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Source: Natural Areas Journal, 34(4):409-422. 2014.
Published By: Natural Areas Association
DOI: http://dx.doi.org/10.3375/043.034.0403
URL: http://www.bioone.org/doi/full/10.3375/043.034.0403

RESEARCH ARTICLE

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Short-term Response of Breeding Birds to Oak Regeneration Treatments in Upland Hardwood Forest

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Natural Areas Journal 34:409–422

ABSTRACT: Population declines of several successional-scrub bird species are partly associated with decreased habitat availability as abandoned farmlands return to forest and recently harvested forests regrow. Restoration of mixed-oak (*Quercus* spp.) forest is also a concern because of widespread oak regeneration failure, especially on moist, productive sites where competition from faster-growing tree species is fierce following stand-replacing disturbances. Several silvicultural methods are proposed to promote oak regeneration but many are not experimentally tested, especially on productive sites. We surveyed birds in 19 stands to assess response to initial application of three proposed oak regeneration treatments on productive sites: prescribed burning (B); oak shelterwood by midstory herbicide (OSW); shelterwood harvests (SW); and controls (C), for one breeding season before, and two breeding seasons after, implementation. Relative density of successional-scrub species Indigo Buntings (*Passerina cyanea*), Eastern Towhees (*Pipilo erythrophthalmus*), and Chestnut-sided Warblers (*Setophaga pensylvanica*) increased, while Ovenbirds (*Seiurus aurocapilla*) decreased within 11 to 18 months after SW harvests; understory disturbance treatments B or OSW had no effect. Our results indicated that partial harvests created habitat for breeding birds associated with both young and mature forests, whereas understory treatments had little effect. Additionally, we show that even small patches of young forest habitat are used by more individuals and more species of breeding birds than surrounding closed-canopy forest, and may benefit successional-scrub species by enabling their occurrence in an otherwise forested landscape. Absence of several lower-elevation successional-scrub bird species in our mid-elevation SW harvests suggests that comprehensive conservation in the southern Appalachians necessitates creating and maintaining young forest habitats across elevation gradients.

Index terms: bird community, breeding birds, early successional habitat, oak regeneration, prescribed fire, silviculture

INTRODUCTION

Forest structure, including vertical strata and heterogeneity across the landscape, is an important driver of breeding bird species composition and diversity at local and regional scales (MacArthur and MacArthur 1961; King and DeGraaf 2000; Askins 2001; Shifley and Thompson 2011). In upland hardwood forest, many breeding bird species are associated with a mature closed overstory, whereas others are associated with natural or anthropogenic disturbances that create open, young-forest habitats with thick shrub cover, forest gaps, or open woodlands (Hunter et al. 2001). Breeding bird density and richness generally are higher in disturbed forests where some canopy trees remain because species typical of mature- and young-forest conditions co-occur (e.g., Annand and Thompson 1997; Newell and Rodewald 2012); in contrast, understory disturbances such as low-intensity prescribed fire or mechanical cutting of the understory may cause few or transitory changes to breeding bird community composition (Greenberg et al. 2007). Populations of many neotropical migratory bird species are declining, but species associated with successional-scrub habitats are of particular conservation concern (Brawn et al. 2001; Greenberg et al. 2011), and declines of some successional-scrub species in our study area may be more pronounced in the southern Appalachians than in other parts of the southern Central Hardwood Region (Franzreb et al. 2011). Different silvicultural methods that alter forest structure through harvest or pre-harvest treatments are used by land managers in upland hardwood forest to control species composition to meet forest management goals. These silvicultural methods are potentially important tools for creating habitat for breeding birds, but likely vary in functional value to different species depending on how forest structure is altered.

Restoration of structure and function of mixed-oak (*Quercus* spp.) forest is a focal issue of forest land managers in the eastern United States. Widespread oak regeneration failure – the failure of oak seedlings or saplings to attain canopy status – is problematic, especially on moist, intermediate to highly productive sites after canopy release because of competition from faster-growing species such as yellow-poplar (*Liriodendron tulipifera* L.) (Aldrich et al. 2005). In the past, high-grading, livestock grazing, loss of American chestnut (*Castanea dentata* (Marsh.) Borkh.), and burning by American Indians and (later) European settlers, likely promoted understory light conditions conducive to oak establishment, development, and eventual recruitment into the forest canopy (Abrams 1992; McEwan et al. 2011), at least on drier sites.

Several silvicultural methods for regenerating oak have been proposed (e.g., Loftis 1990; Brose et al. 1999), but most have not been experimentally tested on intermediate to highly productive sites of southern Appalachian upland hardwood forests. Treatments involve changing light levels and hardwood competition by altering forest structure through prescribed fire, midstory reduction (Loftis 1990), or shelterwood harvests followed a few years later by prescribed fire (Brose et al. 1999), thus promoting the growth of oak seedlings to 'advance regeneration' size (≥1.37 m ht) and giving them a head-start against faster-growing competition.

To better manage populations and communities in conjunction with ecosystem restoration or other forest management objectives, forest managers and conservationists need to know how silvicultural treatments intended to promote oak regeneration affect breeding birds. As part of the multidisciplinary Regional Oak Study (Keyser et al. 2008), we assessed experimentally how breeding bird communities (total density, richness, nest- and primary-breeding habitat guilds) and species responded to initial application of three silvicultural methods proposed to promote oak regeneration: prescribed burning; midstory herbicide application (Loftis 1990); and shelterwood harvests (initial treatment of the shelterwood-burn method; Brose et al. 1999) compared to untreated controls, for one breeding season before and two breeding seasons after initial treatments were fully implemented. We hypothesized that changes in breeding bird community composition, species richness, and abundance would be greatest in shelterwood harvests, where changes to forest structure was most evident.

