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Proceedings of the 2022 Forest Inventory and Analysis (FIA 2022) Science Stakeholder Meeting

Grow. Adapt. Regenerate: Monitoring and Responding to Global Change to Promote Resilient and Productive Forests

Virtual Conference
November 14–17, 2022

Citation

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Abstract

The Forest Inventory and Analysis (FIA) program of the U.S. Department of Agriculture, Forest Service, implements the Nation's only comprehensive inventory of forest resources across all ownerships. Through its continuous forest monitoring, FIA provides strategic-level information necessary to evaluate the status and changing trends in forest resources and the sustainability of forest management practices; FIA data serve as the foundation for a broad array of scientific studies. These proceedings report findings from invited and contributed presentations and posters from the 15th biennial Forest Inventory and Analysis Science Stakeholder Meeting (FIA 2022, formerly known as the Forest Inventory and Analysis Symposium). Hosted by the Northern Research Station's FIA program, the conference was held virtually November 14–17, 2022. Topics were based on the theme "Grow. Adapt. Regenerate: Monitoring and Responding to Global Change to Promote Resilient and Productive Forests" and included landscape change, remote sensing, ecocultural resources and people, forest disturbance, understory vegetation and invasive plants, and monitoring changes in forest composition. These proceedings include 15 papers and extended abstracts, a list of papers published in a special issue of Frontiers in Forests and Global Change, the conference program, and the titles of poster presentations.

Keywords: forest inventory, landscape change, disturbance, forest health, remote sensing, vegetation, invasive plants, carbon, ecocultural resources, ownership, land use, urban, climate, nontimber forest products, modeling, wildlife

Cover Art

Fall colors emerging at Buzzard Swamp, Allegheny National Forest. USDA Forest Service photo by Kathleen Creek.

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Proceedings of the 2022 Forest Inventory and Analysis Science Stakeholder Meeting

Grow. Adapt. Regenerate: Monitoring and Responding to Global Change to Promote Resilient and Productive Forests

An International Conference to Highlight Innovation and Evolutions in Forest Inventory Research

Virtual Conference
November 14–17, 2022

Susan J. Crocker, USDA Forest Service, Northern Research Station, Editor

FOREWORD

The 15th biennial FIA Stakeholder Science Stakeholder Meeting (FIA 2022), formerly the FIA Symposium, was held virtually November 14–17, 2022. This meeting is intended to bring together scientists, partners, practitioners, managers, and policymakers with regional, national, and international inventory and monitoring missions to engage in scientific and technical exchange.

Initially scheduled as an in-person conference, the challenges in a post-COVID world brought opportunities for FIA 2022, hosted by the USDA Forest Service, Northern Research Station, Forest Inventory and Analysis (FIA) Program, the National Council of Air and Stream Improvement, and the Society of American Foresters, to grow its audience and partners, to adapt to a new virtual space, and to regenerate into a new forum for scientific engagement and collaboration. Transitioning to a 4-day event, FIA 2022 hosted 500 registered scientists, students, managers, and policymakers from 23 countries. The meeting included oral presentations, posters, and digital demonstrations from 181 presenters; keynote presentations from nine plenary speakers; and multiple opportunities for engagement in a variety of networking and breakout sessions.

The proceedings includes 15 papers and extended abstracts from FIA 2022, a list of the papers published in a special issue of Frontiers in Forests and Global Change, the meeting program, and poster presentations.

Susan Crocker, January 2024

ACKNOWLEDGMENTS

The Steering and Planning Committees wish to thank the Society of American Foresters and the National Council for Air and Stream Improvement for co-hosting this meeting. We thank the presenters, attendees, technology support staff, and American Sign Language (ASL) interpreters for making this first-ever virtual meeting a huge success. We thank the manuscript reviewers and the Northern Research Station's Communications and Science Delivery staff for handling the publication of the proceedings.

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A single-blind review process was used in reviewing manuscripts submitted for publication. Each manuscript was peer-reviewed by at least two professionals. Reviews were returned to authors to revise their manuscripts. Revised manuscripts were submitted to the Northern Research Station for final editing and publishing.

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LANDSCAPE CHANGE AND REMOTE SENSING

Fifteen-Year Changes in the Landscape Context of FIA Forest Land in the Conterminous United States

Jennifer K. Costanza, Karen G. Schleeweis, and Kurt H. Riitters[1]

Abstract.—We assessed historical changes in the landscape context of forest (circa 2016) that occurred between 2001 and 2016. We quantified three measures of context—forest cover fragmentation, anthropogenic interface, and forest edge typology—within a 15.2 ha neighborhood centered on representative forest inventory plot locations in the conterminous United States. Net change of interface area was attributable mainly to privately owned land in the East, amounting to a 4.9 percent decrease of forest area in the agriculture interface and a 3.7 percent increase of area in the developed interface. Overall, net loss of interior forest area was due primarily to losses on Federal land in the West and corporate land in the East. Consistent with the dynamics of interface classes and interior forest area, edge typology revealed an overall increase in forest cover adjacent to developed and shrub/grass covers and a decrease in forest adjacent to agricultural cover.

INTRODUCTION

The forest area of the conterminous United States (CONUS) occurs in a variety of landscape settings ranging from primarily urban or agricultural areas to remote wilderness areas. Forest threats often depend on these landscape settings (i.e., the spatial context), and novel threats to the extant forest area can emerge when the surrounding landscape changes because of human activities. For example, the risk of exotic plant invasion on U.S. Department of Agriculture (USDA), Forest Service, Forest Inventory and Analysis program (FIA) plots in the East is related to disturbance and propagule pressure from nearby roads and other development (Riitters et al. 2017), and the expansion of developed area near a forested location is expected to increase such risk at that location. Similarly, interior forest is required to support many species (e.g., Fischer and Lindenmayer 2007), and the types of vegetation, land uses, or land covers at the edges of forest affect a variety of edge-sensitive ecological processes (e.g., Murcia 1995).

We investigated CONUS landscape changes from 2001 to 2016 in support of the 2020 USDA Forest Service Resources Planning Act (RPA) Assessment. An earlier contribution summarized forest cover fragmentation trends and patterns (Riitters and Robertson 2021), while overall changes in landscape context were addressed by Riitters et al. (2020). Here, we report a third aspect of landscape change supporting the 2020 assessment: the integration of landscape data based on land cover maps with estimation of forest areas using FIA plot-level data to evaluate changes in landscape context near land defined as forest land by FIA circa 2016.

METHODS

Landscape Context Data

Our description of landscape context generally follows the framework used in earlier RPA assessments, wherein context is measured using the National Land Cover Database (NLCD) (e.g., Riitters 2011, USDA Forest Service 2016). We consider three aspects of landscape context: forest cover fragmentation, anthropogenic interface, and forest edge typology. Within a 15.2 ha neighborhood (hereafter, "neighborhood") centered on each FIA plot location, we measured those three aspects of context using the 2001 and 2016 NLCD maps (Homer et al. 2020). The NLCD 2016 classifies land cover into 16 (Level II) classes with a spatial resolution of 0.09 ha per pixel. We combined the 16 classes into the following groupings: forest, developed, agriculture, shrub & grass, water, and barren based on current (NLCD 2021) Level I classes

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provided at the Multi-Resolution Land Characteristics Consortium website. Importantly, the "forest" class included the NLCD "woody wetlands" class, and herbaceous wetlands were assigned to the "water" class. To assess fragmentation, we assigned interior status (yes or no) to a given plot location if the neighborhood contained at least 90 percent forest cover. To assess anthropogenic interfaces, we measured the proportions of agriculture and developed land cover in the surrounding neighborhood and assigned plots to the "agriculture" or "developed" interface classes if the proportion of either of the corresponding land cover classes occupied at least 10 percent of the neighborhood. The "both" interface class corresponds to locations where agriculture and developed classes each occupy 10 percent simultaneously; in the "neither" class, there is less than 10 percent of either agriculture of developed classes. To assess forest edge typology, we tabulated the adjacency (pixel-level co-occurrence) of the six land cover types and examined the adjacencies containing forest within the neighborhood. Thus, the types of forest adjacencies were forest to forest, forest to developed, forest to agriculture, forest to shrub & grass, forest to water, and forest to barren. For each plot, the frequency of each type of forest adjacency was expressed as the proportion of total forest adjacencies in the neighborhood.

Forest Inventory Plot Data

A total of 137,911 forest and nonforest FIA plots from the 2016 inventory period for each state in CONUS were used in the analysis. We used condition class information (Burrill et al. 2018) for stratification and population estimation (Bechtold et al. 2005), but all condition classes on a given plot were attributed with the same set of landscape context descriptors in that neighborhood. We used the proprietary ownership data and the exact plot locations. For analysis, we excluded 17 forest types that occupied less than 405 km^2 each, eight exotic forest types, and the "unassigned" forest type, which includes nonstocked forest land. The resulting sample represented 96 percent (2.7 million km^2) of total FIA forest area in 2016.

Analysis Methods

For each plot, we identified the geographic region (East or West), ownership (Federal, State and local, corporate, and noncorporate), and the expansion factors needed for population-level area estimates. For interior forest status and interface classes, the estimate of forest area in each landscape context was simply the sum of the expansion factors for the condition classes that had that context. A different procedure was followed to evaluate forest edge typology because both the total number and potential types of forest adjacencies necessarily depend on the amount of forest cover in a neighborhood, which varies among plots. We calculated weighted mean proportions when aggregating the plot-level proportions to a stratum level using the expansion factors as weights (Riitters et al. 2012). All of these procedures were applied to both the 2001 and 2016 measurements of landscape context, and the historical change of landscape context from 2001 to 2016 for the circa 2016 forest area was simply the difference of the stratum area (or proportions) between those years.

RESULTS

Interior Forest Cover Status

Over the CONUS, the share of circa 2016 forest area assigned a status of "interior" decreased from 42.8 percent in 2001 to 40.4 percent in 2016. The gross gain in interior forest area over that time was 112.9 thousand km^2, while the gross loss was 177.2 thousand km^2, resulting in a net loss of 64.3 thousand km^2. Figure 1 illustrates three main points: (1) most of the total gross change (gain and loss) was on privately owned land in the East (188.8 thousand km^2); (2) most of the net loss occurred on Federal land in the West (27.1 thousand km^2) and corporate land in the East (14.2 thousand km^2); and (3) for all ownerships, net percentage change was larger in the West than in the East.

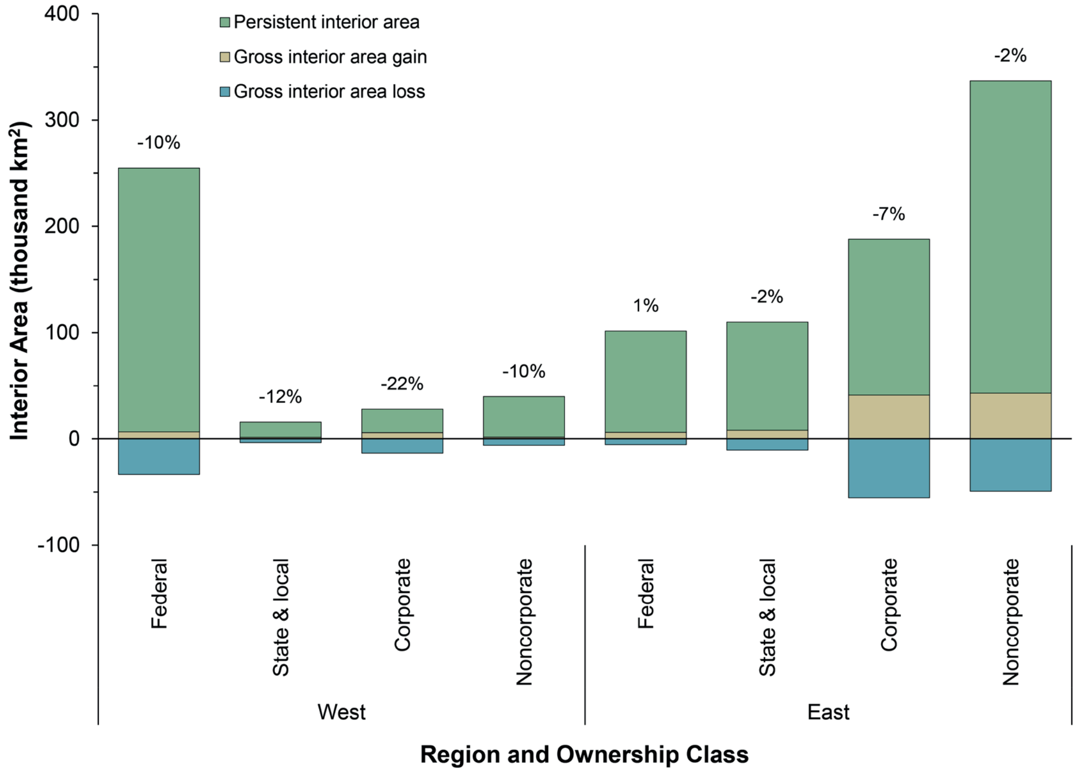

Figure 1.—Change of interior forest area from 2001 to 2016 in the conterminous United States by region and ownership class. The net percent changes are shown above the bars. The East region includes the states in the Northern and Southern FIA units. The West region includes states in the Pacific Northwest and Rocky Mountain FIA units.

Interface Classes

In both 2001 and 2016, privately owned land in the East contained most of the forest area in the agriculture interface (approximately 93 percent) and most of the forest area in the developed interface (approximately 70 percent). Between 2001 and 2016 and driven principally by changes in the East, the share of CONUS forest area in the agriculture interface decreased from 15.9 percent to 15.1 percent, while the share in the developed interface increased from 11.4 percent to 11.8 percent. These changes are consistent with the regional trends of pasture (agriculture) reversion to forest, and of forest conversion to urban land that have been demonstrated in other studies (e.g., Nelson et al. 2020). Those interacting patterns of land use conversions are reflected in the patterns of landscape context changes from 2001 to 2016 (Fig. 2).

Forest Edge Typology

The analysis of changes in forest adjacencies with other forest, agriculture, developed, or shrub & grass (Fig. 3) reflected the stories of landscape change based on interior forest and interface area change. In the West, and consistent with interior forest loss in primarily non-interface landscapes (which include the shrub & grass class), there was a decrease in forest to forest adjacencies, and the largest increases were in forest to shrub & grass adjacencies. A similar change occurred for the eastern corporate forest area only; in other eastern ownerships, there was a decrease in forest to agriculture adjacencies and increases in forest to shrub & grass and forest to developed adjacencies. There was little change in forest adjacencies with water and barren in all regions and ownerships.

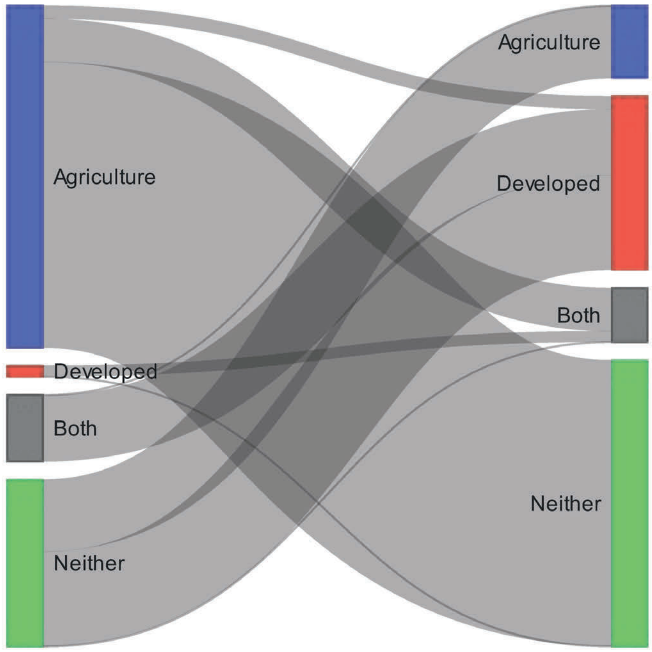

Figure 2.—Flow of area from an interface class in 2001 (left) to an interface class in 2016 (right) for forest area exhibiting a change of interface class in the conterminous United States. The height of a bar is proportional to area in the given year, and the width of a flow is proportional to the area of the flow.

Figure 3.—Change in percentage of forest edge typology from 2001 to 2016 in the conterminous United States by adjacency type, region, and ownership class. Forest to water and forest to barren adjacency types showed little change and are therefore not shown. The East region includes the states in the Northern and Southern FIA units. The West region includes states in the Pacific Northwest and Rocky Mountain FIA units.

DISCUSSION AND CONCLUSION

Although net change statistics are informative, they do not adequately convey the extent or importance of landscape context changes. Considering interior forest, for example (Fig. 1), the total area of gross change (both gain and loss) was 4.5 times larger than the area of net change and was an area equivalent to 25 percent of the original interior area. Gross loss of interior area alone was 16 percent of the original area of interior forest. Some ecological processes or ecosystem services could be substantially affected by that gross change. For example, from the perspective of an obligate interior forest species, the spatial rearrangement of interior forest area, with substantial losses of interior forest in some places, could be more important than the magnitude of net area change. Loss of interior forest anywhere likely means that organisms or populations would need to migrate to new locations, if possible, to stay within interior forest. Furthermore, the 11 percent of the interior forest area that was "new" in 2016 could provide habitat of different conditions, such as earlier successional stages than the existing forest, and thus support a different assemblage of species than in the prior period.

Similarly, considering changes in interface classes (Fig. 2), approximately half of forest area that moved into the developed interface class came from formerly non-interface landscapes (the "neither" category), while the replacement of the lost non-interface landscape area came almost exclusively from formerly agriculture interface landscapes. From the perspective of sustaining forest in non-interface landscapes, a key question is whether or for how long agriculture reversion can continue to replace forest that transitioned into developed interface area as urbanization continues to encroach upon forest land.

Transitions within natural vegetated landscapes are largely considered less permanent than transitions from natural land covers to agriculture or developed land covers. Still, natural transitions represented the largest increases in edge typology metrics (i.e., forest to shrub & grass; Fig. 3) across all ownership classes in the West and East, and perhaps also in interface classes (e.g., shrub & grass interfaces are grouped with the non-interface class; Fig. 2). In the productive eastern landscapes, a 15-year period is enough for land to move from forest to shrub & grass to forest again. Elsewhere, these transitions can take much longer than the duration of this analysis. Additionally, these neighborhood land cover transitions could have occurred at any point in the 15-year window and thus capture change over an aggregate of that time. The three context measures used here can be applied to shorter or longer temporal windows for additional perspectives.

Overall, our estimates of landscape change are likely conservative because we excluded the nonstocked forest condition class from our analysis, a condition that is often associated with a recent disturbance. Although the estimate of total CONUS forest area has been relatively stable for several decades (Oswalt et al. 2019), our work demonstrates that the landscape context of much of that area has changed substantially during that time.

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Forest Land-Use Change in the Conterminous United States

Mark D. Nelson, Jennifer L. Bakken, Holly C. Russon, Sean P. Healey, Tracey Frescino, Thomas A. Albright, Charles E. Werstak, Jr., Sonja N. Oswalt, and Andy N. Gray[1]

Abstract.—Information on status and trends in both land use and land cover are needed to assess the Nation's land resources. The U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis (FIA) program collects annual inventory data on forest land as well as other land use and cover classes. FIA also produces other sources of data and information on land resources. We present an example application of using FIA data to estimate status and change in forest land area, and we introduce the FIA Land Resources Explorer, an online interactive web application. The flagship product in the application is the Land Resources Dashboard, which provides a variety of tabular estimates, maps, and figures pertaining to land resources.

INTRODUCTION

Tracking both the spatial arrangement and changes through time of forest land and other land uses and land covers is essential for monitoring land resource conditions and trends (Nelson et al. 2020). Land cover describes conditions at a given time (Burley 1961, Osborne 1942), and land use describes the social and economic intent for which land is utilized (Coulston et al. 2014, Lund 2002). The area in forest land use is a key sustainability indicator under the Montréal Process (Nelson et al. 2015), and it is the primary measurable factor that addresses jurisdictional and corporate zero net deforestation commitments. While estimates based on land cover maps (e.g., National Land Cover Database) have suggested net losses in United States forest cover area over the past few decades, estimates of forest land produced by the U.S. Department of Agriculture (USDA), Forest Service, Forest Inventory and Analysis (FIA) program show net gains between 1987 and 2012 (rates of change have leveled off since then) (Oswalt et al. 2019). We present an example application of FIA data used to estimate status and change in forest land area, and we introduce the FIA Land Resources Explorer.

METHODS

FIA employs a probability-based sample design; permanent, fixed-radius, remeasured cluster-plots; and corresponding statistical estimators for producing unbiased estimates for a variety of attributes for forest land and other land uses, land covers, and land change, which are managed in multiple tables of the FIA Database (Burrill et al. 2021). FIA's definition of forest land includes elements of both land use and land cover.[2] Detailed forest composition and structure information, as well as land use and land cover, is recorded for each FIA plot containing forest land. Most nonforest plots are not field measured, but all nonforest plots are assessed for land use and land cover attributes using remotely sensed imagery and image-interpretation methods. FIA's data and tools can be used to produce design-unbiased estimates of status and change, and

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[2] FIA defines forest land as land at least 10-percent canopy cover by trees of any size, including land that formerly had such tree cover and that will be naturally or artificially regenerated. Forest land includes transition zones, such as areas between heavily forested and nonforested lands that are at least 10-percent canopy cover with trees and forest areas adjacent to urban and built-up lands. Also included are pinyon-juniper and chaparral areas in the West and afforested areas. The minimum area for classification of forest land is 1 acre and 120 feet wide measured stem-to-stem from the outer-most edge. Unimproved roads and trails, streams, and clearings in forest areas are classified as forest if less than 120 feet wide. This is the domestic reporting definition which is different from the definition used in international reporting (which includes a minimum tree canopy height criteria).

their associated estimates of variance, within and between all land classes. Change estimates are made possible by the remeasurement of conditions at permanent sample locations. Fewer than half of the states experienced more than 1 percent net gain or net loss since the previous measurement. Average plot remeasurement periods (REMPER) differed among states and FIA regions, ranging in years from 5.7 in the Northern region, 6.5 in the Southern region, 9.6 in the Rocky Mountain region, and 9.9 in the Pacific Northwest region. Average REMPER in the Northern and Southern regions has been increasing as many states transitioned from 5- to 7-year measurement cycles. Statistical tests of difference in land change can also be produced (Westfall et al. 2013). We provide an example of statistical tests of change ($p = < 0.05$) in forest land area, which were conducted on 47 of the conterminous United States (CONUS) for which remeasurement data are available during the most recent 5- to 10-year span.

RESULTS

FIA Data and Estimates

A large majority of FIA's sample plots experienced no permanent change in nonforest or forest, and fewer than 2 percent of plots transitioned to or from forest between recent and previous measurements (Fig. 1). Plots with persisting forest or nonforest were prevalent; plots with forest loss or forest gain were sparsely distributed throughout much of CONUS, with a few denser clusters of change in northeastern California, central Oregon, western Texas, along the forest/nonforest tension zone transecting Minnesota and Wisconsin, and in other scattered local areas (Fig. 1). The combined 47-state region showed a net loss of about 1 percent of previous forest land use area, a statistically significant difference. For individual states, 21 had statistically significant loss, 14 had nonsignificant loss, 7 had significant gain, and 5 had nonsignificant gain.

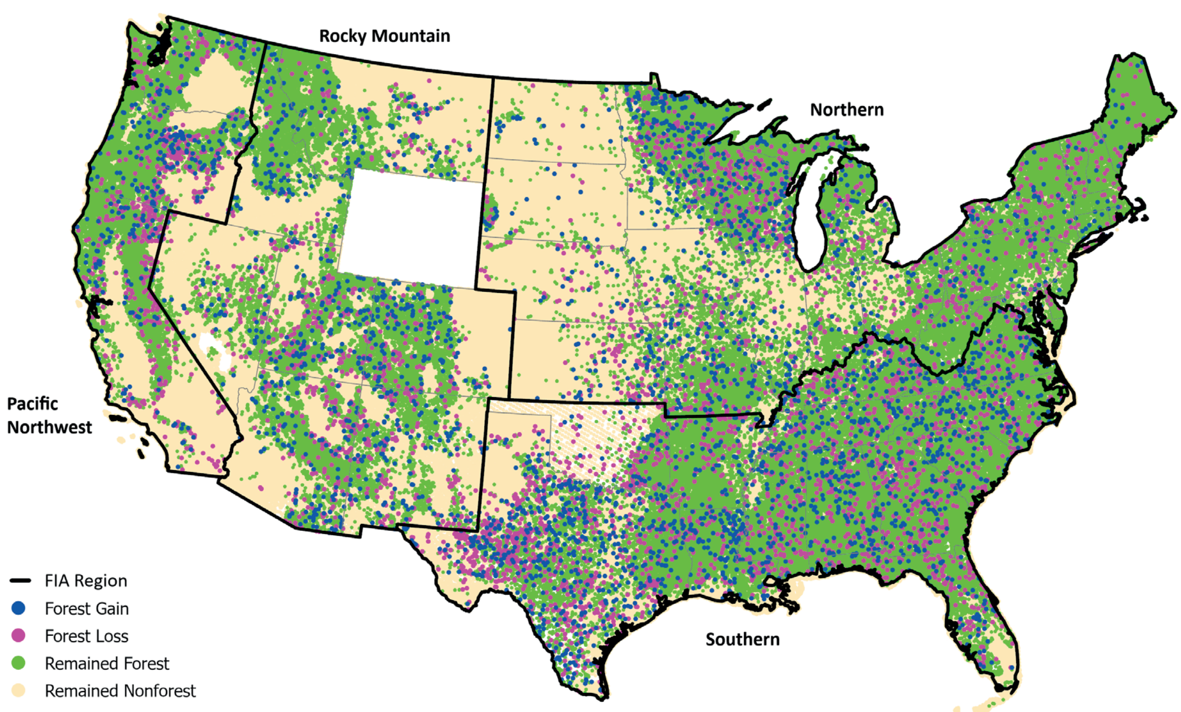

Figure 1.—Forest gain and forest loss of at least 25 percent and persisting forest and nonforest with less than 25 percent change between current (~2019) and previous measurements in the conterminous United States. Approximate locations of remeasured FIA plots show per-plot status. At the time of map creation, Wyoming (large white rectangle) had insufficient remeasurements for assessing change, and western Oklahoma had sparser remeasurement data than eastern Oklahoma. Bold lines delineate FIA regions: Northern, Southern, Rocky Mountain, and Pacific Northwest.

FIA Land Resources Explorer

The FIA program produces additional land change information beyond the FIA-based estimates described in the preceding paragraph. In partnership with the Forest Service Geospatial Technology Applications Center (GTAC), FIA has assessed land use, land cover, and agent of change for all states in the FIA Northern region and selected states in other regions using image-based change estimation (ICE), an approach based on photointerpretation of digital imagery from the National Agriculture Imagery Program (NAIP) at FIA plot locations (Megown et al. 2015, Webb et al. 2012). FIA and partners also developed and produced the Landscape Change Monitoring System (LCMS), which produces per-pixel predictions of land use, cover, and change from the Landsat Time Series. A new tool, the [FIA Land Resources Explorer](), provides comprehensive access to this variety of land resources information.

The Explorer is an interactive, user-friendly suite of tools for viewing land area estimates and maps from multiple information sources. It presents information on land use, land cover, and change as directed by the 2014 Farm Bill (updated in 2018, P.L. 115–334), which can be used to support land management decisions. The flagship tool in the Explorer is the FIA Land Resources Dashboard (Fig. 2), produced by a collaborative team from FIA and GTAC. Users can view estimates for states, FIA survey units, and counties based on the latest available data, which are updated monthly. Although the dashboard presents only land use estimates at this time, future versions are planned to include land-use change, land cover, and land-cover change.

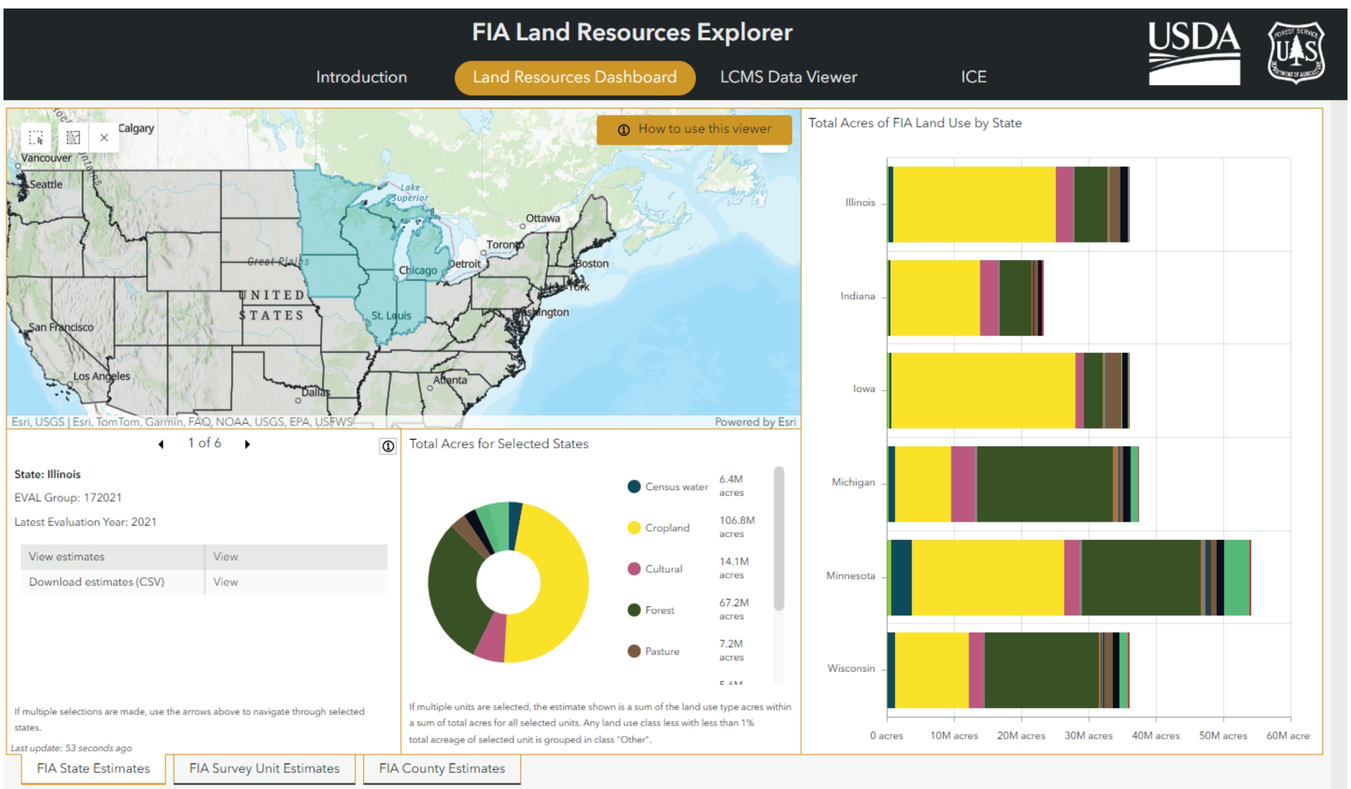

Figure 2.—[FIA Land Resources Explorer]() Land Resources Dashboard. Example of current land use area estimates within each of six upper midwestern states (Minnesota, Wisconsin, Michigan, Indiana, Illinois, and Iowa).

