FOREST STRUCTURE OF OAK PLANTATIONS AFTER SILVICULTURAL TREATMENT TO ENHANCE HABITAT FOR WILDLIFE

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Abstract—During the past 30 years, thousands of hectares of oak-dominated bottomland hardwood plantations have been planted on agricultural fields in the Mississippi Alluvial Valley. Many of these plantations now have closed canopies and sparse understories. Silvicultural treatments could create a more heterogeneous forest structure, with canopy gaps and increased understory vegetation for wildlife. Lack of volume sufficient for commercial harvest in hardwood plantations has impeded treatments, but demand for woody biomass for energy production may provide a viable means to introduce disturbance beneficial for wildlife. We assessed forest structure in response to prescribed pre-commercial perturbations in hardwood plantations resulting from silvicultural treatments: 1) row thinning by felling every fourth planted row; 2) multiple patch cuts with canopy gaps of <1 ha; and 3) tree removal on intersecting corridors diagonal to planted rows. These 3 treatments, and an untreated control, were applied to oak plantations (20 - 30 years post-planting) on three National Wildlife Refuges (Cache River, AR; Grand Cote, LA; and Yazoo, MS) during summer 2010. We sampled habitat using fixed-radius plots in 2009 (pre-treatment) and in 2012 (post-treatment) at random locations. Retained basal area was least in diagonal corridor treatments but had greater variance in patch-cut treatments. All treatments increased canopy openness and the volume of coarse woody debris. Occurrence of birds using early successional habitats was greater on sites treated with patch cuts and diagonal intersection. Canopy openings on row-thinned stands are being filled by lateral crown growth of retained trees whereas patch cut and diagonal intersection gaps appear likely to be filled by regenerating saplings.

INTRODUCTION

Afforestation has been undertaken by the U.S. Fish and Wildlife Service, state wildlife agencies, other conservation groups, and private landowners (often in conjunction with U.S. Department of Agriculture programs such as Wetland Reserve Program) to initiate restoration of forested wetlands on thousands of hectares within the Mississippi Alluvial Valley. Planting hardwood tree seedlings or seeds on restoration sites has resulted in thousands of hectares of oak-dominated, bottomland hardwood plantations. Many of these initial plantings are >20 years old. These maturing stands are often entering the stem-exclusion stage of stand development with closed canopies and sparse understories (Johnson 2004, Oliver and Larson 1996). During this stage, competition for light hinders the growth of canopy trees. Silvicultural treatments prescribed to enhance structural heterogeneity (both vertical and horizontal) and increase the floristic complexity within these stands may increase availability of food and cover for wildlife species within these stands. Although the effects of forest management on forest structure have been examined (Lorimer 1989, Meadows 1996) and the suitability of this resultant habitat for wildlife species has been evaluated (Twedt 2012, Twedt and Somershoe 2009, Wigley and Roberts 1994), little is known of the effects of forest management within relatively young (<30 year-old) plantations. Despite lack of empirical studies, enhanced wildlife habitat and improved timber production are expected to result from prescribed silvicultural treatments.

Analogous forest modification has been ongoing within coniferous forests where managers have used early-stage thinning in young (33-45 years old) stands to emulate late-successional forest conditions: Thinning was deemed successful as a preliminary restoration treatment (Plummer and others 2012). Although we are not advocating late-successional conditions within young (20-30 years old) bottomland hardwood plantations, silvicultural treatment may result in more rapid attainment of stand conditions desired for wildlife - as identified by the Lower Mississippi Valley Joint

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Venture (LMVJV Forest Resource Conservation Working Group 2007).

Despite the perceived benefit from reducing canopy cover within these hardwood stands, silvicultural treatments have rarely been undertaken because most young oak-dominated plantations lack sufficient volume of forest products (timber or pulpwood) for commercial harvest. However, where markets exist, harvest for woody biomass may provide an economically viable means to introduce beneficial disturbance in hardwood plantations. Because prescribed perturbations in young, oak-dominated, hardwood plantations are not common, subsequent stand development has not been widely studied. Evaluating stand development and wildlife response to prescribed silvicultural treatments is needed to inform development of proactive silvicultural treatments for oak-dominated hardwood plantations within the Mississippi Alluvial Valley.

OBJECTIVES

This study was intended to evaluate pre-treatment and post-treatment forest stand conditions within oak-dominated hardwood plantations as a base upon which subsequent stand development can be evaluated. We sought to gain insight regarding the ability of silvicultural prescriptions to improve wildlife habitat within hardwood plantations that differ in amount and configuration of canopy removed. We evaluated pre-commercial silvicultural treatments applied to oak-dominated hardwood plantations on National Wildlife Refuges (NWR) to assess initial changes in forest structure, woody species recruitment, and avian abundance.

