ASSESSING ANTHROPOGENIC AND NATURAL DISTURBANCES: FOREST RESPONSE TO SIMILARLY AGED CLEARCUT AND TORNADO DISTURBANCES IN AN EAST TENNESSEE OAK-HICKORY FOREST

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Abstract—In February of 1993, an F3 tornado caused a large-scale disturbance in an east Tennessee oak-hickory (*Quercus* spp.-*Carya* spp.) forest. Vegetation response to anthropogenic and natural disturbances was compared by examining two tornado-disturbed areas and five adjacent 1-acre silvicultural clearcut areas unaffected by the tornado disturbance. Nested overstory, midstory, and understory plots (0.1-, 0.02-, and 0.001-acre plots, respectively) were measured to determine species composition, species diversity, stocking, and structure, as well as coarse woody debris (CWD) volume, density, and percent cover. Results, 14 years postdisturbance, indicate that similarities exist in species composition and diversity between the clearcut and tornado areas, though differences in density do exist. Structural differences also occur between the two disturbance types. The presence of residual overstory and midstory trees in the tornado-disturbed areas caused the diameter distribution to have an irregular distribution compared to the typical even-aged distribution of the clearcut. CWD volume, density, and percent cover were significantly higher in the tornado-disturbed blocks.

INTRODUCTION

Prior to human settlement, forests were shaped by natural disturbances such as fire, insect infestations, and wind events. In mesic hardwood forests of the Eastern United States, where humidity limits fire frequency, wind is reported to be one of the main causes of large-scale natural disturbances (Canham and Loucks 1984). Large-scale wind disturbance is relatively irregular in this region but can have more of a long-term effect on stand composition than smaller, more frequent single-tree blowdowns (Clinton and Baker 2000).

On February 21, 1993, the University of Tennessee Forest Resources Research and Education Center (FRREC) in Oak Ridge, Anderson County, TN, was hit by an F3 (Fujita scale) tornado. Since 1950, there have been four recorded tornadoes in Anderson County (National Oceanic and Atmospheric Administration 2007). The aforementioned tornado was the most destructive tornado in the county during that timeframe. The main path of this tornado was roughly 10 miles (16.1 km) long, 0.45 miles (0.72 km) wide, and irregularly shaped (Newbold 1996). On the FRREC, 249 acres of forest were heavily damaged by the tornado and 103 acres had light to moderate damage, totaling roughly 352 acres of damage.

Due to the moderately infrequent and unpredictable nature of tornadoes and large-scale wind disturbances in the Ridge and Valley region, there is little work examining the successional pattern following such disturbance. The tornado disturbance site at the FRREC provides a unique opportunity to evaluate vegetation development following different disturbances. Because vegetation response to large-scale wind disturbance is unpredictable and no predictive outline has yet been created (Peterson and Pickett 1995), we evaluated the vegetation and coarse woody debris (CWD) response of tornado disturbance compared to a silvicultural clearcut (SCC) harvested 4 years prior to tornado disturbance to evaluate differences and similarities between natural and anthropogenic disturbances. The SCC and tornado-disturbed areas were adjacent to each other and had similar site conditions. We recognize that some variation is associated with the 4-year temporal difference between the two disturbances.

Objectives

Fourteen years after the tornado damage and roughly 18 years after the clearcut harvest, vegetation and CWD data were collected and used to meet the following objectives:

- Evaluate the impacts of tornado disturbance and SCC harvests on stand characteristics, including species composition, diversity, diameter distribution, and density
- Assess the impacts of tornado disturbance and SCC harvests on CWD density, CWD volume, and CWD biomass

The objectives listed were met by testing a null hypothesis that all treatments are not significantly different from each other for a given stand characteristic. The alternative hypothesis is that the treatments are significantly different for a given stand characteristic.

STUDY SITE

The University of Tennessee FRREC is located in Oak Ridge, TN, in Anderson County. The FRREC is a 2,260-acre (915-ha) tract that is part of the University of Tennessee Agricultural Experiment Station. The FRREC is found in the Ridge and Valley physiographic province, which is characterized by long, parallel, northeast-southwest running ridges that create narrow valleys between them (Moneymaker 1981).

Average annual precipitation for Oak Ridge is 55.1 inches (140.0 cm), 11.1 inches (28.2 cm) from snowfall. Average monthly temperatures range from 57.2 °F (14 °C) to 77.3 °F (25.2 °C) during spring and summer growing season months (April through September) (National Oceanic and Atmospheric Administration 2007). Soils within the research

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area are in the Fullerton series and are described as very deep, well-drained cherty silt loam soils. These soil types have slopes ranging from 5 to 45 percent (Natural Resources Conservation Service 2007). The average slope in the study area is 22.5 percent (research data).

