Systems II	Cluster 1	Cluster 2	357
3124	Columbia Plateau Low Sagebrush Steppe	Cluster 1	Cluster 1	335
3006	Rocky Mountain Alpine/Montane Sparsely Vegetated Systems	Cluster 1	Cluster 3	330
3162	Western Great Plains Floodplain Forest and Woodland	Cluster 1	Cluster 3	325
3085	Northwestern Great Plains Shrubland	Cluster 1	Cluster 2	307
3001	Inter-Mountain Basins Sparsely Vegetated Systems	Cluster 1	Cluster 2	290
3503	Chihuahuan Loamy Plains Desert Grassland	Cluster 1	Cluster 1	262
3064	Colorado Plateau Mixed Low Sagebrush Shrubland	Cluster 1	Cluster 2	258
3296	Developed-Low Intensity	Cluster 1	Cluster 1	241
3106	Northern Rocky Mountain Montane-Foothill Deciduous Shrubland	Cluster 1	Cluster 2	199
3258	North American Warm Desert Riparian Herbaceous	Cluster 1	Cluster 1	193
3215	*Quercus turbinella* Shrubland Alliance	Cluster 1	Cluster 3	174
3123	Columbia Plateau Steppe and Grassland	Cluster 1	Cluster 1	144
3204	Western Great Plains Mesquite Shrubland	Cluster 1	Cluster 1	142
3132	Central Mixedgrass Prairie Grassland	Cluster 1	Cluster 1	139
3904	Western Cool Temperate Urban Shrubland	Cluster 1	Cluster 2	139
3076	Chihuahuan Stabilized Coppice Dune and Sand Flat Scrub	Cluster 1	Cluster 1	136
3986	Western Warm Temperate Fallow/Idle Cropland	Cluster 1	Cluster 1	136
3075	Chihuahuan Mixed Salt Desert Scrub	Cluster 1	Cluster 1	131
3297	Developed-Medium Intensity	Cluster 1	Cluster 1	128
3903	Western Cool Temperate Urban Herbaceous	Cluster 1	Cluster 1	126
3007	Western Great Plains Sparsely Vegetated Systems	Cluster 1	Cluster 1	113
3928	Western Warm Temperate Developed Ruderal Shrubland	Cluster 1	Cluster 1	94
3091	Sonoran Mid-Elevation Desert Scrub	Cluster 1	Cluster 1	93
3147	Western Great Plains Foothill and Piedmont Grassland	Cluster 1	Cluster 2	92
3213	*Quercus havardii* Shrubland Alliance	Cluster 1	Cluster 1	88
3133	Chihuahuan Sandy Plains Semi-Desert Grassland	Cluster 1	Cluster 2	86
3144	Rocky Mountain Alpine Turf	Cluster 1	Cluster 2	80
3072	Wyoming Basins Dwarf Sagebrush Shrubland and Steppe	Cluster 1	Cluster 1	75
3259	Introduced Riparian Shrubland	Cluster 1	Cluster 1	68
3164	Rocky Mountain Wetland-Herbaceous	Cluster 1	Cluster 2	64
3984	Western Warm Temperate Row Crop	Cluster 1	Cluster 1	61
3121	Apacherian-Chihuahuan Semi-Desert Shrubland	Cluster 1	Cluster 1	56
3116	Madrean Juniper Savanna	Cluster 1	Cluster 3	54
3295	Quarries-Strip Mines-Gravel Pits	Cluster 1	Cluster 1	51

Note: The first and second column represent the original EVT code and classification name. Column three is based on $k = 5$ and column 4 is based on $k = 10$. The last column represents the number of Interior West ground plots in that EVT class.

(continued)

Look-up table for Interior West existing vegetation type (EVT) classification (continued)

