Forest Ecology and Management 396 (2017) 176–183

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

The lack of adequate quality assurance/quality control data hinders the assessment of potential forest degradation in a national forest inventory

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ARTICLE INFO

Article history:
Received 17 February 2017
Accepted 22 April 2017

Keywords:
Tree quality
Forest degradation
Forest inventory
Quality control
Quality assurance
Repeated measures

ABSTRACT

Hardwood lumber harvested from the temperate broadleaf and mixed broadleaf/conifer forests of the east-central United States is an important economic resource. Forest industry stakeholders in this region have a growing need for accurate, reliable estimates of high-quality wood volume. While lower-graded timber has an increasingly wide array of uses, the forest products sectors in those states would be negatively affected if there is ongoing forest degradation due to the relative loss of higher graded timber. The United States national forest inventory provides data that could answer whether the supply of higher graded timber is decreasing despite an overall increase in merchantable wood volume. To study trends over time, however, one must take into account the partial lack of independence within forest inventory and monitoring datasets with repeated measurements on the same permanent plots and the trees within them. By doing this, we demonstrate that the data show significant decreases in the relative saw-log volume found in higher-graded, commercially valuable hardwood trees in the states of Kentucky and Tennessee from 2001 to 2013, most notably a decrease in the percentage of tree grade 1 saw-log volumes in Kentucky and a decrease in tree grade 2 saw-log volumes in Tennessee. We also identified a potential increase in lower quality (tree grade 4) saw-log volume in both states. These findings would be consistent with indirect and anecdotal evidence of degradation in hardwood resource in portions of the region. However, substantial annual fluctuations in the volume percentages by grade led us to question the validity of those observed trends. Quality assurance and quality control (QA/QC) data collected in conjunction with those tree grade data were not sufficient or consistent enough to allow us to verify whether we are observing real trends or data collection anomalies, thereby compromising our ability to provide important information to land managers and decision makers. The occurrence of hardwood tree grade fluctuations over time illustrates the need for robust QA/QC procedures in national forest inventories. More frequent QA/QC data collection and analysis, field data collection training consistency across regions, and potentially simplifying field measures of tree stem quality could provide more clarity and confidence when assessing the condition of forest resources.

Published by Elsevier B.V.

1. Introduction

The temperate broadleaf and mixed broadleaf/conifer forests of the east-central United States (U.S.) are an important ecological and economic resource. The production of hardwood lumber makes a substantial contribution to these states' economies. In 2011 Kentucky had 213 sawmills and production of 3.15 million cubic meters of hardwood lumber while Tennessee's 244 sawmills produced 3.27 million cubic meters of hardwood lumber (Bentley et al. 2014a, 2014b). Despite high annual production levels and overall trends of increasing sawtimber volume, some analyses (Oswalt 2015; Oswalt and King 2014; Oswalt et al. 2012, 2015) and anecdotal evidence have suggested a progressive degradation in the hardwood saw-log resource in these states. If true, a trend of declining resource quality could indicate forest management shortcomings or large-scale demographic changes in the hardwood forests of these southern states. Such trends have been observed in the past in other southern states; for example, Kelly and Sims (1989) noted a decrease in the amount of higher quality saw-log volume in Mississippi from the late 1970s to the late 1980s amid a statewide increase in merchantable hardwood volume. They attributed the decrease in tree quality to increasing amounts of

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http://dx.doi.org/10.1016/j.foreco.2017.04.036
0378-1127/Published by Elsevier B.V.

rot and other log quality degradation factors; they also noted the negative effects of "the inattention given to replacing harvested trees" (Kelly and Sims, 1989), which might indicate the removal of higher quality trees and the retention of lower quality ones. More recently, Cumbo et al. (2003) and Luppold and Bumgardner (2003) expressed concern about evidence of increasing amounts of low-value, small-diameter timber in the hardwood forests of the eastern United States.

The aforementioned analyses have shown decreasing prevalence of higher quality trees as defined by their tree grade in the national forest inventory data collected annually by the U.S. Forest Service's Forest Inventory and Analysis (FIA) program. Tree grade is a description of the quality of the standing live tree; better grades indicate that greater quantities of clearer lumber can be sawn from the stem. Hardwood tree grade, as used in the FIA program, is defined as the log grade of the 16-foot butt log or the log grade of the best 12-foot section within the 16-foot butt log, whichever is higher. Log grade is based on the specifications for Forest Service standard grades for hardwood factory lumber logs, as described by Rast et al. (1973).

It would seem reasonable, therefore, to use the decrease in the proportion of total volume that is in higher graded trees as estimated by FIA as an indicator of forest degradation. Although forest degradation is commonly used to refer to the loss of carbon storage or sequestration capacity, it is more broadly defined as the reduction in the capacity of a forest to deliver ecosystem services (Miles and Kapos, 2008; Thompson et al., 2013). For this study, we define forest degradation as the loss of higher-quality hardwood sawtimber volume even while total timberland area and total volume are stable or increasing. The in-depth analysis of volume by tree grade required to assess this situation, however, also requires scrutiny and understanding of the methods used in the field to grade a tree. Tree grading is one of the most subjective evaluations made on an FIA plot and requires that field crew members have considerable training and experience before accuracy and repeatability of evaluations are achieved.