In February 1993, an F3 tornado impacted the FRREC with maximum wind speeds of 158 to 206 miles per hour (254 to 332 kph) (City-Data 2007). The tornado was limited to the Chestnut Ridge portion of the FRREC and caused extensive levels of windthrow on roughly 350 acres (142 ha). As part of Karen Adreadis's (1995) and Chris Newbold's (1996) thesis projects, three treatments were implemented to evaluate small mammal and avian communities, respectively, and their usage of postdisturbance habitats. These three treatment areas were laid out in the spring of 1994. The tornado-disturbance-only treatment (no subsequent salvage harvest) was the natural disturbance used in this study to compare to anthropogenic disturbance (fig. 1).

A clearcut treatment was the anthropogenic disturbance used in this study. The clearcut was part of a site preparation study conducted in 1989 (Andrews 1995) to determine the most efficient way to regenerate a mixed pine-hardwood stand. The four treatments were SCC, SCC followed by burning, SCC followed by herbicide application then burning, and commercial clearcut. Treatments were broken into 1-acre (0.4-ha) blocks, replicated five times. Following site preparation, all treatments were planted on a 20- by 20-foot (6.1- by 6.1-m) spacing with 50 eastern white pine (*Pinus strobus*) seedlings on half of the block and 50 loblolly pine (*P. taeda*) seedlings on the other half, totaling 100 trees per acre (247 trees/ha).

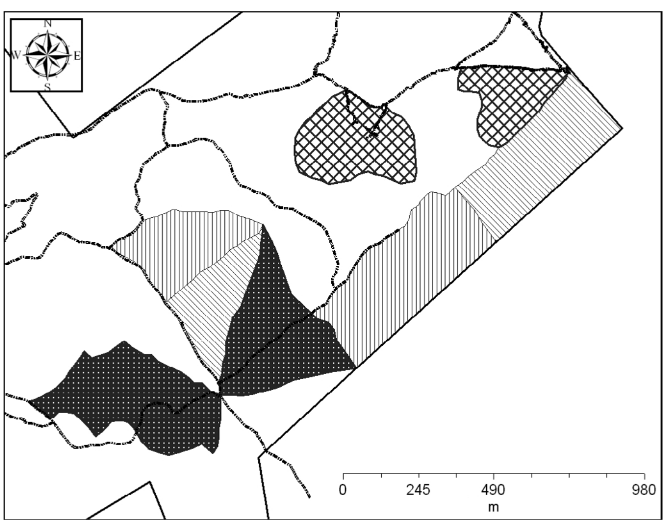

Figure 1—Treatment areas: Tornado (black) and Clearcut (crosshatch) at the University of Tennessee Forest Resources Research and Education Center in Oak Ridge, TN. (Other areas with hatched pattern were salvaged following tornado disturbance and are not part of this study.)

For the purpose of this research, only SCC blocks were assessed. Seedling survivorship for white pine and loblolly pine were 55 and 70 percent, respectively, 1 year after planting. Since then, the component of planted pine is negligible. The only remaining individuals are along replicate block edges, outside of vegetation and CWD plots of this study.

No predisturbance inventory was conducted on the tornado-disturbance study area. However, Newbold (1994) cited the predisturbance stand as a two-aged oak-hickory (*Quercus* spp.-*Carya* spp.) forest. The two-age classes consisted of a 100- to 120-year-old cohort of mostly oak species and a 60- to 80-year-old cohort that consisted of a significant amount of yellow-poplar (*Liriodendron tulipifera*). Timber cruises and preharvest inventories conducted in surrounding stands prior to tornado disturbance also indicate that the study area was an oak-hickory forest. More specifically, the stand was dominated by red oak species (mainly *Q. rubra*), white oak (*Q. alba*), and chestnut oak (*Q. prinus*). Inventories indicate that yellow-poplar, hickory, and miscellaneous hardwood and pine species also existed within the stand, but to a lesser extent than the oak species.

METHODS

Vegetation

Vegetation data were collected beginning in August 2007 within the tornado-disturbed area, and July 2008 in the clearcut area. Within a single treatment some variability exists between treatment areas due to different slope positions, aspects, and, within the tornado treatment, level of disturbance caused by the tornado. Although this variability exists, analysis has been conducted at the treatment level. Pseudoreplication occurs as each plot is statistically treated as a replicate considering low number of true replicates resulting in low statistical power. The assumption of true replication in the complete randomized design is admittedly not satisfied because natural disturbances such as tornadoes cannot be replicated.

