REGENERATION IN BOTTOMLAND FOREST CANOPY GAPS 6 YEARS AFTER VARIABLE RETENTION HARVESTS TO ENHANCE WILDLIFE HABITAT

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Abstract—To promote desired forest conditions that enhance wildlife habitat in bottomland forests, managers prescribed and implemented variable-retention harvest, a.k.a. wildlife forestry, in four stands on Tensas River National Wildlife Refuge, LA. These treatments created canopy openings (gaps) within which managers sought to regenerate shade-intolerant trees. Six years after prescribed harvests, we assessed regeneration in 41 canopy gaps and 4 large (>0.5-ha) patch cut openings that resulted from treatments and in 21 natural canopy gaps on 2 unharvested control stands. Mean gap area of anthropogenic gaps (582 m^2) was greater than that of natural gaps (262 m^2). Sweetgum (*Liquidambar styraciflua*) and red oaks (*Quercus nigra*, *Q. nuttallii*, and *Q. phellos*) were common in anthropogenic gaps, whereas elms (*Ulmus* spp.) and sugarberry (*Celtis laevigata*) were numerous in natural gaps. We recommend harvest prescriptions include gaps with diameter >25 m, because the proportion of shade-intolerant regeneration increased with gap area up to 500 m^2. The proportion of shade-intolerant definitive gap fillers (individuals likely to occupy the canopy) increased with gap area: 35 percent in natural gaps, 54 percent in anthropogenic gaps, and 84 percent in patch cuts. Sweetgum, green ash (*Fraxinus pennsylvanica*), and red oaks were common definitive gap fillers.

INTRODUCTION

Within bottomland hardwood forests, low-intensity harvests, e.g., individual selection, favor regeneration and development of shade-tolerant tree species, whereas for regeneration of shade-intolerant tree species, managers have relied on clearcut or shelterwood harvests (Meadows and Stanturf 1997). However, harvest methods that remove most of the forest canopy may be unacceptable when forests are managed for multiple objectives or where maintaining forest integrity is paramount.

Alternative management methods are needed that regenerate shade-intolerant species while retaining forest integrity. This joint objective has been assessed by studies that found regeneration of shade-intolerant species was greater in anthropogenic gaps than in natural gaps (Dickinson and others 2000) and that an intermediate level of harvest may be optimal for regeneration and growth of some shade-intolerant species (Battaglia and Sharitz 2005, Battaglia and others 2004, Collins and Battaglia 2002, Gardiner and others 2004, Paquette and others 2006). These alternative methods have been espoused by the Forest Resource Conservation Working Group of the Lower Mississippi Valley Joint Venture to achieve desired forest conditions for priority wildlife habitat (Wilson and others 2007) that generally are attained through a reduction in canopy cover and basal area. Variable-retention clustered-thinning (VR-CT) harvest is a silvicultural practice that promotes development of desired forest conditions. VR-CT harvests have been undertaken to enhance wildlife habitat and retain biodiversity (Mitchell and Beese 2002), whereas traditional silvicultural thinning has been used to maximize growth and promote the health of residual stems so as to increase future timber volume (Nix 2006). Residual large, dominant stems surrounded by smaller trees and multiple canopy gaps that vary in area are hallmarks of VR-CT harvests. The resultant forest structure is spatially heterogeneous with dense shrubs and herbaceous understory intermixed with clusters of retained trees often with larger diameter trees at their foci (Twedt and Wilson 2007). Within the bottomland forests of the Mississippi Alluvial Valley, this silvicultural system is intended to be economically viable and provide sustainable habitat for priority wildlife, such as Louisiana black bear, migratory birds, and resident game species (Wilson and others 2007).

An additional expectation of VR-CT harvest is regeneration, development, and retention of shade-intolerant tree species, especially within canopy gaps. To further encourage regeneration of shade-intolerant tree species and to support prolonged retention of dense, shrubby understory conditions, up to 10 percent of VR-CT harvest areas may be in patch cut openings of 0.5 to 1.5 ha (Wilson and others 2007). Even so, a concern regarding implementation of VR-CT harvests is that canopy reduction may be insufficient to promote widespread regeneration of shade-intolerant trees [particularly oaks (*Quercus* spp.)], resulting in successional change favoring shade-tolerant tree species. To assess potential promotion of shade-intolerant species to the forest canopy following prescribed VR-CT harvest, we evaluated regeneration and dominance of trees within anthropogenic canopy gaps and compared these with regeneration in natural canopy gaps.

