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Original Article

Bird Community Response to Mid-Rotation Management in Conservation Reserve Program Pine Plantations

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ABSTRACT Open pine–grasslands are one of the most threatened ecological communities in the southeastern United States and provide essential habitat for many regionally declining bird species. While open pine–grassland forests have diminished, acreage of pine plantations has increased throughout the Southeast, in part because of the U.S. Department of Agriculture Farm Bill conservation programs. To understand whether fire and herbicide treatments would be effective in creating pine–grassland structure in plantations suitable for a suite of declining early successional and pine–grassland adapted species, we evaluated combined effects of selective herbicide and prescribed fire on plant and bird communities in thinned, mid-rotation pine stands established under the Conservation Reserve Program (CRP) in Mississippi, USA. Within each of the 12 replicate sites, we assigned 2 paired 8.1-ha plots to either treatment (herbicide + prescribed fire) or control in a randomized complete block design. We applied treatments during autumn and winter of 2002–2003. During 2003–2006 breeding seasons, we characterized the bird community using repeated (4–6 repetitions/yr), standardized, 10-minute point counts from which we estimated species richness, total relative abundance, total avian conservation value, and density of select species. Managed plots exhibited reduced hardwood midstory and a greater abundance of grasses and forbs in the ground layer. Although avian species richness and total relative abundance were similar in treatment and control stands, we observed a shift in the bird community from closed-canopy forest species to early successional and pine–grassland adapted species, many of which are experiencing population declines. We recommend thinning, hardwood midstory control, and prescribed burning within CRP pine plantations to provide habitat for a suite of regionally declining bird species.

KEY WORDS breeding-bird community, conservation reserve program, herbicide, imazapyr, mid-rotation management, loblolly pine plantation, Mississippi, pine–grassland, *Pinus taeda*, prescribed fire.

Prior to European settlement, fire was the dominant natural force responsible for creation and maintenance of open, old-growth pine–grasslands that covered >37 million ha across the southeastern United States (Frost 1993, 1998; Brockway and Lewis 1997). Many species of wildlife are adapted to this fire-dependent plant community composed of pine overstory and herbaceous understory (Engstrom 1993, Guyer and Bailey 1993, Simberloff 1993). In the absence of natural fire regimes, frequent prescribed fire (every 1–3 yr) is essential for maintaining an open canopy, controlling hardwood midstory, and establishing a diverse herbaceous understory in pine systems (Mobley and Balmer 1981, Masters et al. 2005). However, use of prescribed fire has declined due to changing management objectives and growing liability concerns (Frost 1993, 1998; Sun 2005). This broad-scale fire exclusion in the southeastern United States has resulted in changing the dominant forest structure from open canopy pine–grasslands to closed canopy mixed pine–hardwood forests. Less than 1% of old-growth longleaf pine (*Pinus palustris*)–grasslands currently exist (Engstrom and Sanders 1997). Consequently, many wildlife species dependent on the pine–grassland ecosystem are declining regionally or nationally (Engstrom 1993, Guyer and Bailey 1993, Simberloff 1993), particularly bird species such as the Bachman's sparrow (*Aimophila aestivalis*), brown-headed nuthatch (*Sitta pusilla*), and northern bobwhite (*Colinus virginianus*; Sauer et al. 2008).

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Whereas open pine–grasslands have greatly diminished, pine plantations occupy approximately 20% of the forested landbase in the southeastern United States (Smith et al. 2009). U.S. Department of Agriculture (USDA) Farm Bill conservation programs, such as the Conservation Reserve Program (CRP), have contributed to the installment of pine plantations throughout the Southeast. Of the 1.3 million CRP ha in the southeastern United States, >319,000 ha are enrolled in the Conservation Practice (CP)-11—mid-rotation (10- to 25-yr-old) pines (USDA 2010).

The CRP was created under the Food Security Act of 1985 to initially address commodity control and soil erosion (Allen and Vandever 2003), but continued revisions of the CRP in subsequent Farm Bills have explicitly identified creation and maintenance of wildlife habitat as a programmatic objective (Allen and Vandever 2003). The wildlife value of southeastern CRP pine plantings has been specifically questioned (Hays and Farmer 1990, Carmichael 1997) because these plantations are often characterized by low diversity and biomass of understory plants. Numerous authors (Carmichael 1997; Burger 2000, 2005) have suggested that active management of extant CRP pine stands could enhance wildlife value and, to some degree, mitigate loss of historical pine–grasslands.