METHODS

Study Areas

We identified >4250 ha that were afforested before 1991 through query of a forest restoration database maintained by the Lower Mississippi Valley Joint Venture. Most restorations on federally owned land were on Tensas River NWR (~900 ha), Theodore Roosevelt NWR Complex (~900 ha), Central Louisiana NWR Complex (~670 ha), and Cache River NWR (~300 ha). From these restorations, cooperating refuge personnel selected 3 plantations with density and height of trees such that prescribed silvicultural treatments would likely improve forest structure for wildlife by increasing within-stand structural heterogeneity. Selected study sites were:

Cache River NWR (Fig. 1) – A site of ~88 ha that was planted in 1990, located ~8 km north of Biscoe, AR. UTM coordinates (NAD83; Zone 15N): N3862700; E649190; S3861600; W648140,

Grand Cote NWR – A site of ~190 ha that was planted in 1990, located ~ 5 km west of Marksville, LA at T2N, R3E, Section 24: N3445800; E585660; S3443640; W585480, and

Yazoo NWR – A site of ~40 ha that combined small, adjoining oak plantings that were established during February or March of 1981, 1987, and 1990. Located ~18 km SW of Hollandale, MS: N3661900; E686180; S3660600; W685460.

Prior to implementation of treatments, forest managers randomly selected 10 permanent plots, using Universal Transverse Mercator (UTM) coordinates in the 1983 North American Datum (NAD83), within each treated stand at each study site (10 plots per stand = 40 plots per study site). Plot centers were located using hand held global positioning systems (GPS). To facilitate relocation, plot centers were marked with buried steel rebar or flat fiberglass pole and adjacent trees were basally marked with numbered aluminum tags. Notably, compared to post-treatment assessments which used international system (SI) units, pre-treatment data included measurement of smaller diameter trees within smaller sample plots and were recorded using English measurement units.

Pre-treatment Assessment

Within 0.05 acre circular sample plots, relative canopy closure and ground cover were visually estimated within 10 percent increments. At the Yazoo site, canopy closure was also assessed using hemispherical photography obtained from vertical projection of camera located 5 feet above forest floor (Chianucci and Cutini 2012). For each tree within sampled plot with diameter at breast height (dbh) ≥2 inch, observers recorded species, dbh, total tree height, crown class (dominant, co-dominant, intermediate, or suppressed), live crown ratio (10 percent increments of tree height that supported live green foliage), tree condition (1= no dieback; 2 = lower crown dieback; 3 = <1/3 crown dieback; 4 = >1/3 crown dieback; 5 = dead, twigs remain; 6 = dead, large limbs remain; 7 = dead, bole only; 8 = down wood ≥4 inch diameter), and distance (feet) and azimuth (degrees) from plot center. Diameters were recorded to 0.01 inch at Cache River and Yazoo, but to 1 inch at Grand Cote and are reported as the dbh of the tree of average basal area (quadratic mean diameter; QMD).

Tree regeneration was assessed within a nested 0.01 acre circular plot and recorded by number and species of seedlings (<3 feet tall) and saplings (>3 feet tall with dbh <2 inch). The relative volume (percent of vegetation that filled the cylindrical space) of each regeneration plot within 2 height classes (0-3 feet; 3-6 feet) was estimated in 10 percent increments for 6 vegetation classes (trees/shrubs; forbs/ferns; grass/sedge; blackberry; vines; other).