STUDY AREA

Tensas River National Wildlife Refuge (NWR) encompasses >26 000 ha of bottomland hardwood forest in northeast Louisiana. Habitat on the refuge is predominately mature second-growth forest intermixed with recently (<15 years) reforested land that is surrounded by private agriculture. On Tensas River NWR, silviculturally prescribed timber harvests have been used to enhance wildlife habitat within

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bottomland hardwood forests. Although most timber harvests were undertaken before formulation of current management recommendations (Wilson and others 2007), they presaged recommended prescriptions via implementation of VR-CT harvests and incorporation of 0.5 to 1.5 ha patch cut openings within VR-CT harvests.

We surveyed canopy gaps within six separate forest areas (hereafter stands). Each stand was >40 ha and subjected to one of three silvicultural treatments that were equally divided between two forest management units on Tensas River NWR. All forest stands were second growth, having been subjected to historical timber harvest, but prior to the treatments evaluated in this study, stands had not been harvested since refuge establishment in 1980. Stands were predominately sweetgum (*Liquidambar styraciflua*)-willow oak (*Q. phellos*) (Eyre 1980), but the ridge and swale topography supported "ribbons" of other forest types such as sugarberry (*Celtis laevigata*)-American elm (*Ulmus americana*)-green ash (*Fraxinus pennsylvanica*), and overcup oak (*Q. lyrata*)-water hickory (*Carya aquatica*). Upon recommendation of forest managers, three treatments (one per stand) were applied within each management unit: (1) VR-CT, (2) VR-CT with embedded 0.5 to 1.5 ha patch cut openings, and (3) untreated control. Treatment harvests were initiated during summer of 1999 and completed during summer 2000.

METHODS

Forest Sampling

During summer 2004 we characterized species composition, diversity, and basal area of canopy trees within the extant forest on each study stand using a one-basal-area factor metric prism for live stems ≥10 cm diameter at breast height (d.b.h.) at systematically located grid points (250 m apart). We made estimates of angular canopy cover at these points using a spherical densiometer (Fiala and others 2006). Additionally, we recorded the number of species and number of woody stems <10 cm d.b.h. (excluding vines) within 5 m (78.5 m^2) of each point.

Gap Regeneration

During fall 2005, we surveyed canopy gaps within the six study stands. Gaps were surveyed as encountered along line intercept transects (Runkle 1982) that spanned each stand. Gaps were defined as areas lacking forest canopy cover as a result of mortality owing to harvest, fall, or death of one or more canopy trees. Canopy gap area (basic) was estimated for each gap from six laser rangefinder distance measurements, at equally spaced azimuths (60 degrees apart), from the gap "center" to points directly below the edge of canopy vegetation of trees with dominant or codominant crown classes (Runkle 1981). If gap boundaries were excessively irregular, additional distance measurements at intervening azimuths were obtained. We estimated expanded gap area (Runkle 1981) using laser distance measurements from gap center to the base of all dominant or codominant boundary trees—we recorded species and diameter (d.b.h.) of these boundary trees.

We assessed tree regeneration within each gap via a census of all trees with heights >1 m but <10 m. We recorded the species and height (m) of each regenerating tree and categorized its location within the gap as "interior" when within the exposed (basic) gap area and thus potentially a canopy gap filler, or "edge" when within the expanded gap area and thus unlikely to fill the canopy gap due to competition with boundary trees. Up to four definitive gap fillers were identified within each gap as those individuals likely to occupy the canopy void by virtue of their species, stature, and location within the gap. We recorded the species, height, and d.b.h. of definitive gap fillers.

All stems within gaps that were >10 m tall but that did not have a dominant or codominant crown class were identified and recorded as "residual" stems. Residual stems were present as advanced regeneration, or suppressed crown class trees, within the expanded gap at the time of gap formation. Due to their frequent position near boundary canopy trees, most residual stems were unlikely to fill the canopy gap. However, any residual stem deemed likely to fill a canopy gap was recorded as definitive gap filler. The presumed "age" of randomly selected definitive gap fillers within each canopy gap was determined using annual growth rings from basal stem wafers of felled small-diameter saplings or from basal increment bore cores of larger trees (Telewski and Lynch 1991).