Plot setup was as follows: 27 plots were established in the tornado-disturbed study areas, and 10 plots were established in the clearcut study area. Within the tornado treatment, plots were systematically laid out with a series of transect lines connecting plots, with a random starting point. Thirteen plots were established in the northern tornado study cell, and 14 plots were established in the southern study cell. Within the clearcut treatment, two vegetation plots were measured at each of the five 1-acre SCC blocks. The two plots were positioned 40 feet (12.2 m) north and south of the SCC block center stake along the division line between eastern white pine and loblolly pine plantings. If a planted pine was inside the plot or was determined to have an effect on the natural development of the vegetation within the plot, the plot was systematically moved 54 feet (16.5 m) parallel to the block boundary to the side of the block planted with eastern white pine. Since planted white pine survival was so low in the SCC, no plots were adversely affected. For both treatments, plots landing on a skid trail, road, old-log landing or treatment area boundary were moved one chain (66 feet or 20.1 m) perpendicular to the transect line away from the obstruction.

At each plot, three nested, fixed-area plots were established to measure the overstory, midstory, and understory. Percent slope, aspect, and slope position were recorded at the center stake of each plot. Percent slope was assessed using a Suunto clinometer. Aspect was categorized as being one of the four cardinal directions or a midpoint between two of the four cardinal directions, i.e., N, NE, E, SE, etc. Slope position was classified as being on the upper, middle, or lower third of the slope. These data were used as explanatory variables for variability between plots within treatments.

Each vegetation plot was broken into five strata categories:

- Overstory vegetation
- Midstory vegetation
- Understory woody vegetation >4 feet (1.2 m) tall
- Understory woody vegetation <4 feet (1.2 m) tall (presence/absence only)
- Understory herbaceous vegetation (presence/absence only)

One-tenth-acre (0.04-ha) overstory plots were centered along the predetermined transect line. At each overstory plot, trees with a diameter at 4.5 feet (1.4 m) from the ground (d.b.h.) ≥4.5 inches (11.4 cm) were tallied, and species and d.b.h. were recorded for e ach tree. D.b.h. was measured by 1-inch diameter classes where the i^{th} inch-class ranged from [i–1].5 to [i].4. Midstory plots were 0.02 acres (0.008 ha) with the same plot center as the overstory plot. At each midstory plot, trees from 1.5 to 4.4 inches (3.8 to 11.2 cm) d.b.h. were measured and recorded by species and diameter class. Two understory plots were measured at each overstory plot. The center of each of the two plots was 0.33 chains (6.7 m) perpendicular to and on either side of the transect line. The plots measured 0.001 acres (0.0004 ha) and every woody stem measuring <1.5 inches (3.8 cm) d.b.h. was recorded. Woody stems with a height ≥4 feet (1.2 m) were tallied by species. All woody plants <4 feet (1.2 m) as well as herbaceous plant species were recorded by species.

Coarse Woody Debris

In the spring of 2008, CWD was evaluated using the line intersect method, described by Waddell (2002). For every downed tree along a transect line, diameter at large and small end and length were measured. CWD measurement parameters included density, volume, and total biomass based on formulas derived from De Vries (1973) and presented by Waddell (2002) and Woodall and Monleon (2007). All of the following methods for CWD data collection are based on Waddell (2002).

CWD plots were placed at the same plot location as the vegetation plots for both treatments. Each plot contained three transect lines, 37.2 feet (11.3 m) long, from the center of the circular plot. Transect lines were oriented at 0, 135, and 225 degrees. Transect lines were traversed and a piece of CWD was measured if:

1. The central longitudinal axis of the piece intersected the transect
2. The diameter at the point of the intersections was at least 5 inches (12.7 cm)
3. The piece length was at least 3.3 feet (1 m)
4. The piece was not decayed to the point of having no structural integrity

In situations where large limbs from the main bole of the tree intersected the transect line or a tree forked and both forks crossed the transect line, they were treated as two separate pieces. In this instance, the larger diameter stem was considered the main bole of the tree, and smaller segment(s) were measured to the main bole as a separate piece.

For each CWD piece crossing the transect line, diameter at the large end and small end, and the total length were measured, and a decay class of 1 to 5 was assigned to each CWD piece (Waddell 2002) (table 1). Cubic-foot-volume for a single CWD piece was first calculated using the following equation:

$$\text{Volume of a log: } V_{ft} = [(\pi/8)(D_S^2 + D_L^2)l]/144 \qquad (1)$$

where
V_{ft} = the volume (cubic feet)
D_S = the small-end diameter (inches)
D_L = the large-end diameter (inches)
l = the piece length (feet)

Table 1—Decay-reduction constants for coarse woody debris pieces by species group in the tornado disturbance treatments at the University of Tennessee Forest Resources Research and Education Center in Oak Ridge, TN

	Species group	
Decay class	Softwood	Hardwood
1	1	1
2	0.84	0.78
3	0.71	0.45
4	0.45	0.42
5	0	0

Source: Waddell (2002, table 4).