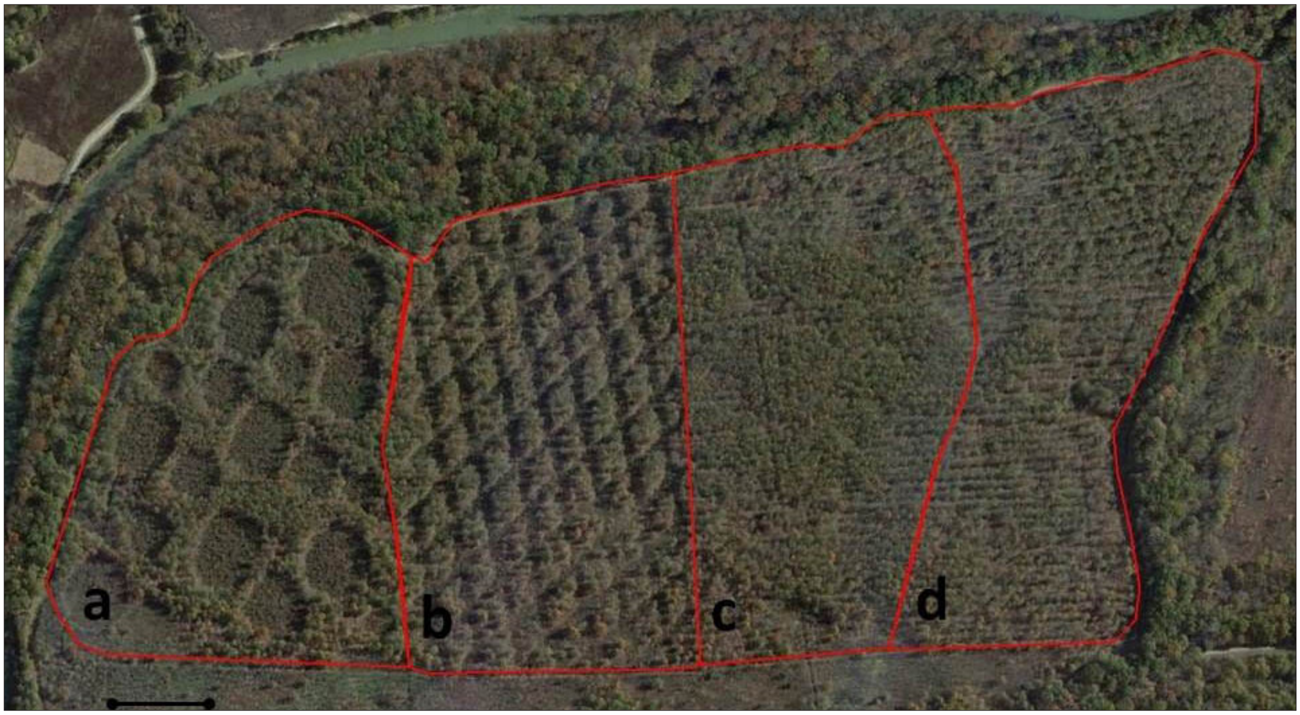

Figure 1—Aerial view (2012) of 4 treatments applied to ≥20 year-old oak plantation during 2010 to enhance wildlife habitat on Cache River National Wildlife Refuge (NWR), Arkansas. Treatments from left to right were: (a) variable patch clearcuts, (b) diagonal corridor thinning, (c) untreated control, and (d) single (1 of 4) row thinning.

Treatments

Each study site was divided and quadrates subjected to 1 of 4 treatments during summer 2010: (1) control with no harvest, (2) row thinning, (3) patch clearcuts, and (4) diagonal cross-row harvest. Due to the small acreage and relatively small volume of timber harvested during treatments, all treatments were pre-commercial with trees felled and left in situ as woody debris.

The long-term desired objective of these silvicultural treatments was to move stand structure toward desired forest conditions for wildlife which include: 1) maintaining or increasing species diversity, 2) increasing vertical and horizontal structural diversity, 3) retaining or increasing tree cavities, snags, and coarse woody debris, and 4) ensuring adequate (≥1000 stems/ha) regeneration of shade-intolerant tree species on 40 percent of stand (table 1; LMVJV Forest Resource Conservation Working Group 2007). Presumably, achieving these conditions will require major disturbance from a combination of clustered harvest (e.g., small, patch clearcuts) and an area-wide thinning (e.g., removal of individual trees and/or rows of trees). As such, one appropriate prescription may be a variable harvest that combines irregularly shaped group cuts and patch clearcuts (<2 ha) and thinning of the remaining stand. Recognizing that such a prescription may require considerable effort by forest managers, we opted to use 3 more easily implemented silvicultural treatments:

Row thinning—wherein ~25 percent of the existing canopy on treated stand was prescribed to be removed via felling of all trees within every fourth row of the original planting. Although some increase in species diversity and structural complexity was expected within treated stands, this treatment was presumed more beneficial for timber production than for wildlife habitat. We anticipated increased growth and vigor of retained trees but that understory development within the narrow openings created by removal of a single row of trees would be limited by lateral crown growth of residual trees.

Variable patch clearcut—wherein ~30-40 percent of the existing canopy on treated stand was prescribed to be removed via in patch clearcuts that ranged in area from 0.1 ha to 0.8 ha. Prescription stipulated that ≥2 patch clearcuts within each treated stand must be >0.4 ha, that ≥20 m of forest must be retained between edges of patch clearcuts, and that openings should be distributed throughout the entirety of the treated stand. Anticipated outcome was that natural regeneration and stump-sprouts within opening will increase species diversity and structural complexity within treated stand. Increased growth and vigor was anticipated for residual trees along edges of openings. Increased competition among regenerating saplings within openings may result in better bole quality of future timber than was present in felled trees.

