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# Effects of intermediate-severity disturbance on composition and structure in mixed *Pinus*-hardwood stands

Benjamin W. Trammell [a], Justin L. Hart [a,*], Callie J. Schweitzer [b], Daniel C. Dey [c], Michael K. Steinberg [a]

[a] Department of Geography, University of Alabama, Tuscaloosa, AL 35487, USA
[b] Southern Research Station, USDA Forest Service, Huntsville, AL 35801, USA
[c] Northern Research Station, USDA Forest Service, Columbia, MO 65211, USA

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ABSTRACT

Increasingly, forest managers intend to create or maintain mixed *Pinus*-hardwood stands. This stand assemblage may be driven by a variety of objectives but is often motivated by the desire to enhance native forest diversity and promote resilience to perturbations. Documenting the effects of natural disturbances on species composition and stand structure, and thus successional and developmental pathways, in stands with these mixtures is essential to achieve these goals. The specific objectives of this study were to quantify and compare the impacts of an intermediate-severity canopy disturbance on woody species composition, canopy structure, understory light regimes, and species diversity in mixed *Pinus* (*Pinus taeda* and *Pinus virginiana*)-hardwood stands on the Cumberland Plateau in Alabama. The natural intermediate-severity disturbance disproportionately removed large *Pinus* stems, promoted hardwood dominance, and effectively accelerated succession. The resultant stand structure did not resemble one of the widely recognized stages of stand development and was best characterized by the mixed-stage of development. The canopy disturbance did not significantly alter canopy-layer species diversity, but seedling- and sapling-layer diversity was significantly greater in disturbed neighborhoods. Results from this study may be used as guidelines by managers of mixed *Pinus*-hardwood systems. To maintain a *Pinus* component in stands that are succeeding to hardwood dominance, canopy disturbance alone is insufficient and must be planned in conjunction with competition reduction measures in the regeneration layer, such as fire or herbicide application. Conversely, if managers wish to promote a hardwood component in pure or near pure *Pinus* stands, creation of variably sized canopy openings throughout the stand may recruit hardwood reproduction to larger size classes, as the intermediate-severity disturbance documented here accelerated succession toward hardwood dominance.



## 1. Introduction

Forest disturbances, events to which all forest ecosystems are subject, disrupt the biophysical environment and influence developmental and successional processes (White and Pickett, 1985; Foster et al., 1998). Forest disturbances are typically classified based on severity, spatial extent, and frequency and range from small, frequent, single-tree gaps to large, infrequent, stand replacing events (Oliver and Larson, 1996). Intermediate-severity disturbances (ISD) occur along the gradient between the two endpoints (Cowden et al., 2014). Natural agents that may result in an ISD include strong wind events (e.g., tornadoes, downbursts from convective storms, and hurricanes), mixed-severity fires, ice storms, insect outbreaks, and diseases (Oliver and Larson, 1996; Peterson, 2000; Nagel and Diaci, 2006; Hart et al., 2008). Although disturbance agents and the effects of discrete ISD events vary widely, all ISDs typically alter the availability of light in the understory, which is regarded as the most common limiting abiotic factor in closed canopy forests (Canham and Loucks, 1984; Oliver and Larson, 1996; Hanson and Lorimer, 2007; Grayson et al. 2012). Intermediate-severity disturbances disrupt larger areas than gap-scale events and have a shorter return interval than the lifespan of most canopy trees (Canham and Loucks, 1984; Lorimer, 2001; Seymour et al., 2002; Hanson and Lorimer, 2007; Cowden et al., 2014; White et al. 2015), yet surprisingly little quantitative information is available on their influence in forest ecosystems.

The mixed *Pinus*-hardwood forest type spans millions of hectares throughout the eastern USA (Cooper, 1989; Smith and Darr, 2004). In the southeastern USA, many contemporary mixed *Pinus*-hardwood stands established as a result of land clearing for agriculture and subsequent abandonment (Cooper, 1989; Keeley

* Corresponding author.
*E-mail address:* hart013@ua.edu (J.L. Hart).

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and Zedler, 1998). Patterns of natural succession in such mixed *Pinus*-hardwood stands have been established (Peet and Christensen, 1980; Cooper, 1989; Shelton and Cain, 1999). The open, and sometimes low-fertility, conditions in old fields favor the establishment of early-seral *Pinus* stems. In the absence of fire, more shade-tolerant hardwoods typically establish in these stands, and an abundance of hardwood advanced reproduction in the understory inhibits *Pinus* regeneration. Without active management or relatively broad-scale natural disturbance, the *Pinus* component of these stands will diminish and the dominance of hardwood species will increase (Cooper, 1989; Guyette et al., 2007; Hart et al. 2012a; Weber et al., 2014).

