TIMBER HARVESTING PATTERNS FOR MAJOR STATES IN THE CENTRAL, NORTHERN, AND MID-ATLANTIC HARDWOOD REGIONS[1]

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(Received September 2017)

Abstract. Timber harvesting is a major disturbance agent influencing the composition and structure of eastern hardwood forests. To better understand timber harvesting practices, we examined roundwood harvesting patterns in 13 eastern states in the Central, Mid-Atlantic, and Northern regions that contained high proportional volumes of hardwood in their forest inventories. Nearly 5400 Forest Inventory and Analysis sample plots in which timber was cut and assumed to be used were examined for the period 2009-2015. Nine patterns based on basal area removed were isolated and defined, of which six were partial removals and three were clear-cuts. Of the patterns observed, four involved primarily hardwoods, three involved primarily softwood, and two were mixed. Large diameter–influenced partial hardwood harvesting practices were found to be predominant in the Central hardwood region, but mixed diameter hardwood and softwood partial harvesting patterns were noted in Wisconsin, Michigan and Maine. Harvesting patterns examined in Pennsylvania and New York appeared to be a transition between the patterns found in the Central and three most Northern states. Large diameter–influenced harvesting also occurred less frequently in the Mid-Atlantic states. Clear-cuts were noted in all states examined but were associated with higher levels of removal in the Mid-Atlantic states. Softwood cuts were more common in the Northern and Mid-Atlantic states and pine thinning cuts were noted in Tennessee, Wisconsin, Michigan, Virginia, and North Carolina. Although this study provides insight into current timber harvesting processes, additional information is needed to determine how timber management practices can be developed to complement the economic considerations associated with harvests.

Keywords: Timber harvest, hardwood, harvest patterns.

INTRODUCTION

Timber harvesting has been a major disturbance agent influencing the composition and structure of eastern hardwood forests (Carvell 1986; Luppold and Baumgras 2000). Still, other than specific case studies (Luppold and Alderman 2007; Bumgardner et al 2013), little is known about what timber is actually removed in the harvesting process over the broad hardwood regions of the eastern United States. This lack of knowledge is unfortunate because it is difficult to discuss how to encourage harvesting practices that could achieve a suggested timber management or ecological objective if what is actually occurring is poorly understood. It has been asserted that the processes primarily involve the

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Wood and Fiber Science, 50(2), 2018, pp. 143-153
https://doi.org/10.22382/wfs-2018-016

selection of trees based on diameter- limits, commonly termed diameter-limit cuts (Fajvan et al 1998), or other forms of high-grading that remove all trees with commercial value (Johnson et al 2009). However, as discussed in Alderman and Luppold (2005), roundwood markets can exist for a variety of products ranging from veneer logs to pulpwood that would indicate demand for trees of varying diameters and quality.

One reason that more is not known about timber harvest patterns is the time and expense of collecting pre- and postharvest data. This factor is compounded by the variable composition and structure of hardwood stands and variations in the demand for hardwood products. A potential solution to these data issues is to examine what type of timber is being removed from remeasured United States Department of Agriculture (USDA), Forest Service, Forest Inventory and Analysis (FIA) plots. FIA plots are revisited in 5- to 7-yr increments in the eastern United States and changes that result from recent harvest activity are noted. Although these plots are small in size, they are large in number. Given the large number of potential observations, we decided to focus on states producing large volumes of the most important hardwood product, lumber.

Hardwood lumber is produced in every eastern U.S. state (U.S. Census Bureau 2009), but 75% of production is within states in the West-Central, East-Central, Northern, and Mid-Atlantic hardwood regions, as defined by Luppold and Miller (2014). Within these regions, 12 states (Missouri, Indiana, Ohio, West Virginia, Kentucky, Tennessee, Pennsylvania, New York, Wisconsin, Michigan, Virginia, and North Carolina) accounted for 70% of the volume of eastern hardwood lumber produced in 2008 (Fig 1). As shown in Fig 2, the timber resource in these states ranges from 97% hardwood in Indiana to 64% hardwood in North Carolina. Maine is another state within Northern region that has a large volume of hardwood timber (exceeding that of Indiana [Miles 2017]) but is a minor producer of hardwood lumber (U.S. Census Bureau 2009). We include Maine in this study because of its diverse timber resource and unique set of timber industries (Luppold and Sendak 2004), which could result in different timber harvesting patterns. Because of the variety of markets for timber products, the diversity of the timber resource in these states, and the potential applications of prescribed silvicultural procedures, other harvesting processes were expected to exist in addition to diameter-limit cuts. By identifying and examining patterns that result from harvesting activities, we can develop a baseline necessary to better understand what is actually occurring as

