Changes in the Quality of the Northern U.S. Hardwood Timber Resource from 2008 to 2017

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High quality North American hardwood lumber and veneer is increasingly exported and used worldwide. A large portion of the timber resource utilized in the production of these products is contained within the northern region of the eastern United States. The cubic volume of this resource has increased by 15% since 2000, with most of this increase occurring in trees greater than 43.2 cm diameter at breast height. Although the volume of high-quality timber is likely at its highest level in over 100 years, 60% of the increase in the volume between 2008 and 2017 was in sawtimber-size (27.9 cm and larger) trees of low quality. Region wide, the species group "other white oaks" had the largest increase in high-quality volume. The largest increases in low-quality volume were for the soft maple and "other red oaks" species groups. While the volume of poletimber (12.7 to 27.7 cm) growing stock decreased between 2008 and 2017, the volume of cull poletimber-size trees increased more than 50%. These trends indicate a future decline in timber quality. Research is needed to determine the cause of these declines and how they may be reversed. One question that should be examined is the role of natural mortality and damage *versus* human disturbance on timber quality.

Keywords: Hardwood sawtimber; Hardwood poletimber; Timber quality; Cull volume

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INTRODUCTION

The northern region of the eastern United States (hereafter referred to as the Northern Region) is composed of 20 states, stretching from Missouri to Minnesota in the west and Maryland to Maine in the east (Fig. 1). This region contains 50% of live tree volume and 53% of the growing stock (live trees excluding culls) portion of the hardwood timber resource in the United States east of the Rocky Mountains. While the northern portion of this region contains relatively large amounts of maple (*Acer* spp.), oak (*Quercus* spp.), and aspen (*Populus* spp.), the southern portion has relatively large quantities of oak and hickory (*Carya* spp.). This variance in species mix divides the Northern Region into two tiers, the northern and southern (Fig. 1).

Since the beginning of the twenty-first century, live hardwood tree volume in the Northern Region has increased by 878 million cubic meters (Mm^3), a 15% gain (Fig. 2). Nearly 75% of this increase was in trees with diameter at breast height (1.372 meters or dbh) of 43.2 cm and greater, while the net volume of poletimber-size trees (12.7 to 27.7 cm dbh) decreased by 5% (USDA FS 2019a).

Because larger logs are associated with lower processing costs (Rast 1974; Hanks *et al.* 1980), these changes will have near-term benefits for hardwood processing industries manufacturing lumber, veneer, and plywood. Diameter also is a key consideration when

assessing tree grade. Still, little is known about how these changes have affected current and future timber quality, as measured by tree grade (which is defined by diameter and bole quality) and tree class (which is defined by bole quality and existence and proportion of rot).

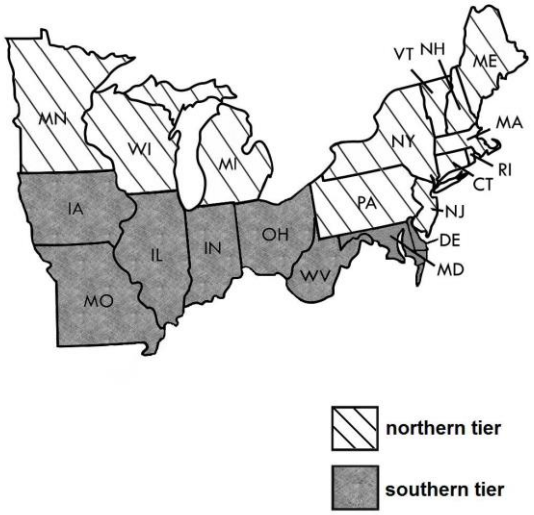

Fig. 1. The Northern Region for U.S. hardwoods along with the northern and southern tiers

Timber quality is an important consideration in hardwood markets because the value of higher-quality logs is considerably greater than that of lower-quality roundwood (Luppold and Baumgras 1995). Higher-quality logs yield greater volumes of clear lumber, which is used in the production of higher-value-added hardwood products, including kitchen cabinets, flooring, furniture, and millwork (Luppold and Bumgardner 2016). Higher-grade lumber and logs also are important hardwood export products (Wang *et al.* 2010).