Mid-rotation management to meet habitat objectives generally consists of implementing a silvicultural thinning, followed by application of herbicide and/or prescribed fire. In long-term fire-excluded pine forests, use of selective herbicides may be necessary to control established hardwood midstory (Thompson 2002, Shepard et al. 2004, Woodall 2005). Pine thinning and midstory control opens the canopy and allows sunlight to reach the forest floor, which stimulates germination of herbaceous ground cover (Hurst 1989). Following hardwood control, prescribed fire can be reintroduced on a 1- to 3-year rotation to eliminate residual litter, control hardwood re-colonization, and promote growth of understory grasses and forbs (Cain et al. 1998, Masters et al. 2005, Iglay 2010).

Although selective herbicide treatment and prescribed fire have been shown to improve wildlife habitat quality in commercial pine plantations (Thompson 2002, Woodall 2005, Iglay 2010) and naturally reforested pine stands (Edwards et al. 2004), additional research is needed to validate benefits of these management strategies on CRP pine stands. Afforested CRP fields, representing lands that were previously in agricultural use, could potentially exhibit different vegetation responses to succession and management than sites that have always been forested or forested through multiple rotations, due to differences in seed banks. Under CRP, selective herbicide and prescribed fire are cost-shared, mid-contract management practices. However, wildlife benefits of these practices applied to CRP have not been evaluated. Therefore, our objectives were to determine combined effects of selective herbicide and prescribed fire on vegetation structure and avian community composition in thinned, mid-rotation loblolly pine (*Pinus taeda*) stands enrolled in CRP. We hypothesized that hardwood midstory would be reduced following treatment, which would result in a more open canopy, reduced foliage height density, and a more developed herbaceous understory. Furthermore, we expect to observe a shift in the bird community from closed-canopy and midstory-associated species to early successional and pine–grassland bird species. We also hypothesized that the treatment would produce a net increase in species richness and improve conservation value of CRP pine stands.

METHODS

Study Area and Treatments

We evaluated 12 privately owned, thinned, mid-rotation (15- to 18-yr-old) loblolly pine stands in Kemper, Neshoba, Lincoln, and Covington counties, Mississippi, USA. Each site was approximately 18.2 ha and enrolled in the CRP CP-11 (existing trees). All CRP stands used in this study were thinned 1–6 years prior to implementation of treatments and exhibited a midstory dominated by either sweetgum (*Liquidambar styraciflua*) or Chinese privet (*Ligustrum sinense*). Pine basal area ranged from 14.3 m^2/ha to 22.3 m^2/ha, and pre-treatment plantation characteristics (trees/ha; mean, min., and max. diam at breast ht; mean total ht; basal area; and vol./ha) were comparable between treatment and control plots (Sladek et al. 2008). Within each site, we defined 2 rectangular 8.1-ha treatment plots and assigned 1 of 2 treatments (selective herbicide + prescribed fire or control) in a randomized complete block design. The herbicide + prescribe burn treatment consisted of an imazapyr herbicide application (Arsenal Applicators Concentrate®; BASF Corporation, Raleigh, NC) followed by a single dormant-season prescribed burn. We applied the herbicide using skidders during October–November 2002; it consisted of 0.56 kg of the active ingredient imazapyr (1.16 l/ha Arsenal AC®) and 0.35 L mentholated seed oil surfactant in 187 L total spray solution per ha. We conducted dormant-season prescribed fires during January and February 2003 under the following conditions: a temperature range of 4.4° C to 15.5° C, relative humidity 40–60%, wind speed <8.04 km/hour, and a mixing height of >500 m. Over the 4-year study, 5 of the 12 initially treated sites were removed from the study because of circumstances that compromised treatments (e.g., disking, escaped prescribed fire, or hurricane damage that precipitated a salvage harvest), and data were excluded from analyses following unintended disturbance. Thus, sample size varied among years, which created an unbalanced design; however, we accounted for this during analyses.

Vegetation Sampling

We measured vegetation characteristics in the fourth growing season following treatments during June–July 2006. We also included results from vegetation sampling conducted 1–2 growing seasons post-treatment (2003 and 2004; Sladek et al. 2008, Jones et al. 2009, Mixon et al. 2009). Within each 8.1-ha treatment plot, we systematically distributed 9 sampling points (3 rows of 3 points) using a random starting point for avian and vegetation sampling. We sampled vegetation along 2, 30-m line transects on each of 3 bird sampling points along the grid diagonal and one 30-m line transect on each of the remaining 6 points ($n = 12$ 30-m transects/plot). We began each line transect at a random distance in a random direction of each sampling point.

