EFFECTS OF GAP SIZE ON NATURAL REGENERATION IN A PINE-HARDWOOD STAND A QUARTER CENTURY AFTER HARVEST

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Abstract—In 1992, an experiment to assess the effect of harvest gap size on natural regeneration of coastal plain mixedwoods was installed in a mature stand on the Crossett Experimental Forest in southeastern Arkansas. Three levels of a gap-size treatment (0.25 acre, 0.625 acre, and 1 acre) were installed in a randomized complete block design with three replications. Gaps were revisited in 2016 to evaluate the effect of gap size on natural regeneration. Gap size significantly (p <0.05) explained variation in pine density (diameter at breast height [d.b.h.] ≥3.5 inches), but not the densities of hardwood species groups. Gap size was also significant in a model for pine importance value. Mean separation revealed that pine density and importance value were highest in 1-acre gaps, lowest in 0.25-acre gaps, and intermediate in 0.625-acre gaps. These results provide further support for research indicating gap size plays an important role in natural pine regeneration.

INTRODUCTION

There is growing interest in management strategies that enhance compositional diversity and structural complexity of forests (for example, Puettmann and others 2009). Compared to forests dominated by a single species, mixed-species forests are generally less vulnerable to perturbations from insect pests and microbial pathogens (Drever and others 2006, Jactel and Brockerhoff 2007). Species-rich, structurally heterogeneous forests offer a wide range of ecological niches, which, in turn, can support higher biodiversity (Hunter 1999). More recently, there has been interest in increasing tree species richness and structural heterogeneity as part of a climate change adaptation strategy designed to enhance resiliency and the capacity of forests to adapt to future uncertainty (Messier and others 2013).

In the southern pine region, a mixture of pine and hardwood species ("mixedwood") may offer several of the aforementioned benefits. For example, mixedwoods have been shown to provide a wider range of forage for both game and non-game wildlife species than stands dominated by either hardwood or pine (Wigley and others 1989). By recruiting both pine and hardwood species into merchantable size classes, mixedwood management can diversify timber resources to supply a wider range of forest product markets than pure stands of either pine or hardwood alone (Zahner and Smalley 1989). Since mixedwoods can offer a variety of economic and ecological values at a low cost, mixedwood management may be attractive to landowners less interested in intensive forest management.

Multi-aged silviculture also offers considerable management flexibility and can be used to create or maintain structurally complex mixedwood stands. Where the objective is to sustain recruitment of an ecologically diverse assemblage of tree species while retaining mature forest cover, gap-based silviculture methods may be appropriate (Nyland 2016). Although there are some operational challenges associated with gap-based methods, particularly with harvesting of older gap cohorts (Murphy and others 1993), gap-based methods have the flexibility to meet a wide range of landowner objectives. For example, group selection openings can be sized to allow adequate light into the understory to regenerate shade-intolerant species (Marquis 1965) while developing and releasing advance reproduction of shade-tolerant species (Arseneault and others 2011). An additional benefit of partial overstory removal is the ability to help mitigate the negative visual impacts of timber harvesting.

Group selection is an understudied area of silviculture in southern pine-hardwood stands, yet it may be attractive to landowners interested in multi-aged, mixedwood management. To help fill this knowledge gap, a study was initiated to investigate the effectiveness of harvest

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gap size for regenerating pine-hardwood mixtures in the West Gulf Coastal Plain. Early results of this study (Shelton 1998) indicated that gap size had no effect on pine seedling density or stocking in the third year after harvest; however, pine regeneration was more abundant than the oak species in gaps, and pine seedlings were significantly taller in the largest gaps than the smallest gaps (1 acre versus 0.25 acre, respectively). Although this preliminary research provided insights on early gap-phase dynamics in southern pine-hardwood stands, much remains unknown about the long-term outcomes of within-gap development in relation to gap size. The purpose of this followup investigation was to assess natural regeneration and gap-cohort development a quarter century following gap creation.