The goal of this paper is to assess how the quality of the hardwood timber resource in the Northern Region has changed during the twenty-first century. The first objective is to develop an approach that separates the northern timber resource into component parts based on size and market-based quality considerations. The second objective is to examine recent changes in the volume of these components on a regional and sub-regional level for all hardwood species and major hardwood species groups. The final objective is to examine the implications of this information for future research to monitor changes in the northern timber base.

EXPERIMENTAL

Data

Data used in this study were developed for the Northern Region by the Northern Research Station, Forest Inventory and Analysis (FIA) unit of the USDA Forest Service. This data were collected through multiyear survey panels, as described by Gillespie (1999) using procedures that are presented in USDA FS (2019b). Using this data, changes in the timber resource are examined based on tree class (growing stock and cull trees), tree size class (poletimber [12.7 to 27.7 cm] and sawtimber [27.9 cm and larger] dbh), and tree grade

(measurement of bole quality and size of growing stock trees). Definitions of growing stock trees, cull trees, and tree grade are presented in USDA FS (2019b). The use of tree classes and tree grades to define the quality of sawtimber size trees is presented in the next section.

Although tree-grade data were collected for some FIA plots in the Northern Region prior to the implementation of the multiyear survey design, they were only collected on all plots after implementation. The first year that a complete set of panels was collected for all states in the Northern Region was the panel period ending in 2008, and the last year that a complete data set is available is 2016. For the remainder of this paper, panel periods are identified by the ending panel year.

All data were accessed through the EVALIDator web application (USDA FS 2019a). The EVALIDator application also generates standard errors in percentage form that are used to develop volumetric estimates of these errors. These standard errors are used in the current study to determine if volumetric changes between the time intervals examined are significant at the 95% or higher confidence level.

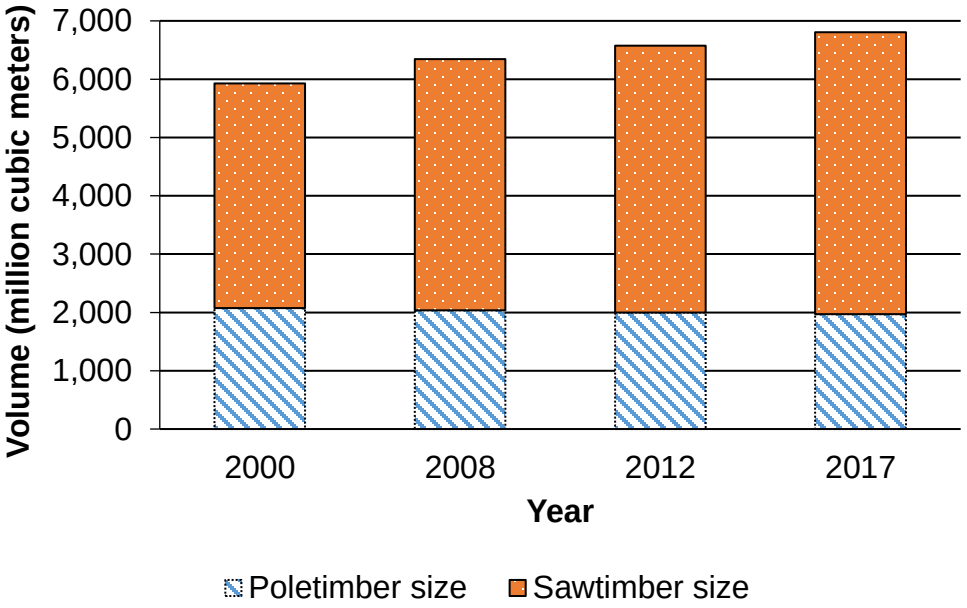

Fig. 2. Merchantable live hardwood tree volume in the Northern Region in poletimber and sawtimber size trees in 2000, 2008, 2012, and 2017, excluding rotten cull (Source: USDA FS 2019a). Standard errors (in Mm^3) associated with the estimate of poletimber: 2000=10.6, 2008=8.8, 2012=8.8, and 2017=8.5; for sawtimber: 2000=25.8, 2008=24.1, 2012=25.6, and 2017=26.1.

