SPECIES COMPOSITION AND SUCCESSION IN YELLOW PINE STANDS FOLLOWING SOUTHERN PINE BEETLE OUTBREAKS IN TENNESSEE – PRELIMINARY RESULTS

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Abstract—The southern pine beetle (*Dendroctonus frontalis*) is a bark beetle that is native to the Southern United States, including Tennessee. The beetle is periodically epidemic and can cause high levels of mortality during epidemic years, particularly in dense or aging pine (*Pinus* spp.) stands. An epidemic outbreak of the Southern pine beetle occurred in 1999-2001. By 2001, at the peak of the epidemic, 55 counties in Tennessee were in outbreak status. Subsequent estimations suggest that over 350,000 acres of pine timber in the State were affected by the outbreak, causing hundreds of millions of dollars in damage. Given the relative scarcity of the softwood resource in the State compared to the abundance of hardwood species and the significant economic importance of softwoods in Tennessee, the composition and successional trajectory of pine stands impacted by southern pine beetle in the most recent 1999-2001 outbreak is of interest. Here, we measure and quantify the impacts of this southern pine beetle outbreak on the successional trajectory of impacted yellow pine stands. Plots from the Forest Service, U.S. Department of Agriculture Forest Inventory and Analysis Program measured prior, during, and after the outbreak are used to estimate the changes that occurred in southern yellow pine systems within Tennessee. The results from this study suggest that approximately 25 percent of the softwood-dominated forests in Tennessee was lost following the 2000 southern pine beetle event. The majority of that lost acreage transitioned into hardwood-dominated communities.

INTRODUCTION

The southern pine beetle (*Dendroctonus frontalis*) is a bark beetle that is native to the Southern United States, including Tennessee. The beetle is periodically epidemic (Thatcher and others 1980) and can cause high levels of mortality during epidemic years, particularly in dense or aging pine (*Pinus spp.*) stands (Harrington and others 2000). In the southern Appalachians, epidemic outbreaks are common every 10 to 25 years, while areas with warmer winters (Coastal Plain, Piedmont) may experience outbreaks every 7 to 12 years (Price and others 1998, Waldron and others 2007). The Southeastern States, including Tennessee, experienced an epidemic period from 1973 to 1977 that reportedly resulted in the mortality of about 4.5 billion board feet of pine timber (Thatcher and others 1982). Though Tennessee experienced a small outbreak in the mid-1980s, an epidemic outbreak occurred in 1999-2002 that rivaled the destruction of the mid-1970s epidemic (Oswalt and others 2009). By 2001, at the peak of the epidemic, 55 counties in Tennessee were in outbreak status. Subsequent estimates suggest that over 350,000 acres of pine timber in the State were affected by the outbreak, resulting in hundreds of millions of dollars in damage (Cassidy 2004).

Pine species occur throughout Tennessee, but overall the State is dominated by hardwood species (Oswalt and others 2009, Oswalt and others 2012). The most recent complete survey of Tennessee's forests indicated that in 2009 softwood forest acreage was at its lowest in over 50 years, while hardwood acreage continued to increase (Oswalt and others 2012). Although softwood acreage is low in comparison with hardwood acreage, softwood species are of economic and ecological importance and account for 22 percent of all timber product output in the State (Oswalt and others 2012).

Given the relative scarcity of the softwood resource in the State compared to the abundance of hardwood species, and given the significant economic importance of softwoods in Tennessee, the composition and successional trajectory of pine stands impacted by southern pine beetle in the most recent 1999-2002 outbreak (hereafter, 2000 outbreak) are of interest. Casual field observations during and following the 2000 outbreak suggested what appeared to be a large number of shade-tolerant hardwoods (e.g., *Quercus spp.*) in the understory of beetle-infested pine trees. To date, however, no empirical study has attempted to quantify the impact of the 2000 outbreak on the status of softwood-dominated forests in Tennessee.

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Citation for proceedings: Schweitzer, Callie J.; Clatterbuck, Wayne K.; Oswalt, Christopher M., eds. 2016. Proceedings of the 18th biennial southern silvicultural research conference. e–Gen. Tech. Rep. SRS–212. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 614 p.

