Forest Ecology and Management 330 (2014) 240–251

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Effects of intermediate-scale wind disturbance on composition, structure, and succession in *Quercus* stands: Implications for natural disturbance-based silviculture

Merrit M. Cowden [a], Justin L. Hart [a,*], Callie J. Schweitzer [b], Daniel C. Dey [c]

[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

ARTICLE INFO

Article history:
Received 30 May 2014
Received in revised form 3 July 2014
Accepted 4 July 2014

Keywords:
Light regime
Quercus (oak)
Species diversity
Succession
Wind disturbance

ABSTRACT

Forest disturbances are discrete events in space and time that disrupt the biophysical environment and impart lasting legacies on forest composition and structure. Disturbances are often classified along a gradient of spatial extent and magnitude that ranges from catastrophic events where most of the overstory is removed to gap-scale events that modify local environmental conditions only. Without question, a paucity of data is available on disturbance events of the intermediate scale (i.e. those events too localized to be classed as catastrophic and too widespread to be considered gap scale). The specific objectives of this study were to quantify and compare canopy structure, understory light regimes, woody species composition, and tree species diversity along a gradient of canopy disturbance caused by an EF1 tornado and to analyze the influence of intermediate-scale disturbance on the successional trajectory of an upland *Quercus* forest. Statistically significant differences in diversity measures between control (no storm damage), light, or moderate damage class plots were only found in the sapling layer. We documented significant differences ($P < 0.01$) in percent of intercepted PAR between the control and moderate damage classes and between moderate and light classes. Three growing seasons post-disturbance, the understory light regime had largely returned to pre-disturbance conditions. The disturbance event acted primarily as a release mechanism for advanced reproduction in the understory and for stems in the midstory. Our results provide quantitative information on disturbances of this extent and magnitude and can be used to guide silvicultural systems designed to emulate natural disturbance processes, which is an increasingly popular management approach especially on public lands.

1. Introduction

Forest disturbances are discrete events in space and time that disrupt the biophysical environment (White et al., 1985) and impart lasting legacies on forest composition, structure, and stand development patterns (Lorimer, 1980; Foster et al., 1998; White and Jentsch, 2001; Foster et al., 2002). Disturbances are often classified along a gradient of magnitude and spatial extent. This gradient spans from catastrophic, stand-replacing events to highly localized, gap-scale events (Oliver and Larson, 1996). The range between endpoints of this disturbance classification gradient is vast and makes quantifying disturbances that are too broad to be considered gap-scale and those too localized to be considered catastrophic difficult. Within this framework, disturbances can differ widely from each other yet have the same intermediate-scale classification.

Natural disturbance agents that often cause intermediate-scale damage include strong winds, ice storms, insect attacks, and pathogens (Oliver and Larson, 1996). In *Quercus*-dominated stands through the Central Hardwood Forest of the eastern US, the return interval of stand-wide canopy disturbances (events which remove at least 25% of canopy trees) ranges from ca. 30 to 50 years (Nowacki and Abrams, 1997; Ruffner and Abrams, 1998; Hart et al., 2012a). In the eastern US, the return interval for intermediate-scale disturbance is shorter than the life span of most canopy individuals, and much shorter than the return interval of catastrophic disturbances (Lorimer, 1989; Stueve et al., 2011; Lorimer, 2001). The effects of intermediate-scale disturbances range from the removal of significant portions of overstory vegetation, which initiates secondary succession, to the death of single

* Corresponding author. Tel.: +1 205 348 1673.
E-mail address: hart013@ua.edu (J.L. Hart).

http://dx.doi.org/10.1016/j.foreco.2014.07.003
0378-1127/© 2014 Published by Elsevier B.V.

canopy trees, which modifies fine-scale environmental conditions only (White, 1979; Christensen and Peet, 1981; Oliver, 1981). Regardless of the spatial extent, these canopy disturbance events remove canopy trees thereby altering the quantity, quality, and spatial distribution of light in the understory, which is typically the factor most limiting in forests of the eastern US (Canham and Loucks, 1984; Hanson and Lorimer, 2007; Grayson et al., 2012). Finally, intermediate-scale disturbances may increase stand heterogeneity and promote multi-aged structure (Hanson and Lorimer, 2007).

Approximately 1250 tornadoes occur in the USA annually, and 95% of these are classified as EF0, EF1, or EF2 events (NCDC, 2013). Tornadoes of this magnitude typically result in intermediate-scale disturbances. These storms are characterized by a central track associated with catastrophic damage, and damage severity typically decreases with increased distance from the main storm path. Consequently, forest damage from low intensity tornadoes varies spatially from zones of catastrophic damage, to zones with progressively less damage, and eventually to undamaged areas. Despite the high frequency of these intermediate-scale disturbances, there is a paucity of data available on the effects of these events on forest composition, biodiversity, and sub-canopy light regimes, especially when compared with gap-scale and catastrophic disturbances (Fujita, 1978; Foster and Boose, 1992; Trickel, 2002; Stueve et al., 2011).