The hardwood timber resource can be examined by species groups historically utilized by the US Forest Service and accessible through USDA FS (2019a). The 10 groups examined in this study (Table 1) account for over 75% of live volume in the Northern Region. The "select white oaks" group is primarily composed of white oak (*Quercus alba* L.), bur oak (*Q. macrocarpa* Michx.), and chinkapin oak (*Q. muehlenbergii* Engelm.); the important "select red oaks" species on a volumetric basis is northern red oak (*Q. rubra* L.). The most important species of the "other white oaks" group are chestnut oak (*Q. prinus* L.) and post oak (*Q. stellate* Wangenh.); the most important "other red oaks" are black oak (*Q. velutina* Lam.), scarlet oak (*Q. coccinea* Muenchh.), northern pin oak (*Q. ellipsoidalis* E.

J. Hill), and pin oak (*Q. palustris* Muenchh.). Other important hardwood species groups in the Northern Region include the hickories, hard maple (primarily sugar maple [*Acer saccharum* Marsh.]), soft maple (primarily red maple [*A. rubrum* L.] and silver maple [*A. saccharinum* L.]), ash (primarily white ash [*Fraxinus Americana* L.], green ash [*F. pennsylvanica* Marsh.], and black ash [*F. nigra* Marsh.]), aspen/cottonwood (primarily quaking aspen [*Populus tremuloides* Michx.] and bigtooth aspen [*P. grandidentata* Michx.] in the northern tier and eastern cottonwood [*P. deltoids* var. *deltoides* Bartr. ex Marsh.] in the southern tier, and yellow-poplar (*Liriodendron tulipifera* L.).

Component Parts of the Hardwood Resource, Markets, and Relative Volumes

Live tree volume includes the two size classes previously discussed (poletimber and sawtimber) and three tree classes: growing stock, rough culls, and rotten culls. Cull trees do not meet the criteria necessary to be classified as growing stock (USDA FS 2019b). Rotten culls were excluded from this analysis because such trees represent less than 2% of the Northern Region hardwood resource and are considered trees in the process of dying. Rough culls (termed cull in the remainder of this paper) are included in this study because they represent 11% of the Northern Region live tree volume and can be utilized for production of lumber, pulp, and composite products.

In this study, hardwood tree volume is classified into the following five component parts:

1. High-quality sawtimber (tree grades 1 and 2);
2. Mid-quality sawtimber (tree grade 3);
3. Low-quality sawtimber-size trees (tree grades 4 and 5, and cull sawtimber-size trees);
4. Poletimber growing stock; and
5. Cull poletimber-size trees.

For most species groups, trees must be at least 40.6 cm dbh to be classified as tree grade 1, and 33.0 cm dbh to be classified as tree grade 2 (USDA FS 2019b). Butt logs of tree grades 1 and 2 are normally sawn into lumber, processed into veneer, or exported. Material obtained from harvested grade 3 trees may be processed into appearance or industrial lumber products, but smaller-diameter grade 3 trees also may be passed over in the harvesting process. A smaller but well-formed grade 3 tree normally progresses to grade 2, then grade 1, as its diameter increases (Miller *et al.* 2008).

Roundwood from tree grades 4 and 5 and sawtimber-size culls have a relatively high probability of being used for industrial, pulp, or composite products, which depend upon local market conditions. Unlike small-diameter but well-formed tree grade 3 stems, sawtimber-sized trees classified as grade 4, grade 5, and cull likely will never advance to tree grades 1 or 2. Sawtimber-size trees also can regress in grade over time. An older tree of any grade can start to have cull portions develop through damage or the aging process, or development of epicormic branches after a disturbance, which can lower its tree grade classification (Miller *et al.* 2008). Eventually, most hardwood trees will move through the rotten cull classification before dying, unless they are cut.

Growing stock poletimber-size trees are commercial species with good form; cull poletimber-size trees are commercial species with poor form or non-commercial species. An unknown proportion of cull poletimber-size trees may improve in form and become growing stock at some future point. Similarly, an unknown proportion of poletimber-size trees will die through natural processes and never reach sawtimber size. Poletimber-size

trees can be harvested for pulp or composite products, left to develop into larger-diameter categories, or removed as part of a silvicultural prescription.