METHODS

Study Area

Our study was conducted in Haywood County, North Carolina, on Cold Mountain Game Land (CMGL), which encompassed 1333 ha of second growth, upland mixed-oak forests with elevations ranging from 940 to 1280 m. The general area was mostly mature forest, although CMGL ownership is fragmented in places by forested lands of the Pisgah National Forest, two two-laned country roads, and some private lands that are rural in nature (Figure 1). CMGL was managed by the North Carolina Wildlife Resources Commission for diverse wildlife habitat and was located in the Blue Ridge Physiographic Province. CMGL terrain was mountainous with gentle to steep slopes with predominant overstory trees of oak, hickory (*Carya* spp.), and yellow-poplar. Species composition in the midstory consisted primarily of shade-tolerant species, including sourwood (*Oxydendrum arboreum* L.), flowering dogwood (*Cornus florida* L.), silverbell (*Halesia tetraptera* J. Ellis), blackgum (*Nyssa sylvatica* Marshall), and red maple (*Acer rubrum* L.). The climate was characterized by warm summers and cool winters and precipitation averaged 1200 mm annually.

Study Design

We established five, 5-ha units (approximately 225 m × 225 m) of three oak regeneration treatments, plus a control for a total of 20 units scattered throughout the study area; only 19 units were used in this study (see *treatments* section). We randomly assigned treatments (prescribed fire, midstory removal using herbicide, and shelterwood harvest) and controls to each unit, resulting in a completely randomized design. All units were between 940 and 1240 m in elevation, and adjacent units were separated by a minimum 20-m to 60-m buffer (Figure 1). Each contained mature (>70 years old), fully stocked, closed-canopied stands where oaks comprised at least 10% of the overstory tree basal area (≥25.0-cm diameter at breast height (dbh)). We selected stands that contained >1000 oak seedlings/ha, few ericaceous shrubs, ~2 m^2/ha of tree basal area beneath the main canopy, and no substantial disturbance within the last 15–20 years.

Treatments

Treatments for the Regional Oak Study were designed to evaluate three oak regeneration practices: (1) three prescribed burns at ~4-year intervals; (2) removal of midstory trees using herbicide (Loftis 1990); and (3) a two-step shelterwood, consisting of a heavy establishment cut with 6.8–9.0 m^2/ha of basal area retention followed by a prescribed fire when oak seedlings averaged 6.4-mm root collar diameter (Brose et al. 1999). All three treatments will be followed by overstory removal approximately eleven years after initial treatments.

This study encompassed one year before (2008) and two years after (2010 and 2011) initial treatments were fully implemented. Herbicide was applied in the oak shelterwood treatment units in early fall 2008, prior to leaf fall. Trees within the midstory strata except oak or hickory (e.g., red maple, sourwood, blackgum, flowering dogwood) ≥5.0 cm and <25.0 cm dbh were treated with herbicide (~1 ml of diluted Garlon 3A solution) using the hack-and-squirt method (Loftis 1990). The shelterwood-burn treatment (Brose et al. 1999) included only the establishment cut of the two-step shelterwood sequence with no prescribed burning, which is planned for 3–4 years post-harvest. Three of the establishment cuts were implemented during winter 2009–2010 and completed by March 2010. One unit (unit 3) was nearly completed in April 2010, but a small patch of remaining timber was harvested in early June (completed by 6 June 2010). Bird surveys were conducted there after all harvesting was complete, and we included unit 3 in our data analyses. Another shelterwood treatment unit (unit 19) was omitted from analyses because timber harvesting continued well into the breeding season in 2010 and birds could not be sampled (Figure 1).

Prescribed burns in the burn treatment were implemented in two different years (two on 25 February 2009 and three on 1 April 2010). Prescribed burns on both dates were cool, backing fires ignited with short, strip lighting and/or flanking strip lighting. Burns were incomplete across treatment units; many areas showed no or little evidence of burning, and fire temperatures near ground surface reached a maximum of 371 ºC (Greenberg et al. 2012). A repeated measures analysis (Proc Mixed; SAS 9.3) comparing pre- (2008) and post-

