RESEARCH ARTICLE

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Structural Changes in the Growing Stock of Important Tree Species Groups in the Central Hardwood Region

William G. Luppold and Matthew S. Bumgardner

Increasing hardwood growing stock volume in the eastern United States from the 1950s to the 1990s was led by increases in poletimber volume. In the current century, volumetric growth has become concentrated in larger trees at least 17 in. dbh (≥17 in.). In the Central Hardwood region, the volume of such trees now exceeds poletimber volume by 75%. In this paper, we examine proportional and cubic volume increases of trees ≥17 in. across major species groups in the Central Hardwood region. In 2012, at least 40% of the volume of select white and red oaks, other red oaks, and yellow-poplar was in trees ≥17 in. While hard maple and hickory had less than 25% of their volume in this size class. In the short run, these changes will benefit hardwood industries because larger trees are more economical to harvest and process. In the long run, there could be challenges as larger-diameter trees are harvested or die without a similar timber base emerging in their absence.

Keywords: hardwood resource, hardwood structure, oak depletion

The hardwood timber base of the eastern United States is vital to the numerous industries that utilize it, with lumber, plywood, and veneer manufacturers being economically the most important. Since 1953, eastern hardwood growing stock has been steadily increasing (Oswalt et al. 2014). As shown in Figure 1, this increase was initially led by increasing volumes of poletimber (trees with 5 to 10.9 in. dbh). After 1987, a structural shift in the diameter of growing stock started to occur as poletimber transitioned to mid-size trees (11 to 16.9 in. dbh) and mid-size trees transitioned to large trees 17 in. and greater dbh (trees ≥17 in.) through ingrowth. Total poletimber volume remained relatively constant between 1987 and 1997 while the volume of mid-size trees and trees ≥17 in. continued to increase. The diameter structure of the eastern hardwood timber base continued to change in the current century, and by 2012, the volume of growing stock in both mid-size trees and trees ≥17 in. exceeded that of poletimber.

In the coming decade, the increased number of hardwood trees ≥17 in. will be beneficial to the industries that utilize this resource because larger logs require shorter processing time and normally provide greater yields of higher value material (Rast 1974, Hanks et al. 1980). Still, there could be long-term economic and ecological issues associated with a maturing hardwood timber base including higher mortality, slower growth rates of surviving trees, and changes in forest composition. For example, species composition has been cited as the most important factor determining the output of benefits from Appalachian forests (Miller and Kochenderfer 1998).

Two of the most important geographic areas of the eastern United States for the primary hardwood processing industries are the East Central and West Central Hardwood regions (Luppold and Pugh 2016), which when combined form the Central Hardwood region. This region is composed of eight states: Illinois, Indiana, Iowa, Kentucky, Missouri, Ohio, Tennessee, and West Virginia. These states contained 29% of the eastern hardwood growing stock (Miles 2018) and produced 35% of the eastern hardwood lumber manufactured in 2008, the last year state-level data was available (US Census Bureau 2009).

An examination of Figure 2 indicates that mid-size tree volume had already exceeded that of poletimber in 1989 in the Central Hardwood region (Miles 2018), which is temporally comparable to the 1987 estimates in Figure 1 for the entire eastern United States. By 2012, the volume of growing stock in trees ≥17 in. in the Central Hardwood region exceeded that of poletimber by 75%. Have these shifts been similar or dissimilar across species groups, and what are the implications of these shifts?

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Affiliations: *William G. Luppold (wluppold@fs.fed.us), USDA Forest Service, Northern Research Station, Princeton, WV. Matthew S. Bumgardner (mbumgardner@fs.fed.us), USDA Forest Service, Northern Research Station, Delaware, OH.*