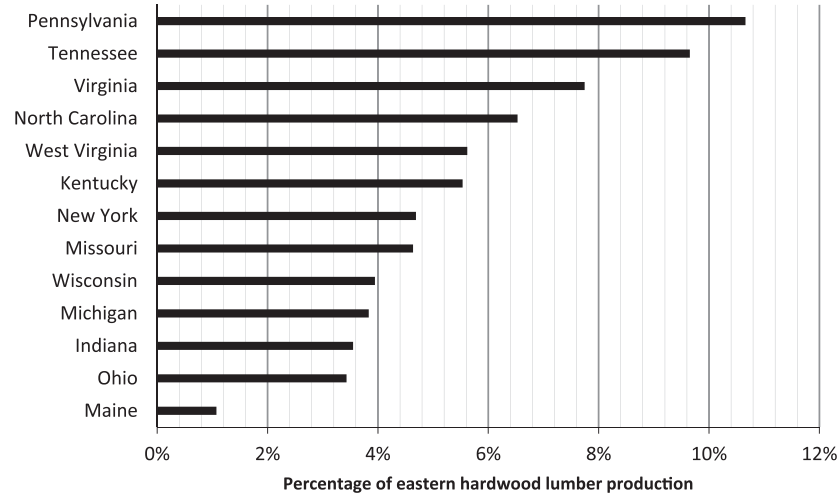

Figure 1. Percentage of total eastern hardwood lumber production in 2008 for the 13 states examined (U.S. Census Bureau 2009). These states (all but Maine) accounted for 70% of all eastern hardwood production in 2008.

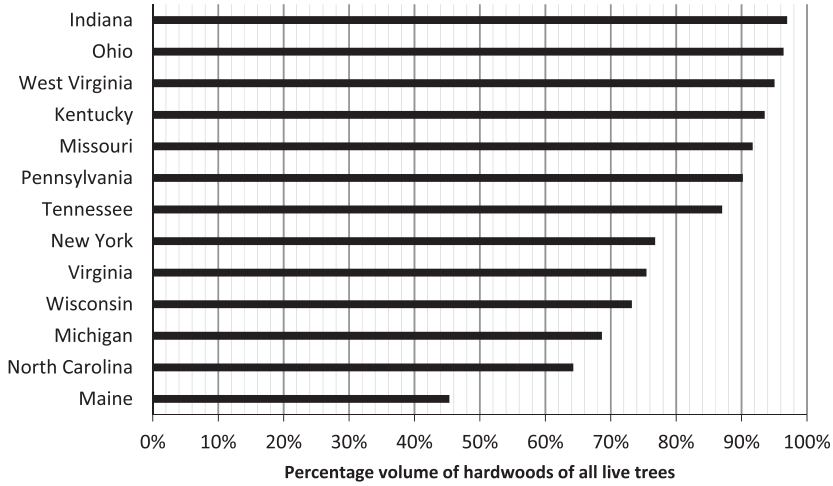

Figure 2. Percentage volume of live trees being hardwoods for the 13 states examined in the 2009-2015 study period (USDA Forest Service 2016-2017).

a result of these activities. Such information also is important to wood technologists as it helps explain the characteristics of the roundwood material being processed by primary manufacturers.

In this article we isolated, defined, and measured timber harvest patterns using FIA plot data. Although the focus of this study was on hardwood timber harvests, softwood timber was harvested in conjunction with hardwood in several of the states examined, which compelled the inclusion of softwood harvests as well. Once harvest patterns were defined, we measured the relative amount of hardwood and softwood trees removed by each and examined if there were differences at the state or regional level. We then examined the percentage basal area of different diameter groups for timber removed under the different harvesting patterns. Because the primary objective of this article was to determine the patterns that are occurring with respect to harvesting, the Summary section was used to discuss some of the potential reasons for variations in harvest patterns that could be explored in future research.

METHODS

Data

All data used in this study were obtained from the USDA Forest Service, FIA (USDA Forest Service, 2016-2017). Data on all available plots were downloaded for the states examined, but only plots remeasured since implementation of the annual inventory design in which at least one tree was counted as a live tree harvest removal were analyzed. All diameter data for live trees were recalculated in terms of square feet of basal area.