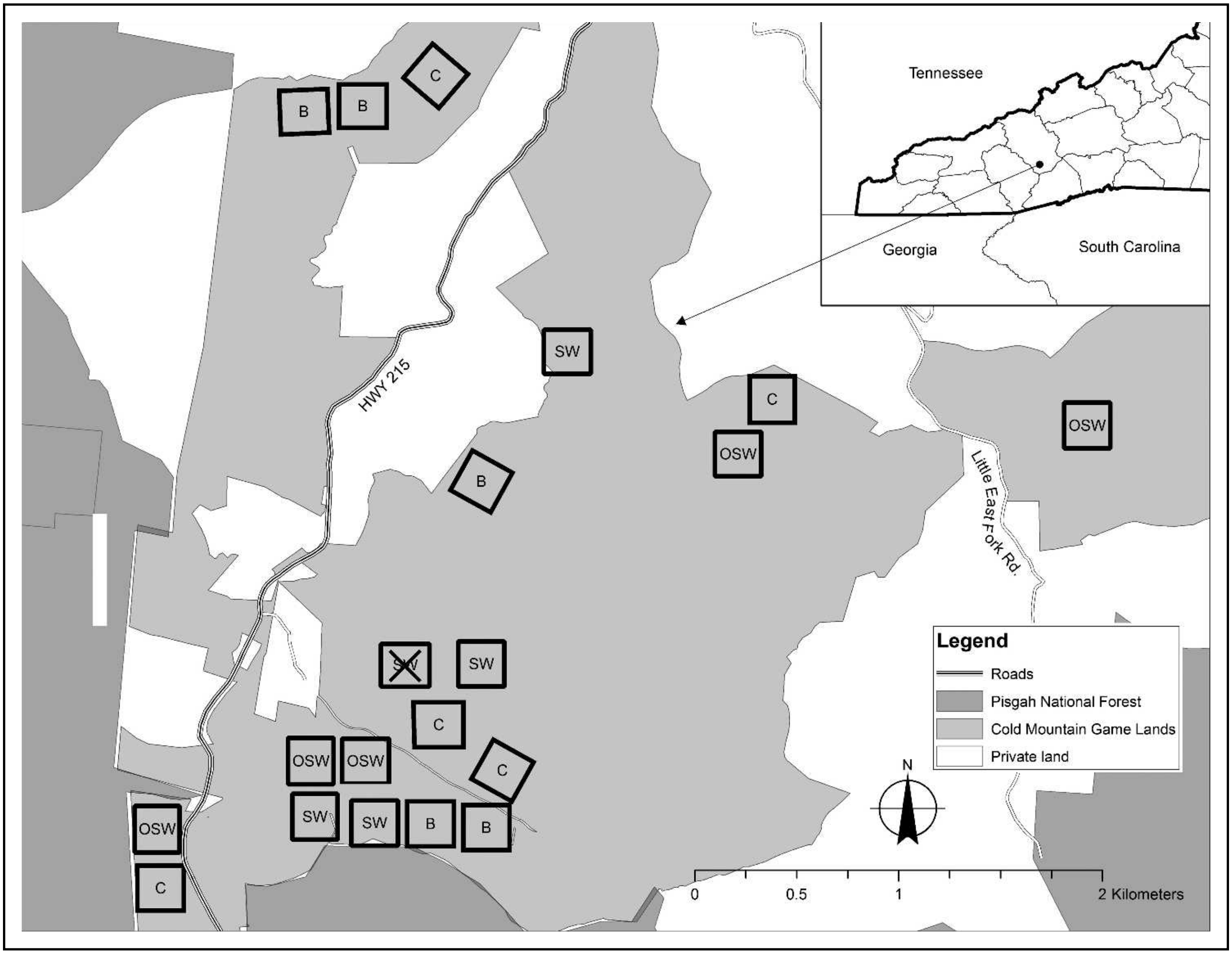

Figure 1. Location of the Cold Mountain Game Land study area in Haywood County, NC and experimental treatment units including control (C), oak shelterwood (OSW), shelterwood harvest (SW), and a single prescribed burn (B). One SW unit (unit 19) is crossed out because it was not used in the current study.

burn (2010, 2011) breeding bird relative density and species richness between the 2009 and 2010 burn treatments showed no significant differences ($p_{trt} = 0.7384$, $p_{yr} = 0.6814$, $p_{trtXyr} = 0.3579$ for relative density; $p_{trt} = 0.6614$, $p_{yr} = 0.6949$, $p_{trtXyr} = 0.0929$ for richness). Therefore, for simplicity, we considered units from both burn years to be the same burn treatment ($n = 5$).

In summary, treatments evaluated in this study included: (1) oak shelterwood (OSW) midstory removal using Garlon 3A herbicide in 2008 ($n = 5$); (2) a single prescribed burn (B; $n = 5$); (3) establishment cut with 6.8–9.0 m^2/ha of basal area retention (no burning in this phase of the study) (SW; $n = 4$); and (4) untreated mature forest control (C; $n = 5$).

Forest Structure Measurements

We established two vegetation transects in each treatment unit, parallel to and >30 m from a boundary and oriented across slope gradient. The first transect was located by selecting a random distance along the boundary line from the farthest downslope corner of each unit. We established three 0.05-ha permanent circular plots at approximately 50 m, 112 m, and 175 m along each of the two transects per unit. Within each 0.05-ha permanent plot, all overstory trees ≥25 cm dbh were inventoried and tagged. Midstory trees ≥5 cm and <25 cm dbh were inventoried and tagged within a 0.01-ha subplot concentrically nested within the 0.05-ha plot. We recorded status (live/dead), species, dbh, and crown class (i.e., suppressed, intermediate, co-dominant, or dominant) of all tagged trees in all treatment units. In addition, in 2011 we recorded post-treatment data on stump sprouts of all live, dead, fire-killed, herbicided, and cut trees, including sprout presence (yes/no), number of sprouts per parent tree, and the height (m) of the dominant sprout in an individual clump. We used a spherical densiometer to measure canopy openness at the center of two 0.004-ha circular regeneration subplots originating 8 m from the 0.05-ha plot center at bearings of 45° and 225°. Measurements were taken both pre-treatment (2008) and post-treatment (2011), except for the sprout data (2011 only).

We also established two 11.2-m line transects in a "t" orientation (one east-west and another north-south) through the center point of three randomly selected midstory vegetation plots that included lower-, middle-, and upper-slope positions within each treatment unit. Shrub (shrubs, stump sprouts, and tree seedlings <2 m in height) cover was measured by recording intercept distances (start to stop) of all shrub foliage above, touching, or below transects and summing to calculate total percent shrub cover. Percent cover of leaf litter and bare ground was visually estimated within a 0.5-m^2 frame at five locations along transects ("t" center and both ends of both transects). These data were recorded only in 2010, post-treatment.

