Exploring alternative methodologies to estimate by-species sawlog volume in the southeastern United States

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ABSTRACT

The Forest Inventory and Analysis (FIA) conducts Timber Products Output (TPO) studies to assess timber resource use across the United States. The TPO studies gather information through surveys of primary wood processing facilities to quantify the utilization of roundwood by geographic location, tree species, and timber product type. However, not all responding mills provide information on tree species utilized. As a result, a portion of the reported volume falls into the "unknown/unclassified" softwood or hardwood category, which account for up to 74% of total hardwood/softwood southern volumes in some cases. In addition, the detailed species in the TPO survey forms do not correspond with those species reported. To correct the issue, Southern TPO allocates the by-species volume by using the species proportion generated from the *Average Annual Harvest Removals* in FIA inventory.

The purposes of this study were to (1) quantify the differences of by-species volumes between the mill survey and current methodology, and (2) evaluate alternative data selection methodologies to estimate species proportions across the southern states for sawlogs and other products. Large differences exist for some tree species, states, and years when comparing the species proportions reported by mills and estimated using the current methodology. All alternative methodologies provided improvements for varying product classes, but none of the alternatives showed enough improvement for sawlogs to justify switching the current methodology. The findings of this study provide insights on the current methodology in producing by-species volumes and can subsequently be applied to evaluate future methods in TPO.

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CHAPTER 1: INTRODUCTION

1.1 Introduction

The mission of the Resource Use Monitoring team in Forest Inventory and Analysis (FIA) program is to monitor utilization of timber resources for national timber market analyses and forest sustainability assessment. Quantitative information includes the amount of roundwood removed by species, ownerships, and products at the county and state levels along with the movement of industrial roundwood. Two main datasets are collected: the mill surveys in the Timber Products Output (TPO) program and the harvest utilization studies. The mill surveys provide information about the total volume produced in each state and year. However, one challenge is missing information of species by product classes in mill surveys because not all mills are able to provide a detailed species list by products. This results in a portion of the total volume in the surveys being classified as “unknown/undifferentiated,” which accounts for up to 74% of total hardwood/softwood southern volumes in some cases. To correct the issue, Southern TPO allocates by-species volume by using the species proportion generated from the *Average Annual Harvest Removals* in FIA inventory. For a given product class and year, the procedure includes: (1) mill reported volumes are aggregated by detailed species group at the FIA unit level for each state. (2) A species proportion of total volume is estimated using FIA *Average Annual Harvest Removals* at the FIA unit level and applied to the corresponding detailed species group aggregated volume. (3) FIA unit level volumes by species are then aggregated to the state level to yield FIA-unit-level by-species volumes.

While this species allocation methodology has been implemented for many years, the current method has yet to be evaluated for accuracy when compared against mill reported detailed species volumes, or compared to other methodologies (e.g., estimates produced from other available FIA datasets under the same procedure). In the preliminary analysis, the estimates of by-species volume produced from the current methodology were generally close to those reported by the mills, but for some cases, the current methodology reported less volume for certain species than those reported by mills. This signals that the current methodology may be failing to capture the volumes reported by mills for some species.

In this study, alternative methods to calculate by-species volumes were investigated to determine if a better methodology exists or if the current methodology is satisfactory enough for use. These alternative methodologies have been explored for the twelve states in the southern United States and for the years 2013, 2015, and 2017, which are the last three years for which the full mill census data are available. The results of this study increased the confidence of methodology the Southern TPO uses, as the group will know they are using the best methodology and by-species estimates available at this time, and they are also valuable for future work that may be done to examine any issues that may arise from the current mill sampling design that is used in place of full mill censuses. In addition, identifying a methodology that accurately captures the by-species volumes as reported by the mills in full census years can then eliminate the need to continue asking mills to report their by-species volumes.

1.2 Objectives

The main objective of this study was to evaluate the accuracy of the current methodology or suggest alternatives that yield volume estimations closer to the true values reported by mills for states within the southeastern United States. Specific objectives include:

1. Comparing the species proportions produced by the current methodology and reported by mills.
2. Exploring alternative data selection methodology to estimate species proportions for hardwoods and softwoods across states and years.
3. Comparing the estimates from the alternative methodologies with those from the current methodology and from the mill surveys.

CHAPTER 2: LITERATURE REVIEW

2.1 History of Timber Production in the southeastern United States

2.1.1 Changes in timber production prior to 2008

The report “the Historical Trends of Timber Product Output in the South” by Johnson et al. (2008) shows the changes in the southern timber industry from 1930s to 2008. The report categorizes industrial timber outputs into different product classes and wood groups, providing a comprehensive overview of the volumes produced in the region.

From 1940 to 2008, the overall output of all wood products increased, albeit at different rates. Sawlog production grew in most states, although there were fluctuations and occasional declines in some regions. Louisiana’s sawlog volumes dropped from 287,620 thousand cubic feet in 1937 to 181,431 in 1996, for example, before rebounding to 343,061 in 2005. Among all product classes, the increase of pulpwood production was significant between the start of monitoring to the time of this report. Pulpwood production increased sometimes by two orders of magnitude, surpassing sawlogs as the dominant product in some states and years. For example, in 1936, South Carolina generated 3,340 thousand cubic feet of pulpwood, and reached peak production in 1995, when the state produced 319,518 thousand cubic feet. This was an increase of 9466.41%. In 2008, the state produced 317,736 thousand cubic feet, which was only a slight decrease from 2005, but an increase from a few years prior in 2001 (269,788 thousand cubic feet).

While year-to-year fluctuations in timber production were observed, the report showed obvious trends over the course of 70 years. The major differences of production among various product classes offer valuable insights into the future of mill operations in the region. Detailed discussion will be given in the following sections by combining with the upcoming recession and pressures of global trade.

2.1.2 Impacts of globalization and other economic factors on timber markets leading up to 2008

During the late 20th century and early 21st century, globalization was one of the biggest challenges facing the industry. Portions of the supply chain for timber products were moving overseas, and the domestic housing market was also beginning to slow. Traditional mass producers took the brunt of these effects, while smaller markets were able to better survive by focusing on customized products and catering to niche sectors (Anderson 2006). As a result, these smaller producers did not face as much competition from their overseas counterparts. In particular, distribution yards, which were not significant players prior to this point in time, became more prominent as these smaller markets began to rely on these distribution yards over unequipped sawmills to source the specific lumber they required for various projects (Buehlmann et al. 2010). This demonstrates a large contrast to the demands of secondary wood products in the 20th century, where the majority of processing to increase value were performed in-house at sawmills.

These changing markets played a role in the quantities and types of products now being produced in by U.S.-based mills. The results of a study conducted by Buehlmann et al. (2010) showed that between 2003 and 2007, total sales volume of hardwood lumber distributors who responded to the study's survey grew by 8 percent, but the average increase of each distributor was not significant. Customer size was also observed to have increased while average order sizes decreased. In addition, changes in sales volumes of major hardwood lumber species reinforced the broader trends observed, as certain species exhibited new higher demands while the previously dominant species' demands decreased. These species changes also highlight the changes in the types of markets now served, with railroad ties significantly increasing, the furniture sector heavily decreasing, and generally more services offered for customizing products with decreased delivery times.

Overall, these changes show that U.S.-based timber companies have shifted their focus to markets where they have advantages over their overseas counterparts, such as catering to more niche fields, more customization, having timber of various certifications, environmental or otherwise, and faster service.

2.1.3 Impacts of the 2008 Recession on the timber industry in the southeastern U.S.

Leading up to 2008, some sectors of the timber industry in the South faced pressures from globalization and international trade, resulting in an overall decrease in the number of mill operations. Despite those challenges, the market for wood products was strong and growing, with exported wood products increasing by $65 million dollars from 2002 to 2008 (Hodges et al. 2011). However, this changed after 2008.

Triggered by a collapse in the U.S. housing market, the "Great Recession" that lasted from December 2007 to June 2009 led to the worst conditions of the U.S.'s housing and wood products market since the Great Depression in the 1930s. As these markets collapsed rapidly and recovered slowly, housing starts dropped to their lowest point in 50 years, lumber production and consumption declined by nearly half, and the timber, forestry, and related sectors lost 1.1 million jobs across the nation (Woodall 2011).

The southeastern region of the United States was severely impacted by this economic downturn, as this region is a particularly significant contributor to the timber industry. The region produced approximately 72% of the nation's annual pulpwood volume and 53% of the nation's sawlog and veneer products (Brandeis et al. 2012). While employment was already declining due to increased globalization and global competition, as observed in the paper manufacturing market, the recession exacerbated these losses in the following years for all wood products sectors. Between 2005 and 2010, furniture manufacturing lost 90,000 jobs, followed by 87,000 jobs lost in wood manufacturing, and 31,000 jobs lost in paper manufacturing. In addition to reducing the number of jobs available in these sectors, the recession also had an impact on employees' salaries and wages, with the decreases of up to 32% (Hodges et al. 2011).

2.2 Changes in sawmills in the southeastern U.S.

2.2.1 General trends experienced among sawmills

Many countries have experienced a decline in sawmills since the 1990s, even though overall production and capacity have increased. In the United States, the number of sawmills had been gradually decreasing since the 1970s, with over 70% of sawmills closing by 2009 (Hodges et al. 2011). However, while new small mills continued to open over time, new larger mills formed as smaller firms began to consolidate, giving them momentum to continue to grow further, such as investing in new technology and leveraging their increased negotiating power (Manchester et al. 2009). Therefore, despite the decrease in the number of operating mills, production did not decrease. This general trend was observed internationally, as counties around the world saw a drop in the number of sawmills, while overall production and capacity increased (Spelter and McKeever 1999, Spelter et al. 2009, Roos et al. 2001, Eastin and Sasatani 2013).

The recession undoubtedly contributed to the decrease in sawmill numbers, as many of the 949 mills lost between 1999 and 2009 had closed since 2007 and output from sawmills and wood preservation industries fell by 40% (Hodges et al., 2011).

2.2.2 Effects of external economic factors on southeastern US hardwood sawmills

Hardwood sawmills in the southeastern United States followed the general trend of sawmill closures occurring during the beginning of the 21st century. Driven by many of the economic factors described, hardwood lumber experienced a decrease in demand, and subsequently led to lower prices.

Between 2004 and 2008, average hardwood lumber sales in the South dropped by 11.5%, based on a survey conducted by Espinoza et al. (2011). In addition, the decrease in the number of operating hardwood sawmills led to changes in the overall distribution of size (based off different measures, e.g., number of employees) for remaining sawmills. Dominating most of the hardwood production, larger sawmills began to supply timber for more construction-related and export markets instead of the furniture markets they formerly supplied to. In contrast, the number of smaller mills increased by finding success through capitalizing on their advantages in other markets. These new markets consisted of those in which more customization is required as well as other declining markets, like housing (Baumgardner et al. undated).

These changes elaborate on previously discussed changes in markets served, as sawmills shifting from direct sales, furniture, and mill work to distribution yard and retailers, which consist of intermediaries in the supply chain line. While pallets remained the dominant consumer of hardwood lumber, railroad ties markets jumped to the third largest direct market during 2008. In addition, order sizes and pool of customers have generally decreased, while mills increased the types of customization services provided and reduced production times. These trends were found both by Espinoza et al. (2011) and Buehlmann et al. (2010). Demand of various hardwood species changed as well; yellow-poplar's sales increased while white oak and cherry sales declined.