SUMMARY

Small net changes in forest land area can obscure larger, offsetting gross gains and gross losses. Definitional and other operational changes further confound comparisons of change estimates, highlighting the need for additional national consistency efforts. Remeasurement periods differ among states and within states during the same period, prompting a need to report more comparable change estimates on an average annual basis. The continued development of user-friendly tools such as the FIA Land Resources Explorer can help to demystify not only estimates of current land use and land cover, but also changes over time.

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Analysis of Photogrammetric Point Clouds for Wisconsin, USA

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Abstract.—Height information derived from National Agriculture Imagery Program (NAIP) data using photogrammetric methods is an alternative to airborne laser scanning (lidar) for strategic-scale forest inventory. The imagery-derived data are lower in cost relative to lidar and could be produced every 2 to 3 years in conjunction with regularly scheduled NAIP collections. In situ tree measurements were compared to co-located height metrics from the 2020 collection of NAIP in Wisconsin, USA. We found a moderately strong relationship between mean overstory height and 95th percentile height from NAIP-derived point clouds using the full plot area (r = 0.72) and using the central subplot (r = 0.71) for locations where only a forested land use is reported (single condition, forested plots). Correlations were lower in the presence of mixed land use (r = 0.61 for full plot area, r = 0.65 for the central subplot). The magnitude of correlation was sensitive to location and the presence of mixed land use.

INTRODUCTION

Precision of population estimates of forest attributes from a probability sample can be improved by using auxiliary data (e.g., multispectral satellite imagery) that are correlated with attributes of interest. When estimating volume, biomass, and carbon estimation, data related to tree or stand height can often provide estimates with less variance than spectral information from planar (2D) imagery data. Lidar has been shown to be highly effective in this role. In the United States, however, lidar acquisitions are performed piecemeal; they have varied collection specifications, gaps in coverage, and very few repeat collections. Digital aerial photogrammetry (DAP) is an alternative to lidar, as heights derived from stereoscopic imagery can be used to improve estimates, and DAP can be collected over large areas at lower cost than lidar. For example, DAP has been used by the Swiss National Forest Inventory (Pulkkinen et al. 2018) and by the U.S. Department of Agriculture (USDA), Forest Service, Forest Inventory and Analysis (FIA) program in the U.S. states of Washington, Tennessee, and Virginia (Schroeder et al. 2022, Strunk et al. 2017). Our objective was to analyze DAP data collected in Wisconsin and to assess its relationship to in situ data collected by the FIA program.

DATA AND METHODS

3D NAIP

DAP data were acquired during the leaf-on season in Wisconsin in 2020 as part of the USDA's National Agriculture Imagery Program (NAIP). Stereo-photogrammetric methods using Leica XPro software were applied to create three-dimensional point clouds, and each point was attributed with red, green, blue, and near-infrared (RGB-NIR) data from the source imagery. Products were delivered as compressed LAS format (.laz) in 4 km × 4 km tiles. The collection of approximately 9,500 files included 143 billion points with a nominal point density of 0.9 points per m^2. These data are referred to as 3D NAIP hereafter. Point clouds were normalized (converted to above-ground heights) using the National Elevation Dataset 1/3 arcsecond (10 m) product because of its consistent statewide coverage.

Comparisons to FIA Data

To assess the potential of 3D NAIP to increase the precision of estimates of volume and related forest attributes in Wisconsin, we conducted several comparisons to FIA plot data.

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We calculated a series of height metrics from the point cloud data using the lidR package in R (Roussel et al. 2020), including quantile heights (100th, 95th, and 75th percentiles), mean height, and quadratic mean height. These metrics were calculated for the central subplot and for a 43.9 m (144 ft) radius circle that encompassed all four subplots. FIA tree height information was summarized for each central subplot and plot; specifically, the mean height for dominant and co-dominant trees was calculated (referred to hereafter as the mean overstory height). Plots or subplots for which in situ tree measurements were available were divided into two categories: those with forest and other land uses recorded (mixed land use plots) and those with only forested land use recorded. Plots or subplots with no forest land use present (and therefore no tree measurements) were excluded from the analysis. The collection of plots used in the analysis included field visits from 2013 to 2021. We further subdivided plots into FIA survey units (aggregations of counties with similar forest characteristics). Pearson's correlation coefficient was calculated between 3D NAIP height metrics and FIA mean overstory height for the various combinations of land use (mixed versus forest only) and location (FIA unit or statewide). The five FIA units in Wisconsin represent a gradient from Laurentian Mixed Forest in the northern part of the state (Units 1 and 2) to more agricultural land use in the southern part of the state (Units 4 and 5) with a Broadleaf Forest transition zone in between (Unit 3). Analyzing each unit separately was motivated by an interest in understanding how the relationship between 3D NAIP and FIA heights varied with different forest conditions while maintaining a sufficient sample size.

RESULTS

The 95th percentile height from the 3D NAIP data exhibited the best combination of correlation and lower systematic overestimation or underestimation in relation to FIA mean overstory height (Fig. 1). For the sake of brevity, we focus on results derived from 95th percentile height only. We note a cluster of plots with in situ heights corresponding to zero or very low 3D NAIP heights (Fig. 1). There are a variety of potential causes, including spatial mismatch due to GPS errors, errors in the DEM used to normalize heights, temporal mismatch (harvest or disturbance occurring between FIA field measurements and 3D NAIP collections), and misrepresented heights in the 3D NAIP point cloud. Our results suggest that these outliers are not due entirely to the temporal mismatch between the two data sources because a similar pattern of potential outliers is present in the 2020–2021 data.

Using the statewide collection of plots for which forest was the only recorded land use, correlations were r = 0.71 (n=4,962) and r = 0.72 (n=3,959) when calculated using data from the central subplot only or using the full plot footprint, respectively (Fig. 2). When those same data were split into FIA units, correlations ranged from r = 0.56 (n=573) to r = 0.78 (n=708), with the lowest correlations occurring in Unit 4 in the southwest portion of the state.

Correlations were also calculated separately for plots with mixed land use (including at least one forested condition of any size). These values were generally smaller than those of their forest-only counterparts and ranged from r = 0.61 (n=2,154) to r = 0.65 (n=1,433) for the statewide collection and r = 0.46 (n=258) to r = 0.72 (n=263) across the five FIA units. The impact of using the data for the full plot versus data for only the central subplot was mixed. In general, using data for the full plot resulted in greater correlations for the forested locations, whereas the central subplot data exhibited greater correlations for the mixed land use locations.

The statewide root-mean-square difference (RMSD) for in situ heights and 3D NAIP was 4.1 m for forested plots and 4.9 m for mixed land use plots when using the full plot footprint. When using the central subplot only, the RMSDs were 5.1 m and 6.7 m for forested and mixed plots, respectively. The mean differences (3D NAIP minus FIA) using the full plot footprint were −0.1 m and −1.0 m for forested and mixed plots, respectively. For the central subplot only, the mean difference was −2.4 m for forested plots and −3.6 m for mixed plots.

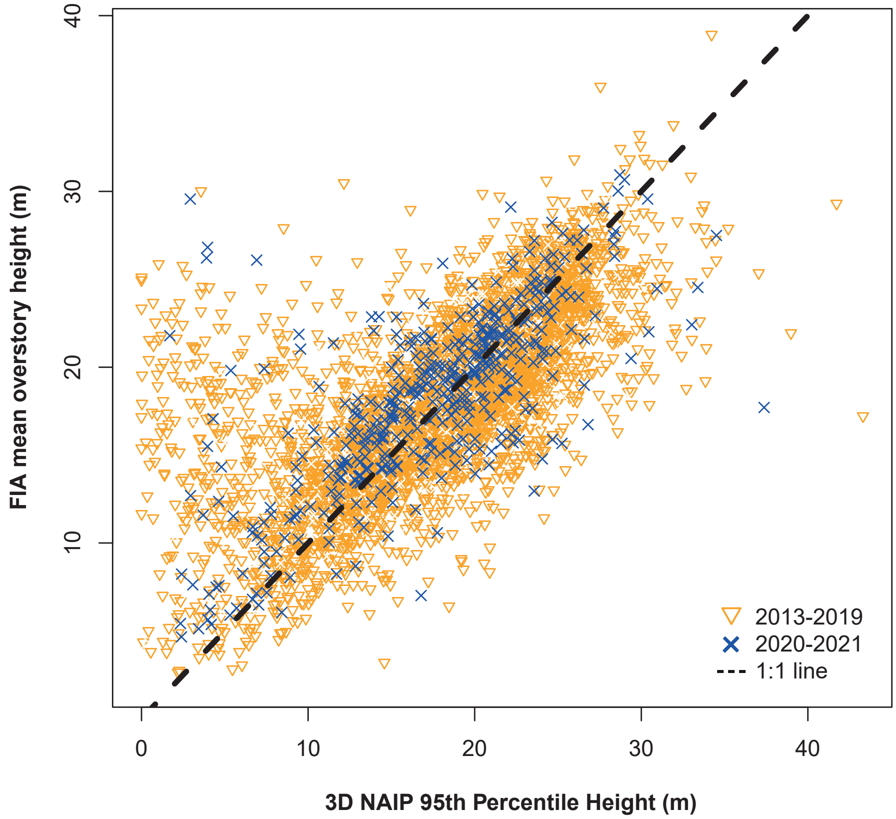

Figure 1.—Comparison of 95th percentile height calculated from 3D NAIP point clouds in Wisconsin in 2020 to co-located measurements of mean overstory tree height from the Forest Inventory and Analysis (FIA) program from 2013 to 2021. 3D NAIP height metrics were calculated for a circular area encompassing the FIA plot footprint and were compared to field-measured heights on four subplots. The heavy dashed line is the 1:1 line. Plots are categorized by the time period in which in situ measurements occurred.

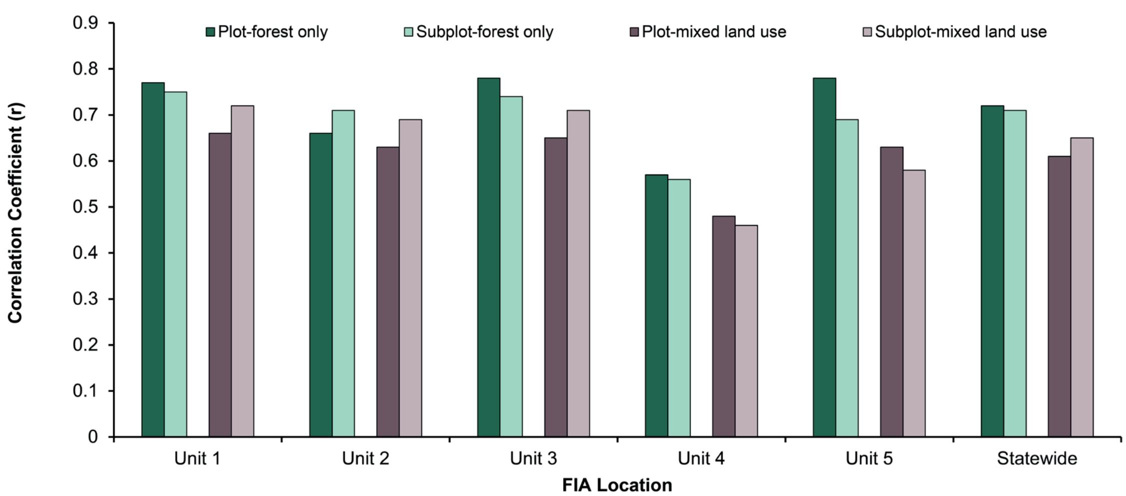

Figure 2.—Pearson correlation coefficient for 95th percentile height from 3D NAIP in Wisconsin and mean overstory height of field-measured trees from the FIA program for four alternative sets of measurements. Plot denotes that 3D NAIP height metrics were calculated for a circular area encompassing the Forest Inventory and Analysis (FIA) plot footprint and were compared to field measured heights on four subplots. Subplot denotes that height metrics were calculated for the central subplot only and compared to trees measured only in that same area.

SUMMARY

Auxiliary data related to FIA variables of interest can be used to increase the precision of estimates and can be a cost-effective alternative to intensifying the plot network, particularly if the data are collected for multiple purposes and can be acquired for little or no additional cost. Lidar has been shown to be highly effective at reducing variance in inventory estimates, but the inconsistent way in which it is acquired and spatial and temporal gaps in coverage create challenges to implementation for a nationwide forest inventory. In this study, we examined the relationship between 3D NAIP data and FIA tree height information for Wisconsin. The 3D NAIP data are moderately correlated to tree heights and therefore should provide sufficient information to improve estimates of height-related attributes, such as volume and biomass. This finding is consistent with those using 3D NAIP data in other parts of the United States. We also found potential outliers with zero or low 3D NAIP height values in the presence of trees and reduced correlation in the presence of mixed land use.

We note that this analysis focused on locations for which in situ tree height measurements were available and therefore did not include nonforest locations. To obtain an estimate using a probability sample, all locations should be used, regardless of land status. Although not shown here, we found that nonzero heights are present in the 3D NAIP data for a substantial number of plots with no forest land (due to buildings, nonforest trees, and more). Additional work to restrict the calculation of 3D NAIP heights to vegetation using either the spectral information contained in the 3D NAIP data or an independent source of land cover data could improve the correlation and increase precision of estimates.

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FOREST DISTURBANCE

Biotic and Abiotic Forest Disturbance Trends in the Conterminous United States

KaDonna C. Randolph, Randall S. Morin, Thomas C. Goff, Greg C. Liknes, and Mark D. Nelson[1]

Abstract.—Quantifying trends and relative impacts of forest disturbances can inform forest managers, landowners, and other decision makers. We analyzed U.S. nationwide forest inventory data from 2010 and 2020 to quantify trends in biotic and abiotic natural disturbances across forests of the United States. Results showed that the direction (increase or decrease) and degree of change in disturbed forest area varied by disturbance agent, region of the country, and whether changes were evaluated on the basis of total area disturbed or average annual area disturbed. Overall, from 2010 to 2020, total disturbed forest area in the conterminous 48 States increased by 45.2 million acres, average annual disturbance increased by 3.3 million acres, and the top three primary disturbance agents (by total area) shifted from animal, weather, and fire to insect, fire, and disease.

INTRODUCTION

The number of individual weather- and climate-related disaster events causing more than $1 billion in damages has increased steadily in the United States over the last 40 years. In 2022, the United States had 18 such events, including drought and fire in the West, flooding in the Midwest, hurricanes and tornadoes in the Southeast, and scattered severe storms in the North (NOAA NCEI 2023). In addition to these events, U.S. forests are continuously at risk from insects and pathogens (Fei et al. 2019, Potter et al. 2019) and invasive plants (Oswalt et al. 2015). Our study sought to answer two questions:

1. What are the leading forest disturbance agents in the United States?
2. Is there evidence of increased forest disturbance in recent years?

METHODS

The U.S. Department of Agriculture (USDA), Forest Service, Forest Inventory and Analysis (FIA) program collects forest disturbance data on a network of permanent, remeasured field plots across the country (Westfall et al. 2022). For an event to be recorded as a disturbance, it must have occurred since the previous plot measurement (or within the last 5 years for new plots and remeasurements following a nonsampled visit) and caused mortality and/or damage to 25 percent or more of all trees or to 50 percent or more of a single species across at least 1 acre. Up to three disturbances may be recorded, in order of importance, per plot condition (USDA Forest Service 2019). We considered only the most important disturbance (i.e., the first recorded) to simplify reporting and to avoid replicative accounting of conditions with multiple disturbances. Using the FIA online EVALIDator tool (USDA Forest Service 2022), we estimated disturbed forest area (DF) by region and disturbance agent for the most recent decade (ending in approximately 2020) and the previous decade (ending in approximately 2010) (Fig. 1). Disturbance agents were categorized as insect, disease, fire, animal, weather, and other (nonsilviculture-related human activities, geologic events, vegetation, and unknown). Silviculture activities recorded separately from disturbances as treatments (USDA Forest Service 2019) were not included.

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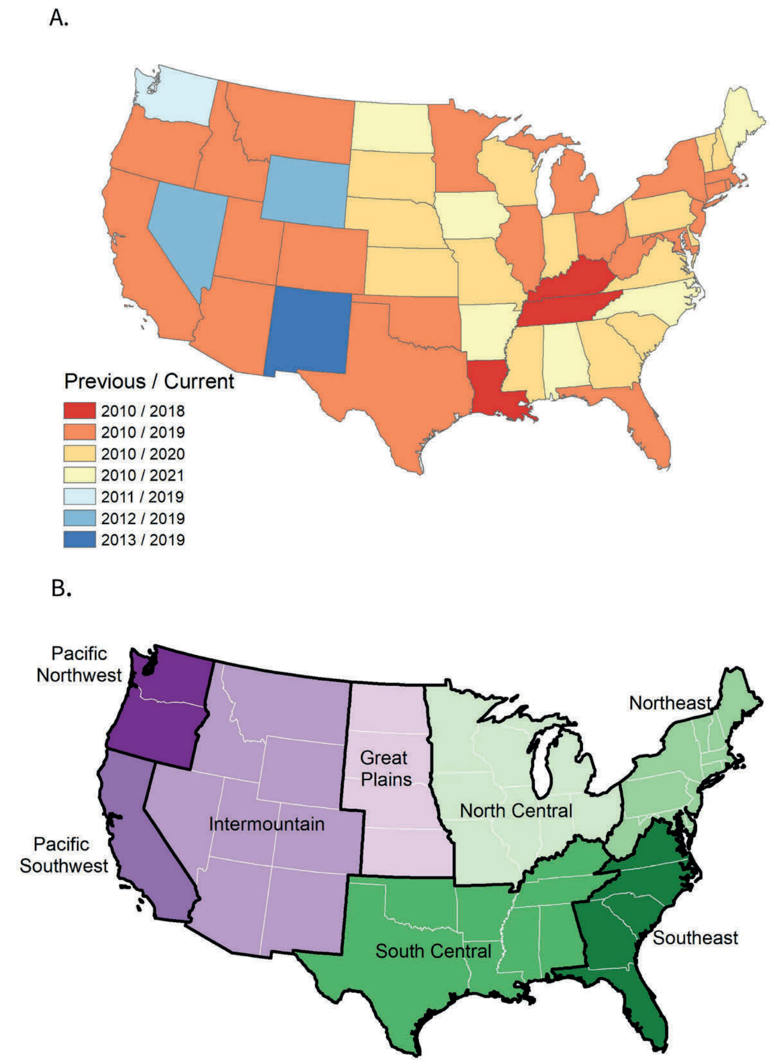

Figure 1.—Terminal inventory year for the previous and current decade (A) and regional grouping (B) for states included in the analysis.

We calculated average annual forest area disturbed (DFA) by agent, region, and time period as

$$DFA_{jkt} = DF_{jkt}/\hat{r}_{kt} \qquad (1)$$

where

DF_{jkt} = area of forest (acres) disturbed by agent j in region k at time t

$\hat{r}_{kt}$ = the average remeasurement period for region k at time t, calculated as

$$\hat{r}_{kt} = \frac{\sum_{i=1}^{n_{kt}} r_{ikt}}{n_{kt}} \qquad (2)$$

where

r_{ikt} = remeasurement period for plot i in region k at time t

n_{kt} = number of forested plots in region k at time t

We queried the REMPER column in the FIA database plot table (Burrill et al.2021) to obtain r_{ikt}. If REMPER was null because the record was for an initial plot measurement or measurement following a skipped (nonsampled) visit, r_{ikt} was set to 5 years in accordance with guidance provided in the FIA data collection field guide (USDA Forest Service 2019).

Changes in DF and DFA from 2010 to 2020 were evaluated with ratios (2020 estimate : 2010 estimate). Ratios greater than1 indicate increases, ratios less than1 indicate decreases, and ratios equal to 1 indicate no change. Larger values of $|1 - ratio|$ indicate greater change.

RESULTS

Change in Disturbed Forest Area

Estimates of DF, DFA, and the change ratios are provided in Table 1. Because we considered only primary disturbances, estimates for individual disturbance agents should be treated as minimum estimates. The direction and degree of change varied by region, agent, and metric of evaluation. For all regions combined, the direction of change (increase or decrease) for insect, disease, fire, weather, and all agents combined was the same for both metrics; however, the degree of change, as estimated by the change ratio, was greater for DF than DFA because DFA adjusts for variable remeasurement periods inherent in DF. Disturbances attributed to animals and other agents showed no changes when evaluated by DF but declined when evaluated by DFA. Within the North Central, Northeast, South Central, and Southeast regions, changes for DF and DFA were similar in direction and degree. Within the Great Plains, Pacific Northwest, and Pacific Southwest regions, changes in DF and DFA were opposite in direction but similar in degree. In the Intermountain region, changes in DF and DFA were opposite in direction and dissimilar in degree. Differing conclusions drawn from the DF and DFA ratios about whether disturbed forest area increased, decreased, or remained the same highlight the need to temporally standardize estimates, as is done for FIA estimates of growth, removals, and mortality.

Leading Disturbance Agents

For all regions combined, DF was apportioned across disturbance agents rather evenly in 2010: 20 percent each for animal, weather, and fire; 15 percent insect; 14 percent disease; and 11 percent other. In 2020, this distribution was reordered and less balanced: 26 percent insect, 21 percent fire, 20 percent disease, 14 percent animal, 13 percent weather, and 7 percent other. Among the individual regions, shifts in the leading disturbance agent from 2010 to 2020 occurred in the Northeast (from other to disease), North Central (from animal to insect), South Central (from weather to fire), and Pacific Southwest (from animal to fire). The leading disturbance agents in the Southeast, Great Plains, Intermountain, and Pacific Northwest regions (respectively, fire, animal, insect, and disease) remained unchanged.

SUMMARY

Forest disturbances in the United States increased from 2010 to 2020 and were driven primarily by insect, disease, and fire. Increases were greatest in the Northeast, North Central, and Southeast regions. Evaluating changes based on DF and DFA are both informative; however, DFA is preferred, especially at national and regional levels, because of the retrospective observation period for disturbances outlined in the FIA data collection field guide and different remeasurement cycle lengths within and among states.

Table 1.—Average plot remeasurement period ($\hat{r}$), disturbed forest area (DF), average annual disturbed forest area (DFA), and metrics of change by region, disturbance agent, and time period (2010 and 2020). Within rows, metrics of change that diverge in direction are in bold.

Region	Agent	$\hat{r}_{2010}$ (years)	$\hat{r}_{2020}$ (years)	DF_{2010} (million acres)	DF_{2020} (million acres)	DFA_{2010} (million acres/year)	DFA_{2020} (million acres/year)	DF_{ratio} [a]	DFA_{ratio} [b]
All	All	5.6	6.9	94.31	139.54	16.87	20.19	1.5	1.2
All	Insect	5.6	6.9	14.16	35.60	2.78	5.38	2.5	1.9
All	Disease	5.6	6.9	13.46	27.38	2.59	3.90	2.0	1.5
All	Fire	5.6	6.9	18.69	29.67	3.35	4.23	1.6	1.3
All	Animal	5.6	6.9	18.83	19.24	3.61	3.01	**1.0**	**0.8**
All	Weather	5.6	6.9	18.82	17.49	3.16	2.58	0.9	0.8
All	Other	5.6	6.9	10.36	10.17	1.83	1.64	**1.0**	**0.9**
Great Plains	All	5.0	5.9	3.33	3.59	0.66	0.61	**1.1**	**0.9**
Intermountain	All	5.1	8.0	23.07	32.58	4.55	4.07	**1.4**	**0.9**
North Central	All	5.0	5.6	12.65	20.89	2.53	3.71	1.7	1.5
Northeast	All	5.9	5.6	7.11	17.63	1.21	3.17	2.5	2.6
Pacific Northwest	All	5.1	9.2	10.51	13.96	2.07	1.52	**1.3**	**0.7**
Pacific Southwest	All	4.9	9.2	7.33	9.96	1.51	1.08	**1.4**	**0.7**
South Central	All	6.5	6.7	19.97	24.07	3.09	3.59	1.2	1.2
Southeast	All	5.9	5.9	10.39	16.86	1.78	2.87	1.6	1.6

Note: Forest Inventory and Analysis defines forest land as land at least 10-percent canopy cover by trees of any size, including land that formerly had such tree cover and that will be naturally or artificially regenerated. Forest land includes transition zones, such as areas between heavily forested and nonforested lands that are at least 10-percent canopy cover with trees and forest areas adjacent to urban and built-up lands. Also included are pinyon-juniper and chaparral areas in the West and afforested areas. The minimum area for classification of forest land is 1 acre and 120 feet wide measured stem-to-stem from the outer-most edge. Unimproved roads and trails, streams, and clearings in forest areas are classified as forest if less than 120 feet wide. This is the domestic reporting definition which is different from the definition used in international reporting (which includes a minimum tree canopy height criteria).

[a] $DF_{ratio} = DF_{2020} / DF_{2010}$

[b] $DFA_{ratio} = DFA_{2020} / DFA_{2010}$

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Grazing Disturbance on Forest Land in the Midwestern and Northeastern United States

Thomas C. Goff, Todd A. Kellerman, and Greg C. Liknes[1]

Abstract.—To better understand the prevalence and distribution of grazing activity on forest land in the midwestern and northeastern United States, we analyzed and compared disturbance data from the U.S. Department of Agriculture (USDA), Forest Service, Northern Research Station, Forest Inventory and Analysis (NRS-FIA) program and woodland pasture data from the USDA National Agricultural Statistical Service (NASS). NRS-FIA estimates indicate that grazing disturbance was observed in 20 of 24 states and the proportion of forest affected ranged from 0.03 percent (Maine) to 57 percent (Nebraska). Grazing was the most prevalent disturbance across the states of Iowa, Kansas, Missouri, Nebraska, North Dakota, and South Dakota. Woodland pasture was reported by NASS in every state, with a total estimate of 4.7 million acres. The area of grazing-disturbed forest land was less correlated with the area of woodland pasture in the Great Plains and strongly correlated in the North Central and Northeastern subregions.

INTRODUCTION

There is strong interest in the role of disturbances (such as insects, disease, and wildfire) in the health and sustainability of forest ecosystems. In the United States, less attention is paid to the effects of agricultural activities on forests, which historically have had long-lasting impacts on forest ecology (Borman 2005). For example, livestock grazing in woodlots can suppress understory regeneration, compact soil, and in some cases, damage trees and increase stand mortality (Mabry 2002, McQuilkin and Scholten 1989). Conversely, well-managed forest grazing can mitigate wildfire risk through reduced fuel loading, aid in ecological restoration, and increase the size and quality of trees for timber (Cutter et al. 1999, Ruiz-Mirazo 2011).

Brantly (2014) placed the relationship between grazing animals and trees along a continuum based on intensity and duration of grazing, density of trees, and overall management objectives. On one end of the spectrum, “turning livestock into the woods” is less structured and leads to degradation of forests and their related resources (i.e., soil and water). At the other extreme, “silvopasture” is a very deliberate and intensively managed practice that often involves planted trees. “Forest grazing” lies somewhere in between and can be successfully implemented in existing forests with skillful management. Although we were interested in understanding the continuum of grazing management across the Midwest and Northeast regions of the United States, that amount of detail is not collected on Northern Research Station, Forest Inventory and Analysis (NRS-FIA) plots. Our objectives were to (1) analyze regional patterns of forest land grazing disturbance and (2) corroborate the data against a secondary source to assess consistency in the application of NRS-FIA’s grazing disturbance code.

METHODS

The NRS-FIA program maintains a sample-based forest inventory to monitor the status and changes in the forest resources of the United States (USDA Forest Service 2021). Up to three disturbances can be recorded for the forested portion of a field plot. Disturbances can be natural or human in cause and positive or negative in effect. A disturbance must be a minimum of at least 1 acre and meet a significant threshold, wherein mortality and/or damage affects 25 percent of all trees or 50 percent of an individual species. Some disturbances, such as domestic animal/livestock (grazing), affect the land and/or the ground vegetation. In these instances, a disturbance is coded when at least 25 percent of the soil surface or understory vegetation has been affected. Disturbances need to have occurred since the previous inventory or in the 5 years

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prior if the plot is not a remeasurement. A corresponding disturbance year is recorded unless the disturbance is ongoing; then a code is given to indicate it is continuous.

We generated estimates of grazing disturbed forest land for NRS-FIA units (groupings of counties) using the online estimation tool EVALIDator (Fig. 1) (USDA Forest Service 2022). These estimates represent the most recent data available for each state at the time of the data query and are based on plots visited from 2012 to 2021. We also aggregated state-level estimates to larger subregions to facilitate some additional comparisons. For this study, all instances of grazing disturbance were included.