For patch cuts, we assessed boundary trees and expanded gap area similarly to other gaps but a complete census of saplings within these large "gaps" was not practical. Therefore, we sampled regeneration using three, randomly located, 0.04-ha (11.3-m radius) circular plots. However, we identified and recorded species and d.b.h. of all definitive gap fillers deemed likely to occupy canopy space within the entire patch cut opening.

Analysis

Gap and expanded gap areas were determined from field measurements by converting polar coordinates to Cartesian coordinates and employing Geographic Information System software (ArcGIS 9.2, Environmental Systems Research Institute, Redlands, CA). We assigned regenerating trees, by species, as either shade-intolerant or shade-tolerant (table 1), and we calculated the proportion of shade-intolerant regeneration within each canopy gap.

We used nonlinear regression (PROC NLIN, SAS Institute Inc., Cary, NC) to assess the relationship between the proportion of shade-intolerant stems within gaps and expanded gap area. We used analysis of variance (PROC GLM) to compare densities, proportions of shade-intolerant stems, and mean heights of regeneration between natural gaps on unharvested stands and anthropogenic gaps that resulted from VR-CT harvest. Finally, we used logistic regression (PROC GENMOD) to assess the relationship between the presence of a definitive gap filling red oak species (*Q. nigra*, *Q. nuttallii*, or *Q. phellos*) and gap area or treatment.

Table 1—Shade tolerance of regenerating hardwood species detected within natural canopy gaps and silviculturally induced (6 years postharvest) canopy gaps on Tensas River National Wildlife Refuge during fall 2004[a]

Shade-intolerant species	Shade-tolerant species
Eastern cottonwood (*Populus deltoides*) (VI)	Red mulberry (*Morus rubra*) (VT)
Black willow (*Salix nigra*) (VI)	Persimmon (*Diospyros virginiana*) (VT)
Honeylocust (*Gleditsia triacanthos*)	Sugarberry (*Celtis laevigata*) (VT)
American sycamore (*Platanus occidentalis*)	Red maple (*Acer rubrum*)
Cherrybark oak (*Quercus pagodifolia*)	Water elm (*Planera aquatica*)
Water oak (*Q. nigra*)	Cedar elm (*Ulmus crassifolia*) (MT)
Nuttall oak (*Q. nuttallii*)	American elm (*U. americana*) (MT)
Willow oak (*Q. phellos*)	Water hickory (*Carya aquatica*) (MT)
Sassafras (*Sassafras albidum*)[b]	Green ash (*Fraxinus pennsylvanica*) (MT)
Black locust (*Robinia pseudoacacia*)[b]	Boxelder (*A. negundo*) (MT)
Sweet pecan (*Carya illinoinensis*) (MI)	Blackgum (*Nyssa sylvatica*) (MT)
Overcup oak (*Q. lyrata*) (MI)	
Bald cypress (*Taxodium distichum*) (MI)	

Shrub and understory species = dogwood (*Cornus* spp.), swampprivet (*Forestiera acuminata*), deciduous holly (*Ilex decidua*), plum (*Prunus* spp.), buttonbush (*Cephalanthus occidentalis*), American beautyberry (*Callicarpa americana*), redbud (*Cercis canadensis*), blue-beech (*Carpinus caroliniana*), Chinese privet (*Ligustrum chinensis*), pawpaw (*Asimina triloba*), hawthorn (*Crataegus* spp.), sumac (*Rhus* spp.), baccharis (*Baccharis halimifolia*), devil's walkingstick (*Aralia spinosa*), and snowbell (*Styrax* spp.).

[a]Shade-tolerance rating from Meadows and Stanturf (1990): VI = very intolerant, VT = very tolerant, MT = moderately tolerant, MI = moderately intolerant.

[b] Shade tolerance rating from Putnam and others (1960).

RESULTS

Extant Forest

Basal area and percent canopy cover were less on VR-CT treated stands than on untreated control stands (table 2). Conversely, small stem density on treated stands was greater than on control stands. Despite the reduction in canopy trees, the overall species composition of the most common canopy trees was similar between treated and untreated stands (table 2). Notably, the ordinal rank of the three species with greatest basal area remained unchanged by treatment. Similarly, the proportion of shade-intolerant species within the canopy was relatively high on treated (71 percent) as well as untreated (60 percent) stands. Shade-intolerant species were the most abundant boundary trees surrounding gaps on both treated (84 percent) and untreated (70 percent) stands. Sweetgum and red oak species were the most common boundary trees surrounding silviculturally created gaps. Reflecting their prevalence within extant forest canopy (table 2), green ash was among those species commonly surrounding natural canopy gaps.