It should be noted that given the years and unique the state of the economy that some of these studies focused on, the results produced can demonstrate both a larger pattern observed in hardwood sawmills, but also just a small snapshot of the timber industry during the height of the economic recession. Therefore, some of these highlighted observations made may be only temporary changes from the effects of the recession and may not be the same during the present day.

2.2.3 Effects of external economic factors on southeastern US softwood sawmills

Softwood mills experienced the same general trend of large and small hardwood sawmills; number of small mills declined as consolidation occurred so that large sawmills dominated the market. Sasatani and Zhang (2015) examined the factors related to softwood sawmill closures in the South. The main factors included the size of the plant, whether the plant was a part of a larger firm (multiplant firm), and the timber product produced (Sasatani and Zhang 2015).

Due to their size and production capacity, larger mills had an advantage over their smaller counterparts, making them less likely to shut down. Multiplant firms, in general, have more flexibility in shutting down one or more plants than single-plant sawmills. Because closing the doors for a single-plant sawmill was a much graver decision than a multiplant firm that is merely downsizing, chances of closing for single-plant sawmills were lower than for the multiplant firms. Given the inelastic demand for softwood lumber, strong competition among plants increased the chances of closures as some mills were not able to survive when they could not produce enough to continue operating. The survival rates varied among mills producing different timber products. Price sensitive commodities greatly affected profitability, and therefore survivability.

Lastly, the relationship between supply and demand among competitors plays a role in mill closures. During the recession, it was expected that more mills would close than before. However, a curious relationship of competition between mills that arises from lumber production and demand was also revealed. When sawmills increase their carrying capacity and production during periods of high lumber demand, the risk of surrounding inefficient mills shutting down also increases as they are no longer able to compete. But, when lumber demand drops and these expanded mills reduce their capacity, or even close, competition overall decreases, and the risk of closing for surrounding mills actually decreases. This is particularly noteworthy as it explains why mills did not close at a higher rate during the housing market crash and recession in 2008 compared to the housing boom that preceded it (Sasatani and Zhang 2015).

2.2.4 Changes in Tennessee's mill distributions and size

Due to the combinations of economic pressures described above that impact mill survivability and size, the overall distribution of size for mills across the southern U.S. was expected to have changed dramatically over the past few decades, especially following the economic turmoil of the late 2000s. As size distribution changes, it was also expected that spatial distribution would change as well.

To investigate whether these hypotheses were true, Brandeis and Hodges (2018) compared how mill distribution patterns and mill consumption patterns of active Tennessee sawmills varied in 1999 versus 2011. Prior to 2008 in Tennessee, mills were concentrated in the central area of the state, which had the greatest amount of production due to increases in capacity among existing mills. However, as explained in the above sections, the combination of the recession and other economic changes may have altered these patterns, including the distributions of the mills and their sizes. Another possible economic constraint that could affect mill distributions is the incentive for mills to reduce procurement distances and transportation costs that are associated with timber harvests.

From their analysis, Brandeis and Hodges revealed that the west central unit of Tennessee had many procurement hotspots, resulting in a significant reduction in average procurement distance for both large and small mills for only the central unit, which neighbors the west central unit to the east. However, due to the decreased size of procurement locations in other parts of the state, opening new mills to minimize procurement distances may not have been an economical option, considering the limited harvesting areas available. Furthermore, mill exits were also highest in areas of the state where procurement occurred the least. Overall, the results of their study showed that clustering around procurement locations was observed at both years for large mills; however, new clustering for small mills was only observed in 2011. Given that large mills normally formed from smaller mills consolidating, the new clustering observed by small mills in 2011 could be explained by new small mills opening at locations that minimize procurement distances, while also taking into account the reduced procurement areas.

2.3 Timber Products Output (TPO) Monitoring

2.3.1 History of the TPO

In response to concerns over timber supply after World War II, the USDA Forest Service began monitoring timber production the country's timber production in 1948 through the Timber Products Output (TPO) group within the FIA program. The goal of the program is to provide estimates of timber removals for roundwood products on the county and state level across the US that complement forest inventories taken by the FIA (Bentley and Johnson 2011). In addition, these canvasses track the movement of this timber over interstate and cross-regional areas. Since its inception, there have been many iterations of methodologies used to generate these estimates.

2.3.2 Incorporating data from the FIA annual monitoring program

In TPO, surveys are distributed to all primary wood using mills with known active operations. The surveys gather information such as the timber volumes of each product class, which are then divided into their respective detailed species group and the state county where the procurement originated. However, many issues appear, such as non-response of survey recipients or missing information that was unable to be provided by the mills. This missing information often consisted of mills not being able to differentiate between the detailed species groups of timber produced. These unknown timber volumes are then reported on mill surveys as "Unknown/Undifferentiated" hardwoods or softwoods, which has been shown to account for up to 74% of a state's total softwood sawlog volume and 28% of hardwood sawlog volume in the Southeast.

As a result, the TPO group uses a combination of information obtained from the mill surveys along with by-species allocations produced by the *Average Annual Harvest Removals Volume* estimates under the FIA's annual monitoring program. The application of the FIA data in the TPO report is further described in detail in the Chapter 3. This change removed the "Unknown/Undifferentiated" columns from the TPO report and hoped to sufficiently reallocate these unknown volumes to the correct detailed species group.

2.3.3 Transitioning to an annual TPO monitoring program and report

Prior to 2018, pulp mills were the only mills canvassed annually, while mills producing other timber products were canvassed on a periodic basis, with frequencies varying across the regions of the United States, from two years in the South, three to five years in the North, up to five or seven years in the West (Coulston et al. 2018). As the world becomes increasingly reliant on data to inform economic decisions from various market analyses and projections (e.g., the projection of future timber demand), there was a growing interest in producing annual reports of roundwood production and consumption. Annual reports provide forest economists and other users with more detailed insights on the status of timber markets under economic conditions and other correlated trends of interest.

There are several benefits of a sampling-based approach over the previously used census. Utilizing a population sample reduces the time and effort needed to produce reports, allowing the TPO group being able to generate annual reports with a greater consistent reporting across different geographic regions of the US, while prioritizing higher quality data over larger amounts of data by allowing more time to conduct follow ups from non-response. In addition, a sample allows for surveyors to adjust for the non-response that occurs, as well as calculate a quantifiable sampling error.

To transition from periodic mill censuses to an annual mill sample, Coulston et al. (2018) proposed a stratified simple random sampling (STSI) approach, using sampled-with-certainty and approximately equal strata with mills' number of employees as a measure of size (MOS) due to this approach's simplicity and flexibility over other stratification approaches tested. Following the findings of this study, the recommended sampling approach was implemented, and all volume estimates produced and reported by the TPO after 2017 were calculated using this sampling method.

2.3.4 Justification for improving by-species timber estimates reported by TPO

As users of TPO reports represent a wide range of industries, from those in the timber industry, foresters, and wildlife managers, and the decisions made by these users can have enormous influences on shaping public policies, the economy, and other influential matters, there is a great importance placed on ensuring that the division of timber volume among the detailed species groups reported is as free of error as possible.

Accurate by-species volumes reported by the TPO are important to both the timber industry and wildlife managers not only separately, but the TPO reports help bridge the gap between these two groups when objectives are shared. The management practices of timberlands and the subsequent timber harvesting of timber have profound impacts on not only the surrounding ecosystems and habitats, but on a national and global scale as well. The effects from these management practices straddle the balance of being beneficial in some instances and detrimental in others.

For example, throughout the southeast United States, longleaf pine restoration has been an ongoing endeavor to bring the species back onto the landscape after industrial logging and decreased fire practices during the 1900’s threatened its survival. As some of these longleaf pine forests are being grown for timber harvests, closely monitoring the quantity of standing forests as well as estimating how much timber is being harvested on a yearly basis is crucial to understanding how much of the southeastern United States continues to exist as a habitat for these endangered species. Quantifying each species’ habitable area then aids in identifying correlating trends between the yearly amount of longleaf timber harvested and the success of these wildlife species. The TPO report serves an invaluable asset for monitoring these various species’ abundances.

Accurately quantifying the by-species timber volumes harvested also plays a crucial role in the emerging carbon industry. Whether looking on a small stand scale or on a national, or even international, scale, having reliable by-species estimates for harvested timber that is necessary to determine how much carbon is being sequestered by accounting for how much timber is harvested annually. As the models used to calculate these estimates vary from species to species, these volume estimates are highly dependent on the detailed species group volumes reported by the TPO. Incorrectly quantifying the volumes between, for example, white oaks and yellow poplar can drastically impact the calculations for volume of carbon sequestered. Having incorrect by-species volume allocations can also impact calculations attempting to quantify leakage that occurs from delayed harvests as a part of many carbon offset programs.

These by-species reports also play a large role in understanding the current timber economy and markets. As species often determines the market price of various timber products, having the correct by-species volume allocations reported by the TPO can offer insight to market trends, such as an increase in popularity of close-grained species and decline in prices of oak (Luppold and Bumgardner 2007). TPO reports help form a complete picture of the timber markets when combined with other available information, such as market prices for various timber products.

For reasons such as these those described above, the TPO group maintains a great interest in improving the by-species volume allocation that are reported, to make sure the estimates published are as close to the true value as possible.

CHAPTER 3: MATERIALS AND METHODS

3.1 Study area and mill surveys

This study focused on the twelve southeastern states of the U.S.A. as follows: Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, and Virginia. A map of these states is shown in Figure 1. Both by-species (see Table 1) volume estimates from the raw mill surveys and publicly reported Southern TPO volumes were provided. Until 2018, mill surveys in the southeastern United States were conducted every two years by the TPO group. The TPO group sent out these surveys to all operating primary wood using mills and facilities in the SE states (Coulston et al. 2011); these surveys collected various information, such as species used, location of timber procurement if available, and timber products produced. The two largest issues that accompanied these surveys were non-responses from the mills and missing information; the latter which occurred as a result of the surveyed mills not being provided with such information themselves, such as where the timber was originally harvested or which species were used. After the completed surveys were recollected, the by-species reported volumes can then be used to generate state-wide by-species volume estimates as later described in section 3.3 and modified appropriately to safeguard any sensitive information provided by the mills. In this project, 2013, 2015, and 2017 were selected for which the full mill census data are available.