We estimated percent midstory canopy coverage (i.e., woody vegetation >1.37 m high but not extending into pine overstory) in 1-cm increments along the 30-m line transect. We estimated percent coverage of life forms (grass, grass-like [sedges and rushes], forb, legume, woody vine, vine, woody, and fern) that were <1.37 m in height within each 1-cm increment along the 30-m line transect using a modification of Canfield's (1941) line-intercept method. In addition, we estimated understory foliage height obstruction using a 4.8-m Nudds vegetative profile board (Nudds 1977). We measured visual obstruction by estimating percent foliage cover at each 0.8-m vertical increment from a 15-m distance in each of the 4 cardinal directions at 0 m, 15 m, and 30 m along the line transect.

Bird Surveys

Bird communities are diverse, sensitive to environmental change, highly mobile, able to respond quickly to habitat change, and easily measured. As such, avian communities are good indicators of environmental quality and are often used as measures of environmental benefits of conservation practices. To assess avian benefits of managed CRP pine stands, we sampled breeding-bird populations using point counts (Ralph et al. 1995) at 3 permanent survey points along a diagonal of each 8.1-ha plot, with the first point initially picked at random. Each individual point was located within 75 m of stand edge. We conducted surveys during May to the first week of August in 2003 (4 repetitions), 2004 (5 repetitions), 2005 (4 repetitions), and 2006 (6 repetitions). Two observers (Sladek 2006, Singleton 2008) conducted 10-minute point-count surveys using conventional distance-sampling techniques. We began surveys 10 minutes after sunrise and concluded no later than 10:00 a.m. Detections were primarily auditory, and we recorded individual observations by species, time interval (0–3 min; 4–5 min; and 6–10 min) and distance band (0–25 m, 25–50 m, and >50 m; Ralph et al. 1995).

Statistical Analysis

Vegetation.—We analyzed vegetation data collected in the fourth growing season (2006) following treatment. We also included results from vegetation sampling conducted 1–2 years post-treatment (2003 and 2004; Sladek et al. 2008, Jones et al. 2009, Mixon et al. 2009). These earlier data were not re-analyzed because we did not have access to the data and because we used the same analysis techniques. We arcsine-square-root-transformed percent coverage data at the transect level to satisfy assumptions of normality and homogeneity of variance (Zar 1999). We estimated mean transformed percentage midstory canopy cover, cover by growth form, percent visual obstruction for each 0.8-m increment of the Nudds board, and total foliage height obstruction at the plot level. We used a mixed-model analysis of variance (ANOVA) in SAS PROC MIXED (SAS Institute, Inc., Cary, NC) to test the null hypothesis of no difference in vegetation metrics for main effects of treatment (burn/herbicide and control) as a fixed effect and site as a random blocking effect (Littell et al. 2006). We used the Kenward–Roger adjustment for degrees of freedom and estimated treatment-specific least-square means using the LSMEANS option following a significant main effect ($\alpha = 0.05$; Littell et al. 2006). Where appropriate, we report back-transformed means and confidence intervals for ease of interpretation.

Breeding birds.—We estimated relative abundance of breeding birds (mean no. of calling male individuals/point) by year and treatment, species richness (mean no. of bird species/point), and total avian conservation value (TACV; Nuttle et al. 2003) from observations recorded within a 50-m radius of the survey point. Recognizing that vegetation differences resulting from treatments might influence detection probability, we truncated call count data at 50 m to maximize detection probability and ensure independence among experimental units. Fifty meters was close to the effective detection radius for most species. Total avian conservation value is an index to the overall conservation value of a bird community in a given plot-specific plant community and is calculated as a function of the species-specific relative abundance, weighted by Partners in Flight (PIF) region-specific priority ranks (PIF 2006). We used equation 1 (Nuttle et al. 2003) to calculate total avian conservation value for each treatment plot:

$$\mathrm{TACV}_{ij} = \sum_{k=1}^{S} (A_{ijk} \times \mathrm{PIF}_k) \tag{1}$$

where TACV_{ij} = average avian conservation value of plot i in year j, S = total number of species at the plot, A_{ijk} = mean relative abundance for species k at plot i in year j, and PIF_k = Partners in Flight priority rank score for species k in Physiographic Area 27 of the Southeastern Coastal Plain (PIF 2006).