Our objective was to quantify changes to Tennessee forests that were softwood dominated prior to the 2000 southern pine beetle outbreak. Specifically, we were interested in quantifying the impact of the 2000 event on softwood forest, how those forests changed, and identifying southern pine beetle as culpable for those changes. We used broad-scale forest inventory data collected by the Forest Service, U.S. Department of Agriculture Forest Inventory and Analysis Program.

METHODS

The Forest Inventory and Analysis (FIA) Program is the primary source for information about the extent, condition, status, and trends of forest resources across all ownerships in the United States (Oswalt and others 2014). FIA applies a nationally consistent sampling protocol using a quasi-systematic design to conduct a multiphase inventory of all ownerships. The national sample intensity is approximately one plot per 6,000 acres of land (Bechtold and Patterson 2005), with plots consisting of four 24-foot fixed-radius subplots spaced 120 feet apart in a triangular arrangement with one subplot in the center (Woudenberg and others 2010). Forested plots, approximately 125,000 in total, are visited every 5 to 7 years in the Eastern United States and every 10 years in the West. Forest land is defined as areas at least 10 percent stocked with tree species, at least 1 acre in size, and at least 120 feet wide (Bechtold and Patterson 2005). Permanent fixed-area FIA inventory plots (approximately one-sixth of an acre in total size) are established in forested conditions when field crews visit plot locations that have accessible forest land. Field crews collect data on more than 300 variables, including ownership, forest type, tree species, and site conditions (Oswalt and others 2014; Woudenberg and others 2010).

Data were obtained from the publicly available Forest Inventory and Analysis Database (FIADB) (Woudenberg and others 2010). All plots measured during the 1999 inventory (using the current annual design) in the East, Plateau, and Central FIA Units (fig. 1) of Tennessee that contained at least one condition identified as softwood or a mixed forest type per FIA definitions (Woudenberg and others 2010) were identified for inclusion in the study. A total of 575 plots met the above criteria (table 1). Data were obtained from every measurement, beginning in 1999, of each of the selected plots through 2013. All plots were measured at least twice, and many plots had three measurements during the period from 1999 to 2013. While all plots were measured during the 1999 inventory (hereafter labeled as Time 1), remeasurement of each plot occurred at a rate of approximately 100-120 plots per year from 2000-2013.

Changes in forest type were tracked and compared across two points in time, the initial Time 1 measurement and the last measurement of the same plot, usually observed between 2009 and 2013 (hereafter labeled as Time 2). Changes in forest type condition proportion (the proportion of the plot accounted for by a particular forest type), softwood species stocking, and softwood species density were calculated using Time 1 and Time 2 measurements. Between Time 1 and Time 2, any recorded disturbance was noted. Paired t-tests were performed to identify any significant changes in condition proportion, softwood stocking, and softwood density through time for each forest type. One-way analysis of variance with Tukey's mean separation was used to identify differences among disturbance types (insects, weather, human, etc.) within given forest types. The R software environment (R Core Team 2013) was used for all statistical analyses.

To further quantify forest changes, plots included in this study were used to generate area estimates by forest type for each of three FIA inventory years, 2003, 2008, or 2012. Area estimates were generated using standard FIA area estimation procedures (Bechtold and Patterson 2005). Forest type changes were tracked across all three times by comparing each plot to its previous measurement within the dataset.

RESULTS AND DISCUSSION

According to estimates based on FIA data from 1999 to 2012, softwood-dominated forests have declined from 1.1 million acres to 848 thousand acres across Tennessee, a decline of 24 percent. At the same time, mixed (softwood and hardwood) forests declined 22 percent from 912 thousand acres to 711 thousand acres.

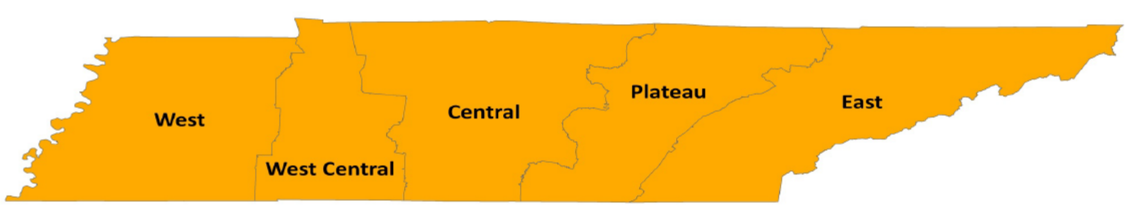

Figure 1—Forest Inventory and Analysis units in Tennessee.