evtLF	Class name	Coarse clusters	Fine clusters	Count
3495	Western Great Plains Depressional Wetland Systems	Cluster 1	Cluster 1	50
3115	Inter-Mountain Basins Juniper Savanna	Cluster 1	Cluster 3	47
3293	Snow-Ice	Cluster 1	Cluster 2	47
3222	Rocky Mountain Alpine/Montane Sparsely Vegetated Systems II	Cluster 1	Cluster 3	46
3914	Western Warm Temperate Urban Shrubland	Cluster 1	Cluster 1	41
3250	Inter-Mountain Basins Curl-leaf Mountain Mahogany Shrubland	Cluster 1	Cluster 1	37
3070	Rocky Mountain Alpine Dwarf-Shrubland	Cluster 1	Cluster 3	36
3119	Southern Rocky Mountain Juniper Woodland and Savanna	Cluster 1	Cluster 3	32
3900	Western Cool Temperate Urban Deciduous Forest	Cluster 1	Cluster 3	32
3254	Western Great Plains Floodplain Herbaceous	Cluster 1	Cluster 3	30
3251	Rocky Mountain Montane Riparian Shrubland	Cluster 1	Cluster 3	27
3180	Introduced Riparian Forest and Woodland	Cluster 1	Cluster 2	24
3078	Colorado Plateau Blackbrush-Mormon-tea Shrubland	Cluster 1	Cluster 1	21
3103	Great Basin Semi-Desert Chaparral	Cluster 1	Cluster 3	21
3108	Sonora-Mojave Semi-Desert Chaparral	Cluster 1	Cluster 1	21
3921	Western Cool Temperate Developed Ruderal Evergreen Forest	Cluster 1	Cluster 2	20
3253	Western Great Plains Floodplain Shrubland	Cluster 1	Cluster 1	15
3385	Western Great Plains Wooded Draw and Ravine	Cluster 1	Cluster 3	15
3101	Madrean Oriental Chaparral	Cluster 1	Cluster 2	12
3929	Western Warm Temperate Developed Ruderal Grassland	Cluster 1	Cluster 1	11
3216	*Cercocarpus montanus* Shrubland Alliance	Cluster 1	Cluster 2	8
3122	Chihuahuan *Gypsophilous* Grassland and Steppe	Cluster 1	Cluster 2	8
3902	Western Cool Temperate Urban Mixed Forest	Cluster 1	Cluster 3	6
3910	Western Warm Temperate Urban Deciduous Forest	Cluster 1	Cluster 1	5
3214	*Arctostaphylos patula* Shrubland Alliance	Cluster 1	Cluster 3	4
3221	Mediterranean California Sparsely Vegetated Systems II	Cluster 1	Cluster 1	4
3016	Colorado Plateau Pinyon-Juniper Woodland	Cluster 2	Cluster 4	3419
3019	Great Basin Pinyon-Juniper Woodland	Cluster 2	Cluster 4	1911
3025	Madrean Pinyon-Juniper Woodland	Cluster 2	Cluster 4	681
3217	*Quercus gambelii* Shrubland Alliance	Cluster 2	Cluster 6	419
3059	Southern Rocky Mountain Pinyon-Juniper Woodland	Cluster 2	Cluster 4	405
3179	Northwestern Great Plains-Black Hills Ponderosa Pine Woodland and Savanna	Cluster 2	Cluster 5	267
3062	Inter-Mountain Basins Curl-leaf Mountain Mahogany Woodland	Cluster 2	Cluster 4	261
3146	Southern Rocky Mountain Montane-Subalpine Grassland	Cluster 2	Cluster 4	185
3140	Northern Rocky Mountain Subalpine-Upper Montane Grassland	Cluster 2	Cluster 4	178
3107	Rocky Mountain Gambel Oak-Mixed Montane Shrubland	Cluster 2	Cluster 6	169
3169	Northern Rocky Mountain Subalpine Deciduous Shrubland	Cluster 2	Cluster 4	157
3023	Madrean Encinal	Cluster 2	Cluster 4	127
3252	Rocky Mountain Subalpine/Upper Montane Riparian Shrubland	Cluster 2	Cluster 4	118
3155	North American Warm Desert Riparian Forest and Woodland	Cluster 2	Cluster 5	105

Note: The first and second column represent the original EVT code and classification name. Column three is based on $k = 5$ and column 4 is based on $k = 10$. The last column represents the number of Interior West ground plots in that EVT class.

(continued)

Look-up table for Interior West existing vegetation type (EVT) classification (continued)

evtLF	Class name	Coarse clusters	Fine clusters	Count
3117	Southern Rocky Mountain Ponderosa Pine Savanna	Cluster 2	Cluster 5	99
3049	Rocky Mountain Foothill Limber Pine-Juniper Woodland	Cluster 2	Cluster 4	94
3012	Rocky Mountain Bigtooth Maple Ravine Woodland	Cluster 2	Cluster 6	76
3154	Inter-Mountain Basins Montane Riparian Forest and Woodland	Cluster 2	Cluster 4	71
3017	Columbia Plateau Western Juniper Woodland and Savanna	Cluster 2	Cluster 4	51
3031	California Montane Jeffrey Pine(-Ponderosa Pine) Woodland	Cluster 2	Cluster 4	24
3901	Western Cool Temperate Urban Evergreen Forest	Cluster 2	Cluster 5	12
3920	Western Cool Temperate Developed Ruderal Deciduous Forest	Cluster 2	Cluster 6	11
3098	California Montane Woodland and Chaparral	Cluster 2	Cluster 5	4
3232	*Abies grandis* Forest Forest	Cluster 2	Cluster 4	2
3026	Madrean Upper Montane Conifer-Oak Forest and Woodland	Cluster 2	Cluster 5	2
3009	Northwestern Great Plains Aspen Forest and Parkland	Cluster 2	Cluster 6	1
3054	Southern Rocky Mountain Ponderosa Pine Woodland	Cluster 3	Cluster 7	1462
3011	Rocky Mountain Aspen Forest and Woodland	Cluster 3	Cluster 7	1039
3050	Rocky Mountain Lodgepole Pine Forest	Cluster 3	Cluster 8	1024
3061	Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland	Cluster 3	Cluster 8	782
3046	Northern Rocky Mountain Subalpine Woodland and Parkland	Cluster 3	Cluster 7	605
3235	Xeric Montane Douglas-fir Forest	Cluster 3	Cluster 8	603
3051	Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland	Cluster 3	Cluster 7	545
3159	Rocky Mountain Montane Riparian Forest and Woodland	Cluster 3	Cluster 7	479
3166	Middle Rocky Mountain Montane Douglas-fir Forest and Woodland	Cluster 3	Cluster 8	298
3024	Madrean Lower Montane Pine-Oak Forest and Woodland	Cluster 3	Cluster 7	170
3053	Northern Rocky Mountain Ponderosa Pine Woodland and Savanna	Cluster 3	Cluster 8	157
3234	Mesic Montane Douglas-fir Forest	Cluster 3	Cluster 8	89
3167	Rocky Mountain Poor-Site Lodgepole Pine Forest	Cluster 3	Cluster 8	71
3208	*Abies concolor* Forest Alliance	Cluster 3	Cluster 8	58
3160	Rocky Mountain Subalpine/Upper Montane Riparian Forest and Woodland	Cluster 3	Cluster 7	46
3161	Northern Rocky Mountain Conifer Swamp	Cluster 3	Cluster 7	29
3057	Rocky Mountain Subalpine-Montane Limber-Bristlecone Pine Woodland	Cluster 3	Cluster 8	23
3020	Inter-Mountain Basins Subalpine Limber-Bristlecone Pine Woodland	Cluster 3	Cluster 5	15
3228	Dry-mesic Montane Western Larch Forest	Cluster 3	Cluster 7	9
3055	Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland	Cluster 4	Cluster 9	1627
3056	Rocky Mountain Subalpine Mesic-Wet Spruce-Fir Forest and Woodland	Cluster 4	Cluster 9	1012
3045	Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest	Cluster 4	Cluster 9	918
3227	Dry-mesic Montane Douglas-fir Forest	Cluster 4	Cluster 8	894
3047	Northern Rocky Mountain Mesic Montane Mixed Conifer Forest	Cluster 4	Cluster 9	573
3052	Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland	Cluster 4	Cluster 8	395
3233	Subalpine Douglas-fir Forest	Cluster 4	Cluster 8	237
3032	Mediterranean California Red Fir Forest	Cluster 4	Cluster 9	12

