STRUCTURAL COMPLEXITY AND DEVELOPMENTAL STAGE AFTER AN INTERMEDIATE-SCALE WIND DISTURBANCE ON AN UPLAND *QUERCUS* STAND

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Abstract.—Promoting stand structural complexity is an increasingly popular silvicultural objective, as complex structures are hypothesized to be more resistant and resilient to perturbations. On April 20, 2011 in Lawrence County, Alabama, an EF1 tornado tracked 5 km, leaving a patchwork mosaic of disturbed areas. In summer 2014, we established a 100 m × 200 m (2 ha) rectangular plot perpendicular to the swath of the storm within an affected *Quercus alba* stand to document the effects of wind disturbance on stand structure. Stem mortality was clustered near the swath of the tornado. Within the 2 ha plot, 22 percent of the basal area was removed by the wind event. To compare structural attributes across areas of increasing disturbance severity, we divided the plot into disturbance classes (minimal, light, and moderate). Our results will improve our understanding of the structural attributes of upland *Quercus* stands after an intermediate scale wind event and may be used to determine types of silvicultural systems needed to enhance structural complexity and minimize the disparity between natural and managed stands.

INTRODUCTION

The enhancement and maintenance of stand structural complexity is an increasingly popular management objective because stand structure is often used as a proxy for managing stand function (Franklin et al. 2002, O'Hara 2014, Puettmann 2011). Relative to more homogeneous stand structures, complex structures with heterogeneity in stem size, canopy architecture, and presence of deadwood are hypothesized to be more resistant and resilient to perturbations and typically promote biodiversity (Hansen et al. 1991, O'Hara and Ramage 2013). One approach to achieving complex structures is to use natural disturbance-based silviculture because natural disturbances often enhance structural complexity. Natural disturbance-based silviculture attempts to emulate the biological legacies of disturbance regimes, and the complexities of these legacy structures vary by disturbance type, intensity, and severity. More information on intermediate scale disturbances, which may create multi-aged stands and more complex structures, is needed to refine silvicultural treatments intended to enhance structural heterogeneity or to emulate the biological legacies created by natural disturbances.

METHODS

The study site was located in an upland *Quercus alba* stand in the Sipsey Wilderness on the William B. Bankhead National Forest in north Alabama. On April 20, 2011, an EF1 tornado tracked 5 km through the Sipsey Wilderness, leaving a patchwork mosaic of disturbed areas. In summer 2014, we established a 100 m × 200 m rectangular plot perpendicular to the swath of the storm in an affected *Q. alba* stand. Within the plot we recorded the species, diameter at

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breast height (d.b.h.), and height of all living stems ≥5 cm d.b.h.; and the species, diameter at 1.37 cm above the root collar, and decay class of all dead woody stems. Decay classes assigned to each dead stem included: decay class 1 (least decayed; sound wood); decay class 2 (sound to somewhat rotten wood); decay class 3 (substantially rotten wood); or decay class 4 (most decayed; mostly rotten wood) (Fraver et al. 2002).

Using the basal area removed by the storm, we created a kriged surface to divide the plot into three approximately equal area disturbance severity classes: minimal, light, and moderate disturbance. The minimum and maximum contour values were 0.0-2.3 m^2 ha^{-1} (0-8 percent basal area removed) for minimal disturbance, 2.3-6.4 m^2 ha^{-1} (8-24 percent basal area removed) for light disturbance, and 6.4-20.0 m^2 ha^{-1} (24-75 percent basal area removed) for moderate disturbance. These values corresponded to the wind disturbance classification criteria used by Hanson and Lorimer (2007). To determine the structural complexity of each disturbance class, we used multiple spatial and nonspatial indices, including the Gini coefficient, the Clark-Evans aggregation index (R), the diameter differentiation index (DT), and the structural complexity index (SCI). The Gini coefficient describes how evenly basal area is distributed among stems. A Gini coefficient value of 0 indicates all stems have the same d.b.h., whereas a value of 1 indicates that all stems have unequal d.b.h. values. The Clark-Evans aggregation index indicates the spatial pattern of stems and ranges from 0 to 2.15. A value of 0 indicates complete clustering, 1 represents a random distribution, and 2.15 represents a perfectly uniform distribution. The diameter differentiation index is a spatially explicit index that uses the four nearest neighbors of each tree within a plot to describe the variation in d.b.h. among neighboring trees within a stand. A value of 0 represents neighborhoods within a plot that have no size differentiation, and a value of 1 represents neighborhoods within a plot that have maximum size differentiation: small variation (0.0-0.3); average variation (0.3-0.5); large variation (0.5-0.7); very large variation (0.7-1.0) (Pommerening 2002). The structural complexity index incorporates x and y coordinates of each stem and stem height to describe three-dimensional structural variability. The SCI has a minimum value of 1 (i.e., all stems have the same height) and has no maximum value. We also assigned each disturbance class to a stand-size class using guidelines by Lorimer and Halpin (2014) to describe the stand structure of each disturbance class (Hanson and Lorimer 2007). The stand size classes outlined by Lorimer and Halpin (2014) include sapling, pole, mature-sapling mosaic, mature, and old-growth classes, which respectively correspond to the stand initiation, stem exclusion, mixed stage, understory reinitiation, and complex stages of development described by Oliver and Larson (1996) and Johnson et al. (2009).