We tested the hypotheses that total relative abundance, species richness, and TACV would be significantly different between treated stands and-or plots. We tested main effects of year, treatment, and year × treatment interactions using a repeated-measures mixed-model ANOVA in SAS PROC MIXED (Littell et al. 2006). We modeled treatment (herbicide–burn vs. control) as a fixed effect, site as a random block effect, and year as a repeated effect with site × treatment as the subject. We selected an appropriate covariance structure (autoregressive [AR(1)], compound symmetry [CS], unstructured [UN]) based on minimum Akaike Information Criteria (AIC; Burnham and Anderson 1998). We used a Kenward–Roger adjustment for degrees of freedom (Littell et al. 2006). We used the LSMEANS SLICE option to identify treatment effects within years or year effects within treatments following a significant year × treatment interaction ($\alpha = 0.05$; Littell et al. 2006). We estimated treatment-specific least-square means using the LSMEANS option following a significant main effect ($\alpha = 0.05$; Littell et al. 2006).

Table 1. Number of observations, model selection, detection probability, and effective detection radius for select bird species in herbicide–burn treated and control plots, in thinned, mid-rotation Conservation Reserve Program loblolly pine (*Pinus taeda*) plantations in Mississippi, USA (2003–2006).

	Treatment				Control			
Species	*n*[a]	Model selected	*P*-value[b]	EDR[c]	*n*	Model selected	*P*-value	EDR
Early successional–pine grassland								
Common yellowthroat	154	Hazard-rate	0.37	61.14	59	Half-normal + year covariate	0.30	55.05
Eastern wood-pewee	147	Hazard-rate + year covariate	0.44	66.13	50	Uniform + simple polynomial	0.32	56.60
Indigo bunting	899	Half-normal + year covariate	0.18	42.71	552	Half-normal + year covariate	0.20	44.87
Northern bobwhite	94	Half-normal + year covariate	0.21	45.95	45	Uniform	1.00	100.00
Pine warbler	479	Half-normal + year covariate	0.17	40.71	362	Half-normal + year covariate	0.19	44.14
Summer tanager	104	Half-normal + year covariate	0.10	32.02	65	Half-normal + cosine	0.08	28.80
Forest interior–forest edge								
Hooded warbler	113	Half-normal + year covariate	0.20	45.12	280	Half-normal + year covariate	0.11	33.06
Kentucky warbler	142	Half-normal	0.28	52.92	199	Half-normal	0.22	46.45
Red-eyed vireo	77	Half-normal	0.22	47.32	98	Hazard-rate	0.32	56.78
White-eyed vireo	177	Half-normal + year covariate	0.28	52.58	348	Hazard-rate + year covariate	0.16	39.92
Wood thrush	80	Half-normal	0.65	80.63	110	Half-normal	0.42	64.61

[a] No. of observations.
[b] Detection probability.
[c] Effective detection radius.

To further investigate avian–habitat relationships, we estimated density of 11 species with >60 observations pooled over all 4 years in both treatment and control plots separately using conventional distance sampling in Program DISTANCE 5.0 (Thomas et al. 2006). Species analyzed included common yellowthroat (*Geothlypis trichas*), eastern wood-pewee (*Contopus virens*), indigo bunting (*Passerina cyanea*), northern bobwhite, pine warbler (*Dendroica pinus*), hooded warbler (*Wilsonia citrina*), Kentucky warbler (*Oporornis formosus*), white-eyed vireo (*Vireo griseus*), wood thrush (*Hylocichla mustelina*), red-eyed vireo (*Vireo olivaceus*), and summer tanager (*Piranga rubra*). We assumed *a priori* that vegetation structure might influence detection probability; thus, we modeled treatment- and species-specific detection functions for each of the 11 bird species stratified by year (Bibby and Buckland 1987, Buckland et al. 2001). Because we incorporated detection probabilities in the density estimations, we were able to include observations at greater distances from point center. Therefore, we truncated data to include observations within 100 m of point center. We used model selection via AIC adjusted for small sample size (AIC_c; Akaike 1974) to evaluate the fit of 3 key-function models (half normal, hazard rate, and uniform) with and without series expansion terms (cosine, simple polynomial, and hermite polynomial) for the detection function with and without a year covariate parameter (Table 1; Buckland et al. 2001). Because only 2 observers were involved in bird surveys, we did not model observer effects.

RESULTS

Vegetation Structure and Composition

Vegetation structure and composition differed substantively between herbicide–burn treatment and control plots all 4 sampling years post-treatment. The herbicide–burn treatment reduced hardwood midstory while promoting growth of herbaceous vegetation. Sladek et al. (2008) reported significantly less midstory canopy cover in treatment plots compared with control plots during the first and second growing seasons (2003 and 2004) following herbicide and burn treatment. Similarly, mean midstory canopy cover was greater ($F_{1,6} = 67.72$, $P < 0.001$) in control plots ($\bar{x} = 59.9\%$, CI: 44.1–74.7) than in herbicide–burn plots ($\bar{x} = 6.3\%$, CI: 0.9–16.1) during the fourth growing season (2006; Table 2).