Development of Timber Harvesting Patterns

Because diameter-limit harvesting has been cited as a common form of hardwood timber removal for commercial purposes, we first examined plot level data for evidence of this behavior in four important hardwood states: Pennsylvania, West Virginia, Kentucky, and Tennessee. These states accounted for 34% of eastern hardwood lumber production in 2008 on a volume basis (Fig 1). Pennsylvania, West Virginia, and Kentucky seemed to exhibit harvest cuts consistent with diameter-limit harvests, but there was evidence of other harvesting practices as well. In addition, even when diameter seemed to be influential in the harvesting, not all large-diameter trees were cut as would be implied by the term "diameter-limit." Because of this observation, we decided to use the term "large diameter–influenced" to refer to cuts in which large-diameter tree harvest appeared to be the primary objective.

When the Tennessee data were examined, a smaller proportion of large diameter–influenced cuts were noted, and additional harvesting patterns including a recurring pattern of partial harvests of loblolly pine (*Pinus taeda*) became evident. Tennessee was an early adopter of Phase 2 plot design and had a large number of plots between 2000 and 2013 with harvesting activity. Because of this large amount of available data, we decided to examine this state intensely to isolate and define harvesting patterns using three criteria: the relative basal area of hardwood and softwood removed; the amount of total basal area removed; and the relative basal area of large-diameter hardwood trees removed. As a result, the first 8 of the 10 harvest patterns listed in Table 1 were developed.

The harvesting patterns delineated in Table 1 can be classified into two broad categories: major species groups removed (hardwood, softwoods, or mixed) and level of cut (partial cuts or clear-cuts). A hardwood cut was defined as one in which at least 85% of the live basal area removed was not softwood within the pine family (Pinaceae), including all pines (*Pinus* spp.), all firs (*Abies* spp.), all spruces (*Picea* spp.), larch/tamarack (*Larix laricina*), hemlock (*Tsuga canadensis*), and Douglas-fir (*Pseudotsuga menziesii*). A softwood cut was one in which at least 85% of the cuts were one or more of the prior-mentioned coniferous species groups. Softwood species belonging to the cypress family (Cupressaceae), including cypress (*Taxodium distichum*), redcedar (*Juniperus virginiana*), Atlantic white-cedar (*Chamaecyparis thyoides*), and northern white-cedar (*Thuja occidentalis*) were combined with hardwood species when estimating basal area and harvest removals. These species have specialized (ie usually high value) end markets, and in the case of cypress, lumber is graded under hardwood rules. Mixed cuts were ones in which neither major species group (as defined previously) exceeded the 85% threshold. Partial cuts were defined as cuts in which less than 85% of the live tree basal area was removed and clear-cuts were cuts in which more than 85% of live basal area was removed.

One softwood harvest pattern that was noticed in southern Tennessee involved sites in which all larger diameter trees were loblolly pine. These sites were partially harvested in a manner that suggested a softwood thinning (TH-SW) harvest pattern. This pattern initially isolated for loblolly pine was extended to red pines in Wisconsin and Michigan because of the similarity of the two patterns. The last harvest pattern listed in Table 1 is termed "other." This group includes specialty cuts of primarily atypical hardwood species such as black locust (*Robinia pseudoacacia*), atypical softwood species, or cuts that did not appear to correspond to any of the defined patterns. After the development of the original eight harvest patterns defined in Table 1, timber harvests in Pennsylvania, West Virginia, and Kentucky were reexamined using the initial eight specific harvesting patterns specified. The analysis was then extended to Indiana, Ohio, Missouri, Virginia, North Carolina, New York, Wisconsin, Michigan, Maine, and North Carolina. Because of the repeated observed hardwood cuts in which only small-diameter (under 11 inches) hardwood timber was removed in Wisconsin, Michigan, and New York, it was decided that an additional partial harvesting pattern termed small-diameter hardwood (SD-HW) cuts should be included (Table 1). Data from all states were reexamined to see if any observations originally classified as "other" were to be moved to this new category.

Data Analysis

Total basal area of live timber on a plot before harvest was calculated as the sum of the basal area of live remaining trees (status code 1), past diameter of trees killed through silvicultural or landclearing activity but not utilized (status code 2, death agent 80), and past diameter of trees killed through silvicultural or landclearing activity and assumed to be utilized (status code 3 death agent 80). Basal area of harvest and silvicultural removals was calculated as prior-measured diameter because no estimate of diameter at time of removal was calculated for states in the northern FIA region.

Table 1. Definitions of hardwood and softwood harvest patterns.