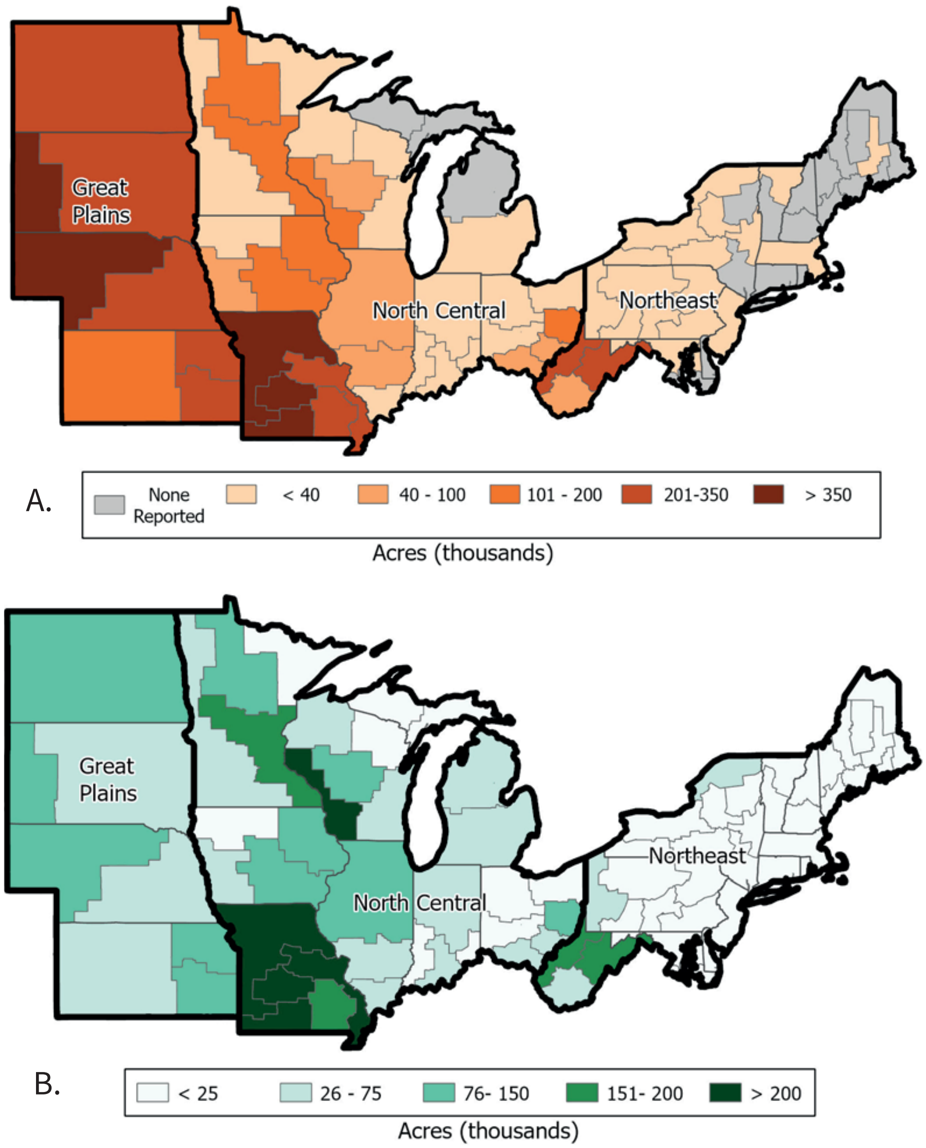

Figure 1.—Area of grazing-disturbed forest land (A) and woodland pasture (B), in thousand acres, by NRS-FIA unit and subregion. Results were aggregated by subregion (thick boundary line). Thin boundary lines represent units. Estimates of the area of grazing-disturbed forest land are derived from NRS-FIA data. Estimates of the area of woodland pasture are derived from the 2017 Census of Agriculture (USDA-NASS).

The U.S. Department of Agriculture (USDA), National Agricultural Statistics Service (NASS), Census of Agriculture, conducted once every 5 years, provides information about U.S. farms, ranches, and the producers who operate them, including the number and type of livestock owned, as well as producer characteristics and practices (USDA NASS 2022). Public lands leased for grazing (e.g., State or Forest Service lands) are generally excluded from the census. NASS does not provide a definition of "woodland" in the census instructions, but it does direct respondents to exclude the following: land planted for Christmas tree production, deforested land improved for pasture, and pastureland containing desert vegetation. NRS-FIA's forest land definition contains similar exclusions but also includes requirements for size, width, and canopy cover percent. Estimates of woodland acres grazed were compared to estimates of grazing disturbance for each unit. We calculated Pearson's correlation coefficient for each subregion and also fit a zero-intercept ordinary least-squares regression model in order to compare the two data sources.

RESULTS

More than 7 million acres of the region's 181 million acres of forest land were impacted by grazing. Grazing disturbance was observed by NRS-FIA in 20 of 24 states, and the proportion of forest affected ranged from 0.03 percent (Maine) to 57 percent (Nebraska) (Table 1). Grazing is the most prevalent disturbance across the central states of Iowa, Kansas, Missouri, Nebraska, North Dakota, and South Dakota (Fig. 1a). Additionally, grazing exceeded the area impacted individually by fire, weather, and disease in Illinois, Ohio, and West Virginia. Nearly all (97 percent) of grazing disturbed conditions were indicated to be continuous rather than occurring in a specific year. When grazing disturbance was present, it was most often the only disturbance recorded (84 percent of grazing disturbance observations were not associated with other types of disturbance observations).

Woodland pasture was reported by NASS in every state, with particularly high acreage in Missouri and southwestern Wisconsin (Fig. 1b). The area of woodland pasture was 4.7 million acres, or 37 percent lower than the estimate of grazing disturbance. We compared the area of grazing to woodland pasture, and while the data were well correlated overall ($r = 0.78$), results were mixed when analyzed at the subregion level. Strong correlation was observed in the Northeast ($r = 0.97$) and North Central ($r = 0.93$) subregions, but not in the Great Plains ($r = 0.63$). In the North Central and Northeastern subregions, unit-level estimates of grazing disturbance are very similar to woodland pasture (Fig. 2). Notably, the slope of the regression line fit to the Great Plains data is substantially greater than the other subregions and indicates grazing estimated by NRS-FIA averages four times higher than NASS woodland pasture.

Table 1. —Estimates of forest land, grazing disturbance, and woodland pasture by state and subregion, 2012–2021

Subregion	State	Forest land area (acres [a])	Area disturbed by grazing (acres [a])	Area of woodland pasture (acres [b])	Percentage of forest land area disturbed by grazing [a]
Great Plains	Kansas	2,467,240	823,002	260,647	33
	Nebraska	1,433,522	813,363	159,107	57
	North Dakota	823,407	252,903	84,714	31
	South Dakota	1,908,467	996,521	162,561	52
	Subtotal	6,632,636	2,885,789	667,029	44
North Central	Illinois	4,854,960	190,633	204,967	4
	Indiana	4,792,843	82,227	113,647	2
	Iowa	2,851,077	399,412	317,946	14
	Michigan	20,167,228	28,295	83,820	0.14
	Minnesota	17,675,446	320,006	345,240	2
	Missouri	15,394,132	2,270,693	1,521,125	15
	Wisconsin	16,943,544	277,369	438,059	2
	Subtotal	82,679,230	3,568,635	3,024,804	4
Northeast	Connecticut	1,763,460	0	13,444	0
	Delaware	354,925	0	2,519	0
	Maine	17,521,754	5,500	20,956	0.03
	Maryland	2,448,338	9,235	25,340	0.38
	Massachusetts	2,984,347	1,211	17,481	0.04
	New Hampshire	4,691,525	0	11,256	0.00
	New Jersey	1,988,518	12,384	8,377	1
	New York	18,622,212	48,372	137,555	0.26
	Ohio	7,809,811	275,115	228,144	4
	Pennsylvania	16,621,968	102,210	127,575	1
	Rhode Island	361,127	0	1,255	0
	Vermont	4,522,889	9,945	24,024	0.22
	West Virginia	12,017,823	492,844	372,340	4
	Subtotal	91,708,697	956,816	990,266	1
	Total	181,020,563	7,411,240	4,682,099	4.1

[a] Estimates of the area of forest land and the area of grazing-disturbed forest land are derived from U.S. Department of Agriculture, Forest Service, Northern Research Station, Forest Inventory and Analysis data.

[b] Estimates of the area of woodland pasture are derived from the U.S. Department of Agriculture, National Agricultural Statistics Service, 2017 Census of Agriculture.

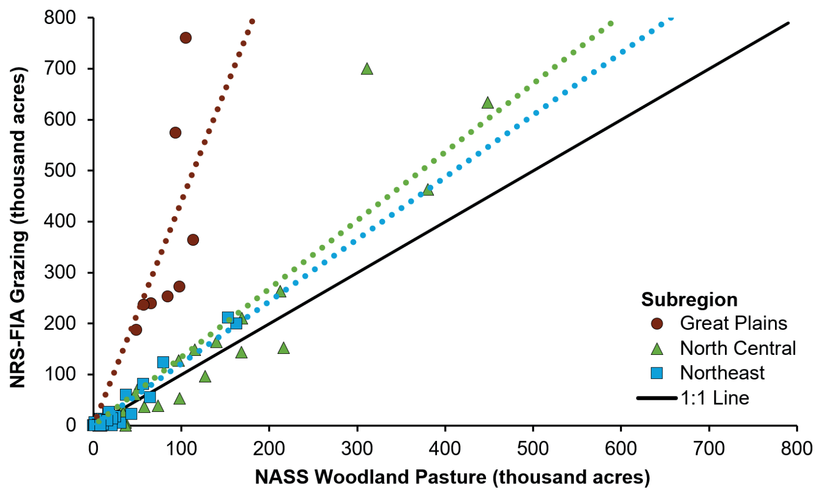

Figure 2.—Comparison of grazing-disturbed forest land to woodland pasture. Each point represents a unit, and units are grouped by subregion. Zero intercept regression lines are shown for each subregion. Estimates of the area of grazing-disturbed forest land are derived from NRS-FIA data. Estimates of the area of woodland pasture are derived from the 2017 Census of Agriculture (USDA-NASS).

CONCLUSIONS

Grazing by domestic animals is a common forest disturbance in several of the states included in this study yet may not be the first category of disturbance that comes to mind by those interested in forest health. Our objectives were to examine regional patterns of grazing and to compare NRS-FIA data to another source of grazing information to assess consistency in the application of NRS-FIA's grazing disturbance code. We found grazing to be the most prevalent forest disturbance in six states with localized areas of high activity in Missouri, Wisconsin, and South Dakota. Additionally, grazing disturbances were almost always reported as continuous (ongoing) rather than attributed to a specific year, and therefore there are long-term impacts that may be worthy of additional study. We corroborated NRS-FIA estimated grazing disturbance by comparing to woodland pasture data from the NASS program and found a strong correlation in some parts of the region and a lower correlation with a substantially upward bias in the Great Plains (overestimation of grazing by NRS-FIA relative to NASS). Some of this disparity could be attributed to the high proportion of grazed forest land in South Dakota that is government-owned and therefore not included in NASS woodland pasture estimates. However, it may be an indicator that the determination of grazing disturbance is not performed consistently across the region.

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UNDERSTORY VEGETATION AND INVASIVE PLANTS

Using a Regional Database to Determine the Extent of the Invasive Vine, *Celastrus orbiculatus*, in the Southeastern States and Its Relationship with Soil Moisture Regimes

W. Henry McNab, Tracy Roof, and Erik C. Berg[1]

Abstract.—Oriental bittersweet (*Celastrus orbiculatus*) (bittersweet) is an introduced, invasive vine in the United States. Its botanical characteristics, including shade-tolerance, rapid growth response to increased light, and prolific production of seeds distributed by birds have resulted in a widespread distribution in northeastern U.S. forests, particularly on mesic sites. This study's purpose was to determine the distribution of bittersweet in the southeastern United States and evaluate its presence in relation to soil moisture regimes. Using data from the U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis (FIA) program, we found that the vine was identified on plots in eight southeastern states, particularly in the southern Appalachian Mountains. In North Carolina and Virginia, where data were sufficient for analysis, the presence of bittersweet differed between the Mountains and Piedmont Units and was strongly associated with mesic soil moisture regimes. Our results add to the scant information on this invasive species and increase our understanding of ecological conditions associated with its occurrence.

INTRODUCTION

Oriental bittersweet (*Celastrus orbiculatus*) (bittersweet) is an introduced vine that has long been recognized as an aggressive invasive species in deciduous forests of the eastern United States and Canada (Patterson 1974). Native to eastern Asia, bittersweet was listed in an 1898 New York nursery catalog as an ornamental plant that was easy to establish, grew rapidly, and had dependable fall production of attractive red fruits; records indicate it had been planted in Maryland in 1912 (Del Tredici 2014). Bittersweet was first described as an undesirable species in 1947 because of its invasion into upland forests and tendency to displace the native American bittersweet (*C. scandens*) due to its faster growth rate and hybridization (White and Bowden 1947).

The occurrence and ecology of bittersweet has received extensive study in states north of the Ohio River. Using data from the U.S. Department of Agriculture (USDA), Forest Service, Forest Inventory and Analysis (FIA) program, Kurtz (2013) reported the presence of bittersweet from the Great Lakes States east to the Atlantic Ocean. Leicht (2005) reported that the vine produces prolific, annual crops of berry-like fruits with multiple seeds that persist on dormant vines. The fruit provides winter food for birds, which facilitates the distribution of seeds that have a high germination rate. Seedlings are highly shade tolerant and can survive several years beneath a tree canopy (Leicht and Silander 2006). Upon canopy disturbance, seedlings respond quickly to increased light and ascend to the canopy by twining on nearby tree stems. Prescribed burning can be effective in top killing small diameter stems; however, fire tends to increase root sprouting (Pavlovic et al. 2016). Targeted manual methods of bittersweet control include herbicides, cutting stems, and grubbing of root systems (Miller et al. 2013).

Analyses in the Northern FIA region by Kurtz (2013) and Kurtz and Hansen (2018) reported that bittersweet presence was greatest in New England and declined westward. Many local studies have demonstrated greater occurrence of bittersweet on mesic compared to xeric sites (Del Tredici 2014, Leicht 2005, Leicht and Silander 2006, Leicht-Young et al. 2009). Other important factors related to bittersweet occurrence in New England include the presence of roads and recent forest disturbances (Lundgren et al. 2004).

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Although bittersweet has been recorded in the southeastern United States since 1974 (Patterson 1974), its distribution and ecology have been studied far less there than in the northeastern United States. Miller et al. (2008) conducted a regional-scale study of bittersweet in the Southeast using FIA data and reported its presence in 12 counties across 5 states. In a landscape-scale study in the mountains of North Carolina, Albright et al. (2009) reported a strong association between bittersweet presence and distance from an initial point of introduction and reported a weak correlation with environmental variables. In two local studies, also in the North Carolina mountains, Kuhman et al. (2013) reported that bittersweet tended to occur on previously cultivated, old-field sites associated with mesic soils. Horton and Francis (2014) concluded that canopy disturbance of yellow-poplar (*Liriodendron tulipifera*) stands on mesic sites facilitated bittersweet establishment.

The purpose of our exploratory study was to examine the occurrence of bittersweet in the Southeast at regional and local scales. Our specific objectives were (1) to determine the current extent of bittersweet occurrence in relation to a previous assessment by Miller et al. (2008), and (2) to evaluate our hypothesis that bittersweet occurrence is greater in areas with mesic environments compared to drier conditions.

METHODS

Study Area

We began our analysis by looking at the number and distribution of FIA plots containing bittersweet in the southeastern United States.[2] States with low sample sizes were judged to be inadequate for analysis (fewer than 50 plots); therefore, we limited our study area to North Carolina and Virginia. Plot data for these states were used to analyze bittersweet occurrence at two scales of evaluation: (1) regionally by state, unit, and county, and (2) locally at the plot level in relation to soil moisture regimes.

Units used in the analysis were constructed by grouping FIA survey units based on similarity to U.S. Environmental Protection Agency (EPA) ecoregions (Fig. 1) (US EPA 2013). For each state, three units were created:

- **Mountains Units**—EPA ecoregions 66 (Blue Ridge Mountains) and 67 (Ridge and Valley): This is a region of dissected, rugged mountains and narrow valleys. Local relief is several hundred feet to a few thousand feet from valley floor to ridge crest. Soils are derived from gneisses and schists, are moderately shallow on steep ridges, and are relatively deep in broad valleys and basins. In Virginia, the low mountains west of the Blue Ridge include the valley and ridge province where rock formations consist of sedimentary, calcareous limestones. Mean annual precipitation, which varies depending on topography, ranges from 38 to over 90 inches. Inceptisols and Ultisols are the primary soil orders. Forests are dominated by deciduous hardwoods, primarily oaks.

- **Piedmont Units**—EPA ecoregion 45 (Appalachian Piedmont): This region of foothills adjacent to the mountains is gently rolling to hilly with narrow stream valleys. Elevation decreases gradually from west to east. Local relief is mainly in tens of feet but can range to several hundred feet. Soils, which are typically eroded from extensive cotton cultivation during the 1800s, are primarily Ultisols with high clay content. Mean annual precipitation ranges from 43 to 45 inches. Forest composition is primarily pine-hardwood mixtures.

- **Coastal Plains Units**—EPA ecoregions 65 (Southeastern Plains) and 63 (Middle Atlantic Coastal Plains): Two types of topography and moisture regimes are found in the Coastal Plains: (1) nearly level areas inland from the ocean cut by broad valleys with meandering

[2] Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, and Tennessee.

streams with local relief of a few feet to ten feet and (2) gently sloping areas with increased dissection of uplands approaching the piedmont. Soils are variable depending on drainage and consist of four orders: Inceptisols, Ultisols, Histosols, and Entisols. Mean annual precipitation ranges from 45 to 47 inches. Upland forests are typically dominated by southern yellow pines; hardwoods occupy broad river basins and lowland swamps.

Inventory Data

The FIA plot design at each sample location consists of a cluster of four 0.04175 acre subplots, each of which was inventoried for bittersweet if 10 percent or more of its area was stocked with trees (Bechtold and Patterson 2005). Variables extracted from subplot data included state, county, FIA unit, assessed soil moisture regime (hydric, mesic, or xeric), and presence of bittersweet. Data for the four subplots at each location were combined to represent a larger plot of 0.167 acres. The soil moisture regime was assigned to a plot based on the majority of conditions at each of the four subplots. For example, a plot consisting of one hydric and two mesic subplot conditions was classified as mesic. If there was no majority of similarly classified subplot conditions, such as two mesic and two xeric, the soil moisture regime was randomly

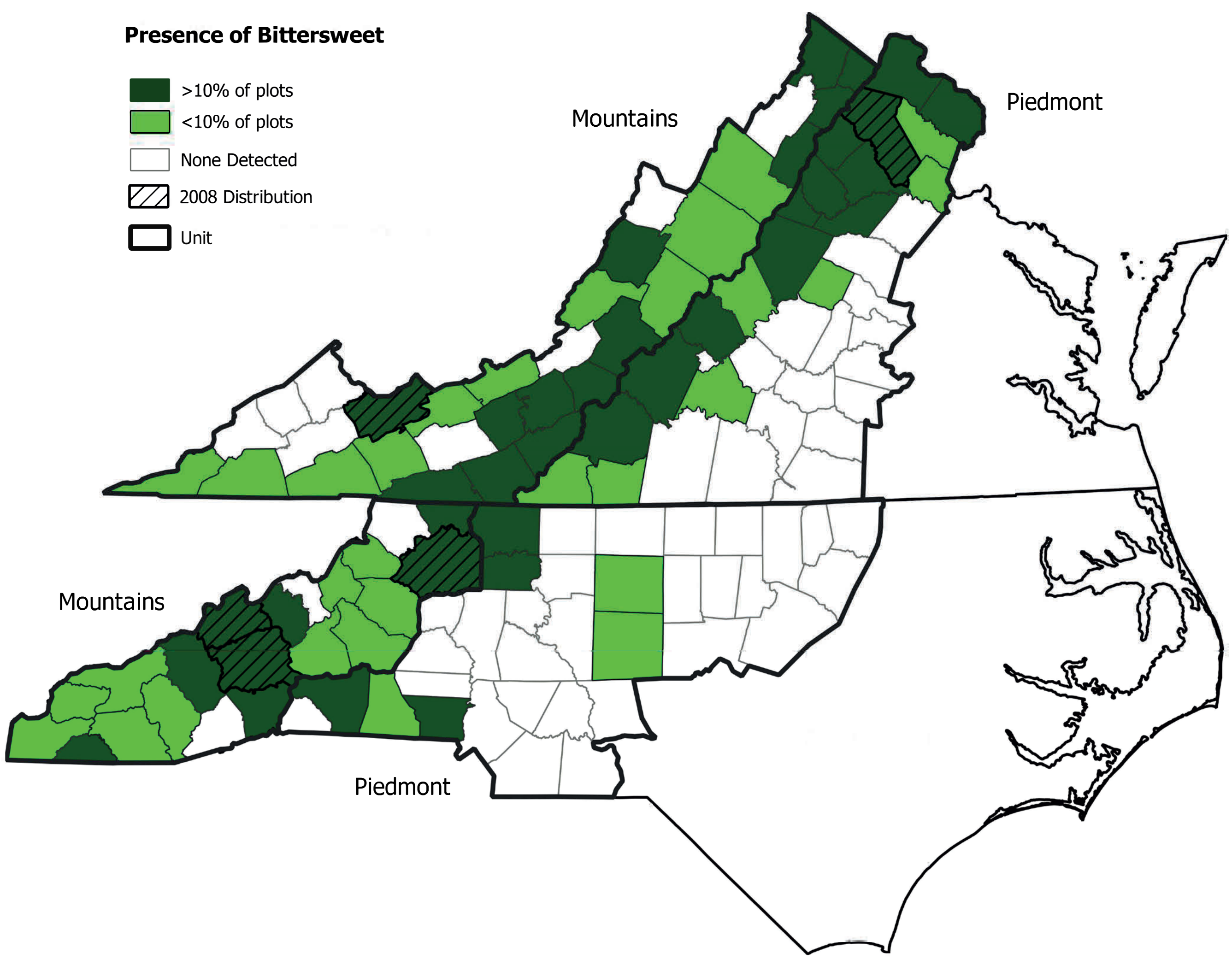

Figure 1.—Distribution of *Celastrus orbiculatus* (bittersweet) on FIA plots by abundance (present on greater than or less than 10 percent of plots within a county) between 2012 and 2022, and the historical distribution of bittersweet circa 2008 (Miller et al. 2008) by county and unit, North Carolina and Virginia.

assigned. Preliminary examination of FIA plot data revealed that bittersweet was restricted to plots in the Mountains and Piedmont Units of both states. Also, bittersweet did not occur on plots with a hydric soil moisture regime. After omitting plots in both Coastal Plains Units and plots with hydric moisture regimes, the data for analysis consisted of 1,204 plots in North Carolina and 1,799 plots in Virginia (Table 1).

To assess the regional distribution of bittersweet, plot-level presence or absence was summed to the county, unit, and state. To assess the local level occurrence of bittersweet, the percentage of plots containing bittersweet was determined for each county (Fig. 1). Finally, plots containing bittersweet were summarized by soil moisture regime and expressed as a percentage by county.

Analysis

We evaluated the occurrence of bittersweet in relation to large regions (states and units) and small, local areas (plots). The first test conducted was a chi-square analysis of bittersweet presence or absence on all plots in each state and determined whether state data should be pooled or remain separate for the subsequent analysis of units. Next, chi-square analysis was used to determine if units in each state should be pooled or remain separate for the next analysis of soil moisture effects (mesic, xeric) of plots containing bittersweet. Student t-tests with unequal variances were used to evaluate differences of mean percentages of bittersweet occurrence between the two soil moisture regimes (mesic, xeric) in all counties of each unit. All tests of differences were conducted at the $p = 0.05$ level of significance.

RESULTS AND DISCUSSION

Change of Occurrence

The presence of bittersweet in the two-state study area increased from 5 counties in 2008 to 67 counties in 2020 (Fig. 1). Based on a study of invasive species using 2008 FIA data (Miller et al. 2008), bittersweet was observed in three North Carolina counties and two counties in Virginia.

Table 1.—Number and percent of counties and Forest Inventory and Analysis (FIA) plots containing *Celastrus orbiculatus* (bittersweet) by state and unit

North Carolina

Unit	Counties		FIA plots	
	Total	With bittersweet (%)	Total	With bittersweet (%)
Piedmont	35	20.0	497	2.2
Mountains	21	85.7	707	9.9
All	56	44.6	1,204	6.7

Virginia

Unit	Counties		FIA plots	
	Total	With bittersweet (%)	Total	With bittersweet (%)
Piedmont	34	55.9	722	15.1
Mountains	31	74.2	1,077	7.5
All	65	64.6	1,799	10.6

Except for one county in the Piedmont Unit in northeastern Virginia, all other 2008 occurrences of bittersweet were in the Mountains Units of both states. By 2020, bittersweet was found in 7 Piedmont and 18 Mountains counties of North Carolina; in Virginia, bittersweet occurred in 19 Piedmont and 23 Mountains counties (Table 1).

Regional Scale

Bittersweet was present on 6.7 percent of plots in North Carolina and 10.6 percent of plots in Virginia (Table 1). A chi-square test of independence indicated a significant difference in bittersweet occurrence between states ($X^2 = 61.7$, $P < 0.01$). Based on results of this test, data for the two states were not merged. Between the two units in North Carolina, bittersweet was present on 70 (9.9 percent) Mountains plots and 11 (2.2 percent) of Piedmont plots (Table 1). A chi square test of independence indicated this difference was significant ($X^2 = 27.5$, $P < 0.01$). In Virginia, the relationship was reversed; bittersweet was present on 109 (15.1 percent) Piedmont plots compared to 81 (7.5 percent) Mountains plots. A chi square test of independence indicated a significant difference ($X^2 = 26.3$, $P < 0.01$) in the presence of bittersweet between Virginia Piedmont and Mountains Units.

Several situations are plausible explanations for the high occurrence of bittersweet on Mountains plots in the North Carolina and the opposite results in Virginia, where bittersweet was greatest on Piedmont plots. In North Carolina, Miller et al. (2008) reported bittersweet in four Mountains counties in 2008 (Fig. 1), which gave it a head start there in comparison with the Piedmont. However, Oswalt (2006) suggests that the Piedmont in general is a “hot spot” for invasion by nonnative species because of more favorable “… land use, site productivity, length of growing season, forest type characteristics or other environmental differences.” In a study of invasive species (including bittersweet) in relation to provinces in Virginia, Small and Chamberlain (2015) concluded that the Piedmont is more susceptible than the Mountains because of several centuries of periodic, extensive land disturbances, particularly cycles of forests cleared for agriculture followed by abandonment of cultivation and old-field succession.

Local Scale

We used t-tests to evaluate differences by units within states of the mean percentage of plots with bittersweet classified as either mesic or xeric (Table 2). In the North Carolina Mountains Unit, the percentage of mesic plots with bittersweet (88.6 percent) was higher ($P < 0.01$) compared to xeric plots (11.4 percent). In the Piedmont Unit of North Carolina, bittersweet was not found on plots with a soil moisture regime classified as xeric. In the Virginia Mountains Unit, mesic plots (87.7 percent) had a significantly higher ($P < 0.01$) mean percentage of plots containing bittersweet compared to xeric plots (12.3 percent). In the Piedmont Unit of Virginia, the mean percentage of plots with bittersweet was also significantly higher ($P < 0.01$) for mesic plots (94.5 percent) compared to xeric plots (5.5 percent).

Results of our local scale analysis were particularly informative to address our hypothesis that bittersweet is a species primarily of mesic soil moisture regimes. In all tests of soil moisture conditions, we found that bittersweet was strongly associated with mesic soils; this agrees with findings by Horton and Francis (2014), who observed bittersweet occupying the same ecoregions that overlap the Mountains Units. Our findings also agree with many studies in northeastern states that classify bittersweet as a species of mesic soils (Del Tredici 2014, Leicht-Young et al. 2009). We were surprised to find a significant soil moisture relationship between bittersweet and FIA units, particularly in North Carolina, where bittersweet was absent on Piedmont xeric soils. It was sparsely present on those sites in Virginia (Table 2). However, the small number of plots with bittersweet in the Piedmont of both states suggests these findings are likely tenuous.

Table 2.—Number of Forest Inventory and Analysis plots containing *Celastrus orbiculatus* (bittersweet) by unit, state, and soil moisture regime

Unit	North Carolina			Virginia		
	Mesic[a]	Xeric[b]	Total	Mesic[a]	Xeric[b]	Total
Piedmont	11	0	11	103	6	109
Mountains	62	8	70	71	10	81
All	73	8	81	174	16	190

[a] Mesic water is available for plant growth throughout the growing season.

[b] Xeric water is limited for growth for an interval during the growing season, usually fall.

SUMMARY AND CONCLUSIONS

The purpose of our study was to investigate the current distribution of bittersweet in southeastern states at regional and local scales and test for differences in occurrence that may be related to environmental conditions that characterize each area. Compared with a similar 2008 study that reported bittersweet in 5 counties in North Carolina and Virginia (Miller et al. 2008), our study revealed bittersweet occurrence in 67 counties, corresponding to an increase of 1,240 percent. Similar analyses of data from adjoining states could determine if the rapid expansion of bittersweet observed in our study area has occurred elsewhere in the Southeast. We found bittersweet was strongly associated with units that generally delineate topographically different areas of mountain and piedmont landscapes. At the local scale (sample plots), we found bittersweet was associated with mesic soil moisture regimes, which agrees with findings from studies in New England states. Our results add to the sparse information available to better understand the ecology and distribution of bittersweet in North Carolina and Virginia.

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Urban Forests as Sources for Invasive Tree Species

Mark J. Ambrose[1]

INTRODUCTION

Previous studies have shown that invasive forest insects and pathogens have often first been introduced in urban areas (Paap et al. 2017). Many invasive plants were also initially introduced in urban areas as ornamentals, such as Chinese privet (*Ligustrum sinense*) (Cuda and Zeller 2019). I used street tree inventory data as well as nationwide forest inventory (NFI) data and urban forest inventory data (UFI) from the U.S. Department of Agriculture (USDA), Forest Service, Forest Inventory and Analysis (FIA) program to determine the relative abundance of tree species that are known to be invasive in different subpopulations of the urban forest as well as in the surrounding rural forest. Differences in the relative abundance of these invasive species may suggest whether urban areas are serving as sources of invasive species expanding into surrounding rural forests.

DATA

I used street tree inventory data, UFI data, and NFI data from five cities and their surrounding areas. The scope of the analysis was limited by data availability; cities were included only if the following criteria were met: street tree inventory data were available, the first UFI was complete, and the city fell within an FIA region where known invasive trees species had been tallied in the NFI for the most recent inventory cycle. Cities included in this analysis were Houston (TX), Austin (TX), Springfield (MO), Greater Kansas City (MO), and Greater St. Louis (MO).

Street tree inventory data were obtained from various sources. For St. Louis and Kansas City, where the UFI covered the city center and the surrounding metropolitan area, street tree inventories from multiple municipalities were combined so that the extent of the street tree data matched the extent of the UFI data as closely as possible. Street tree inventories were completed between 2010 and 2022.

METHODS

Estimates of tree (at least 1 inch diameter) composition by city and major land use type were derived using each of the three inventory types (street tree, UFI, and NFI). Urban estimates were exported as summary tables from the My City's Trees application (Texas A&M Forest Service 2022). NFI estimates were generated using the EVALIDator estimation tool and were used to represent surrounding rural forests (USDA Forest Service 2022). For each city, EVALIDator was used to estimate the species composition of forests in the county where the city was located and all adjacent counties. I identified invasive tree species in each tree inventory summary and calculated the relative abundance (percentage) of each invasive species in each inventoried subpopulation.