3.2 Species groups and product classes

Detailed species groups reported in TPO consist of species that are economically important, comprise large portions of the timber industry, or are frequently harvested. The list of species can be found in Table 1. Any species that does not fall into one of these detailed species groups will

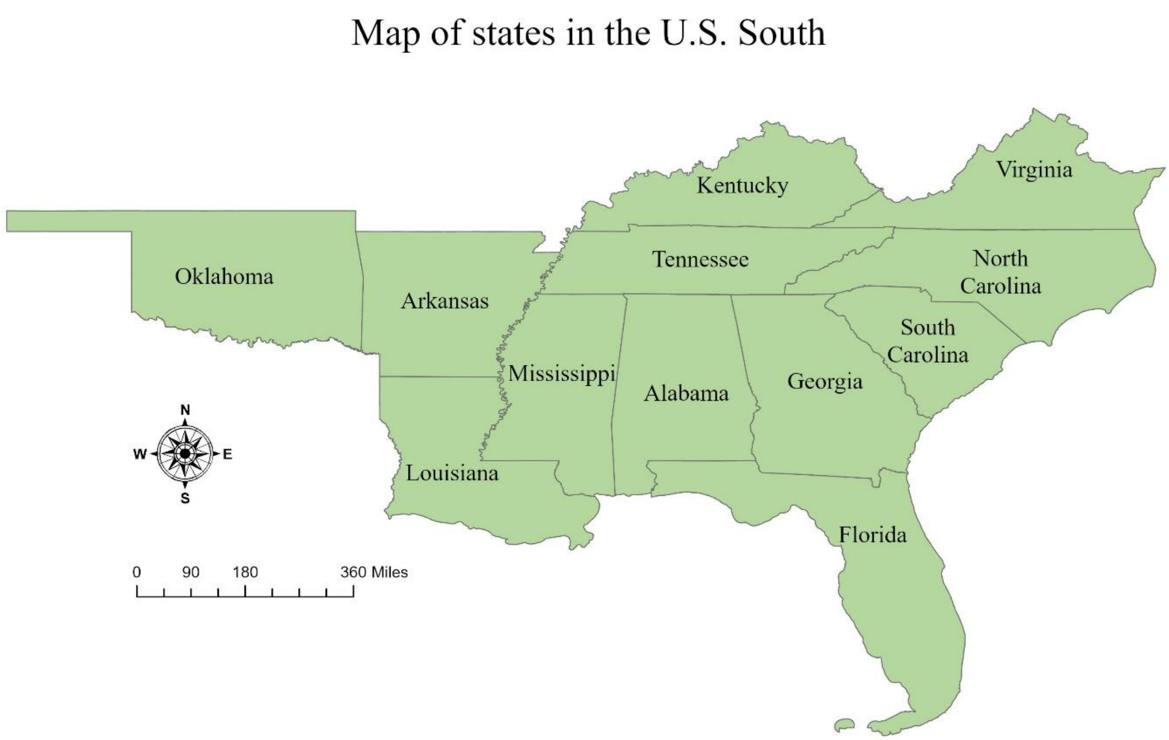

Figure 1: Map of southeastern U.S. states investigated in this study

Table 1: List of detailed species groups reported by the TPO

Softwoods		***Hardwoods***	
Cedars	Sugar pine	Alder	Hard maple
Cypress	White pine	Ash	Soft maple
Douglas-fir	Other pines	Aspen/balsam poplar	Red oak
True firs	Redwood	Basswood	White oak
Hemlock	Spruce	Beech	Sweetgum
Larch	Unknown/ Undifferentiated softwoods	Yellow birch	Sycamore
Jack pine		Other birch	Tupelo/black gum
Loblolly-Shortleaf pine		Paper birch	Black walnut
Lodgepole pine		Black cherry	Yellow-poplar
Longleaf-Slash pine		Cottonwood	Other hardwoods
Ponderosa-Jeffrey pine		Elm	Unknown/ Undifferentiated hardwoods
Red pine		Hickory	

be categorized into “Other pines” for pines or “Other hardwoods” for hardwoods. In the instances that the receiving mills cannot identify or distinguish between the species of the incoming timber, these volumes will be classified under the “Unknown/undifferentiated” hardwood or softwood categories.

In this study, timber products were broken into two groups based on the size of timber required to generate such products: large and small. “Large” timber products included sawlogs, veneer logs, poles, and pilings. “Small” timber products consist of pulpwood, composite, and posts. Explanations of these timber products are listed in Table 2, with definitions pulled from the Forest Service website (https://www.fs.usda.gov/srsfia/php/tpo_2009/tpo_docs/DEFINITIONS.htm).

3.3 Current methodology and TPO-reported volumes

Total volumes reported by mill surveys were further processed by the Southern TPO group to produce publicly available by-species volumes for product classes in all states. Specifically, the TPO’s current methodology for producing by-species volume estimates is given below.

1. Divide *Mill-Reported Volumes* and *Average Annual Harvest Removals Volumes* from the FIA database into FIA unit level volumes
2. Calculate *species percentages* for *Average Annual Harvest Removals* and aggregate the mill-reported volumes on the FIA unit level to produce the *unit-level Mill-Reported Volumes.*
3. Apply *unit-level species percentages* to *unit-level Mill-Reported Volumes*, which yields *unit-level species volumes*
4. Aggregate to state level to yield *state-level species volumes*

Table 2: Definitions of timber products as used by the USFS

Term (Product Code)	Definition
Composite (4)	Roundwood products manufactured into chips, wafers, strands, flakes, shavings or sawdust and then reconstituted into a variety of panel and engineered lumber products.
Posts, poles, and pilings (9, 8, and 7, respectively)	Roundwood products milled (cut, peeled, etc.) into standard sizes (lengths and circumferences) to be put in the ground to provide vertical and lateral support in buildings, foundations, utility lines and fences. May also include nonindustrial (unmilled).
Pulpwood (3)	Roundwood logs, bolts, or chips reduced to individual wood fibers by chemical or mechanical means for the manufacture of a variety of paper and paperboard products.
Sawlogs (1)	a roundwood product, usually 8 feet in length or longer, processed into a variety of sawn products (lumber, cants, blocks, squares, etc.).
Veneer Logs (2)	A roundwood product peeled, sliced, stamped or sawn into a variety of veneer products (sheathing, plywood, panels, containers, sticks, etc.).

Once completed, the following steps were performed individually for each state and year of interest. First, the alternative methodology dataset and raw mill data were divided into the state's respective survey units (see Figure 2) and hardwood/softwood categories. Within each unit and species category, all species volumes in the raw mill data were summed up to produce a unit-level total volume, and the following formula was used on the alternative methodology's dataset to calculate the unit-level by-species group percentages.

$$species\ percentage_i\ (\%) = \frac{species\ volume_i}{\sum_{n=1}^{total\ number\ of\ species} species\ volume_n} * 100$$

These unit-level species percentages were applied to the unit-level total volumes to yield the unit-level species volumes. Then, these unit-level volumes were aggregated across units and by detailed species group to produce state-level species volumes for the alternative methodology. Using the same formula above, state-level by-species group percentages were then calculated with the state-level volumes produced from the alternative methodology and reported volumes from the raw mill data and the Southern TPO report. The state-level by-species group percentages from the alternative methodologies could then be compared to the raw mill's and Southern TPO report's by-species group percentages to assess the alternative methodologies.

Tennessee was used as an example below. There are five FIA units in the state, as seen in Figure 2, and total volumes calculated from the mill surveys and by-species percentages were calculated from the FIA's *Average Annual Harvest Removals Volume* for each unit. Once the by-species volumes were calculated for each of the five units, which is done by multiplying the unit-level by-species percentages to the unit-level total volumes, they were summed to produce the state-level by-species volumes. For simplicity, the by-species volumes given by mills were denoted as "raw mill data", whereas those reported by the TPO groups were denoted as "TPO-

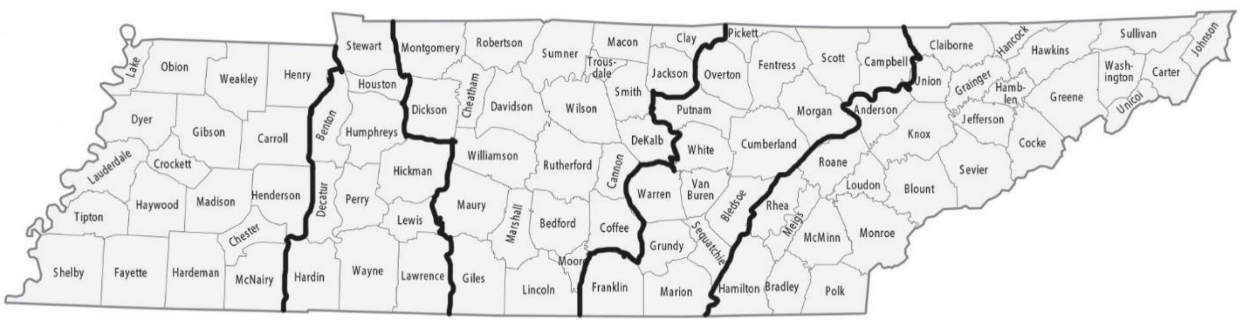

Figure 2: Tennessee's Division of Counties into FIA Units

reported volumes".

3.4 Alternative methodologies and alternative estimate volumes

The current procedure in producing by-species volume was used with the current methodologies. However, in the current method, only the total volumes of *Average Annual Harvest Removals* were applied for all species and product classes, which may be improved by using a subset of data groups. The different timber products classes investigated may come from timber stands of differing sizes. For example, timber products that are considered "large" (such as sawlogs, veneer logs, and poles) will be able to be produced from timber that came from a stand in which the predominant diameter class of trees, based on stocking, will be at least 11 inches in diameter for hardwoods and 9 inches DBH for softwoods. The "small" timber products would, by similar logic, come from trees at least 5 inches in diameter. Therefore, the alternative methodologies investigated centered on using stand class size to generate by-species volume estimates. Additional criteria to further subset these stand size classes into groups are as follows:

- Species group: Hardwoods and softwoods were divided into the two respective groups, as is done by the TPO reports.
- Removals classes: Both *Average Annual Harvest Removals Volume* and *Average Annual Removals Volume* were tested. In theory, either estimate group could provide valid by-species proportions, therefore both groups were investigated to determine if one group provided better estimates than the other.
- Volume classes: Three different volume classes were used, depending on which volume class could be appropriately applied to each of the different timber product groups. These volume classes are *soundbole*, *sawlog*, and *non-sawlog*. How each volume class was used is further described in section 3.5.

Therefore, for both hardwoods and softwoods, all alternative methodologies tested are shown in Table 3. The by-species volumes produced via these alternative methodologies will be further referred to as "alternative estimate volumes".

3.5 Data queries

In this study, volumes divided into stand-class sizes with different volume classes were explored as an alternative method to calculate by-species volume estimates.

All datasets used for the alternative methodologies were obtained from the FIA's EVALIDator program, which is accessible through their website. Within EVALIDator, the following selections were chosen to query the data to calculate the by-species proportions for the alternative methodologies.

1. "Timberland" was selected for the land basis, and two types of removal volumes (i.e., *Average Annual Harvest Removals Volume* and *Average Annual Removals Volume*) were selected for the numerator estimate group on page 1. The description of the two removal volumes types is given in section 3.6.
2. On page 2, "Soundbole volume of trees, in cubic feet" and "Sawlog volume of sawtimber trees, in cubic feet" were the options alternatively selected. The description of the volume classes is given in section 3.7, and "Show all available inventories" was always selected as well.

Table 3: Combinations of alternative methodologies tested

Removal Class	*Volume Class*	*Stand Size Class*	*Timber Product Classes*
Average Annual Harvest Removals Volume	Soundbole	Large	Large
		Medium	Small
	Sawlogs	Large	Large
	Non-sawlog	Medium	Small
Average Annual Removals Volume	Soundbole	Large	Large
		Medium	Small
	Sawlogs	Large	Large
	Non-sawlog	Medium	Small

3. All combinations of the southeastern states and years of interest (2013, 2015, 2017) were selected in step 3.
4. In step 4, "Unit" was selected as the page variable, which divided and reported the FIA volumes on the unit level. "Species" was selected as the row variable, as this reported the volumes for individual species, which were then later aggregated into the detailed species groups used by the TPO via "RPA_SPGRPCD" codes. The column variable chosen was "Stand-size class" to investigate the stand size methodology.