Note: The first and second column represent the original EVT code and classification name. Column three is based on $k = 5$ and column 4 is based on $k = 10$. The last column represents the number of Interior West ground plots in that EVT class.

AN ALTERNATIVE POST-STRATIFICATION SCHEME TO DECREASE VARIANCE OF FOREST ATTRIBUTE ESTIMATES IN THE INTERIOR WEST

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Abstract

The National Forest Inventory and Analysis (FIA) Program of the Forest Service, U.S. Department of Agriculture, estimates many important forest attributes. Post-stratification with auxiliary data is used in the estimation process to improve precision. Current procedures used by the FIA unit in the U.S. Interior West involve stratifying by predicted forest and nonforest areas. This research aims to increase the efficiency of these post-stratified estimates by exploring alternative stratification schemes. We propose five candidate schemes based on auxiliary data from different sources and compare their relative efficiencies to both a simple random sampling estimator and to the current post-stratification. The best candidate, a four-strata scheme based on forest probability, is shown to improve the precision of forest attribute estimates over the current scheme across the Interior West region.

Keywords: FIA, post-stratification, forest probability, Interior West.

INTRODUCTION

The National Forest Inventory and Analysis (FIA) Program of the Forest Service, U.S. Department of Agriculture, is responsible for monitoring forest ecosystem attributes across the United States. The FIA program is important for forest land managers, policymakers, and scientists concerned with U.S. forests because it is the sole source of consistent annual forest survey data across the entire country (McRoberts 2005).

The FIA uses a two-phase system for collecting forestry data used in the estimation of these attributes (Reams and others 2005). The first phase involves using remotely sensed data to create large-scale maps that show nationwide landscape and forest patterns. Auxiliary data from a number of sources, including aerial photography, satellite imagery, and lidar, is used in this phase (McRoberts and others 2012). The second phase requires measuring data on sample plots with an intensity of approximately one plot per approximately 6,000 acres throughout the United States (Brand and others 2000). At this stage, the forest attributes of interest, usually related to the vegetation components of the forest, are measured on each field plot (McRoberts 2005).

For our work, we were interested in combining the data sources from Phase 1 and Phase 2. The Phase 1 data are wall-to-wall data products, which allow for a full enumeration of the desired landscape. We call these data pixel-level data because we can divide the entire landscape into pixels of equal and known size with the resolution based on the data product. In the Interior West, the Phase 2 data are collected in the field from forested plots. A subset of data variables are then collected from aerial photographs of nonforested plots. These two types of forest data can be used jointly to produce estimates of forest attributes through a method called post-stratification.

FIA is interested in producing estimates over many different types of geographic areas. Users are interested not only in estimates of forest

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attributes within States, but also within smaller geographic areas such as counties, groups of counties, National forests, ecological subsections, and congressional districts. For the analyses in this paper, we focus on counties as the reporting areas of interest, but any geographic area could be substituted.