RESULTS AND DISCUSSION

Within the 2 ha plot, 22 percent of the basal area was removed by the storm, reducing basal area from 26.5 m^2 ha^{-1} to 20.5 m^2 ha^{-1}. Within the minimal, light, and moderate disturbance classes, 8, 17, and 44 percent, respectively, of the basal area was removed by the storm. All disturbance classes exhibited negative exponential diameter distributions for all stems ≥5 cm d.b.h., thus the storm did not affect the shape of the diameter distribution. The Gini coefficients for the minimal, light, and moderate disturbance classes were 0.68, 0.73, and 0.69, respectively. Although all disturbance classes exhibited an unequal distribution of basal area, the Gini coefficients indicated that basal area was the most unevenly distributed among stems (i.e., more heterogeneous structure) in the light disturbance class. Based on the Clark-Evans aggregation index, live stems were regularly distributed in the minimal (R = 1.14) and light disturbance classes (R = 1.07) and randomly distributed in the moderate disturbance class (R = 0.97). Decay class 1 stems were regularly distributed in the minimal disturbance class (R = 1.88), randomly distributed in the light disturbance class (R = 0.97), and clustered in the moderate disturbance class (R = 0.66). The patterns of stem mortality resulted in a more uniform distribution of living stems post-disturbance. The values for diameter differentiation for the minimal, light, and moderate disturbance classes were 0.46, 0.43, and 0.43, respectively, indicating average variation in neighboring stem size within each disturbance class. A higher proportion of larger stems was removed by the storm, so lower DT values in the light and moderate disturbance classes may be the result of having fewer living large d.b.h. stems. Based on the SCI, the light disturbance class was the most structurally complex (SCI = 3.70). The SCI of minimal and moderate disturbance classes were 2.96 and 2.76, respectively. When assigned stand-size classes, the minimal and light disturbance classes were considered a mature-sapling mosaic size class, whereas the moderate disturbance class was classified as a sapling size class. By relating these size classes to the stages of development (Johnson et al. 2009, Oliver and Larson 1996), we determined that this stand was most likely in the mixed stage of development, although the moderate disturbance neighborhood was classified as sapling size. The classification of the moderate disturbance class as a smaller size class than the minimal and light disturbance classes indicated the increase in intra-stand structural heterogeneity as a result of the wind event. Further analysis based on taxonomic groups will more fully describe the structural complexity of the stand and elucidate the spatial patterns of the biological legacies after the wind disturbance.

ACKNOWLEDGMENTS

This research was funded as a Joint Venture Agreement between the U.S. Forest Service, Northern Research Station and the University of Alabama. We would like to thank Win Cowden, Amanda Keasberry, and Cindy Taylor for assistance in the field.

LITERATURE CITED

Franklin, J.F.; Spies, T.A.; Van Pelt, R.; Carey, A.B.; Thornburgh, D.A.; Berg, D.R.; Lindenmayer, D.B.; Harmon, M.E.; Keeton, W.S.; Shaw, D.C.; Bible, K.; Chen, J. 2002. **Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example.** Forest Ecology and Management. 155: 399-423.

Fraver, S.; Wagner, R.G.; Day, M. 2002. **Dynamics of coarse woody debris following gap harvesting in the Acadian forest of central Maine, USA.** Canadian Journal of Forest Research. 32: 2094-2105.

Hansen, A.J.; Spies, T.A.; Swanson, F.J.; Ohmann, J.L. 1991. **Conserving biodiversity in managed forests.** BioScience. 41: 382-392.

Hanson, J.J.; Lorimer, C.G. 2007. **Forest structure and light regimes following moderate wind storms: implications for multi-cohort management.** Ecological Applications. 17(5): 1325–1340.

Johnson, P.S.; Shifley, S.R.; Rogers, R. 2009. **The ecology and silviculture of oaks.** 2nd ed. Cambridge, MA: CAB International.

Lorimer, C.; Halpin, C.R. 2014. **Classification and dynamics of developmental stages in late–successional temperate forests.** Forest Ecology and Management. 334: 344-357.

O'Hara, K.L. 2014. **Multi-aged silviculture: managing for complex forest structures.** Oxford, UK: Oxford University Press. 240 p.

O'Hara, K.L.; Ramage, B.S. 2013. **Silviculture in an uncertain world: utilizing multi-aged management systems to integrate disturbance.** Forestry. 86: 401-410.

Oliver, C.D.; Larson, B.C. 1996. **Forest stand dynamics**. New York, NY: John Wiley and Sons.

Pommerening, A. 2002. **Approaches to quantifying forest structures.** Forestry. 75: 306-324.

Puettmann, K.J. 2011. **Silvicultural challenges and options in the context of global change – "simple" fixes and opportunities for new management approaches.** Journal of Forestry. 109: 321-331.