Since the data from EVALIDator lists all individual tree species instead of the detailed species groups used by the TPO as shown in Table 2, all datasets from EVALIDator were required to undergo data manipulation before it was able to be used. The individual species within the alternative datasets were matched with their respective detailed species group code (RPA_SPGRPCD) and the species' respective volumes were aggregated by these codes.

3.6 *Average Annual Harvest Removals* vs *Average Annual Removals*

Average Annual Harvest Removals volume and *Average Annual Removals volume* were tested in this study, as *Average Annual Harvest Removals* are a subset of *Average* A*nnual Removals*. *Harvest Removals* consists of only cut timber, while *Removals* includes the cut timber along with diverted timber, which is volume of land diverted from forest/timberland to non-forest/non-timberland, regardless of if cut or not.

Therefore, while *Average* A*nnual Harvest Removals* may logically produce good by-species volumes as it consists of only cut timber, the diverted timber that is included in the *Average Annual Removals* may yield by-species volumes closer to the raw mill-reported volumes than cut timber alone.

3.7 Soundbole volume class vs Sawlog/Non-sawlog volume classes

Three volume classes were tested: soundbole, sawlogs, and non-sawlogs volumes. The sawlogs volume class selections were used for large-sized product classes (sawlogs, veneer logs, poles, and pilings), as the sawlog volumes should include only timber large enough to produce these products. "Soundbole" volume is total volume reported, without any differentiation between the size of the timber. Therefore, the difference in volume between the soundbole and sawlog volume classes, which will be further referred to as non-saw or non-sawlog volumes, was used for small-sized product classes (pulpwood, composite, mulch, and posts), since this difference in volumes removes the larger sawtimber-sized timber that would not be used to produce these smaller timber products. Unaltered soundbole volumes were used to test on both saw and non-saw product classes, since these volumes can be representative of all timber products investigated.

In place of the *Average Annual Harvest Removals* used in the original methodology, the first alternative procedure applied the soundbole volume class directly queried from EVALIDator. This alternative procedure also used specific size columns, as seen in Table 4, for the two different product class sizes: the "Large" diameter column was selected to generate by-species group volume estimates for previously defined large timber product classes, and for small timber products, the "Medium" diameter column was used to calculate the estimates.

In the second procedure, sawlogs and non-sawlogs volume were used for the large and small timber product groups, respectively. Once again, specific stand size columns were selected depending on the timber products group being investigated. For this alternative procedure, the "Large" stand-size column was selected for the sawlogs/large timber products group combination, and the "Medium" stand-size column was selected for the non-sawlog/medium timber products group combination.

Table 4: Example of data produced by EVALIDator for "Stand-size class"

Species	***Total***	***Large diameter***	***Medium diameter***	***Small diameter***	***Nonstocked***	***Not available***
Total	970,748,986	302,452,834	93,028,524	492,428,923	27,120,697	55,718,008
eastern redcedar	1,895,506	192,391	521,903	395,575	14,784	770,852
shortleaf pine	25,664,234	5,956,240	270,596	18,026,379	23,387	1,387,632
slash pine	26,779,504	2,064,646	4,395,700	19,361,268	0	957,890
spruce pine	3,789,922	1,202,135	301,202	2,192,877	0	93,707
longleaf pine	11,358,741	5,458,974	42,319	4,276,706	0	1,580,743
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3.8 Exploratory Data Analysis

Exploratory data analysis was conducted to examine the characteristics of the data and quantify the TPO-reported and raw mill data by-species percentages were plotted in the form of bar graphs. Differences were visually identified and summarized for each state and year of interest to find trends that existed. While some states demonstrated strong similarities between the Southern TPO and mill-reported volumes, large inconsistencies were observed between the by-species percentages reported by the Southern TPO and mills for certain detailed species groups, which were especially of concern in cases where the methodology currently used by the Southern TPO fails to capture at least the same amount of volume that was reported by the mills.

3.9 Evaluation of methods

The statistical analysis program R was used to manipulate the datasets, as well as produce the volume estimates under the new methodologies. Excel was also used when needed throughout the process to examine and further compile results as needed.

Chi-squared tests were used to determine how well the alternative methodology performed. Since several detailed species groups comprise the majority of the volumes produced in the southeastern states, it was important that the alternative methodologies produced volume estimates similar to those reported by the mills for these detailed species groups. For hardwoods, these major detailed species groups are as yellow-poplar, sweetgum, white oaks, red oaks, hard and soft maples, and hickory. For softwoods, major detailed species groups were white pine, loblolly-shortleaf pine, longleaf-slash pine, and cedars. The by-species group percentages for all these major detailed species group were selected from the alternative estimate volumes, raw mill data, and TPO-reported volumes to perform the chi-squared tests on.

Chi-squared tests were performed on all combinations as listed in Table 3 on major hardwood and softwood species datasets for all states and years of interest. One group of chi-squared tests were performed between the raw mill data and TPO-reported data served as a baseline for how well the current methodology performs to the true, raw data. Another group of chi-squared tests were conducted between the alternative estimate volumes and raw mill data to determine if the alternative methodology captures similar values to those reported by the mills.

These chi-squared tests were performed for all states and years of interest, individually for each timber product class and detailed species group. The p-values produced from these tests were compiled into a table, and to identify how the alternative methodologies performed against the current methodology and compares to the mill reports, the total number of significant p-values were tallied for each class. It should be noted that there were cases in which the p-values produced were *NA*, which were cases in which the raw mill data did not report any timber product volumes for that specific state and year, therefore both the raw mill data, TPO-reported data, and alternative estimate volumes do not have volumes to compare.

3.10 Ranking and comparing alternative methodologies against the current methodology

One means of identifying the best alternative methodology tested was to determine how many improvements and losses within all southeastern states and years occurred for each alternative methodology. These improvements and losses were determined via the chi-squared tests performed. Improvements were defined as cases in which the alternative methodology tested against the mill-reported volumes produced a p-value greater than 0.05 and the current methodology tested against the mill-reported volumes produced a p-value less than 0.05. Likewise, losses were defined as the inverse: p-values for alternative/mill were less than 0.05 and current/mill were greater than 0.05. This allowed us to identify the cases in which the current methodology provided better estimates than the alternative, and vice versa.

For each alternative methodology, a total count of improvement and losses from both hardwoods and softwoods were combined to examine the overall improvement between the wood groups, since the overall methodology will be applied indiscriminately to both groups. For both the soundbole and sawlog/non-sawlog volume classes, hardwood and softwood totals could be summed over timber product classes, along removal classes to overall compare how the *Average Annual Harvest Removals* class performs against *Average Annual Removals* for all product classes along with the different alternative methodologies. The totals from the sawlog/non-sawlog volumes were combined accordingly by the two removals classes; since sawlog volume classes were used for the large timber products and non-sawlog volumes were used for small timber products, it is appropriate to treat them together as one. The alternative methodology with the greatest net gain of improvements was then identified as best alternative methodology.

To compare how the sawlog estimates produced by best alternative methodology (soundbole volume with *Average Annual Removals*) compared to the current methodology, we estimated the average percent difference of all detailed species groups, excluding "Unknown/Undifferentiated" volumes, over the three years and states of interest. To calculate these, we subtracted the mills' reported volumes from the current and alternative methodologies' estimates, divided it by the reported mill volumes, and multiplied by 100.

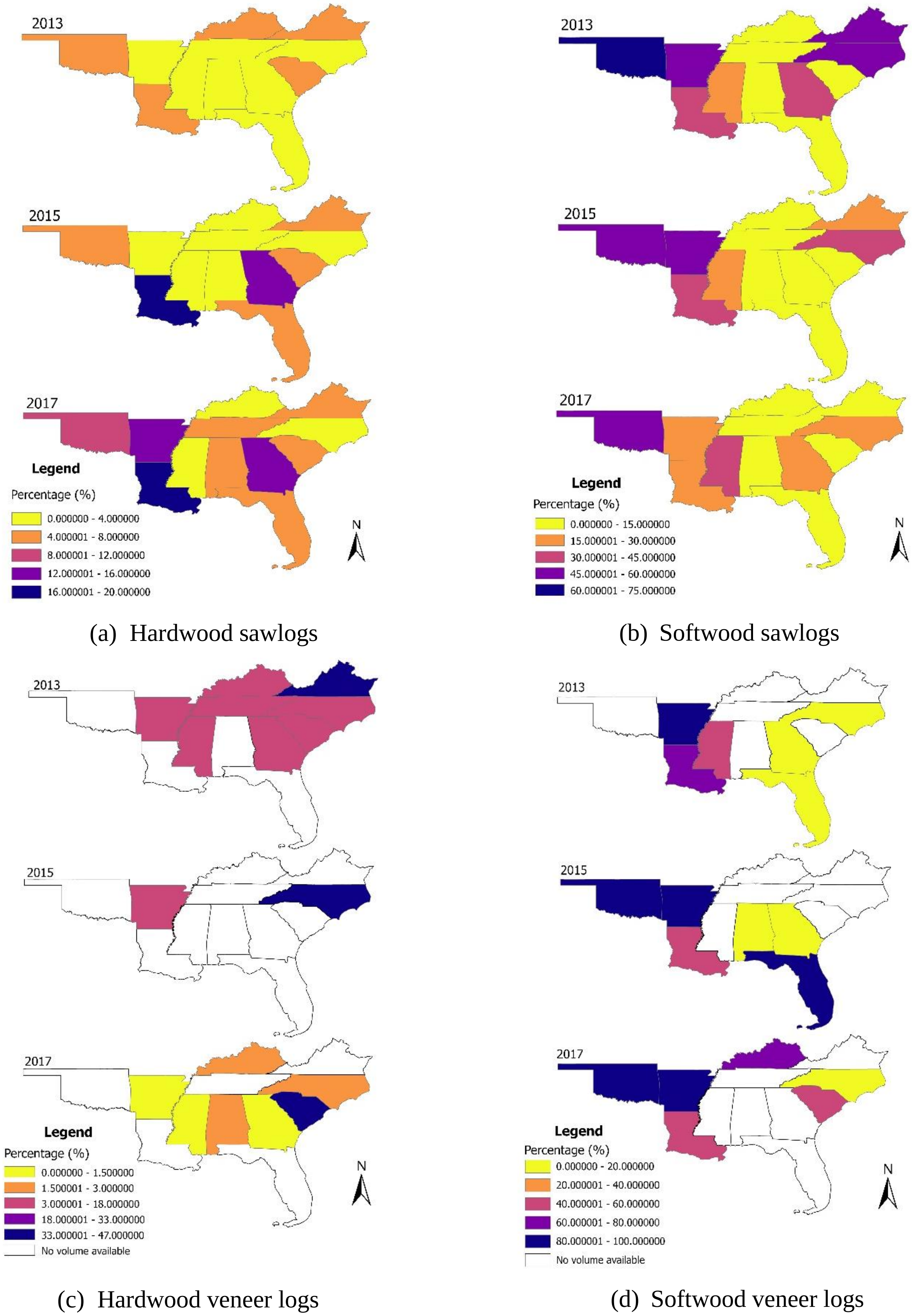
CHAPTER 4: RESULTS AND DISCUSSION

4.1 Exploratory data analysis of current methodology and mill-reported volumes

4.1.1 Spatial patterns of “Unknown/Undifferentiated” volumes

For hardwood sawlogs, the percent volume of the “Unknown/Undifferentiated” group generally increased over the three years as shown in Figure 3(a). All states, except for Kentucky, Mississippi, North Carolina, South Carolina, and Virginia, reported greater percent volumes in 2017 than 2013. Some states exhibited drastic increases; Georgia reported “Unknown/Undifferentiated” volumes that totaled up to 0.039% of the states total volume in 2013, but that percentage increased to 13.430% in 2017.