POST-STRATIFICATION

To produce population estimates of forest attributes, FIA uses a statistical technique known as post-stratification (Holt and Smith 1979). Instead of estimating the mean of an attribute with a simple average of the attribute for the Phase 2 data, post-stratification adjusts the estimator based on a single categorical variable from Phase 1. The plots are grouped into categories, called strata, based on the Phase 1 variable and the mean is computed for each stratum. The strata sample means are summed up, weighted by the proportion of pixels in a landscape that fall in their respective stratum. The post-stratified estimator of the mean is given by

$$\bar{Y}_{PS} = \sum_h^H \frac{N_h}{N}\left(\frac{\sum_i^{n_h} y_{h_i}}{n_h}\right) = \sum_h^H W_h \bar{Y}_h \qquad (1)$$

where H is the number of strata (indexed by h), N is the total county area in pixels, N_h is the number of pixels within stratum h, n_h is the number of plots in stratum h (indexed by i), and y_{h_i} is the value of variable Y for the ith plot in stratum h (Scott and others 2005). We can write $N^{-1}N_h$ as W_h, the weight for stratum h, which represents the portion of the landscape in stratum h. We can also write $n_h^{-1}\sum_i^{n_h} y_{h_i}$ as $\bar{Y}_h$, the mean estimate of Y for stratum h. Therefore, the post-stratified estimator can be viewed as a weighted average of the means within each stratum where we are calibrating our estimator to the known size of each stratum. The post-stratified estimator is asymptotically unbiased and typically has a lower variance than a simple random sampling estimator, which is computed by taking the mean across all observations.

Specific groupings of observations into strata are called stratification schemes, and as with pre-stratification, should be chosen such that within-stratum observations are as similar as possible, with respect to the forest attributes, and between-stratum observations are as dissimilar as possible (McRoberts and others 2005). High homogeneity within strata increases the precision of the post-stratified estimator, while low homogeneity will result in a variance similar to or even worse than the variance of the simple random sampling estimator. Stratifying after the sample is selected instead of before does potentially lead to fewer gains in precision because the post-strata sample sizes are random. However, with FIA's permanent sample design, it is not possible to restratify with each remeasurement.

FOREST-NONFOREST STRATIFICATION SCHEME

The Rocky Mountain Research Station's FIA Program (RMRS-FIA) is responsible for maintaining an inventory of forest attributes in the Interior West (IW), which comprises Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming. Currently, the RMRS-FIA produces attribute estimates using a stratification scheme that divides field plots into forest or nonforest strata based on a forest probability map from Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery (Blackard and others 2008). This scheme does not differentiate between different types of forest. All varieties of forest plots in the IW region, such as pinyon, pine, and aspen, are placed in the same stratum. Thus, this scheme might suffer from high variance as it fails to account for the ecological variability of all the plots within the forest stratum. In addition, the 250-m spatial resolution plays a role in the ecological variability captured in each stratum (Nelson and others 2009).

Our goal is to examine other stratification schemes that could be used in the IW as an alternative to the forest-nonforest scheme. Because the post-stratified estimator is approximately unbiased, our objective was to improve the efficiency of the estimator by decreasing the variance. We propose a number of new schemes based on auxiliary pixel data that are available to FIA and compare the precision of these schemes to the current forest-nonforest framework.

DATA

We utilized both pixel-level and plot-level data in our analyses. The plot data included the most current 10-year measurement cycle for each Interior West State, downloaded on February 6, 2019, from the FIA database, version FIADB_1.8.9.99 (last updated Dec. 3, 2018). These data were collected between 2007 and 2017 and represent 86,085 sample plots. All States included a complete 10-year cycle of data except Wyoming, which had only 7 of 10 years of data collected at the time of download.

Forest Attributes

To evaluate the efficiency of the current and proposed stratifications schemes, we produced post-stratified estimates of four forest attributes: basal area (square-foot), trees per acre, aboveground biomass (pounds), and net volume (cubic-foot), which were extrapolated and summed to the plot level using only live trees. These variables make up only a small fraction of the inventory composed by the FIA, but can be used to compare estimation efficiency across the different schemes because they are some of the most frequently analyzed variables and are highly correlated to many other forest attributes of interest.

Auxiliary Data

Our proposed schemes were created with three sources of auxiliary data: forest probability, biomass, and tree canopy cover. These variables are derived from pixel-level maps created from satellite imagery. The proposed stratification schemes were created based on observed patterns in the auxiliary data only.

Forest probability

The forest probability map, which is used to create the current forest-nonforest classification, is a measure of uncertainty in pixel assignments (Blackard and others 2008). The current scheme used by the RMRS-FIA has a forest threshold of 0.5, such that observations with 0.5–1.0 probability of forest are considered forest (table 1). These data have a spatial resolution of 250 m.

Biomass

Forest biomass is defined to be live tree, aboveground biomass, measured in Mg/ha. Another MODIS-based data set developed in Blackard and others (2008), these data have a spatial resolution of 250 m and attain a maximum value of 118 and a minimum value of 0 in the IW region.

Tree canopy cover

Tree canopy cover data are sourced from the National Land Cover Database (NLCD) canopy cover map (Yang and others 2018). The NLCD utilizes imagery data from the National Agriculture Imagery Program (NAIP), Landsat 5 Thematic Mapper (and its derivatives), as well as previous NLCD data. Percent tree canopy cover has a spatial resolution of 30 m.