The overarching goal of this study was to elucidate the effects of intermediate-scale wind disturbances on forest composition, structure, and succession. The specific objectives were to quantify and compare canopy structure, understory light regimes, woody species composition, and species diversity along a gradient of canopy disturbance and to analyze the influence of intermediate-scale disturbance on the successional trajectory of an upland hardwood forest. Successful implementation of a natural disturbance-based management approach requires quantitative information on natural disturbance processes (Long, 2009). Our results may be used to develop operational guidelines for the implementation of natural disturbance-based management (Seymour et al., 2002; Franklin et al., 2007) and lessons learned can be used to guide silvicultural treatments to achieve desired conditions.

2. Methods

2.1. Study area

This study was conducted in the Sipsey Wilderness on the William B. Bankhead National Forest in Lawrence and Winston counties of north Alabama (Fig. 1). The Sipsey Wilderness is a 10,085 ha portion of the National Wilderness Preservation System and occurs on the Cumberland Plateau section of the Appalachian Plateaus physiographic province (Fenneman, 1938) and within the Southwestern Appalachian (level III) ecoregion (Griffith et al., 2001). The topography in this region consists of narrow ridges and valleys, steep slopes, and is so strongly dissected that it does not resemble a true plateau (Smalley, 1979). The geology is mainly composed of the Pennsylvania Pottsville formation, which consists of a gray conglomerate, fine to coarse grained sandstone, and is known to contain limestone, siltstone, and shale, as well as anthracite and bituminous coal (Szabo et al., 1988). The region contains soils that are acidic, shallow, and poorly drained (USDA SCS, 1959). The regional climate is humid mesothermal characterized by short, mild winters and long, hot summers (Thornthwaite, 1948). Mean annual temperature is 16 °C (January mean: 5 °C, July mean: 26 °C). The frost-free period is approximately 220 days in duration from late-March to early-November (Smalley, 1979). Mean annual precipitation is 1390 mm with monthly means of 135 and 113 mm for January and July, respectively (PRISM Climate Group, 2011). During winter most precipitation events are a result of frontal lifting, whereas summer precipitation may also be the result of convective storms (Smalley, 1979).

This area of the Cumberland Plateau is classified as a transitional region between the *Quercus–Pinus* Forest Region to the south and the Mixed Mesophytic Forest Region to the north (Braun, 1950). Species composition in this region varies locally based on topography (Zhang et al., 1999) and soil–water availability (Hinkle, 1989). Zhang et al. (1999) classified 14 ecological communities on the Sipsey Wilderness and found *Quercus* was the most abundant genus and occurred in the majority of the delineated community types. Ridges and upper slope positions are often dominated by *Pinus taeda* L. and *Pinus echinata* Mill. Over a distance of less than 100 m along a topographic gradient, stands may transition to support a stronger component of hardwood species (Zhang et al., 1999; Parker and Hart, 2014). Middle and lower slope positions are characterized by mesic hardwood stands that include strong components of *Fagus grandifolia* Ehrh., *Liriodendron tulipifera* L., and *Magnolia macrophylla* Michx. (Hardin and Lewis, 1980; Martin et al., 2008; Zhang et al., 1999; Richards and Hart, 2011; Parker and Hart, 2014).

On 20 April 2011 a long-lived, quasi-linear convective system developed in north-central Mississippi and tracked eastward through north Alabama (NCDC, 2012). A bow echo with a strong meso-vortex produced damaging straight-line winds across a five county region in north Alabama. The system also produced an EF1 tornado that tracked ca. 5 km and directly damaged portions of the Sipsey Wilderness. A wake low developed after the storms which produced a short period of damaging non-thunderstorm winds in the area. Wind gusts of 152 km hr^{-1} were recorded with the wake low system. These types of wind disturbances are representative of damage that occurs throughout the Eastern Deciduous Forest Formation; hence findings may be applicable to similar sites in the eastern US.

2.2. Field methods

Stands were surveyed during the third growing season post-disturbance. All stands selected were within the same biophysical setting according to Smalley's (1979) land classification system to ensure analogousness of results. The majority of *Quercus alba* L. stands within the Sipsey Wilderness established between 1890 and 1905 following anthropogenic clearing, and are at least 9 ha in size. The Sipsey Wilderness is divided into compartments and subdivided into stands, as is required by the USA Forest Service, and stand boundaries were consistent with those established by management personnel on the Bankhead National Forest. For this study, we conducted a comprehensive inventory of post-disturbance biophysical conditions across a gradient of disturbance in each stand. Undamaged neighborhoods within stands were considered the controls in this study, and we assumed that they were representative of pre-disturbance conditions using a space-for-time substitution.

We overlaid shapefiles of stand boundaries, topography, and the tornado track using ArcGIS v. 10 in combination with aerial photographs and field reconnaissance to determine stands that would be included in the study. In each stand, we subjectively established sample points (plot locations) using GIS software to ensure adequate spatial coverage. These locations were inputted as waypoints into a handheld GPS device. In the field, we used a GPS receiver to navigate to the pre-determined waypoints. Plots that occurred in streams or on hiking trails were moved 15 m in one direction and the new coordinate pair for the plot was recorded. Plots were visually assigned to one of three damage classes based on the number of downed trees within or crossing through a plot and