To address the question of whether the hardwood resources of Kentucky and Tennessee were being degraded over time, we investigated trends in hardwood tree grade for a subset of high-value timber species in those states. We used as a response variable the proportion of net cubic foot saw-log volume on FIA plots measured from 2001 to 2013. For this examination, we considered different statistical methods to make statistically valid comparisons of means between individual years of annualized forest inventory permanent plot data that were remeasured at regular intervals. We also examined older, periodic forest inventory data to better understand long-term trends in tree grade. Then, we explored the Quality Assurance/Quality Control (QA/QC) data for tree grade collected from 2001 to 2013 to analyze whether field crew members' assessments consistently differed from the assessments of more experienced QA/QC foresters. This final part of the study was meant to help us determine how confident we could be in deciding whether the observed trends were real and providing this information to forest resource stakeholders.

2. Methods

2.1. Study area

The hardwood-dominated forests of Kentucky and Tennessee fall primarily within the Central Hardwoods and Southeastern mixed-forest ecoregions of the U.S. (Bailey, 1983). The oak-hickory forest type is the most common and stands frequently have a significant oak (*Quercus* spp.) species component. Historically these forests were extensively cleared for agriculture, and the remaining forests on less-arable land were selectively harvested. Socioeconomic changes across the region resulted in partial reforestation through both natural and artificial regeneration starting in the first half of the twentieth century. More recently, timberland area continues to slowly increase across the region despite increasing urbanization. Merchantable volume has also increased (Brandeis et al., 2012), as can be seen in Kentucky and Tennessee (Oswalt, 2015; Oswalt and King, 2014; Oswalt et al., 2012).

2.2. Forest inventory and tree grading procedures

The FIA program maintains a permanent plot network across the U.S., associated territories and commonwealths that shares a consistent sampling design, plot layout and field data collection procedures. More information on this program and detailed documentation on its methods and estimation procedures can be found in Bechtold and Patterson (2005). National and regional variations of field data collection procedures, such as the southern regional field manual (U.S. Department of Agriculture Forest Service, 2014), are also available.

There is one permanent, systematically located forest inventory and monitoring plot for every 2428 hectares (5998 acres) of land on the continental U.S. Each of these plots is a cluster of four subplots with a total sampled area of 0.07 ha (one-sixth acre). Where there is forest, all trees with a d.b.h. (diameter at breast height, 1.37 m (4.5 ft) of 12.7 cm (5.0 in.) or greater are identified and measured. Each tree is individually tracked and remeasured at 5-year intervals in Kentucky and Tennessee. Tree height and d.b.h., along with deductions for defect and cull, are used to estimate net tree volume using volume equations detailed in Oswalt and Conner (2011).

Volume of the saw-log portion of the tree is estimated for sawtimber-size trees that meet certain minimum requirements. This is the variable VOLCSNET in the publicly accessible FIA database, FIADB, the calculation of which is described in Oswalt and Conner (2011) and Woudenberg et al. (2010). For southern hardwood timber species, the tree must have a d.b.h. greater than or equal to 27.9 cm (11.0 in.) and the saw-log portion of the main stem must have a merchantable log that is at least 3.6 m (12 ft) long to a minimum 22.9 cm (9 in.) diameter (outside bark) at the top (Oswalt and Conner, 2011). In the southern states, trees that meet these sawtimber size requirements are graded for tree quality. There are five possible tree grades. Grading is judged within the lower 4.9 m (16 ft) of the stem, and the stem section actually graded represents the best 3.6 m (12 ft) of log within that zone. Tree grades 1 through 4 are in descending order of quality. Put in simplified terms, a grade 1 tree is larger than lower-grade trees, with a minimum d.b.h. of 40.6 cm (16 in.), and has more clear wood free of defects within the saw-log. Grades 2, 3 and 4 are of smaller d.b.h. or have less clear wood in the saw-log. Grade 5 is different. Trees of this grade do not meet the requirements for grades 1 through 4 but have a saw-log located somewhere in the tree other than in the butt portion (e.g., upper stem or branch), or have at least two non-contiguous 2.4 m (8 ft) long logs. Additional detailed rules for tree grading can be found in the FIA southern regional field manual (U.S. Department of Agriculture Forest Service, 2014).

2.3. Data queried from the FIA database

We queried the FIADB in August of 2015 to extract data on selected sawtimber-size hardwood trees measured in Kentucky and Tennessee from 2001 to 2013. Annualized inventory data were available for 1999 and 2000, but we chose to start our query with 2001 data due to the limited number of plots measured in the previous 2 years. Both states were on a 5-year remeasurement cycle

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