Managers in the Central Hardwood Forest region are increasingly tasked with maintaining or creating *Pinus*-hardwood mixtures to meet a range of objectives including increased biodiversity, achieving desired fuel loads, enhanced resiliency to perturbations, commodity production, and restoration goals (Hart et al., 2012a; Clabo and Clatterbuck, 2015). Mixed *Pinus*-hardwood stands may be more structurally heterogeneous than pure *Pinus* or pure hardwood stands. As mixed stands contain tree species that represent a range of life history characteristics and growth forms (e.g. deciduous v. evergreen foliage), these stands may promote biological diversity by providing a comparatively wide range of habitat niche space for other organisms. For example, some wildlife species such as *Picoides borealis* Vieillot (red-cockaded woodpecker), *Sitta pusilla* Latham (brown-headed nuthatch), and *Setophaga pinus* Wilson (pine warbler) are associated with mature *Pinus* trees (Johnston and Odum, 1956; Dickson, 1982; Buckner, 1982; Owen, 1984). The acidic and highly flammable *Pinus* litter also provides a pathway for change in these systems. *Pinus* litter is considered highly flammable relative to some hardwood litter and promotes the spread of fire (Keeley and Zedler, 1998; Kane et al., 2008; Ellair and Platt, 2013). The *Pinus*-hardwood mixture may also promote resiliency to future disturbances, as well as provide options for uncertain future timber markets (Cooper, 1989; Clabo and Clatterbuck, 2015). Quantitative descriptions of the effects of natural and anthropogenic intermediate-severity disturbances in mixed *Pinus*-hardwood stands are needed to provide data necessary to actively manage in accord with natural processes, and develop silvicultural systems designed to create or maintain mixed *Pinus*-hardwood systems.

This study addressed a void in our understanding of the effects of intermediate-severity wind disturbance on species composition and succession, stand structure and development, and sub-canopy light regimes in mixed *Pinus*-hardwood stands. Additionally, this study serves as a reference point for natural disturbance-based management in this forest type. The specific objectives of this study were to quantify and compare effects of an ISD on woody species composition, stand structure, understory light regimes, and species diversity in mixed *Pinus*-hardwood stands. Our results provide quantitative information on the effects of natural intermediate-severity disturbances, which have been vastly understudied relative to catastrophic and gap-scale disturbances. This information may be used to develop silvicultural systems designed to retain a *Pinus* component in stands that are transitioning to hardwood dominance or conversely, to accelerate succession to hardwood dominance to achieve mixed *Pinus*-hardwood assemblages in pure or nearly pure *Pinus* stands.

## 2. Study area and methods

### *2.1. Study area*

Our study was conducted on the William B. Bankhead National Forest in northern Alabama. The Bankhead National Forest occurs on the Cumberland Plateau section of the Appalachian Plateaus physiographic province (Fenneman, 1938). The topography of the region is distinguished by its locally high relief with narrow ridges, steep slopes, and deep valleys. The area is so strongly dissected that it does not resemble a true plateau (Smalley, 1979). The underlying geology of the region is Pennsylvanian quartzose sandstone containing interstratified layers of limestone, shale, siltstone, and discontinuous anthracite and bituminous coal (Szabo et al., 1988). Soils in the region are generally shallow, acidic and well-drained (USDA SCS, 1959). The regional climate is classified as humid mesothermal, characterized by long, hot summers and short, mild winters (Thornthwaite, 1948). The mean annual temperature is 16 °C, with average temperatures in January and July of 5 °C and 26 °C, respectively. The growing season typically begins in mid-March and ends in early-November, lasting ca. 220 days. Mean annual precipitation is 149 cm with no formal dry season (PRISM Climate Group, 2015).

Forests on the Cumberland Plateau are known for having high plant species richness and gamma diversity (Hinkle et al., 1993). Topography and soil-water availability exhibit strong influences on the species composition of plant communities in the region (Hinkle, 1989). The southern Cumberland Plateau is classified as a transition zone between the Mixed Mesophytic Forest region to the north and the *Quercus*–*Pinus* Forest region to the south by Braun (1950). Environmental gradients are steep and stands may contain taxa that would typically dominate at both higher and lower latitudes (Zhang et al., 1999; Richards and Hart, 2011; Parker and Hart, 2014). *Pinus taeda* and *Pinus virginiana* often dominate the ridges and upper slope positions. Less than 100 m down slope of the ridgetops, stands transition to a strong hardwood component as middle and lower slope positions are largely dominated by mesic hardwood species (Zhang et al., 1999; Parker and Hart, 2014). The stands sampled for this study were in the Oak-Pine USDA forest cover type group. Within this cover type, upland hardwoods comprise a plurality of the relative density of tree species, and *Pinus* spp. account for 25–50% relative tree density. This cover type spans millions of hectares with a geographic range from east Texas to the Atlantic coast, and from central Florida to Delaware.

On 20 April 2011, a long-lived bow echo system tracked eastward across northern Alabama (NCDC, 2012). The system produced an EF1 tornado that affected multiple stands within the Bankhead National Forest. The tornado and the winds from the wake low that followed produced wind gusts reaching 153 kph (NWS, 2011). The most heavily impacted areas within the Bankhead National Forest were concentrated in the path of the tornado, while patches of disturbed areas and blowdowns decreased in severity with distance from the swath (Cowden et al., 2014; White et al., 2015; Keasberry et al., 2016; Cox et al., 2016).

### *2.2. Stand sampling*

Stands impacted by the 2011 tornado were surveyed in the fifth growing season post-disturbance. All stands were within the same biophysical setting based on Smalley's (1979) land classification system. An inventory of post-disturbance biophysical conditions was conducted in each stand. A stratified subjective sampling scheme was used to capture the gradient of wind disturbance in the area and categorize effects into severity classes (c.f. Cowden et al., 2014; White et al., 2015). A geo-referenced dataset provided by the USDA Forest Service was used in ArcMap v. 10.2 to determine which stands met the predetermined sampling criteria. The dataset consisted of quantitative information on stand-level species composition, establishment year, roads, established trails, streams, and the tornado damage track. To determine terrain features such as slope and aspect, USGS quadrangles and geo-referenced aerial photographs were imported into ArcMap as base-