RESULTS AND DISCUSSION

The Quality of the Northern Resource by Species Group

The relative volume of high- and low-quality sawtimber-size trees for the northern and southern tiers of the Northern Region are presented by species group in Table 1. While over a third of the total volume of sawtimber-size trees in the northern tier was classified as high-quality in 2017, the proportion of yellow-poplar and select red oak in this component were 64% and 54%, respectively. Soft maple and cottonwood/aspen had the lowest proportion of high-quality trees at 24% and 25%, respectively. The low proportion of cottonwood/aspen group is in part the result of a relatively low proportion of larger diameter (33 cm and greater) quaking and bigtooth aspen trees (USDA FS 2019a). Species groups with high relative volumes in the low-quality component in the northern tier were other red oaks and soft maple.

Table 1. Relative Volume of High-Quality Sawtimber Trees (Tree Grades 1 and 2) and Low-Quality Sawtimber Trees (Tree Grades 4 and 5, and Sawtimber – Size Cull Trees) in the Northern and Southern Tiers of the Northern Region for Important Hardwood Species Groups and All Hardwoods in 2017

	Northern Tier		Southern Tier	
	High-quality	Low-quality	High-quality	Low-quality
	---Percent---			
Select white oaks	35.6	33.3	43.9	28.1
Select red oaks	54.0	17.7	50.5	30.3
Other white oaks	44.2	15.9	43.0	29.1
Other red oaks	32.5	38.8	24.1	53.1
Hickory	34.7	30.3	32.1	34.0
Hard maple	32.7	28.1	32.7	35.4
Soft maple	23.8	37.8	25.7	48.4
Ash	43.7	22.0	45.7	29.6
Cottonwood/aspen	25.3	30.6	48.9	26.0
Yellow-poplar	63.9	14.6	61.9	19.2
All hardwoods	34.5	30.8	38.6	36.1

Nearly 39% of the sawtimber-size trees in the southern tier were in the high-quality component in 2017. Yellow-poplar, select red oak, and cottonwood/aspen all had relative large high-quality volumes that approached or exceeded 50%. The proportion of high-quality cottonwood/aspen in the southern tier is in part the result of relatively large volumes of eastern cottonwood trees 33 cm and greater in diameter. The species groups with the largest proportions of low-quality trees in the southern tier were other red oaks and soft maple.

Changes in the Quality of Sawtimber-Size Trees

Figure 3 presents the volumes of the sawtimber-size components in the northern tier for 2008, 2012, and 2017. The three components had a combined increase of 327 Mm^3

between 2008 and 2017. The high-quality component increased 50 Mm^3 (6%) between 2008 and 2017, but over 75% of this increase occurred between 2008 and 2012. The increase in the high quality sawtimber–size component in this early time interval was significant at the 99% confidence level. The small increase in the high quality component between 2012 and 2017 was not statically significant at 95% confidence level.

The volumes of mid- and low-quality sawtimber-size trees increased at much greater rates than the high-quality component in the northern tier between 2008 and 2017, 129 Mm^3 (15%) and 147 Mm^3 (21%), respectively (Fig. 3). The increase in mid- and low-quality components were relatively evenly spaced with 45% of the increase occurring between 2008 and 2012 and 55 % of the increase occurring between 2012 and 2017 for both components. All increases in the mid- and low-quality components were significant at the 99% confidence level.

