FROM LOBLOLLY TO LONGLEAF: FIFTH-YEAR RESULTS OF A LONGLEAF PINE RESTORATION STUDY AT TWO ECOLOGICALLY DISTINCT SITES

Benjamin O. Knapp, G. Geoff Wang, Joan L. Walker, and Huifeng Hu[1]

Historical land-use and management practices in the southeastern United States have resulted in the widespread conversion of many upland sites from dominance of longleaf pine (*Pinus palustris* Mill.) to loblolly pine (*P. taeda* L.) in the time following European settlement. Given the ecological, economic, and cultural significance of the longleaf pine ecosystem, there is current interest in restoring longleaf pine and its associated plant communities on sites across the historical longleaf pine range. In many cases, this requires artificial regeneration to establish longleaf pine as a significant component of the regeneration cohort, particularly in stands that no longer include longleaf pine in the canopy as a seed source. However, other southern pines that commonly make up extant forest canopies can provide important ecosystem services during longleaf pine restoration, including wildlife habitat for species such as the red-cockaded woodpecker (*Picoides borealis*), needlefall for a continuous fuel bed important to fire management, and the suppression of the growth of hardwood competitors that can form an undesirable mid-story layer. Although longleaf pine is considered intolerant of competition and therefore traditional artificial regeneration practices typically include complete canopy removal, Kirkman and others (2007) proposed that retaining canopy trees in slash pine (*P. elliottii* Engelm.) stands during underplanting can help to reach restoration objectives despite an expected decrease in longleaf pine seedling growth. To date, no studies have been conducted to understand how alternative silvicultural practices may be used for longleaf pine restoration in existing loblolly pine forests. The objectives of this study were to determine: (1) the effects of canopy density on underplanted longleaf pine seedling growth and survival through five growing seasons; and (2) the effects of cultural treatments (herbicide and fertilizer) on underplanted longleaf pine seedling growth and survival through five growing seasons.

This study was replicated on two ecologically distinct study sites within the longleaf pine range: Fort Benning Military Installation in Georgia and Alabama and Marine Corps Base Camp Lejeune in North Carolina. At each site, we installed a replicated field experiment with a randomized complete block, split-plot design. Main-plot treatments included canopy manipulation to four levels of residual basal area: (1) Control [uncut, with basal area (BA) of 16 m^2/ha]; (2) medium BA (uniform thinning to BA of 9 m^2/ha); (3) low BA (uniform thinning to BA of 5 m^2/ha); and (4) Clearcut (basal area of 0 m^2/ha). Split-plot treatments included three levels of cultural treatment applied to improve longleaf pine seedling establishment: (1) NT (no treatment); (2) H (herbicide control of woody vegetation with a direct foliar application of 1 percent imazapyr to woody vegetation); and (3) H+F (the herbicide treatment combined with 280 kg/ha of 10-10-10 NPK fertilizer). Harvesting was completed in 2007, and longleaf pine seedlings were planted in January 2008. The herbicide split-plot treatment was applied in October 2008, and the fertilizer was applied in April 2009. In each 20- by 20-m split-plot measurement unit, we tagged a random selection of 30 longleaf pine seedlings in May 2008. We monitored seedling survival and measured root collar diameter and seedling height in October of 2008, 2009, 2010, and 2012. We considered seedlings to have emerged from the grass stage and entered active height growth if the terminal bud was ≥ 15 cm above the root collar.

[1]Assistant Professor, University of Missouri, School of Natural Resources, Columbia, MO 65211; Professor, Clemson University, Forestry and Natural Resources, Clemson, SC 29634; Research Plant Ecologist, USDA Forest Service, Southern Research Station, Clemson, SC 29634; and Associate Professor, Chinese Academy of Sciences, Institute of Botany, Beijing, China.