Pattern	Abbreviation	Definition
Partial cut 1	DI-HW	Large diameter–influenced hardwood cut, at least 80% of basal area removed were hardwood sawtimber size trees (11 inches and larger), 85% of basal area removed were hardwood species,[a] and basal area harvest does not exceed 85% of basal area of live trees.
Partial cut 2	PC-HW	Hardwood partial cut of all diameters, at least some sawtimber size hardwood trees were cut, at least 85% of basal area removed were hardwood species, and basal area harvest does not exceed 85% of basal area of live trees.
Partial cut 3	PC-MX	Mixed hardwood and softwood[b] partial cut of all diameters with hardwood plus softwood basal area removed not exceeding 85% of total live trees basal area and the proportion of hardwood or softwood basal area removed not exceeding 85% total cut.
Partial cut 4	PC-SW	Softwood partial cut of all diameters with hardwood cut not exceeding 15% of basal area removed and basal area harvest does not exceed 85% of basal area of live trees.
Clear-cut 1	CC-HW	More than 85% of basal area of live trees was removed with at least 85% of harvest being hardwoods.
Clear-cut 2	CC-SW	More than 85% of basal area of live trees was removed with at least 85% of harvest being softwoods.
Clear-cut 3	CC-MX	More than 85% of basal area of live trees was removed with the proportion of hardwood or softwood basal area harvest not exceeding 85% total cut.
Loblolly or red pine thinning	TH-SW	Partial harvest or apparent thinning of loblolly pine (North Carolina, Virginia, Tennessee, and Kentucky) or red pine (Wisconsin and Michigan) and total basal area harvest does not exceed 85% of the basal area of live trees. All larger diameter trees on plots were loblolly or red pine (*Pinus resinosa*) and removal of multiple diameters over all or most sub plots.
Small-diameter hardwood cut	SD-HW	Hardwood partial cut small-diameter, no sawtimber size hardwood trees were cut, at least 85% of basal area removed were hardwood species, and basal area harvest does not exceed 85% of basal area of all trees.
Other cuts	Other	Special cuts involving black locust, redcedar, or sassafras (*Sassafras albidum*), and hardwood and softwood cuts not covered by other categories including harvests that have no apparent explanation.

[a] Also included softwood species with specialized markets including redcedar, Atlantic white-cedar, northern white-cedar, baldcypress, and pondcypress.
[b] All pines, all spruces, all firs, Douglas-fir, and larch/tamarack.

Initially, all remeasured plots were examined for the years available, which ranged from 2000-2014 for Tennessee to 2009-2015 for West Virginia. In an effort to examine all states in a consistent time frame, we decided that the time range of West Virginia data (2009-2015) was to be used for all states. The state data presented in Tables 2-5 start with the West-Central state of Missouri and then extend to states in the East-Central hardwood region before moving to the Northern region states of Pennsylvania and New York. Data for the Northern States of Wisconsin, Michigan, and Maine are then presented followed by data for the two Mid-Atlantic States, Virginia, and North Carolina.

Table 2. Number of plots examined by harvest pattern and state 2009-2015.

State	Region[a]	Harvest pattern[b]									
		DI-HW	PC-HW	PC-MX	PC-SW	CC-HW	CC-SW	CC-MX	TH-SW	SD-HW	Other
Missouri	WC	173	28	19	6	8	—[c]	2	—	25	25
Indiana	EC	78	4	—	2	4	—	—	—	12	27
Ohio	EC	114	16	6	3	16	2	—	—	12	22
W. Virginia	EC	93	18	3	2	8	—	1	—	8	17
Kentucky	EC	177	22	9	3	11	1	2	1	12	20
Tennessee	EC	157	36	12	17	40	11	5	11	14	18
Pennsylvania	N	191	52	14	13	9	—	5	—	21	24
New York	N	126	57	37	38	9	—	2	—	44	47
Wisconsin	N	197	251	104	77	73	17	21	71	169	86
Michigan	N	110	128	62	41	22	11	14	20	65	37
Maine	N	44	96	290	161	27	7	35	—	23	88
Virginia	MA	99	52	76	37	27	41	37	95	24	40
N. Carolina	MA	39	42	95	58	48	63	70	148	14	25

[a] WC, West-Central region; EC, East-Central region; N, Northern region; MA, Mid-Atlantic region (Luppold and Miller 2014).
[b] DI-HW, diameter-influenced hardwood cuts; PC-HW, hardwood partial cuts; PC-MX, mixed partial cuts; PC-SW, softwood partial cuts; CC-HW, hardwood clear-cuts; CC-SW, softwood clear-cuts; CC-MX, mixed clear-cuts; TH-SW, softwood thinning; SD-HW, small-diameter hardwood.
[c] Denotes no observations in the database.

