EFFECTS OF TORNADO AND SALVAGE HARVESTING DISTURBANCES ON VEGETATIVE COMMUNITY DYNAMICS IN UPLAND MIXED PINE—HARDWOOD STANDS WITHIN THE DAVY CROCKETT NATIONAL FOREST, TEXAS

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ABSTRACT

Natural disturbances have the potential to alter forest successional and developmental patterns. We examined vegetative community structure and composition 18 months following an EF-3 tornado (April 2019) and salvage operations (completed July 2019 to June 2020) within the Johnson Creek and Burrantown timber sale areas of the Davy Crockett National Forest in east Texas. A total of 25 plots were located across undisturbed, tornado damaged without salvage, and tornado damaged with salvage areas. Tornado severity was measured based on the tornado path, with high-severity damage being within the touch down event and medium-severity damage was adjacent to the event. Multivariate analysis indicated distinct differences within the vegetative communities across the disturbance groups. Unharvested tornado-disturbed areas had the greatest diversity of seedlings while tornado disturbed with salvage areas had the greatest diversity of herbaceous vegetation with the greatest occurrence of invasive species. The medium- and high-severity levels tended to have an overall higher diversity with a lower overstory basal area compared to the control. A more diverse and complex forest structure and community composition can be obtained by adjusting salvage operations and retaining patches of unharvested areas.

INTRODUCTION

Wind disturbance has been recognized as a major driver of forest dynamics (Holzmueller and others 2012; Nelson and others 2008, 2010; Peterson 2000; Peterson and others 1997; Rossi and others 2017). These uncontrollable natural disturbances can alter species composition, canopy structure and gap size, and overstory distribution (Holzmueller and others 2012, Peterson and others 1997). Forest successional patterns following tornado disturbances can also differ from that of other natural and anthropogenic disturbances due to the sporadic nature of catastrophic wind events (Holzmueller and others 2012, Nelson and others 2010, Peterson 2000, Peterson and others 1997). On many forests following a natural disturbance, foresters tend to implement salvage operations as a means to lessen economic losses caused by these unexpected disturbances. Salvage logging is a forestry practice in which standing and fallen trees are removed following natural stand altering disturbances. Multiple disturbances in quick succession may have impacts beyond the scope of single, discrete disturbance events (Kleinman and others 2017).

Most wind disturbances have a positive relationship with forest dynamics by enhancing habitat heterogeneity, resource availability, and variation in microtopography (Kleinman and others 2017, Nelson and others 2008, Peterson and others 1997, Rossi and others 2017). The results of natural disturbances, such as woody debris or tip-up mounds, often promote species diversity (Santoro and D'Amato 2019). Salvage harvesting is often viewed negatively for reducing these beneficial effects. The compound disturbance of wind severity and salvage harvesting may result in a plant community adapted to high-disturbance levels with prolific reproductive capabilities out competing plants with more sensitive requirements (Curtze and others 2018, Kleinman and others 2017, Santoro and D'Amato 2019). As the severity and frequency of natural and anthropogenic disturbances intensifies with global change and increasing human demand, it has become increasingly pertinent to obtain a greater understanding of vegetative recruitment and forest

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successional patterns following interacting disturbances (Kleinman and others 2017).

In April 2019, an EF-3 tornado damaged a large swath of a mixed upland forest within the Davy Crockett National Forest in east Texas. Some of the disturbed areas were subject to salvage logging of downed trees from July 2019 to June 2020. These activities resulted in a wide array of canopy and ground disturbances. The primary objectives of this study were to assess the vegetative response and determine if responses in species diversity differed among undisturbed, tornado disturbed, and tornado + salvage areas within the Johnson Creek and Burrantown timber sale areas of the Davy Crockett National Forest in east Texas.

MATERIALS AND METHODS

Study Area

This study was conducted on the Davy Crockett Ranger District in the national forests and grasslands in Houston and Trinity Counties, located about 120 miles north of Houston, in east Texas. At an elevation of 360 feet, the Davy Crockett Ranger District has an average summer high temperature ranging in the low-90s, winter high temperatures in the mid-60s, receives 48 inches of rain annually, and experiences, on average, 205 sunny days each year (U.S. Department of Agriculture 2020). The overstory consists predominantly of loblolly pine (*Pinus taeda* L.) and shortleaf pine (*Pinus echinata* Mill.). The midstory is characterized by white oak (*Quercus alba* L.) southern red oak (*Quercus falcata* Michx.), water oak (*Quercus nigra* L.), post oak (*Quercus stellata* Wangenh.), sweetgum (*Liquidambar styraciflua* L.), and winged elm (*Ulmus alata* Michx.). Soils consisted of Kirin and Cuthbert fine sandy loam along the Johnson Creek, medium-severity impacted area, as well as the Lilbert and Darco loamy fine sands along the Burrantown, high-severity area. The Johnson Creek location consists predominantly of loblolly and shortleaf pine with a mix of white oak, southern red oak, water oak, post oak, and sweetgum. A similar mix was observed in the Burrantown locations with the inclusion of hickory species (*Carya spp.*) and winged elm with the exclusion of southern red oak. This area is primarily managed for timber production with an emphasis on wildlife management.