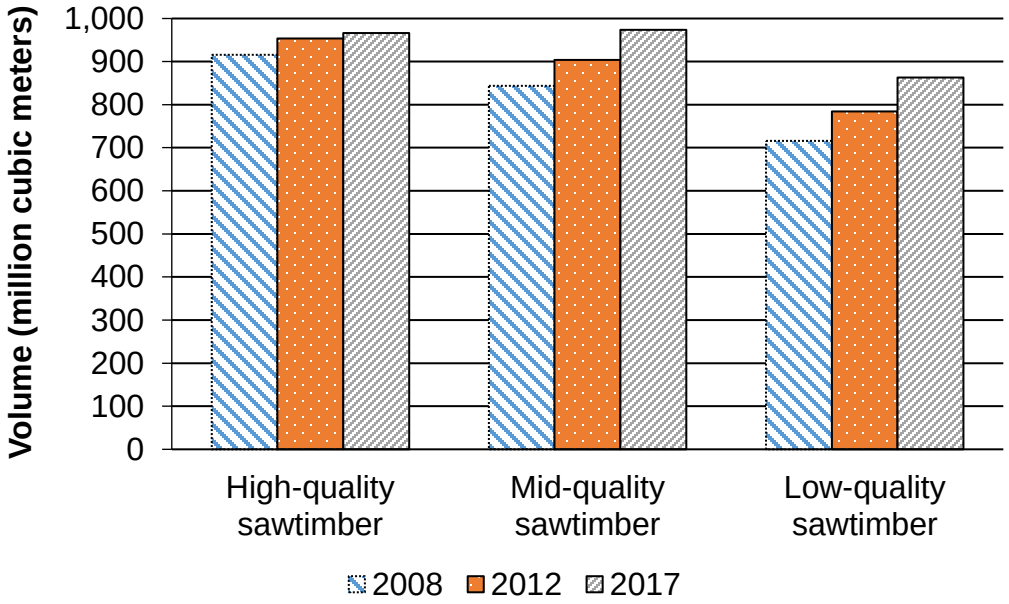

Fig. 3. Volume of live high-quality sawtimber trees (tree grades 1 and 2), mid-quality sawtimber trees (tree grade 3), and low-quality sawtimber size (tree grades 4 and 5, and sawtimber-size rough cull trees) in the northern tier of the Northern Region in 2008, 2012, and 2017 (Source: USDA FS 2019a). Standard errors (in Mm^3) associated with the estimates of high-quality sawtimber: 2008=13.1, 2012=14.2, and 2017=14.2; for mid-quality sawtimber: 2008=7.0, 2012=7.8, and 2017=8.2; for low-quality sawtimber: 2008=12.0, 2012=13.5, and 2017=14.2.

In the southern tier, the volume of high-quality sawtimber increased by 54 Mm^3 (8%) between 2008 and 2017 (Fig. 4). Over 67% of this increased occurred between 2008 and 2012. The increase in the high-quality component between 2008 and 2012 was statistically significant above the 99% confidence level. The smaller increase in this component between 2012 and 2017 was not significant at the 95% level. The volume of mid-quality sawtimber-size trees remained nearly constant between 2008 and 2017 with a slight but statically insignificant decline between 2008 and 2012. The largest increase in volume in the southern tier occurred in the low-quality component (112 Mm^3 or 62% of the total increase), and the periodic increases were statistically significant above the 99% level for both time intervals.

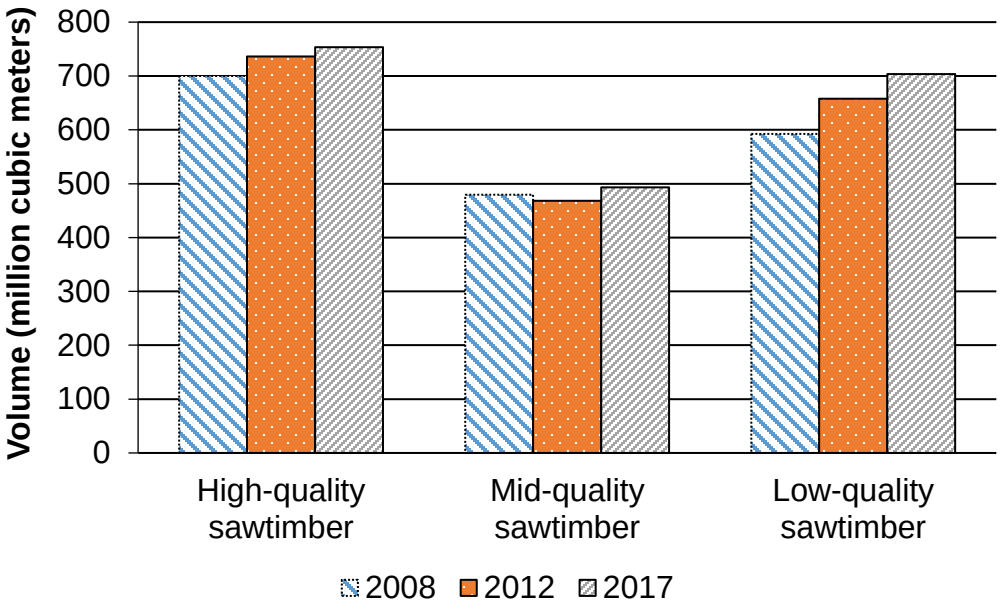

Fig. 4. Volume of live high-quality sawtimber trees (tree grades 1 and 2), mid-quality sawtimber trees (tree grade 3), and low-quality sawtimber size (tree grades 4 and 5, and sawtimber-size rough cull trees) in the southern tier of the Northern Region in 2008, 2012, and 2017 (Source: USDA FS 2019a). Standard errors (in Mm^3) associated with the estimates of high-quality sawtimber: 2008=13.6, 2012=15.3, and 2017=13.4; for mid-quality sawtimber: 2008=5.9, 2012=5.9, and 2017=5.7; for low-quality sawtimber: 2008=12.5, 2012=13.5, and 2017=13.0.