Table 1—Number of Forest Inventory and Analysis plots measured by year in Tennessee identified as a softwood or mixed forest type

Year	Plots
1999	575
2000	118
2001	121
2002	103
2003	101
2004	121
2005	111
2006	119
2007	101
2008	101
2009	121
2010	108
2011	120
2012	93

Based on plots measured at Times 1 and 2, five softwood-dominated forest types and three mixed forest types experienced significant declines in condition proportion (the area of the plot accounted for by a given forest type) (fig. 2). Concomitantly, no hardwood-dominated forest types declined, and four hardwood-dominated forest types increased in condition proportion. The Yellow poplar/white oak/northern red oak and white oak forest types experienced the largest increases, while the Table Mountain pine, shortleaf pine, and shortleaf pine/oak forest types experienced the largest declines over the period of this study. The Table Mountain pine forest type declined in condition proportion by an average of 64 percent (table 2) per plot between Times 1 and 2. Each of the eight forest types that experienced significant declines shrank in condition proportion by at least 20 percent.

Changes in softwood stem density between Times 1 and 2 were found to be significant for only six forest types. All significant changes were negative (table 3). Mean stem-density decline was largest for the Table Mountain pine forest type (mean = -412 trees per acre). Of the six forest types identified as having significant average declines in stem density, three were softwood dominated (specifically pine dominated) and three were softwood-hardwood mixes.

Softwood species stocking significantly declined over the period of this study for a number of forest types (fig 3). Softwood stocking declines were largest for the Table Mountain pine, followed by eastern hemlock, Virginia pine, shortleaf pine, and loblolly pine forest types. Softwood stocking declined nearly 60 percent in plots where the Table Mountain pine forest type was found at Time 1. Softwood species stocking declines were not as severe for plots containing softwood-hardwood mixed forest types at the Time 1 measurement. However, softwood species stocking declines were still significant for four mixed forest types (fig. 3).

Softwood-dominated forest types experienced losses of approximately 219,000 acres during the early period of this study (approximately 1999-2003) (table 4). Area losses of mixed forests types were even larger, accounting for 272,000 acres during the same period. The largest changes were from mixed and softwood forest types transitioning to hardwood forest types. During the middle years of this study (approximately 2004-2008), considerable losses of softwood and mixed forest types were still occurring. The losses were not as large as during the early years. During the later years of this study (approximately 2009-2012), losses and transitions were essentially absent.

Softwood-dominated forests have declined significantly in the East, Plateau, and Central units of Tennessee following the 2000 southern pine beetle outbreak. In some cases, such as for Table Mountain pine (*Pinus pungens*), the resource was reduced beyond a level detectable by the FIA Program. While it is known through personal observation that Table Mountain pine stands still exist in the State of Tennessee, the area occupied by the Table Mountain pine forest type has declined to the point where it is no longer observed on any FIA plot in Tennessee (Oswalt and others 2012). In addition to the Table Mountain pine forest type, others such as the Virginia pine, shortleaf pine, and loblolly pine forest types have been significantly impacted and altered since 1999, prior to the 2000 southern pine beetle event.

It is clear from this study that many of the forests dominated by softwoods in 1999 no longer exist in the same condition. Many of those stands are now hardwood-dominated stands and are classified as a hardwood forest type. According to Oswalt and others (2012), approximately 1.1 million acres of softwood-dominated forests existed across the three units in this study in 1999. The results from this study suggest that approximately 25 percent of that resource was lost following the 2000 southern pine beetle event. The majority of that lost acreage transitioned into hardwood-dominated communities. Concomitantly,