RESULTS

Number of Plots

Table 2 presents the number of plots with timber harvest activity from 2009 to 2015 by harvest pattern and state. In total, nearly 5400 remeasured plots in which harvesting activity was noted during remeasurement were examined. Missouri, Indiana, Ohio, West Virginia, and Kentucky had a relatively high number of large diameter–influenced hardwood partial cuts (DI-HW), and few to no softwood partial cuts (PC-SW), softwood clear-cuts (CC-SW), mixed hardwood softwood clear-cuts (CC-MX), and softwood thinning cuts (TH-SW) were found in these states. DI-HW hardwood cuts were also the predominant harvest pattern in Tennessee, Pennsylvania, and New York but these states also had higher numbers of partial hardwood cuts (PC-HW), partial hardwood and softwood cuts (PC-MX), and PC-SW. Tennessee had a relatively high number of hardwood clear-cuts (CC-HW) and an initially unexpected number of TH-SW cuts given previous studies of this state's primary processing industries (Luppold and Bumgardner 2009; Luppold et al 2012). The PC-HW pattern was more frequent than DI-HW cuts in Wisconsin and Michigan and these states also had relatively high numbers of SD-HW cuts. The two most recurrent harvest patterns noted in Maine were PC-MX and PC-SW. Virginia had a similar number of DI-HW and TH-SW cuts whereas TH-SW was the predominant pattern noted in North Carolina.

Basal Area Removed—Hardwood and Specialty Softwood

Table 3 presents the percentage of hardwood (and specialty softwood) basal area removed by harvest pattern for each state. The percentage basal area of hardwood timber removed by DI-HW cuts ranged from 86.0% in Indiana to 7.2% in Maine. With the exception of Tennessee, states in the Central regions had at least 64% of basal area of hardwood removed in DI-HW cuts. CC-HW was the second most important hardwood timber harvest pattern in Ohio, West Virginia, Kentucky, and Tennessee. The DI-HW and CC-HW patterns accounted for 80-90% of the hardwood timber removed in all states in the East-Central hardwood region. By contrast, SD-HW cuts accounted for less than 3% of the hardwood basal area removed in these states.

Missouri was the only state examined in the West-Central region but had a similar DI-HW cut percentage to that of Kentucky but a much lower

Table 3. Percentage of hardwood (and specialty softwood) basal area harvest for roundwood production by harvest pattern for each state.[a]

State	Region[b]	Harvest pattern[c]									
		DI-HW	PC-HW	PC-MX	PC-SW	CC-HW	CC-SW	CC-MX	TH-SW	SD-HW	Other
Missouri	WC	67.3	11.8	6.6	—[d]	4.6	—	—	—	2.6	6.1
Indiana	EC	86.0	3.0	—	—	6.7	—	—	—	2.4	*t*[e]
Ohio	EC	64.2	11.1	*t*	*t*	21.3	*t*	—	—	*t*	*t*
W. Virginia	EC	66.3	13.4	*t*	—	16.3	—	*t*	—	*t*	*t*
Kentucky	EC	65.6	10.7	2.9	—	16.9	—	*t*	—	*t*	*t*
Tennessee	EC	51.8	12.3	3.1	*t*	28.6	*t*	*t*	—	*t*	*t*
Pennsylvania	N	62.3	22.6	4.2	*t*	4.3	—	3.6	—	*t*	*t*
New York	N	41.9	31.2	14.3	*t*	5.6	—	*t*	—	4.1	*t*
Wisconsin	N	19.8	38.5	9.4	*t*	19.7	*t*	3.5	*t*	7.3	*t*
Michigan	N	25.7	39.5	12.3	*t*	10.3	*t*	6.0	*t*	4.8	*t*
Maine	N	7.2	24.6	42.1	*t*	9.5	*t*	9.5	—	4.8	*t*
Virginia	MA	28.0	18.5	13.5	*t*	18.4	*t*	15.2	*t*	2.6	*t*
N. Carolina	MA	12.8	14.5	14.7	*t*	32.0	2.3	20.7	*t*	*t*	*t*

[a] State results may not add to 100.0 because of rounding and/or presence of trace amounts.
[b] WC, West-Central region; EC, East-Central region; N, Northern region; MA, Mid-Atlantic region (Luppold and Miller 2014).
[c] DI-HW, diameter-influenced hardwood cuts; PC-HW, hardwood partial cuts; PC-MX, mixed partial cuts; PC-SW, softwood partial cuts; CC-HW, hardwood clear-cuts; CC-SW, softwood clear-cuts; CC-MX, mixed clear-cuts; TH-SW, softwood thinning; SD-HW, small-diameter hardwood.
[d] Denotes no observations in the database.
[e] Trace amount of less than 2%.

level of CC-HW cuts. This state also was the only one with more than 2% of basal area removed in the "other" category. Ninety-five percent of the basal area removed in the other category for Missouri was where redcedar was the primary or only species cut.