Gap Area

The basic (internal) area of canopy gaps was positively correlated with their expanded area (r = 0.81). Mean area of gaps resulting from VR-CT treatment (basic = 142±16 m^2, expanded = 582±54 m^2, n = 41) was greater (F > 9.5, P < 0.01) than mean area of natural gaps (basic = 56±22 m^2, expanded = 262±76 m^2, n = 21). Patch cut openings ranged from 0.47 to 1.78 ha.

Gap Regeneration

We recorded 5,188 stems within anthropogenic gaps and 1,854 stems within natural gaps. Additionally, within sample plots in patch cuts we recorded 443 stems. The proportion of woody stems comprised of shrubs or understory tree species (table 1) within natural gaps (15 percent) was similar to that within anthropogenic gaps (14.5 percent). The density of regenerating canopy species varied widely among canopy gaps (range = 295 to 20 976 stems/ha), being greater (F = 4.3, P = 0.04) in the smaller natural gaps (4415±801) than in the larger silviculturally created gaps (2363±573). These differences were largely due to much greater densities of elms (*Ulmus* spp.), but also more sugarberry, maples (*Acer* spp.), and other shade-tolerant species within natural gaps (fig. 1). Conversely, sweetgum, red oak species, and other shade-intolerant species were more abundant within anthropogenic gaps (fig. 1). We found an overall density of 685 shade-intolerant stems/ha in gaps on treated stands

Table 2—Mean basal area of live trees >10 cm diameter at breast height, density (number of stems <10 cm/ha), and angular canopy cover, as well as the distribution of basal area among the most common species and among shade-tolerance classes on untreated control bottomland hardwood forest stands and after variable-retention clustered-thinning silvicultural treatments on Tensas River National Wildlife Refuge, LA (stands were surveyed during summer 2004, 5 years after treatments were initiated)

Treatment	*n*	Basal area	Canopy	Density	Species (BA)	Shade (BA)
		m²/ha±SE	*percent*			
VR-CT	4	14.4±0.8	89.3±1.1	3912±488	*Liquidambar styraciflua* = 3.1±0.5	I = 10.3±1.0
					Quercus nigra = 2.6±1.4	MI = 0.5±0.3
					Q. nuttallii = 1.5±0.3	MT = 2.3±0.6
					Q. phellos = 1.5±0.3	T = 1.4±0.4
Control	2	20.9±1.9	98.5±0.9	3079±64	*L. styraciflua* = 3.5±2.5	I = 12.7±0.3
					Q. nigra = 3.3±3.2	MI = 1.5±0.5
					Q. nuttallii = 3.2±0.5	MT = 5.6±0.4
					Fraxinus pennsylvanica = 3.1±0.9	T = 1.2±0.7

BA = basal area; VR-CT = variable-retention clustered-thinning; I = intolerant and very intolerant; MI = moderately intolerant; MT = moderately tolerant; T = tolerant and very tolerant.