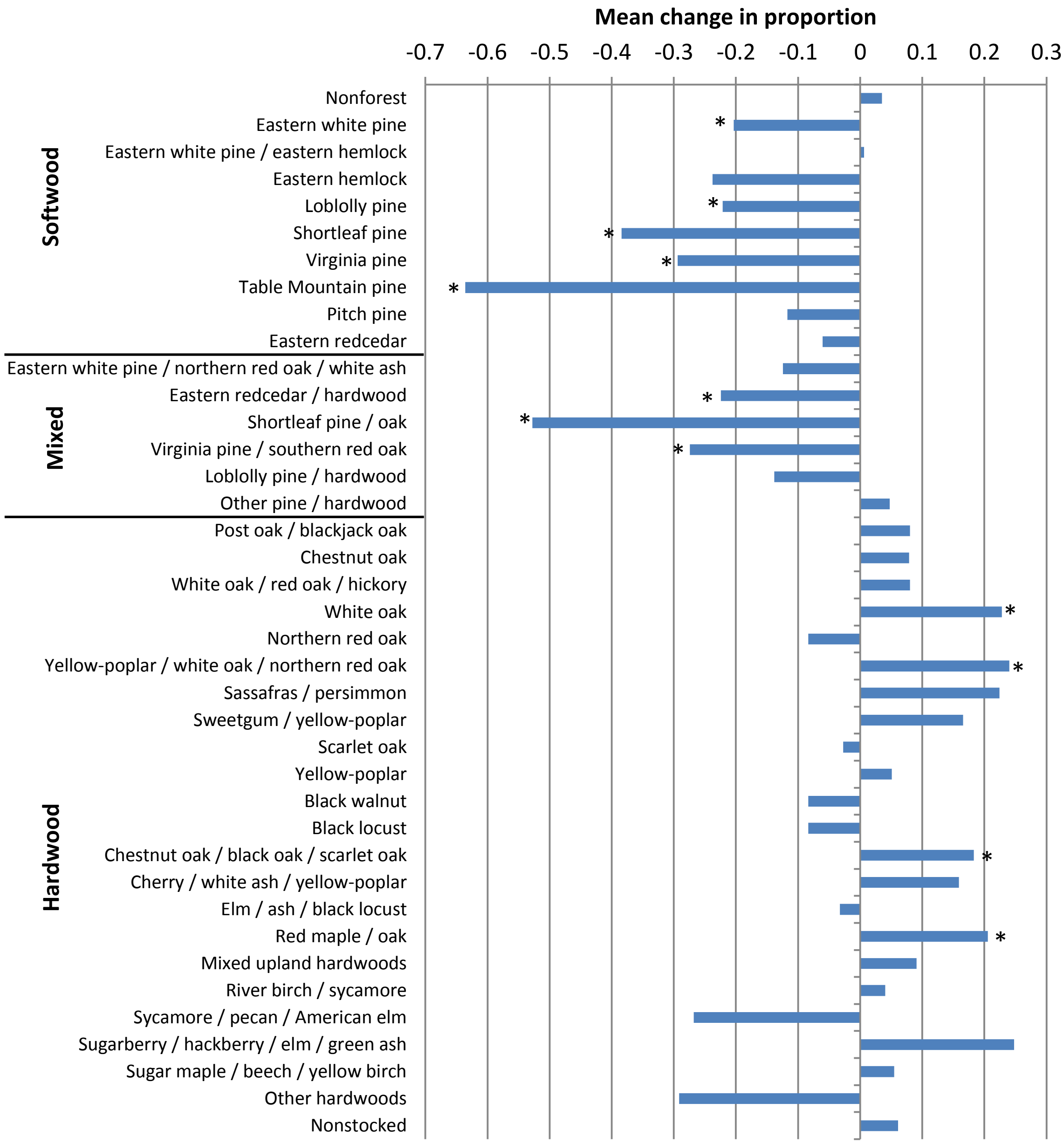

Figure 2—Mean change in condition proportion between 1999 and 2012 by forest type for plots dominated by softwood forest type in 1999 for the East, Plateau, and Central Forest Inventory units in Tennessee.

Table 2—Paired t-test results comparing condition proportion for each forest type for plots dominated by softwood forest type in 1999 for the East, Plateau, and Central Forest Inventory and Analysis units in Tennessee

Forest Type	MeanDiff	SE	t	p
Eastern white pine	-20%	9%	-2.2647	0.0337
Loblolly pine	-22%	7%	-3.0042	0.0039
Shortleaf pine	-38%	12%	-3.2972	0.0027
Virginia pine	-29%	4%	-7.5891	< 0.0001
Table Mountain pine	-64%	16%	-3.908	0.0174
Eastern redcedar / hardwood	-22%	6%	-3.9941	0.0001
Shortleaf pine / oak	-53%	10%	-5.4862	< 0.0001
Virginia pine / southern red oak	-27%	6%	-4.9784	< 0.0001
White oak	23%	10%	2.345	0.0269
Yellow-poplar / white oak / northern red oak	24%	10%	2.4369	0.022
Chestnut oak / black oak / scarlet oak	18%	8%	2.1785	0.0346
Red maple / oak	21%	9%	2.2628	0.0326