Although the volume of maple species in Pennsylvania places it in the Northern hardwood region (Luppold and Miller 2014), the proportion of DI-HW cuts resembled that of states in the Central regions. However, the higher percentage in PC-HW suggests that it is a transitional state between the Central and Northern regions. The importance of the PC-HW pattern increased in New York and was the dominant harvest pattern in Wisconsin and Michigan. However, the importance of PC-HW was overshadowed by PC-MX in Maine. The Northern region states of New York, Wisconsin, Michigan, and Maine were the only states in which SD-HW cuts exceeded 4% of the hardwood harvests. Although DI-HW cuts made up the largest share of the harvest patterns in Virginia, CC-HW, PC-HW, PC-MX, and CC-MX patterns all exceeded 10%. The harvesting patterns in North Carolina were also diverse with CC-HW being the most dominant pattern for hardwood harvests.

Basal Area Removed Softwood

Table 4 presents the proportion of softwood basal area removed by harvest pattern for each state. The softwood proportion of the total cut for most states in the Central regions was less than 10%, making any analysis of the first five states in Table 4 difficult. Tennessee is again the exception, with 20% of total harvest during the time period examined being softwood. The prevalent harvest pattern for softwoods in Tennessee was CC-SW, followed by TH-SW, PC-SW, and PC-MX. The relatively high number of TH-SW cuts was unexpected because previous studies indicated no large softwood sawmills in this state (Luppold et al 2012). But there are large pulpmills in southern Tennessee/northern Alabama and a lot of hardwood stands were converted to pine plantations in the 80s and 90s that would now be in full pine management.

Nearly 15% of total harvests in Pennsylvania during the study period were softwood, with PC-SW and PC-MX being the most important (Table 4). Similarly, 20% of the total timber cut in New York was softwood, with PC-SW and PC-MX accounting for more than 90% of softwood basal area removed. Softwood cuts in Wisconsin

Table 4. Percentage of softwood basal area harvest for roundwood production by harvest pattern for each state.[a]

State	Region[b]	Harvest pattern[c]									
		DI-HW	PC-HW	PC-MX	PC-SW	CC-HW	CC-SW	CC-MX	TH-SW	SD-HW	Other
Missouri	WC	*t*[d]	—[e]	42.3	28.2	—	—	26.0	—	—	*t*
Indiana	EC	—	—	—	100.0	—	—	—	—	—	—
Ohio	EC	—	*t*	17.6	15.8	*t*	—	65.9	—	—	—
W. Virginia	EC	3.2	—	53.3	20.5	—	—	22.9	—	—	*t*
Kentucky	EC	—	—	45.9	8.2	—	32.0	5.0	8.2	*t*	*t*
Tennessee	EC	*t*	*t*	11.1	17.1	*t*	42.8	9.2	18.2	*t*	—
Pennsylvania	N	2.2	*t*	29.6	45.4	*t*	—	22.0	—	—	*t*
New York	N	*t*	*t*	42.3	49.1	—	—	6.2	—	*t*	*t*
Wisconsin	N	*t*	*t*	23.4	22.9	*t*	16.0	7.8	25.9	*t*	*t*
Michigan	N	—	2.1	21.6	23.7	*t*	20.8	13.5	17.0	*t*	*t*
Maine	N	*t*	*t*	45.4	37.5	*t*	3.7	11.3	—	*t*	*t*
Virginia	MA	*t*	*t*	14.0	7.5	*t*	29.1	14.7	33.7	*t*	*t*
N. Carolina	MA	*t*	*t*	12.2	9.4	*t*	27.4	18.0	32.1	*t*	*t*

[a] State results may not add to 100.0 due to rounding and/or presence of trace amounts.
[b] WC, West-Central region; EC, East-Central region; N, Northern region; MA, Mid-Atlantic region (Luppold and Miller 2014).
[c] DI-HW, diameter-influenced hardwood cuts; PC-HW, hardwood partial cuts; PC-MX, mixed partial cuts; PC-SW, softwood partial cuts; CC-HW, hardwood clear-cuts; CC-SW, softwood clear-cuts; CC-MX, mixed clear-cuts; TH-SW, softwood thinning; SD-HW, small-diameter hardwood.
[d] Trace amount of less than 2%.
[e] Denotes no observations in the database.

and Michigan were distributed over multiple patterns, with PC-MX, PC-SW, CC-SW, and TH-SW all accounting for more than 15% of the harvest removals in both states. Softwood harvests in Maine also tended to be concentrated in the PC-MX and PC-SW patterns. Maine was the only state in which a specific harvesting pattern (PC-MX) was the most important for both hardwoods and softwoods.