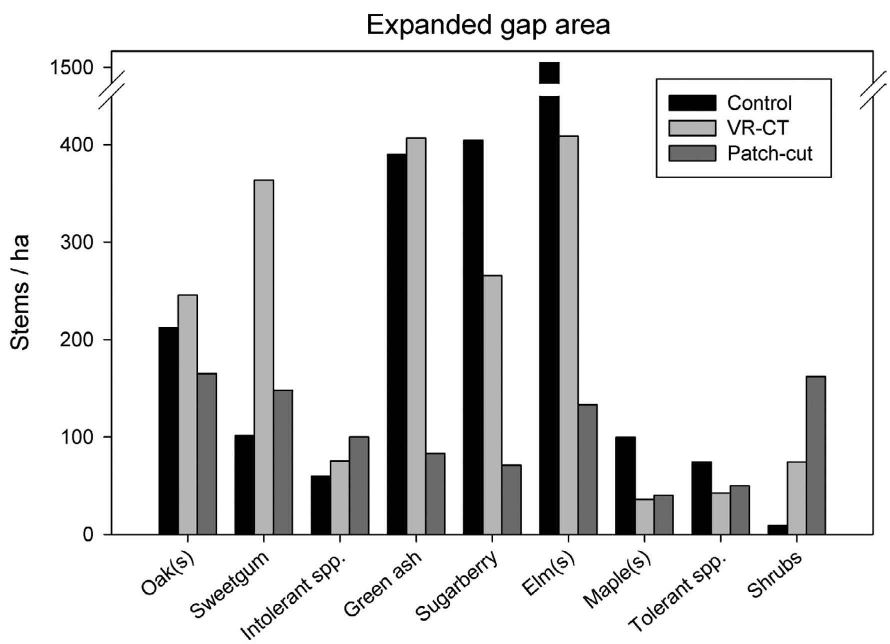

Figure 1—Density of all regenerating stems within expanded canopy gaps of 21 natural gaps (Control), 41 anthropogenic gaps created during variable-retention, clustered thinning silvicultural treatments (VR-CT), and 4 patch cuts (Patch-cut) in bottomland hardwood stands on Tensas River National Wildlife Refuge, northeast Louisiana, 6 years after treatments were initiated.

compared to 374 shade-intolerant stems/ha in natural gaps on control stands.

Because most regenerating stems within natural gaps were of shade-tolerant species, the proportion of stems that were shade-intolerant (0.14±0.04) was significantly less (F = 21.0, $P < 0.01$) than the proportion of shade-intolerant stems on treated stands (0.36±0.03). Over half (51 percent) of regenerating stems on patch cuts were shade intolerant. Although the proportion of shade-intolerant stems varied widely among canopy gaps (range = 0.0 to 0.78), we found a significant (F = 64.6, $P < 0.01$) nonlinear relationship with the expanded gap area (fig. 2). Moreover, shade-intolerant stems tended to be taller (height = 5.5±0.1 m) than their shade-tolerant counterparts (3.9±0.1 m) regardless of treatment (fig. 3).

Differences in density of species between natural and anthropogenic gaps were further amplified by consideration of only interior regenerating stems within the basic canopy area. Densities of shade-intolerant species, especially sweetgum and red oak species, were markedly greater on treated stands than on control stands (fig. 4). Densities of green ash as well as shrub and understory species were also greater within anthropogenic gaps whereas shade-tolerant species, most notably elms, had greater densities within natural canopy gaps (fig. 4).

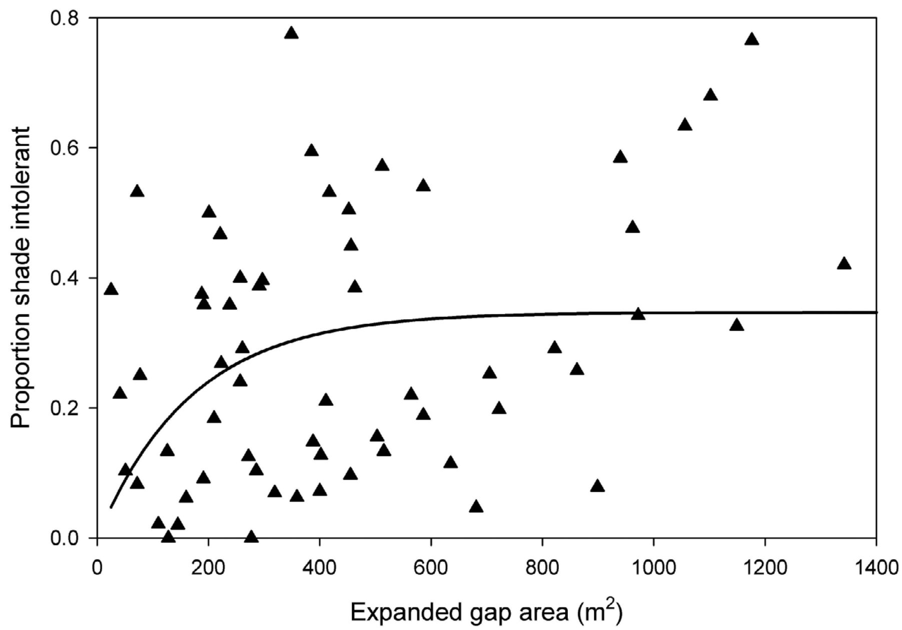

Figure 2—Relationship between the proportion of regenerating stems that were shade intolerant within canopy gaps and expanded gap area for 62 canopy gaps of natural and anthropogenic origin in bottomland hardwood stands on Tensas River National Wildlife Refuge, northeast Louisiana.

