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Catastrophic wind and salvage harvesting effects on woodland plants

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ABSTRACT

Compound disturbances may result in novel forest successional and developmental patterns. This study investigated effects of post-wind disturbance salvage harvesting, a unique compound disturbance of which the ecological consequences are unresolved, in fire-restored longleaf pine woodlands of the Alabama Fall Line Hills, a characteristically biodiverse and rare ecosystem. Plot-level data were collected May–June 2016 in areas undisturbed, wind-disturbed, and compound-disturbed (salvage harvested within seven months of an April 2011 EF3 tornado). Disturbance-mediated differences in (1) physical site conditions, (2) woody plant composition and structure, and (3) ground flora (herbaceous and woody plants ≤ 1 m in height) were assessed. Multivariate analyses revealed distinct differences in ground flora across disturbance categories. Biophysical drivers most correlated with differences in species assemblages included volume of coarse woody debris, sapling density, percent canopy cover, and basal area. Unharvested wind-disturbed plots had the greatest diversity of saplings and ground flora, and had indicator species with unique habitat requirements (specialists). Indicator species of compound-disturbed plots were mostly generalists that also had a relatively high frequency and abundance in the other disturbance categories. Reduced plant diversity on compound-disturbed plots was attributed to salvage harvest-mediated reductions in habitat heterogeneity and resource availability. Thus, leaving patches unharvested within salvaged stands is recommended to promote stand-scale plant diversity.

1. Introduction

Forest succession and development are influenced by disturbance agents, each with a unique frequency, severity, and spatial extent (Frelich, 2002; Oliver and Larson, 1996; White and Pickett, 1985). Variation in the spatiotemporal relationship and collective severity of disturbances results in distinct species assemblages and spatial arrangements (Roberts, 2004). Multiple disturbances in quick succession (i.e. compound disturbances) may have impacts beyond the scope of discrete disturbance events (Paine et al., 1998). As the frequency and severity of natural and human-induced disturbances intensify with global change and growing human demands, it is becoming increasingly relevant to study forest dynamics in the context of multiple interacting disturbances (Buma, 2015; Dale et al., 2001).

Longleaf pine (*Pinus palustris* P. Miller) ecosystems of the southeastern United States provide an excellent model for assessing effects of interacting disturbances, both natural and anthropogenic, because desirable conditions are clearly defined. Contrary to most temperate forests with complex woody plant assemblages and a broad range of conditions from desirable to degraded, proper-functioning longleaf pine ecosystems are relatively simple, approaching monospecific canopy strata situated above relatively open midstories. Degraded longleaf pine ecosystems that do not meet these criteria are easily recognized.

Continuity of longleaf pine dominated canopies and open midstories often requires surface fires to suppress small-statured woody competition coupled with canopy disturbances to facilitate canopy recruitment of longleaf pine (Gilliam et al., 2006; Platt et al., 1988). These fire-maintained conditions may also support some of the most species-rich assemblages of ground flora (woody and herbaceous plants ≤1 m height) in temperate forests of North America (Gilliam, 2007; Van Lear et al., 2005; Walker and Silletti, 2006). However, starting in the late 1800s, industrial-scale exploitation, land-use change, and fire suppression have made longleaf pine ecosystems one of the most endangered ecosystems in the United States (Frost, 1993, 2006; Noss et al., 1995), providing additional incentive to study contemporary disturbance effects on maintaining longleaf pine ecosystems.

Most wind disturbances enhance habitat heterogeneity and resource availability through canopy removal, generation of litter and debris associated with stripped leaves and broken stems, soil scarification, and creation of pit-and-mound microtopography (Beatty, 1984; Gardiner et al., 2016; Mitchell, 2013). Natural disturbance legacies (e.g. coarse woody debris) often support increased species diversity during early stages of development by providing suitable microclimatic conditions and resources (light, moisture, and nutrients) that were previously

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limited (Bartels and Chen, 2010; Swanson et al., 2011). Contrarily, salvage harvesting may be criticized for removing natural disturbance legacies, thereby diminishing species diversity and ecosystem functions (Lindenmayer et al., 2004; Lindenmayer and Noss, 2006). Furthermore, the interaction and collective severity of wind disturbance and salvage harvesting may result in novel forest recovery trajectories (Buma and Wessman, 2011). With the removal of wind-disturbance legacies, plants with prolific reproductive capabilities on heavily disturbed sites (i.e. invasive plants and other ruderal species) may outcompete those adapted to specific habitat requirements (Rumbaitis del Rio, 2006).

Biodiversity is closely linked to ecosystem processes and services that benefit human life, and human impacts on biodiversity have both direct and indirect effects on human well-being (Díaz et al., 2006; Millennium Ecosystem Assessment, 2005). Although some studies suggest salvage harvesting reduces biodiversity, Royo et al. (2016) and Waldron et al. (2014) posited that salvage harvesting can be conducted in ways that maintain or even enhance broad-scale species diversity, especially when some wind-disturbed patches are left unharvested. Because salvage harvesting is used globally to reclaim economic losses on damaged wood products and reduce risks of intense fire and insect outbreaks associated with wind-killed and weakened trees, there is need for a better understanding of salvage harvesting effects on forest recovery and biodiversity, especially ground flora diversity (Rumbaitis del Rio, 2006).