For softwood sawlogs, the percent volume that is comprised of “Unknown/Undifferentiated” softwoods decreased, as seen in the map on the right in Figure 3. Compared to hardwood sawlogs, percentages of “Unknown/Undifferentiated” volumes were much greater, accounting for up to 75% in Oklahoma, which consistently produced the largest percentages for all three years. Comparing the “Unknown/Undifferentiated” percentages for composites with sawlogs in the southeast United States demonstrates the major difference between sawlogs and all other timber products: sawlogs were the only timber product that states consistently report “Unknown/Undifferentiated” volumes for. For example, for all three years investigated, Tennessee never reported any “Unknown/Undifferentiated” volumes for veneer logs, as shown in Figure 3. Because of these unreported “Unknown/Undifferentiated” volumes from mills for timber products other than sawlogs, when choosing the best alternative methodology to produce these by- species volume estimates, priority should be placed on improving sawlogs while maintaining the volume distributions reported by mills for the remaining product classes.



(a) Hardwood sawlogs

(b) Softwood sawlogs

(c) Hardwood veneer logs

(d) Softwood veneer logs

Figure 3: "Unknown/Undifferentiated" hardwood and softwood sawlog and veneer log volumes as percentages of total state volume for 2013, 2015, and 2017

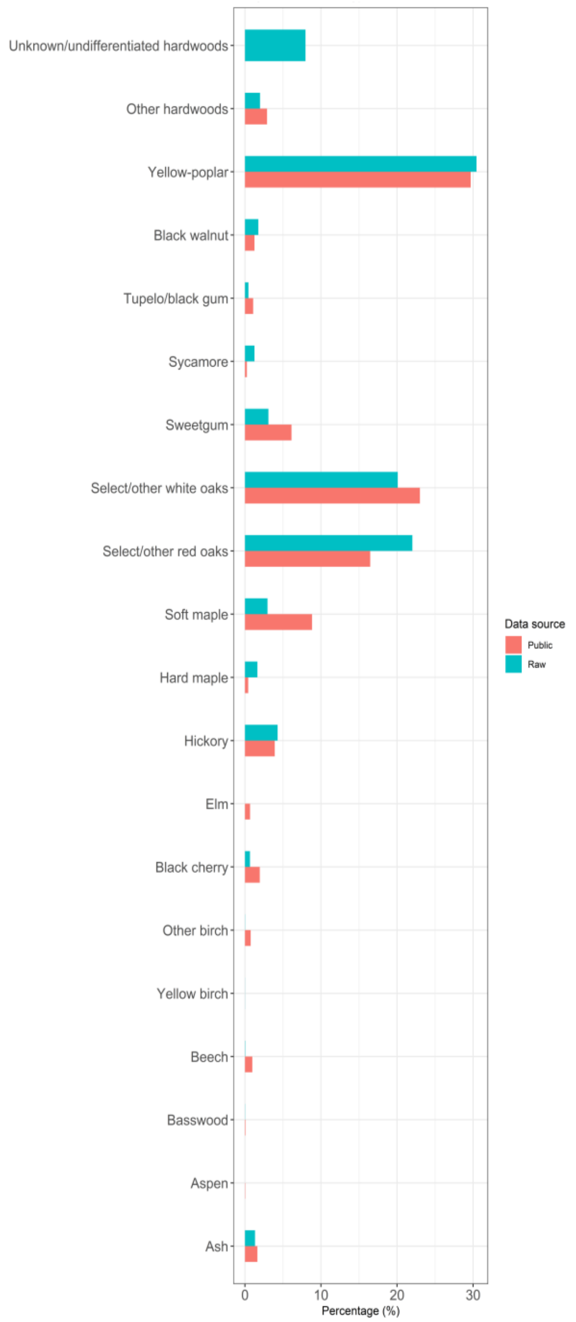
4.1.2 Comparing current methodology by-species estimations against mill-reported volumes

The exploratory analysis assessed the differences in by-species volume allocations between the current methodology estimations and mill-reported values for all states and years of interest. This was done via graphs in which the two datasets were plotted against each other. These cases mostly fell into one of two groups: estimated and reported values showed fairly similar distributions or estimated and reported values obviously that did not follow the similar distributions. Two examples of each group are presented in Figures 4 and 5. Looking at the two examples in which distributions are similar, we can see just how closely the percentages of species allocation are to each other, especially for the major detailed species groups of concern. In almost all the cases, regardless of if the datasets follow similar distributions, the current methodology consistently allocates volumes to species alphabetically listed between Ash to Elm whereas the mills usually do not report volumes for these species. This is to be expected somewhat, as we would not expect mills to closely track these volumes in detail, instead grouping them into the "Unknown/Undifferentiated" categories. However, given how small of a percent these non-dominant species make up out of the total volume, the detailed species groups between Ash to Elm were not the main focus of this study, as explained in the Materials and Methods section.

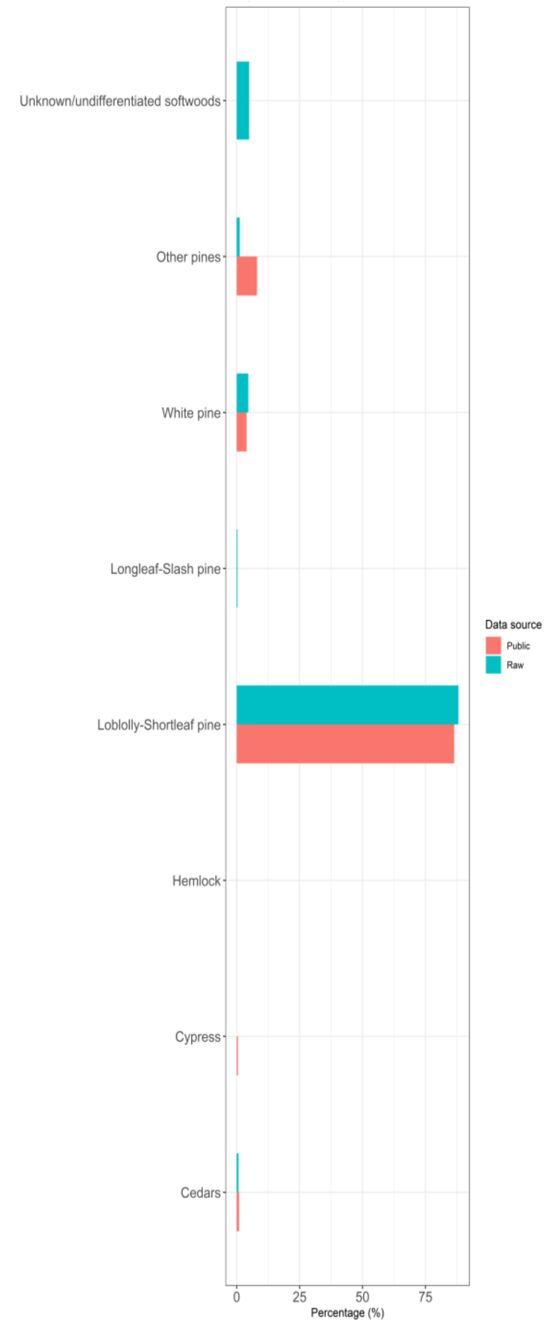
Looking at the two examples given where the by-species distributions from the current methodology and mill reports do not match, we can see how drastically these distributions can differ. With the exception of "Select/other red oaks" in the Florida 2017 hardwoods example, there are no similarities between the by-species allocations. Again, we see that the current methodology allocates volumes to the detailed species groups between Ash and Elm whereas the mills do not.

Whether distributions are similar or not, by-species volume allocations did not match exactly. In fact, cases where the current or alternative methodologies produced larger by-species

Comparison of by-species volume percents between mill reports and current methodology with similar distributions