Table 1—Mean forest metrics within ≥20 year-old oak plantations in Arkansas, Louisiana, and Mississippi during 2009 pre-treatment assessment of stands prescribed for treatment to enhance wildlife habitat. Prescribed treatments included untreated control, diagonal corridor thinning, variable patch clearcuts, and single (1 of 4) row thinning. P-values are for $F_{3,6}$ from analysis of variance comparing treatments

Metric	Control	Diagonal	Patch	Row	P
Canopy Closure (%; ocular)	77.0 ± 3.2	69.0 ± 3.3	67.3 ± 3.8	68.6 ± 4.3	0.218
Canopy Closure (%; photo)[a]	74.0	73.7	74.7	76.4	
Ground Cover (%)	28.3 ± 4.6	51.8 ± 4.9	54.0 ± 5.5	31.5 ± 5.5	0.118
Basal Area (m^2/ha)	14.1 ± 2.5	14.1 ± 4.1	12.1 ± 1.9	14.7 ± 3.8	0.678
Density (stems >5 cm / ha)	866 ± 198	678 ± 154	652 ± 236	812 ± 162	0.087
QMD (cm)	15.1 ± 2.0	16.4 ± 2.6	16.2 ± 1.7	15.7 ± 3.3	0.694
Tree height (m)	10.8 ± 1.6	11.9 ± 2.7	10.6 ± 1.4	12.3 ± 2.7	0.427
Snags (stems dbh > 5 cm / ha)	13.2 ± 6.7	14.8 ± 6.8	1.6 ± 1.6	13.2 ± 7.5	0.789
Dead wood (m^3/ha)	0.42 ± 0.30	0.79 ± 0.46	0.01 ± 0.01	0.65 ± 0.53	0.740
Regeneration (stems/ha)	2372 ± 535	2438 ± 427	2743 ± 562	3583 ± 776	0.620
Shade intolerant regeneration	1433 ± 357	1516 ± 314	1952 ± 450	2232 ± 511	0.388
Shade tolerant regeneration	939 ± 298	922 ± 207	791 ± 192	1351 ± 407	0.763

[a]Yazoo NWR only.

Diagonal corridor thinning—wherein ~56 percent of overstory canopy was prescribed to be removed by cutting cross-diagonal swaths as wide as the average canopy tree height with residual leave-tree patches of width approximately twice the canopy height. Where possible, cross-diagonal cut swaths were oriented 60°-240° and 120°-300° to enhance sunlight penetration of openings, but generally harvest was implemented diagonal to the planted tree rows. Because tree rows may be of a single species due to original planting protocol, tree harvest diagonal to planted rows lessens the likelihood that all or a large percentage of the stems of any tree species are removed during harvest. Finally, because diagonal harvests are implemented in a crossing pattern (i.e., an X shape), the intersection of harvest diagonals may simulate larger canopy gaps such as those of group harvests or small patch clearcuts.

Control—wherein no trees were felled or otherwise manipulated. Because management of reforested bottomland hardwood stands is poorly understood, a portion of each study area was retained as an untreated control. Control stands were used to compare post-treatment stand conditions with conditions where no treatments were implemented.

At the Grand Cote NWR site, concern regarding Chinese tallow (*Triadica sebifera*) establishment within treated stands prompted managers to aerially apply Clearcast™ herbicide (imazamox, SePRO Corp., Carmel, IN) at the rate of 4.68 L/ha after silvicultural treatments (September 2010). Mortality of Chinese tallow, green ash (*Fraxinus pennsylvanica*), and black willow (*Salix nigra*) appeared to result from this treatment.

Post-treatment Assessment

During summer 2012, we used circular sampling plots of 0.05 ha (>twice the area of pre-treatment plots) that were centered at previously marked plot locations. If we were unable to relocate a permanent plot marker, either due to discrepancy in recorded coordinates or due to presence of harvest debris, we located sample plot at GPS coordinates recorded during pre-treatment assessment.

For each tree within sampled plots with dbh ≥6 cm (note slightly larger dbh than used for pre-treatment assessment), observers recorded the same metrics as recorded during pre-treatment assessments. We measured dbh using metric tree calipers and recorded to 1.0 cm. Distance and height were measured using a laser rangefinder and recorded to 0.1 m.

Tree regeneration and vegetation density estimates were assessed within four 20 m^2 circular plots (2.52 m radius) located at cardinal directions each 5 m from 0.05 ha plot center. Number and species of woody plants ≥0.5 m tall were recorded within 0.5 m height classes up to 2.5 m and taller stems were recorded within 1.0 m height classes. We visually estimated, within 1 percent increments, the relative percent of cylindrical space (volume) that was filled by vegetation within 0-1 m and 1-2 m above ground level for the same 6 vegetation classes used during pre-treatment assessments. Finally, at each regeneration plot, percent canopy closure was estimated using a concave densiometer.

The 12 experimental units used for analysis were the 4 treated stands at 3 study site locations. We used analysis of variance (ANOVA; Proc GLM) to compare forest metrics among treatments (df = 3) and locations (df = 2) wherein the experimental error term was the treatment by location interaction (df = 6).