New Schemes

To create categories to be used in the stratification schemes, the above continuous variables were

Table 1—Descriptions of the five candidate stratification schemes

Scheme name	No. of strata	Categories
Current scheme	2	Nonforest, Forest
Biomass	3	Low Biomass, Moderate Biomass, High Biomass
Forest probability	4	Nonforest, Low Forest, Moderate Forest, High Forest
Tree canopy cover	4	No Coverage, Low Coverage, Moderate Coverage, High Coverage
Forest/Biomass	4	Nonforest, Low Biomass Forest, Moderate Biomass Forest, High Biomass Forest
Forest/Tree canopy cover	5	Nonforest, No Coverage Forest, Low Coverage Forest, Moderate Coverage Forest, High Coverage Forest

Note: the mapping of the numerical auxiliary variables to the specific categories can be found in Appendix A.

split into a small number of bins. Biomass was split at cut points 5 and 32; forest probability was split at points 0.03, 0.23, and 0.77; and tree canopy cover was split at points 5, 25, and 50. These cut points were selected to ensure a roughly equal distribution of plots within each class with the intent of effectively representing IW forests. We used these binned variables and the current forest-nonforest scheme to create five proposal schemes, as shown in table 1. Two of the schemes combine the current scheme with these additional binned variables. A more detailed description of each stratification scheme can be found in Appendix A.

Collapsing

The FIA calculates post-stratified estimates of forest attributes at the county level. Some counties contain very few plots belonging to a specific stratum, which can make post-stratified estimates less reliable. Recent work has suggested that the minimum within-strata sample size for a county should be 10 (Westfall and others 2011).

Because this minimum sample size is not met for all counties in the dataset for all of the proposed schemes, we devised a strategy for collapsing observations into a different stratum if too few of them belong to a specific stratum. The strategy we chose was as follows:

1) For a given county, find the stratum with the least representation (i.e., the fewest observations).
2) If there are fewer than 10 plots within this stratum, collapse those plots into the nearest stratum with at least 10 plots, with nearness measured in terms of the ordinal structure.

    If the nearest strata have fewer than 10 plots, the algorithm goes to the next closest stratum.

    If there are 2 nearest strata and both have at least 10 plots, the plots are collapsed into the stratum with a larger number of plots.
3) Repeat until all strata are represented by at least 10 plots (or zero plots).
4) Repeat for all counties in the dataset.

For example, suppose County A has 58 observations in Stratum One, 3 observations in Stratum Two, 7 observations in Stratum Three, and 19 observations in Stratum Four. Using this strategy, the 3 observations in Stratum Two would be collapsed into Stratum One. Next, the 7 observations in Stratum Three would be collapsed into Stratum Four. The final observation counts for County A would be 61 in Stratum One, 0 in Strata Two and Three, and 26 in Stratum Four. Note that for the current forest-nonforest stratification scheme, the two strata are simply collapsed when there are fewer than 10 plots.

METHODS

Our goal is to propose more efficient alternatives to the forest-nonforest stratification scheme currently used by the RMRS–FIA. This requires comparing the performance of the variance estimator of the post-stratified mean estimator across the schemes.

Post-Stratified Mean and Variance

The post-stratified mean estimator of variable Y is given by equation (1) and its estimated variance is given by

$$v(\overline{Y}_{PS}) = \frac{1}{n}\left[\sum_{h}^{H} W_h\, n_h v(\overline{Y_h}) + \sum_{h}^{H} (1 - W_h)\frac{n_h}{n} v(\overline{Y_h})\right]$$

where $v(\overline{Y}_h)$ is the variance of Y for stratum h, and n is the total number of sampled plots (Scott and others 2005).

Scheme Evaluation

The efficiency of an estimator can be evaluated using relative efficiency, which is computed as

$$RE_{srs} = \frac{v(\overline{Y}_{SRS})}{v(\overline{Y}_{PS})} \qquad (2)$$

where $\overline{Y}_{SRS} = n^{-1}\sum_{i}^{n} y_i$, the mean estimator using simple random sampling and no stratification and its corresponding variance estimator is $v(\overline{Y}_{SRS}) = n^{-1}\, v(\overline{\mathrm{Y}})$ where $v(\overline{\mathrm{Y}})$ is the variance of Y in the sample (McRoberts and others 2005). Equation (2) is used to perform initial comparisons between the candidate schemes.

However, because our task is to compare multiple stratification schemes, we additionally computed the relative efficiency of the best candidate scheme against the current forest-nonforest scheme, as given by

$$RE_{cur} = \frac{v(\overline{Y}_{CUR})}{v(\overline{Y}_{NEW})}.$$

Here $\overline{Y}_{CUR}$ refers to the post-stratified mean estimator under the current scheme, and $\overline{Y}_{NEW}$ refers to the post-stratified mean estimator under a proposed scheme. The desired result is $RE_{cur} > 1$, which indicates that the proposed scheme is effectively lowering the variance of the mean estimator. Because FIA estimation is often done at the county level, we calculated a relative efficiency measure for each county.

Bootstrapping

The REs are actually estimated REs because we are comparing the ratio of the estimated variances, not the true variances. To more rigorously evaluate the effectiveness of our best proposed scheme, we used the statistical technique bootstrapping on the RE measure (Efron and Tibshirani 1986) to obtain 95 percent confidence intervals for the true RE_{cur}. The bootstrapping process for a county-level analysis is as follows:

1) Draw a sample of *n* plots from a county with replacement, where *n* is the original number of plots in the county.
2) Compute post-stratified variance estimates (for both the current and proposed scheme) and RE_{cur} for the sample.
3) Repeat steps 1 and 2 1000 times to produce 1000 different measures of RE_{cur}.
4) Repeat steps 1–3 for each county.