Per-unit-area attributes were computed based on De Vries' (1973), Waddell's (2002), and Woodall and Monleon's (2007) formulas:

$$\text{Volume (ft}^3\text{/acre)} = (\pi/2L)(V_{ft}/l_i)f \quad (2)$$

$$\text{Density (logs/acre)} = (\pi/2L)(1/l_i)f \quad (3)$$

$$\text{Biomass (tons/acre)} = (1/2000)*[(\pi/2L)(V_{ft}/l_i)f]*BD*DC \quad (4)$$

where

f = the per-unit-area expansion factor [43,560 square feet per acre (10 000 m^2/ha)]

L = the transect length [37.2 feet (11.3 m)]

BD = the bulk density of hardwood [28.7 pounds per cubic foot (459.7 kg/m^3)] (Woodall and Monleon 2007, appendix 7.3)

DC = the decay-reduction constant (table 1)

Because species group was not recorded during data collection and most of the tree composition at the time of the storm was in the hardwood species, hardwood decay-reduction constants were used.

Data Analysis

Upon completion of data collection, vegetation and CWD data were analyzed for multiple stand and community characteristics. Species diversity (H') was calculated for woody vegetation >4 feet (1.2 m) tall, midstory, overstory, and combined midstory/overstory using the Shannon index (Shannon 1948).

Midstory and overstory density and basal area were calculated. Overstory and total basal area were reported for each treatment with associated stand errors to evaluate variability within treatments. Relative density and relative dominance (basal area) were calculated to determine species importance values (IV). Relative frequency was omitted from the standard IV calculation (Curtis and McIntosh 1951). If included, it would have caused bias based on the low abundance of many species in the overstory strata and spatial variability associated with the tornado disturbance. Therefore, the total IV summation index was calculated out of 200 instead of 300. Midstory and overstory IVs were calculated as separate strata, then together to determine species importance of all trees 2 inches (5.1 cm) and greater in diameter. Black oak (*Q. velutina*), scarlet oak (*Q. coccinea*), and northern red oak were grouped together as "red oaks"; chinquapin oak (*Q. muhlenbergii*), chestnut oak, and white oak were grouped as "white oaks"; and red elm (*Ulmus rubra*), winged elm (*U. alata*), and American elm (*U. americana*) were grouped as "elms."

Once IVs were calculated, species scoring <4.0 were dropped from the analysis. This value was selected because there was a natural break in the dataset, where species scoring <4.0 were usually observed on a single occasion within a given treatment. The five species with the highest IVs for each treatment were then used in diameter distribution curves and species density tables.

All statistical analyses were performed to test the null hypothesis, stating that there is no significant difference between treatments. To test this, a Mann-Whitney analysis (Mann and Whitney 1947) was computed where plot means were ranked and an analysis of variance was performed on the rank to determine statistical significance between treatments. Shannon (H') index scores, IVs, and CWD volume, density, and biomass were all tested in this manner by treatment.

RESULTS

Variability

Total basal area and the associated errors were similar between the two treatments, having high variability (table 2). Overstory basal area was much greater in the tornado treatment, but had a standard error that was 2.5 times greater than the clearcut treatment, illustrating the high variability in the tornado treatment.

Importance Values

Thirteen species/species groups had an IV >4.0 in either the tornado or clearcut areas. Of those 13 species only 3 species showed significant differences ($\alpha = 0.05$) between tornado and clearcut treatments: blackgum (*Nyssa sylvatica*), redbud (*Cercis canadensis*), and sugar maple (*Acer saccharum*) (table 3). Yellow-poplar, red maple (*A. rubrum*), black cherry (*Prunus serotina*), sourwood (*Oxydendrum arboreum*), and the white oak group have the five highest IV for both tornado and clearcut treatments. However, red maple has the highest IV for tornado and yellow-poplar has the highest IV for clearcut treatments. Although large differences occur for IVs between species such as red oaks, smooth sumac (*Rhus glabra*), eastern white pine, and yellow-poplar there are no significant differences between the two treatments for those species.