Bird Counts

From 2012-2014, within each treated stand we annually conducted 2 or 3 point counts for breeding birds between May 10 and June 30. Each count was 10-minutes in duration with detections recorded in time-distance intervals (Farnsworth and others 2005). Count locations were selected to optimize coverage of treated stands while maintaining independence of observations among bird counts. We tested for differences in bird communities among treatments, and among years post-treatment, using nonparametric multivariate analysis of variance (Anderson 2001). We used indicator species analysis (Dufréne and Legendre 1997) to evaluate the relationships between species and silvicultural treatments while blocking by location. Bird data were restricted to detections within 100 m and standardized to mean number of detections per species per count per year within a stand before analyses.

RESULTS

We detected no significant pre-treatment differences among treatments for any of the forest metrics measured (table 1); but stands prescribed for control and row thinning treatments may have had slightly greater tree density ($F_{3,6}$= 3.55, P = 0.09) and less ground cover ($F_{3,6}$= 2.98, P = 0.11). Study sites, however, differed markedly in pre-treatment structure (table 2). Grand Cote NWR had less canopy closure at just under 60 percent ($F_{2,6}$ = 13.33, P <0.01), less basal area with 9.0 m^2 per ha ($F_{2,6}$ = 14.73, P < 0.01), and less shade intolerant regeneration at only 43 stems/ha ($F_{2,6}$ = 26.03, P < 0.01). Greatest stem densities of trees >5 cm dbh at >1100 stems/ha ($F_{2,6}$ = 45.21, P<0.01) and greatest total regeneration of ~5600 stems/ha ($F_{2,6}$ = 18.14, P <0.01) were found at Cache River NWR. Yazoo NWR had the largest trees with mean height >15 m, QMD >20 cm, and mean basal area >19 m^2 per ha (table 2). Dead standing trees (snags) were rare (~1 percent of stems >5 cm dbh; table 1) and coarse woody debris was sparse (<1 m^3/ha; table 2).

Post-treatment stand conditions were assessed from 116 of the original 120 sample plots: Flooding prevented access to 1 sample plot in variable patch clearcut treatment at Grand Cote NWR and logistic-time constraints resulted in 3 permanent plots (1 each in control, variable patch clearcut, and diagonal corridor thinning treatments) not being resampled at Cache River NWR. Stands subjected to variable patch clearcut and diagonal corridor thinning had reduced canopy

Table 2—Mean forest metrics within ≥20 year-old oak plantations on National Wildlife Refuges (NWR) in Arkansas, Louisiana, and Mississippi during 2009 pre-treatment assessment of stands prescribed for treatment to enhance wildlife habitat. P-values are for $F_{2,6}$ from analysis of variance comparing study site locations

Metric	Cache River NWR	Grand Cote NWR	Yazoo NWR	P
Canopy Closure (ocular)	73.5 ± 3.1	59.4 ± 3.2	78.5 ± 2.6	0.006
Ground Cover	49.7 ± 5.2	43.5 ± 4.9	31.0 ± 3.7	0.212
Basal Area (m^2/ha)	13.1 ± 0.7	9.1 ± 0.3	19.2 ± 2.0	0.005
Density (stems dbh > 5 cm / ha)	1119 ± 58	540 ± 77	598 ± 57	<0.001
QMD (cm)	12.3 ± 0.3	14.8 ± 0.7	20.4 ± 0.8	<0.001
Tree height (m)	9.6 ± 0.2	9.0 ± 0.2	15.6 ± 1.1	<0.001
Snags (stems/ha)	9.9 ± 5.4	9.9 ± 5.1	12.4 ± 5.5	0.975
Dead wood (m^3/ha)	0.10 ± 0.05	0.59 ± 0.35	0.72 ± 0.45	0.613
Regeneration (stems/ha)	5591 ± 552	463 ± 190	2298 ± 323	0.003
Shade intolerant regeneration	3193 ± 398	43 ± 23	2113 ± 320	<0.001
Shade tolerant regeneration	2397 ± 277	420 ± 189	185 ± 43	0.006

closure (56 and 68 percent, respectively) compared to 92 percent canopy closure on post-treatment control stands ($F_{3,6}$ = 7.43, P=0.019; table 3). Density of trees with dbh ≥ 6 cm ($F_{3,6}$ = 3.96, P=0.071) appeared to be reduced and understory vegetation volume 0-1 m above ground ($F_{3,6}$ = 3.29, P=0.100) likely increased in response to silvicultural treatments (table 3). Density of snags did not differ among treatments ($F_{3,6}$ = 1.06, P=0.431), but relative to control stands, coarse woody debris appeared to be more abundant (table 3; $F_{3,6}$ = 3.42, P=0.093). Regeneration did not differ among treatments (table 3; $F_{3,6}$ < 2.36, P>0.17).