RESULTS AND DISCUSSION

The relative abundance of the predominant invasive tree species in each city or metropolitan area is shown in Tables 1 and 2. Note that because most invasive tree species are relatively rare in both the UFI and the NFI, the sampling errors (not presented here) for estimated abundance are rather large. The most abundant invasives in Houston and Austin were chinaberry (*Melia*

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azedarach), Chinese tallow tree (*Triadica sebifera*), and mimosa (*Albizia julibrissin*). In the Missouri cities, the most abundant invasives were mimosa, Siberian elm (*Ulmus pumila*), and tree-of-heaven (*Ailanthus altissima*).

In Houston (Table 1), Chinese tallow tree was much more abundant in rural forests and the recreation urban land use (i.e., parks) than in other land uses, suggesting that urban areas are not an important source for this species. This finding aligns with the known history of the species; tallow tree was introduced as a potential biofuel crop and planted widely in rural areas. In Austin, chinaberry was relatively common in several urban land uses and occurred in trace amounts in the rural forest, suggesting that urban populations may be a source for this species.

In all Missouri cities (Table 2), Siberian elm occurred across multiple urban land uses, including street trees. However, in the NFI data, it occurred only in the area around Kansas City, even though its urban relative abundance was lower there than in the other Missouri cities. This suggests that the forests around Springfield and St. Louis may be more resistant to invasion by Siberian elm than those around Kansas City. It is also possible that the high relative abundance of Siberian elm in greater Kansas City street tree and recreation area populations meant that the species occurred in locations closer to natural areas, facilitating spread to rural forests. In Springfield, tree-of-heaven was very abundant in the UFI and occurred in trace amounts in the NFI, suggesting that this species may be spreading from urban populations to rural forests. Mimosa was relatively rare across all cities and all urban land uses, as well as in rural forests. Therefore, even if mimosa may be spreading from urban areas to rural forests, it currently does not seem to be having a major impact on tree community composition in urban or rural areas.

Table 1.—Relative abundance (percent of total tree population) of the three most common invasive tree species in inventoried Texas cities by land use for each inventory type: street tree inventory, urban forest inventory (UFI), and nationwide forest inventory (NFI)

Houston, TX

	Street tree inventory	UFI						NFI
Species	All land uses (%)	Overall (%)	Agriculture (%)	Developed (%)	Forest (%)	Recreation (%)	Residential (%)	All land uses (%)
Chinaberry (*Melia azedarach*)	0.59	0.39	0.00	3.18	0.06	0.00	1.48	0.03
Chinese tallow (*Triadica sebifera*)	4.70	12.16	6.94	11.54	12.77	22.75	4.93	23.34
Mimosa (*Albizia julibrissin*)	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.07

Austin, TX

	Street tree inventory	UFI						NFI
Species	All land uses (%)	Overall (%)	Agriculture (%)	Developed (%)	Forest (%)	Recreation (%)	Residential (%)	All land uses (%)
Chinaberry (*Melia azedarach*)	1.79	1.58	2.10	0.31	1.15	2.20	0.00	0.03
Chinese tallow (*Triadica sebifera*)	0.63	0.08	0.00	0.27	0.17	0.00	0.00	0.00
Mimosa (*Albizia julibrissin*)	0.21	0.01	0.00	0.05	0.00	0.00	0.00	0.00

Table 2.—Relative abundance (percent of total tree population) of the three most common invasive tree species in inventoried Missouri cities/metropolitan areas by land use for each inventory type: street tree inventory, urban forest inventory (UFI), and nationwide forest inventory (NFI)

Greater Kansas City, MO

Species	Street tree inventory	UFI						NFI
	All land uses (%)	Overall (%)	Agriculture (%)	Developed (%)	Forest (%)	Recreation (%)	Residential (%)	All land uses (%)
Mimosa (*Albizia julibrissin*)	0.07	0.04	0.00	0.00	0.00	0.00	0.22	0.00
Siberian elm (*Ulmus pumila*)	3.85	0.97	0.14	1.69	0.89	12.73	1.00	0.49
Tree-of-heaven (*Ailanthus altissima*)	0.28	0.42	0.00	0.00	0.71	0.00	0.27	0.12

Greater St. Louis, MO

Species	Street tree inventory	UFI						NFI
	All land uses (%)	Overall (%)	Agriculture (%)	Developed (%)	Forest (%)	Recreation (%)	Residential (%)	All land uses (%)
Mimosa (*Albizia julibrissin*)	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Siberian elm (*Ulmus pumila*)	0.93	3.86	0.00	49.26	0.45	0.00	1.01	0.00
Tree-of-heaven (*Ailanthus altissima*)	0.22	0.20	0.00	0.00	0.20	0.00	0.28	0.45

Springfield, MO

Species	Street tree inventory	UFI						NFI
	All land uses (%)	Overall (%)	Agriculture (%)	Developed (%)	Forest (%)	Recreation (%)	Residential (%)	All land uses (%)
Mimosa (*Albizia julibrissin*)	0.37	0.06	0.00	0.56	0.00	0.00	0.00	0.00
Siberian elm (*Ulmus pumila*)	3.11	7.30	0.00	2.82	0.00	0.00	20.97	0.00
Tree-of-heaven (*Ailanthus altissima*)	0.74	12.09	0.00	29.79	16.07	0.00	0.86	0.01

CONCLUSIONS

This approach of comparing relative abundance of nonnative and, especially, identified invasive species in various types of inventories may be useful for understanding invasion dynamics, targeting invasive species monitoring efforts, and targeting control efforts. Analyses are currently limited to species historically tallied by FIA. However, now that FIA has adopted a unified tree species list that includes all tree species tallied in urban inventories, future analyses can include other species. Such analyses will help improve our understanding of source populations of invasive tree species and may facilitate effective control measures. Future analyses should also consider sampling error and the adequacy of the FIA inventories for estimating populations of relatively rare invasive species before drawing conclusions regarding invasive potential of particular species from urban areas.

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Estimating Vegetation Percent Cover by Vertical Layer and Growth Habit

Mark D. Nelson, Lisa H. Elliott, Scott A. Pugh, Kathryn C. Baer, Andrew N. Gray, and Patrick A. Landisch[1]

Abstract.—Information on the abundance and structure of understory plant communities can be used to assess wildlife habitat and many other ecosystem services. We used U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis (FIA) Vegetation data to produce estimates of percent canopy cover of vegetation by vertical layer and structure growth habit across two ownership classes, at the state and substate level, on Michigan forest land during 2013–2019. All scales and ownerships had the greatest cover within the highest and lowest vertical height layers and the least cover in the two intermediate layers. Forb, grass, and shrub were the predominant growth habits in vertical layers up to 6 feet in height; tally tree cover predominated above 6 feet. Vegetation structure differed more between ownerships than between geographic areas. We present additional results and recommendations for improving estimates of forest vegetation structure.

INTRODUCTION

Vegetation structure can serve as an indicator used in ecosystem management (Rutten et al. 2015). The U.S. Department of Agriculture (USDA), Forest Service, Forest Inventory and Analysis (FIA) program collects data on vegetation structure at the subplot level from a subsample of plots via the Vegetation protocol (Veg) (Burrill et al. 2021). These data have been collected since the early 2000s in the Pacific Northwest and Rocky Mountain FIA regions and since 2012 in the Northern and Southern FIA regions. We present an example application for using FIA vegetation structure data to estimate characteristics of forest land vegetation cover in Michigan, USA.

METHODS

FIA vegetation structure data are collected on 24-foot radius subplots, as percent vegetation canopy cover by structure growth habit (hereafter, growth habit) and vertical layer (USDA Forest Service 2021). Vertical layers include 0 to 2.0 feet, 2.1 to 6.0 feet, 6.1 to 16.0 feet, greater than 16 feet, and aerial (total canopy cover across all layers). Five standard vegetation growth habits include tally tree (TT), non-tally tree (NT; woody plants that do not qualify as a tally tree species), shrubs/subshrubs/woody vines (SH), forbs (FB), and graminoids (GR). For each growth habit, cover cannot exceed 100 percent within any vertical layer. Multiple growth habits may overlap within any vertical layer, and the sum of cover across growth habits may exceed 100 percent. FIA does not measure cover across all growth habits within each vertical layer (i.e., there is no measure of growth habit horizontal cover aggregation corresponding to the aerial vertical layer aggregation).

To normalize the sum of covers across growth habits to a maximum of 100 percent, we incorporated a procedure from Appendix K of the National Vegetation Classification Standard (FGDC 2008), which is based on Jennings et al. (2006):

$$C_i = \left[1 - \prod_{j=1}^{n} \left(1 - \frac{\%\text{cov } j}{100}\right)\right] \times 100 \qquad (1)$$

where C_i is the percent cover of vertical layer i for species or growth habit j (equation from Jennings et al. 2006). We applied this aggregation method to calculate per subplot total percent cover across all growth habits within each layer and for total aerial cover.

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Estimates of percent vegetation cover and corresponding variance estimates were produced using a ratio of means estimator, Y/X, where Y represents the coverage area (e.g., acres) of vegetation for a vertical layer *i* and growth habit *j* and X represents the area of accessible forest land.[2] Estimates were also produced for cover aggregated across growth habits, C_i, defined in the preceding paragraph. We used data from FIA Veg plots measured during 2013–2019 to estimate percent vegetation canopy cover on forested conditions in Michigan (n=406 plots), within 16 counties encompassing the Huron-Manistee National Forests (H-M NF; n=78 plots), and for two subareas of H-M NF: Huron (eastern 6 counties; n=30 plots) and Manistee (western 10 counties; n=48 plots). Within each geographic extent, we also produced estimates for National Forest System (NFS) and non-NFS land (all other public and private ownerships).

RESULTS

Michigan statewide total aerial vegetation canopy cover across all vertical layers was 92 percent when aggregated across all growth habits. Likewise, within 16 counties encompassing H-M NF, vegetation canopy cover on forest land was 92 percent, ranging from 91 percent in 10 Manistee counties to 94 percent in 6 Huron counties. H-M NF vegetation canopy cover was greatest in both the highest and lowest vertical layers (greater than 16.0 feet = 64 percent and less than 2.1 feet = 62 percent, respectively), and least in the middle layers (2.1 to 6.0 feet = 40 percent and 6.1 to 16.0 feet = 32 percent). Huron had more canopy cover in the lowest layer (65 percent) than Manistee (59 percent), but Manistee had more cover in the highest layer (66 percent) than Huron (62 percent) (Fig. 1).

Michigan statewide aerial vegetation canopy cover (aggregated across all growth habits) on forest land had similar percentages between NFS lands (91 percent across all three Michigan national forests: H-M NF, Hiawatha NF, and Ottawa NF) and non-NFS lands (92 percent) (Fig. 1). However, analysis of relative cover by layer and ownership revealed potential differences in vegetation structure between these two ownership classes at both the state and multicounty scales. Michigan NFS lands had more cover in the highest layer and less cover in the three lower layers than non-NFS lands. Cover by layer and ownership within H-M NF counties follows a similar pattern, with the greatest differences observed between NFS and non-NFS lands in six counties encompassing the Huron subarea.

At both statewide and H-M NF scales, vegetation cover in NT growth habit was less than 0.5 percent in every vertical layer; therefore, we omitted NT from further analyses. Within the H-M NF 16-county study area, TT cover was 15 percent in the 0 to 2.0 foot layer, 18 percent in the 2.1 to 6.0 foot layer, 28 percent in the 6.1 to 16.0 foot layer, 64 percent in the greater than 16 foot layer, and 71 percent aggregated vertically across all aerial cover (Fig. 2). H-M NF FB (23 percent), GR (24 percent), and SH (22 percent) predominated the lowest layer but comprised little or none of the vegetation canopy cover in the two highest layers (Fig. 2). Michigan statewide distribution of cover by layer and habit was similar to H-M NF (statewide results are not reported here).

[2] Estimator implemented via SQL script, developed by Scott Pugh and documented in Vegetation_indicator_for_Population_Estimation_User_Guide.docx. Available upon request.

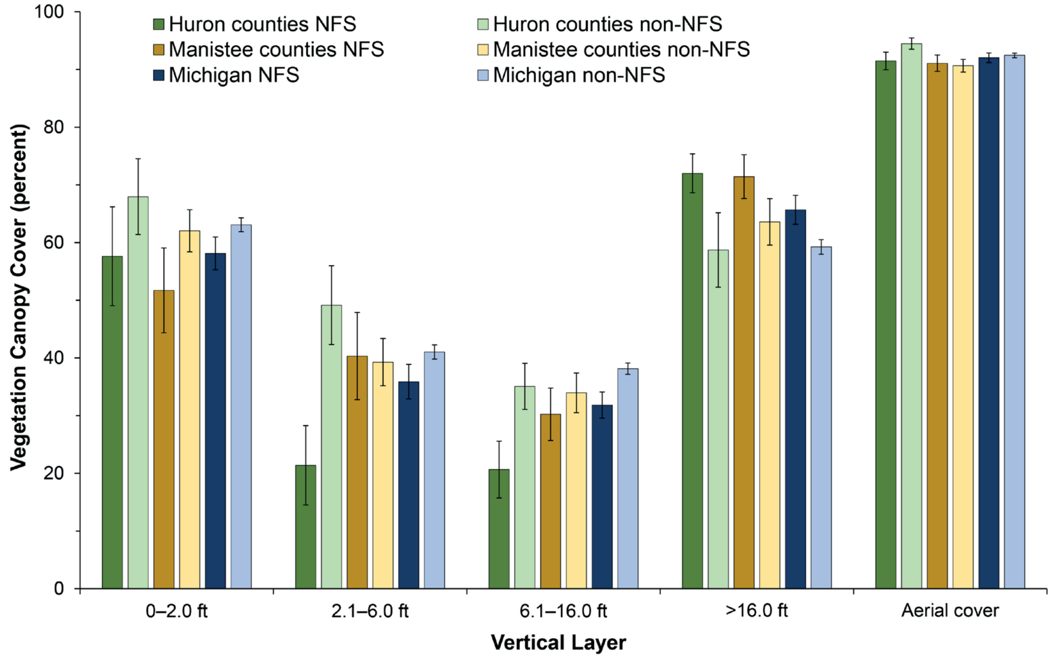

Figure 1.—Vegetation canopy cover (percent) on forest land, aggregated across growth habits, by vertical layer, general ownership category (National Forest System [NFS] or non-NFS), and geographic extent (16 counties encompassing the Huron-Manistee National Forests), Michigan, 2013–2019. Vertical layers include 0 to 2.0 feet, 2.1 to 6.0 feet, 6.1 to 16.0 feet, greater than 16 feet, and aerial cover. Totals are constrained to 100 percent after weighting for overlapping cover among growth habits within each layer and within total aerial cover. Error bars represent ±1 standard error of the estimate (percentage points).

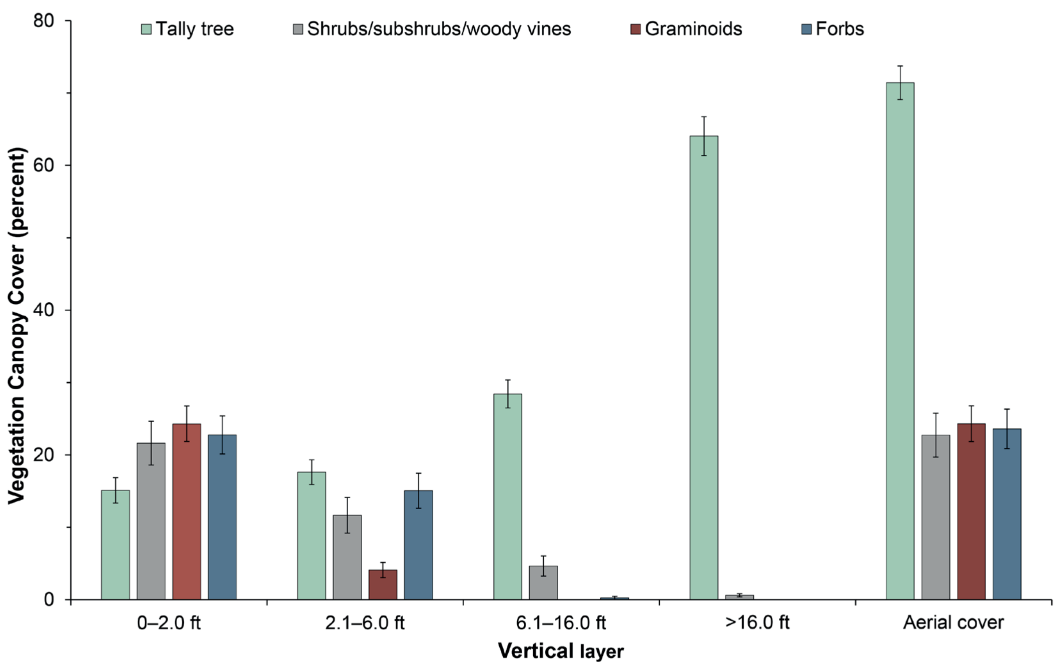

Figure 2.—Vegetation canopy cover (percent) on forest land, by growth habit and vertical layer, within 16 counties encompassing Huron-Manistee National Forest, Michigan, 2013–2019. Growth habits include tally tree (TT), shrubs/subshrubs/woody vines (SH), forbs (FB), and graminoids (GR). Vertical layers include 0 to 2.0 feet, 2.1 to 6.0 feet, 6.1 to 16.0 feet, greater than 16 feet, and aerial cover. Error bars represent ±1 standard error of the estimate (percentage points).

SUMMARY

FIA vegetation structure data were used to produce estimates of vegetation canopy cover by vertical layer, growth habitat, and two broad ownership classes at statewide and substate spatial scales. FIA does not measure total cover of all growth habits combined within each layer, so we applied a mathematical approach to approximate this attribute. We did not test the validity of this approach. This study presents an example from FIA's Northern region, where cover of growth habits is measured but cover by individual species is not. Data on vegetation cover by species may provide additional information in those FIA regions that collect species data. The ratio of means estimator of vegetation cover used in this study may result in less bias than use of a mean of ratios estimator. We did not test for bias and recommend further research on this topic. Vegetation cover differed more between ownership classes than between geographic extents at both statewide and substate extents. State-level estimates obscure larger differences within more local areas (e.g., the Huron counties). Estimates for individual vertical layers' growth habits revealed information not evident from estimates based on total (aerial) canopy cover and aggregated growth habits. These results illustrate that FIA Veg data are useful for assessing forest vegetation structure in multiple ways.

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ECOCULTURAL RESOURCES AND PEOPLE

Leveraging FIA Data to Evaluate Ecocultural Impacts of Climate Change in the Southwest

Sara Souther and Nanebah Lyndon[1]

Abstract.—As Indigenous communities often use plants and animals in cultural activities, they will be disproportionately impacted by the effects of climate change and resulting shifts in the spatial distributions of species because geopolitical boundaries of Native American reservations and public lands remain fixed. We used U.S. Department of Agriculture (USDA), Forest Service, Forest Inventory and Analysis (FIA) data to parameterize species-specific ensemble species distribution models (SDMs) to forecast changes in the spatial distribution of three tree species used by Arizona tribes: Douglas-fir (*Pseudotsuga menziesii*), Emory oak (*Quercus emoryi*), and pinyon pine (*Pinus edulis*). Models were used to forecast expected changes in the distribution of these species under four climate-change scenarios, particularly on tribal and Forest Service lands. Resultant models support implementation of restoration and conservation projects on Forest Service and tribal lands in the Southwest and show how FIA data may be used to enhance the protection of ecocultural resources.

INTRODUCTION

Indigenous cultural practices often rely on ecosystems to provision traditional foods, medicines, and materials like fiber, wood, and dyes (Souther et al. 2023). Cultural significance of natural resources has been valued in the scientific literature through the lens of cultural ecosystem services (CESs), a broad classification that includes other ecological functions important to human experience, such as the ability of ecosystems to provide aesthetically pleasing views, recreational opportunities, and a sense of place and awe (Pascua et al. 2017). Species harvested for cultural practices may be particularly important to human populations because they are entwined with cultural identity and may fill fundamental needs within communities (Burquez-Montijo and Quintana 1994). Management of these culturally significant species is distinct from managing viewsheds and recreational spaces and often requires species-specific ecological information as well as an understanding of how human populations interact with harvested species. Here, we use the term "ecocultural resources" to reference nonagricultural species used in cultural practices. We embed within this term the acknowledgement that conservation of these natural resources must include strategies to sustain human-ecological connections.

Climate change may threaten ecocultural resources and disrupt human interactions with these species. One of the most widely observed ecological responses to climate change is a shift in spatial distribution (Parmesan and Yohe 2003). As warming occurs, species tend to move poleward or upward to track the climatic regime to which they are adapted (Parmesan and Hanley 2015). Climate-driven shifts in ecocultural resources have the potential to disrupt human interactions with these species because geopolitical boundaries remain fixed while populations of species move, decline in performance, or are extirpated. Changes in distribution of species with cultural value may increase travel times to harvest locations or result in reduced accessibility, particularly if ecocultural resources are no longer on public or tribal lands. The geographic scale of climate change calls for management of ecocultural resources to be coordinated at the landscape level and to incorporate an understanding of how both focal species and communities will be affected. In the southwestern United States, a large portion of the landscape is managed by the U.S. Federal Government, which provides public access to ecocultural resources. For this reason, Federal lands play an outsized role in the conservation of culturally important species regionally. Here, we use U.S. Department of Agriculture (USDA), Forest Service, Forest Inventory and Analysis (FIA) data to explore the response of plant species traditionally used by Arizona Tribal Nations to climate change. The model projections generated

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here may be used by land managers to identify populations of ecocultural resources particularly vulnerable to climate change in order to prioritize areas for restoration treatments aimed at increasing resilience of these ecosystems.

METHODS

Species Selection

To select focal species for modeling, we met with representatives from seven Arizona Tribal Nations in August of 2020 (Souther et al. 2021b). In this meeting, we identified plant species of value to each tribe and three tree species of concern for conservation and restoration: Douglas-fir (*Pseudotsuga menziesii*), Emory oak (*Quercus emoryi*), and pinyon pine (*Pinus edulis*).

Data

We used FIA plot data to build species distribution models (SDMs) for selected species: Douglas-fir, Emory oak, and pinyon pine. Because we had established connections with tribal communities, we constrained the study area to Arizona. In Arizona, inventories of FIA plots conducted prior to 1999 were sporadic. After 1999, FIA data were collected annually, with 10-year gaps between inventories at a particular plot. For this study, we used the complete data set for all Arizona plots collected over the 2001–2010 period. We used data from that period rather than more recently collected data (2011–2020) to capture habitat suitability prior to recent climatic changes.

Environmental Predictor Variables

Predictor variables included 19 bioclimatic variables attained from the WorldClim database at a resolution of approximately 4.5 km (2.5 minutes of a longitude/latitude degree) (Hijmans et al. 2005). Bioclimatic variables were derived from near-current (1960–1990) measures of temperature and precipitation and summarized to maximize biological relevance by reflecting variation in climatic means, extremes, and seasonality. For final SDMs, the 19 bioclimatic variables were culled by calculating the variance inflation factor (VIF), which estimates collinearity among predictor variables, and removing highly correlated variables (VIF greater than 10). The final predictor variables used in the model included mean temperature of driest quarter, mean temperature of wettest quarter, temperature seasonality (standard deviation ×100), mean diurnal range (mean of monthly [max temp − min temp]), precipitation of coldest quarter, precipitation seasonality (coefficient of variation), and precipitation of driest month.

Future Climate Scenarios

We investigated species response to climate change using downscaled data from 43 global climate models (GCMs) from the Coupled Model Intercomparison Project Phase 5 (CMIP5) (IPCC 2014) for three Representative Concentration Pathways (RCPs)—RCP2.6, RCP6.0, and RCP8.5—projecting forward to the mid-21st century (2046–2065) (Hijmans et al. 2005). Briefly, RCP2.6 reflects a CO_2 emissions scenario (low radiative forcing scenario) in which emission reductions are initiated in 2020 and decline to zero by 2100; RCP6.0 (mid-range radiative forcing scenario) projects a future emissions peak around 2080 and then a decline; and RCP8.5 (high radiative forcing scenario) represents the highest level of warming due to continued fossil fuel use and limited technological increases in energy-use efficiency that results in rise of emissions over the next century.

Analysis

We built ensemble SDMs to predict current and future suitable habitat for Douglas-fir, Emory oak, and pinyon pine. We created ensemble models by integrating six modeling techniques: two parametric, regression-based approaches (flexible discriminant analysis and generalized linear modeling); two nonparametric regression-based techniques (multivariate adaptive regression spines and generalized additive modeling); and two machine-learning approaches (random forest and boosted regression trees). Models were compiled into an ensemble model by weighting predictions using the true skill statistics (TSS) with the sdm package (Naimi and Araújo 2016) in R version 4.0.3 (R Core Team 2020). The TSS incorporates sensitivity and specificity by comparing models against random, yielding values that range from −1 to 1, where a TSS of 1 indicates perfect prediction, and a TSS of 0 or less indicates a model that performs no better than random.

Model accuracy assessments were performed using training and test datasets using k-fold partitioning without replacement (k = 5; runs = 10) (Naimi and Araújo 2016). For each iteration, we calculated the area under the receiver operating characteristic curve (AUC; AUC greater than 0.75 indicates a high-performing model) and the TSS to assess the predictive performance of each model in the ensemble (Allouche et al. 2006). To calculate differences in current and future habitat, we converted continuous habitat suitability probabilities to binary projections (i.e., presence or absence). To do this, we derived a threshold that maximized TSS values and converted all grid cells with values at or above this threshold to “present” and below this threshold to “absent.” We could then apply simple raster mathematics to derive changes in habitat across different areas under different climate scenarios. We compared present and future habitat for the state of Arizona, as well as for areas on tribal and Forest Service lands. For comparisons on tribal lands, we identified tribes that most frequently harvested each species and analyzed habitat loss and gains for those territories. Specifically, we examined habitat loss and gain for Emory oak on western Apache Tribal lands and for pinyon pine on Navajo Nation lands. Because several tribes use Douglas-fir, we examined changes in distribution for all participating nations in the workshop that we used to identify focal species (western Apache Tribes, Navajo, Hopi, Zuni, Havasupai, and Hualapai).

RESULTS

Models accurately predicted occurrence for all three species: Douglas-fir (mean AUC across models = 0.92; mean TSS = 0.72); Emory oak (mean AUC = 0.91; mean TSS = 0.71); and pinyon pine (mean AUC = 0.87; mean TSS = 0.59). Each species demonstrated changes in distribution in response to climate change (Table 1; Figs. 1, 2). By the end of the 50-year projection period, all species experienced net loss in habitat across Arizona for the most severe climate change scenario, although Douglas-fir and Emory oak showed expansion events in response to lower levels of climate change. As expected, distributions of these species are generally anticipated to shift northward and upward in elevation (Figs. 1, 2). Across all climate scenarios, Forest Service lands increased in habitat suitability for Emory oak, while western Apache Tribal Nations experienced loss of Emory oak at high levels of climate change (Table 1, Fig. 2). Douglas-fir was lost from tribal lands across all climate scenarios, but it gained habitat on Forest Service lands in all but the high climate change scenario. The opposite pattern was observed for pinyon pine, which was projected to decrease in occurrence on Forest Service lands under all climate change scenarios and to decrease on Navajo only at the highest levels of warming (Table 1, Fig. 2).

Table 1.—Change in suitable habitat over a 50-year time frame by species for three climate scenarios for Arizona, Arizona Tribal Nations, and Forest Service lands, in square kilometers. A positive net change indicates habitat gain. A negative net change (bold) indicates loss.

Species	Climate scenarios	Arizona			Arizona Tribal Nations			USDA Forest Service		
		Habitat loss (km²)	Habitat gain (km²)	Net change (km²)	Habitat loss (km²)	Habitat gain (km²)	Net change (km²)	Habitat loss (km²)	Habitat gain (km²)	Net change (km²)
Douglas-fir (*Pseudotsuga menziesii*)	chp50_26	2,356.2	1,980.4	**-375.8**	1,166.4	0.0	**-1,166.4**	1,030.2	1,911.5	881.3
	chp50_60	2,951.4	5,943.5	2,992.2	1,471.3	415.8	**-1,055.5**	1,052.2	4,802.0	3,749.8
	chp50_85	7,283.0	644.0	**-6,639.0**	2,459.2	0.0	**-2,459.2**	4,202.1	714.3	**-3,487.8**
Emory oak (*Quercus emoryi*)	chp50_26	4,778.7	10,152.2	5,373.6	1,568.2	2,504.0	935.8	1,740.6	4,715.0	2,974.4
	chp50_60	6,975.8	14,054.6	7,078.8	2,137.2	2,558.7	421.5	2,585.3	6,294.4	3,709.1
	chp50_85	15,179.5	12,152.4	**-3,027.1**	4,363.7	1,919.8	**-2,443.9**	6,185.6	7,439.0	1,253.4
Pinyon pine (*Pinus edulis*)	chp50_26	9,249.1	4,821.3	**-4,427.8**	384.4	1,653.1	1,268.7	2,858.6	335.7	**-2,522.9**
	chp50_60	15,578.6	6,340.3	**-9,238.3**	1,376.8	2,772.6	1,395.8	3,481.3	602.9	**-2,878.4**
	chp50_85	27,052.3	1,738.6	**-25,313.7**	3,295.0	347.5	**-2,947.5**	5,243.5	941.0	**-4,302.5**

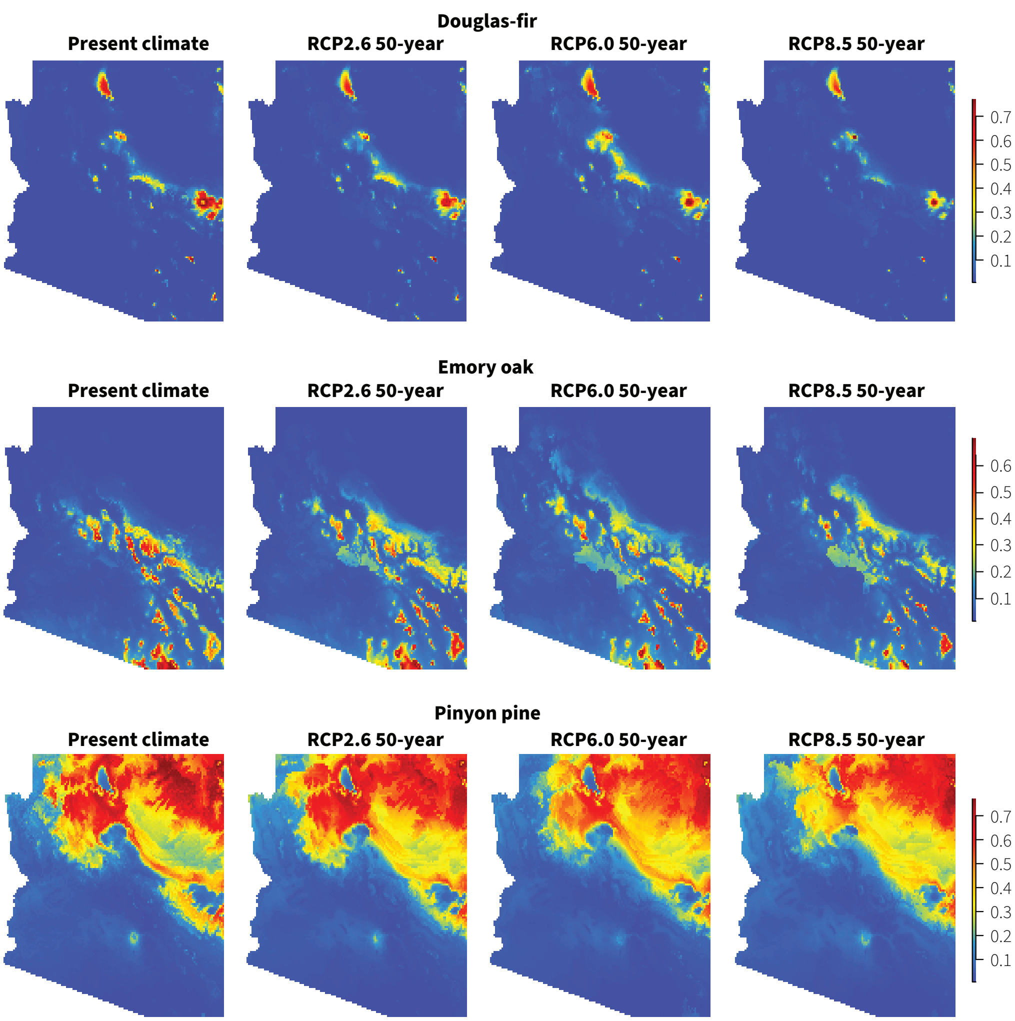

Figure 1.—Habitat suitability expressed as a probability for Douglas-fir, Emory oak, and pinyon pine for the current period and for three climatic futures. Red areas indicate highly suitable habitat. Blue areas indicate unsuitable habitat.