The overarching goal of this study was to assess the early response of a longleaf pine ecosystem to the collective impacts of catastrophic wind and salvage harvesting. Plot-level data were collected May–June 2016 in areas undisturbed, wind-disturbed, and compound-disturbed (salvage harvested within seven months of an April 2011 EF3 tornado) to compare disturbance-mediated differences in (1) physical site conditions, (2) woody plant composition and structure, and (3) ground flora. Results provide a reference condition for monitoring succession and development in this and other longleaf pine ecosystems, and highlight biophysical drivers and forest strata interactions associated with short-term recovery. This information may assist decision making on salvage harvesting in other forest types and enhance understanding of the role of disturbance in the maintenance of biodiversity.

2. Methods

2.1. Study area

This study was conducted on the Oakmulgee District of the Talladega National Forest in Bibb County, Alabama, USA (Fig. 1). The Oakmulgee District is located in the Fall Line Hills, a series of marine-deposited, sedimentary rock belts spanning the inland border of the Coastal Plain that have been carved by streams into steep slopes and ridges resembling the adjacent Appalachian Highlands (Fenneman, 1938; Griffith et al., 2001). Landforms in the study area are composed of the Late-Cretaceous Gordo Formation (GSA 2006). Soils in the Maubila series, which are common on hillslopes and ridges, are deep, moderately-well drained, and have a subangular blocky structure resulting in slow percolation of water (USDA NRCS 2008, 2016). Ironstone fragments occur throughout the soil profile, consisting of a sandy loam or loam surface layer to 10 cm deep situated on clay-based substrata over 200 cm deep to bedrock (USDA NRCS 2008).

The region has a humid mesothermal climate with year-round rainfall and a long, hot growing season (Thornthwaite, 1948). Annual precipitation averages 1376 mm (PRISM 2016). February has the highest mean monthly precipitation of 139 mm and October has the lowest mean monthly precipitation of 87 mm (PRISM 2016). Annual temperature of the study area averages 17 °C, with July having the highest mean monthly temperature of 27 °C and January having the lowest mean monthly temperature of 7 °C (PRISM 2016). The frost-free period spans ca. 230 days from March to November (USDA NRCS 2008).

Plant communities correspond to the Oak (*Quercus*)-Pine (*Pinus*) forest region of the southeastern United States (Braun, 1950). Harper (1943) distinguished these forests as the central longleaf pine belt of Alabama. Although longleaf pine dominates the canopy, loblolly pine (*Pinus taeda* Linnaeus), shortleaf pine (*P. echinata* P. Miller), and a diversity of hardwoods may also attain canopy and subcanopy positions (Beckett and Golden, 1982; Cox and Hart, 2015). Serving as a physiographic transition zone, the Fall Line Hills support species assemblages representative of the Coastal Plain and Appalachian Highlands (Shankman and Hart, 2007).

Harper (1943) speculated that longleaf pine ecosystems in the region "burned originally at least five years out of ten, but likely at irregular intervals." Following industrial-scale harvesting of longleaf pine coupled with an annual fire return interval in the early 1900s, many foresters incorrectly thought fire exclusion would protect these forests from further degradation (Harper, 1943; Reed, 1905). Since federal acquisition of the land in 1943, staff on the Oakmulgee District have prioritized longleaf pine restoration (Cox and Hart, 2015). Today, most restoration efforts are motivated by the intention to improve habitat for the federally endangered red-cockaded woodpecker (*Leuconotopicus borealis* Vieillot), which nests in living longleaf pine trees (Engstrom, 1993). Restoration efforts include regeneration harvests followed by site preparation and longleaf pine outplanting, tree and shrub density reductions in overstocked stands, and implementation of a two to five year prescribed fire rotation (USDA, 2005).

The Oakmulgee District occurs in one of the most tornado-prone regions of the United States (Coleman and Dixon, 2014). Sometimes called Dixie Alley, the Gulf Coast experiences a disproportionately high number of tornadoes (NCDC 2016a). Indeed, Harper (1943) and Reed (1905) recognized Bibb County, Alabama for commonly experiencing high-intensity tornadoes. Since 1950, the National Climatic Data Center (NCDC 2016b) reported three high-intensity (EF3 and greater) tornadoes in Bibb County. Among these was a strong, long-tracked wedge tornado classified as EF3 that tracked across the Oakmulgee District on 27 April 2011 with estimated wind speeds of 233 km/h (NWS 2011). This tornado was one of 362 confirmed tornadoes during the 2011 Super Outbreak event from 25 to 28 April 2011.

The tornado was followed by a salvage harvesting operation July–November 2011. This operation was designed as a cost-effective strategy to mitigate risks of intense fire, smoke, insect outbreaks, and other safety hazards associated with an abundance of wind-damaged trees (Ragland, 2011). Operators were permitted to sever wind-damaged trees of all species and size classes with wheeled feller bunchers and chainsaws. Wheeled skidders were used to elevate logs and skid them to a ramp site for processing and loading by a stationary knuckleboom loader onto truck/trailer combinations for over-the-road transportation (Caylor, personal communication). Because the wood-products market was oversupplied with salvaged timber following the 2011 Super Outbreak, only the most accessible and merchantable stems were salvaged. Salvage harvesting occurred close to pre-existing road networks, leaving some wind-disturbed patches that were less accessible, but analogous from a biophysical perspective, unaffected by salvage harvesting. Combined with the presence of areas undisturbed by the tornado, these conditions provided the opportunity to compare undisturbed, wind-disturbed, and compound-disturbed (wind + salvage) sections of the Oakmulgee District (Fig. 2).

2.2. Field methods

Sites with similar pre-disturbance biophysical site characteristics were selected to distinguish disturbance-mediated differences in site conditions from differences resulting from environmental variation before the storm. Geospatial data provided by the USDA Forest Service were used to select sites characterized by longleaf pine dominance (FSVeg code 21) that established naturally prior to 1940. These second-growth sites occurred on upper and middle slope positions within a