Larger trees remained present on Yazoo NWR post-treatment compared to other study sites (table 4), with taller trees ($F_{2,6}$=23.3, P=0.001), greater diameters ($F_{2,6}$ = 18.5, P=0.003), and more basal area ($F_{2,6}$ = 3.7, P=0.089). Greater understory vegetation volume 1-2 m above ground ($F_{2,6}$ = 7.80, P=0.021) and greater regeneration ($F_{2,6}$>40.2, P<0.001) were present at Cache River NWR (table 4). The number of snags at Grand Cote NWR increased markedly to 97 stems/ha after treatment ($F_{2,6}$ = 7.84, P=0.021), whereas coarse woody debris increased most at Yazoo NWR ($F_{2,6}$ = 6.67, P=0.03).

As one of the objectives of these treatments was to promote increased species diversity, we evaluated the density and stature of oaks ≥6 cm dbh (presumed to be planted), with those of non-oak species (presumed to be colonizers). Although density of non-oak species was low within stands treated with variable patch clearcuts (80 stems/ha) and diagonal corridor thinning (84 stems/ha), density did not increase in response to treatments (table 5; $F_{3,6}$ = 2.85, P=0.127). Moreover, non-oak species were markedly shorter, with heights <9 m compared to oaks at >10 m, and had smaller diameters, with QMD of <10 cm compared to oaks at >16 cm (table 5).

During point counts of breeding birds we detected 42 bird species (table 6). Empirically, we detected fewer birds and species within control stands than within treated stands. For 28 species with >2 detections, we noted bird community differences among treatments (F=2.93, P<0.01) but no differences among years since treatment (F=1.34, P = 0.15). Species associated with control stands (Indicator Value [IV]>24.6, P<0.09) included Acadian flycatcher (*Empidonax virescens*), eastern towhee (*Pipilo erythrophthalmus*), and red-eyed vireo (*Vireo olivaceus*). Two species, Carolina wren (*Thryothorus ludovicianus*) and summer tanager (*Piranga rubra*), were associated with row thinning (IV>36.1, P<0.06). Species commonly associated with early successional habitat were associated with the other 2 treatments: brown-headed cowbird (*Molothrus ater*), indigo bunting (*Passerina cyanea*), and white-eyed vireo (*Vireo griseus*) were associated with patch clearcuts (IV>33.7, P<0.09), whereas yellow-breasted chat (*Icteria virens*) was associated with diagonal corridor thinning (IV = 42.0, P<0.01).

Table 3—Mean forest metrics within ≥20 year-old oak plantations in Arkansas, Louisiana, and Mississippi during 2012 post-treatment assessment of stands treated to enhance wildlife habitat during 2010. Prescribed treatments included untreated control, diagonal corridor thinning, variable patch clearcuts, and single (1 of 4) row thinning. P-values are for $F_{3,6}$ from analysis of variance comparing treatments

Metric	Control	Diagonal	Patch	Row	P
Canopy Closure (%; densiometer)	91.8 ± 1.3	67.6 ± 3.5	55.9 ± 3.8	78.6 ± 2.2	0.019
Ground Cover (%)	28.6 ± 2.8	49.8 ± 3.5	55.7 ± 3.5	33.4 ± 2.6	0.172
Vegetation volume 0-1 m	18.6 ± 1.4	36.3 ± 2.5	41.9 ± 2.8	22.4 ± 1.5	0.100
Vegetation volume 1-2 m	10.0 ± 0.8	14.6 ± 1.3	16.2 ± 1.3	11.3 ± 0.9	0.342
Basal Area (m^2/ha)	11.1 ± 0.8	8.3 ± 1.2	6.4 ± 0.9	9.6 ± 0.9	0.254
Density (stems dbh ≥ 6 cm/ha)	588 ± 45	323 ± 34	282 ± 42	467 ± 48	0.071
QMD (cm)	15.9 ± 0.7	17.4 ± 0.9	16.3 ± 1.2	16.8 ± 1.0	0.793
Tree height (m)	11.3 ± 0.5	12.7 ± 0.8	11.0 ± 0.6	13.1 ± 0.7	0.256
Snags (stems/ha)	27.1 ± 9.7	40.0 ± 12.7	19.3 ± 7.7	68.0 ± 22.6	0.431
Dead wood (m^3/ha)	1.4 ± 0.5	11.6 ± 3.1	12.8 ± 3.0	13.0 ± 2.8	0.093
Regeneration (stems ≥0.5 m/ha)	1732 ± 449	1832 ± 354	1942 ± 485	2596 ± 440	0.171
Shade intolerant regeneration	924 ± 311	797 ± 216	1071 ± 262	1312 ± 294	0.222
Shade tolerant regeneration	808 ± 168	1034 ± 182	871 ± 320	1283 ± 228	0.267