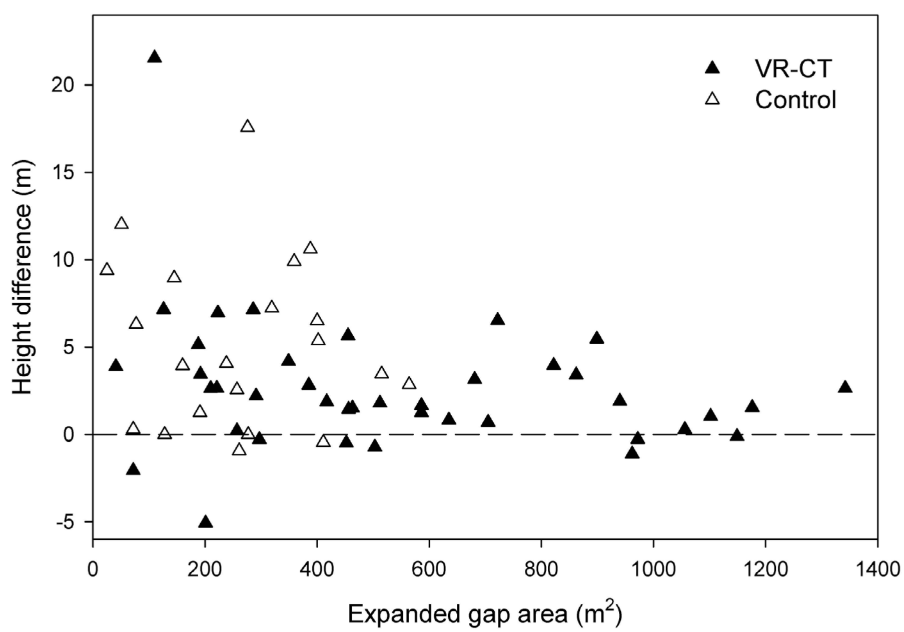

Figure 3—Height difference between shade-intolerant and shade-tolerant regenerating stems within 62 canopy gaps of natural and anthropogenic origin in bottomland hardwood stands on Tensas River National Wildlife Refuge, northeast Louisiana. Height differences >zero indicate shade-intolerant stems were taller than shade-tolerant stems.

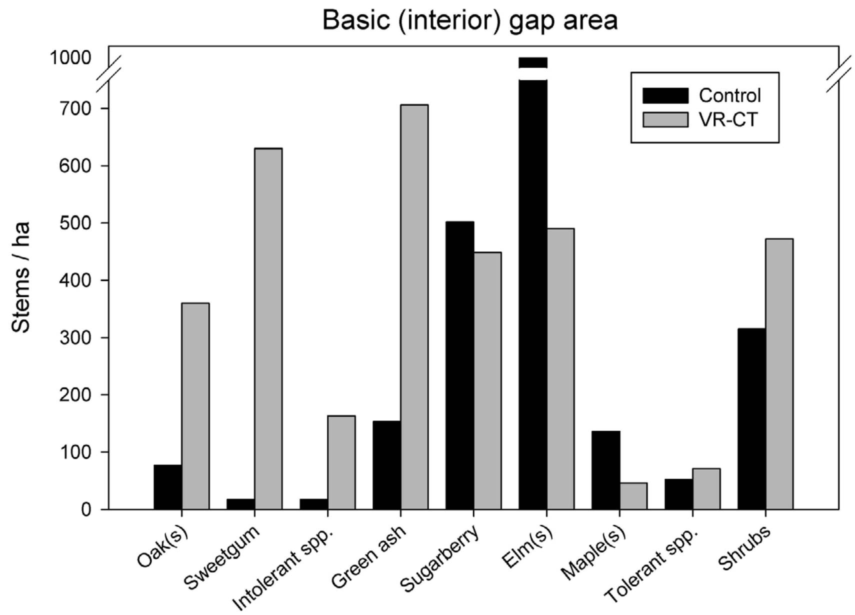

Figure 4—Density of interior regenerating stems within basic canopy gap area (area lacking canopy cover) on 21 natural gaps (Control) and 41 anthropogenic gaps created during variable-retention, clustered thinning silvicultural treatments (VR-CT) in bottomland hardwood stands on Tensas River National Wildlife Refuge, northeast Louisiana, 6 years after treatments were initiated.