On April 13, 2019, the Davy Crockett National Forest was hit by three tornadoes. The tornado paths were in a northeasterly direction and ranged in severity from EF-1 (up to 110 miles per hour winds) to EF-3 (135-160 miles per hour winds). It was estimated that more than 3,000 acres of the forest were impacted. All tornado-affected areas occurred on the northern half of the Davy Crockett National Forest. Salvage operations were conducted from July 2019 to June 2020. The requirement for salvage included non-hardwood trees that were broken, recently dead, leaning at more than a 45-degree angle with extensive bole damage, and susceptible to insect-induced mortality. Snags were left for wildlife habitat.

Data Collection

Sample plots were randomly identified by overlaying a 650-foot (200 m) grid within the Burrantown and Johnson Creek EF-3 affected areas. A total of five plots was located in each treatment of tornado damage and tornado + salvage harvest. Five plots were also identified adjacent to these areas to represent non-affected areas for a total of 25 plots. Treatment areas included control (non-affected areas), high-severity tornado damage and tornado + salvage areas, and medium-severity tornado damage and tornado + salvage areas. Tornado-damaged areas were located within the path of the tornado but did not undergo salvage logging operations. The tornado damage + salvage were tornado damage areas located within the path of the tornado and underwent salvage logging operations within 1 year of the tornado event. Tornado severity was measured based on the tornado path, with high-severity damage within the touch down event and medium-severity damage adjacent to the event. The control plots were not impacted by the tornado event or salvage operations.

Plots were located at a minimum of 650 feet from roads and outside of streamside management zones. Plots were located 650 feet apart. Each plot consisted of a circular 1/10th-acre overstory plot, a 1/100th-acre nested regeneration plot, and five 3.28- by 3.28-foot understory quadrats. In the 1/10th-acre overstory plot, all standing live trees and snags were tallied to species and diameter at breast height, 4.5 feet aboveground level. The total height was measured for all trees >5 inches. In the regeneration layer, seedlings (<12 inches in height) were tallied by species. Understory vegetation (including both woody and herbaceous growth forms) occurrence was quantified within a 1-m by 1-m quadrat. The species and percent coverage were recorded for each of the five nested quadrates (plot center, north, east, south, and west). The ground cover was estimated using Daubenmire cover classes (Daubenmire 1959) for subplot vegetation, bare ground, and downed woody debris. Data were not recorded before the tornado event, so all the collected data represents post-disturbance conditions.

Data Analysis

The basal area was calculated for overstory by species. The density was calculated by species for the seedling strata. The importance value for each stratum and for each treatment level were calculated following the protocols of Curtis and McIntosh (1950). The species diversity was calculated using the Shannon-Wiener Diversity index (Dejong 1975) using Past 4.06b (Hammer and others 2001) for each stratum at each treatment level. The Shannon-Wiener Diversity index was chosen because it was the most sensitive for the presence of rare or uncommon species (Beals and others 2000, Morris and others 2014) and took into account the total number of species sampled while adjusting for relative frequency and relative cover. The Hutcheson t-test was conducted to determine significances between the diversity indices calculated, significance was based on p-values < 0.1. The N-way analysis of variance (ANOVA) of expected mean squares was used to examine species abundance of each stratum for each site. The abundance data were transformed using log base-10 and significance was based on p-values < 0.1. The analysis of similarity (ANOSIM) comparisons using the Bray-Curtis dissimilarities was used to test for differences in community composition for each of the treatment levels previously listed using RStudio and the vegan package (version 1.7.8) (Oksanen and others 2020).

The indicator species analysis (ISA) is typically used to determine ecological indicators of community types (De Cáceres and others 2010). For this study, the ISA was used to determine if disturbance levels could be skewed as an indicator for vegetative species present (Bakker 2008), using RStudio and indicspecies package (version 1.7.8) (De Cáceres and others 2012). The ISA was run using species abundance data for each vegetative species, in each stratum, for each treatment level. Host specificity and intercardinal specificity were determined based on p-values <0.1.