SE - standard error; t - t-test; p - p-value

Table 3—Paired t-test results comparing softwood tree density (trees per acre) for each forest type for plots dominated by softwood forest type in 1999 for the East, Plateau, and Central Forest Inventory and Analysis units in Tennessee

Forest Type	MeanDiff	SE	t	p
Shortleaf pine	-98.78	47.0213	-2.1008	0.0451
Virginia pine	-76.729	34.5387	-2.2215	0.028
Table Mountain pine	-414.2	134.529	-3.0789	0.037
Eastern redcedar / hardwood	-69.406	20.6003	-3.3692	0.0011
Shortleaf pine / oak	-62.874	19.2273	-3.2701	0.0024
Virginia pine / southern red oak	-55.102	16.9021	-3.2601	0.0015

SE - standard error; t - t-test; p - p-value

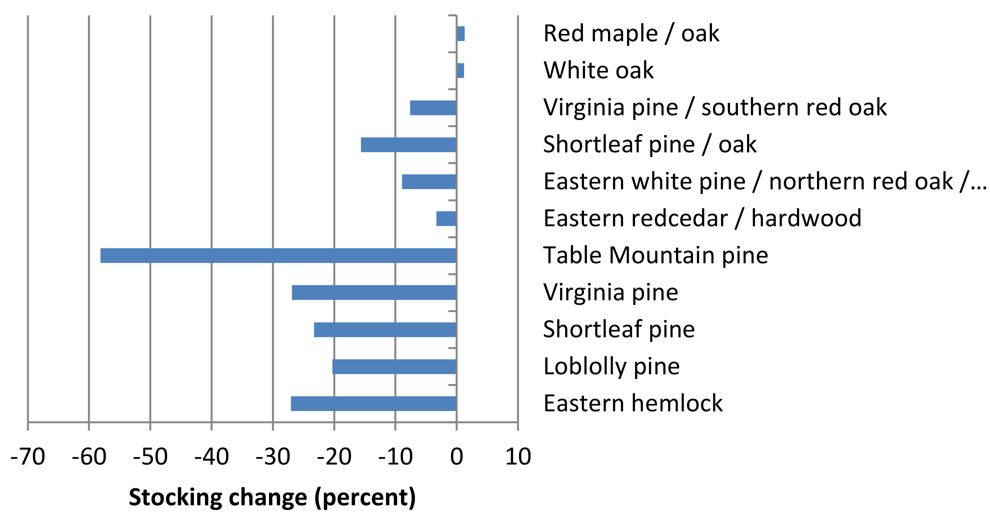

Figure 3—Mean change in relative stocking between 1999 and 2012 by forest type for plots dominated by softwood forest type in 1999 for the East, Plateau, and Central Forest Inventory and Analysis units in Tennessee.

Table 4—Broad forest type transitions for three different time periods for plots dominated by softwood forest type in 1999 for the East, Plateau, and Central Forest Inventory and Analysis units in Tennessee

Forest type transition	2003	2008	2012
Softwood to mixed	10%	6%	5%
Softwood to hardwood	14%	15%	6%
Mixed to hardwood	32%	29%	20%
Hardwood to mixed	8%	12%	9%
Hardwood to softwood	7%	7%	6%
Softwood to mixed	193,862	100,430	73,916
Softwood to hardwood	254,532	239,028	88,152
Mixed to hardwood	352,221	236,343	130,814
Hardwood to mixed	60,749	131,785	124,468
Hardwood to softwood	54,761	72,971	79,633
Softwood (net change)	(218,870)	(100,648)	35,132
Mixed (net change)	(272,373)	(169,967)	(49,997)
Hardwood (net change)	491,243	270,615	14,865

many mixed softwood-hardwood forests shifted to hardwood-dominated forests as well. At this time, these data cannot definitively identify the southern pine beetle as culpable for these changes. However, it can be inferred that the insect was at least one of the primary causes for this rapid shift of forest communities.

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