EFFECTS OF ICE DAMAGE ON GROWTH AND SURVIVAL OF SHORTLEAF PINE TREES

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Extended abstract—Natural disturbance events, such as ice storms, may last from hours to a few days, but their impacts may create long-term disturbance in forest structure and development (Bragg 2016, Turcotte and others 2012). Following ice storms, the development and survival of individual trees may be affected by numerous factors such as extent of damage, residual density, stand age, vigor, site condition, and species (Bragg and others 2003, Dipesh and others 2015, Saud and others 2016a). In the Southwestern United States, pine species experience considerable crown damage from ice storms since they retain foliage throughout the year and provide large surface area for ice accumulation. Damage is especially likely in younger stands that are densely stocked and have low crown ratio (Guldin 2011).

Shortleaf pine (*Pinus echinata* Mill.), an important commercial tree species in the Southern region, has received little research attention regarding its growth and survival following ice storm damage unlike studies on growth-and-yield modeling (Saud and others 2016b). In December 2000, ice storm events affected millions of forested hectares in Oklahoma, Arkansas, and Texas (Bragg and others 2003, Stevenson and others 2016). Individual trees of even-aged, naturally occurring shortleaf pine forests were damaged. We quantified the damage in permanent growth-and-yield monitoring research plots of shortleaf pine established between 1985–1987 in the Ouachita and Ozark National Forests and subsequently monitored them the following years. A repeated measurement provided an opportunity to investigate variables influencing growth and survival probabilities of individual trees following ice storm damage.

The original dataset consisted of 207 research plots. In 1998–1999, 181 of these plots were thinned. The ice storm damaged trees in 101 plots, 85 of which were thinned plots. Three post-ice storm measurements were recorded in 2000–2001, 2006–2007, and 2012–2014. We used a multiple treatment design analysis to evaluate annual growth response and survival probability of individual trees over a 12-year period. Data analysis consisted of multiple factors including 1) stand basal area [low (7), average (14), moderate (21), and high (>21 m^2 ha^{-1})]; 2) ice storm effect on plot (ice damage, no ice damage); 3) crown damage [no damage, low (≤25 percent), high (>25 percent)]; 4) aspect (east, west, north, and south); and 5) thinning intensity [no thinning, low (0–5 $m^2 ha^{-1}$), high (>5 $m^2 ha^{-1}$)]. A generalized linear mixed model was used to predict annual basal area growth (ABAG) of individual trees selecting the best covariates out of 12 different tree- and stand-level attributes, five factors, and elevation. We used Cox proportional hazard (PH) model for survival analysis assuming right-censored data and tree mortality as the event of interest.

Over a 12-year period, results showed that high crown-damaged trees in high basal area stands had significantly reduced ABAG rates as compared to trees from low crown damage and low basal area. The model suggested that ABAG rates of individual trees were significantly affected by relative spacing, stand age, and stand basal area based on crown damage level. The model also indicated that ice-damaged trees growing on mesic sites (east and north aspects) had better ABAG rates than trees growing on xeric sites (west and south aspects).

Reduced ABAG following an ice storm could be the result of compressed radial growth patterns as observed in dendrochronological study of ice-damaged shortleaf pine by Stevenson and others (2016), a result of reduced photosynthetic capacity due to crown loss. Given the impact of ice damage on height gain on individual trees, crown-damaged trees showed significantly less ABAG than undamaged trees as reported in previous studies (Dipesh and others 2015, Stevenson and others 2016, Turcotte and others 2012). Low crown-damaged trees showed improved ABAG compared to high crown-damaged trees in the subsequent measurements, as reported

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in other studies that the 4- to 5-year interval following the event is enough for the recovery of low crown-damaged trees (Dipesh and others 2015, Stevenson and others 2016). This suggests high crown-damaged trees have slower recovery than low crown-damaged trees. However, crown growth would also vary depending upon stand density, relative spacing, and stand age (Saud and others 2016b).

The greatest individual tree mortality rates over the 12-year period were for ice-damaged plots as compared to no ice-damaged plots. Lower survival rates for crown-damaged trees were correlated with increasing stand basal area, decreasing elevation, and decreasing thinning levels. Over the decade, high crown-damaged trees had substantially reduced survival probability (60 percent) as compared to low crown-damaged trees (80 percent). Ice-damaged trees experienced 2.2 times greater mortality than undamaged trees, and at times, due to random plot effects, some trees were at a fourfold greater relative risk than average-damaged trees. Thus, we conclude that over time low crown-damaged trees will have better survival rates similar to undamaged trees.

Trees occupying dominant-crown positions were more heavily damaged than codominant and suppressed trees. Stand density also might have influenced ice damage risk by collisions from falling neighbor trees as discussed by Bragg and others (2003). Thinned stands experienced higher mortality rates than unthinned stands but the effect was confounded with tree size as observed in plantation forest (Bragg 2016). Further, a study on time-dependent mortality suggested that individual tree attributes such as larger basal area, height, and crown ratio increased survival of ice-damaged trees while crown damage level and stand-level competition decreased survival probability (Saud and others 2016a).

Understanding the response of ice-damaged shortleaf pine trees is important for devising management strategies of damaged stands. We believe these results will be helpful to increase our understanding of effects tree- and stand-level attributes have on resilience and response of individual trees following an ice storm in context to biological and economical optimal rotations.

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