Tree Density and Structure

Tree density curves for tornado and clearcut treatments had similar shape but different densities, especially in the larger diameter classes. In the 2- to 7-inch diameter classes, the clearcut treatment averaged a higher stem density. However, all diameter classes >7 inches (where trees were present)

Table 2—Overstory and total basal area calculations for tornado and clearcut treatments at the University of Tennessee Forest Resources Research and Education Center in Oak Ridge, TN

Mean basal area	Tornado	Clearcut
	------- *square feet per acre* -------	
Overstory	63.30	25.91
(Standard error)	7.20	2.85
Total	90.11	82.99
(Standard error)	6.05	5.69

Table 3—Importance values by species based on a maximum 200 possible value in the tornado disturbance treatments at the University of Tennessee Forest Resources Research and Education Center in Oak Ridge, TN

Species	Tornado	Clearcut	*p*-value
Black cherry	24.07	28.36	0.4392
Blackgum*	8.25	1.4	0.0073
Flowering dogwood	10.39	5.85	0.0883
Hickory spp.	5.81	4.87	0.8083
Redbud*	7.6	0	0.0072
Red oaks	9.36	3.83	0.7089
Red maple	38.13	42.05	0.8934
Smooth sumac	0.39	4.13	0.2592
Sourwood	14.46	23.89	0.0541
Sugar maple*	4.69	0.39	0.0411
White oaks	21.58	19.83	0.7248
Eastern white pine	4.7	0	0.0796
Yellow-poplar	36.65	55.35	0.2504

P-values are reported (* signifies $P \leq 0.05$).

had greater stem densities in the tornado treatment (figs. 2 and 3). No trees in the 10-inch class or greater were found in the clearcut treatment.

The diameter distributions of both tornado and clearcut treatments indicated that red maple is a dominant species in the 2-inch class (table 4). This pattern continues in the tornado treatment for red maple into the 3-inch class as well. Yellow-poplar, which has the highest overall density in the tornado area, has the greatest density from the 5- to 18-inch diameter classes, as well as the 25-, 28-, and 30-inch classes (table 4). No trees exist for red maple beyond the 13-inch class, for black cherry beyond the 11-inch class, and sourwood beyond the 10-inch class. White oak, however, has a similar distribution shape as yellow-poplar from the 11- to 30-inch diameter classes with a lesser density.

In the clearcut, red maple density quickly dropped and yellow-poplar had the greatest density in all other diameter classes (table 4). Sourwood was competitive in the 2- and 3-inch classes, but no trees existed beyond the 5-inch class. Black cherry had its highest density in the 4-inch class and had a slightly lesser density, but a similar distribution curve, as yellow-poplar in the 4- to 9-inch classes. White oak had the lowest overall density of the five selected species, but had the greatest density in the 7- to 9-inch classes (table 4).

Shannon Diversity

Tornado areas had higher species diversity than clearcut areas in the overstory and combined midstory/overstory strata while having lower diversity in the midstory and understory strata (table 5). Differences in diversity were only significant in the overstory vegetation strata between treatments.

Coarse Woody Debris

CWD volume, density, and biomass were all significantly different between treatments (table 6). CWD volume was over four times greater in the tornado treatment. Similarly, CWD density was 2.5 times higher and CWD biomass was over seven times greater in the tornado treatment compared to the clearcut treatment.