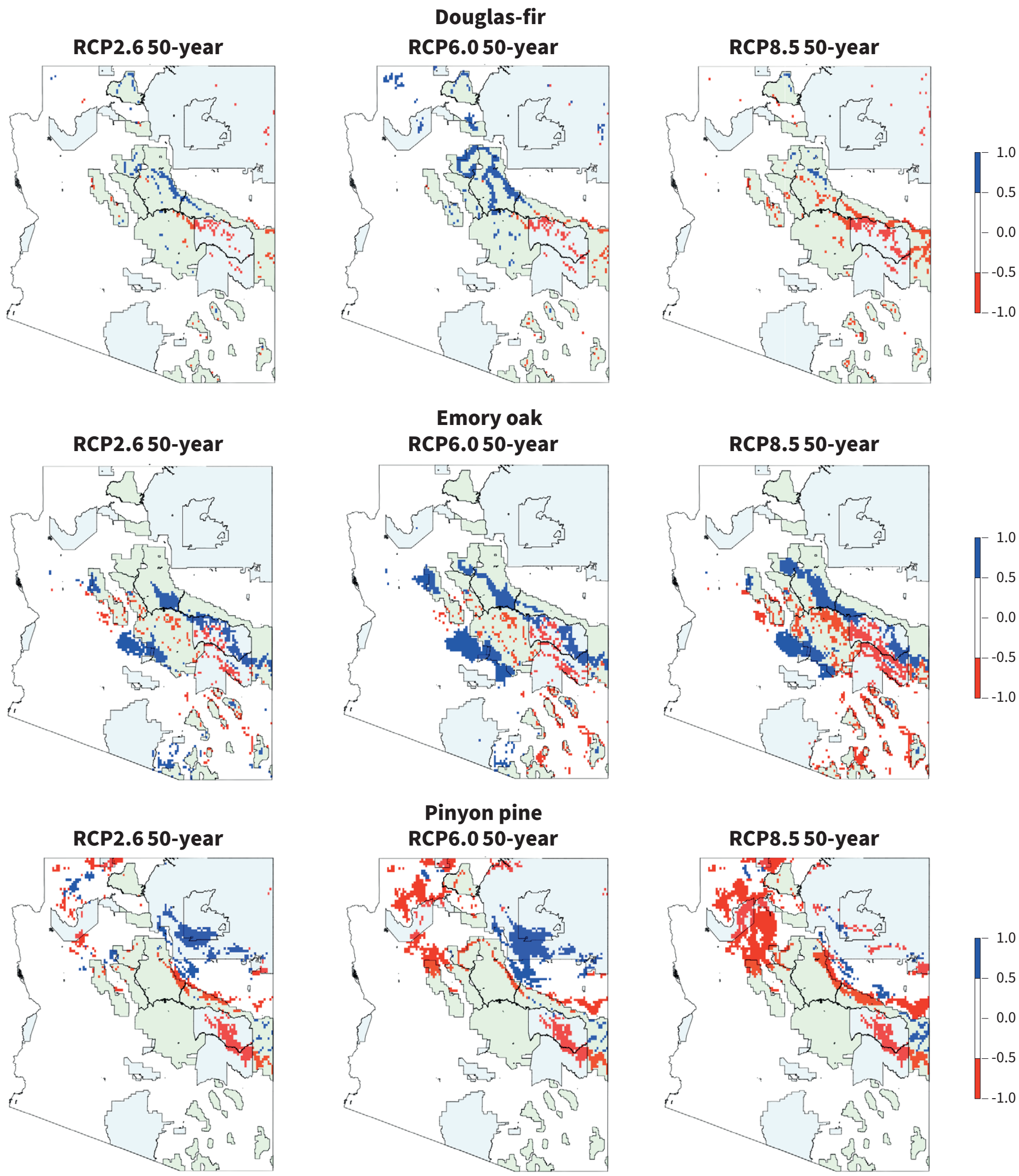

Figure 2.—Change in habitat suitability for Douglas-fir, Emory oak, and pinyon pine for each climate scenario, low (RCP2.6), moderate (RCP6.0), and high (RCP8.5). Within Arizona, key jurisdictions are highlighted. Light blue areas indicate Tribal Nations, and light green areas indicate lands managed by the Forest Service. Red pixels indicate areas that decline in predicted occurrence for each species, and blue pixels show increases in predicted occurrence.

DISCUSSION

We anticipate shifts in distribution driven by climate change for the three culturally important species examined here: Douglas-fir, Emory oak, and pinyon pine. Ability of species to track their climatic niche will depend on numerous factors, such as species-specific dispersal distances, habitat availability, and barriers to dispersal (Angert et al. 2011). While SDMs provide excellent hypotheses for species response to climate change, these models are correlative and do not capture changes in factors like species interactions or patterns of intraspecific genetic variation, which may shape ultimate responses to climate change (Guisan and Thuiller 2005). Here, we examined the response of these culturally important species across three areas—Arizona, Tribal lands in Arizona, and Forest Service lands in Arizona—because this geographic area corresponds with the current homeland of Indigenous communities whose members informed the selection of species in our study. Our study did not quantify potential range shifts beyond the Arizona state boundary.

Change in the probability of occurrence in response to climate change varied across species and the two primary land ownership categories evaluated here: Tribal lands and Forest Service lands. Douglas-fir, used for lumber and medicine by Indigenous groups, is predicted to experience reductions in habitat suitability across tribal lands. It is predicted to experience increases on Forest Service properties if climate change is not too severe. Tree-ring analyses of Douglas-fir have indicated that the species is sensitive to increasing temperatures, and thus it is predicted to shift to cooler regions in response to climate change (Chen et al. 2010). Previous climatic niche modeling for Douglas-fir indicated loss of suitable climatic conditions along the equatorial and lowland range margins, with negative effects of climate change most pronounced in inland continental Douglas-fir populations, particularly those occurring in Mexico (Rehfedlt et al. 2014).

Emory oak acorns are a first food for western Apache people (Coder et al. 2005, Souther et al. 2021a). The San Carlos and White Mountain Apache Nations are conjoined and located in the central eastern portion of Arizona. Changes in habitat suitability are variable across ownership types for this species, depending on the magnitude of climate change. If the climate change occurs at the highest rates, western Apache reservations will experience a significant decrease in suitable habitat. Across all climate change scenarios, Forest Service lands are expected to gain Emory oaks. Model results presented here are supported by previous research suggesting that shifting climatic regimes will negatively impact Emory oaks on tribal lands, particularly the establishment of new seedlings (Nyandiga and McPherson 1992, Souther et al. 2021a). Emory oak acorns remain viable for a short period of time post-dispersal and do not form a seed bank. Previous research has shown that a delay in the arrival of summer rains (monsoons) of only two weeks can reduce germination rates by up to 80 percent. Currently, an estimated 70 percent of Emory oaks occur on Forest Service managed property. With increases in abundance of Emory oak expected for Forest Service lands as a consequence of climate change, effective management of Emory oak that promotes resilience of this species as well as provides harvest access to tribal communities should be a focus for the Forest Service in Arizona.

Pinyon nuts are eaten by numerous groups in the western United States but are particularly important to the Diné (Navajo) people. Increases in pinyon habitat suitability are predicted for Navajo Nation, located in the northeastern corner of Arizona, at low to moderate warming levels, but loss is expected at high levels of warming. The finding again supports previous research that found that changing climate conditions, particularly increasing aridity and summer temperatures, will depress growth, reproduction, and survival of pinyon pine (Barger and Woodhouse 2013). Drought events, in particular, are associated with high mortality events and have been documented to drive widespread pinyon die-offs (Macalady and Bugmann 2014).

Differential changes in habitat suitability across land ownership categories demonstrates the need for coordinated, landscape-level conservation strategies. In Arizona, home to numerous Indigenous groups and characterized by high levels of public land ownership, the Forest Service and other agencies play a critical role in the conservation of ecocultural natural resources. Public lands provide habitat connectivity for species shifting distributions in response to climate change and may also support continued cultural connections to harvest locations if populations of wild-harvested species decline or are extirpated on tribal territories.

CONCLUSIONS

We examined the effects of climate change on three tree species valued by Native American tribes in Arizona. Ecocultural resources are inherently important to conserve, given their dual ecological and cultural importance. Forest Inventory and Analysis data can support such endeavors by providing critical information on species occurrence to model suitable habitat and identify patterns of vulnerability to climate change. Management plans for culturally important species in a changing climate require cross-boundary collaboration between Tribal Nations and land management agencies, such as the Forest Service. Action is urgently needed to initiate collaborative endeavors to conserve ecocultural resources and prevent cultural erosion of communities connected to these landscapes.

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The Role of Tree Species with Nontimber Forest Products in the Secondary Stands of Puerto Rico

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Abstract.—This study focuses on the ethnobotany of tree species within the archipelago of Puerto Rico. Making use of tree inventory data, I analyzed the proportion of tree species and stems with a known nontimber forest product (NTFP) in the private secondary forests of Puerto Rico. An average of 280 unique tree species were recorded in four consecutive forest inventories between 2004 and 2019; of these, a mean of 77 percent have a known NTFP (where 41.7 percent of the species represent four to seven known NTFPs). The potential products from these species are wood handicrafts (59 percent of the NTFP species), fuel and technology (32 percent), medicinal (31 percent), beekeeping (22 percent), edible (19 percent), and fodder (8 percent). Of the estimated total number of trees in private forests that ranged from 1,048 million to 1,023 million between 2004 and 2019, approximately 91 percent of all stems have a known NTFP. Tree and NTFP data offer insight into how species serve multiple purposes.

INTRODUCTION

Considering the role of nontimber forest products (NTFPs) in naturally regenerated forests is vital for the sustainability of tropical landscapes, especially where economic returns are necessary under a climate change scenario. The archipelago of Puerto Rico is represented by the main island of Puerto Rico, the islands of Culebra, Vieques, Mona, and a number of small islets and cays, and is characterized by a tropical maritime climate and exposure to extreme climatic events such as hurricanes (Brandeis et al. 2007) and droughts (Helmer et al. 2023). Currently, forests cover 52 percent of the land area, and they consist of predominantly secondary stands that reverted to forest land after the abandonment of agricultural land (Marcano-Vega 2023); this transition has taken place at a time when 83 percent of all the food groups consumed and most of the wood products used are imported (Centro para la Conservación del Paisaje 2021, Gregory-Crespo and González-Martínez 2017). Most of the forests in Puerto Rico (84 percent) are privately owned (Marcano-Vega 2017). Data from the U.S Department of Agriculture (USDA), Forest Service, Forest Inventory and Analysis (FIA) program offer the opportunity to contribute to a broader understanding of ecosystem services in these islands as they relate to the diversity and dynamics of NTFPs sourced from trees (e.g., edible and medicinal).

METHODS

Making use of tree data from permanent plots maintained by FIA, I analyzed the proportion of tree species and stems (as a proxy of availability) with a known NTFP in the private secondary forests of Puerto Rico. The proportion of species representing different uses was analyzed based on four consecutive forest inventories conducted in Puerto Rico in 2004, 2009, 2014, and 2019, and by categorizing species in seven classes of NTFPs within the dry, moist, and wet/rain forest types (Ewel and Whitmore 1973). The classes of use included beekeeping, edible (e.g., fruits and seeds), fodder, fuel, medicinal, technology, and wood handicrafts. Beekeeping was included as a category because other studies have highlighted forest honey as a relatively overlooked NTFP (Lowore et al. 2018). Technology is a wide category that has been used in quantitative ethnobotanical studies of tropical trees (Phillips et al. 1994, Prance et al. 1987); in Puerto Rico, this category includes lashing material, glue, dye, and soap. Wood handicrafts were included as a category because wood processing in Puerto Rico is small scale, and domestic wood products are mainly used by local artisans to make handicrafts, traditional furniture, and musical instruments (Forero-Montaña et al. 2018, Kicliter 1997). Information on the uses of tree species was gathered from the literature (Cordero and Boshier 2003, Forero-Montaña et al. 2019, Francis and Lowe 2000, Little and Wadsworth 1989, Little et al. 1974, Nellis 1994) and from a published survey conducted among artisans and sawyers in Puerto Rico (Forero-Montaña 2015).

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RESULTS AND CONCLUSIONS

On average, a total of 280 tree species have been recorded in the private forests of Puerto Rico during the forest inventories carried out from 2004 to 2019. Between 74 and 79 percent of the recorded tree species were found to have a known NTFP (Fig. 1), for a mean of 77 percent of the total species tallied. Additionally, a mean of 41.7 percent of all pecies with a known NTFP represented four to seven products, and 24 percent represented at least three different products. The major potential product was wood handicrafts, which represented 59 percent of NTFP species, and was followed by fuel and technology (32 percent), medicinal (31 percent), beekeeping (22 percent), edible (19 percent), and fodder (8 percent).

The moist forest type covers the majority of land area in Puerto Rico (58 percent of total land area; Ewel and Whitmore 1973), and it contains the highest number of NTFP tree species on private land. The wet/rain forest type and the dry forest type represent 23 percent and 18 percent of total land area, respectively. According to literature and the published survey discussed in the methods section, 159 of the tree species recorded by FIA in the private moist forests of Puerto Rico during the study period offer quality wood for handicrafts, 97 species have potential for technology uses (as defined previously), 89 species have medicinal properties, 68 species can be used for beekeeping, 64 species produce edible fruits, and 26 species can be used as fodder (Fig. 2). In the wet/rain forest type, 137 species offer quality wood for handicrafts, 67 species have medicinal properties, 60 have potential for technology uses, 44 have uses for beekeeping, 41 offer edible fruits, and 19 can be used as fodder. In the dry forest type on private land, 81 species offer quality wood for handicrafts, 55 have potential medicinal properties, 44 have potential for technology uses, 42 have uses for beekeeping, 27 offer edible fruits, and 13 can be used as fodder (Fig. 2). Within privately owned dry forests, 77 percent of the 141 tree species offer from one to seven potential NTFPs, which is comparable to the percentage and potential NTFP species density of the trees in private moist forest types (75 percent of 290 tree species) and wet/rain forest types (75 percent of 228 species).

Regarding the structural function of NTFP tree species in the private forests of Puerto Rico, it was found that from an estimated total number of 1,048 million (±72 million) trees to 1,023 million (±78 million) trees between 2004 and 2019, approximately 91 percent of all stems were from a species with a known NTFP. The NTFP species found represent a combination of early and late successional species, showing the character of the forested landscape in Puerto Rico to be a mosaic of stands of different ages (Kennaway and Helmer 2007).

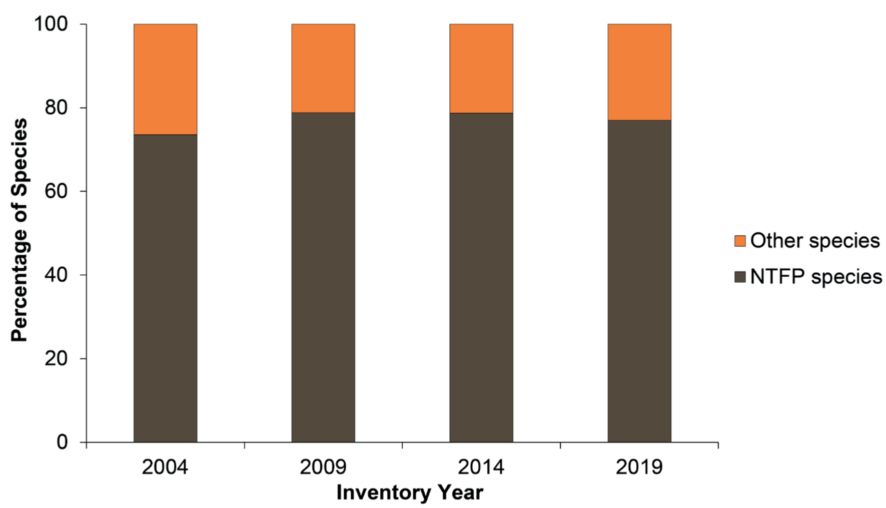

Figure 1.—Percentage of tree species by inventory year and offering of nontimber forest products (NTFP), Puerto Rico, 2004–2019.

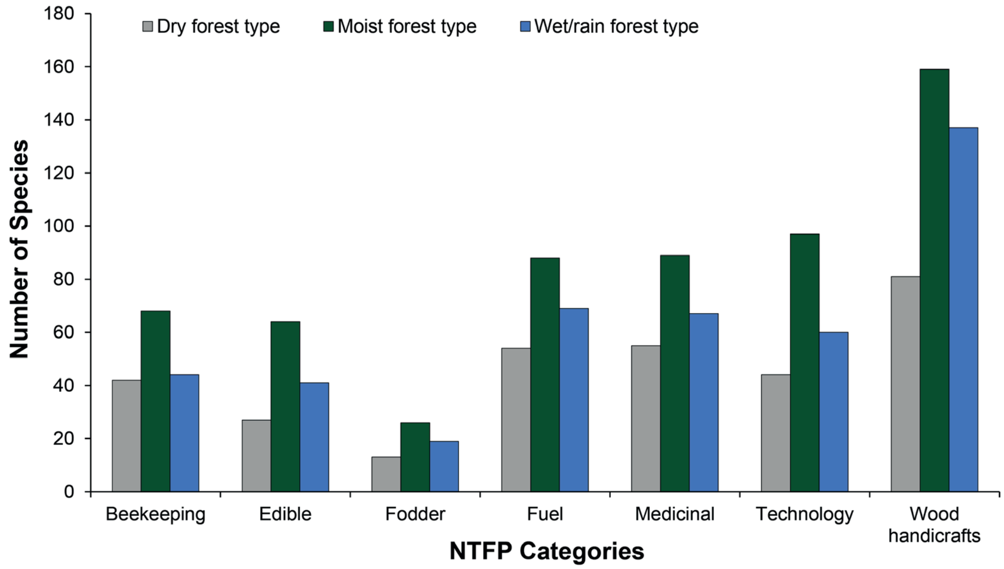

Figure 2.—Number of tree species by nontimber forest product (NTFP) category and forest type, Puerto Rico, 2004–2019.

The combination of forest inventory data and NTFP information offer insights into how tree species serve multiple purposes in our forests (Chamberlain at al. 2018). The results from this analysis highlight the potential of Puerto Rican forests on private land for the growing local wood culture in the artisanal sector (GreenWood 2020), as well as the potential for medicinal products and other NTFPs. The remeasurement of permanent sampling plots is accordingly fundamental to the design of tropical forest restoration and management projects based on the dynamics of natural regeneration after the abandonment of agricultural lands and the cultural importance of trees.

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Ecological Decoupling and Family Forest Landowners: What Do We Know?

Jesse Caputo and Emma M. Sass[1]

Abstract.—According to the theory of ecological decoupling, modernization in the developed world is characterized by increasingly intensive management of natural resources, leaving more land open to rewilding and other nonextractive uses. Consequently, one might hypothesize that extractive uses in the United States would be becoming more concentrated on larger land holdings, while family forest ownerships would be shifting their emphasis from extractive uses to nonextractive uses. We explore this hypothesis using longitudinal data from the National Woodland Owner Survey (NWOS). Although changes in survey instruments and sample methodology over time make direct comparisons over a multidecadal time scale difficult, a comparison of some key results offers some suggestive insights. Here we propose three metrics for use with NWOS data based on the preference for and prevalence of extractive uses among landowners, which will allow us to draw broad conclusions about whether ecological decoupling may be occurring among family forest landowners nationwide.

INTRODUCTION

Ecological decoupling refers broadly to the socioecological theory that extractive uses of ecosystems by humans become more efficient (in terms of land and other inputs) and less extensive as economies develop and industrialize over time (Asafu-Adjaye et al. 2015, Blomqvist et al. 2015). According to the theory, this process results in greater and greater amounts of productive land being freed up for conservation, rewilding, and passive/amenity uses. Support for the theory in the literature is mixed (e.g., Szigeti et al. 2017, Vadén et al. 2020). One problem is that analyses on a country-by-country or sector-by-sector basis often do not account for the "illusion of preservation" (Berlik et al. 2002). In other words, it is difficult to determine whether developed economies are truly decoupling from a dependence on natural resources or whether extractive uses in these economies are simply being exported elsewhere.

There is anecdotal support for the idea that human use of forests, specifically, has been following a decoupling trajectory in the developed world. Forest resources improve along with human well-being, which suggests a negative relationship between economic development and exploitative uses (e.g., Kauppi et al. 2018). In terms of family forest ownerships (FFOs), there is a perceived increase in emphasis on amenity ownership among these owners (e.g., Abrams and Bliss 2013). Amenity and production values are both important to FFOs (Baker et al. 2017, Beach et al. 2005, Butler et al. 2021, Caputo and Butler 2017, Hartman 1976), however, making it difficult to formulate hypotheses about whether decoupling among FFOs is occurring now or is likely to occur in the future.

One source of data with potential for investigating ecological decoupling among U.S. FFOs is the National Woodland Owner Survey (NWOS). The NWOS canvasses private forest owners about their attitudes, intentions, behaviors, and demographics and is a long-standing product of the U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis (FIA) program and the Family Forest Research Center (FFRC) at the University of Massachusetts Amherst (Butler et al. 2021). NWOS implementation began with sporadic surveys in the 1950s and transitioned into a standardized, nationwide survey beginning in 2006. Implementation of the NWOS was annualized starting in 2019 with an eye towards longitudinal analysis and change estimates (Sass et al. 2023).

In this paper, we demonstrate the potential utility of three simple metrics derived from NWOS items that are intended to track ecological decoupling over time. Specifically, we implement these metrics to look for recent signals of possible ecological decoupling on forest land owned by FFOs between the 2013 and 2018 cycles of the NWOS.

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METHODS

We developed three binary metrics of ecological decoupling using items from the NWOS. Each metric is an index of four different extractive uses: timber harvesting, firewood cutting, hunting, and foraging for nontimber forest products (NTFPs). These uses represent four of the most prevalent extractive activities on family forest land (Butler et al. 2021). The metrics serve as negative indicators of the extent of ecological decoupling. Two of the metrics refer to landowner preferences. The first metric (PREF1) identifies landowners who rate the importance of at least one of the four uses as a reason for owning their land as "important" or "very important." The second metric (PREF2) is a less conservative metric and identifies landowners who rate at least one of these uses as "moderately important" as well as "important" or "very important." We include both versions of the preference metric to assess the extent to which they differ in terms of interpretation and conclusions. The third metric, prevalence (PREV), is a measure of use. It identifies landowners who have indicated that they engaged in one or more of the four activities within the 5 years prior to submitting the survey.

To investigate change over time, we estimated the amount of acreage owned by FFOs (at least 1 acre) satisfying each of the three metrics using both the 2013 (n=8,256) and 2018 (n=9,518) cycles of the NWOS (excluding Alaska). Point estimates were calculated using the standard NWOS methodology (Butler et al. 2021). Confidence intervals of 95 percent on both point estimates and differences were calculated using the percentile interval method (e.g., Jung et al. 2019). These methods are equivalent to the methods developed for standard population-level longitudinal analysis of NWOS data by Sass et al. (2023).

RESULTS AND DISCUSSION

Between 2013 and 2018, the total amount of family forest land owned by people who valued and engaged in extractive uses decreased according to all three metrics (Table 1). At face value, these results would seem to support the idea that ecological decoupling is well underway among family forest landowners. However, during the same period, the total amount of family forest land declined, potentially obscuring conclusions regarding the prevalence of extractive uses (Sass et al. 2023). As a result, for each of the three metrics, we focus on the percentage of family forest land. In both time periods, the prevalence of extractive activities was more widespread than landowners' stated preference for those activities (Table 1, Fig. 1). This agrees with prior findings that extractive uses are common, even though FFOs do not rate those uses as being as important as many nonextractive objectives (Butler et al. 2021). The PREF2 (less conservative) metric tracked the PREV metric very closely (Fig. 1). More than 84 percent of family forest land was associated with extractive uses according to these two metrics. A smaller value was found using the stricter PREF1 metric, but still a substantial majority of the acreage (greater than 70 percent) was associated with extractive uses. Interestingly, all metrics showed an increase in extractive uses between 2013 and 2018, although the change was only statistically significant (i.e., confidence intervals didn't include zero) for PREF1. In the case of that metric, the acreage owned by landowners who prioritized extractive uses increased by 1.5 percent (CI = [0.3 percent, 3.4 percent]). In terms of comparing the PREF1 and PREF2 metrics, both have slightly different interpretations in terms of statistical significance, but PREF2 has an advantage in its interpretability in that it more closely tracks the PREV metric.

Do these results then suggest that ecological decoupling is not occurring on U.S. family forest land? We cannot answer that question unambiguously, but we can say that we do not see a strong signal for decoupling during the period analyzed in this study. That said, historical results associated with the NWOS have suggested a broadly similar emphasis on extractive uses over time. For example, with regard to timber harvesting, Barraclough and Rettie (1950) found that 62 percent of forest landowners in 23 towns in New England owned land for its timber value. Birch (1996) found that 69 percent of FFOs had harvested timber. Butler et al. (2021) found that 76 percent of FFOs reported timber harvesting at least once over the tenure of their ownership. Taken together, these data points do not seem to support the idea that significant decoupling is taking place.

Table 1.—Change in three metrics for tracking ecological decoupling on U.S. family forest land between 2013 and 2018

METRIC	UNIT	YEAR	VALUE	CI_LOWER	CI_UPPER
PREF1[a]	total acreage	2013	200,342,700	196,137,600	205,591,300
PREF2[b]	total acreage	2013	243,497,700	239,047,100	247,776,700
PREV[c]	total acreage	2013	249,282,500	244,822,300	254,870,600
PREF1	total acreage	2018	195,285,100	192,743,000	200,123,400
PREF2	total acreage	2018	233,786,600	231,407,600	238,695,200
PREV	total acreage	2018	238,805,000	236,551,700	243,313,400
PREF1	% acreage	2013	70.37	68.94	71.64
PREF2	% acreage	2013	85.53	84.46	86.32
PREV	% acreage	2013	87.57	86.61	88.60
PREF1	% acreage	2018	71.82	71.02	73.43
PREF2	% acreage	2018	85.98	85.69	87.35
PREV	% acreage	2018	87.83	87.31	89.13
PREF1	% acreage	2018–2013	1.45	0.31	3.41
PREF2	% acreage	2018–2013	0.45	-0.19	2.52
PREV	% acreage	2018–2013	0.26	-0.45	2.11

Note: Data come from the National Woodland Owner Survey, 2013 (n=8,256) and 2018 (n=9,518) surveys, respectively.

[a] PREF1 measures landowners who rate one or more of four extractive uses (timber harvest, firewood cutting, hunting, and collection of nontimber forest products) as "important" or "very important" reasons for owning their land.

[b] PREF2 measures landowners who rate one or more of four extractive uses (timber harvest, firewood cutting, hunting, and collection of nontimber forest products) as "moderately important," "important," or "very important" reasons for owning their land.

[c] PREV measures landowners who have engaged in at least one or more of four extractive uses (timber harvest, firewood cutting, hunting, and collection of nontimber forest products) in the five years prior to submitting the survey.

There are important caveats to this tentative conclusion. These metrics do not reveal anything about the magnitude of extractive uses. If extraction is intensifying on the same or fewer acres, then the amount of land required to produce a unit of timber (or other product) would still be declining at the margin. This is sometimes called relative decoupling (as opposed to absolute decoupling) (Vadén et al. 2020). However, FIA data suggest that this is not the case; in fact, wood production on family forest land declined during the study period from 2013 to 2018.[2]

Another important consideration is the role of global trade on the potential interpretation of these results. Ecological decoupling as a theory is best understood at the level of the entire planet, and sector-by-sector analyses are complicated by product flows that cross the boundaries of the sector. In the case of U.S. family forests, flat trends in terms of extractive uses (i.e., local measures of decoupling) could still be contributing to global decoupling if U.S. family forests are providing a greater share of global production. This does not appear to be the case regarding timber. FIA data show that production of wood on corporate forest land increased by 2.3 percent from 2013 to 2018.[3] During the same period, imports of wood products were greater than exports (Howard and Liang 2019). This finding does not suggest that U.S. family forests are

[2,3] Caputo, J. 2022. Unpublished data on file with author.