It is important to note that the average dbh of growing stock trees in both tiers of the Northern Region is larger than in any period since forest inventories began in the early 1950s (Oswalt *et al*. 2014; USDA FS 2019a). Given that timber harvesting peaked in the Northern Region over a century ago (Steer 1948), the current volume of high-quality timber is most likely greater today than any time during the last 100 years.

Table 2 presents changes in high-quality sawtimber in the Northern Region by species group and tier between 2008 and 2017. In the northern tier, the volume of high-quality sawtimber increased for most species groups, with the largest increases occurring for select red oak, hickory, and yellow-polar. However, the combined volumes of hickory and yellow-poplar accounted for less than 4% of the live tree volume in the northern tier (USDA FS 2019a). The species groups with the largest declines in high-quality sawtimber in the northern tier were cottonwood/aspen and other white oaks. Similar to hickory and yellow-poplar, the other white oaks represent only a small portion of the timber base in this sub-region.

Between 2008 and 2017, large increases in the relative volume of high-quality hard maple, other white oaks, and soft maple, occurred in the southern tier (Table 2). In contrast, the volume of high-quality other red oaks declined in this region by 16%. The largest increases in the Northern Region as a whole were for other white oaks, hickory, yellow-poplar, select red oak, and soft maple. The largest declines in high-quality trees were for the other red oaks, ash, and cottonwood/aspen species groups.

Although high-quality sawtimber volume increased for most species groups in the Northern Region, these increase were relatively smaller than the increases in the low-quality component (Table 3). In the northern tier, there were large increases in low-quality yellow-poplar, hickory, other white oaks, and other red oaks. However, the combined

volumes of these species groups only accounted for 10% of the total tree volume in this sub-region (USDA FS 2019a). Soft maple, the most abundant species group in the northern tier, had a 21% increase in the volume of the low-quality component between 2008 and 2017. In contrast, the cottonwood/aspen group had the smallest increase in low-quality. For all hardwood species in the northern tier, low-quality sawtimber-size tree volume increased by 21% in the time period examined.

Table 2. Percentage Change in Volume of High-Quality Sawtimber-Size Trees (Tree Grades 1 and 2) between 2008 and 2017 in the Northern Region and Sub-Regions for Important Hardwood Species Groups and All Hardwoods

	Northern Tier	Southern Tier	Northern Region
	---Percent---		
Select white oaks	8.9	7.9	8.2
Select red oaks	12.7	2.3	9.7
Other white oaks	-7.7	25.5	10.8
Other red oaks	8.3	-16.0	-6.2
Hickory	19.2	7.4	10.7
Hard maple	3.2	26.3	7.3
Soft maple	7.1	17.9	9.6
Ash	0.3	-10.3	-3.1
Cottonwood/aspen	-6.3	7.4	-2.5
Yellow-poplar	12.4	10.3	10.8
All hardwood species	5.5	7.7	6.4

Table 3. Percentage Change in Volume of Low-Quality Sawtimber-Size Trees (Tree Grades 4 and 5, and Cull) between 2008 and 2017 in the Northern Region and Sub-Regions for Important Hardwood Species Groups and All Hardwoods

	Northern Tier	Southern Tier	Northern Region
	---Percent---		
Select white oaks	16.2	3.1	8.0
Select red oaks	24.4	36.6	29.0
Other white oaks	38.9	2.2	9.1
Other red oaks	34.6	16.3	21.6
Hickory	55.4	31.6	37.0
Hard maple	15.1	15.6	15.2
Soft maple	24.0	20.3	23.0
Ash	17.7	12.4	15.8
Cottonwood/aspen	3.7	-2.3	2.7
Yellow-poplar	88.0	61.0	65.3
All hardwood species	20.5	18.8	19.8

In the southern tier, yellow-poplar, select red oaks, and hickory had large increases in the volume of the low-quality component during the study period (Table 3). These species groups accounted for 24% of the sawtimber size tree volume in this sub-region in 2017 (USDA FS 2019a). Two important species groups in the southern tier, select and other white oaks, had relatively low increases in the low-quality category. For all hardwood species in the southern tier, there was a 19% increase in low-quality sawtimber size tree volume between 2008 and 2017.