RESULTS AND DISCUSSION

Overstory

The dominant species consisted of *P. taeda, P. echinata, L. styraciflua*, and *Q. alba* across all treatment levels (table 1). The basal area decreased for all species as disturbance intensity increased (ANOVA, P=0.073) (fig. 1). Tukey's pairwise comparison between treatments showed significant differences between tornado damage + salvage and tornado damage (p<0.001) regardless of the tornado intensity at each site with the addition of the salvage harvest having a smaller overstory basal area per acre than that of the control and the tornado-impacted locations. The Hutcheson t-test indicated a difference in Shannon's diversity (table 2) between disturbance, tornado damage (P=0.083), and tornado damage + salvage (P=0.066).

The overstory vegetation within each treatment type showed a dissimilarity between treatment areas (ANOSIM statistic R: 0.2072; P=0.010). Significant dissimilarity occurred between high-severity tornado damage + salvage and medium-severity tornado damage + salvage, this included snags (p=0.032), *L. styraciflua* (p=0.029), and *F. pennsylvanica* (p=0.045).

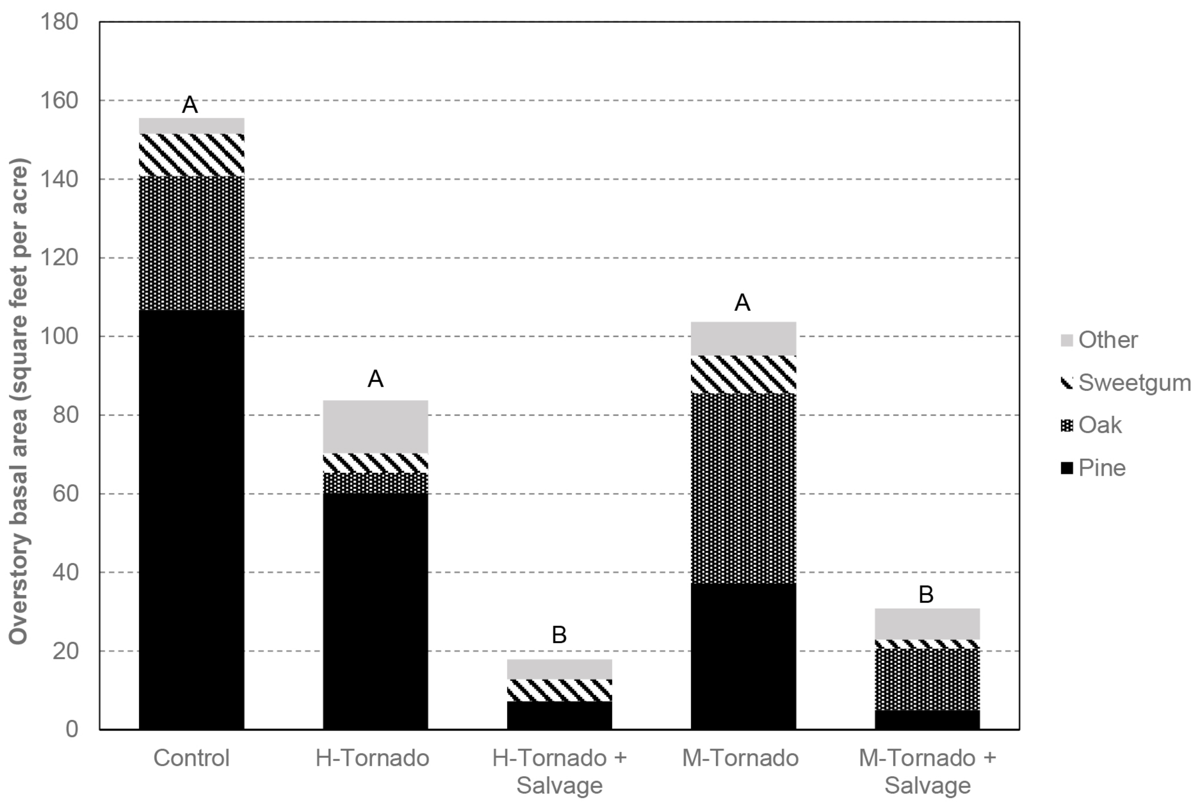

Figure 1—Total basal area per acre of the overstory live standing trees and snags (mixture of spp.) for each treatment area (ANOVA, P=0.073). Values represented by the same letter are not significantly different at α=0.1 level. Tukey's pairwise comparison between treatments showed significant differences between tornado damage + salvage and tornado damage (p<0.001).