Mixon et al. (2009) reported that percent coverage of forbs was 3 times greater in treated plots during years 1 and 2 post-treatment; grasses and grass-like species were similar during

Table 2. Main effect of herbicide–burn treatment, least-squares mean estimate, lower confidence limit (LCL), and upper confidence limit (UCL) for mean percentage midstory canopy cover, mean percentage cover per height designation of Nudd's profile board, and mean total visual obstruction in thinned, mid-rotation Conservation Reserve Program loblolly pine (*Pinus taeda*) plantations in Mississippi, USA, during May–July 2006.

	Treatment			Control			Treatment		
Variable	$F_{1,ddf}$	ddf	*P*-value	$\bar{x}$	LCL	UCL	$\bar{x}$	LCL	UCL
Midstory canopy cover	67.72	6.00	<0.001	59.87	44.07	74.67	6.32	0.91	16.10
Nudd's section 1 (0–30 cm)	1.30	12.00	0.277	90.47	83.50	95.68	84.85	76.65	91.53
Nudd's section 2 (30–60 cm)	4.90	12.00	0.047	83.99	73.09	92.47	65.75	52.65	77.73
Nudd's section 3 (60–90 cm)	8.84	12.00	0.012	79.35	66.74	89.58	50.68	36.55	64.76
Nudd's section 4 (90–120 cm)	13.91	6.00	0.010	75.65	61.81	87.19	39.05	25.11	53.96
Nudd's section 5 (120–150 cm)	20.31	6.00	0.004	74.90	61.22	86.42	32.33	19.50	46.68
Nudd's section 6 (150–180 cm)	26.17	6.00	0.002	74.46	59.57	86.89	25.56	13.12	40.45
Total visual obstruction	11.83	6.00	0.014	79.13	67.85	88.49	50.03	37.33	62.73

Table 3. Main effect of herbicide–burn treatment, least-squares mean, and pooled standard error estimate for life-form canopy coverage in thinned, mid-rotation Conservation Reserve Program loblolly pine (*Pinus taeda*) plantations in Mississippi, USA, during May–July 2006.

	Treatment			Control		Treatment	
Growth form	$F_{1,ddf}$	ddf	*P*-value	$\bar{x}$	SE	$\bar{x}$	SE
Grass	11.74	6.00	0.014	1.98	1.96	7.23	1.96
Grass-like	0.47	6.00	0.518	1.06	0.47	0.69	0.47
Forb	58.28	6.00	0.000	1.58	0.54	6.24	0.54
Legume	3.73	6.00	0.102	0.23	0.37	0.81	0.37
Woody vine	0.61	6.00	0.466	50.32	7.94	57.34	7.94
Vine	1.46	6.00	0.272	0.32	0.95	1.89	0.95
Woody	5.43	6.00	0.059	10.12	1.40	7.01	1.40
Fern	0.49	6.00	0.512	1.85	1.79	2.69	1.79

1 year post-treatment, but were 2.5 times greater in treatment plots during the second year post-treatment; vine coverage was 2.6 times greater in controls during year 1, but was similar during year 2 post-treatment; woody species coverage was 3.5 times greater in control plots at 1 and 2 years post-treatment; and fern and legume coverage did not differ between treated and control plots. By year 4 post-treatment, grasses ($F_{1,6} = 11.74$, $P = 0.01$) and forbs ($F_{1,6} = 58.28$, $P < 0.001$) were greater in treatment plots than in control plots (Table 3). Grasses were 2.7 times greater in treatment plots ($\bar{x} = 7.23$, SE = 1.96) compared with control plots ($\bar{x} = 1.98$, SE = 1.96). Forbs were 2.9 times greater in treatment plots ($\bar{x} = 6.24$, SE = 0.54) compared with control plots ($\bar{x} = 1.58$, SE = 0.54; Table 3).

Jones et al. (2009) reported a significant difference in visual obscurity along all sections of the Nudds board in years 1 and 2 post-treatment. Vegetative coverage was greater in control plots at all Nudds board heights. Coverage differed by 7% in section 1 (0–30 cm) and differences increased with height of the board. During the fourth year post-treatment, mean vegetation coverage for Nudds board sections 2–6 (30–180 cm) were greater in control plots than treatment plots (Table 2). Visual obscurity from 0 cm to 30 cm did not differ between treatment and control plots (see Supplementary Materials, available online at www.onlinelibrary.wiley.com).