After completing this process, we extracted the middle 95 percent of the bootstrapped RE_{cur} measures for each county to create a 95 percent confidence interval of the efficiency of the candidate scheme. More work should be done to explore the accuracy of the bootstrapped confidence intervals over varying sample sizes.

RESULTS

Initial Comparisons

To perform an initial evaluation of our proposed schemes, we calculated the relative efficiency of each candidate against a simple random sampling approach for each of our four forest attribute variables, using equation (2), for each county. With these preliminary explorations, we didn't conduct a bootstrap analysis, but instead we computed the means of these REs across all counties for each forest attribute. As seen in table 2, all of the schemes are more efficient, on average, than the simple random sampling estimator as expected. The *Tree Canopy Cover* scheme was the most efficient, followed by the *Forest Probability* scheme, on average.

However, visual analysis of maps such as figure 1 showed that while *Tree Canopy Cover* had the highest mean RE_{srs}, *Forest Probability* had $RE_{srs} > 1$ for many more counties than *Tree Canopy Cover*. This implies that *Forest*

Table 2—Mean relative efficiencies compared to the simple random sampling estimator, within Interior West-Forest Inventory and Analysis (IW-FIA) counties.

Scheme	Current scheme	Tree canopy cover	Biomass	Forest probability	Forest/tree canopy cover	Forest/ biomass
AG biomass	3.89	10.00	4.34	8.20	7.49	4.91
Trees per acre	3.44	7.04	3.73	6.61	5.14	4.14
Basal area	3.74	8.92	3.82	8.17	6.35	4.47
Cubic volume	3.86	9.62	4.82	8.09	7.41	4.85
# RE >1	197	209	187	242	180	189

Note: the numbers of counties with $RE_{SRS} > 1$ is given in the last row. For each scheme, the numbers of counties with $RE_{SRS} > 1$ was the same for the four response variables.

Probability is more consistently efficient across the entire IW, while *Tree Canopy Cover* is extremely efficient in certain regions, but inefficient in others. Therefore, we chose *Forest Probability* as the focus of our subsequent analysis, comparing it to the current stratification scheme.

Forest Probability Scheme

The *Forest Probability* scheme is a four-strata scheme based on Blackard and others' (2008) forest probability map, which is also used as a basis for the RMSR-FIA's current stratification scheme. We performed a bootstrap experiment on the RE of the *Forest Probability* scheme against the current scheme to more rigorously assess whether the candidate scheme improves the precision of the estimates. We found that even for the lower bound on the bootstrapped 95 percent confidence interval, the *Forest Probability* scheme had $RE_{cur} > 1$ for the majority of IW counties and land area. This finding was true for all four of the studied forest attributes. Figure 2 shows where the $RE_{cur} > 1$ occurs for estimation of aboveground biomass, and for the upper and lower bounds of the 95 percent confidence interval. Graphs of the confidence bounds of the other response variables follow a similar pattern. Because the lower bound of the CI is above 1 for the majority of the counties, this provides evidence that the true RE is greater than 1 and that the new scheme is an improvement over the old scheme. It should be noted that there are a few counties where the upper bound of the CI is below 1, signifying that the new scheme is worse in those regions. Similar graphical results for all four attributes can be found in Appendix B.

The mean values for the upper and lower bounds on the RE_{cur} confidence intervals (across all counties), as well as the proportion of counties for which $RE_{cur} > 1$, can be found in table 3. The *Forest Probability* scheme has a statistically significant improvement in precision for 84.0–85.2 percent of IW counties, and has almost no improvement for only 5.9–6.2 percent of counties. On average, the use of this scheme in place of the current scheme improves the precision of attribute estimates by at least a factor of 1.71–1.92, and at most by a factor of 3.77–4.12.

CONCLUSIONS

Of our five proposed schemes, the *Forest Probability* scheme was the most effective at consistently reducing the variance of the post-stratified estimates in the IW. *Forest Probability* appears to improve the precision of estimates considerably when compared to the current forest-nonforest scheme used by the RMRS–FIA. This candidate scheme can be thought of as a refinement to the current scheme, because both are based on Blackard and others' forest probability map. While it might be expected that the schemes that offered finer spatial resolution and information contemporary with the FIA plot data would result in dramatic improvements in precision, this was not the case. This could

Table 3—Forest probability relative efficiencies compared to the current Interior West (IW) stratification scheme, and the mean values for the upper and lower bounds on the RE_{cur} confidence intervals (across all counties), as well as the proportion of counties (and number of counties) for which $RE_{cur} > 1$

Scheme	% Lower >1 (#)	Lower mean	% Upper >1 (#)	Upper mean
AG biomass	84.4 (216)	1.92	93.8 (240)	4.04
Trees per acre	84.0 (215)	1.71	94.1 (241)	3.77
Basal area	85.2 (218)	1.82	94.1 (241)	4.12
Cubic volume	84.0 (215)	1.89	93.8 (240)	4.01

be explained by the tight consistency in forest land definition between the Blackard and others product and FIA field observations, as well as by the possibility that the 250-m spatial resolution of the forest probability map was more compatible with the size of FIA plots, plus positional uncertainty. Showing improvement by simply allowing more bins to be derived from the map currently used as the basis for stratification inspires further investigation into new and improved spatial data layers for stratification in the IW in the future.