Definitive Gap Fillers

We recorded 158 definitive gap fillers within 41 anthropogenic gaps but only 37 within 21 natural gaps. Within patch cuts we indentified 49 definitive gap fillers of which 84 percent were shade intolerant. In contrast, only 54 and 35 percent of definitive gap fillers were shade intolerant within anthropogenic and natural gaps, respectively (fig. 5). The occurrence of a red oak species as a definitive gap filler was independent of gap area ($\chi^2 = 1.06$, $P = 0.30$) and treatment ($\chi^2 = 0.11$, $P = 0.74$).

Definitive gap fillers were markedly taller on untreated stands (11.5±1.1 m) than on treated stands (6.6±0.4 m). Similarly, the age of definitive gap fillers on untreated sites (33.3±4.6 years, $n = 21$) was over twice the age of definitive gap fillers on treated stands (15.2±2.8 years, $n = 46$). Notably, heights of definitive gap fillers within patch cuts (6.1±0.2 m) were similar to their heights within gaps on treated stands, yet their mean age (4.7±0.2 years, $n = 10$) was less than a third the age of definitive gap fillers on treated stands.

DISCUSSION

Most regeneration within canopy gaps was present before gap creation or originated as sprouts from harvested trees. Even so, seeds provided by extant canopy trees, especially boundary trees surrounding canopy gaps may contribute to regeneration within gaps. As such, both treated and untreated stands, with >70 percent of trees surrounding gaps being shade-intolerant species, were well endowed to provision propagules of shade-intolerant trees.

The density of shade-intolerant stems within canopy gaps that resulted from VR-CT harvest (685 stems/ha) was less than the circa 1,000 stems/ha (400 stems per acre) recommended as a desired forest condition (Wilson and others 2007). However, this recommendation was based on stocking levels developed by Hart and others (1995) who incorporated seedling classes <1 m in height (<1 foot and 1 to 3 feet). As we only recorded regeneration ≥1 m in height, we were unable to account for numerous shade-intolerant seedlings within shorter height classes.

We classified green ash among shade-tolerant species but it has been variously reported as moderately shade tolerant (Meadow and Stanturf 1997), intermediate in shade tolerance (Zhao and others 2005), and shade intolerant (King and Antrobus 2005). Green ash was the most common regenerating species within anthropogenic gaps and the third most common regenerating species within natural gaps (fig. 1), as well as being a common canopy tree (table 2). Therefore, had we considered green ash among shade-intolerant species, the proportion of shade-intolerant species would be markedly greater than those we report.

Our data suggest an increased proportion of shade-intolerant regeneration as expanded gap area increased up to circa 500 m^2 (fig. 2). Approximately 35 percent shade-intolerant regeneration occurred within gaps of 500 m^2 with only modest increases thereafter as canopy gap area increased to 2000 m^2 (0.2 ha). Even so, we found the proportion of shade-intolerant regeneration was markedly greater within patch cut openings of 0.5 to 1.8 ha than within canopy gaps. The threshold of

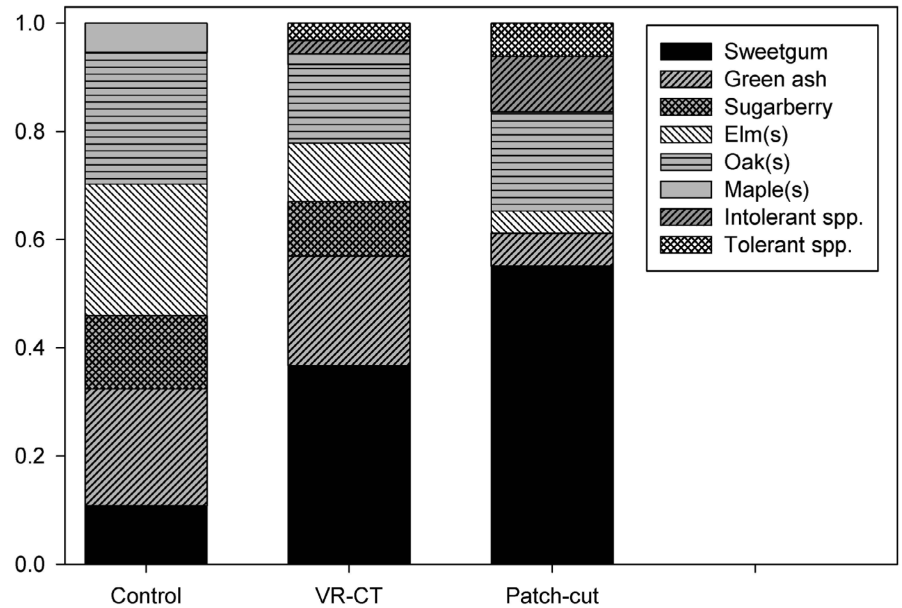

Figure 5—Proportions of definitive gap fillers (individuals deemed likely to ultimately occupy the forest canopy) by species within 21 natural gaps (Control), 41 anthropogenic gaps created during variable-retention, clustered thinning silvicultural treatments (VR-CT), and 4 patch cuts (Patch-cut) in bottomland hardwood stands on Tensas River National Wildlife Refuge, northeast Louisiana.