Avian Community

During the 2003–2006 breeding seasons, we observed 67 avian species, 49 of which were detected in herbicide–fire-treated plots and 48 in control plots. Total relative abundance did not exhibit a significant treatment × year interaction ($F_{3,29.7} = 2.58$, $P = 0.07$) and did not differ between treatments ($F_{1,11.3} = 3.43$ $P = 0.09$) or among years ($F_{3,28.2} = 2.6$, $P = 0.07$). Similarly, species richness did not exhibit a treatment × year interaction ($F_{3,30} = 1.59$, $P = 0.21$) and did not differ between treatments ($F_{1,11.5} = 1.01$, $P = 0.33$); however, species richness did differ among years ($F_{3,28.6} = 21.22$, $P < 0.001$). Species richness steadily increased each year, ranging from an average of 4.9 species/point in 2003 to 6.5 species/point in 2006 (Table 4). Total avian conservation value exhibited a significant treatment × year interaction ($F_{3,29.4} = 2.95$, $P = 0.05$). Total avian conservation value was similar between control and treatment plots in 2003 and 2004, but was greater in treatment plots than control plots in 2005 and 2006 (Table 4). Overall TACV relative effect size (treatment relative to control) was 7.8% and varied from −3.6% in 2004 to 19.4% in 2005.

Density of Select Species

Three migrant species (common yellowthroat, eastern wood-pewee, and indigo bunting) and 2 resident species (northern bobwhite and pine warbler) exhibited greater densities in herbicide–burned plots, whereas 4 migrant species (hooded warbler, Kentucky warbler, white-eyed vireo, and wood thrush) exhibited greater densities in the control plots. Difference in density of red-eyed vireo and summer tanager between treatments was negligible (Table 5).

Open pine forest, pine–grassland, and early successional vegetation associated species were more abundant in herbicide–burn treated plots than in control plots. Both the common yellowthroat and eastern wood-pewee species increased >100% following treatment. Pine warbler and indigo bunting species exhibited densities that were 57% and 81% greater in treatment plots than control plots, respectively. Northern bobwhite exhibited a substantial response to

Table 4. Least-squares mean and pooled standard error estimates of avian community metrics (total relative abundance, species richness, and total avian conservation value), by treatment (herbicide–burn and control) and year, in thinned, mid-rotation Conservation Reserve Program loblolly pine (*Pinus taeda*) plantations in Mississippi, USA, years 2003–2006.

	2003				2004				2005				2006			
	Control		Treatment		Control		Treatment		Control		Treatment		Control		Treatment	
Community index	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Abundance	7.87	0.45	7.85	0.45	8.17	0.48	7.84	0.48	8.13	0.52	9.59	0.52	7.65	0.55	8.83	0.55
Species richness	5.00	0.27	4.80	0.27	6.00	0.29	5.80	0.29	6.10	0.31	6.60	0.31	6.20	0.33	6.90	0.33
Total avian conservation value	110.92	6.33	110.95	6.33	114.83	6.74	110.71	6.74	112.46	7.29	134.27	7.29	105.74	7.62	122.77	7.62

Table 5. Density estimate (*D* [M birds/ha]), 95% confidence interval (CI), and coefficient of variation (CV) for select bird species by treatment (herbicide–burn and control), total effect size with 95% confidence interval pooled over 4 years (2003–2006), in thinned, mid-rotation Conservation Reserve Program loblolly pine (*Pinus taeda*) plantations in Mississippi, USA.

	Treatment			Control				
Species	*D*	95% CI	% CV	*D*	95% CI	% CV	Effect size	95% CI
Early successional–pine grassland								
Common yellowthroat	0.25	0.16–0.40	23.57	0.12	0.07–0.19	25.58	0.13	0.00–0.26
Eastern wood-pewee	0.21	0.15–0.29	15.89	0.10	0.06–0.16	26.08	0.11	0.03–0.19
Indigo bunting	3.09	2.81–3.41	4.93	1.71	1.49–1.96	7.02	1.39	1.01–1.77
Northern bobwhite	0.28	0.17–0.46	26.11	0.03	0.02–0.05	25.26	0.25	0.11–0.40
Pine warbler	1.82	1.59–2.08	6.89	1.15	0.98–1.36	8.20	0.66	0.36–0.97
Summer tanager	0.62	0.44–0.86	16.79	0.52	0.33–0.82	23.26	0.10	−0.21–0.41
Forest interior–forest edge								
Hooded warbler	0.36	0.26–0.50	16.86	1.57	1.23–2.01	12.42	−1.21	−1.61–−0.81
Kentucky warbler	0.34	0.25–0.47	15.58	0.61	0.48–0.77	11.97	−0.26	−0.44–−0.09
Red-eyed vireo	0.23	0.15–0.34	21.39	0.19	0.12–0.30	23.83	0.04	−0.09–0.17
White-eyed vireo	0.39	0.32–0.48	10.51	1.38	1.14–1.68	9.75	−0.99	−1.27–−0.72
Wood thrush	0.07	0.05–0.12	25.08	0.16	0.11–0.24	20.62	−0.08	−0.16–−0.01