METHODS

The original experiment (Shelton 1991) was established in a 34-acre mature, pine-hardwood stand on the U.S. Department of Agriculture Forest Service's Crossett Experimental Forest (CEF) in southeastern Arkansas (33°2'36" N, 91°56'22" W). The study site was a broad, somewhat poorly drained upland flat dominated by Bude silt loam soils with a loblolly pine (*Pinus taeda*) 50-year site index of 90 feet. Years earlier (from 1982 to 1984), the stand had been a part of a study of herbicide treatment of certain hardwoods using annual stem injections. In February 1992, the study site received a site preparation burn. In November and December of that year, a gap-size treatment with three levels (0.25 acre, 0.625 acre, and 1 acre) was installed using a randomized complete block design with three replications. Adjacent harvest openings were separated by at least 100 feet, and the matrix between gaps received an improvement cut targeting the retention of 75 square feet per acre in pine sawtimber (no hardwoods were removed from the matrix). Since then, the only activity in this stand has been scattered, low-impact salvage harvesting of pine.

The study site was revisited in the summer of 2016 to evaluate the long-term effect of harvest gap size on the regeneration within gaps. Gap boundaries were delineated based on the locations of mature tree stems at the border of openings (in other words, the expanded gap) and georeferenced using a recreation-grade GPS unit. A complete census of all live trees at least 3.5 inches in diameter at breast height (d.b.h.) was conducted in each gap. For each tallied tree, the species, d.b.h., and amount of vine growth in the crown were recorded.

Analysis of variance (ANOVA) was used to test for an effect of gap size on stem densities of pine [loblolly and shortleaf pine (*P. echinata*)], oak [cherrybark (*Quercus pagoda*), post (*Q. stellata*), southern red (*Q. falcata*), water (*Q. nigra*), white (*Q. alba*), and willow (*Q. phellos*)], sweetgum (*Liquidambar styraciflua*), and other species [mainly black cherry (*Prunus serotina*), blackgum (*Nyssa sylvatica*), eastern hophornbeam (*Ostrya virginiana*), flowering dogwood (*Cornus florida*), hickories (*Carya* spp.), red maple (*Acer rubrum*), sassafras (*Sassafras albidum*), and winged elm (*Ulmus alata*)]. ANOVA models were run to test for a gap-size effect on pine-hardwood composition using the importance value of pine (pine IV) as the response variable. Pine IV was calculated as the average of pine relative density and relative basal area. Pine IV was arcsine square-root transformed to improve normality. Mean separation was performed using Tukey's Honestly Significant Difference test. All analyses were conducted using SAS 9.4 using $\alpha = 0.05$.

RESULTS

Mean area of harvest gaps measured in 2016 were consistently larger than the area of the original gap-size treatments (table 1). This difference arose because the original determination of harvest gap size was based on the opening produced by removing trees within the specified area, and since we could not reconstruct the

Table 1—Description of gap size treatments based on the original study design and measurements of gaps in 2016

Original gap treatment (acres)	Gap size class	2016 Mean gap attributes	
		Area (acres)	Diameter:height[a]
0.25	Small	0.37	1.5
		(0.35-0.39)	(1.3-1.6)
0.625	Medium	0.86	2.0
		(0.79-0.99)	(1.9-2.2)
1	Large	1.34	2.7
		(1.31-1.37)	(2.4-2.9)

[a] Diameter:height is the ratio of gap diameter to the average height of co-dominant and dominant trees bordering the gap.

Range is given in parentheses.

exact location of these gaps, we resorted to delineation using the remaining evidence (uncut border trees). In 2016, the mean gap diameter to canopy height ratios of small, medium, and large gaps were 1.5, 2.0, and 2.7, respectively (table 1).

Comparison of diameter distributions in the gaps showed an increasing tree density with increasing gap size (fig. 1). Most of this increasing trend in total density appeared to be attributable to more pines, especially in the small diameter classes. Gap size was a significant factor in ANOVA models explaining pine density ($p = 0.04$) but not in models for oak ($p = 0.50$), sweetgum ($p = 0.38$), or other species ($p = 0.46$). Mean separation indicated that large gaps had a significantly higher density of pine than small gaps (89 versus 14 trees per acre), with an intermediate level of pine density (40 trees per acre) in medium gaps (fig. 2). The slight increases in oak and sweetgum density with increasing gap size were not statistically significant, and the other species group showed no trends with gap size.

Although their numbers were small, pines also increased appreciably in the larger diameter classes with increasing gap size (fig. 1). For instance, in the small gaps, the largest diameter pines were 9 inches in d.b.h. while the medium and large gaps both had pines greater than 12 inches in d.b.h. Increasingly larger gaps had some impact on both the number and size of hardwoods but not as consistently or as pronounced as for pine.