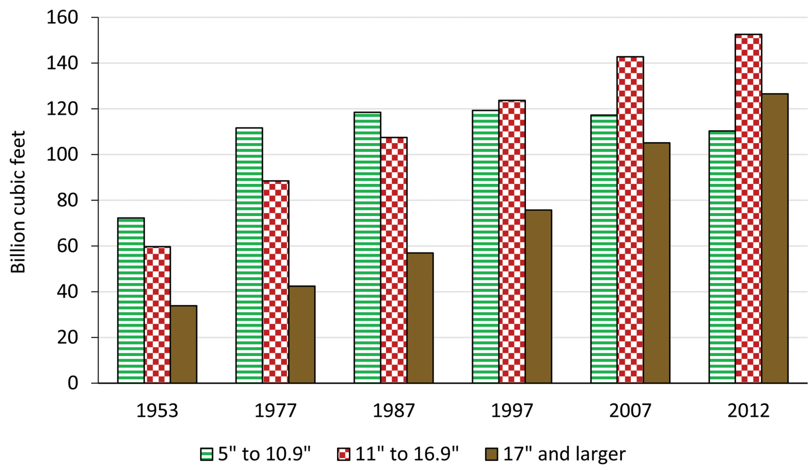

Figure 1. Eastern hardwood growing stock volume 1953, 1977, 1987, 1997, 2007, and 2012 by major size class (developed from Oswalt et al. 2014).

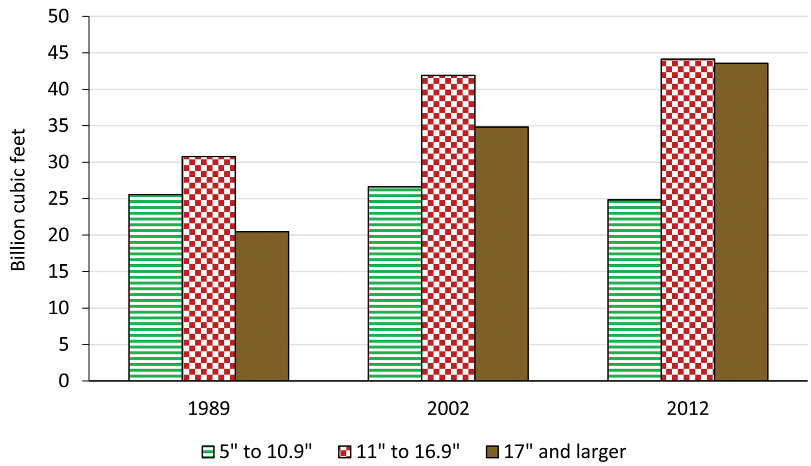

Figure 2. Volume of growing stock on timberland in the Central Hardwood region in 1989, 2002, and 2012 by major size class (developed from Miles 2018).

Objectives

In this paper, we examined changes in hardwood growing stock volume in the Central Hardwood region for important species groups since the late 1980s by three size classes: poletimber, mid-size trees, and trees ≥17 in. We then examined net changes in growing stock volume by species group and size class prior to and after 2002, with an emphasis on changes that have occurred since 2002. We conclude with a discussion of some of the factors driving these changes and the potential implications for utilization and future research.

Methods

This study utilized data collected by the Northern and Southern Forest Inventory and Analysis (FIA) units of the USDA Forest Service. While growing stock volume has been estimated since the 1950s, historically consistent estimates by state and species group are not available for the Central Hardwood region until the mid-1980s or early 1990s, depending on the state. For this period and beyond, data are available using the FIA online application EVALIDator (Miles 2018).

Volume data for the initial period was calculated from FIA data collected in different years ranging from 1985 and 1986 for Illinois and Indiana, respectively, to 1990 for Iowa and 1991 for Ohio. However, data for four states containing over 70% of the growing stock volume in the Central hardwood region (Kentucky, Missouri, Tennessee, and West Virginia) were collected in 1988 or 1989. A weighted average of the years in the first period based on relative growing volume was rounded to the closest full year, 1989.

Data used in the second and third periods (2002 and 2012) were collected using the multiyear panel process discussed by Gillespie (1999) using plot design presented in USDA FS (2017). The first data available for all states in the Central Hardwood region were for panels ending in 2004 with an average midpoint year of 2002. Similarly, the last period examined represented panels ending in 2015 with an average midpoint year of 2012. While the data used in this study were collected using two different survey methods, the results of these methods are comparable for this paper. All references to a specific year in this paper will be the average panel midpoint year unless otherwise specified.