herbicide–burn treatment by increasing in density 875% relative to control plots. Although we had too few detections to estimate density, 2 species of regional conservation concern, Bachman's sparrow and brown-headed nuthatch, were detected almost exclusively in herbicide- and prescribed-fire-treated plots. In contrast, most species associated with multilayered mixed pine hardwood stands were more abundant in untreated control plots. Kentucky warbler and wood thrush densities were almost 50% and the hooded warbler and white-eyed vireo 70% lower in treatment plots, relative to controls. Red-eyed vireo, however, exhibited 20% greater densities in treatment plots than in control plots (Table 5).

DISCUSSION

Despite the agricultural history and lack of hardwood rootstock at time of planting, CRP pine plantations in this study exhibited substantive hardwood midstory following thinning. Application of selective herbicide followed by prescribed fire effectively reduced midstory canopy cover by 90% while also promoting growth of grasses and forbs. Visual obstruction was significantly reduced above 30 cm, reflecting reduced midstory canopy and established herbaceous understory following the herbicide and burn treatment. We observed no difference in visual obstruction below 30 cm between treatment and control plots. From personal observation, this is a result of the thick hardwood midstory in the control plots and the herbaceous understory in the treated plots.

Silvicultural treatments, such as herbicide and prescribed fire, affect bird communities indirectly by altering vegetation structure and composition (Engstrom et al. 1984, Burger et al. 1998, Iglay 2010). Following herbicide and prescribed fire treatment, we observed a shift in the bird community from midstory and hardwood-associated species to those with open pine stand and early successional vegetation associations. The selective herbicide and prescribed fire applied in this study created a forest structure with 2 distinct vertical foliage layers (i.e., pine overstory and herbaceous understory). Herbicide application reduced hardwood midstory canopy, which allows sunlight to reach the forest floor and subsequent application of prescribed fire promoted germination of grasses and forbs. This change in vegetation community provided habitat components suitable for many species of birds. Species associated with mature pine forests (i.e., pine warbler), early successional–brushy vegetation types (i.e., common yellowthroat, indigo bunting, and northern bobwhite), and open midstories (i.e., eastern wood-pewee) exhibited greater densities in treated stands than untreated stands. The treatment did not, however, create habitat beneficial to all species of birds, specifically those adapted to the multi-layer mixed hardwood midstory found in control stands (i.e., hooded warbler, Kentucky warbler, white-eyed vireo, and wood thrush). Nevertheless, we observed that herbicide and prescribed burn treatments produced a net enhancement of the overall conservation value in southern mid-rotation pine stands based on total avian conservation value scores for treated and untreated stands. Other research has also documented a shift in bird communities from forest-interior species to early successional or mature pine–grassland species following hardwood midstory removal and prescribed fire in mid-rotation pine stands (Wilson et al. 1995, Wood et al. 2004, Iglay 2010).

Because pine–grasslands historically dominated the southeastern United States, covering >37 million ha, many species of birds in this region are adapted to the open structure of this community (Engstrom 1993, Frost 1993). Thus, it is not surprising that species richness and total relative abundance did not decline with a reduction of foliage layers; rather, a shift in the bird community was observed. Conversion of pine–grassland ecosystems to pine plantations or other land uses, combined with broad-scale fire exclusion within pine stands, has presumably caused many species dependent on this vegetation type to exhibit regional or range-wide declines (Engstrom et al. 1984, Burger et al. 1998, Trani et al. 2001). Although sites used in this study were afforested pine plantations, treatment with herbicide and prescribed fire created an herbaceous–shrub understory that mimics elements of natural pine–grasslands and improves habitat conditions for some avian species. Initially following treatment, species richness and TACV declined, but as the understory vegetation developed, many avian species of high conservation priority began to respond and use treated stands, as was observed by Iglay (2010). Therefore, these managed CRP pine stands provided appropriate habitat structure for regionally declining species of conservation concern and contributed more to regional bird conservation than did the unmanaged CRP stands. Among the 5 species more abundant in treatment plots, the common yellowthroat, eastern wood-pewee, indigo bunting, and northern bobwhite have exhibited negative 40-year population trends based on the North American Breeding Bird Survey (Sauer et al. 2008). Furthermore, species such as the brown-headed nuthatch and Bachman's sparrow have high PIF priority scores and dominantly occurred in treated stands. In contrast, 3 of the 4 species (white-eyed vireo, hooded warbler, and Kentucky warbler) with greater densities in control plots are exhibiting stable to positive population trends (Sauer et al. 2008). Active management of mid-rotation pine plantations may help to restore regionally scarce plant and bird communities in the southeastern United States, as opposed to the omnipresent fire-excluded pine–hardwood forests. In addition to the benefits we observed for early successional species, pine–grassland specialists of highest regional conservation concern may also benefit. Although we had too few detections from which to estimate the species' density, Bachman's sparrows were observed exclusively in herbicide–prescribed burned stands during years 2–4 of our study. This species has decreased throughout its range by 15–49%, and is of high conservation priority (PIF Priority Score 21; PIF 2006). Tucker et al. (1998) reported that mid-rotation pine plantations could provide breeding habitat for Bachman's sparrows if appropriately managed. In a study of the influence of fire on Bachman's sparrows, Tucker et al. (2004) reported that breeding density increased with an increase in grass coverage. Another pine–grassland specialist, the brown-headed nuthatch, occurred in our treated stands during all 4 years, whereas they were observed in control stands during just 2 years.