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Table 1--Effects of main-plot treatments and split-plot treatments on mean root collar diameter and percentage of seedlings in height growth five growing seasons after planting (with one standard error) at Fort Benning and Camp Lejeune. The same letter indicates no significant difference among levels within an effect for each site

		------------------Fort Benning------------------				-----------------Camp Lejeune-----------------			
		Root collar diameter		Height growth		Root collar diameter		Height growth	
Effect	Level	Mean	SE	Mean	SE	Mean	SE	Mean	SE
		----------*mm*---------		--------*percent*--------		---------*mm*---------		-------*percent*--------	
Main-plot treatment	Control	21.17C	1.08	2.97D	2.00	21.72B	1.04	13.32B	5.08
	Med BA	25.50BC	1.42	22.96C	5.92	30.01A	1.98	45.53A	9.73
	Low BA	31.78B	1.58	61.70B	7.18	30.37A	2.20	46.43A	9.76
	Clearcut	43.25A	3.05	86.61A	4.92	35.04A	4.07	56.88A	8.81
	p-value	< 0.0001		< 0.0001		0.0005		0.0002	
Split-plot treatment	NT	28.57	1.09	38.16	4.46	25.25B	1.46	28.96B	6.42
	H	31.07	1.67	46.21	4.90	32.37A	2.93	46.16A	10.36
	H+F	31.63	1.49	46.32	5.09	30.28A	1.73	47.3A	5.74
	p-value	0.0595		0.3170		< 0.0001		<0.0001	

Seedling survival displayed different patterns at the two study sites, with the lowest first-year survival in Clearcut plots at Fort Benning but the lowest survival in Control plots at Camp Lejeune (fig. 1). Although seedling survival was highest on uncut Control plots in the first year at Fort Benning, by the end of the fifth growing season the survival was similarly low on both Clearcut plots and Control plots. Results from previous studies have also suggested that early survival of planted longleaf pine seedlings is higher beneath canopy trees than in canopy openings during harsh conditions associated with drought (Gagnon and others 2003, McGuire and others 2001, Rodríguez-Trejo and others 2003). Our results suggest that facilitation effects of canopy trees on longleaf pine seedling survival may not persist over time if canopy density is high. The contrasting results of our two study sites also suggest that site-specific growing conditions can affect the impacts of canopy retention on planted longleaf pine seedling survival.

At both sites, seedling growth was lowest on the uncut Control plots, but an incremental pattern of growth increase with greater canopy removal was observed at Fort Benning but not at Camp Lejeune (table 1). In longleaf pine forests, canopy retention has been found to reduce seedling growth (Kirkman and Mitchell 2006, Palik and others 1997), and our results support this general finding in loblolly pine forests.

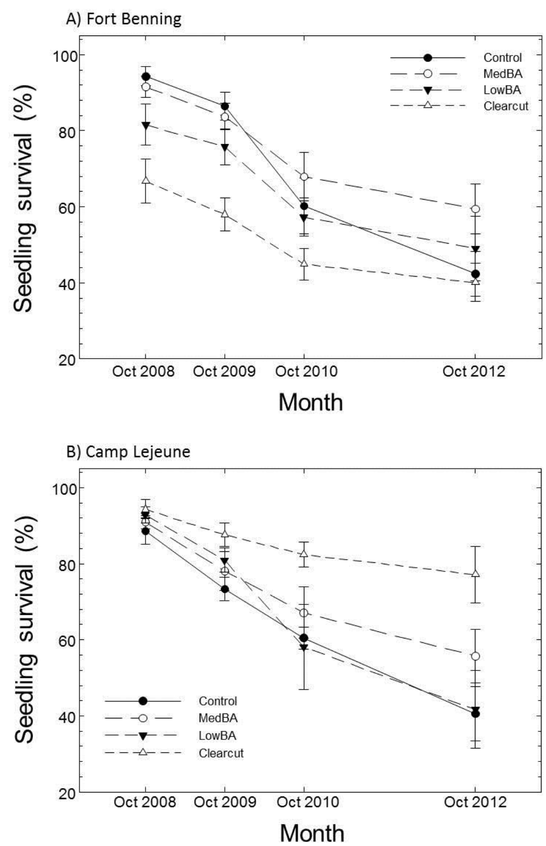

Figure 1--Planted longleaf pine seedling survival (mean ± one standard error) at the end of the first, second, third, and fifth growing seasons at: (A) Fort Benning and (B) Camp Lejeune.

However, the Clearcut plots at Fort Benning resulted in a higher percentage of seedlings out of the grass stage than that seen at Camp Lejeune. The herbicide split-plot treatments increased seedling growth at Camp Lejeune but not at Fort Benning, and Camp Lejeune generally had more abundant sub-canopy vegetation (data not shown) that our data suggest provided enough competition to limit seedling growth. We found no differences between the H and H+F treatments, suggesting that fertilizer did not improve seedling growth at either site. Generally, our results indicate that site-specific growing conditions must be considered when determining appropriate silvicultural prescriptions for restoring longleaf pine in loblolly pine stands.

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