Table 4—Mean forest metrics within ≥20 year-old oak plantations on National Wildlife Refuges (NWR) in Arkansas, Louisiana, and Mississippi during 2012 post-treatment assessment of stands treated to enhance wildlife habitat during 2010. P-values are for $F_{2,6}$ from analysis of variance comparing study site locations

Metric	Cache River NWR	Grand Cote NWR	Yazoo NWR	P
Canopy Closure (%; densiometer)	68.7 ± 3.1	79.2 ± 2.1	72.4 ± 2.7	0.368
Ground Cover	48.5 ± 3.2	35.9 ± 2.3	41.3 ± 2.7	0.502
Vegetation volume 0-1 m	37.7 ± 2.5	24.2 ± 1.4	27.7 ± 1.8	0.249
Vegetation volume 1-2 m	19.6 ± 1.1	12.0 ± 0.8	7.8 ± 0.7	0.021
Basal Area (m^2/ha)	7.6 ± 0.8	7.2 ± 0.5	11.7 ± 1.0	0.089
Density (stems dbh ≥ 6 cm/ha)	479 ± 49	419 ± 37	350 ± 35	0.424
QMD (cm)	13.5 ± 0.6	15.0 ± 0.4	21.2 ± 0.8	0.003
Tree height (m)	10.5 ± 0.4	9.8 ± 0.1	15.8 ± 0.5	0.002
Snags (stems/ha)	3.8 ± 2.7	96.9 ± 18.2	14.8 ± 4.6	0.021
Dead wood (m^3/ha)	6.8 ± 1.1	4.8 ± 0.7	17.4 ± 3.5	0.030
Regeneration (stems ≥0.5 m/ha)	4463 ± 413	865 ± 144	897 ± 151	<0.001
Shade intolerant regeneration	2470 ± 272	61 ± 15	631 ± 127	<0.001
Shade tolerant regeneration	1993 ± 246	804 ± 140	266 ± 63	<0.001

Table 5—Mean stem density of trees with diameter at breast height (dbh) ≥6 cm, their quadratic mean diameter, and average height for presumably planted oaks (*Quercus* spp.) and presumed colonizing non-oak canopy tree species in ≥20 year-old oak plantations in Arkansas, Louisiana, and Mississippi in 2009 before application, and in 2012 after application of silvicultural treatments to enhance wildlife habitat during 2010

	2009		2012					
	Density (stems >5 cm/ha)		Density (stems ≥6 cm/ha)		QMD (cm)		Height (m)	
Treatment	Oaks	Non-oaks	Oaks	Non-oaks	Oaks	Non-oaks	Oaks	Non-oaks
Control	448 ± 36	400 ± 39	327 ± 36	250 ± 39	19.3 ± 0.8	9.5 ± 0.8	12.4 ± 0.5	8.6 ± 0.7
Diagonal	355 ± 33	244 ± 16	237 ± 33	84 ± 16	19.5 ± 0.8	6.7 ± 0.9	13.4 ± 0.7	6.0 ± 0.8
Patch	288 ± 33	292 ± 17	201 ± 33	80 ± 17	16.5 ± 1.5	9.0 ± 1.2	10.3 ± 0.9	7.2 ± 0.8
Row	369 ± 27	440 ± 52	219 ± 27	243 ± 52	16.1 ± 1.5	9.9 ± 1.3	16.1 ± 1.5	8.5 ± 0.9

DISCUSSION

Pre-treatment tree densities on control stands and row thinning stands were greater than on these stands post-treatment (tables 1 and 3). We attribute this apparent discrepancy to differences in minimum stem diameter included in assessments (≥2 inch dbh vs. ≥6 cm dbh), but differences in plot size (0.05 acre vs. 0.05 ha) and tree mortality between assessments may have also influenced live tree density.

The greater age of plantings at Yazoo NWR likely contributed to taller trees with larger diameters and greater basal area per ha at this location. Felling of larger trees likely contributed to greater volume of coarse woody debris post-treatment at Yazoo NWR. Apparent increases in understory vegetation at Cache River NWR may be a response to reduced canopy closure at Cache River NWR (~69 percent) compared to 72 percent and 79 percent canopy closure at Yazoo and Grand Cote NWR, respectively.