Our observations may seem counterintuitive relative to commonly accepted avian conservation paradigms that value structural complexity and vertical stratification. MacArthur and MacArthur (1961) suggested that avian species diversity can be predicted in terms of height profile of foliage density rather than actual plant species present and avian species diversity increases with an increase in foliage layers (i.e., more vertical layers support a greater number of niches). This theory has been supported by multiple studies in a variety of landscape types and vegetation communities (MacArthur and MacArthur 1961, Karr and Roth 1971, Willson 1974, Moss 1978, Mills et al. 1991) and is taught in numerous textbooks as being broadly applicable across most habitat types (e.g., Wiens 1989, Hunter 1990, Gill 1994). Although foliage height diversity was not specifically estimated in our study, different components of vertical stratification were measured. The herbicide–prescribed fire treatments clearly diminished structural complexity of the midstory and vertical stratification of the stand. Avian species richness and total relative abundance did not decrease with a reduction in foliage layers and, in fact, were slightly greater in managed pine stands. Our observations are consistent with those of multiple studies conducted in fire-dependent southern pine systems (Engstrom et al. 1984, Brennan et al. 1995, Burger et al. 1998, Wood et al. 2004, Woodall 2005). In general, avian species richness and total relative abundance were greater in pine–grassland restored stands (i.e., 2-layered stands) than in mixed pine–hardwoods in uplands throughout the southeastern coastal plain. Silvicultural techniques such as midstory removal and prescribed fire benefited more species of conservation concern in pine stands than did traditional management. Therefore, the foliage height diversity theory, although broadly accepted, may not apply to fire-dependent southeastern pine ecosystems.

Active management of mid-rotation pine stands in the southeastern United States, to promote open pine canopy conditions and herbaceous understory and limit hardwood midstory establishment, improves habitat quality and contributes to wildlife conservation for a diversity of declining bird species. Depending on the age and condition of the stand, active management should include thinning, selective herbicide, repeated (1- to 3-yr return interval) prescribed fire or a combination of management activities. After successful control of the hardwood component and establishment of herbaceous ground cover, a regular (2- to 3-yr) prescribe fire regime is needed to prevent the reestablishment of hardwoods and maintain an open canopy and 2-layer structure. Maintenance of a basal area $<13.77\ m^2/ha$ is a compromise between wildlife habitat quality and timber management (Masters et al. 2007). In addition to avian conservation value, treatments applied in our study have also been shown to benefit forage quantity and quality for white-tailed deer (*Odocoileus virginianus*; Jones et al. 2009, Mixon et al. 2009, Iglay 2010) and eastern wild turkey (*Meleagris gallopavo silvestris*; Dickson 1992), species of recreational and economic importance in the southeastern United States.

MANAGEMENT IMPLICATIONS

Farm Bill conservation programs, such as CRP, the Environmental Quality Incentives Program, and the Wildlife Habitat Incentives Program, provide economic incentives to assist private landowners in managing pine plantations to produce and maintain a pine–grassland structure. Active management could accrue substantially greater conservation benefits for mid-rotation CRP pine plantations than does the low-intensity passive management broadly observed on these lands. Insofar as wildlife benefits are a statutory objective of most Farm Bill Programs, USDA, state forestry commission, and state wildlife conservation agencies should actively encourage or require management regimes that produce additional conservation benefits from CRP acres planted in pine.

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