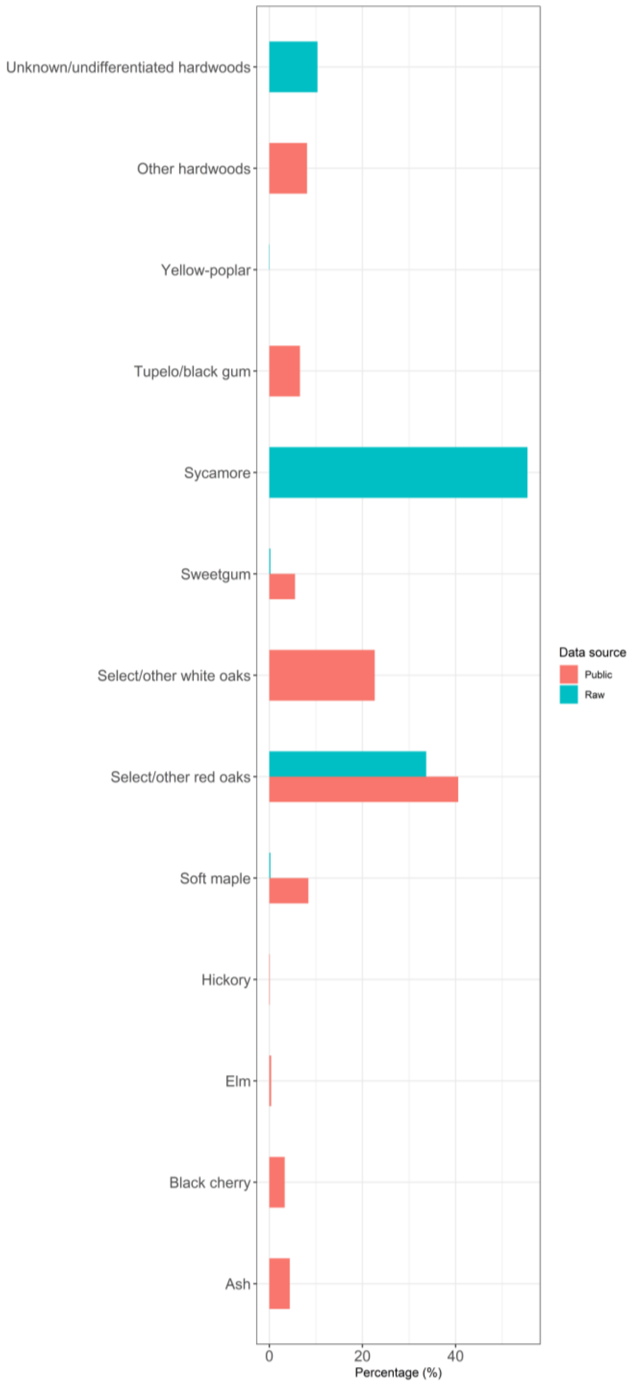
(a) 2017 Virginia hardwoods



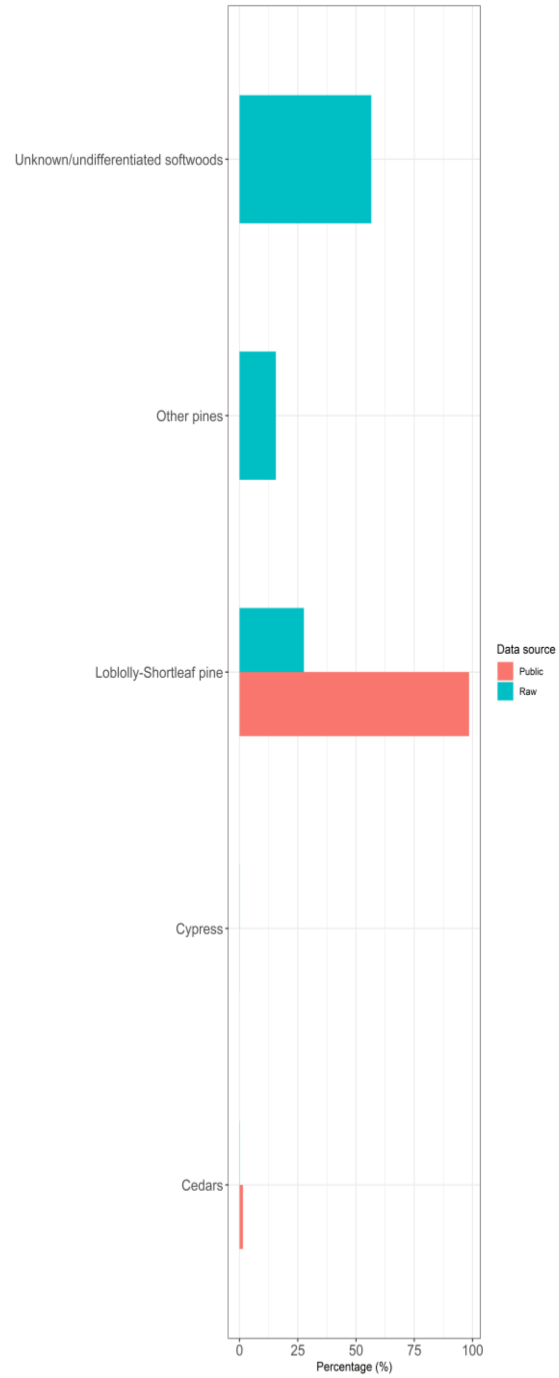
(e) 2015 Virginia softwoods

Figure 4: Bar graphs of by-species volume percentages where allocations of volumes between the current methodology and mill-reported values are similar for sawlogs. "Public" represents the current methodology, and "Raw" represents the mill-reported values.

Comparison of by-species volume percents between mill reports and current methodology with non-similar distributions



(a) 2017 Florida hardwoods



(b) 2015 Arkansas softwoods

Figure 5: Bar graphs of by-species volume percentages where allocations of volumes between the current methodology and mill-reported values are not similar for sawlogs. "Public" represents the current methodology, and "Raw" represents the mill-reported values.

percentages than the mill-reported species percentages were not considered an issue. In cases where the "Unknown/Undifferentiated" volume percentages were large, ideally the current or alternative methodology produced larger species percentages for detailed species groups, as it can be seen as a way that the methodology "reallocated" the unknown mill-reported volumes to a known detailed species group. However, this reallocation does become an issue if the larger volume from the current methodology comes from a reallocation from another detailed species group, and therefore reducing the allocation to the other detailed species group which was identified by the mill as being utilized in a larger proportion. There is also a concern in cases where the current or alternative methodology produced a smaller by-species percentage than what the mills report that it becomes a concern, since this is interpreted as the current or alternative methodology failing to at least encompass the amount of volume that mills have definitively reported for those detailed species groups. Bar charts for other states, species groups and years are available upon request.

For each product class, species group, state and year, the species that produced the maximum difference, either positive or negative, between the current methodology estimates and mill-reported volumes are shown in Tables 5 through 8. Maximum differences demonstrate the species for which the current methodology produced larger estimates than the volumes reported by mills, and how large those differences are. With hardwoods, the species that produced the largest difference the most times varied among product classes. Sweetgum produced the greatest differences the most frequently in sawlogs, with the average volume difference being in the 100,000s of cubic feet. Softwoods exhibited a much easier trend to identify due to fewer detailed species groups than hardwoods, which influences potential differences. The species that most frequently has the greatest volume differences is "Loblolly-Shortleaf pine". These volume

Table 5: Species with maximum percent differences between current methodology estimates and mill-reported values for hardwood sawlogs, by species group, state, and year

Detailed species groups with the largest difference when current methodology estimates larger volumes than the mills reported larger for sawlogs, by species group, state, and year

Product Class	Species Group	State	Year	Species Name	Difference (volume) (current - mill)	Mill report (%)	Current method (%)	Total Volume (GT)	Unknown/ Undifferentiated (volume in GT)
Sawlogs	Hardwood	Alabama	2013	Sweetgum	179,715.97	10.86	21.08	1,758,194.10	1,377.82
			2015	Sweetgum	122,783.36	13.16	19.00	2,102,360.08	7,555.13
			2017	Sweetgum	215,945.93	8.65	20.68	1,794,576.49	126,355.65
		Arkansas	2013	Sweetgum	86,827.76	9.58	14.76	1,678,557.07	72,579.94
			2015	Sweetgum	102,942.62	9.12	15.76	1,550,022.10	57,635.94
			2017	Sweetgum	269,754.08	7.46	19.84	2,179,591.79	518,382.46
		Florida	2013	Tupelo/black gum	11,986.84	0.00	15.89	75,455.08	3,766.80
			2015	Other hardwoods	7,509.97	0.00	12.29	61,092.18	7,423.66
			2017	Select/other white oaks	6,126.09	0.00	22.64	27,063.48	2,800.00
		Georgia	2013	Tupelo/black gum	252,386.64	2.52	15.02	2,018,004.13	1,167.37
			2015	Tupelo/black gum	257,906.33	2.77	14.00	2,296,675.27	494,487.52
			2017	Tupelo/black gum	312,120.39	1.39	14.09	2,457,976.60	436,343.40
		Kentucky	2013	Select/other white oaks	287,065.47	20.42	26.76	4,523,842.96	394,550.55
			2015	Select/other white oaks	155,831.24	22.44	25.83	4,604,925.20	172,946.04
			2017	Other hardwoods	183,757.42	1.37	5.09	4,948,269.25	189,639.02
		Louisiana	2013	Sweetgum	97,799.53	10.83	24.82	699,079.20	63,648.61
			2015	Sweetgum	101,058.08	7.71	23.18	652,894.40	179,737.95
			2017	Other hardwoods	81,217.87	1.94	16.32	564,669.02	140,059.07
		Mississippi	2013	Sweetgum	284,707.16	8.11	22.53	1,973,377.79	69,381.11
			2015	Sweetgum	305,587.73	6.17	23.85	1,728,512.84	80,953.48
			2017	Sweetgum	347,056.77	9.25	24.43	2,286,536.91	66,682.26
		North Carolina	2013	Sweetgum	186,504.07	5.55	11.40	3,186,512.05	65,801.15
			2015	Sweetgum	217,008.85	5.35	12.12	3,207,992.63	69,271.28
			2017	Sweetgum	146,490.82	5.60	10.01	3,318,374.66	63,993.69
		Oklahoma	2013	Select/other white oaks	14,481.46	23.95	38.86	97,160.65	12,109.22
			2015	Select/other white oaks	12,420.85	17.37	30.84	92,220.41	11,421.91
			2017	Other hardwoods	6,926.32	0.93	9.58	79,983.28	10,641.90
		South Carolina	2013	Sweetgum	111,270.48	11.77	26.05	779,230.88	54,407.00
			2015	Sweetgum	114,021.16	12.87	25.72	887,592.67	71,382.84
			2017	Sweetgum	147,252.42	8.53	25.74	855,593.20	67,364.06
		Tennessee	2013	Hickory	127,979.48	7.67	10.52	4,496,918.07	86,484.20
			2015	Other hardwoods	179,482.61	0.52	4.52	4,486,897.85	169,420.79
			2017	Hickory	273,007.47	5.23	10.62	5,057,718.48	540,113.22
		Virginia	2013	Select/other white oaks	250,310.19	17.87	26.42	2,926,219.10	216,474.20
			2015	Select/other white oaks	226,331.04	16.56	24.22	2,955,194.96	250,933.79
			2017	Soft maple	236,370.76	2.96	8.82	4,032,017.64	320,839.00

Table 6: Species with maximum percent differences between current methodology estimates and mill-reported values for softwood sawlogs, by species group, state, and year

Product Class	Species Group	State	Year	Species Name	Difference (volume) (current - mill)	Mill report (%)	Current method (%)	Total Volume (GT)	Unknown/ Undifferentiated (volume in GT)
Sawlogs	Softwood	Alabama	2013	Loblolly-Shortleaf pine	639,904.91	80.38	87.62	8,834,720.59	488,891.44
			2015	Loblolly-Shortleaf pine	714,749.38	82.50	90.30	9,169,521.09	404,274.00
			2017	Loblolly-Shortleaf pine	507,635.25	86.03	91.04	10,132,864.19	499,787.37
		Arkansas	2013	Loblolly-Shortleaf pine	4,619,477.74	25.29	98.51	6,308,628.68	3,713,017.51
			2015	Loblolly-Shortleaf pine	4,496,686.06	27.65	98.51	6,345,457.81	3,589,496.80
			2017	Loblolly-Shortleaf pine	2,686,994.39	68.55	98.59	8,943,821.03	1,789,628.39
		Florida	2013	Longleaf-Slash pine	922,970.29	44.94	66.61	4,258,798.30	374,743.10
			2015	Other pines	587,308.09	0.00	12.48	4,706,232.64	2,425.32
			2017	Other pines	552,304.39	0.00	10.73	5,148,803.84	42,880.83
		Georgia	2013	Loblolly-Shortleaf pine	2,228,713.51	43.50	64.13	10,804,227.18	3,509,098.44
			2015	Loblolly-Shortleaf pine	1,513,726.31	54.73	66.87	12,470,430.30	1,806,938.76
			2017	Longleaf-Slash pine	1,155,686.61	22.68	31.30	13,411,819.56	2,026,947.00
		Kentucky	2013	Other pines	118,102.83	0.03	28.71	411,736.59	3,890.46
			2015	Other pines	28,753.11	0.00	21.32	134,878.64	6,003.17
			2017	Cedars	230,549.49	37.77	72.28	668,053.85	146.97
		Louisiana	2013	Loblolly-Shortleaf pine	2,701,884.66	21.74	87.08	4,135,176.27	1,706,495.42
			2015	Loblolly-Shortleaf pine	2,885,220.62	22.28	88.54	4,354,353.99	1,863,558.60
			2017	Loblolly-Shortleaf pine	779,794.04	74.05	90.53	4,732,383.29	1,187,731.60
		Mississippi	2013	Loblolly-Shortleaf pine	4,348,571.09	27.58	95.51	6,401,484.41	1,486,818.53
			2015	Loblolly-Shortleaf pine	4,477,419.46	36.89	95.09	7,692,855.35	1,632,169.41
			2017	Loblolly-Shortleaf pine	3,338,050.08	61.20	96.02	9,586,231.46	3,151,297.81
		North Carolina	2013	Loblolly-Shortleaf pine	3,168,656.45	37.68	83.38	6,933,722.66	3,564,813.23
			2015	Loblolly-Shortleaf pine	2,561,848.10	51.93	84.81	7,790,874.46	2,972,331.28
			2017	Loblolly-Shortleaf pine	1,115,372.50	72.37	87.37	7,436,079.91	1,641,109.28
		Oklahoma	2013	Loblolly-Shortleaf pine	929,982.76	0.00	94.90	979,994.68	717,607.65
			2015	Loblolly-Shortleaf pine	856,916.77	26.06	94.77	1,247,179.59	717,788.65
			2017	Loblolly-Shortleaf pine	894,286.73	25.83	96.69	1,262,077.69	730,568.45
		South Carolina	2013	Loblolly-Shortleaf pine	442,747.13	86.09	92.84	6,562,317.38	42,764.04
			2015	Other pines	114,887.13	0.02	1.56	7,452,759.89	60,764.04
			2017	Other pines	101,324.25	0.02	1.23	8,407,363.31	50,490.16
		Tennessee	2013	Other pines	23,224.08	0.55	7.79	320,686.09	13,437.07
			2015	Loblolly-Shortleaf pine	16,442.40	60.14	68.55	195,396.78	11,083.70
			2017	Cedars	160,095.34	2.69	31.58	554,225.48	9,117.07
		Virginia	2013	Loblolly-Shortleaf pine	1,254,459.48	34.61	80.40	2,739,359.62	1,286,350.30
			2015	Loblolly-Shortleaf pine	649,717.33	59.91	80.52	3,151,932.89	708,184.44
			2017	Other pines	240,183.99	1.22	8.10	3,489,177.80	172,606.31