Management and Policy Implications

This paper examines changes in the structure of hardwood growing stock in the eastern United States from 1953 to 2012, then analyzes these changes in greater detail for the Central Hardwood region for the last 24 years. The main findings of this paper are that current forest structure and future forest composition are rapidly changing. Over the last 24 years, hardwood growing stock volume has been transitioning from a poletimber-dominated to a large-size sawtimber-dominated structure. These changes were evident across all of the states and major species studied in the Central Hardwood region, but were less pronounced for hard maple, soft maple, and hickory. The oak species groups showed the largest declines in poletimber volume over the last decade in all states examined. In some cases, this decline has extended to mid-size sawtimber. In the short run, these changes could benefit industries that produce hardwood products because larger timber is more economical to harvest and process. In the long run, there could be management and utilization challenges (especially for oak) as larger diameter trees are harvested or die without a timber base of similar compositional proportions emerging in their absence. Furthermore, some of the species that seemingly will be replacing oaks over time have different economic and ecological values that will be magnified as oak growing stock volume declines. Proactive processes that incorporate both market and silvicultural considerations are needed to influence future compositional and structural changes of the hardwood timber resource.

The first objective of this study was accomplished through an examination of cubic foot (cubic) and proportional volumes of growing stock trees ≥17 in. for all hardwoods and major hardwood species groups for the years of 1989, 2002, and 2012. For the second objective, net changes in cubic growing stock volume by size class were examined for 1989 to 2002 and 2002 to 2012. Since a continuous series of yearly data is available from 2002 to 2012, we also examined the paths of relative changes in the size classes for all hardwoods, all oaks, all maples, and yellow-poplar within this time frame using indexing.

Indexing is a procedure that allows movement of multiple data series of differing scales to be compared on a relative basis. This process starts with a base year in which all series being examined are set to a value of 100. The value in each additional year in the series is determined by the value in that year divided by the value in the base year times 100. For instance, if the base year is 2002, with growing stock volume of 25 billion cubic feet, and the volume in 2003 expands to 26 billion cubic feet, the index would be 100.0 for 2002 and 104.0 for 2003. Conversely, if year-over-year volume decreases, the index value would decrease by a proportional amount. The convenience of using index value is that relative changes from a base year can be seen in percentage terms.

Results

Change in Relative Volume of Large Trees

In 1989, select red oak (primarily [*Q. rubra* L.]) (Miles 2018) had over 40% of its cubic volume in trees ≥17 in. (Table 1). Cubic volume of trees ≥17 in. approached or exceeded 30% of total volume for yellow-poplar (*Liriodendron tulipifera* L.), other red oak (primarily black oak [*Q. velutina* Lam.] and scarlet oak [*Q. coccinea* Muenchh.], and select white oak (primarily white oak [*Q. alba* L.], chinkapin oak *[Q. muehlenbergii* Engelm.], and bur oak [*Q. macrocarpa Michx*.]). Other white oaks (primarily chestnut oak [*Q. prinus* L.] and post oak [*Q. stellata* Wangenh.]), soft maple (including red maple [*A. rubrum* L.] and silver maple [*A. saccharinum* L.]), hard maple (primarily sugar maple [*A. saccharum* Marsh.], and ash (primarily white ash [*Fraxinus americana* L.] and green ash [*F. pennsylvanica Marsh*]) all had less than 25% of their volume in trees ≥17 in. The hickories (*Carya sp*.) had the lowest relative volume of trees ≥17 in. with less than 15% in this size class.

While the proportional and cubic volume of trees ≥17 in. increased for every species group between 1989 and 2012, the magnitude of these increases differed (Table 1). The cubic volume of select red oak trees ≥17 in. doubled between 1989 and 2012, and the proportional volume in this size class increased from 44% to 64%. Yellow-poplar, select white oak, other white oak, and ash also had relatively large increases in both proportional and cubic volumes between 1989 and 2012. By contrast, other red oak had the third largest change in proportional volume in trees ≥17 in. but the smallest change in cubic volume.

Hard maple, which had the smallest changes in the proportion volume of trees ≥17 in. between 1989 and 2012 (22% to 25%) of any species group, still had a near doubling of cubic volume in this size class. Hickory and soft maple species groups had relatively small increases in proportional volume of trees ≥17 in. between 1989 and 2012, but large increases in cubic volume in this size class. Variations in the changes in proportional and cubic volumes of trees ≥17 in. between species groups are indicative of differences in volumetric changes in the mid-size class relative to the ≥17 in. size classes in these groups (Table 2).

Change in Growing Stock Volume by Size Class

Growing stock volume in the Central Hardwood region increased by over 35 billion cubic feet between 1989 and 2012, but 75% of this increase occurred in the 1989 to 2002 period (Table 2). While the periods shown in Table 2 are of differing lengths, the average annual compound rate of change for total growing stock was 2.3% from 1989 to 2002 versus 0.8% for 2002 to 2012 (calculated from Miles 2018). The average annual compound rate of rate of growth of trees ≥17 in. has also declined from 4.2% to 2.2% for the first and second periods, respectively.