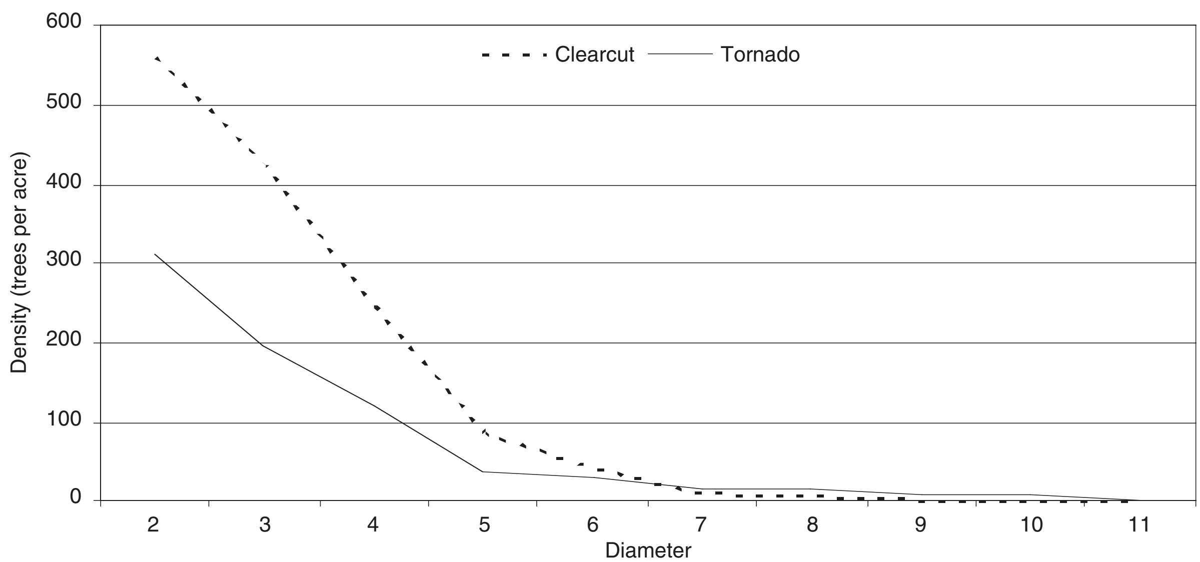

Figure 2—Tree density (trees per acre) for tornado and clearcut treatments for 2- to 11-inch trees at the University of Tennessee Forest Resources Research and Education Center in Oak Ridge, TN.

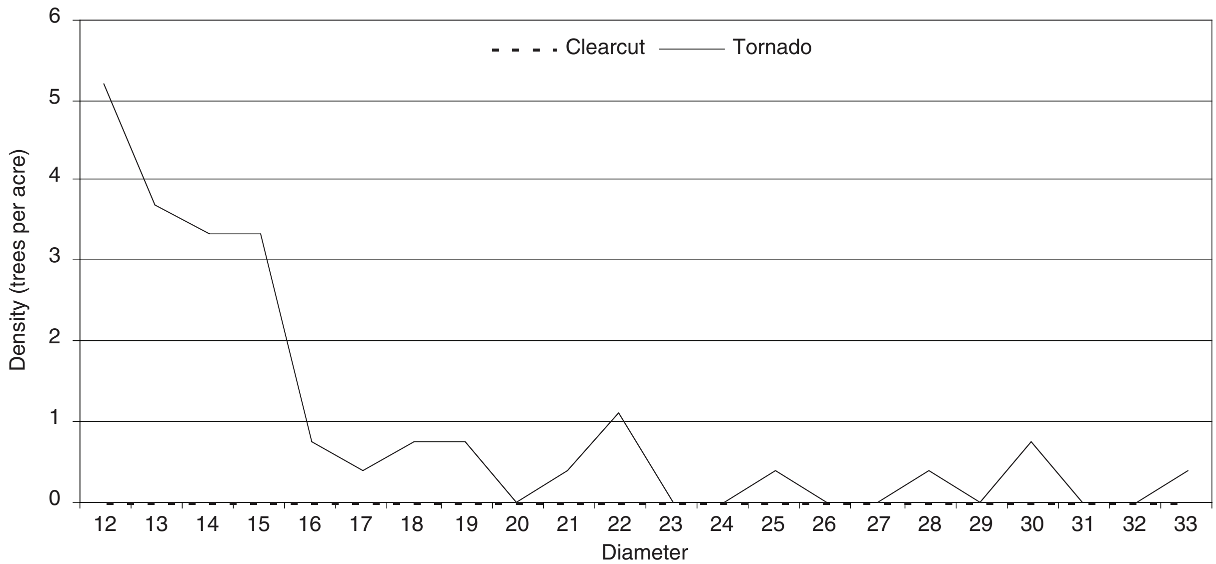

Figure 3—Tree density (trees per acre) for tornado and clearcut treatments for trees >12 inches at the University of Tennessee Forest Resources Research and Education Center in Oak Ridge, TN.

DISCUSSION

Species Composition

Thirteen species had an IV >4.0. The null hypothesis can only be rejected for three species: blackgum, redbud, and sugar maple. All three of these species are considered to be shade tolerant and had significantly greater importance in the tornado areas compared to the clearcut areas. Blackgum and sugar maple had an IV almost 6 and 12 times greater, respectively, in the tornado area. Redbud was not detected in the clearcut areas and therefore had no IV.

The comparison between tornado and clearcut disturbances expressed a relationship between the shade tolerance of the three significantly different species and the two different disturbance types. The clearcut was a stand-initiating disturbance. The tornado was considered to be an incomplete stand-scale disturbance, though one of relatively high intensity, creating large canopy gaps and few widely spaced residual trees. However, enough trees remained standing after the tornado disturbance to create light conditions significantly more suitable for shade tolerants like blackgum, redbud, and sugar maple (Burns and Honkala 1990).