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APPENDIX A—SCHEME DESCRIPTIONS

This section contains the proposed stratification schemes.

Current scheme (2 strata)

- Nonforest: observations in [0, 50] for the forest probability auxiliary variable
- Forest: observations in (.50, 100] for the forest probability auxiliary variable

Biomass (3 strata)

- Low biomass: observations in [0, 5] for the biomass auxiliary variable
- Moderate biomass: observations in (5, 32] for the biomass auxiliary variable
- High biomass: observations in (32, 118) for the biomass auxiliary variable

Forest probability (4 strata)

- No forest: observations in [0, 0.03] for the forest probability auxiliary variable
- Low forest: observations in (0.03, 0.23] for the forest probability auxiliary variable
- Moderate forest: observations in (0.23, 0.77] for the forest probability auxiliary variable
- High forest: observations in (0.77, 1] for the forest probability auxiliary variable

Tree canopy cover (4 strata)

- No coverage: observations in [0, 5] for the tree canopy cover auxiliary variable
- Low coverage: observations in (5, 25] for the tree canopy cover auxiliary variable
- Moderate coverage: observations in (25, 50] for the tree canopy cover auxiliary variable
- High coverage: observations in (50, 100] for the tree canopy cover auxiliary variable

Current strata x biomass (4 strata)

- Low biomass forest: observations in [0, 5] for the biomass auxiliary variable and the IW forest stratum
- Moderate biomass forest: observations in (5, 32] for the biomass auxiliary variable and the IW forest stratum
- High biomass forest: observations in (32, 118) for the biomass auxiliary variable and the IW forest stratum
- Nonforest: observations in the IW nonforest stratum

Current strata x tree canopy cover (5 strata)

- No coverage forest: observations in [0, 5] for the tree canopy cover auxiliary variable and the IW forest stratum
- Low coverage forest: observations in (5, 25] for the tree canopy cover auxiliary variable and the IW forest stratum
- Moderate coverage forest: observations in (25, 50] for the tree canopy cover auxiliary variable and the IW forest stratum
- High coverage forest: observations in (50, 100] for the tree canopy cover auxiliary variable and the IW forest stratum
- Nonforest: observations in the IW nonforest stratum

APPENDIX B—ADDITIONAL VISUALIZATIONS OF THE RELATIVE EFFICIENCIES

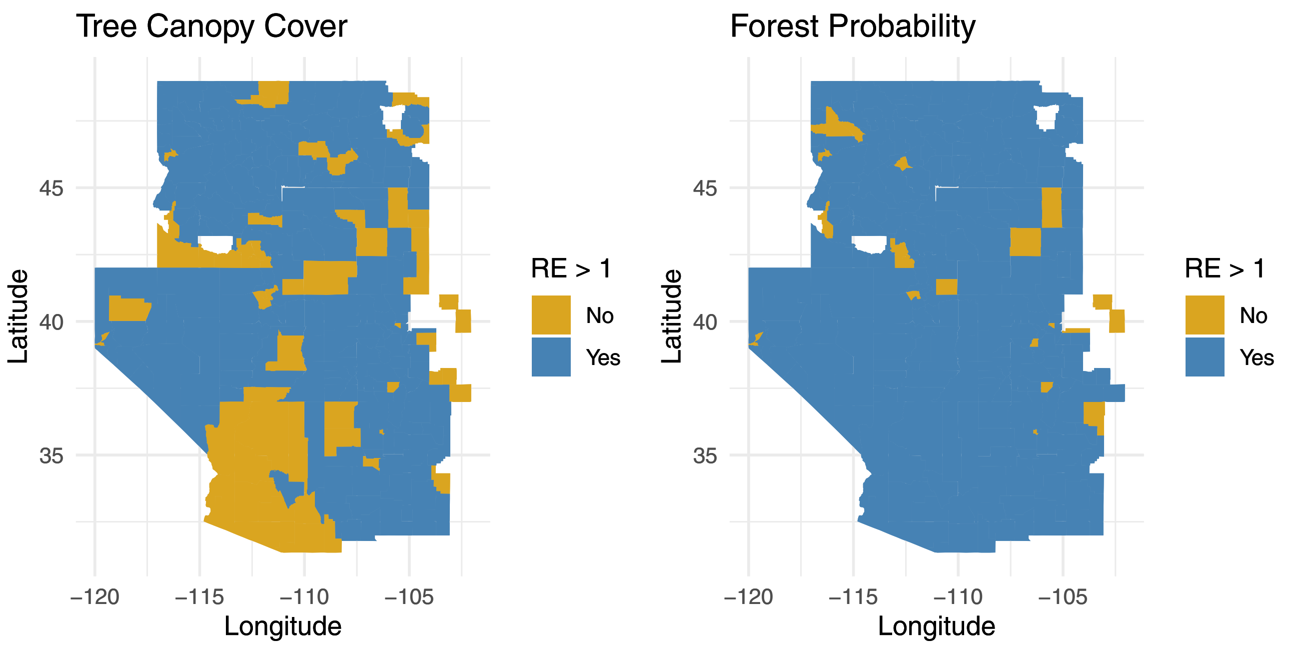

Figure 1—Map of Interior West (IW) counties where RE > 1 for aboveground biomass for *Tree Canopy Cover* and *Forest Probability* schemes.