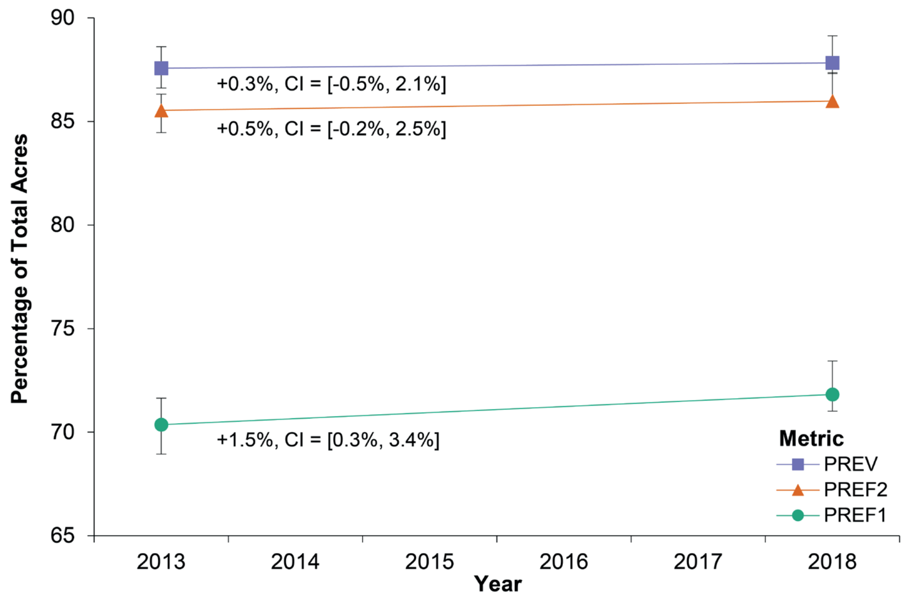

Figure 1.—Change in three metrics for tracking ecological decoupling on U.S. family forest lands between 2013 and 2018. Data come from the National Woodland Owner Survey, 2013 and 2018. PREF1 measures landowners who rate one or more of four extractive uses (timber harvest, firewood cutting, hunting, and collection of nontimber forest products) to be "important" or "very important" reasons for owning their land. PREF2 measures landowners who consider these uses to be "moderately important," "important," or "very important." PREV measures landowners who have engaged in at least one of these uses during the 5 years prior to submitting the survey.

contributing to a larger cross-boundary decoupling. If anything, it suggests a greater reliance on wood products among the population of the United States, of which U.S. FFOs constitute one segment.

CONCLUSION

The prevalence of and preference for extractive uses did not change substantially between 2013 and 2018 among owners of U.S. family forest land. This suggests that absolute, local ecological decoupling did not characterize FFO behavior during the 5-year period. This window is admittedly very short, but historical results suggest a broadly similar emphasis on extractive uses over a much longer time period. These results are not incompatible with the possibility that relative decoupling has taken place, but global trade statistics suggest that this is not likely. The use of the decoupling metrics described in this paper in conjunction with NWOS data show some promise as a simple, standardized method for assessing ecological decoupling within the private forest ownership sector in the United States. Future research will focus on tracking these metrics over a longer period and on looking more closely at the role of global and cross-sectoral trade in mediating the relationship between absolute and relative decoupling. Additional insights will come from comparisons between family ownership and other types of private ownerships (e.g. corporate) and between participants and nonparticipants in tax programs and other landowner programs. Meanwhile, FFOs continue to value and rely on extractive and nonextractive uses for their forest land, with more than four-fifths of family-owned acreage being owned by someone who engaged in at least one extractive use in the 5 years prior to 2018.

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Research Supporting the Sustainability of Culturally Important Paper Birch Trees (Wiigwaasaatigoog) in the Great Lakes

Alexandra Bohman, Rachel I. Riemann, and Cassandra M. Kurtz[1]

INTRODUCTION

Wiigwaas (paper birch tree bark) has furnished material and cultural resources since time immemorial. It is harvested for art, food, medicine, ceremony, storage, cooking, currency, lodging, and transportation, and is essential to the economic welfare of skilled artisans. The extensive use of wiigwaas and the significance of wiigwaasaatigoog (paper birch, plural; *Betula papyrifera*) have deemed it a cultural keystone species. In the early 2000s, the Great Lakes Indian Fish and Wildlife Commission (GLIFWC), an intertribal natural resource agency, began hearing from member tribes that harvesters were experiencing increasing difficulty finding wiigwaas for traditional uses. They suspected the difficulty was related to changes in forest management access, among other causes. The issue of birch decline was discussed at an annual meeting between GLIFWC's 11 member tribes and the U.S. Department of Agriculture (USDA), Forest Service. A technical working group made up of GLIFWC and Forest Service, Northern Research Station (NRS) scientists was created to explore the wiigwaas resource and its decline. Since then, much work has been done to integrate the capacities of the Forest Service, Forest Inventory and Analysis (FIA) program and the Traditional Ecological Knowledge (TEK) observations collected by the tribes. In this study, we focused on better understanding the conditions under which this often short-lived, early seral stage species grows to jiimaan-size and quality (possessing canoe-quality bark). Specifically, we investigated the site and bark characteristics of large-diameter birch (greater than or equal to 15 inches in diameter at breast height [d.b.h.]) within the boundaries of the Lake States Ceded Territories. Here, we present results from this most recent research being led by GLIFWC and supported by FIA and NRS. The success of collaborative efforts like these is not based solely on research results but also on the quality of working relationships built.

MATERIALS AND METHODS

The study was conducted within the boundaries of the Ceded Territories, lands the Ojibwe Tribes ceded to the U.S. Government in the Treaties of 1836, 1837, 1842, and 1854, while retaining usufructuary rights (Fig.1). Publicly available forest inventory data from FIA (all lands), the Wisconsin Department of Natural Resources (WIDNR) (state lands), Bayfield County, Wisconsin (county lands), the Apostle Islands National Lakeshore (National Park Service lands), and interviews with tribal harvesters were used to identify potential sites. Field visits identified 74 wiigwaasmitigoog greater than or equal to 15 inches d.b.h., which became the focal trees around which one-tenth-acre plots were established. Species and d.b.h. were recorded for all trees greater than or equal to 5 inches d.b.h. on each plot. Height and age were recorded for the focal paper birch and its two nearest neighbors. Several measures of wiigwaas quality were also recorded for the focal trees only (Table 1). Plot-level characteristics recorded included ownership category (Federal, Tribal, State, county, or private), habitat type, gap type (waterway, road, trail, or natural opening), and distance from the focal birch, as well as presence or absence of paper birch regeneration. Habitat type was determined based on forest community and habitat guides available for northern Wisconsin (Kotar et al. 2002), Michigan (Burger and Kotar 2003), the Laurentian Mixed Forest Province of Minnesota (MNDNR 2003), and the Grand Portage Reservation (Kotar and Burger 2005), depending on where the site was located. The data collection team included tribal college student interns.

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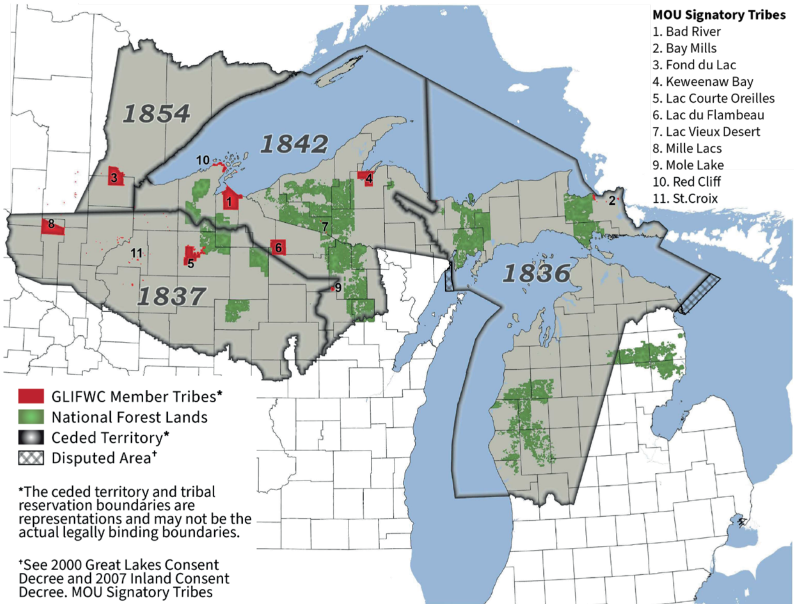

Figure 1.—Map of the Ceded Territory Treaties of 1836, 1837, 1842, and 1854 in Michigan, Wisconsin, and Minnesota.

Table 1.—Measures of wiigwaas quality recorded for focal wiigwaas (large diameter paper birch) on all plots, using techniques from Danielson and White (2003)

Variable	Codes	Definitions
Curvature	0	No curvature
	1	Moderate curvature
	2	Extreme curvature
Branching	0	Absent
	1	Present
Past harvest	0	Absent
	1	Present
Bark texture	1	0–50% rough bark
	2	51–100% rough bark
Lenticels	1	Fine
	2	Coarse
Branch scars	0	Absent
	1	Present
Exfoliating bark	0	Absent
	1	<50% exfoliating bark
	2	>50% exfoliating bark
Blemishes	0	Absent
	1	Present
Fungus	0	Absent
	1	Present
Lichens and moss	0	Absent
	1	Present

RESULTS AND DISCUSSION

During the summers of 2018 and 2019, 74 wiigwaasaatigoog were measured; the average d.b.h. was 19 inches and average height was 75 feet. Tree core samples from each focal wiigwaasaatig (paper birch, singular) and the two nearest neighbors indicated an average site age of 79 years and an average focal wiigwaasaatig age of 92 years, suggesting that these focal wiigwaasaatig are legacy trees. Similarly, focal wiigwaasaatig were typically taller, older, and had a larger d.b.h. than their two closest neighbors. Most sites were on federally managed lands, with fewer on tribal, State, and county lands. One plot was sampled on private land.

Habitat diversity was broader than expected. Focal wiigwaasaatig were found in 17 unique habitat types, which had a range of dominant species. The most common habitat types were ParV (P*inus-Acer Rubrum/Vaccinium*; 24 plots) and ATM (*Acer saccharum-Tsuga canadensis/Maianthemum canadense*; 13 plots). Average distance from focal wiigwaasaatig to the nearest gap was 19 feet. Half of the gaps were natural openings and 35 percent were roads; the remaining gaps were trails, water, or disturbance. More than two-thirds of the sites lacked wiigwaasaatigoog regeneration, and only 5 percent of plots had well represented paper birch regeneration. Across the plots, 19 other tree species were recorded, with sugar maple being most common (Fig. 2). Most of the focal trees had many high quality wiigwaas characteristics: no curvature, no branching, no previous harvest, less than 50 percent rough bark, fine lenticels, some branch scars, less than 50 percent exfoliating bark, some blemishes, no fungus, and some lichens and moss.

Internships allowed the involvement of youth in this research of tribal interest. Children and youth are future leaders who ensure the continuation of the tribe and its traditions; therefore involving youth increases the value of the research to the tribe.

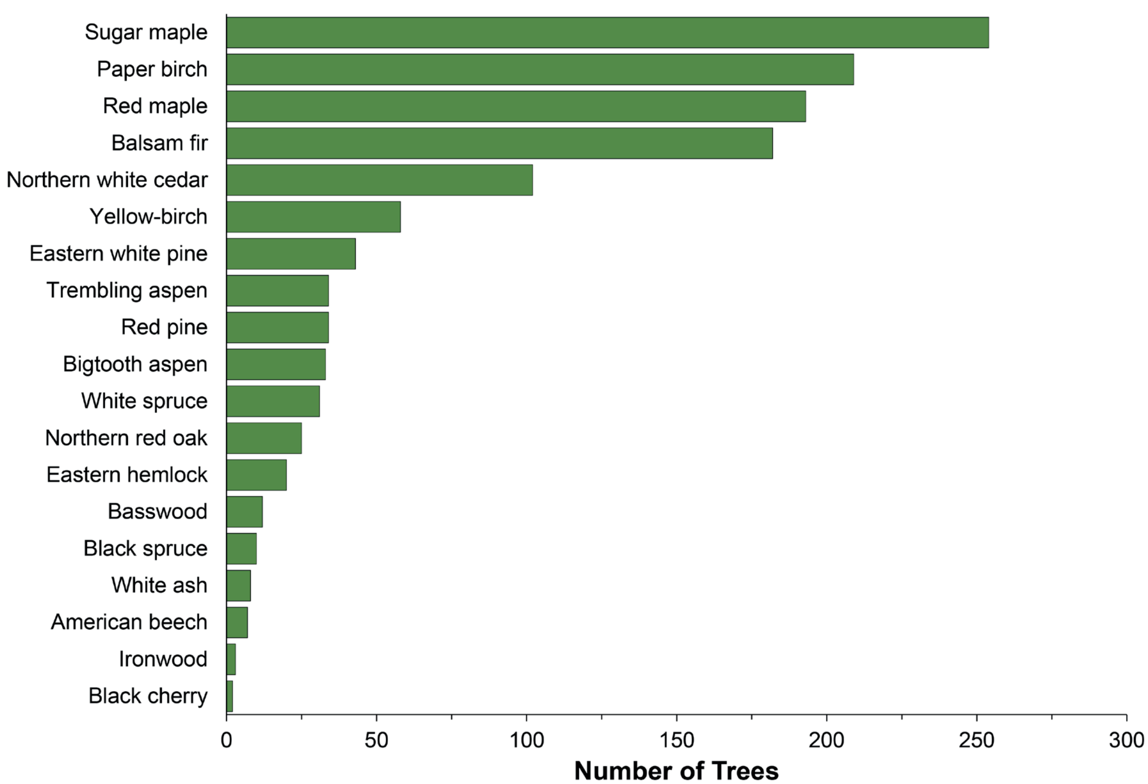

Figure 2.—Number of nonfocal trees, by species, recorded on plots.

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MONITORING CHANGES IN FOREST COMPOSITION

Modeling Shortleaf Pine Plantation Diameter Distributions in the Western Half of the Southeastern United States

Curtis L. VanderSchaaf[1]

Abstract.—Shortleaf pine (*Pinus echinata*) restoration will likely begin through the establishment of plantations; therefore, managers will need tools to help identify how various management practices will impact future diameter distributions. Here, equations were developed using U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis plots to represent diameter distributions within shortleaf pine plantations in the western half of the southeastern United States. Plot age, number of trees, and basal area per acre averaged 45.5 years, 316, and 87 square feet, respectively. Parameter prediction and recovery based on predicted percentiles approaches were tested along with published parameter prediction equations. Data from regional studies were used to validate the parameter estimation methods. Ages ranged from 3 to 16 years, and the number of trees and basal area per acre averaged 672 and 33 square feet, respectively. When predicting the three Weibull parameters as a whole, the percentile approach generally had the best model validation statistics. Future work will quantify errors when directly estimating diameter distributions.

INTRODUCTION

Shortleaf pine (*Pinus echinata*) was found historically in much of the western half of the southeastern United States and in southern Missouri (Guldin 2019, Little 1971). Over the last 30 to 40 years, the once extensive shortleaf pine ecosystem has lost over 50 percent of its former area (Guldin 2019). Changes in timber management practices, altered fire regimes, massive pine beetle outbreaks in poorly managed stands, disease, and land use changes have contributed to this rapid decline. Coordinated efforts to restore the shortleaf pine ecosystem will likely begin largely through the use of plantations because they allow for better initial control of species composition and stand density. According to the U.S. Department of Agriculture (USDA), Forest Service, Forest Inventory and Analysis (FIA) program, as of June 2022, there are 228,000 acres of shortleaf pine plantations in the western half of the southeastern United States (USDA Forest Service 2022).

Modeling efforts for shortleaf pine plantations have been relatively minimal. Smalley and Bailey (1974) developed the only known growth and yield model system for plantations where users can obtain predictions of diameter distributions directly. Weibull distribution parameters can be obtained using the parameter prediction method, where the location (*a*), scale (*b*), and shape (*c*) parameters are predicted within a system based on dominant height and trees surviving per acre.

For this analysis, a three-parameter Weibull-based modeling approach was used:

$$F(\mathrm{x}) = 1\text{-}exp\left[-\left(\frac{\mathrm{x}-a}{b}\right)^{c}\right] \quad (1)$$

where

x = diameter class (inches),

a = location parameter, $a < \mathrm{x} < \infty$,

b = scale parameter, and

c = shape parameter.

In addition, because diameter distributions are being modeled, the location (*a*) parameter must be nonnegative. A model fitting dataset obtained from FIA plots was used to obtain parameters

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using maximum likelihood estimators, and then parameters (*a, b,* and *c*) were modeled using one of two methods: a percentile-based parameter estimation method and a parameter prediction method. An independent testing dataset was then used to determine the predictive ability of these two approaches for younger shortleaf pine plantations. Parameter estimates from these two methods were compared to one another for the testing dataset and also to those parameter estimates when using the estimation procedure found in Smalley and Bailey (1974). The objective of this analysis is to see how well these three approaches predict observed Weibull parameters of diameter distributions for plantations of ages 16 and less in Arkansas, Mississippi, and Oklahoma.

METHODS

Model Fitting Data

To fit equations to estimate diameter distributions designated as shortleaf pine plantations located in the western part of the southeastern United States (Fig. 1), forest inventory data was obtained from the FIA DataMart (USDA Forest Service 2019) for the most current inventory cycles, which varied by state as follows: 2019 data in Arkansas, Mississippi, and Missouri; 2018 data in Oklahoma; and 2017 data in Tennessee.

FIA plots consist of four 24-foot fixed-radius subplots on which trees 5.0 inches diameter at breast height (d.b.h.) and larger are measured. Each subplot contains a 6.8-foot fixed-radius microplot where saplings 1.0 to 4.9 inches d.b.h. are measured. Expansion factors associated with these different plot sizes could impact modeling ability. Condition classes are assigned to differentiate conditions occurring on a plot, such as forest type, ownership, and stand density. A subplot can have more than one condition class. Only those condition classes designated as the shortleaf pine forest type were included. Additionally, only live trees, from all class codes and ownerships, on plots identified as artificial regeneration (plantations) were used in the analysis.

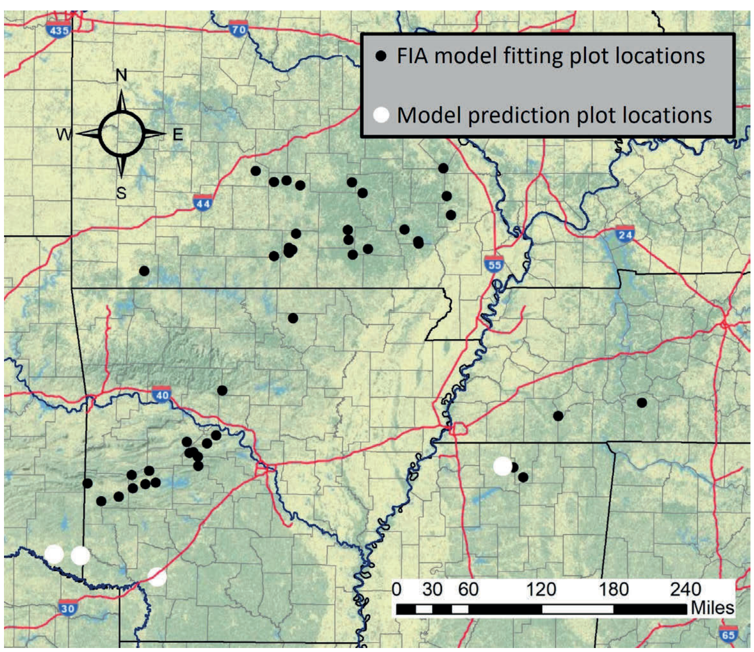

Figure 1.—Approximate location of FIA plots (n = 44) designated as shortleaf pine (*Pinus echinata*) plantations used in model fitting to estimate parameters of the three-parameter Weibull distribution (black circles) and FIA plot (n = 4) locations used in model prediction (validation) (white circles).

Plots with a shortleaf pine basal area per acre less than 60 percent, and plots with a stand age of less than or equal to 4 years or greater than 90 years were eliminated. Additionally, a plot had to have at least 15 trees or more to be included. Beyond that, to reduce the possibility of including plots with trees that were not planted at the time of plantation establishment, equation 2 was also used to eliminate plots:

$$D_{Max} = D_{50} + [D_{50} - D_0] + D_0 \quad (2)$$

where

D_0 = minimum observed d.b.h. of a particular FIA plot, and

D_{50} = d.b.h. of a particular FIA plot at the 50th percentile, or the median diameter.

D_{Max} is an arbitrarily chosen approach to determine what would be a potential maximum d.b.h. in a plot based on the median and minimum diameters. If D_{95}, the d.b.h. at the 95th percentile of the observed diameter distribution, exceeded D_{Max}, then that plot was removed from the sample. The final sample size used in model fitting was n=44 observations (Tables 1 and 2, Fig. 1). Dominant height of a particular plot for model development was defined as the average height of the tallest 50 percent of all surviving shortleaf pine trees. The average dominant height of the n=44 plots was 63.2 feet, with a minimum and maximum of 17.9 feet and 90.4 feet, respectively. For each plot, whenever the maximum likelihood estimation process resulted in the *a* (location) parameter less than 0, it was set to 0, and then the *b* (scale) and *c* (shape) parameters were reestimated.

Modeling of Diameter Distributions

Percentile-Based

A percentile-based, parameter recovery, three-parameter Weibull distribution procedure was used to model diameter distributions (Brooks et al. 1992). Due to potential correlation among residuals of the equations, parameters were estimated using seemingly unrelated regression (SUR). The following system of equations based on Brooks et al. (1992) was estimated:

$$\text{Min}\ (D_0) = exp\ (-0.87332 + 1.555861 \times \ln[D_q] - 0.24522 \times \ln[\text{Age}]) \quad (3)$$

$$D_{25} = exp\ (-0.96341 + 1.309497 \times \ln[D_q]) \quad (4)$$

$$D_{50} = exp\ (-0.1084 + 1.040901 \times \ln[D_q]) \quad (5)$$

$$D_{95} = exp\ (0.511647 + 0.910853 \times \ln[D_q]) \quad (6)$$

where

Min (D_0) = minimum d.b.h. (inches) within a plot,

D_i = predicted value for the d.b.h. (inches) at which the i^{th} percentile occurs,

D_q = quadratic mean diameter (inches), and

Age = stand age, n=44.

All parameter estimates of variables were significant at a $p < 0.0575$ level. Adjusted R^2 were 0.7036, 0.8140, 0.9801, and 0.8770 for equations 3, 4, 5, and 6, respectively. The percentiles were then used within a parameter recovery approach to estimate parameters of the Weibull distribution as found in Brooks et al. (1992). This approach is further referred to as Per.

Parameter Prediction

Although the parameter prediction approach is not as popular today as other parameter estimation techniques, it was used as a means of helping to understand what stand-level variables may impact diameter distributions in these plantations. A variety of stand-level variables were examined. In addition, it is often advantageous to predict either the *b* (scale) or *c* (shape) parameter as a function of the *a* (location) parameter. The parameters of equations 7, 8, and 9 were estimated as a simultaneous system of equations (Borders 1989). The final models, selected based on both statistical considerations of model adjusted R^2, significance of parameter estimates, and biological considerations, which were the magnitude and sign of the parameter estimates, were:

$$a \text{ (location)} = exp\ (-1.54235 + 0.241536 \ln[\text{TPA}] - 0.735 \ln[\text{Age}] + 1.913982 \ln[D_q]) \quad (7)$$

$$b \text{ (scale)} = exp\ (-0.57596 - 0.27016 \ln[a] + 0.692494 \ln[\text{Age}]) \quad (8)$$

$$c \text{ (shape)} = exp\ (0.19981 + 0.482567 \ln[b]) \quad (9)$$

where

a, *b*, *c* = parameters of the three-parameter Weibull distribution to be predicted,

TPA = trees per acre of all species, and

others as previously defined, n=44.

All parameter estimates of variables were significant at a $p < 0.0331$ level. Adjusted R^2 were 0.3922, 0.6969, and 0.5071 for equations 7, 8, and 9, respectively. This approach is further referred to as PP.

Model Prediction and Validation Data

A variety of sources (Table 1 and Fig. 1) were used in model prediction (or validation) to test the ability of the developed equations (Per and PP approaches) and those from Smalley and Bailey (1974) to estimate Weibull distribution parameters. The first source is a spacing study established in February of 1955 on the Southwest Research and Extension Center near Hope, Arkansas. Four planting densities (trees per acre) were established: 1,742 (5 feet by 5 feet), 1,210 (6 feet by 6 feet), 908 (6 feet by 8 feet), and 681 (8 feet by 8 feet). A second source includes old-field plantations established on the North Mississippi Branch Experiment Station at Holly Springs, Mississippi (Kushla 2009). Planting density was 622 trees per acre (7 feet by 10 feet spacing). A third source were plantations from two cutover sites in southeastern Oklahoma: Idabel and Shinewell (Dipesh et al. 2015). Trees were planted at a spacing of 8 feet by 10 feet (544 trees per acre).

Across the four sites, dominant height averaged 15.8 feet, and the minimum and maximum dominant heights were 3.6 and 38.6 feet, respectively.

Model Validation

Predictive abilities of each parameter estimation approach were compared using a commonly used validation process (Arabatzis and Burkhart 1992). The difference between the observed and estimated Weibull distribution parameters (e_{ij} = observed − predicted), respectively, for each individual measurement plot [*i*] was calculated for all measurement ages [*j*] by plot for each of the four studies. The mean residual ($\bar{e}$) and the sample variance (v) of residuals were computed and considered to be estimates of bias and precision, respectively. An estimate of mean square error (MSE) was obtained combining the bias and precision measures using the following formula:

$$\text{MSE} = \bar{e}^2 + v \quad (10)$$

Table 1.—Summary statistics of age, trees per acre, and basal area per acre (square feet) of the n=44 Forest Inventory and Analysis plots designated as shortleaf pine (*Pinus echinata*) plantations used in model fitting and the n=80 plots used in model prediction (validation)

Model Fitting

		Age			Trees per acre			Basal area per acre (square feet)		
State	*n*	Mean	Min[a]	Max[b]	Mean	Min	Max	Mean	Min	Max
AR	17	32	6	51	540	84	1,790	87	29	157
MO	23	55	31	80	161	66	526	87	39	175
MS	2	30	25	34	358	307	409	104	99	108
TN	2	62	61	62	149	90	207	79	59	98
All	44	46	6	80	316	66	1,790	87	29	175

Model Prediction/Validation

			Trees per acre			Basal area per acre (square feet)		
State/Study	*n*	Ages	Mean	Min	Max	Mean	Min	Max
AR, 1	36	3, 5, 7	1,066	626	1,742	34	0.93	89
MS, 2	4	16	500	460	520	148	140.29	155
OK, 3	24	3–5, 8–10	314	198	442	18	0.02	61
OK, 4	16	4, 5, 9, 10	367	326	415	25	0.39	56
All	80		672	198	1,742	33	0.02	155

[a] Minimum

[b] Maximum

Table 2.—Average percentile values (D_0, D_{25}, D_{50}, and D_{95}) and *a* (location), *b* (scale), and *c* (shape) three-parameter Weibull parameters of the n=44 Forest Inventory and Analysis plots designated as shortleaf pine (*Pinus echinata*) plantations used in model fitting, and the n=80 plots used in model prediction (validation)

Model Fitting Dataset

State	*n*	D_0	D_{25}	D_{50}	D_{95}
AR	17	4.129	5.315	6.800	9.521
MO	23	6.043	8.313	10.496	14.252
MS	2	3.400	5.300	7.150	10.650
TN	2	5.350	7.000	9.500	15.100
All	44	5.152	6.958	8.870	12.299

Model Prediction/Validation Dataset

State	*n*	D_0	D_{25}	D_{50}	D_{95}	Study
AR	36	0.972	1.768	2.117	3.040	1
MS	4	4.275	6.300	7.275	9.525	2
OK	24	0.989	2.153	2.683	3.747	3
OK	16	1.411	2.507	2.935	3.832	4
All	80	1.230	2.258	2.708	3.735	

Model Fitting Dataset

State	*n*	*a* (Location)	*b* (Scale)	*c* (Shape)
		Mean	Mean	Mean
AR	17	2.722	5.025	3.289
MO	23	3.633	7.499	3.410
MS	2	2.521	5.755	3.317
TN	2	1.684	9.815	3.821
All	44	3.142	6.569	3.378

Model Prediction/Validation Dataset

State	*n*	*a* (Location)	*b* (Scale)	*c* (Shape)	Study
		Mean	Mean	Mean	
AR	36	0.531	1.756	2.954	1
MS	4	3.014	4.701	3.376	2
OK	24	0.327	2.544	3.079	3
OK	16	0.455	2.646	4.249	4
All	80	0.579	2.318	3.271	

RESULTS AND DISCUSSION

For the *a* (location) parameter, in most cases for the two approaches using the current FIA modeling dataset (percentile prediction [Per] and parameter prediction [PP]), the parameter was overestimated within the validation datasets, particularly with increases in age. In work by Smalley and Bailey (1974), referred to hereafter as the SB approach, the parameter was underestimated. The percentile prediction approach (Per) had a slightly better mean square error (MSE) across all conditions relative to the SB approach.

For the *b* (scale) parameter, the SB approach greatly overestimated, and in some cases the variance was high. In some cases, on average by site, Per performed better than the PP approach in terms of bias (error), and in other cases the PP approach produced better average site estimates. However, the PP approach produced extreme variation among the estimates (variance). Therefore, overall, the Per approach had vastly superior MSE statistics.

For the *c* (shape) parameter, the Per and PP approaches generally overpredicted, while the SB approach generally underestimated. Of the three parameters, the *c* (shape) parameter estimates seemed to have the lowest amount of variability among the three approaches. Despite having a slightly greater amount of bias (error) relative to the PP approach, the Per approach had the smallest MSE.

CONCLUSIONS

Across the three parameters, the Per approach generally had the lowest bias (error), but in some cases had vastly superior MSE statistics, most likely resulting from lower estimation variances. Based exclusively on estimates of the three parameters, the Per approach is suggested. However, future work needs to look more closely at the ability of these three parameter estimation approaches to predict diameter distributions directly. Examining the direct ability of the approaches to estimate diameter distributions will better quantify the significance of predictive errors for an individual parameter. However, based on these results of predicting the parameters themselves, it is anticipated that the Per approach will likely be superior when predicting diameter distributions directly.