Since the tornado created light conditions more suitable for shade-tolerant species, one would expect to see the inverse, where shade-intolerant species were significantly more important in the clearcut areas. The IV for many of the shade-intolerant species, e.g., yellow-poplar, black cherry, and white oaks (Burns and Honkala 1990), were much greater for both treatments than the shade-tolerant species. Their relatively high density and importance indicate that light conditions were suitable for intolerant species to grow in both treatments. Therefore one can deduce that absence of shade, in conjunction with higher stem densities in the clearcut made it more difficult for shade-tolerant species to compete. On the other hand, the few residual trees left in the tornado areas created more shade and lower stem densities, allowing shade-tolerant species to remain as part of the species composition. Miller and others (2006) support the theory that residual trees have an effect on the amount of light reaching the forest floor and thus the species composition of the new cohort.

Tree Density and Structure

No statistical analysis was conducted to test for treatment differences for diameter distribution and thus, density. Analysis could not be done for all diameter classes due to lack of residual overstory trees in the clearcut. Although the clearcut treatment was harvested almost 4 years before the tornado disturbance, total stem density is nearly two times greater in the clearcut areas. However, data in table 4 showed that proportions of yellow-poplar, red maple, black cherry, and white oaks were similar across both treatments.

The greatest differences in stem density occurred in smaller diameter classes (fig. 2), where the clearcut had roughly twice the density of the tornado areas. In the 7-inch diameter class, tornado densities became greater than clearcut densities and continue to be greater for the remaining diameter classes. Tornado disturbance has been noted to provide a greater range of diameter classes compared to clearcut disturbances (Price and others 1998). Similarly, no trees >9 inches (22.9 cm) were measured in the clearcut areas, while tornado areas had a greater range of diameters, with the largest tree having a 33-inch (83.8-cm) diameter. Both treatments have negative exponential curves, but the tornado areas have more trees

Table 4—Tree densities by diameter class for tornado and clearcut treatments at the University of Tennessee Forest Resources Research and Education Center in Oak Ridge, TN

	Tornado treatment					
D.b.h.	YEPO	REMA	BLCH	SOWO	WO	Total
	trees per acre					
2	28	96	50	20	13	313
3	31	50	31	17	6	196
4	22	17	24	7	2	119
5	38	8	6	4.8	9	38
6	29	6	3.3	2.2	7	29
7	14	3	1.1	3	3.7	14
8	14	4.4	0	2.2	2.6	14
9	8	1.5	0	0.7	2.6	8
10	8	0	0.7	0.7	2.6	8
11	3	0.4	0.4	0	1.1	3
12	5	0.4	0	0	3	5
13	3.7	0.7	0	0	0	4
14	3.3	0	0	0	1.9	3
15	3.3	0	0	0	0.7	3
16	0.7	0	0	0	0.4	1
17	0.4	0	0	0	0	0
18	0.7	0	0	0	0	1
19	0.7	0	0	0	0.7	1
20	0	0	0	0	0	0
21	0.4	0	0	0	0.4	0
22	1.1	0	0	0	0	1
23	0	0	0	0	0	0
24	0	0	0	0	0	0
25	0.4	0	0	0	0	0
26	0	0	0	0	0	0
27	0	0	0	0	0	0
28	0.4	0	0	0	0	0
29	0	0	0	0	0	0
30	0.7	0	0	0	0	1
Total density	216.3	187	117.4	58.1	56.3	763
Relative density (%)	28.40	24.50	15.40	7.60	7.40	

	Clearcut treatment					
D.b.h.	YEPO	REMA	BLCH	SOWO	WO	Total
	trees per acre					
2	135	255	20	65	55	560
3	135	65	35	90	25	425
4	70	55	65	30	20	245
5	29	11	24	1	15	87
6	14	8	11	0	5	41
7	3	1	0	0	4	10
8	1	0	2	0	2	7
9	1	0	1	0	0	2
Total density	388	395	158	186	126	1377
Relative density (%)	28.20	28.70	11.50	13.50	9.20	

YEPO = yellow-poplar; REMA = red maple; BLCH = black cherry; SOWO = sourwood; WO = white oak group.

Table 5—Shannon H' values by treatment reported for each vegetation strata in the tornado disturbance treatments at the University of Tennessee Forest Resources Research and Education Center in Oak Ridge, TN

Vegetation strata	Tornado	Clearcut	*P*-value
Understory >4 feet	0.663	0.788	0.6218
Midstory	1.337	1.475	0.1978
Overstory	1.505	1.323	0.0144
Midstory/overstory	1.785	1.646	0.4002

Table 6—Coarse woody debris volume, density, and biomass by treatment at the University of Tennessee Forest Resources Research and Education Center in Oak Ridge, TN

CWD attribute	Tornado	Clearcut	*P*-value
Volume (cubic feet per acre)	635.9	155.2	0.0057
Density (logs per acre)	108.1	42.4	0.0129
Biomass (tons per acre)	0.666	0.089	0.0023

intermittently spaced in the larger diameter classes. Although sparse, the trees in the larger diameter classes are from the residual stand. Since the residual stand was two-aged, the tornado areas are now in the complex stage of development. The complex stage is reached when gaps created at different points in time result in a multiaged stand (Oliver and Larson 1996). On the other hand, the clearcut areas are currently in the stem exclusion stage as the clearcut itself was a complete stand-initiating disturbance.