Virginia and North Carolina are both major producers of eastern hardwood lumber and produce intermediate amounts of eastern softwood lumber (U.S. Census Bureau 2009) and hardwood and softwood pulpwood (Bentley and Cooper 2015). In both states, TH-SW cuts accounted for around a third of softwood basal area harvest followed by a relatively high proportion of CC-SW. The PC-MX and CC-MX patterns also were important harvest patterns in these Mid-Atlantic States.

Basal Area Removed—Live Trees

Table 5 presents the percentage of live tree basal area removed when each harvest pattern was used by state. The percentages of harvests for the first six states (the West- and East-Central region states) fall within a fairly narrow range for DI-HW cuts but show greater variability and higher harvest rates for PC-HW (except for Indiana where only four PC-HW were found). The greatest degree of variability across all states was the SD-HW pattern, which ranged from 1.5% in Ohio to 20.3% in Tennessee. But as evident in Tables 2 and 3, SD-HW cuts, although numerous, were relatively insignificant in the actual basal area of hardwood timber removed. All other partial cuts (PC-MX and PC-SW) also showed larger degrees of variability for states in the Central regions. The percentage values for the five states with more than five observed CC-HW were high, but this high percentage would be expected by definition of clear-cuts in Table 1. The relatively high values for basal area removed in "other" cuts for Missouri and Kentucky were the result of redcedar cuts.

Tennessee was the only state in the Central regions with more than five observations for all harvest patterns. Still, other than slightly higher harvest rates for all partial cuts than other states in the Central regions, the only major difference was a reportable value for the TH-SW category. Of the basal area removed in the "other" cut category for Tennessee, 90% were redcedar cuts.

Table 5. Percentage basal area of live trees removed when each harvest pattern was used by state.

State	Region[a]	Harvest pattern[b]									
		DI-HW	PC-HW	PC-MX	PC-SW	CC-HW	CC-SW	CC-MX	TH-SW	SD-HW	Other
Missouri	WC	27.6	37.7	37.1	18.8	97.0	—[c]	NR[d]	—	9.7	23.0
Indiana	EC	27.3	NR	—	NR	NR	—	—	—	6.4	2.9
Ohio	EC	28.8	34.7	24.8	NR	95.5	NR	—	—	1.5	5.7
W. Virginia	EC	32.3	31.9	NR	NR	97.8	—	NR	—	5.3	2.8
Kentucky	EC	31.9	46.9	48.6	NR	96.8	—	NR	NR	14.4	14.0
Tennessee	EC	35.8	43.8	54.3	27.1	92.0	98.2	92.1	33.0	20.3	9.7
Pennsylvania	N	25.9	36.2	34.9	27.7	98.5	—	97.8	—	9.7	2.7
New York	N	19.8	34.8	37.5	25.3	98.9	—	NR	—	7.6	2.6
Wisconsin	N	24.5	36.2	37.6	25.4	94.7	96.7	96.1	21.6	13.4	4.9
Michigan	N	26.1	32.9	36.6	24.1	97.0	95.4	98.9	27.6	10.8	4.7
Maine	N	25.4	41.8	43.0	31.6	90.0	94.5	92.9	—	11.0	10.6
Virginia	MA	32.3	43.7	45.2	27.7	96.9	96.9	97.8	37.1	21.1	4.0
N. Carolina	MA	33.4	44.3	40.7	33.7	96.2	93.6	95.4	34.7	7.5	4.9

[a] WC, West-Central region; EC, East-Central region; N, Northern region; MA, Mid-Atlantic region (Luppold and Miller 2014).
[b] DI-HW, diameter-influenced hardwood cuts; PC-HW, hardwood partial cuts; PC-MX, mixed partial cuts; PC-SW, softwood partial cuts; CC-HW, hardwood clear-cuts; CC-SW, softwood clear-cuts; CC-MX, mixed clear-cuts; TH-SW, softwood thinning; SD-HW, small-diameter hardwood.
[c] Denotes no observations in the database.
[d] Not reported because of five or fewer observations.