The largest percentage increase in low-quality sawtimber-size trees in both tiers was for yellow-poplar. However, this species still had the lowest proportion of low-quality

sawtimber-size trees of any major species group in 2017 (Table 1). Similarly, select red oak had relatively large increases in low-quality sawtimber-size tree volume, but this increase was from a relatively low base. The increases in volume of low-quality other red oaks, hickory, and soft maple are more significant from a utilization perspective because these three species groups currently account for 27% of total hardwood volume in the Northern Region in 2017 (USDA FS 2019a). Region wide, low-quality sawtimber volume increased by 20% from 2008 to 2017.

Relative Volume of Cull Poletimber-Size Trees

The volume of poletimber-size trees in the Northern Region has declined by 103 Mm^3 this century (USDA FS 2019a). Since 2008 this decline has been confined to growing stock trees as the volume of cull poletimber-size trees has increased by more than 50% in both the northern and southern tiers between 2008 and 2017. However, the southern tier contained a larger relative volume of cull trees during this period (Fig. 5). In 2017, the relative cull volume in the poletimber size class was 12% and 19% in the northern and southern tiers, respectively.

The most abundant species group in the northern tier, soft maple, had relative cull poletimber volume of 11% in 2017 (Table 4). Other white oaks and select white oaks also had relative cull volumes exceeding 10% while other red oak cull poletimber volume was 15%. The smallest relative poletimber size cull volume of important species groups in the northern tier was for cottonwood/aspen (2%).

In the southern tier, ash had the highest relative volume (23%) of cull poletimber size trees followed by soft maple (16%) (Table 4). The relative cull volume of hard maple and the four oak species groups approached of exceeded 10% in 2017. The species groups with the smallest level of cull poletimber in the southern tier were yellow-poplar and cottonwood/aspen.

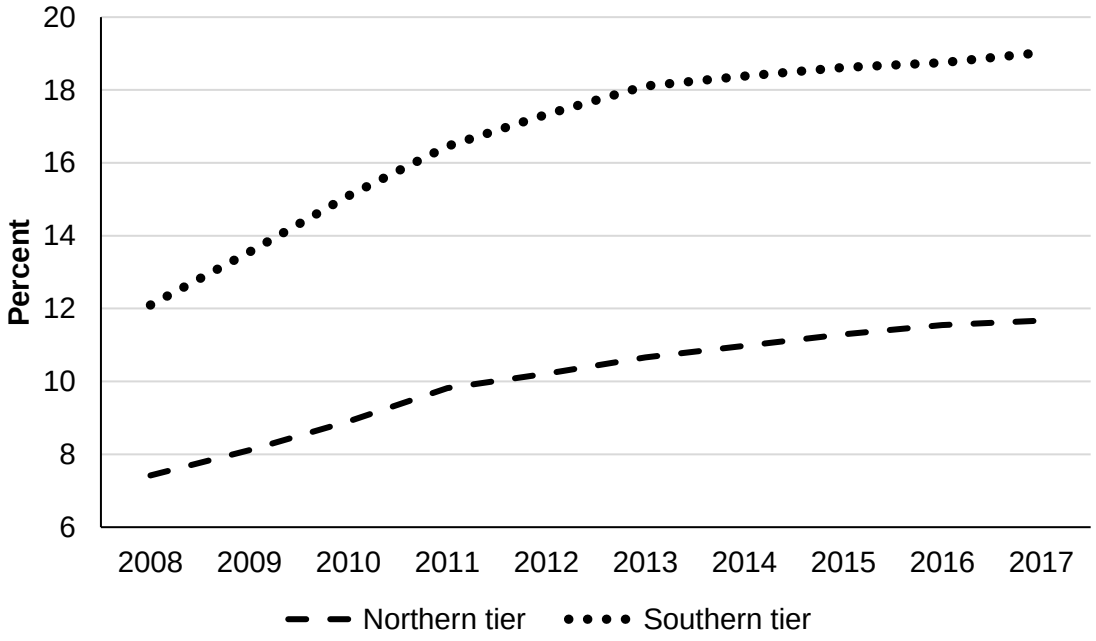

Fig. 5. Change in rough cull poletimber-size tree volume as a percentage of total poletimber-size tree volume less rotten cull for the northern and southern tiers of the Northern region (from 2008 to 2017)