In both areas, red maple had similar diameter distribution, with high densities in the 2- and 3-inch classes. However, the number of red maple stems quickly descended to the densities of the other five important species with increasing size class. Red maple has a tendency to vigorously stump sprout. Many of these sprouts would likely decrease in the stand in the near future as intraspecific competition causes mortality of smaller stems (Burns and Honkala 1990). Considering only the new cohort of trees, yellow-poplar had the highest densities in the remaining diameter classes. White oaks existed in relatively low densities in all but the larger diameter classes for each treatment.

Species Diversity

Differences in H' diversity were not detected in any of the strata except in the overstory; therefore, the null hypothesis can be rejected for the overstory stratum. Here, the tornado areas had significantly greater diversity than the clearcut, due to a greater number of residual large diameter trees and more tree species.

Coarse Woody Debris

The tornado treatment had significantly greater CWD volume, density, and biomass; hence the null hypothesis can be rejected for all three attributes. In the tornado areas, there was more than four times the CWD volume, more than two times the CWD density, and more than seven times the CWD biomass. Much of the fine woody debris in the clearcut has decayed since the time of harvest and most of the large or CWD was removed at part of the harvest prescription. Pole stands (the category the clearcut treatment is most comparable to) tend to have the lowest CWD loads of all the even-aged developmental stages (McCarthy and Bailey 1994) due to the lack of large CWD pieces left after harvest (Price and others 1998).

The nature of each disturbance led us to expect that there would be more CWD loads in the tornado area which was supported by the data. Both CWD volume (155.2 and 157 cubic feet per acre, respectively) and CWD biomass (0.089 and 0.073 tons per acre) were similar between these two treatments. Although the harvests between the clearcut and salvage/slash were similar (removing to the 2-inch (5.1-cm) diameter class), small diameter trees were removed from the clearcut to allow for the planting of pines.

MANAGEMENT IMPLICATIONS

As the value of forest management becomes more recognized as an integral part of ecosystem management, there is a heightened interest in how silviculture can be used to emulate natural disturbances. Data from this study indicate that clearcuts and tornados are structurally two different disturbances. Although species importance and relative density are similar in both treatments, the tornado area is more structurally diverse. Overall, diameter distributions had greater ranges and CWD loading was greater in the tornado areas.

If silvicultural methods are used to imitate natural disturbance, a more irregular and erratic marking prescription is needed to ensure leaving residual trees that will have similar effects as the residual trees in the tornado areas. Diameter distributions and field observations for the tornado area show that trees from all crown classes must be left to imitate such conditions. Furthermore, to emulate the CWD loads from a tornado disturbance, some downed trees of all sizes would need to be left onsite.

From a timber management perspective, lower stem densities seen in the tornado areas will likely result in shorter, lower grade trees because early competition played less of a part in individual tree growth (Clatterbuck and Hodges 1987).

Although relative densities and IVs for individual species are similar, density-related competition occurs to a lesser extent in the tornado areas.

RESEARCH IMPLICATIONS

Some level of warning should be given along with the results of this research. The tornado areas had high levels of variability in them due to the nature of wind disturbances. Silvicultural clearcuts, however, tended to have less variability associated with them because such a disturbance is fairly constant across the stand.

As discussed in the “Methods” section, vegetation measurements were conducted in the same manner at each plot location for both treatments. However, the number of plots and plot layout was different for each treatment because of the small area of the SCC areas from the mixed pine-hardwood study (Andrews 1995). The low number of plots from the clearcut treatment compared to tornado area, in conjunction with the variability in the tornado treatment may have increased the chances making type II error. For instance, table 3 indicated a difference of almost 20 between treatments of yellow-poplar IVs. The theories behind stand dynamics would indicate that yellow-poplar should have more success in a complete stand-initiating disturbance such as a clearcut versus an incomplete disturbance such as a tornado, yet no significant differences were detected.

Conversely, the aforementioned difficulties in experimental design should strengthen the importance of detected differences. This is especially true in the vegetation stand characteristics, i.e., IVs and Shannon H', where both low number of clearcut plots and tornado-treatment variability could have hidden stand differences. For this reason, the dissimilarities discovered between these two treatments signify that differences are apparent for those stand characteristics.

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