Table 7: Species with minimum percent differences between current methodology estimates and mill-reported values for hardwood sawlogs, by species group, state, and year

Detailed species groups with the largest difference when mills reported larger volumes than current methodology estimates for sawlogs, by species group, state, and year

Product Class	Species Group	State	Year	Species Name	Difference (volume) (current - mill)	Mill report (%)	Current method (%)	Total Volume (GT)	Unknown/ Undifferentiated (volume in GT)
Sawlogs	Hardwood	Alabama	2013	Select/other red oaks	-258,343.25	41.99	27.30	1,758,194.10	1,377.82
			2015	Select/other red oaks	-133,797.03	37.21	30.85	2,102,360.08	7,555.13
			2017	Select/other red oaks	-214,221.15	41.45	29.52	1,794,576.49	126,355.65
		Arkansas	2013	Select/other red oaks	-112,334.04	40.04	33.34	1,678,557.07	72,579.94
			2015	Select/other red oaks	-120,988.14	41.89	34.09	1,550,022.10	57,635.94
			2017	Select/other red oaks	-117,095.85	38.28	32.90	2,179,591.79	518,382.46
		Florida	2013	Select/other red oaks	-19,235.43	58.51	33.02	75,455.08	3,766.80
			2015	Select/other red oaks	-11,837.39	57.46	38.08	61,092.18	7,423.66
			2017	Sycamore	-15,001.98	55.43	0.00	27,063.48	2,800.00
		Georgia	2013	Select/other red oaks	-159,804.17	40.04	32.12	2,018,004.13	1,167.37
			2015	Select/other white oaks	-240,666.84	19.70	9.22	2,296,675.27	494,487.52
			2017	Sycamore	-513,486.57	21.02	0.13	2,457,976.60	436,343.40
		Kentucky	2013	Select/other red oaks	-265,266.78	25.70	19.83	4,523,842.96	394,550.55
			2015	Select/other red oaks	-263,936.44	25.57	19.84	4,604,925.20	172,946.04
			2017	Select/other red oaks	-420,956.54	24.46	15.96	4,948,269.25	189,639.02
		Louisiana	2013	Select/other red oaks	-111,384.28	45.64	29.70	699,079.20	63,648.61
			2015	Select/other red oaks	-24,065.98	32.39	28.71	652,894.40	179,737.95
			2017	Select/other white oaks	-44,721.37	15.33	7.41	564,669.02	140,059.07
		Mississippi	2013	Select/other red oaks	-301,917.86	46.79	31.49	1,973,377.79	69,381.11
			2015	Select/other red oaks	-244,416.52	44.66	30.52	1,728,512.84	80,953.48
			2017	Select/other red oaks	-394,783.59	46.79	29.53	2,286,536.91	66,682.26
		North Carolina	2013	Yellow-poplar	-266,182.33	34.98	26.63	3,186,512.05	65,801.15
			2015	Yellow-poplar	-259,500.54	35.33	27.24	3,207,992.63	69,271.28
			2017	Select/other red oaks	-209,299.13	22.71	16.41	3,318,374.66	63,993.69
		Oklahoma	2013	Select/other red oaks	-10,051.20	39.48	29.13	97,160.65	12,109.22
			2015	Select/other red oaks	-5,559.99	38.18	32.15	92,220.41	11,421.91
			2017	Select/other red oaks	-5,624.12	40.68	33.65	79,983.28	10,641.90
		South Carolina	2013	Yellow-poplar	-93,077.33	20.50	8.56	779,230.88	54,407.00
			2015	Yellow-poplar	-92,142.17	19.64	9.25	887,592.67	71,382.84
			2017	Yellow-poplar	-128,967.23	22.35	7.27	855,593.20	67,364.06
		Tennessee	2013	Yellow-poplar	-289,368.15	19.75	13.32	4,496,918.07	86,484.20
			2015	Select/other red oaks	-307,473.62	27.65	20.80	4,486,897.85	169,420.79
			2017	Select/other red oaks	-395,844.22	28.01	20.18	5,057,718.48	540,113.22
		Virginia	2013	Yellow-poplar	-221,782.68	33.73	26.15	2,926,219.10	216,474.20
			2015	Yellow-poplar	-249,544.59	33.86	25.42	2,955,194.96	250,933.79
			2017	Select/other red oaks	-223,446.15	22.01	16.47	4,032,017.64	320,839.00

Table 8: Species with minimum percent differences between current methodology estimates and mill-reported values for softwood sawlogs, by species group, state, and year

Product Class	Species Group	State	Year	Species Name	Difference (volume) (current - mill)	Mill report (%)	Current method (%)	Total Volume (GT)	Unknown/ Undifferentiated (volume in GT)
Sawlogs	Softwood	Alabama	2013	Longleaf-Slash pine	-146,234.09	10.24	8.59	8,834,720.59	488,891.44
			2015	Longleaf-Slash pine	-292,244.47	9.38	6.20	9,169,521.09	404,274.00
			2017	Longleaf-Slash pine	-239,488.76	8.73	6.37	10,132,864.19	499,787.37
		Arkansas	2013	Other pines	-991,525.40	15.72	0.00	6,308,628.68	3,713,017.51
			2015	Other pines	-990,941.15	15.62	0.00	6,345,457.81	3,589,496.80
			2017	Other pines	-990,941.15	11.08	0.00	8,943,821.03	1,789,628.39
		Florida	2013	Loblolly-Shortleaf pine	-947,531.85	42.47	20.22	4,258,798.30	374,743.10
			2015	Longleaf-Slash pine	-416,073.40	78.80	69.96	4,706,232.64	2,425.32
			2017	Loblolly-Shortleaf pine	-279,564.95	21.30	15.87	5,148,803.84	42,880.83
		Georgia	2013	White pine	-11,657.54	0.19	0.08	10,804,227.18	3,509,098.44
			2015	White pine	-14,755.56	0.18	0.07	12,470,430.30	1,806,938.76
			2017	Other pines	-161,702.23	2.21	1.00	13,411,819.56	2,026,947.00
		Kentucky	2013	Loblolly-Shortleaf pine	-199,386.05	78.27	29.85	411,736.59	3,890.46
			2015	Loblolly-Shortleaf pine	-42,538.10	37.97	6.43	134,878.64	6,003.17
			2017	Loblolly-Shortleaf pine	-290,410.07	51.29	7.82	668,053.85	146.97
		Louisiana	2013	Other pines	-1,479,549.53	36.22	0.44	4,135,176.27	1,706,495.42
			2015	Other pines	-1,478,852.44	34.40	0.44	4,354,353.99	1,863,558.60
			2017	Cedars	1,419.98	0.00	0.03	4,732,383.29	1,187,731.60
		Mississippi	2013	Other pines	-2,869,754.11	45.33	0.50	6,401,484.41	1,486,818.53
			2015	Other pines	-2,866,086.47	37.72	0.46	7,692,855.35	1,632,169.41
			2017	Longleaf-Slash pine	-233,421.74	5.56	3.12	9,586,231.46	3,151,297.81
		North Carolina	2013	Longleaf-Slash pine	-216,282.90	5.30	2.18	6,933,722.66	3,564,813.23
			2015	Longleaf-Slash pine	-171,514.86	4.64	2.44	7,790,874.46	2,972,331.28
			2017	White pine	-57,939.56	4.03	3.25	7,436,079.91	1,641,109.28
		Oklahoma	2013	Other pines	-202,963.85	20.71	0.00	979,994.68	717,607.65
			2015	Other pines	-202,963.85	16.27	0.00	1,247,179.59	717,788.65
			2017	Other pines	-202,963.85	16.08	0.00	1,262,077.69	730,568.45
		South Carolina	2013	Longleaf-Slash pine	-564,453.44	12.65	4.05	6,562,317.38	42,764.04
			2015	Longleaf-Slash pine	-189,986.78	6.75	4.20	7,452,759.89	60,764.04
			2017	Longleaf-Slash pine	-176,546.90	5.98	3.88	8,407,363.31	50,490.16
		Tennessee	2013	White pine	-14,266.54	8.57	4.13	320,686.09	13,437.07
			2015	White pine	-20,086.25	14.59	4.31	195,396.78	11,083.70
			2017	Loblolly-Shortleaf pine	-219,301.46	89.87	50.30	554,225.48	9,117.07
		Virginia	2013	Longleaf-Slash pine	-321,694.40	11.74	0.00	2,739,359.62	1,286,350.30
			2015	Longleaf-Slash pine	-311,873.19	9.89	0.00	3,151,932.89	708,184.44
			2017	Loblolly-Shortleaf pine	-57,837.92	88.10	86.45	3,489,177.80	172,606.31

differences ranged from a few thousand cubic feet up to millions of cubic feet.

For some of these cases, there was a reported “Unknown/Undifferentiated” volume large enough to allow these maximum differences to be considered reallocations of these unknown volumes, although we cannot know if these reallocations are correct. In situations where the “Unknown/Undifferentiated” volumes were reported to be zero cubic feet, these differences were viewed as ways in which the current methodology were not producing accurate volumes, as these estimates did not match those reported by mills.

Tables with the absolute minimum differences revealed the species in which the mill reported volume was larger than the current methodology’s by-species estimate. Similar to the maximum differences, these minimum differences highlight the cases in which the current methodology was failing, as the current methodology is not producing estimates that encompass at least the same amount of volume as the mill are reporting. Many of these absolute minimum differences occurred specifically from instances in which the mills report some volume whereas the current methodology does not allocate any volume to that species.