While the rate of growth of total growing stock between 2002 and 2012 had slowed, net growth of poletimber in the Central Hardwood region was negative 1.8 billion cubic feet during this period (Table 2). A closer examination of change in volume by indexing them at 2002 levels (2002 = 100) indicates that poletimber volume continued to increase until 2005, then started to decline (Figure 3). An examination of changes in mid-size tree volume found that all the net growth shown in Table 2 (2.2 billion cubic feet) occurred between 2002 and 2008, and since 2008

Table 1. Cubic and proportional volume of growing stock on timberland in size class 17 inches dbh and larger for important hardwood species groups in the Central Hardwood region in 1989, 2002, and 2012 (developed from Miles 2018).

	1989		2002		2012		1989–2012	
Species	Million CF	Percent	Million CF	Percent	Million CF	Percent	Million CF (% change)	Percent (point-change)
Select white oak	3,112	28.6	5,592	37.0	6,464	41.9	107.7	13.3
Select red oak	2,235	44.4	3,393	53.1	4,505	63.7	101.6	19.3
Other white oak	1,453	23.4	2,445	29.8	3,181	36.6	118.9	13.2
Other red oak	3,058	29.9	4,992	39.1	5,727	46.0	87.3	16.1
Hickory	1,106	14.3	1,966	19.1	2,673	23.4	141.7	8.7
Hard maple	859	21.9	1,374	23.7	1,652	24.7	92.3	2.8
Soft maple	1,059	22.4	1,871	27.6	2,591	31.3	144.7	8.9
Ash	670	21.7	1,310	29.0	1,766	36.1	163.6	14.4
Yellow-poplar	2,489	31.0	4,986	44.2	6,458	48.7	159.5	17.7

Table 2. Net changes in the volume of growing stock on timberland for important hardwood species groups in the Central Hardwood region by size class from 1989 to 2002 and from 2002 to 2012 (developed using information from Miles 2018).

Species group	Time period	Total[1]	5" to 10.9 in.	11" to 16.9 in.	17 in. and larger
			----Million cubic feet----		
Total	1989 to 2002	26,541	1,045	11,139	14,357
	2002 to 2012	9,228	-1,775	2,238	8,765
Select white oak	1989 to 2002	4,237	73	1,685	2,479
	2002 to 2012	317	-568	13	872
Select red oak	1989 to 2002	1,356	-114	316	1,154
	2002 to 2012	692	-150	-275	1,117
Other white oak	1989 to 2002	1,990	-65	1,065	990
	2002 to 2012	491	-295	48	739
Other red oak	1989 to 2002	2,540	-407	1,013	1,934
	2002 to 2012	-296	-498	-533	735
Hickory	1989 to 2002	2,527	226	1,447	854
	2002 to 2012	1,119	-341	748	713
Hard maple	1989 to 2002	1,892	487	890	515
	2002 to 2012	874	232	363	279
Soft maple	1989 to 2002	2,051	343	895	813
	2002 to 2012	1,497	149	628	720
Ash	1989 to 2002	1,435	133	663	639
	2002 to 2012	368	-159	71	456
Yellow-poplar	1989 to 2002	3,228	-53	792	2,489
	2002 to 2012	1,986	95	410	1,481

[1] Volume may not add up to total (by row) due to rounding error.

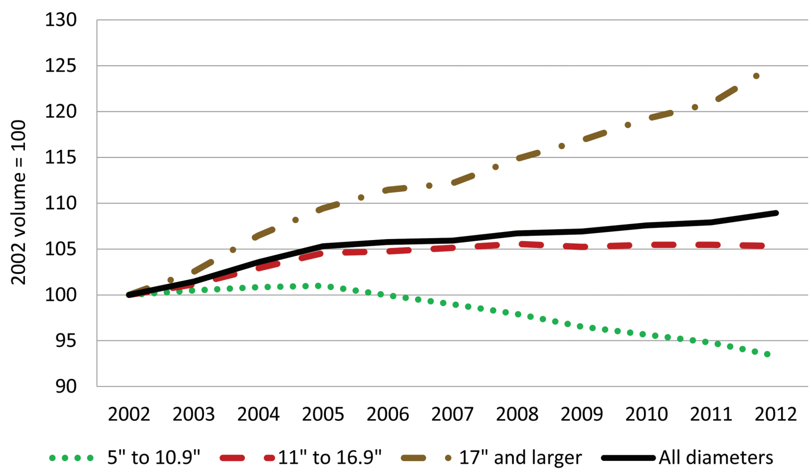

Figure 3. Indexes of relative changes in hardwood growing stock volume in the Central Hardwood region by size class from 2002 to 2012 (developed using information from Miles 2018).