Breeding Bird Surveys

Breeding birds were surveyed twice per season by the same observer between 15 May and 30 June in 2008 (pre-treatment), 2010 and 2011 (post-treatment) along a 175-m × 50-m (0.875 ha) strip transect established through the center of each treatment unit. Because harvesting in one SW treatment unit did not incorporate the entire length of the established bird transect, it was shortened for post-harvest bird surveys; total transect area and bird density estimates were adjusted accordingly. Transect centerlines were walked slowly (about 15 minutes or 0.7 km/hour per transect) between sunrise and four hours after sunrise. All individual birds seen or heard within 25 m on either side of the center line were recorded once by species. We also recorded the distance along and perpendicular from the transect centerline, mode of detection (visual or auditory), age (adult or juvenile), and sex where possible. Flyovers were noted but not included in data analyses. Survey start times were rotated among treatment units and between both visits to each treatment unit to avoid day- or time-of-day detection bias. Each unit was surveyed earlier and later within the six-week survey period to avoid bias associated with differences in singing rates as the breeding season progressed. We did not estimate detectability of different bird species (Alldredge et al. 2008), and assumed that bird detection error was minimal and consistent among units due to a short (25-m) detection distance from transect centerline, surveys conducted by the same observer, repeated surveys within each unit, and rotating repeat surveys over time of day and breeding season. Relative density of adult birds for each treatment unit was calculated by averaging over both visits per unit for each year, and expanding the average number per transect to number per 10 ha. Species richness represented the total number of species detected during both surveys in each unit each year.

STATISTICAL ANALYSES

Forest Structure

We used repeated measures ANOVA (Proc Mixed; SAS 9.3) in a completely randomized design to examine effects of treatment, year (pre-treatment (2008) versus post-treatment (2011)), and treatment × year interactions on percent canopy openness and live tree (midstory and overstory combined) density, basal area, and quadratic mean diameter (Dq). We used one-way ANOVAs to examine post-treatment differences among treatments in shrub height and percent cover of shrubs, leaf litter, bare ground, and "other" (mainly rocks), as well as sprout attributes (percent of trees with sprouts, number of sprouts per parent tree, and height of dominant sprout). Data were natural-log transformed (+0.01) or square-root arcsine transformed (percent cover) for ANOVAs.

Breeding Birds

We used repeated measures ANOVAs (Proc Mixed; SAS 9.3) in a completely randomized design with compound symmetry covariance structure, to examine effects of treatment, year, and treatment × year interactions on breeding birds. Response variables analyzed were species richness and density of breeding birds, density of birds within breeding habitat guilds (woodland, early successional/scrub, and generalist) (www:pwrc.usgs.gov/bbs), and nesting guild (cavity, ground, shrub, or tree) (Hamel 1992), and densities of common ($\geq$3 per 10 ha in any treatment, post-treatment years) species. We omitted juveniles from statistical analyses because of potential biases associated with detection among species and survey dates, and few juveniles detected. Density data (+0.01) were natural-log transformed for ANOVAs.

In all repeated measures ANOVAs (for both breeding birds and forest structure) we considered treatment, year, and their interaction to be fixed effects, and unit to be a random effect and the repeated subject factor. Our primary interest was in treatment × year interaction effects as indicators that at least one treatment was responding differently from the others between pre-treatment (2008) and either of the two post-treatment years (2010 and/or 2011). A nonsignificant treatment × year interaction indicated that treatment differences were consistent between pre-treatment and post-treatment years, and that there was a consistent difference between years across treatments. All significant repeated measures analyses were followed by Tukey's multiple comparisons at the 0.05 significance level on the least square means to determine differences between treatments, years, and treatment × year interactions.

RESULTS

Forest Structure

Live tree density decreased significantly in OSW and SW (47% and 70% decrease, respectively) following treatment implementation, but no change was detected in B or C (Table 1). Decreased live tree density was primarily due to herbicide-caused mortality of midstory trees (≥5 cm and <25 cm dbh) in OSW, and harvesting of both midstory and overstory trees (>25 cm dbh) in SW. Accordingly, post-treatment reduction in basal area was relatively small in OSW (11%) compared to SW (65%) where large trees were removed. Basal area was significantly reduced after treatment only in SW, and was lower in SW compared to the other treatments following treatment implementation (Table 1). Post-treatment changes in live tree Dq reflected differences in the size of trees killed or removed among the oak regeneration treatments. Live tree Dq increased significantly after treatment in OSW (31% increase) as smaller midstory trees were killed, and in SW (19% increase) as midstory and overstory trees were harvested with some large live trees remaining in treatment stands (Table 1). Overstory harvests increased canopy openness from (average) 4% pre-treatment to 40% post-treatment in SW, but canopy cover did not significantly change in the other treatments where the overstory was left intact or in C (Table 1).

In 2010, percent cover of leaf litter was lower in SW than in C, but did not significantly differ among the other treatments. Conversely, percent cover of bare ground was greater in SW than in B or C, but did not differ from OSW. Other measured habitat variables including shrub cover or height, and "other" (mainly rocks) did not differ among the treatments (Table 2).

By 2011, the proportion of trees or stumps with sprouts was greater in SW (39%) than in C (15%), OSW (20%), or B (20%) (Table 2). The average number of sprouts per parent tree was greater in OSW and SW than C (Table 2), and dominant sprout height was greater in SW (2.2 m) than in OSW, B, or C (1.3 m, 1.1 m, and 1.2 m, respectively) (Table 2).