For the minimum differences, hardwoods again exhibited variation in the species which produced the most minimum differences. For sawlogs, “Select/other red oaks” had the highest tally of minimum differences, with an average difference being around -200,000 cubic feet. For softwoods, “Longleaf-Slash pine” had the most tallies for sawlogs. The values of minimum differences can range from approximately -3,000,000 cubic feet and 2,500 cubic feet. This range reveals that there were a few cases in which the minimum difference is a positive value, such as Louisiana 2017 in softwood sawlogs.

Therefore, the current methodology could be producing valid estimates for cases like these, as all the by-species estimates produced by the current methodology are greater than the volumes reported by the mill. This suggests that "Unknown/Undifferentiated" volumes are either being correctly reallocated to the respective by-species group, or the current methodology's estimates are at least encompassing the by-species volumes reported by mills.

One factor that could be limiting the performance of this current methodology as well is that while the TPO reports are produced as point estimates, as the volumes estimates collected via mill surveys are only representative of that year. The *Average Annual Harvest Removals* datasets from the FIA database are average estimates over the period of time in which FIA permanent plots are monitored; in the South, as plots are regularly monitored on a 5–7 year basis, depending on the state, these estimates are the 5-7 year averages, versus one-year point estimates.

4.2 Identifying the best alternative methodology

4.2.1 Ranking alternative methodologies based off overall number of improvements

Using the methods described for ranking the alternative methodologies tested, *Average Annual Removals* removal class with soundbole volume produced the greatest number of improvements, with a total gain of 8 improvements. This methodology is referenced as the "best alternative methodology" throughout the rest of this study. Under *Average Annual Harvest Removals* removal class and soundbole volumes alternative methodology, there was a net gain of 5 improvements, ranking this combination as the second-best alternative methodology tested. The remaining two alternative methodologies tests, sawlog/non-sawlog volumes with both *Average Annual Harvest Removals* and *Average Annual Removals* removal classes, both yielded a net gain of 3 improvements. The net gains and losses of large and small hardwoods and softwoods for all alternative methodologies tested are shown in Tables 9 and 10.

4.2.2 Identifying improved cases and losses in alternative methodologies by product class

For this best alternative methodology, we investigated how many improvements and losses occurred for individual product classes. This is important because while the total counts of improvements versus losses described in the previous section allows us to see which methodology produces the most improvements overall, we are unable to use these counts to identify which alternative methodology produced the most improvements for sawlogs.

Under the alternative methodology with the most overall improvements, which uses soundbole volume and *Average Annual Removals*, large timber had 13 improvements and 11 losses, while small timber had 9 improved cases and 3 losses. Surprisingly, for large timber products under this alternative methodology, all 11 losses occurred for sawlogs, with only two of the 13 improvements coming from sawlogs. The remaining improvements came from poles and veneer logs, 6 and 5 cases, respectively. These results are summarized as shown in Table 11. Considering how dominant sawlogs are as a timber product is, this loss of 11 sawlog cases is significant. While one goal of this study is to identify the overall best alternative methodology to estimate by-species volumes, the main emphasis is placed on improving sawlog volume estimations.

Therefore, we tallied sawlog improvements and losses under the other methodologies tested to determine if one of the alternative methodologies provided significant improvements, specifically for sawlogs. The second-best overall methodology tested, which is soundbole volume and *Average Annual Harvest Removals*, had only improved one sawlog case, but lost eight other cases, which is similar behavior to the best alternative methodology. Although using saw/non-sawlog volume alternatives did not perform well overall for all product classes, the alternative

Table 9: Number of cases in which alternative methodology performs better than the current methodology for soundbole volume.

Soundbole	**Lg. Hardwoods**	**Lg. Softwoods**	**Total**	**Sm. Hardwoods**	**Sm. Softwoods**	**Total**	**Total across product classes**
Average Annual Harvest Removals	4	1	**5**	1	-1	**0**	***5***
Average Annual Removals	3	2	**5**	2	1	**3**	***8***

Table 10: Number of cases in which alternative methodology performs better than the current methodology for sawlog/non-sawlog volume combination.

	Sawlog			**Non-sawlog**			
	Lg. Hardwoods	**Lg. Softwoods**	**Total**	**Sm. Hardwoods**	**Sm. Softwoods**	**Total**	**Total across product classes**
Average Annual Harvest Removals	-1	1	**0**	0	3	**3**	***3***
Average Annual Removals	2	1	**3**	-1	1	**0**	***3***

Table 11: Improvements and losses by product classes for soundbole/Average Annual Removals methodology

Large Timber		
	13 improvements	11 losses
Pole	6	
Veneer Logs	5	
Sawlogs	2	11

Small Timber		
	9 improvements	3 losses
Composites	8	3
Posts	1	

methodology under which sawlogs exhibited the most improvement was with the saw/non-sawlog volume with *Average Annual Harvest Removals*. However, under this methodology, there was only a gain of two improved saw log cases, and it can be argued that this is not a significant enough gain of improvements to offset the limited improvements of this methodology overall for all timber product classes.

As for small timber products, under the alternative methodology with the most improvements, composites were the most improved (see Table 11). This exceptional improvement is not limited to this one alternative methodology though; under all the new methodologies tested, composites showed a considerable number of improvements. It was often the timber product with the most improvements overall, although this was also the small timber product with the most losses.

However, these losses were only a small fraction of total improvements for each alternative methodology. Other timber products may already have sufficient estimates compared with mill-reported values, and alternatives produced equally sufficient estimates, so these products did not experience any improvements or losses.

4.3 Overall sawlogs volume estimation differences between current and alternative methodologies against mill-reported volumes

Tables 12 and 13 show the average percent differences between the best alternative methodology vs mill-reported volumes and current methodology vs mill-reported volumes for all detailed species groups and over all three years investigated for both hardwood and softwood sawlogs. Looking at hardwood sawlogs, the alternative methodology, on average, produced larger percent differences in volume than the current methodology compared to volumes reported by

Table 12: Average species percent differences over 2013, 2015, 2017, comparing the current and best alternative methodology against mill-reported volumes for all detailed species groups of hardwood sawlogs

State	Best Alternative Methodology vs Mill Reported Volumes (% Difference)	Current Methodology vs Mill Reported Volumes (% Difference)
Alabama	219.60	37.14
Arkansas	152.44	36.97
Florida	2016.04	414.05
Georgia	207.29	87.85
Kentucky	116.57	9.17
Louisiana	823.03	289.49
Mississippi	291.63	110.07
North Carolina	130.42	4.30
Oklahoma	34.61	-21.44
South Carolina	92.81	-7.35
Tennessee	123.69	12.70
Virginia	89.76	11.65

Table 13: Average species percent differences over 2013, 2015, 2017, comparing the current and best alternative methodology against mill-reported volumes for all detailed species groups of softwood sawlogs

State	Best Alternative Methodology vs Mill Reported Volumes (% Difference)	Current Methodology vs Mill Reported Volumes (% Difference)
Alabama	984.37	321.18
Arkansas	1021.90	738.35
Florida	1499.93	561.50
Georgia	361.70	474.47
Kentucky	16.71	12.42
Louisiana	1066.92	548.56
Mississippi	859.34	603.39
North Carolina	901.65	322.39
Oklahoma	1807.87	2507.55
South Carolina	19651.61	8973.26
Tennessee	340.84	81.01
Virginia	450.16	373.95

mills. The alternative methodology's average percent differences ranged from 34.71% to 2016.04%. Current methodology vs mill-reported volume average percent difference ranged from -24.44% to 414.05%. The current methodology estimated smaller volumes averages than the mill-reported volumes for two states: Oklahoma and South Carolina.

For softwood sawlogs, the best alternative methodology tested also produced larger average volumes than the current methodology compared to mill-reported volumes, but the current methodology on average did not produce smaller volumes than the mills reported for any state. The average percent differences for alternative methodology vs mill-reported volumes ranged from 16.71% to 19,651.61%. For the average percent differences between the current methodology and mill-reported volumes, the range was from 12.42% to 8973.26%.

While overall, it appears that the best alternative methodology produced larger average percent differences than the current methodology when compared to the mill-reported volumes, which shows that, on average, the best alternative methodology better encompassed the volumes reported by mills than the current methodology did, these average percent differences could be greatly influenced by one species with an extremely high percent difference. Further investigation showed that one example is cedars in South Carolina; the alternative methodology produced an average percent difference of 64,434%, with a volume estimate of 28,278.957 mcf, while the current methodology estimated a volume of 22,085.95 mcf. Relative to these large volumes, mills only reported 43.82 mcf, which shows how such a large percent difference was produced. An outlier of this magnitude may skew the average of the state to a value much higher than if not included. With this taken into account, if looking on a year-by-year basis or species-by-species case, the alternative methodology estimates would not yield as large of average percent differences against the mill-reported volumes and closer to the ranges of average percent differences produced from the current methodology.

Taking all of these considerations into account, given that the best alternative methodology produces greater average percent differences for hardwood sawlogs and relatively comparable differences for softwood sawlogs, there is not strong evidence that the best alternative methodology performs better than the current methodology.

CHAPTER 5: CONCLUSION

The current methodology used by the Southern TPO group to calculate by-species volume estimates was shown to have mixed results when compared to by-species volumes reported by mills. While the current methodology produced similar by-species volume allocations to what is reported by mills for approximately half of the cases investigated in this study, the remaining cases' by-species volume estimates calculated from the current methodology does not closely match the volumes reported by mills, and the difference in distributions is clear.

Even within the cases where the current methodology and mill-reported volumes shared similar distributions, other issues still occurred, as there were many instances where the mill-reported volumes for a particular detailed species group were greater than the estimates generated by the current methodology for that same detailed species group. The current methodology often allocated volumes for "non-major detailed species groups" while the mill did not allocate any volumes for these same species, but the mills often reported larger volumes than the current methodology allocated for the major detailed species groups, where the majority of each cases' volumes were concentrated, and as such, the emphasis of the accuracy of the current methodology was focused.

No alternative methodology tested significantly outperformed the Southern TPO's current methodology used to calculate by-species volume estimates for sawlogs. All alternatives showed improvements for varying product classes, but none of the alternatives showed enough improvement for sawlogs to justify switching the current methodology with one investigated.

In addition to sawlogs, under both removal classes and using soundbole volume, we found a surprising number of improvements for volume estimates of composites. It is valuable information to note when improving composite estimates is needed.

Improving the accuracy of by-species volume allocations reported by the Southern TPO continues to be a goal to provide TPO users with the most accurate volume estimates available. Notably, only a small number of possible alternative methodologies were tested in this study. Many other datasets exist in the FIA database that have a logical basis to use as an alternative methodology for calculating these by-species timber estimates. The data can come from different removal classes, stand, or tree variables available within the FIA database. In addition, another dataset produced by the TPO group, the mill utilization report, was considered by not investigated in this study, and may also be a viable alternative to using a dataset of interval estimates from the FIA database, like *Average Annual Harvest Removals* or *Average Annual Removals*. If other possible datasets are identified, they may be investigated in the future as viable alternative methodologies.

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VITA

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