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Co-occurrence of an Increase in Both the Area of Older Forest and Abundance of Potential Nesting Cavities for Wood Ducks (*Aix sponsa*) in Northern Minnesota, USA

James B. Berdeen, Mark. D. Nelson, Edmund J. Zlonis, and John H. Giudice[1]

Abstract.—Wood duck (*Aix sponsa*) females often nest in cavities within large-diameter deciduous trees. Over the past few decades, changes in northern Minnesota forests positively influenced the abundance of stems with suitable nesting cavities that are available for wood ducks. Here, we examined temporal changes in these forests between 1977 to 2019 to ascertain whether there was a co-occurrence in the areal extent of older forests. In general, the abundance of stems with suitable cavities increased during the analysis period, along with corresponding trends in area of older timberland.

INTRODUCTION

Female wood ducks (*Aix sponsa*) often nest in cavities within large-diameter deciduous trees (Bellrose and Holm 1994). Berdeen et al. (2022) identified temporal changes in the abundance of potential nesting cavity trees in northern Minnesota by attributing tree data collected by the U.S. Department of Agriculture (USDA), Forest Service, Forest Inventory and Analysis (FIA) program with probabilities of suitable cavity occurrence based on tree species, health status, and diameter (Zlonis et al. 2020), from which density estimates were produced. Estimated abundance and density of suitable stems generally increased at all three spatial scales, and in a similar manner on public and private lands at the two largest spatial scales. Findings from Berdeen et al. (2022) demonstrate that the abundance of suitable stems varied for both common and uncommon tree species, more so for live health-impacted stems than for dead stems. Abundance within late-successional tree species (1) increased at all spatial scales, as well as for mid-successional species between 1977 and 2019 at the two larger spatial scales, and only until 2010–2014 at the study-area scale, and (2) peaked for early successional species during 1990 at the two larger spatial scales and during 1977 at the study-area scale. Berdeen et al. (2022) suggested that the increases in estimated abundance of stems with suitable cavities could be at least partly attributed to "…the advancing of forest succession in northern Minnesota." In this paper, we build on previous work by analyzing concurrent temporal changes in the areal extent of older forests.

METHODS

We used FIA data to estimate the area of older forest (i.e., greater than 50 years of age for forest types within the aspen/birch forest-type group, or greater than 80 years of age for other forest types [Berdeen et al. 2022]) for six inventory periods (1977, 1990, 2000–2004, 2005–2009, 2010–2014, 2015–2019) and across three spatial scales (a 618,000-acre study area in Cass County, the three ecological subsections that intersect with the study area [6.9 million acres], and the Laurentian Mixed Forest ecological province [23.2 million acres]) in Minnesota (Fig. 1). FIA data (Burrill et al. 2021) are measured on a sample of permanent, fixed-radius, remeasured cluster plots within a probability-based sample design. Corresponding statistical estimators (Bechtold and Patterson 2005) were implemented via FIA EVALIDator to produce unbiased estimates of forest land area.

To be consistent with Berdeen et al. (2022), we constrained our estimates to timberland to allow for more consistent inclusion of older FIA evaluation cycles (i.e., Minnesota 1977, 1990), during which some attribute estimates are available only for timberland. FIA timberland is

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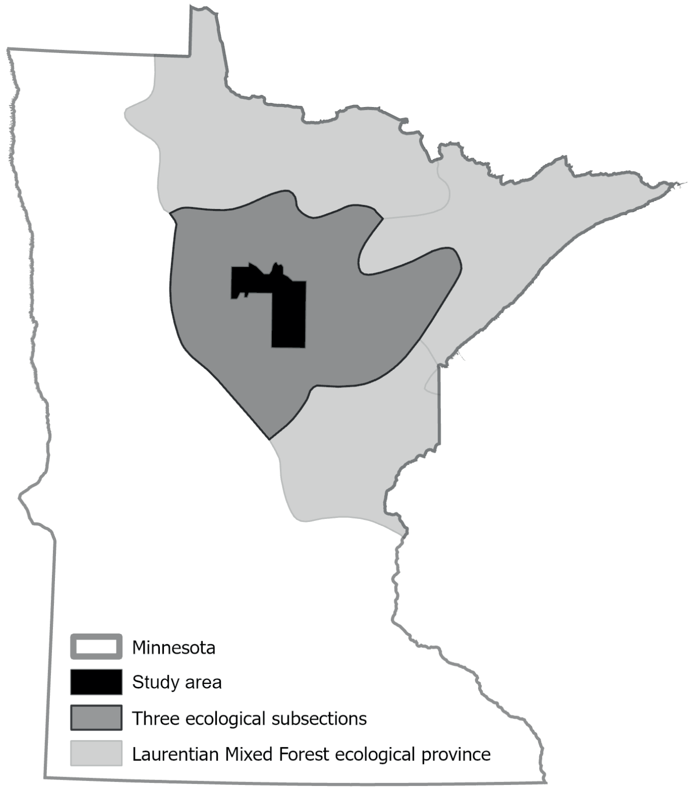

Figure 1.—The abundance of tree stems with cavities suitable for nesting wood ducks was estimated at three spatial scales: a 254,051 ha study area within Cass County, northcentral Minnesota (black); the three ecological subsections that intersect with the study area (dark gray); and the Laurentian Mixed Forest ecological province in Minnesota, USA (light gray).

defined as forest land that is producing or capable of producing in excess of 20 cubic feet per acre per year of wood at culmination of mean annual increment and does not include reserved forest lands (Bechtold and Patterson 2005). We produced area estimates for timberland using the same evaluation cycles and spatial scales as Berdeen et al. (2022) and assessed trends in the areas of older age classes for comparison to Berdeen's trends in abundance of stems with suitable cavities.

RESULTS

Temporal Changes in Timberland Area

During the 2015–2019 inventory cycle, timberland comprised 96 to 97 percent of all forest land at both the study area and three subsection scales, and about 89 percent of forest land in the ecological province. Constraining analyses to timberland resulted in omission of more forest land from the ecological province than for two smaller scales, mostly due to exclusion of large, reserved forest land areas (i.e., Voyageurs National Park and the Boundary Waters Canoe Area Wilderness). Between 1977 and 2015–2019, the estimated area of timberland changed slightly (from 424,000 to 423,000 acres) in the Cass County study area, was essentially unchanged at 3.9 million acres in the three subsections area, and increased substantially (from 11.8 to 13.2 million acres) in the Laurentian Mixed Forest ecological province. Over the same period and scales of analysis, the percentage of timberland in older forest class increased slightly (from 33 to 35 percent) in the study area, substantially (from 24 to 32 percent) in the three ecological subsections, and substantially (from 24 to 36 percent) in the ecological province (Fig. 2).

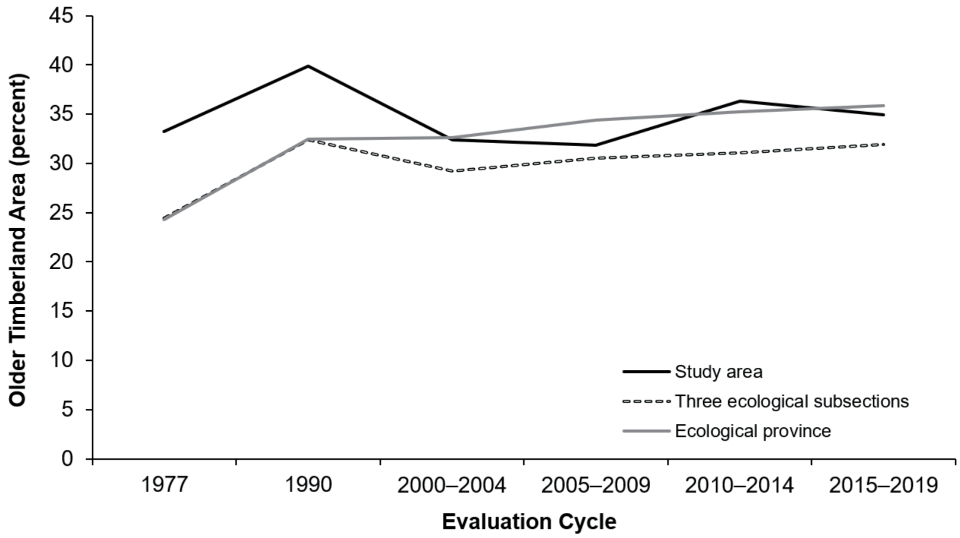

Figure 2.—Percentage of timberland in older age classes (at least 50 years of age for forest types within the aspen/birch forest-type group or at least 80 years of age for other forest types) for each evaluation cycle and spatial scale reported in Berdeen et al. (2022) for northern Minnesota, USA, 1977 to 2015–2019. Note: "Study area" represents a site within Cass County, northcentral Minnesota; "Three ecological subsections" represents results from the subsections that intersect with the study area; and "Ecological province" represents results from the Laurentian Mixed Forest in Minnesota, which contains the study area and the three ecological subsections (Fig. 1).

Trends in Stem Density Versus Older Timberland Area

Trend lines for abundance of suitable stems (Berdeen et al. 2022) and older timberland area are generally similar, with a few differences (Fig. 2). Although the abundance of suitable stems and area of older timberland are both lowest at the ecological-province scale during the earliest inventory cycle, the percentage of older timberland in the ecological province becomes most prevalent by the most recent inventory, while suitable stem density remains relatively low at this scale. Relative rankings also changed at other scales of analysis, but to a lesser degree (Fig. 2).

SUMMARY

In this paper, we estimated a slight increase in the relative abundance of older timberland within the smallest analysis area but more substantial increases at both the intermediate and largest spatial scales examined, providing further support for the conclusion that advancing forest succession may have contributed to the increased abundance of stems with suitable cavities (see Berdeen et al. 2022). Additional insights are revealed when considering absolute and relative abundance of both stems and timberland area. Our results can inform forest management decisions and follow-up studies on nesting wood ducks.

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Recent Estimates and Future Projections of Maine's Timber Volume, Forest Carbon Stocks, and Sequestration Rates: 2003–2048

Jereme Frank[1]

Abstract.— In the face of climate change, states are considering how forests will most efficiently help meet carbon targets while sustaining timber supplies that support forest economies. To examine future carbon stocks under varied harvest regimes, the Maine Forest Service developed a forest planning optimization model using data collected by the U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis program between 2003 and 2021. Assuming current harvest practices are maintained, the baseline model scenario projected that while timber volume continued to increase, it increased at a lower rate. Increasing high-yield forestry could lead to improved growth rates and higher carbon stocks and timber volume. However, increasing harvest rates rapidly with little consideration for harvest regimes could lead to declining carbon stocks. The modeling framework presented here shows promise for rapid trade-off analysis; other potential frameworks are discussed.

INTRODUCTION

In 2019, Maine's forest industry employed over 31,000 people and had an economic impact of $8.1 billion (Bailey and Green 2021). A sustained forest inventory is necessary to ensure a future timber supply, which in turn allows the forest sector to thrive, preserves jobs, and keeps mills open. Assuming markets exist and other parts of the supply chain are solid, the forest industry has the potential to grow. At the same time, knowing the limitations of Maine's forests could help reduce the risk of reaching overcapacity. To that end, the Maine Forest Service is directed by law to periodically conduct Timber Supply Analyses (12 M.R.S. §8877-A [3]).

In addition to providing timber to support the forest economy, Maine's forests sequester large quantities of carbon and may play a key role in achieving net zero greenhouse gas emissions by 2045. Between 2006 and 2016, Maine's forests sequestered approximately 3.7 million metric tons of carbon annually, or 75 percent of the fossil fuel emissions statewide (Bai et al. 2020). This paper examines trends in U.S. Department of Agriculture (USDA), Forest Service, Forest Inventory and Analysis (FIA) program data collected between 2003 and 2021 and utilizes FIA inventory data from 2018 to estimate Maine's future timber volume and carbon stocks under different scenarios that vary by management practice.

METHODS

Estimates of harvest removals (i.e., average annual harvest removals of sound bole volume without rotten cull on forest land), timber volume (i.e., merchantable bole volume without rotten cull on nonreserved forest land), carbon stocks (i.e., aboveground carbon in live trees over 1 inch diameter on forest land) and net change in carbon stocks were generated from the FIA EVALIDator tool (USDA Forest Service 2023). While timber volume and carbon stock estimates were available for 2003 to 2021, harvest removals and net change were available only from 2008 to 2021. Data from 2018 served as the starting point for projections because data from 2018 represented the most recent inventory available at the start of the projection work. Estimates of merchantable bole volume on timberland were tested for statistical significance by comparing inventory years 2006 to 2011, 2011 to 2016, and 2016 to 2021 (Westfall et al. 2013).

To evaluate future carbon stocks and timber supply in Maine's forests, the Maine Forest Service developed Woodstock, a forest harvest planning software package that harnesses linear programming and is excellent for rapid trade-off analysis (Walters 1993). One output of the model is a schedule that illuminates key actions that need to be taken to meet core objectives.

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The key inputs to the model (many of which were parameterized using FIA data) are as follows:

- **Themes:** Themes were largely derived from FIA variables and included physiographic class, differentiated ownership class, land class, treatment type, operability, origin, stand size code, reserved status, and megaregion. Fiber type (Gadzik et al. 1998 [App. C]) was used in lieu of forest type to describe forest composition.
- **Areas:** Areas were delineated for all possible combinations of themes.
- **Yields:** Individual yield curves were developed for each area and varied by harvest method, timing, and intensity of harvest. The Open Stands Model (Hennigar 2020), a growth and yield model developed for the Acadian Region, was used to develop the yield curves by growing out all conditions in the FIA Database for Maine. Yields were based on measured growth rates from FIA plots based on previous conditions.
- **Actions and transitions:** Each area could have one of nine actions/treatments: 68 percent removal, 32 percent removal, shelterwood harvest, clearcut without planting, clearcut and replant, overstory removal, reversion, conversion to nonforest, or conversion to reserved land. Based on the action, the model transitions an area from a baseline (or other) curve to the "treated" yield curve.
- **Constraints:** Total harvest volume was set at the 2018 estimate. FIA data from 2003 to 2018 constrained the bounds on the harvest for fiber type, megaregion, ownership class, species, sawlog volume, harvest type area, conversion area, size class, and plantation acres. Aboveground carbon was not allowed to decline below the estimated level in 2018.
- **Objective function:** In the baseline maximum scenario, volume was maximized subject to primary and secondary constraints. In the baseline minimum scenario, volume was minimized.
- **Additional scenarios:** In both the unconstrained maximum and unconstrained minimum scenarios, most secondary constraints were removed. In the increased plantation scenario, annual plantation establishment acres were increased substantially, and most secondary constraints were removed. The sustained carbon sequestration scenario fixed carbon sequestration rates at 2018 levels while maximizing harvest. In the increased harvest scenario, harvest was increased 1.5 times over 2018 levels, volume was maximized, and secondary constraints were removed.

RESULTS AND DISCUSSION

Recent Trends

Between 2003 and 2021, statewide timber volume and carbon stocks increased 7 percent and 10 percent, respectively (Figs. 1a, b). Timber volume increased marginally between 2006 and 2011 ($p = 0.1$). Volume increased significantly between 2011 and 2016 ($p < 0.000066$) and between 2016 and 2021 ($p < 0.000066$). Statewide harvest removals show a general declining trend after 2011, a potential rebound starting by 2019, and a declining trend thereafter (Fig. 1c). The trend is largely reversed for net change in aboveground carbon (Fig. 1d). (For more on Maine's forests, see Woodall et al. 2022.)

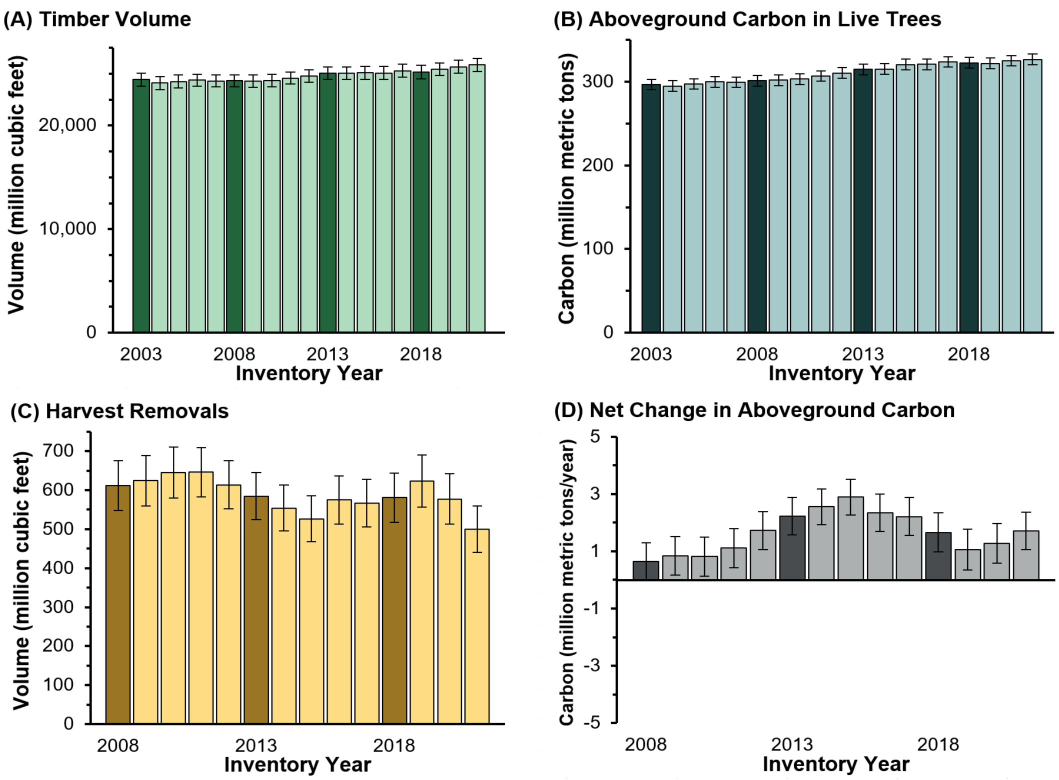

Figure 1.—Estimates of (A) timber volume (i.e., merchantable bole volume without rotten cull) on nonreserved forest land, in cubic feet, Maine, 2003–2021; (B) carbon stocks (i.e., aboveground carbon in live trees over 1 inch diameter at breast height) on forest land, in million metric tons of carbon, Maine, 2003–2021; (C) harvest removals (i.e., average annual harvest removals of sound bole volume without rotten cull) on nonreserved forest land, in cubic feet, Maine, 2008–2021; and (D) annual net change in aboveground carbon without harvested wood products, Maine, 2008–2021. Dark bars denote inventory period (2003, 2008, 2013, 2018). Error bars represent sampling error at the 95 percent confidence level.

Projections

Output from the baseline Woodstock model identified that (1) harvest in the sugar maple and ash fiber type could not be sustained and declined across most periods; this may reflect a need to reduce sugar maple harvest, and (2) harvest in the larger size class areas increased by approximately 10 percent in the early periods. This may be plausible, as the number of acres in the larger size classes is trending upward in Maine. However, it is hard to know precisely which acres, most importantly in the larger size classes, are available for harvest.

Maine's forest volume and carbon stocks have increased significantly over the past 20 years, but net change and net growth may be showing signs of slowing. Assuming current harvest practices, the baseline scenario showed that timber volume would increase and carbon stocks would remain stable (Fig. 2a, b, c).

The other scenarios suggest potential for improving the capacity of the forests to sequester more carbon and/or increase harvest over the baseline projection (Fig. 3), which could be accomplished by improving harvest intensity, residual stocking, and timing and/or increasing acres in high-yield plantation forestry. Without adjusting current practices, increasing annual harvest much beyond 2018 levels may make it difficult to meet the current goal of net zero greenhouse gas emissions by 2045. If harvest increases by more than 1.1 times without adopting high-yield silvicultural practices, carbon stocks and timber volume could potentially decline. If harvest increases by 1.2 to 1.5 times, carbon stocks and timber volume will likely decline, perhaps dramatically. In the sustained carbon sequestration scenario, harvest could increase slightly in the final period.

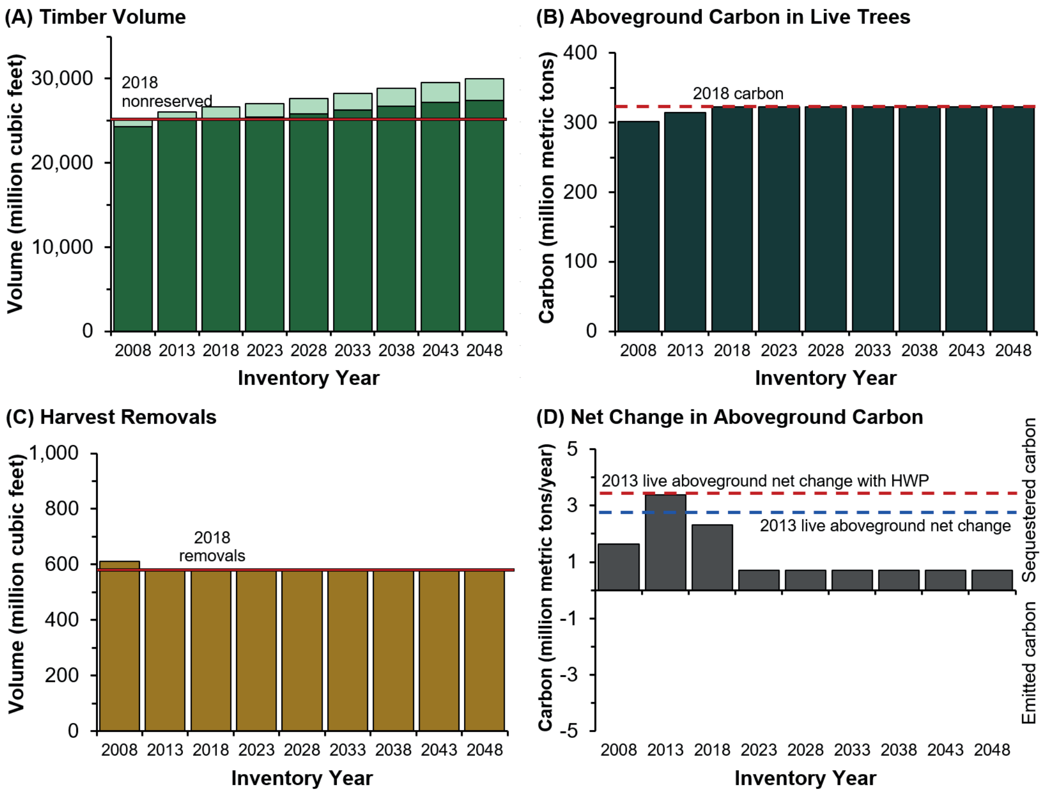

Figure 2.—Model output for the baseline maximum scenario. Statewide estimates for (A) timber volume (i.e., merchantable bole volume without rotten cull) on nonreserved forest land, in cubic feet, Maine, 2003–2021; (B) carbon stocks (i.e., aboveground carbon in live trees over 1 inch diameter at breast height) on forest land, in million metric tons of carbon, Maine, 2003–2021; (C) average annual harvest removals of sound bole volume without rotten cull, in cubic feet, on nonreserved forest land, Maine, 2008–2021; and (D) annual net change in aboveground carbon with harvested wood products (HWP), Maine, 2008–2021, when volume is maximized, harvest is equal to recent levels, and the model is fully constrained.

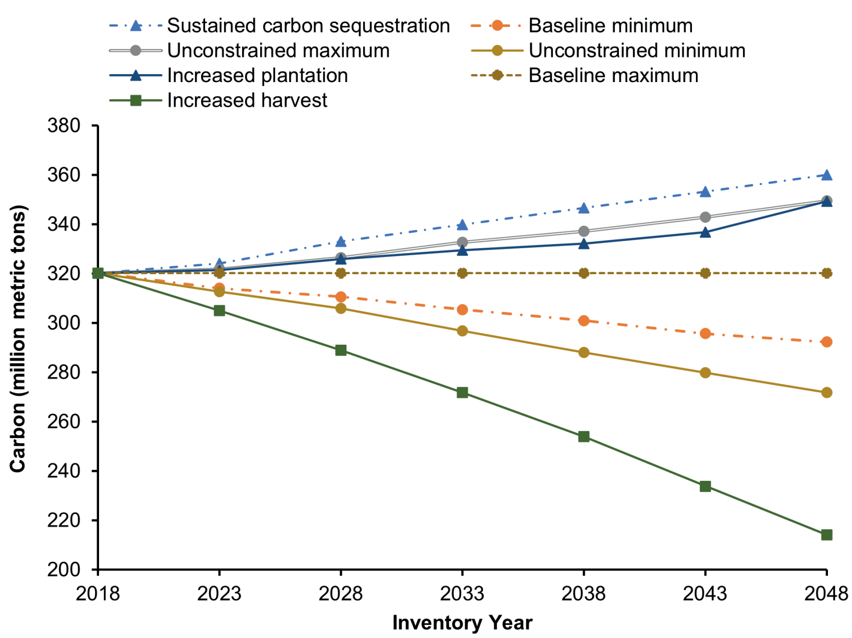

Figure 3.—Aboveground carbon (live trees over 1 inch diameter at breast height) on forest land by scenario and year.

LIMITATIONS AND FUTURE WORK

The projections presented here represent preliminary findings, especially considering that this work used 2018 as the baseline data and given subsequent changes to FIA volume and biomass estimation methods (Westfall et al. 2024). Implementation of these newer methods resulted in a 13 percent increase in biomass of aboveground trees in Maine in 2021. Therefore, trends in carbon stocks and their projections will also change. The diverging trend between carbon stocks and timber volume was an unexpected result (Fig. 2). This could be due in part to different assumptions about harvest between high-density and low-density species, which could shift in the future.

Another limitation is that the model uses potentially outdated assumptions about the fates of harvested wood products (Smith et al. 2006), ignoring updated methods (e.g., Stockmann et al. 2012). No attempt was made to examine substitution effects nor other pools, such as deadwood, litter, and soils. These effects and pools will need to be considered to comprehensively assess carbon in Maine's future forest and the forest products sector.

Future work will continue to explore the current framework and other modeling frameworks, such as the Carbon Budget Model (CBM), as well as the incorporation of geospatial data, such as LANDIS (Kurz et al. 2009, Simons et al. 2021). Exploration of additional frameworks will allow for further consideration of strengths and weaknesses of each approach and help provide an examination of the cost required to develop a working model for a state or region. Ultimately, multiple modeling frameworks may be needed to help address a wide array of questions pertaining to timber volume, carbon sequestration, economics, and biodiversity. For instance, LANDIS may better answer complex questions about climate change, Woodstock may be more suited to explore the effects of different harvest regimes, and CBM may be better able to report on carbon stocks. Users of these models should consider scalability, time and effort, model cost, the need for spatial explicitness, the need to conduct rapid trade-off analysis and adequately constrain certain parameters, measures of uncertainty, and the sufficiency of the methods used to implement harvest.

Recent work using CBM (DeLyser et al. 2022) suggests forests are increasingly being recognized as natural climate solutions by state entities. Given this burgeoning interest, additional work leveraging FIA data could play a substantial role in modeling future carbon and timber supply at the state level. Considering that FIA data have been converted for in use within the Forest Vegetation Simulator, including at the regional scale (Hoover et al. 2021, Shaw and Gagnon 2020), FIA data could be used to report efficiently on statewide projections as described in Smith 2002 and provide opportunities to collaborate on future projections, including state Forest Action Plans.

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The following articles were published as part of a special issue in Frontiers in Forests and Global Change: Monitoring and Responding to Global Change to Promote Resilient and Productive Forests Through Innovative Forest Inventory.

Barnett, K.; Aplet, G.H.; Belote, R.T. 2023. **Classifying, inventorying, and mapping mature and old-growth forests in the United States.** Frontiers in Forests and Global Change. 5: 1070372. https://doi.org/10.3389/ffgc.2022.1070372.

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Conference Program

- Daily schedule (all times in CST).
- Posters available all day on event portal.