Breeding Birds

We detected 39 species of breeding birds within transects during the three years sampled. Post-treatment breeding bird density increased 170% in SW by 2011, 11 to 18 months after harvests were complete; increases were not apparent immediately after harvests (2010). Bird densities did not differ after treatments in OSW, B, or C (Figure 2a). No pre-treatment to post-treatment change in species richness was detected (Figure 2b).

Among the 20 species that were sufficiently common for statistical analysis, most showed no significant response to treatment implementation (Table 3). Indigo Buntings (*Passerina cyanea* L.) (mean ± SE) increased in SW from none before treatment to 7.4 ± 5.7 in 2010 and 18.1 ± 3.2 per 10 ha by 2011. Chestnut-sided Warbler (*Setophaga pensylvanica* L.) and Eastern Towhee (*Pipilo erythrophthalmus* L.) densities increased in SW from none prior to harvests, to 4.5 ± 2.8 and 10.3 ± 4.2 per 10 ha, respectively, within 11 to 18 months following treatments (2011), but no changes were detected in the other treatments or C (Table 3). Northern Flicker (*Colaptes auratus* L.) also increased in the SW treatment after harvests, but not in other treatments or C. Ovenbird (*Seiurus aurocapilla* L.) density decreased in SW relative to C after treatments, but differences were only marginally significant (Table 3). Black-and-white Warblers (*Mniotilta varia* L.) showed a marginally significant lower abundance in all three treatments compared to C, but no treatment x year interaction was detected (Table 3). Blue-headed Vireos (*Vireo solitarius* A. Wilson) were more abundant (marginally significant) in B than SW in 2010, and B in 2010 than C in 2011; response patterns were unclear and did not appear to be biologically meaningful (Table 3).

The density of breeding birds within cavity- shrub- or tree-nesting guilds (Figure 3) did not significantly change after treatments were implemented, although a trend of increasing shrub-nesters in SW was evident (Figure 3b). Abundance of ground-nesters decreased in SW after harvests (2010, 2011) and relative to other treatments or C (Figure 3c).

Densities of birds within the generalist (Figure 4a) or woodland (Figure 4b) primary breeding habitat guilds did not detectably change in response to any treatment. In contrast, the density of breeding birds within the early successional-scrub

Table 1. Mean (±SE) percent canopy openness and live tree density (number per ha), basal area (m^2/ha), and quadratic mean diameter (Dq) before (2008) and after (2011) three oak regeneration treatments and control on Cold Mountain Game Land, Haywood County, NC. Treatments were control (C), oak shelterwood (OSW), shelterwood harvest (SW), and a single prescribed burn (B). *P*-values are results of repeated measures ANOVAs.

Habitat Variable	Year	C	OSW	SW	B	ANOVA P_{trt}	P_{yr}	P_{trtXyr}
		$\bar{x}$ ± SE	$\bar{x}$ ± SE	$\bar{x}$ ± SE	$\bar{x}$ ± SE	df = 3,15	df = 1,15	df = 3,15
Canopy openness	2008	4.2 ± 0.5	4.4 ± 1.3	4.0 ± 0.6	3.4 ± 0.9	<0.0001	<0.0001	<0.0001
	2011	4.0 ± 0.4	7.3 ± 0.3	40.1 ± 2.4	5.4 ± 0.8			
Live tree density	2008	713.3 ± 65.5	669.3 ± 55.9	479.2 ± 90	715.3 ± 26.2	0.0003	<0.0001	<0.0001
	2011	664.0 ± 59.6	355.3 ± 39.2	144.2 ± 31.9	624.7 ± 33.4			
Live tree basal area	2008	34.6 ± 2.2	35.1 ± 3.2	37.1 ± 3.1	36.1 ± 4.2	0.0572	<0.0001	<0.0001
	2011	33.4 ± 2.3	31.4 ± 3.1	12.9 ± 1.3	34.4 ± 4.1			
Live tree Dq (cm)	2008	25.5 ± 2.0	26.8 ± 2.0	33.4 ± 1.8	26.3 ± 1.2	0.0114	<0.0001	0.0028
	2011	26.1 ± 2.0	35.2 ± 2.8	39.7 ± 3.9	27.5 ± 1.1			

Table 2. Mean (±SE) percent cover of leaf litter, bare ground, percent shrub cover, shrub height, and other (mostly rocks) (measured in 2010), and tree- or stump-sprout attributes (percent with sprouts, number of sprouts per parent tree, and sprout height) (measured in 2011) following three oak regeneration treatments and control on Cold Mountain Game Land, Haywood County, NC. Treatments were control (C), oak shelterwood (OSW), shelterwood harvest (SW), and a single prescribed burn (B). *P*-values are results of one-way ANOVAs comparing treatments in 2010 or 2011 (sprout data only). Means within rows followed by the same letter are not significantly different.