Despite a prescription to remove the most canopy using diagonal corridor treatments, less post-treatment canopy was found in variable patch cut treatments (56 percent) than in diagonal corridor treatments (68 percent). Relative to canopy closure in post-treatment

Table 6—Number of birds detected during breeding bird point counts during 2012 – 2014 post-treatment assessment of stand treatments to enhance wildlife habitat during 2010. Prescribed treatments included untreated control, diagonal corridor thinning, variable patch clearcuts, and single (1 of 4) row thinning

Species	Control (n = 19)	Diagonal (n = 20)	Patch (n = 18)	Row (n = 20)
Acadian flycatcher (*Empidonax virescens*)	11	1	4	8
American crow (*Corvus brachyrhynchos*)	3	7	6	9
Baltimore oriole (*Icterus galbula*)	0	3	1	5
Blue-gray gnatcatcher (*Polioptila caerulea*)	1	1	6	3
Blue jay (*Cyanocitta cristata*)	2	3	4	1
Brown-headed cowbird (Molothrus ater)	8	13	15	6
Brown thrasher (*Toxostoma rufum*)	0	1	3	0
Carolina chickadee (*Poecile carolinensis*)	4	4	3	0
Carolina wren (*Thryothorus ludovicianus*)	4	14	9	14
Common grackle (*Quiscalus quiscula*)	0	14	0	5
Downy woodpecker (*Picoides pubescens*)	3	3	4	4
Eastern towhee (*Pipilo erythrophthalmus*)	9	1	5	2
Eastern wood pewee (*Contopus virens*)	1	2	1	2
Great-crested flycatcher (*Myiarchus crinitus*)	1	1	2	3
Indigo Bunting (*Passerina cyanea*)	9	24	25	16
Kentucky warbler (*Geothlypis formosa*)	2	3	2	2
Mourning dove (*Zenaida macroura*)	3	11	10	7
Northern cardinal (*Cardinalis cardinalis*)	60	65	46	66
Prothonotary warbler (*Protonotaria citrea*)	8	4	3	6
Red-bellied woodpecker (*Melanerpes carolinus*)	4	4	3	7
Red-eyed vireo (*Vireo olivaceus*)	4	0	0	1
Ruby-throated hummingbird (*Archilochus colubris*)	1	2	1	1
Summer tanager (*Piranga rubra*)	3	0	1	7
Tufted Titmouse (*Baeolophus bicolor*)	17	7	8	5
White-eyed Vireo (*Vireo griseus*)	11	19	21	14
Wood thrush (*Hylocichla mustelina*)	1	2	4	5
Yellow-billed Cuckoo (*Coccyzus americanus*)	25	28	24	28
Yellow-breasted Chat (*Icteria virens*)	13	67	55	11
Birds detected / count	11.1 ± 1.5	15.4 ± 2.2	15.1 ± 1.9	12.2 ± 1.6
Species detected / count	7.0 ± 0.6	7.8 ± 0.5	8.7 ± 0.6	8.0 ± 0.7

Species with ≤2 detections included: blue grosbeak (*Passerina caerulea*), chimney swift (*Chaetura pelagica*), common yellowthroat (*Geothlypis trichas*), fish crow (*Corvus ossifragus*), great-horned owl (*Bubo virginianus*), hairy woodpecker (*Leuconotopicus villosus*), northern mockingbird (*Mimus polyglottos*), northern parula (*Setophaga americana*), pileated woodpecker (*Hylatomus pileatus*), prai warbler (*Setophaga discolor*), red-shouldered hawk (*Buteo lineatus*), Swainson's warbler (*Limnothlypis swainsonii*), white-breasted nuthatch (*Sitta carolinensis*), and yellow-throated vireo (*Vireo flavifrons*).

control stands, application of treatments were conservative compared to prescription intentions for row and diagonal corridor thinning: Canopy cover was reduced ~13 percent by row thinning (prescription of 25 percent reduction), ~24 percent by diagonal corridor thinning (prescription of ~56 percent reduction), and ~36 percent by variable patch clearcuts thinning (prescription of 30-40 percent reduction). Even so, several desired changes in forest structure likely to promote desired forest conditions for wildlife were associated with diagonal corridor thinning and variable patch clearcut treatments including: Greater canopy heterogeneity as denoted by increased SE of canopy closure, reduced canopy cover and basal area, increased understory vegetation, and increased volume of coarse woody debris. We note however, increased woody debris was a byproduct of these non-commercial treatments where no biomass was removed from stands.

Treated stands were relatively small for evaluation of bird use of these areas. Thus, edge effects due to bird movements among stands and the surrounding landscape were likely. Even so, marked increases in the abundance of birds associated with early successional forest habitats (Thompson and DeGraaf 2001) were noted within stands subjected to variable patch clearcuts and diagonal corridor thinning. Lack of an increase of bird species that are typically associated with shrub-scrub habitats within stands subjected to row thinning suggests that openings within this treatment were insufficient in area to create habitat conditions that attract colonization by these bird species. Indeed, 4 years after treatment (2014), our subjective visual observation of the canopy openings created by row thinning suggests that these single row openings are being captured by lateral crown growth of residual canopy trees such that little understory vegetation is being stimulated.

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