The increasing trend in pine stem density was mirrored by pine IV (fig. 3). Gap size was a significant factor in ANOVA models explaining pine IV ($p = 0.03$), with pine IV significantly higher in large gaps (38 percent) than small gaps (10 percent). No statistically significant differences were detected between pine IV in medium gaps (24 percent) and either of the other gap sizes.

DISCUSSION

One of the original goals of this study was to inform the management of multi-aged pine-hardwood mixtures (Shelton 1991). Therefore, it is also important to consider the development of hardwood species, not just as a competitor of pine but also as a key component of gap cohorts. Similar to what was found for oak regeneration recorded in 1995 on this same study, oak stem density in 2016 was not affected by gap size. Although not individually considered in the earlier study, sweetgum density in 2016 also was unaffected by gap size. However, both oak and sweetgum densities nominally increased along the gap size gradient, suggesting a possible trend of increasing density with gap size, albeit a weak one. Given the general dominance of hardwood regeneration in these gaps, pine regeneration success under this group selection system appears to be the more critical area of concern.

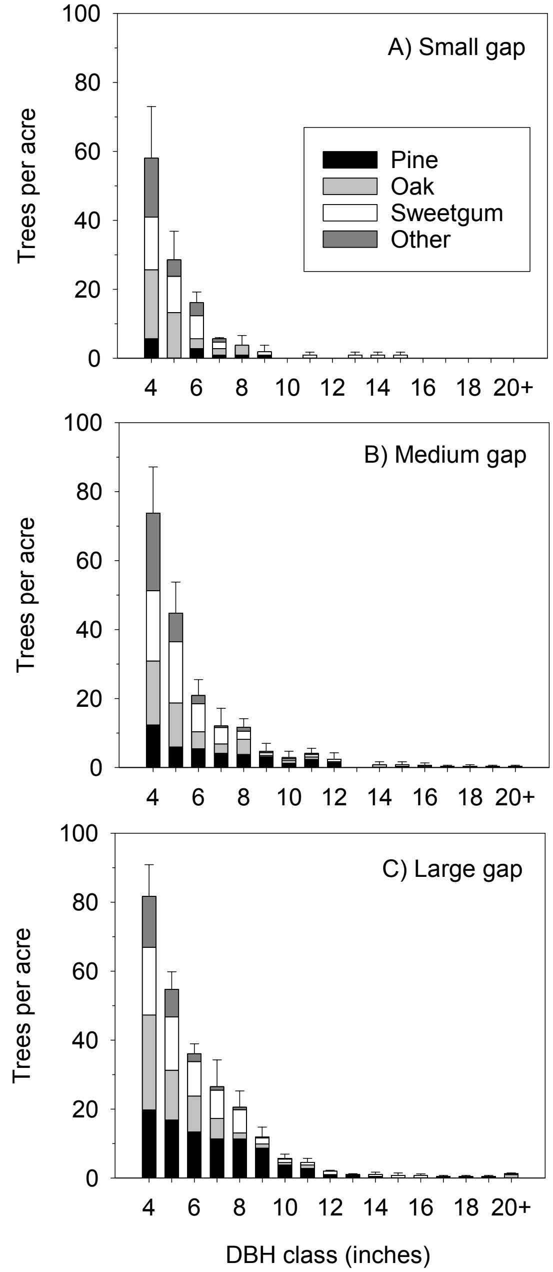

Figure 1—Diameter distribution of small (A), medium (B), and large (C) gap treatments partitioned into pines, oaks, sweetgum, and other species groups. Error bar is equal to one standard error and was calculated from total tree density in each d.b.h. class.

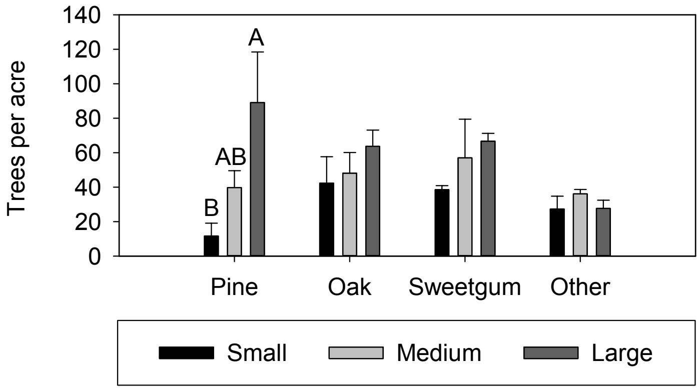

Figure 2—Mean trees per acre of pines, oaks, sweetgum, and other species groups partitioned into gap-size treatments. Error bar is equal to one standard error. Gap treatment means within a species with a different letter are statistically different (α = 0.05).