Habitat Variable	Year	ANOVA				
		C	OSW	SW	B	P_{trt}
		$\bar{x} \pm$ SE	$\bar{x} \pm$ SE	$\bar{x} \pm$ SE	$\bar{x} \pm$ SE	df = 3,15
Leaf litter (% cover)	2010	73.3 ± 5.5^{A}	59.3 ± 6.0^{AB}	12.6 ± 1.3^{B}	56.7 ± 4.9^{AB}	0.0309
Bare ground (% cover)	2010	3.4 ± 1.7^{A}	9.4 ± 3.2^{AB}	15.0 ± 3.1^{B}	2.8 ± 1.0^{A}	0.0081
Shrub (% cover)	2010	30.9 ± 6.0	27.2 ± 4.5	21.0 ± 3.7	24.0 ± 6.5	0.6550
Shrub height (m)	2010	1.2 ± 0.1	0.9 ± 0.1	1.0 ± 0.0	1.0 ± 0.2	0.4928
Other (% cover)	2010	16.2 ± 4.4	23.9 ± 3.2	30.6 ± 9.8	22.6 ± 5.7	0.4588
Sprouts (% of trees)	2011	14.8 ± 2.0^{A}	19.5 ± 3.8^{A}	38.5 ± 4.7^{B}	20.2 ± 3.2^{A}	0.0028
Sprouts/tree, stump	2011	3.5 ± 0.3^{A}	7.9 ± 2.2^{B}	7.2 ± 0.4^{B}	6.7 ± 1.0^{AB}	0.0123
Sprout height (m)	2011	1.2 ± 0.1^{A}	1.3 ± 0.2^{AB}	2.2 ± 0.2^{C}	1.1 ± 0.1^{A}	0.0013

primary breeding habitat guild increased from none pre-treatment (2008) to 39.7 ± 8.2 per 10 ha post-treatment in SW by 2011, significantly higher than in the other treatments or C, where densities ranged from none to 4.6 ± 2.8 per 10 ha pre- and post-treatments (Figure 4c).

DISCUSSION

Forest Structure

Changes in vegetation structure were most apparent in SW, where 70% of live trees and 65% of basal area were removed, substantially opening the forest canopy. Leaf litter cover was somewhat reduced and slightly more bare ground exposed immediately after harvesting (2010) in SW compared to the other treatments, likely due to heavy machinery used during harvesting. In OSW, herbicide treatments killed many small trees that remained standing during our study period, and likely continued to provide some structural functions as midstory strata for breeding birds; the overstory tree canopy and other measured habitat features were not affected by treatments. The low-intensity winter prescribed burns had little to no effect on habitat structure. Fire temperature and burn extent were variable within and among our treatment units, resulting in little to no tree mortality and little change in understory features such as leaf litter or shrub structure. Shrub cover and height were not detectably changed immediately after any treatment (2010 measurements); but rapid stump sprouting, shrub recovery, and development of seedlings in SW created dense cover by 2011.

Breeding Birds

In our study, the density of total breeding birds and four species increased in SW within 11 to 18 months after harvests that substantially opened the forest canopy. In contrast, understory disturbance treatments, including prescribed fire (B), and midstory herbicide (OSW), designed to alter understory light conditions to promote growth of existing oak seedlings, did not substantially affect breeding bird communities or individual species. Our short-term results concur with other studies showing that shelterwood harvests with partial canopy retention have a positive effect on early successional-scrub species, but do not affect densities of generalists or most species associated with mature forest that use young forests for nesting and foraging (Annand and Thompson 1997; Baker and Lacki 1997; Rodewald and Smith 1998; Robinson and Robinson 1999; King and DeGraaf 2000; Lanham et al. 2002; Gram et al. 2003; Whitehead 2003; Augenfeld et al. 2008; McDermott and Wood 2009; Newell and Rodewald 2012).

Species that increased in our SW treatment were successional-scrub specialists (Indigo Buntings, Chestnut-sided Warblers), or prefer successional-scrub (Eastern Towhees), or open woods and woodland margins (Northern Flickers) (Hamel 1992). Many additional early successional-scrub species occurring within the southern Appalachian region can occupy open, disturbed forests with structural similarities to our SW treatments at lower elevations (e.g., Prairie Warblers (*Setophaga discolor* Vieillot), Pine Warblers (*Setophaga pinus* A. Wilson), Eastern Bluebirds (*Sialia sialis* L.), Chipping Sparrows (*Spizella passerina* Bechstein), Gray Catbird (*Dumetella carolinensis* L.)) (McDermott and Wood 2009; Greenberg et al. 2013), but were not detected within our mid-elevation study area. In contrast, our SW treatments created suitable habitat for Chestnut-sided Warblers, which are largely restricted to mid-elevation early successional scrub in the southern Appalachians. Golden-winged Warblers (*Vermivora chrysoptera* L.) are also early successional-scrub specialists restricted to mid-elevations in the southern Appalachians, where they are of high conservation concern. Although we did not detect Golden-winged Warblers within our study area, SW harvests at mid-elevation