circa 500 m^2 for increased shade-intolerant regeneration is nearly double the mean expanded gap area (262 m^2) of natural gaps. Indeed, the maximum area of a natural gap in this study was only 564 m^2. Other studies of natural canopy gaps reported similar gap areas—median expanded gap area in Arkansas bottomland forest was 238 m^2 (King and Antrobus 2005), and mean expanded gap area from old-growth mesic forests in Eastern North America was circa 200 m^2 (Runkle 1981). In an east Texas bottomland forest, however, Almquist and others (2002) found mean natural gap area was 657 m^2.

The relatively old age (35±6 years, max = 60 years) of shade-intolerant definitive gap fillers in natural gaps suggests that shade-intolerant species persist for decades in the understory of bottomland stands. Similarly, average age (18±5 years, max = 48 years) of shade-intolerant definitive gap fillers in anthropogenic gaps predated gap creation by a dozen years. Persistence of shade-intolerant species in the understory is consistent with findings in upland hardwood forests of Eastern North America where four species of oak (*Q. alba*, *Q. rubra*, *Q. velutina*, and *Q. prinus*) had understory residence times of 89, 54, 50, and 38 years, respectively, before being released by a canopy disturbance (Rentch and others 2003).

With mean age of definitive gap fillers on patch cuts of <5 years, it appears that advanced regeneration within patch cuts was greatly reduced during treatment, and most regeneration within patch cuts occurred after harvest. This was evidenced by the prominence of stems of stump sprout origin among definitive gap fillers in patch cuts. Even so, height (6.2±0.2 m, n = 41) of shade-intolerant definitive gap fillers within patch cuts nearly equaled the mean height (6.9±0.5 m, n = 85) of considerably older shade-intolerant definitive gap fillers within silviculturally created gaps. The rapid growth of stems originating from stump sprouts is consistent with mean height (circa 4.5 m) of dominant water oak (*Q. nigra*) root sprouts 5 years after a heavy-thinning silvicultural treatment (Gardiner and Helmig 1997). Notably, regeneration of very shade-intolerant species, such as eastern cottonwood (*Populus deltoides*) and black willow (*Salix nigra*) was only recorded in patch cuts.

As shade-intolerant stems comprised only 35 percent of definitive gap fillers in natural gaps and 54 percent in anthropogenic gaps, it is likely that maintaining 67 percent (basal area) shade-intolerant canopy trees, as currently found on unharvested stands, may require use of patch cuts. Moreover, the benefits we observed from inclusion of patch cuts within the matrix of a VR-CT treated stand is not unique to bottomland hardwood forest systems, as Pinard and others (1999) found harvest of “even-aged groups of trees within an uneven-aged matrix” was necessary to achieve their multiple goals of maintaining biodiversity and ecological integrity of the forest while maintaining viable timber harvest in seasonally dry forests of Bolivia.

MANAGEMENT RECOMMENDATIONS

Because oak regeneration is largely dependent on establishing advanced regeneration and creating canopy openings that provide sufficient light to the forest floor

(Clatterbuck and Meadows 1993), we believe that unlike light-thinning or single-tree selection treatments, silvicultural treatments prescribed to promote desired forest conditions will provide for regeneration of shade-intolerant trees (particularly oaks). Indeed, we found that following wildlife-forestry based VR-CT harvest, 54 percent of definitive gap fillers were shade-intolerant species, but the proportion of shade-intolerant species within silviculturally created gaps increased until gap area exceeded 500 m^2. Thus, managers should strive to ensure prescribed treatments create canopy gaps with diameter >25 m. Even so, including patch cut areas of 0.5 to 1.5 ha within VR-CT harvested stands is likely required to achieve >60 percent shade-intolerant regeneration and these patch cut openings may be required to perpetuate very shade-intolerant species within the forest canopy.

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