The five Northern region states had lower basal area harvest values for DI-HW cuts but had similar harvest rates for PC-HW when compared with other states. These states also had consistent harvest rates for PC-MX and PC-SW, and high percentage values for clear-cuts. The only anomaly was the low value of the DI-HW cut for New York. Wisconsin and Michigan had a number of CC-SW and TH-SW cuts. Although the high percentage of cuts in the "other" category was explainable for states in the Central regions, the high value for Maine was not associated with any specialty cut but rather a large number of seemingly odd cuts. For example, in one case only two 5-inch northern red oak (*Quercus rubra*) trees were removed from an uneven-aged plot with more than 70 stems.

Although the proportion of cuts presented in Table 2 for Tennessee were considerably different from that of Virginia and North Carolina, the percentage of basal area of live trees removed were similar for DI-HW cuts and PC-HW. The softwood (loblolly pine) cuts for these three states were also similar and higher than the thinning cuts in Wisconsin and Michigan. One of the most unexpected but explainable observations of this analysis was the consistency of loblolly pine thinning cuts in Tennessee, Virginia, and North Carolina.

SUMMARY AND FUTURE RESEARCH

Although there were a wide variety of harvesting practices identified and examined in this study, there were discernable regional patterns in hardwood and softwood harvesting. DI-HW cuts accounted for most of the basal area of hardwood timber removed in Missouri, Indiana, Ohio, West Virginia, Kentucky, Tennessee, and Pennsylvania. The plurality of basal area of hardwood timber removed in New York also was in DI-HW cuts, but this state had a higher proportion of PC-HW and PC-MX than did states in the Central regions. Pennsylvania seemed to be a state that transitioned between the Central and Northern regions. In Michigan and Wisconsin, nearly 40% of the hardwood timber removed followed the PC-HW pattern whereas more than 40% of the hardwood cut in Maine was removed with the PC-MX pattern.

Of all the major hardwood lumber producing states examined, Virginia and North Carolina had the lowest proportion of hardwood timber removed by DI-HW cuts. These states also had relatively high proportion of hardwood timber removed under the PC-MX pattern. By contrast, softwood cuts in these states were primarily distributed among TH-SW cuts, CC-SW, CC-MX, and PC-MX.

Missouri, Indiana, Ohio, West Virginia, Kentucky, and Pennsylvania had low numbers of softwood timber harvests and these harvests were primarily some combination of mixed hardwood softwood partial and clear-cuts (PC-MX and CC-MX) or PC-SW. Tennessee was the only state in the Central regions with at least five cuts defined by the PC-MX, PC-SW, CC-SW, CC-MX, and TH-SW patterns, with CC-SW being the most important. Nearly all of softwood timber removed in New York was in PC-MX and PC-SW. Softwood cuts in Wisconsin and Michigan were distributed over a combination of harvesting patterns.

The basal area removed on a given plot seemed to break into two major groups: 55% or less for partial cuts and 90% or more for clear-cuts. The PC-MX pattern normally had a higher level of basal area removed than any other pattern of partial cuts followed by PC-HW. The amount removed through DI-HW cuts was fairly consistent among all states (between 25% and 35% with the exception of New York). The most consistent pattern for basal area removed was TH-SW (primarily loblolly pine) in Tennessee, Virginia, and North Carolina.

Although the information generated by this study provided insight on harvesting practices in the major hardwood producing regions of the eastern United States, more research is needed to ascertain the major factors influencing these timber harvest patterns and their impacts. Foremost among these factors are the influence of ownership, timber markets, and use or nonuse of silvicultural prescriptions. There are some studies that provide information on such influences that could be linked to the baseline observations made in the current article. For example, Bumgardner et al (2013) found that postharvest stump diameters (ie the size of trees removed) differed by ownership type and proximity to pulpwood markets in central Wisconsin, but more research is needed across other regions. Luppold and Alderman (2007) found that removal of specific species could sometimes increase in the presence of new markets for those species.

Another important research area is to better understand how variation in harvesting practices are associated with the types and sizes of timber industries that exist in a region, and how the composition of regional industries can interact with timber management. With the clear-cut patterns, additional research is needed to determine what happens to these plots after these cuts. Variations in regeneration on plots where partial canopy removal occurs also needs to be observed and documented. Once this additional information is developed, long-term timber and ecological management practices can be developed that can possibly complement the economic considerations associated with timber harvests.

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