STRUCTURE AND REGROWTH OF LONGLEAF PINE FORESTS FOLLOWING UNEVEN-AGED SILVICULTURE AND HURRICANE DISTURBANCE AT THE ESCAMBIA EXPERIMENTAL FOREST

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In recent decades, considerable attention has been placed on restoring and managing longleaf pine (*Pinus palustris* Mill.) ecosystems across the southeastern United States. Although, historically, these forests have been successfully regenerated following even-aged shelterwood reproduction methods, uneven-aged silviculture has received increasing attention because it is thought to meet a diversity objectives including timber production, biodiversity enhancement, and habitat conservation and is also thought to emulate some of the natural disturbance regimes that have historically sustained these ecosystems. A long-term project, entitled the "Comparative Analysis of Reproduction Techniques (CART) for Sustainable Management of Longleaf Pine Ecosystems" at the Escambia Experimental Forest in Brewton, AL, was designed as an operational-scale effort to compare a variety of uneven-aged silvicultural methods (single-tree and group-tree selection cutting to 11.5 m^2/ha with small and large gap openings respectively) and even-aged methods (shelterwood cutting to 6 m^2/ha). However in September 2004, 2 months after harvesting was complete, the study sites were directly impacted by Hurricane Ivan resulting in significant damage to the recently cut shelterwood treatments on six plots. Forest damage was less severe, though noticeable, on uncut control plots and plots treated with selection system methods. While the original intent of the study design was to compare regeneration and growth following specific silvicultural treatments to specific residual stocking and spacing, the addition of hurricane disturbance provides an opportunity to evaluate the interactive effects of natural disturbance and the forest reproduction methods and to determine how best to adapt management in "the hurricane zone". The specific objectives of this research were to compare regeneration, density, and basal area and to quantify the spatial structure of residual trees 6 years following harvesting and hurricane impact.

Data were collected in 2003 prior to treatment, in 2005 after silvicultural treatments and hurricane impact, and again in 2010. In 2010, we revisited the remaining intact 9-ha plots comprised of three uncut control plots, three single-tree selection treatment plots and three group selection treatment plots. Within each 9-ha treatment plot, regeneration densities were measured on five randomly established 20- by 50-m subplots. Regeneration was classified as grass stage (< 0.3-m tall), bolt stage [0.3- to 1.8-m tall and < 2 cm in diameter at breast height (d.b.h.)], or sapling (at least 2 cm and < 10 cm d.b.h.). Diameters of all trees at least 2 cm and above were also recorded. Regeneration densities were analyzed by treatment (single-tree, group selection, control) and time (2003, 2005, and 2010). Total basal area of residual overstory trees ≥ 10 cm d.b.h. was analyzed by treatment in 2005 and 2010. Additionally, in each of the nine treatment areas, two 50- by 100-m plots were established in which all trees bolt-sized and larger were stem-mapped. Spatial pattern on each of the stem maps was evaluated using the Ripley's K point pattern process, which evaluated whether a pattern is clumped (also termed aggregated), random, or uniform (also termed dispersed). We used SPPA2.0 software to analyze distances ranging from 2 to 24 m, by 2-m intervals.

By 2010, significant regeneration had developed across the forest due to one or more relatively heavy seed-crop years between 2005 and 2010.

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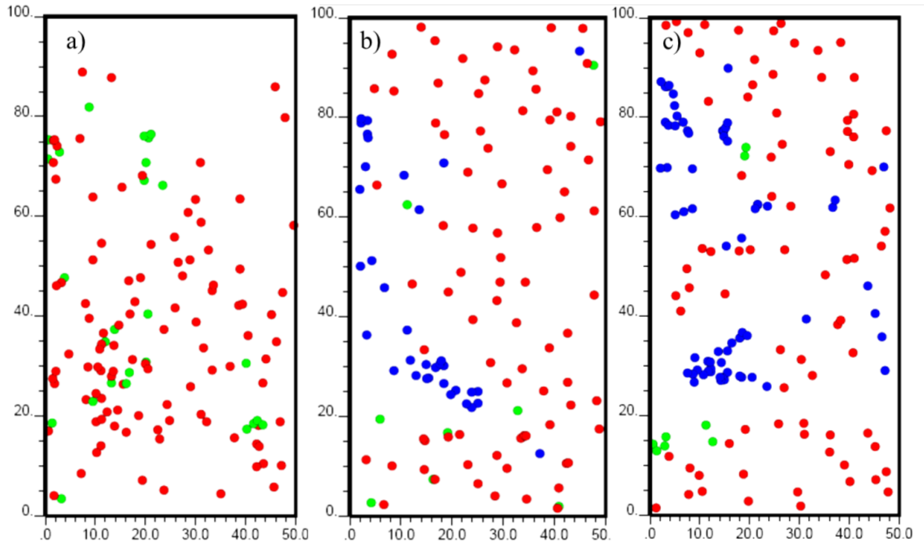

Figure 1--Example stem maps illustrating the spatial distribution of longleaf pine trees in plots treated with: (a) single-tree selection, (b) group selection, and (c) an uncut control and following Hurricane Ivan. Differently colored dots represent residual overstory trees > 10 cm (red), sapling regeneration (green) and bolt-sized regeneration (blue) 6 years following silvicultural treatments and hurricane damage.

The group selection plots contained significantly more grass-stage regeneration in 2010 (17,870 seedlings/ha) followed by single-tree selection (11,190 seedlings/ha) and the uncut control plots (8,070 seedlings/ha). Conversely, by 2010 there were significantly fewer bolt-stage regeneration in the group selection plots (53 stems/ha) than in the single-tree (605 stems/ha) or control plots (278 stem/ha). The number of longleaf saplings was not significant by treatment and ranged from 64 to 103 stems/ha. By 2010, the mean total basal area of residual overstory trees in the control plots was 15.6 m^2/ha, 11.0 m^2/ha in group selection, and 8.8 m^2/ha and in single-tree selection. Between 2005 and 2010, total basal area increased by about 1 m^2/ha in the control and group selection plots and by 0.6 m^2/ha in the single-tree plots, though relative growth rates after compensating for differences in post-hurricane basal areas were not significantly different.

Point pattern analyses using the Ripley's K function also indicate variability in the spatial distribution of residual overstory trees within and between treatments. Point pattern analysis in four of the six plots in single-tree selection treatment areas indicated clumped patterns at all or most spatial scales (fig. 1a), and two plots exhibited random patterns. Clumped patterns at small spatial scales indicates that there were several groups of closely spaced trees, while clumping at large spatial scales is typically indicative of large gap openings with no trees in between the smaller tree groups. Upon visual examination of the stem maps, it is evident that the plots exhibiting the highest degree of clumping also had very large gap openings, which likely was a result of hurricane damage. Conversely, two of the group selection plots exhibited significantly uniform patterns at smaller spatial scales of about 2 to 8 m (fig. 1b), though five of the six plots did show clumped spatial patterns at some larger scale. Overstory trees in most of the control plots exhibited random patterns at all spatial scales (fig. 1c).

Though more regeneration had reached bolt sizes or larger in single-tree selection plots than group selection, basal area growth of larger residual trees appear to be recovering at the same rate across plots. Further, the range of gaps sizes and spatial distribution of trees in either the single-tree or group selection plots did not vary much following the hurricane impacts. Although application of uneven-aged selection system methods requires special attention to both residual basal area and size of regeneration openings, in hurricane-prone areas attention to gap size may be may be less consequential than attention to residual basal area.