Monday, November 14, 2022

Time	Session	Moderator	Title	Speaker
10:30 AM	Opening Plenary	Randall Morin, Susan Crocker	Welcome and Opening Remarks	Susan Crocker, Randall Morin, Charles H. (Hobie) Perry
10:45 AM			The State of Minnesota's Forest Inventory	Dennis Kepler
11:00 AM			The FIA Program: Successes, Expectations, Challenges, and Opportunities	Renate Bush
11:15 AM			How We Think About FIA Data	Jad Daley
11:30 AM			FIA's Importance Within Research and Development	Cynthia West
11:45 AM			Break	
12:15 PM	Global Efforts in Forest Monitoring and Research	Jingjing Liang, Andrew Lister	The Practical Use of Remote Sensing to Enhance Forest Inventories: A Case Study of the United States National Forest Inventory	Andrew Lister
12:30 PM			The Potential of New Age Satellite Data for Forest Biomass Estimation in Vietnam	Hai Pham
12:45 PM			Application of GLAD Tools for LCLUC Mapping and Monitoring in Vietnam	Peter Potapov
01:00 PM			Spatial Predictions of Aboveground Biomass and Carbon Storage in Mexico Forests Using Ensemble Learning and Forest Inventory Data (2015–2020)	Aylin Barreras
01:15 PM			Science-i: A Transparent, Secure, and FAIR Web Platform to Support Large-Team International Research Collaboration in Biodiversity Sciences and Beyond	Jingjing Liang
01:30 PM			Forest Migration Outpaced Tree Species Range Shifts Across North America Under Global Change	Akane Abbasi
12:15 PM	Forest Health Monitoring Science and Applications: Toward Enhanced Integration of FIA and FHM	Erin Berryman, Kerry Dooley	The Use of Damage Causing Agent Codes in FIA and FHM: A Cautionary Tale	Erin Berryman
12:30 PM			The USDA Forest Service Forest Health Monitoring (FHM) Program and the Value of Spatially Explicit (Off-Plot) Data	Christopher Asaro
12:45 PM			Comparing Methods That Quantify Forest Disturbances in the U.S. National Forest Inventory	Lucia Fitts
01:00 PM			Integration Opportunities for Forest Health Monitoring and FIA Data	Christopher Oswalt
01:15 PM			Biotic and Abiotic Disturbance Trends in Forests of the United States	KaDonna Randolph
01:30 PM			The 2011 Texas Drought as an Informative Forest Health Case Study	Frank Koch

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Monday, November 14, 2022 (continued)

Time	Session	Moderator	Title	Speaker
12:15 PM	Carbon I: Advances in Estimating Carbon on Forest Land, Woodlands, and Urban Trees Across Space and Time	Grant Domke, Courtney Giebink	Shifting Forests and Carbon: Linking Community Composition and Aboveground Carbon Attributes	Jonathan Knott
12:30 PM			Including Hawaii in the National GHG Inventory Report Using the Gain-Loss Method	Brian Walters
12:45 PM			Assessing CO_2 Enhancement Effects on Stand Biomass Stocks and Growth Across U.S. Continental Forests	J. Aaron Hogan
01:00 PM			Bayesian Hierarchical Spatial Models to Generate Statistically Rigorous Estimates of Forest Carbon Using Remote Sensing Data	Chad Babcock
01:15 PM			Joint Models for High-Dimensional Discrete and Continuous Outcomes: A Case Study of Forest Biomass by Species for the Continental United States	Andrew Finley
01:30 PM			Linking Forest Dynamics Across Scales to Better Predict Forest Carbon Under Global Change	Malcom Itter
01:45 PM			Estimating Forest Carbon Stocks on School Trust Lands in Minnesota	Jennifer Corcoran
12:15 PM	Scaling Up to Meet New Challenges: Supporting Planning and Monitoring on National Forests with FIA	Sarah Wiener, Mara Alexander	National Forest System Planning and Monitoring: Current Trends, Policies, Initiatives	Sarah Wiener
12:30 PM			Using FIA Data for Forest Planning on the Black Hills National Forest	Jeffrey Underhill
12:45 PM			Use of Forest Inventory and Analysis Data for 2012 Planning Rule Monitoring on the Rio Grande National Forest	Michael Tooley
01:00 PM			Evaluating Existing Longleaf Pine Ecosystem Conditions Using Forest Inventory and Analysis	Amy Nathanson
01:15 PM			FIA Data in Action on Eastern National Forests	Coeli Hoover
01:30 PM			Using FIA and FVS to Develop Future Yield Scenarios in Support of National Forest Planning	John Shaw
12:15 PM	Monitoring Change Using Inventory Data	Kristen Pelz, Scott Hopton	Comparison of Maximum Stand Density for Mixed Hardwood Forests Among Various Physiographic Zones in the Eastern United States	Sheng-I Yang
12:30 PM			Forest Land Use Change in the Conterminous United States	Mark Nelson
12:45 PM			Increasing the Utility of Tree Regeneration Inventories: Linking Seedling Densities to Sapling Recruitment	Lucas Harris
01:00 PM			Shade Tolerance of Tree Species and Drivers of Successional Change in Forests Across the Contiguous United States	Gabriela Krochmal
01:15 PM			Stand and Environmental Conditions Drive Functional Shifts Associated with Mesophication in Eastern U.S. Forests	Margaret Woodbridge
01:30 PM			Towards Development of a Functional Definition of Old-Growth Forests: An Application Using National Forest Inventory Data in the United States	Kevin Barnett
01:45 PM			Estimating the Temporal Change in Abundance of Potential Nesting Cavities for Wood Ducks (*Aix sponsa*) in Northern Minnesota, USA	James Berdeen
02:00 PM			Break	

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Monday, November 14, 2022 (continued)

Time	Session	Moderator	Title	Speaker
02:30 PM			Speed Networking	
03:00 PM			Peer Group Networking I	Grant Domke, Mark Majewsky, Barry (Ty) Wilson, Susan Crocker, Jesse Caputo
03:30 PM			Peer Group Networking II	Jon Knott, Tonya Lister, Barry (Ty) Wilson, Randall Morin, Brett Butler

Tuesday November 15, 2022

Time	Session	Moderator	Title	Speaker
10:30 AM	Demonstration Session I: Web Tools, Apps, and Digital Products	James Garner, Dan Kaisershot	Introducing the FIADB-API	James Garner
10:40 AM			New Ways to Access FIA Data	Cara Leitheiser
10:50 AM			A Hands-On Look at RegRake: A New Web-Based Small Area Estimation Tool for the Southern United States	Nicholas Nagle
11:00 AM			FIA Land Use Estimates Dashboard of the Conterminous United States	Holly Russon, Charles Werstak, Jr., Abbey Schaaf
11:10 AM			A Stand-Alone R-Based Application for Custom Estimation Strategies Using FIA Data	Tracey Frescino
11:20 AM			FIA FIESTA and Esri ArcGIS Pro R-Based Tools for Custom Estimation Strategies Using FIA Data	Charles Werstak, Jr.
11:30 AM			Delivering Apps, Maps, and Other Cool Stuff from Large-Scale Forest Inventory Data	Christopher Oswalt
10:30 AM	Demonstration Session II: Web Tools, Apps, and Digital Products	Randall Morin, Thomas Goff	The Design and Analysis Toolkit for Inventory and Monitoring (DATIM) in Action	James Menlove
10:40 AM			The Peruvian NFI: the Inventories Module	Patricia Durán
10:50 AM			Bringing Multidecadal Landscape Change Data to Life	Ian Housman
11:00 AM			Results from the Summer 2022 Undergraduate Forestry Data Science Program	Julian Schmitt, Maxwell VanLandschoot, Kelly McConville
11:10 AM			Demonstration: OK Tabling Program	Olaf Kuegler
11:20 AM			An Excel-Based Tool to Simplify Data Reporting on Vietnam's National Forest Ecological Research Plots	Ashley Lehman
11:45 AM			Break	
12:15 PM	Cities Here and There: Comparing, Contrasting, and Combining Cross-City Data from the Urban FIA Program	Sjana Schanning, Katherine Johnson	Show Me the Data: Comparing Urban Forest Attributes in City and Metro Areas of Missouri	Tonya Lister
12:30 PM			Planning and Planting for the Future: Using Urban FIA Data to Investigate Planted Trees Within Urban Forests	Sjana Schanning
12:45 PM			Quantifying Urban Forest Attributes and Associated Ecosystem Services to Aid in Developing Sustainable Management Strategies in Two Western U.S. Cities	Kathryn Baer, Suzanne Owen
01:00 PM			Urban Forests as Sources for Invasive Trees	Mark Ambrose
01:15 PM			Developing a Minimally Destructive Sampling Protocol for Urban Tree Mass Modeling for FIA	David MacFarlane

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Tuesday November 15, 2022 (continued)

Time	Session	Moderator	Title	Speaker
12:15 PM	Carbon II: Advances in Estimating Carbon on Forest Land, Woodlands, and Urban Trees Across Space and Time	Grant Domke, Courtney Giebink	Beyond Live Tree Components of Change: Framing Carbon Components of Change in a Forest Inventory	Christopher Woodall
12:30 PM			Historical Time Series Biomass Modeling: To Train on Plots or Pixels?	Lucas Johnson
12:45 PM			Integrating Wood Carbon Fractions into Forest Carbon Estimation Methods and Models	Adam Martin
01:00 PM			Near-Term Aboveground Biomass and Regeneration Responses to Severe Disturbances Across the United States Forests	Karun Pandit
01:15 PM			Wildfires Correlate with Reductions in Aboveground Tree Carbon Stocks and Sequestration Capacity on Forest Land in the Western United States	Panmei Jiang
01:30 PM			Opportunities, Motivations, and Challenges for Incorporating FIA Data into State-Level Carbon Management Decision-Making	Kylie Clay
01:45 PM			Fire, Forest Type, and Landscape Position Interact to Determine Boreal Forest Carbon Stocks	Sean Cahoon
12:15 PM	Monitoring Forest Disturbance	Susan Crocker, Randall Morin	Variable Streamflow Response to Forest Disturbance in the Western United States: A Large-Sample Hydrology Approach	Sara Goeking
12:30 PM			The Use of FIA Data for Use in Insect Outbreak Forecasting	Steven McNulty
12:45 PM			Timing and Extent of Forest Disturbance in the Laurentian Mixed Forest	Christopher Edgar
01:00 PM			Storm Cloud: A Rapid Assessment System for Mapping Post-Hurricane Forest Damage	Gabriel Prata
01:15 PM			Post-Fire FIA Remeasurement Yields Granular Estimates of Fire Effects and an Empirical Test of Fire Resistance Predictors in Western Cascadia	Jeremy Fried
01:30 PM			Geographic Distribution of Invasive Tree Species in the Contiguous United States	Aubrey Franks
01:45 PM			Heavy Metals in Moss Guide Environmental Justice Investigation: A Case Study Using Community Science in Seattle, Washington, USA	Sarah Jovan
12:15 PM	Estimation Methods I: Design-Based Inferential Paradigms and Tools	George Gaines, Tracey Frescino	Model-Assisted Estimation to Support Forest Monitoring in Interior Alaska	Hans Andersen
12:30 PM			Model-Assisted Estimation for Substate Areas Using BIGMAP	Barry (Ty) Wilson
12:45 PM			Model-assisted Small Area Estimation of Post-Fire Stocking Within the Western United States	George Gaines
01:00 PM			R-Based Pathways for Alternative FIA Estimation Strategies Through FIESTA	Tracey Frescino
01:15 PM			RegRake: A Web-Based Tool for Custom Small Area Estimation and Mapping of Forest Survey Data in the Southern United States	Todd Schroeder
01:30 PM			Post-Stratification for Variance Reduction at Rocky Mountain Research Station-FIA	Elizabeth Freeman
01:45 PM			Developing a Deeper Understanding of America's Forests	Gregory Brunner
12:15 PM	FIA Projects and Partners in the Pacific Islands	Ashley Lehman, Olaf Kuegler	The Micronesia Challenge FIA Terrestrial Webviewer: A Visual Display of Variation in Forest Characteristics Within Micronesia	Wendolin Marquez
12:30 PM			The Micronesia Challenge: Using FIA Methodology in Support of Conserving Terrestrial Ecosystems in the Islands of Micronesia	Wendolin Marquez

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Tuesday November 15, 2022 (continued)

Time	Session	Moderator	Title	Speaker
12:45 PM			Adapting the FIA Methodology to Small Tropical Island Forests: A Case Study from Palau	River Thomas
01:00 PM			Biodiversity: A Challenge for Developing Growth Models in Hawaii and the U.S. Affiliated Pacific Islands	Olaf Kuegler
01:15 PM			FIA in the Pacific Islands: A Successful Model of How Partnerships Have Leveraged and Added Value to a Forest Service Program	Ashley Lehman
01:30 PM			Modeling the Growth and Allometric Relationships of Caribbean Tree Species Using Long-Term Permanent Plot Data	Tom Brandeis
01:45 PM			The Micronesia Challenge: Conserving Terrestrial Ecosystems in the Islands of Micronesia	Tamara Greenstone-Alefaio
02:00 PM			Break	
02:30 PM	Beyond Background Mortality: Complex Drivers and Consequences of Tree Death in the Western United States	David Bell, Andy Gray	Tree Size, Forest Structure, and Moisture Limitation Control Forest Landscape Vulnerability to Tree Mortality	David Bell
02:45 PM			Estimation of Dead Wood Pools Before and After Tree Mortality Events in the Rocky Mountains	Erin Berryman
03:00 PM			Mortality of High Elevation Five-Needle White Pines Throughout the Western United States	Sara Goeking
03:15 PM			Live Fast and Die Young, or Go Slow for the Long Haul: Productivity, Density, and Mortality Rates on the U.S. West Coast	Andy Gray
03:30 PM			Climate and Disturbance Drivers of Widespread Subalpine Fir Decline	Daniel Perret
03:45 PM			Aspen Mortality in the Past 20 Years: Is It Dying Up to Expectations?	John Shaw
02:30 PM	New Insights from Recent Canopy Cover Activities	Mark Nelson, Susan Crocker	Temporal Transferability of Remote Sensing Models for Large Area Monitoring of Tree Cover	Steven Filippelli
02:45 PM			Leveraging the National Land Cover Database Tree Canopy Cover to Enhance the Landscape Change Monitoring System	Joshua Heyer
03:00 PM			Forest Service Nationwide Tree Canopy Cover: Branching Out and Restructuring for Modernization and Relevancy	Stacie Bender
03:15 PM			Using Interpolated Satellite Data to Obtain Estimates of Tree Canopy Cover Through Time	Bonnie Ruefenacht
02:30 PM	Estimation Methods II: Model-Based Inferential Paradigms and Tools	George Gaines, Tracey Frescino	Increased Precision of FIA Growing Stock Estimates Using NAIP and GEDI-Derived Canopy Height Models	Philip Radtke
02:45 PM			The Garden of Forking Paths in Forest Inventory	Kelly McConville
03:00 PM			Improving Forest Inventory Small Area Estimates Through Ecological Borrowing and Hierarchical Bayesian Methods	Grayson White
03:15 PM			Small Area Estimation Through FIA's BIGMAP Platform Using Python-Based Geospatial Tools	Christine Blinn
03:30 PM			Using Synthetic Forest Inventory Plots to Approximate k > 1 Nearest-Neighbors Mapping for Accuracy and Operational Considerations	Matt Gregory
03:45 PM			Excelidator: A New FIA Estimation and Data Analysis Tool That Uses Excel Pivot Tables to Generate Standard FIA Summary Reports	Andrew Lister

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Tuesday November 15, 2022 (continued)

Time	Session	Moderator	Title	Speaker
02:30 PM	Forest Ownership I: Methods, Implementation, Emerging Topics, and Landowner Dynamics	Brett Butler, Jesse Caputo	Scaling Up Spatial Analyses: Phase 2 of the FIA Forest Ownership Mapping and Small-Area Estimation Efforts	Vance Harris
02:45 PM			Preliminary Results from the National Woodland Owner Survey in the U.S. Virgin Islands	Kathleen McGinley
03:00 PM			Family Forest Owners' Participation in Carbon Programs and Markets: Initial Findings from the National Woodland Owner Survey	Emma Sass
03:15 PM			Usage of USDA Forest Service National Woodland Owner Survey Data: A Systematic Literature Review	Morgan Bowler
03:30 PM			The FIA National Woodland Owner Survey: Past, Present, and Future	Sarah Butler
02:30 PM	Sample Plot Nonresponse in Forest Inventories: Assessments and Estimation Considerations	James Westfall, Christopher Edgar	Examining Spatial and Temporal Patterns of Nonresponse in the FIA Inventory: Using Remote Sensing Data to Evaluate the Forest Characteristics of Sampled and Nonsampled Plots	Todd Schroeder
02:45 PM			Post-Stratification Process to Reduce Nonresponse Bias Within the Rocky Mountain Research Station-FIA	Jennifer Bakken
03:00 PM			The Importance of Model Assumptions in Nonresponse Analyses	Francis Roesch
03:15 PM			Untangling and Correcting for Nonresponse in FIA Data: Experiences with the Purdue Data Mine	Andrew Lister
03:30 PM			Addressing Nonresponse Bias in Urban Forest Inventories: An Estimation Approach	James Westfall
03:45 PM			Using GEDI and Landsat to Evaluate and Improve Paraguay's National Forest Inventory	Eric Bullock
04:00 PM	FIA 5K Run/Walk/ Bike (Virtual)	Brett Butler	FIA 5K Run/Walk/Bike (Virtual)	
06:00 PM			FIA 5K Virtual Meet Up	

Wednesday, November 16, 2022

Time	Session	Moderator	Title	Speaker
10:30 AM	Plenary	Randall Morin, Susan Crocker	The Future: Mobilizing Women in Forestry to Save the World	Edie Sonne Hall
10:55 AM			Monitoring Old Forests in the Northwest Forest Plan Area	Raymond Davis
11:20 AM			From Monitoring to Mitigation: Advances in Carbon Science and Reporting in the FIA Program	Grant Domke
11:45 AM			Break	
12:15 PM	Applications of Tree-Ring Data to Understand Forest Change	Courtney Giebink, Kelly Heilman	Tree-Ring Data Reject the Leading Edge-Trailing Edge Paradigm for Species Range Change	Margaret Evans
12:30 PM			Tree-Ring Data Reveal the Impacts of Climate Variability and Change on the Health of Navajo Forests	Jaime Yazzie
12:45 PM			Drought and Insect Damage Reduce Aspen Growth in Interior Alaska: Implications for Ecosystem Dynamics in a Warming Climate	Sean Cahoon
01:00 PM			Fusing Tree-Ring and National Forest Inventory Data to Improve Forecasts of Forest Carbon	Kelly Heilman
01:15 PM			Climatic Sensitivities Derived from Tree Rings Improve Predictions of the Forest Vegetation Simulator Growth and Yield Model	Courtney Giebink

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Wednesday, November 16, 2022 (continued)

Time	Session	Moderator	Title	Speaker
12:15 PM	Utility of Forest Inventory Data in Climate Assessments	Matt Russell, Susan Crocker	Forests at the Fringe: Comparing Observed Change to Projected Climate Change Impacts for Five Species in the Pacific Northwest	Karin Kralicek
12:30 PM			Integrating FIA with a New Approach to Make FVS Climate-Aware in the Pacific Northwest	David Diaz
12:45 PM			Tree and Seedling Climate Mismatch: Climate or Sampling?	Erich Dodson
01:00 PM			Climate Change, Tree Demography, and Thermophilization in Western U.S. Forests	Kyle Rosenblad
01:15 PM			Trees as Microclimate Sensors: Inferring Fine-Scale Climate from Forest Inventory Data	Matthew Kling
01:30 PM			Recent and Future Exposure of Forest Land to Drought Across the United States: Toward FIA-Informed Measures of Ecological Drought	Jen Costanza
12:15 PM	Exploring Forest Composition and Health Using FIA's Vegetation and Invasive Plants Datasets	Kathryn Baer, Andy Gray	Estimating Vegetation Percent Cover by Vertical Height Layers in Northern Lower Michigan, USA	Mark Nelson
12:30 PM			Biotic Predictors Improve Species Distribution Models for Invasive Plants in Western U.S. Forests at High but Not Low Spatial Resolutions	Kathryn Baer
12:45 PM			Distribution and Abundance of Invasive Plants in Forests of the Western United States	Andy Gray
01:00 PM			Forest Plant Invasions at the Eastern United States Wildland-Urban Interface	Kevin Potter
01:15 PM			How Invaded Are Hawaiian Forests? Patterns of Non-Native Plants Across Multiple Strata	Kevin Potter
12:15 PM	Remote Sensing I: Incorporating Remote Sensing Techniques with Forest Inventory	Randall Morin, Cara Leitheiser	Fusion of Forest Inventory Data with GEDI for Small-Area Estimation on the OBIWAN Platform	Zhiqiang Yang
12:30 PM			Spaceborne Lidar for Small Area Estimation of Forest Biomass	Paul May
12:45 PM			Use of FIA Data to Assess the Accuracy of Biomass Estimates Based on Data from the Global Ecosystem Dynamics Investigation Space-Based Lidar Mission	Paul Patterson
01:00 PM			Tapping the Nationwide USGS Lidar Data Collection to Inform and Augment Field Measurements	Bob McGaughey
01:15 PM			Using Landsat-Derived Spectral Recovery Metrics to Assess Post-Harvest Recovery Rates in Southeastern Managed Pine Forests	Valerie Thomas
01:30 PM			Utility of Point Clouds for Tree Canopy Cover Estimation	Demetrios Gatziolis
12:15 PM	Applications of Timber Products Output Data	Consuelo Brandeis, James Bentley	Advancing the Development of Delivery Tools to Meet Client Needs: Leveraging TPO to Support National Forest System Planning and Prioritization	Chelsea Pennick McIver
12:30 PM			Analyzing the White Oak Species Group Resource Across the Eastern United States	David Haugen
12:45 PM			Impacts of Pulp and Paper Mill Closures on Sawmills and Other Primary Forest Industry	Rapeepan Kantavichai
01:00 PM			Pacific Coast Forest Carbon: Overview and Regional Results of Carbon in Harvested Wood Products	Glenn Christensen
01:15 PM			User-Friendly Direct-Response Analysis for Diverse Audiences: Coupling TPO Data with Public Databases to Estimate Employment and Wage Ratios	Samuel Scott
01:30 PM			Forest Products Other Than Wood from Trees: What We Can Glean from FIA Data	James Chamberlain
01:45 PM			The Role of Tree Species with Nontimber Forest Products in the Natural Regeneration of Stands in Puerto Rico	Humfredo Marcano-Vega

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Wednesday, November 16, 2022 (continued)

Time	Session	Moderator	Title	Speaker
12:15 PM	Tribal Communities and Natural Resources	Peggy Castillo, Scott Hopton	Using FIA Data to Support Tribal Management Goals for Culturally Important Species and Habitats	Michael Dockry
12:30 PM			The Importance of Tribal Land Management	Brian Bisonette
12:45 PM			The Effects of Timber Allotment in Northern Wisconsin Indigenous Communities	Peggy Castillo
02:00 PM			Break	
02:30 PM			Speed Networking	
03:00 PM	Science Topic Break Out Session I	Christopher Woodall, Lara Murray	FIA and Opportunities in the Nature-Based Climate Solutions Movement	
		Andrew Lister, Tom Brandeis	International Forest Monitoring	
		James Garner	Current FIA Tools	
		Jesse Caputo, Brett Butler	Forest Ownership	
		Jane Terzibashian	Early Career Panel	
03:30 PM	Science Topic Break Out Session II	Kristen Pelz	Old Growth and Old Forests	
		Karen Schleeweis, Randall Morin	Brainstorming on National Science Strategy	
		Erin Berryman	Forest Health Variables: Adapting to Change	
		Christopher Oswalt	Upcoming FIA Tools	

Thursday, November 17, 2022

Time	Session	Moderator	Title	Speaker
10:30 AM	Plenary	Susan Crocker, Randall Morin	Albedo Effects Offset Some U.S. Forest Carbon Storage Benefits	Sean Healey
10:55 AM			A Spin Around the Turntable: How Weyerhaeuser's Carbon Record Is Demonstrating Working Forests and Wood Products Are a Climate Solution	Ara Erickson
11:20 AM			Closing Remarks	Susan Crocker, Randall Morin
11:50 AM			Break	
12:15 PM	Carbon III: Leveraging NFI Data in Support of Nature-Based Climate Solutions	Grant Domke, Courtney Giebink	The Policy and Ecology of Forest-Based Climate Mitigation: Challenges, Needs, and Opportunities	Courtney Giebink
12:30 PM			What Do Data and Models Suggest About the Efficacy of Natural Climate Solutions?	John Coulston
12:45 PM			From Data to Decision Support: Research and Tools Supporting Soil Carbon Management	Luke Nave
01:00 PM			Supporting Nature-Based Climate Solutions with Strategic-Level Forest Inventory	Grant Domke
01:15 PM			Recent Trends in U.S. Forest Relative Density and Dead Wood Resources with Implications for Related Carbon Dynamics	Christopher Woodall
01:30 PM			The Effect of Increasing Atmospheric CO_2 and Shifting Management Paradigms on Aspen Stocking and Height Growth in the Lake States	Michael Carson

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Thursday, November 17, 2022 (continued)

Time	Session	Moderator	Title	Speaker
12:15 PM	Data Quality and Accessibility	Elizabeth Burrill, Mary A. Williams	Accuracy of Whitebark Pine (*Pinus albicaulis*) and Limber Pine (*Pinus flexilis*) Identification by RMRS-FIA Field Crews	Shayla Williams, James Steed
12:30 PM			Data Quality Assessment in RMRS: Improving Analyses and Reporting of Blind Check Data	Rachel Simons
12:45 PM			Development of One Comprehensive Invasive Species List for the RMRS-FIA Footprint: How, When, and Why	Rachel Simons
01:00 PM			Section 508 Compliance: Techniques and Resources for Creating Accessible Content	Ashley Tyler
12:15 PM	Assessing Landscape-Scale Change	Rachel Riemann, Susan Crocker	Distribution of Landscape Characteristics Within Watersheds and Riparian Areas of the Great Lakes Region	Lisa Elliott
12:30 PM			An Iterative Site-Scale Approach to Calibrate and Corroborate Successional Processes Within a Forest Landscape Model	Jacob Fraser
12:45 PM			Forest Dynamics in the United States: An Initial Assessment from the Landscape Change Monitoring System	Sean Healey
01:00 PM			Fifteen-Year Changes in the Landscape Context of FIA Forest Land in the Conterminous United States	Kurt Riitters
01:15 PM			Multiple Uses of FIA Data for Landscape Model Parameterization, Calibration, and Corroboration	Brian Miranda
12:15 PM	Remote Sensing II: Incorporating Remote Sensing Techniques with Forest Inventory	Greg Liknes, Dan Kaisershot	Assessing the Utility of NAIP Photogrammetric Point Clouds for Routinely Updating Canopy Height of Pine Plantations in the Southeastern United States	Alison Ritz
12:30 PM			Analysis of Photogrammetric Point Clouds for Wisconsin, USA	Greg Liknes
12:45 PM			Evaluating the Use of NAIP Digital Aerial Photogrammetric Point Clouds to Improve Operational Forest Inventory Estimates in Mixed Hardwood Forests of the Southeastern United States	Shingo Obata
12:15 PM	Resource Use Monitoring	Ronald Piva, Glenn Christensen	USDA Forest Service Timber Products Output Survey Nonresponse Analysis: Northern and Southern Regions	Marla Markowski-Lindsay
12:30 PM			Understanding Tree Utilization Studies and Utilization Factor Estimation	Dinuka Madhushan Senevirathne
12:45 PM			Linking Tree Utilization Studies and Harvested Plots: A Preliminary Analysis	Consuelo Brandeis
01:00 PM			Recent Estimates and Projections of Maine's Timber Inventory, Forest Carbon Stocks, and Forest Sequestration Rates: 2003–2048	Jereme Frank
01:15 PM			Supply of Wood from America’s Family Forests: Combining Biophysical, Social, and Economic Factors	Brett Butler
02:00 PM			Break	
02:30 PM	Beyond the Basics in Urban FIA: Studies and Datasets Complementary To or Building Upon Current UFIA Data	Kerry Dooley, Katherine Johnson	Urban National Landowner Survey: Results from Baltimore	Dexter Locke
02:45 PM			Nonresponse and Associated Population Characteristics in U.S. Urban Forest Inventories	James Westfall
03:00 PM			Deriving i-Tree Ecosystem Services from FIA Plot Data	Alexis Ellis
03:15 PM			Urban NPP: Baltimore Case Study and Implications for UFIA Growth, Mortality, and Removals	Nancy Falxa Sonti

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Thursday, November 17, 2022 (continued)

Time	Session	Moderator	Title	Speaker
02:30 PM	Forest Inventory in Support of Indigenous Tribal Nations	Jennifer Bakken, Samuel Lambert	White Oak: Using FIA Plot Data to Support Tribal Basket Makers Quest to Find Quality Raw Materials	James Chamberlain
02:45 PM			Research Supporting the Sustainability of Culturally Important Paper Birch Trees (wiigwaasaatigoog) in the Great Lakes	Rachel Riemann, Alexandra Bohman
03:00 PM			Leveraging FIA Data to Evaluate Ecocultural Impacts of Climate Change in the Southwest	Sara Souther
03:15 PM			Using FIA Data to Conserve Large Hardwoods Important to Tribes in the Pacific West	Jonathan Long
02:30 PM	Estimation Methods III	Matt Russell, Scott Hopton	National Volume Estimator Library and Its Usage	Yingfang Wang
02:45 PM			How Do We Assess the Performance of Our Small Area Estimators?	Grayson White
03:00 PM			Comprehensive Review and Evaluation of Whole Stand Volume Yield Models for the Aspen Forest Type in Minnesota	Tyler Gifford
03:15 PM			Challenges of Geospatial Data Fusion in Support of Forest Biomass Estimation	Jonathan Knott
02:30 PM	Forest Ownership II: Methods, Implementation, Emerging Topics, and Landowner Dynamics	Brett Butler, Jesse Caputo	An Assessment of the Sustainability of Family Forests in the USA	Brett Butler
02:45 PM			Trends in U.S. Family Forest Owners' Attitudes, Behaviors, and General Characteristics: 2006–2018	Emma Sass
03:00 PM			Ecological Decoupling and Family Forest Landowners: What Do We Know?	Jesse Caputo
03:15 PM			Modeling Transitions of FIA Landownership Categories	Marla Markowski-Lindsay
03:30 PM			Social Vulnerability and Access to Forest Landowner Assistance	Morgan Bowler
03:45 PM			Wildfire and Family Forest Owners: Initial Findings from the 2018 U.S. National Woodland Owner Survey	Sarah Butler
02:30 PM	Remote Sensing III: Incorporating Remote Sensing Techniques with Forest Inventory	Barry (Ty) Wilson, Dan Kaisershot	State of Maine High Resolution Forest Type and Biomass Mapping Using Multisource Remote Sensing and FIA Plot Data	Kasey Legaard
02:45 PM			BIGMAP and Small-Scale Timber Supply Models: Understanding the Tradeoffs Between Carbon and Timber Market	Bruno Kanieski da Silva
03:00 PM			Plots and Pixels to Maps and Apps: Leveraging BigMap's Information Products for Further Analysis, Modeling, and Decision Support Web Applications	James Sill
03:15 PM			Digital Aerial Photogrammetry Improves Large Tree and Old Forest Mapping	David Bell
03:30 PM			3D Data Products and Forest Inventory: A Conceptual Path Forward for FIA	James Ellenwood

Conference Posters

The following posters were displayed in the online event portal throughout the meeting. Posters were available as searchable images and were accompanied by prerecorded videos (2–3 minutes) describing the work.

Title	Speaker
Timber Products Output Interactive Tools	Jason Cooper
A Regional Look at Grazing Disturbance on Forest Land	Thomas Goff
Analyzing the Impacts of Implementing a Volume-Based Threshold for TPO Sample Inclusion in the North	Ian Kennedy
Mapping Timber Harvest Potential Across TPO's Northern Region	Ian Kennedy
Invasive Plants in Southern Forests: Impact on Fuels and Implication to Fire Behavior	Trisha Markus
Presence of the Invasive Oriental Bittersweet Vine (*Celastrus orbiculatus*) in Relation to Site Moisture Regimes and Time in North Carolina and Virginia	Henry McNab
Developing an Ecology-Focused, New-User Introduction to the Forest Inventory and Analysis (FIA) Database	Bailey McLaughlin
Tracking Wood Imports and Exports in the United States: New Factsheet Added to the One-Click Series	Christopher Oswalt
Ode to the Field	Sjana Schanning
Modeling Shortleaf Pine Plantation Diameter Distributions in the Western Half of the Southeastern United States	Curtis VanderSchaaf
Technological Advancement Substantially Accelerates the Carbon Stored in Harvested Wood Products in Maine, USA	Xinyuan Wei
Estimating Regional Forest Sector Impacts Under Varying Representative Concentration and Shared Socioeconomic Pathways	Jianheng Zhao

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