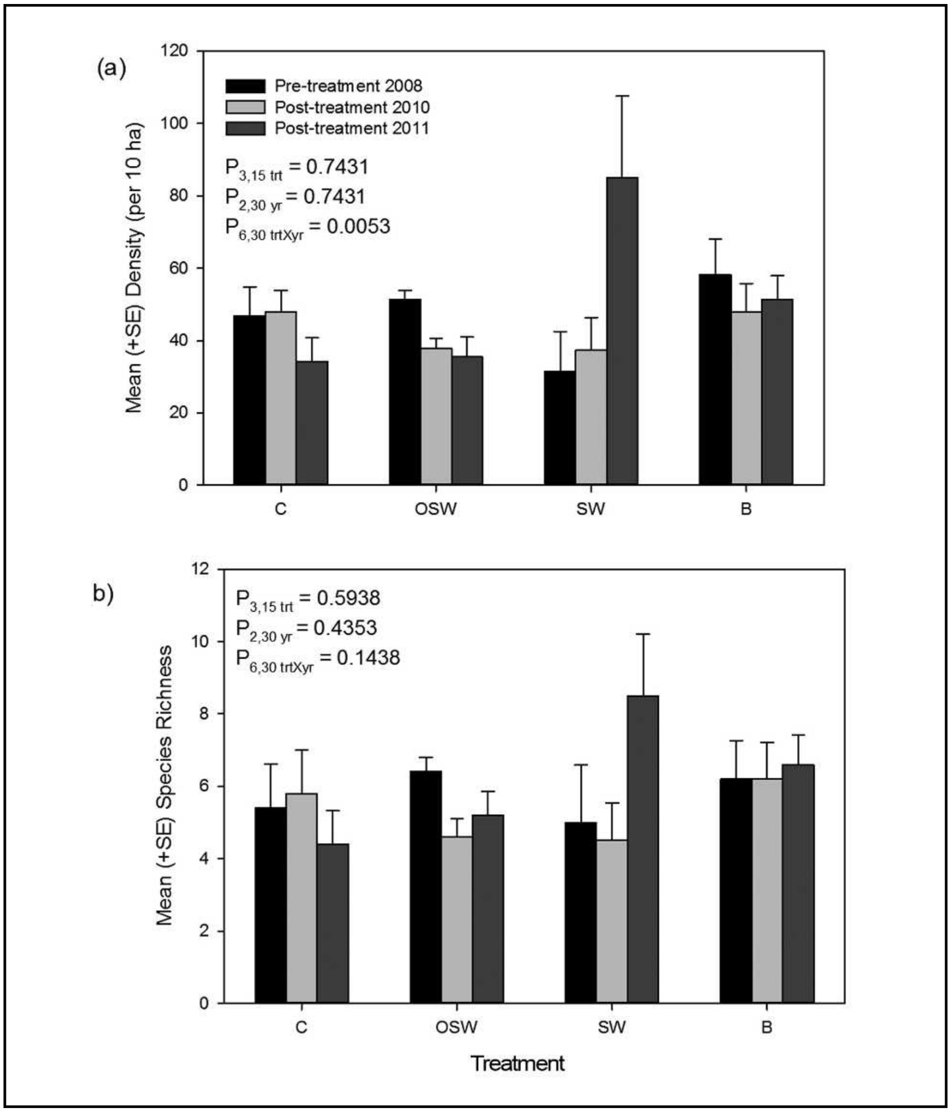

Figure 2. Mean (+SE) (a) total density (number per 10 ha), and; (b) total species richness of breeding birds in pre-treatment (2008) and post-treatment (2010 and 2011) oak regeneration treatments on Cold Mountain Game Land, Haywood County, NC. Treatments were control (C), oak shelterwood (OSW), shelterwood harvest (SW), and a single prescribed burn (B). *P*-values are results of repeated measures ANOVAs comparing treatment, years, and treatment × year interaction effects.

provide potentially suitable habitat for this declining species. However, Golden-winged Warblers require a mosaic of early successional habitat types (i.e., grass/forb and various age classes of early successional scrub) that may require management techniques beyond simple shelterwood harvests (Roth et al. 2012). Conservation of the suite of early successional-scrub bird species in the southern Appalachians will necessitate creation of young forest habitats across elevation gradients.

Several studies indicate that the response of birds within different nesting guilds varies among silvicultural treatments and is closely associated with changes to forest structure. Several studies indicate that densities of canopy-nesting birds do not change or increase following disturbances where a partial canopy is retained, such as shelterwood harvests (Newell and Rodewald 2012) or hot burns that kill many overstory trees (Greenberg et al. 2007). In contrast, understory treatments such as mechanical cutting of small trees and shrubs (e.g., Droege 1985, and Greenberg et al. 2007), or low-intensity winter prescribed burns (Aquilani et al. 2000; Greenberg et al. 2007) do not affect canopy-nesting species. Some studies report declines in midstory-nesting species in shelterwood harvests (Newell and Rodewald 2012) or understory reduction treatments (Rodewald and Smith 1998), but others report no effect on the midstory nesting guild (Droege 1985). Inconsistent results reported for some midstory species may be due to differences among studies in initial shrub or midstory densities and levels of reduction, or initial densities of species associated with those vegetation strata.

In our data analyses, we combined midstory and canopy-nesting species into a single tree-nesting guild because many species nest in either vegetation strata, and guild assignments differ among studies. We found that the tree-nesting guild was not affected by any oak regeneration treatment. This indicates that both low-intensity prescribed burning and midstory herbicide treatments that leave an intact overstory, and partial overstory retention in SW, all maintained canopy-midstory-bole-using birds at densities similar to pre-treatment and controls. Similarly, individual species within the tree-nesting guild, including commonly occurring Black-throated Green Warblers (*Setophaga virens* Gmelin), Scarlet Tanagers (*Piranga olivacea* Gmelin), and others that may also nest in the midstory strata such as Red-eyed Vireos (*Vireo olivaceus* L.) (Hamel 1992; Newell and Rodewald 2012), were not detectably affected by treatments. This lack of bird response to midstory reductions in any of our treatments may reflect the negligible changes to midstory trees or shrubs in B, and suggests that the dead (post-herbicide) standing midstory in OSW, or remaining shrub or understory tree density in OSW and SW, provided adequate midstory function. Alternatively, or in addition, our data suggest that some midstory-nesting species can adapt where a midstory is scant.