volume has remained relatively unchanged. This means that all net growth in aggregate (all species) hardwood growing stock in the Central Hardwood region since 2008 has been confined to growth in trees ≥17 in.

The cubic volume of select white oak growing stock increased by 4.5 billion cubic feet between 1989 and 2012, but almost all this increase occurred prior to 2002 (Table 2). Select white oak poletimber volume decreased in the 2002 to 2012 period, but unlike total hardwood volume, the point where select white oak volume started to decrease is uncertain since decreases were found in every year since 2002 (Miles 2018). Select red oak poletimber also started to decline prior to 2002 (Table 2), and similar to select white oak, mid-size select red oak cubic volume started to decline after 2008. Still, select red oak was the only species group in which the average annual growth rate of trees ≥17 in. was similar in the 2002 to 2012 and 1989 to 2002 periods.

Poletimber volume of other red and other white oak also were already in decline prior to 2002 (Table 2). The net growth of mid-size trees in both groups started to decline after 2004, but the decline in other red oak was more pronounced, causing the net volume to be negative for the 2002 to 2012 period. The net increase in the volume of other white oak trees in the ≥17 in. size class exceeded the total growing stock volume increase by nearly 60% between 2002 and 2012. In contrast to all other species groups shown in Table 2, the growing stock volume of other red oak declined between 2002 and 2012.

An examination of changes in the combined volumes of all oak species groups since 2002 by size class is presented in Figure 4. Between 2002 and 2012, combined oak poletimber volume declined 18%. This decline caused the volume of mid-size trees to begin declining after 2005 through reduced ingrowth. Even as the volume of growing stock in trees ≥17 in. continued to increase, downward volume of poletimber and mid-size trees caused total oak volume to remain relatively flat, increasing by less than 3% between 2002 and 2012. As a result of these changes, the proportion of oak growing stock in trees ≥17 in. went from 30% in 1989, to 39% in 2002, to 45% in 2012 (Miles 2018).

Similar to the oak groups, ash and hickory had declines in net volume of poletimber between 2002 and 2012 (Table 2). The net change in ash growing stock volume by size class was similar to that of the oak species. However, unlike the oaks, the net increase in the volume of mid-size hickory exceeded that of trees ≥17 in.

Hard and soft maple are the only species groups shown in Table 2 that had relatively high net growth of poletimber and mid-size trees in both time periods. However, year-over-year increase in combined maple poletimber volume appeared to subside after 2008 but annual increases in mid-size tree volume continued through 2012 (Figure 5). Of the two maple groups, hard maple has continued to have small year-over-year increases in poletimber volume through 2012 while soft maple poletimber volume has remained relatively constant since 2006. By contrast, soft maple had a 41% increase in the volume of trees ≥17 in. between 2002 to 2012 compared to a 19% increase in the volume of hard maple trees in this size class.

Yellow-poplar is the only species shown in Table 2 with a negative net growth of poletimber between 1989 and 2002 and a positive net growth between 2002 and 2012. The relatively small net increase in poletimber volume since 2002 is the result of fluctuating upward trending increases between 2002 and 2012 (Figure 6). The volume of yellow-poplar in the mid-size class also seems to have plateaued after 2010, but volume of trees ≥17 in. continued to increase.

Discussion

Many of the volumetric changes in the size classes described in this analysis are consistent with the long-term expectations conveyed by previous research (Loftis and McGee 1993). However, the speed with which the forest in the Central Hardwood region has transitioned from one in which trees ≥17 in. comprised less than 27% of growing stock volume to over 38% is noteworthy (Miles 2018). The absolute decline in hardwood poletimber volume is a recent change occurring after 2005 (Figure 3). This was followed by a flat to small decline in net mid-size tree volume after 2008, resulting in aggregate net growth to be confined to trees ≥17 in. since that year. Still, there were considerable species differences in the proportional volume of trees ≥17 in. in 2012, ranging from 25% for hard maple to 64% for select red oak.