Table 4. Relative Volume of Cull Poletimber-Size Trees as a Percent of All Poletimber-Size Trees in 2017 in the Northern Region and Sub-Regions for Important Hardwood Species Groups and All Hardwoods

	Northern Tier	Southern Tier	Northern Region
	---Percent---		
Select white oaks	10.9	10.2	10.4
Select red oaks	6.0	11.2	7.2
Other white oaks	10.2	11.6	11.2
Other red oaks	15.2	11.8	13.2
Hickory	6.1	8.3	7.7
Hard maple	6.4	9.9	7.1
Soft maple	10.7	15.6	11.4
Ash	7.8	22.9	10.5
Cottonwood/aspen	2.4	5.6	2.5
Yellow-poplar	6.8	3.3	3.9
All hardwood species	11.7	19.0	13.8

CONCLUSIONS

1. *Changes in Overall Sawtimber Volume* – Since the beginning of the twenty-first century, live hardwood tree volume in the Northern Region has increased by 878 Mm^3. All of this increase has been confined to sawtimber-size trees, and nearly three-quarters of this gain has been in trees 43.2 cm and greater dbh. Because consistent hardwood tree grade measurements were not conducted in all states in the Northern Region until the implementation of the multi-year panel survey system, it is difficult to ascertain how timber quality changed between the early 1990s through 2008.
2. *Changes in High-Quality Sawtimber Volume* – The volume of the high-quality sawtimber component has continued to increase in the northern and southern tiers of the Northern Region. In both tiers, there was a statistically significant increase in the high quality component between 2008 and 2012 but slower growth between 2012 and 2017. However, there likely is a greater volume of high-quality sawtimber in the region currently than any time in the last 100 years. The largest relative increases in the high-quality component in the northern tier were for select red oak, hickory, and yellow-polar. Hard and soft maple and other white oaks had the largest increases in relative volume in the southern tier.
3. *Changes in Mid- and Low-Quality Sawtimber Volume* **–** The mid-quality component in the northern tier increased between 2008 and 2017 but remained nearly constant in the southern tier over this period. The portions of the Northern Region forest that have had the greatest increase in volume since 2008 are the low-quality components. These changes were similar in both the northern and southern tiers. These changes are not likely to contribute to increases in the high-quality component in the future. It will require additional research at the survey plot level to determine what is causing these changes. The negative impact of diameter-limit cutting on timber quality over time has been noted (Brown *et al.* 2018), but trees also can decline in quality because of damage caused by weather, logging, insects, disease, or some combination of disturbance and natural processes. One of the major questions that should be examined is the role of natural mortality and damage versus human intervention on timber quality.

4. *Changes in Poletimber Volume* – As the forests of the Northern Region have continued to increase in volume, there has been a decline in poletimber volume. Furthermore, this decline has been realized only in the growing-stock portion of this size class. Conversely, there has been a greater than 50% increase in the volume of cull poletimber since 2008, and culls accounted for nearly 14% of poletimber volume in 2017. The rate that poletimber cull trees have increased is similar for the northern and southern tiers, but the level of increase is notably higher in the southern tier. While this trend seems troubling with respect to future forest quality and utilization, its implications are impossible to project given the current lack of knowledge. Again, plot-level data must be examined and monitored to determine why this trend is occurring. Two questions that could be addressed are as follows. Is the increase in cull poletimber-size trees leveling out? And, what will be the rate of mortality of cull poletimber-size trees relative to the mortality of growing stock poletimber?

5. *Future Timber Harvests* – Perhaps the most important factor that can influence the future quality of the northern U.S. forest resource is what will occur during future timber harvests. What timber will be removed and what silvicultural practices and/or harvesting methods will be incorporated? Harvest outcomes are subject to economic realities including market availability for harvested roundwood products, new technologies to utilize and increase the value of these products, and perceived value of the products removed. Research that leads to a combined understanding of markets, management costs, silviculture, and timber resources may have the greatest potential in assuring a continuous supply of high-quality hardwood timber in the future.

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