Table 1—Importance values (IV), with a total IV >20, of the overstory live standing trees and snags for each treatment

Species	Control	H-tornado + salvage	H-tornado	M-tornado + salvage	M-tornado
Liquidambar styraciflua	8	32	12	6	13
Pinus echinata	8	–	15	6	23
Pinus taeda	38	19	35	7	4
Quercus alba	13	–	3	17	12
Snag (mixture of spp.)	6	19	4	16	6

– = no values; species were not observed in that area.

Table 2—Species richness and diversity using the Shannon-Wiener diversity index for herbaceous cover, overstory, and seedling cover for each treatment

		Control	H-tornado + salvage	H-tornado	M-tornado + salvage	M-tornado
Overstory	Richness	12	5	11	10	11
	Diversity	1.6	1.7	1.8	2.2	2.1
Seedling	Richness	13	14	16	14	17
	Diversity	1.9	1.7	2.3	2.4	2.4
Herbaceous	Richness	21	34	33	35	37
	Diversity	2.2	3.1	2.9	3.1	2.9

Seedlings

The seedling density (stems per acre) increased within the medium-severity areas despite treatment type, excluding the high-severity tornado damage + salvage (p=0.054) (fig. 2). Tukey's pairwise comparison between treatments showed significant differences between tornado intensity (p<0.001) and tornado damage + salvage and tornado damage (p<0.001). Shannon's diversity of seedlings increased with disturbance excluding the high-severity tornado damage + salvage when compared to the control groups, with the medium-severity plots having a higher diversity than that of the high-severity plots (table 2). The Hutcheson t-test showed a difference in Shannon's diversity between severity of disturbance for the compound disturbance but no difference in just the severity of tornado damage; tornado damage (P=0.471) and tornado damage + salvage (P=0.0001). Seedling density, richness, and diversity (excluding shrub species) were the greatest within the tornado-affected areas although not significantly different between the tornado and tornado + salvage areas. Similar results were documented in other research (Kleinman and others 2017).

Seedlings within each disturbance type showed a dissimilarity between treatment locations (ANOSIM statistic R: 0.433; P=<0.0001). Significant dissimilarity occurred between high-severity tornado damage + salvage and medium-severity tornado damage + salvage that included *Q. falcata* (p=0.013), *Q. nigra* (p=0.009), *U. alata* (p=0.006), *S. nigra* (p=0.010), *Q. stellata* (p=0.092), and *F. americana* (p=0.011). Significant dissimilarity occurred between three medium-severity impacted areas, *P. taeda* (p=0.009), *L. styraciflua* (p=0.012), and *O. virginiana* (p=0.001). Significant dissimilarity occurred between three high-severity impacted areas that included *S. albidum* (p=0.001), *I. opaca* (p=0.004), and *F. caroliniana* (p=0.001).

Herbaceous

Species richness and diversity increased with disturbance compared to the control groups (table 1). The Hutcheson t-test had no difference in Shannon's diversity between severity of disturbance of tornado damage; tornado damage (P=0.201) and tornado damage + salvage (P=0.620). However, the Hutcheson t-test had differences between the compound disturbance diversity; high severity (P=0.004) and medium severity (P=0.031).

Herbaceous vegetation within each treatment type showed a dissimilarity between treatment locations (ANOSIM statistic R: 0.4219; P=<0.0001). Significant dissimilarity occurred between two medium-severity impacted areas, leaf litter (p=0.007) and *L. japonicum* (p=0.004).

On the short-term response, salvage logging appeared to have a negative impact on species richness and diversity compared to that of just the tornado-impacted location for the overstory. The compound disturbance did provide a greater species richness and diversity of seedlings and