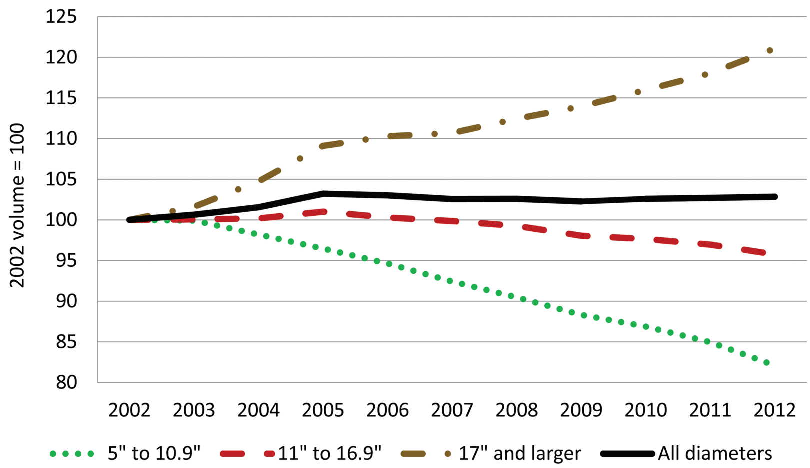

Figure 4. Indexes of relative changes in combined red and white oak growing stock volume in the Central Hardwood region by size class from 2002 to 2012 (developed using information from Miles 2018).

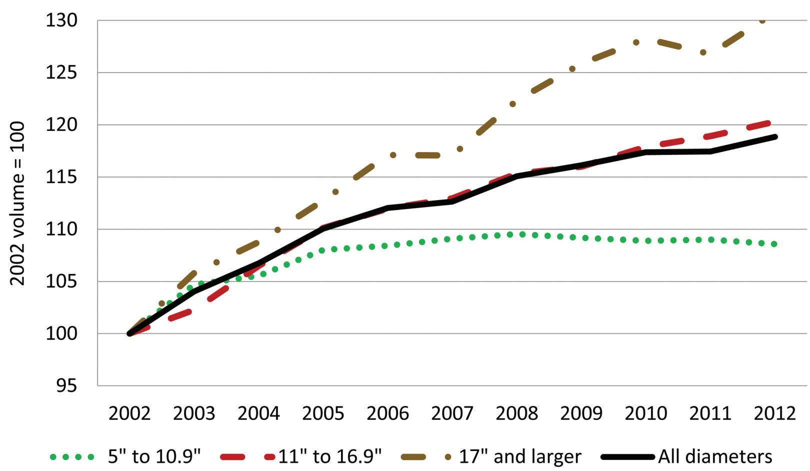

Figure 5. Indexes of relative changes in combined maple growing stock volume in the Central Hardwood region by size class from 2002 to 2012 (developed using information from Miles 2018).

Oak growing stock volume in trees ≥17 in. increased from 30% in 1989 to 45% in 2012 (Miles 2018). This increase was associated with an 18% decline in oak poletimber volume and a 4% decline in the volume of mid-size trees (Figure 4). As a result of the combined declines in oak poletimber and mid-size trees, total oak growing stock volume only increased by 3% between 2002 and 2012.

Numerous studies have described the difficulties associated with oak regeneration on many types of stands (Loftis and McGee 1993, Johnson et al. 2009). So it might be expected that oak poletimber volume would be declining over time while volume of oak trees ≥17 in. would be increasing. Similarly, the decline in mid-size tree volume was reflective of long-observed oak regeneration issues.

In contrast to the oak species groups, hard maple, soft maple, and yellow-poplar all had double-digit percentage increases in total volume (Figures 5 and 6). In the near term, total growing stock volume of these species groups is likely to continue to increase as increasing mid-size trees transition to trees ≥17 in. Still, poletimber volumes of these species groups have either plateaued or started to decline.

The hickory and ash species groups also started to have declines in net growing stock volume after 2002. But while net growth in total ash volume was the result of increased volume in trees ≥17 in., increased hickory volume was more affected by increasing volumes of mid-size trees. It is not known if the smaller increase in hickory trees ≥17 in. is the result of slower ingrowth from mid-size trees to trees ≥17 in., or higher levels of mortality of the larger-size trees.