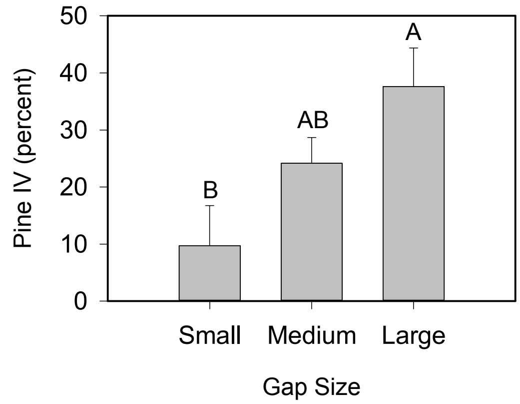

Figure 3—Mean percent pine importance value (IV) of small, medium, and large gap treatments. Error bar is equal to one standard error. Gap treatment means with a different letter are statistically different (α = 0.05).

Interestingly, the possibility that pine regeneration may not prove adequate was not immediately apparent. Unlike our findings, third-year results of the original study determined that pine seedling densities were comparable among all gap size treatments (Shelton 1998). A related experiment in northern Louisiana testing the same gap sizes likewise failed to detect an effect of gap size on pine seedling density in the first few years after gap creation (Cain and Shelton 2001). In both of these studies, initial pine seedling densities exceeded 2,500 seedlings per acre, which is considered adequate natural reproduction in uneven-aged forests at that stage of development (Baker and others 1996, Shelton 1998). During the intervening years, attrition of the shade-intolerant pine seedlings was expected, even in the largest gaps. After 24 years, the differential survivorship as a function of gap size can probably be attributed to a combination of enhanced competitiveness of pine within larger canopy openings and higher pine mortality in smaller gaps.

While even relatively small gaps in mixedwood forests can support significant numbers of shade-intolerant pine and hardwood seedlings (for example, Rantis and Johnson 1998), their growth performance will generally increase with gap size. Shelton (1998) noted that pine seedlings were significantly taller in the large gaps than in the small gaps. A different gap study found that pine seedlings were significantly taller in 1/3-acre harvest gaps compared to 1/10-acre harvest gaps, suggesting enhanced growth of southern pine in larger openings (Perry and Waldrop 1995). At 24 years, the greater numbers of larger pines (without concurrent responses by hardwoods) in bigger gaps (fig. 1) provide further support that pines become increasingly competitive with greater resource availability.

The largest openings created for this study still had average pine IV that would have produced a mixedwood composition (between 25 and 75 percent) after 24 years of development. While the composition of medium gaps fell just short of the 25-percent pine threshold, the higher proportion of pine in larger size classes suggests that these gaps may develop naturally into mixedwoods, barring any unexpected mortality. It is apparent in figure 3 that the small gaps have failed to sufficiently recruit a mixedwood gap cohort. The higher rate of mortality in small gaps is certainly related to the greater influence of the surrounding mature overstory on gap light and lower competitiveness of young pine in the more heavily shaded environment of smaller gaps. Silviculturally based light management in mixedwood stands is further challenged by differential impacts of hardwoods and pines on light availability, as other studies in uneven-aged pine-hardwood stands have shown (for example, Guo and Shelton 1998). Although not presented here, the level of vine infestation of tree crowns generally increased with decreasing gap size. Therefore, vine infestation may have also contributed to higher pine mortality in small openings.

CONCLUSIONS

An understanding of gap-cohort development in relation to gap size and other silvicultural treatments (for example, site preparation, artificial regeneration, release) informs the development of gap-based silviculture systems. This study yielded insights on the role of harvest size in the development of this particular mixedwood stand a quarter-century after gap formation. This study suggests that if regenerating a mixedwood composition is desired, harvest gaps may need to be at least 0.625 acres to ensure adequate pine regeneration without further intervention. In medium-sized gaps, sufficient pine recruitment and retention may be achieved but would benefit from a later tending that preferentially retains pine. However, a late intervention in small gaps is unlikely to produce mixedwood cohorts—earlier treatments to reduce competition from hardwoods and vines would be required to maintain a pine component.

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