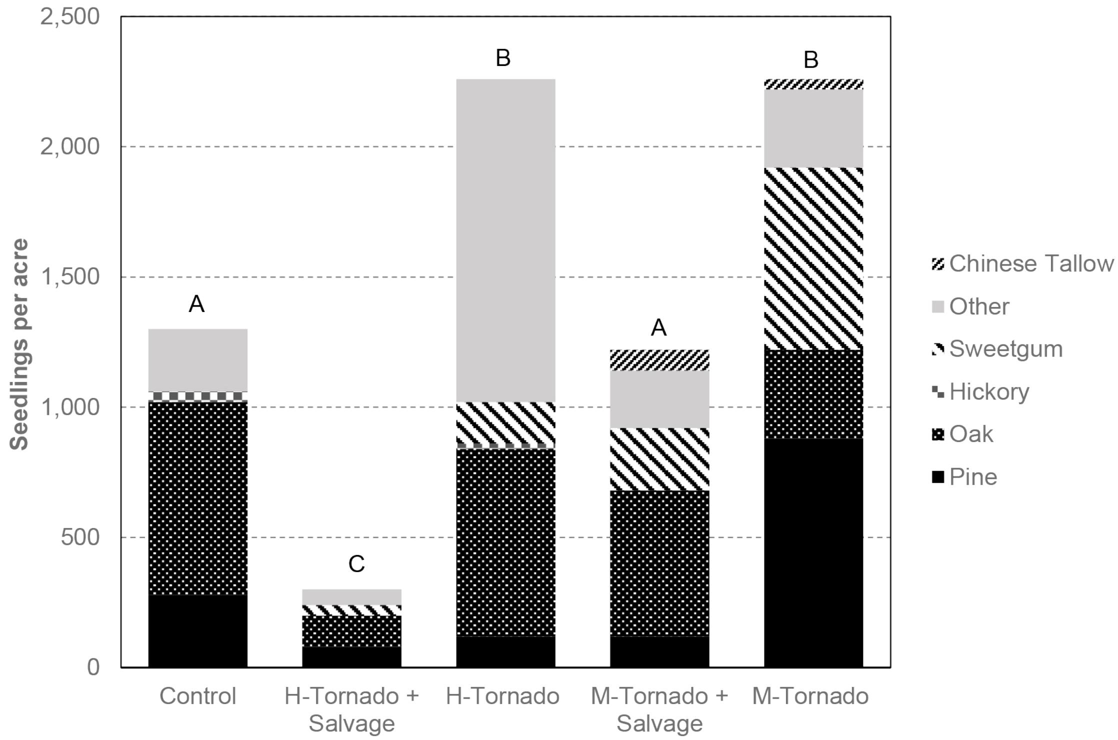

Figure 2—Number of seedlings per acre for each treatment. Other category includes maple, ash, elm, and sassafras species (ANOVA, P=0.054). Values represented by the same letter are not significantly different at α=0.1 level. Tukey's pairwise comparison between treatments showed significant differences between tornado intensity (p<0.001) and tornado damage + salvage and tornado damage (p<0.001).

herbaceous vegetation compared to that of the control areas. Other studies investigating salvage logging and vegetation responses have observed similar results (Kleinman and others 2017, Lindenmayer and Noss 2006, Nelson and others 2010, Palik and Kastendick 2009, Santoro and D'Amato 2019).

Two species had an indicator value of significance across all disturbance levels and strata. For the high-severity tornado damage + salvage areas within the herbaceous layer, *Lygodium japonicum* had a significance of (p=0.016). The medium-severity tornado damage areas and tornado damage + salvage areas had a significant ISA result for *Triadica sebifera* (p=0.007).

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Overall, our study identified the primary short-term response post-tornado and salvage logging within the understory facilitated regeneration. These results may be in response to favorable growing conditions such as greater solar radiation available along the soil surface. These favorable conditions also facilitate regeneration for disturbance-adapted species. The significance of *L. japonicum* and *T. sebifera* on compound-disturbed areas based on indicator species analysis suggest that compound disturbance (salvage logging following a natural disturbance) may ultimately alter community structure and composition as compared to the noncompound-disturbed areas. These impacts can shift species and functional composition of the regeneration layer, resulting in a different future forest community. Because the observed trends were only recorded for short-term recovery, we are unable to determine if salvage logging together with a natural disturbance will permanently result in successional trajectories varying from that of undisturbed or natural disturbed areas. While there are many benefits of salvage operations following a disturbance (Lindenmayer and Noss 2006), our results together with results from others show that it has an immediate, and possibly lasting, impact on the surrounding forest community (Curtze and others 2018; Kleinman and others 2017; Nelson and others 2008, 2010; Palik and Kastendick 2009; Santoro and D'Amato 2019). Structural legacies are essential in facilitating the recovery of species diversity; therefore, management should focus on retaining some of these structures during salvage operations (Franklin and others 2002, 2007; Kleinman and others 2017; Santoro and D'Amato 2019). The creation of a patchy mosaic of salvage and non-salvage areas will contribute to community and structural diversity, helping to emulate historical disturbance patterns and encourage structural and spatial diversity of the recovering forest.

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