The greatest increases in growing stock volumes were for soft maple, yellow-poplar, hickory, and hard maple. Collectively, these

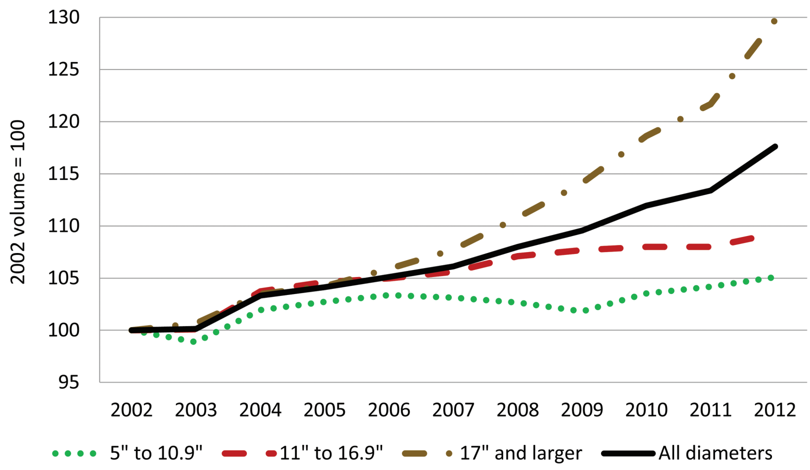

Figure 6. Indexes of relative changes in yellow-poplar growing stock volume in the Central Hardwood region by size class from 2002 to 2012 (developed using information from Miles 2018).

species accounted for 33% of the growing stock volume in 2002 (Miles 2018) but 60% of the net growth between 2002 and 2012. However, even within these relatively high net growth species groups, only hard maple had a (small) net increase in poletimber volume since 2008. This finding is not surprising given that sugar maple can persist for long periods under overstory canopies and growth in the pole stage is slower than for most associated hardwoods (Burns and Honkala 1990). However, sugar maple also responds well to release and it can be a long-lived tree (Harlow et al. 1991).

Numerous factors likely have influenced these changes in the hardwood timber base across the area studied. There is a broad spectrum of land use histories that have impacted the general arc of forest succession (Yaussy et al. 2003); most notably, large-scale forest disturbance by settlement and timbering that ultimately affected all portions of the Central Hardwood region during the twentieth century (Johnson et al. 2009) and has created a forest that is maturing today. Heiligmann et al. (1985) showed that higher residual overstory density after harvesting led to lower frequency, diameter, and basal area of reproduction. Thus, changes in fire regimes, management, and/or harvesting methods are influencing forest dynamics over time, including changes in composition to more mesophytic and shade-tolerant species (Miller and Kochenderfer 1998, Brose et al. 2001). However, a similar trend also has been noted on unmanaged lands, where shade-tolerant species were found to be increasing in relative density (Schuler 2004).

Additionally, market activity likely has played a role in forest structure more recently through reduced harvest activity. For example, US hardwood lumber consumption declined by nearly 10 million m^3 (4.2 billion board feet) from the peak in 1999 to 2014 (Luppold and Bumgardner 2016). A high proportion of this decline has been higher-value lumber used in appearance-based applications. Higher-quality large-diameter trees yield a disproportional volume of higher-value lumber (Hanks et al. 1980). Additionally, the primary timber removal processes in the Central Hardwood region have been partial cuts in which over 80% of the basal area removed was sawtimber-sized trees (Luppold and Bumgardner 2018). Reduced harvesting activity means that more large trees have remained as harvest levels have decreased.

Forest structure is changing in the Central Hardwood region, characterized by relatively rapid advancement of volume of trees ≥17 in. and decreasing relative volumes of trees in smaller size classes. This trend was evident for all species groups studied, but was less pronounced for hard maple, soft maple, and hickory. In the short run, these changes might benefit industries that produce hardwood products because larger timber is more economical to harvest and process (Rast 1974).

In the long run, there could be a challenge as trees ≥17 in. are harvested or die without similar-sized timber emerging in their absence. Furthermore, some of the species that are likely to replace oaks over time, for example maples and yellow-poplar, have different economic and ecological values that will be magnified as oak growing stock volume declines. Estimates of the future rate of change and how the individual species groups will fare within these changes are subjects for future research. Future research also needs to be conducted on how markets influence timber harvests. Proactive processes that incorporate both market and silvicultural considerations could be developed to influence future compositional and structural changes of the hardwood timber resource.

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