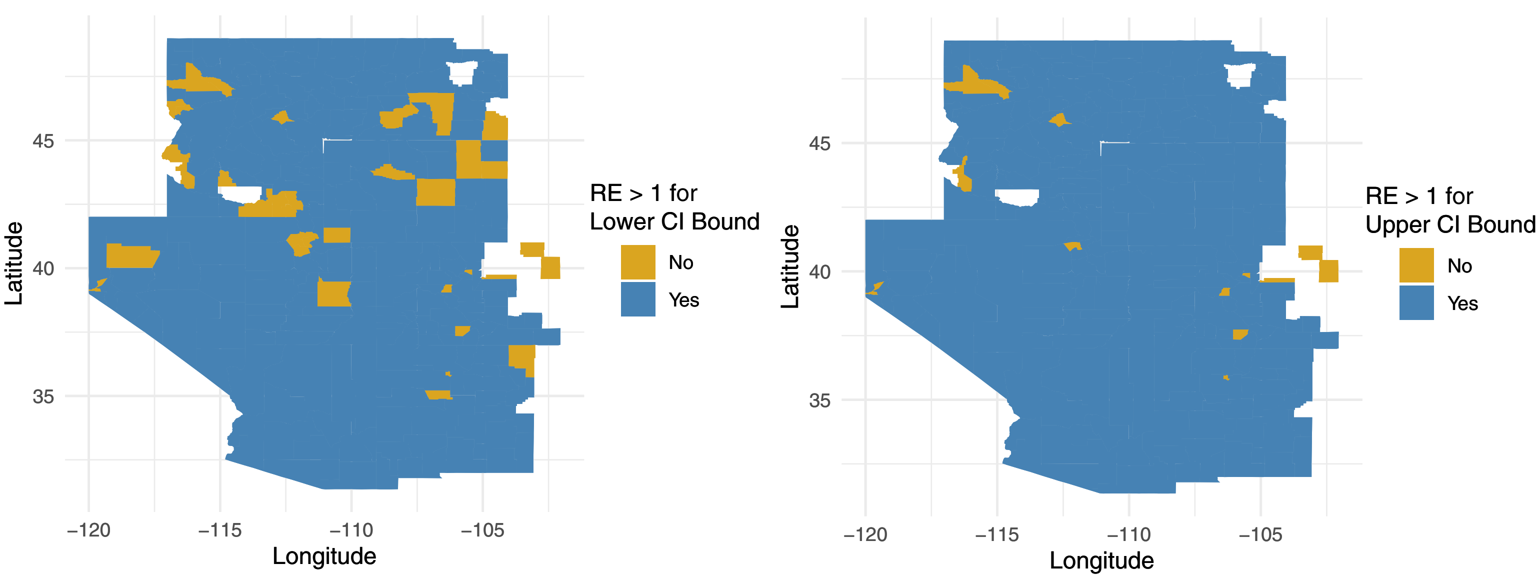

Figure 2—Map of Interior West (IW) counties where the *Forest Probability* stratification scheme outperforms the current scheme for aboveground biomass estimation, at lower and upper bounds of a 95 percent confidence interval.

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The USDA Forest Service's Forest Inventory and Analysis Program (FIA) is the primary source of information about our Nation's forests' status and trends. Built on a statistically robust sampling network of permanent forest inventory and monitoring plots, the program has created a framework upon which a diverse variety of scientific studies have been built. An FIA Science Stakeholder Meeting was held November 19–21st, 2019 in Knoxville, TN, to bring together FIA personnel, researchers from peer organizations, academia, policymakers, and members of the international scientific community under the theme "Celebrating progress, possibilities and partnerships". Presentations given at this meeting showed the evolution of FIA over time, innovative uses of the data collected by the program now, and looked to future applications in the fields of vegetation monitoring, land use and land cover change, and methods for delivering this information to stakeholders. These biennial meetings serve to maintain and expand the community of FIA data users by providing them with a forum in which to share and explore their ideas on how to make use of this ever growing body of data and information. This proceedings document includes abstracts of the presentation given and expanded details from selected papers presented at the meeting.

Keywords: Cover estimation, data integrity, environmental monitoring, estimation, forest health, forest inventory, international forest monitoring, modeling, remote sensing, sampling.

NOTE TO READER:

This publication was revised in October, 2020.

An error occurred during the compilation of abstracts for this publication, resulting in some author names being omitted. We have added those missing names, and we also added a missing paper entitled, "An Alternative Post-Stratification Scheme to Decrease Variance of Forest Attribute Estimates in the Interior West" by Rintoul and others (pages 268–276).

A copy of this general technical report is available for download at www.srs.fs.usda.gov/pubs/.