The cavity-nesting guild was not affected by any oak regeneration treatment tested. This was not surprising because none of the treatments substantially changed the abundance of large snags suitable for cavity nests. High mortality of small-diameter midstory trees in OSW did not affect cavity-nesting species, including woodpeckers that probe dead standing boles for insects. Among cavity-nesting species, Northern Flickers increased in the shelterwood treat-

Table 3. Mean (±SE)[a] number of birds per 10 ha for common (mean ≥3 individuals per 10 ha in any treatment, post-treatment years) species in pre-treatment (2008, first line) and post-treatment (2010, second line; 2011, third line) oak regeneration treatments on Cold Mountain Game Land, Haywood County, NC. Treatments were control (C), oak shelterwood (OSW), shelterwood harvest (SW), and a single prescribed burn (B). *P*-values are results of repeated measures ANOVAs comparing treatment, years, and treatment × year interaction effects.

Species[b,c]	Guilds[d] Hab/Nest	Density (no./10 ha)				RM MIXED ANOVA		
		C	OSW	SW	B	P_{trt}	P_{yr}	P_{trtXyr}
		$\bar{x}$ ± SE	$\bar{x}$ ± SE	$\bar{x}$ ± SE	$\bar{x}$ ± SE	df = 3,15	df = 2,30	df = 6,30
AMRO	G/S	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5703	0.0416	0.9484
		0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0			
		1.1 ± 1.1	1.1 ± 1.1	2.9 ± 1.6	3.4 ± 2.3			
BHVI	W/T	2.3 ± 1.4	2.3 ± 1.4	4.3 ± 1.4	5.7 ± 3.6	0.0705	0.7899	0.0786
		2.3 ± 1.4	5.7 ± 2.5	0.0 ± 1.0	13.7 ± 2.3			
		0.0 ± 0.0	3.4 ± 2.3	3.1 ± 1.8	5.7 ± 1.8			
BLBW	W/T	2.3 ± 2.3	1.1 ± 1.1	1.4 ± 1.4	3.4 ± 2.3	0.8602	0.3406	0.6405
		3.4 ± 2.3	1.1 ± 1.1	0.0 ± 0.0	1.1 ± 1.1			
		0.0 ± 0.0	2.3 ± 2.3	0.0 ± 0.0	1.1± 1.1			
BTBW	W/S	2.3 ± 1.4	6.8 ± 2.8	2.9 ± 1.6	5.7 ± 3.1	0.0241	0.0089	0.9961
		0.0 ± 0.0	2.3 ± 1.4	0.0 ± 0.0	1.1 ± 1.1			
		0.0 ± 0.0	3.4 ± 1.4	0.0 ± 0.0	1.1 ± 1.1			
BTNW	W/T	3.4 ± 2.3	4.6 ± 2.1	4.3 ± 4.3	3.4 ± 2.3	0.8547	0.9263	0.2813
		4.6 ± 2.8	0.0 ± 0.0	3.4 ± 2.0	5.7 ± 3.1			
		3.4 ± 3.4	2.3 ± 1.4	4.8 ± 3.2	4.6 ± 2.1			
BWWA	W/G	6.8 ± 2.1	2.3 ± 1.4	1.4 ± 1.4	3.4 ± 2.3	0.0540	0.0208	0.9871
		4.6 ± 2.1	1.1 ± 1.1	0.0 ± 0.0	0.0 ± 0.0			
		3.4 ± 1.4	1.1 ± 1.1	0.0 ± 0.0	0.0 ± 0.0			
CACH	W/C	1.1 ± 1.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.6667	0.3870	0.3100
		2.3 ± 1.4	1.1 ± 1.1	0.0 ± 0.0	1.1 ± 1.1			
		0.0 ± 0.0	0.0 ± 0.0	2.9 ± 2.9	3.4 ± 2.3			
CAWR	S/C	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3615	0.1767	0.2575
		1.1 ± 1.1	0.0 ± 0.0	0.0 ± 0.0	1.1 ± 1.1			
		2.3 ± 2.3	3.1 ± 1.8	0.0 ± 0.0	0.0 ± 0.0			
CSWA	S/S	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0296	0.0211	0.0051
		0.0 ± 0.0	0.0 ± 0.0	0.0 ± 1.5	0.0 ± 0.0			
		0.0 ± 0.0	0.0 ± 0.0	4.5 ± 2.8	0.0 ± 0.0			
EATO	S/S	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0037	<0.0001	0.0001
		0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0			
		2.3 ± 2.3	0.0 ± 0.0	10.3 ± 4.2	2.3 ± 2.3			
EAWP	W/T	0.0 ± 0.0	0.0 ± 0.0	1.4 ± 1.4	2.3 ± 1.4	0.2448	0.7796	0.5832
		0.0 ± 0.0	2.3 ± 2.3	4.3 ± 2.7	1.1 ± 1.1			
		1.1 ± 1.1	0.0 ± 0.0	2.9 ± 1.6	1.1 ± 1.1			
ETTI	W/C	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.1 ± 1.1	0.0190	0.7207	0.9068
		0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 1.0			
		0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	4.6 ± 2.8			
HAWO	W/C	3.4± 2.3	0.0 ± 0.0	1.4+ 1.4	1.1 ± 1.1	0.6838	0.0328	0.2398
		0.0 ± 0.0	0.6 ± 0.6	0.0 ± 0.0	0.0 ± 0.0			
		0.0 ± 0.0	1.1 ± 1.1	4.5 ± 2.8	2.3 ± 1.4			
INBU	S/S	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	<0.0001	0.0007	<0.0001
		0.0± 0.0	1.1 ± 1.1	7.4 ± 5.7	0.0 ± 0.0			
		0.0± 0.0	0.0 ± 0.0	18.1 ± 3.2	0.0 ± 0.0			
MODO	G/S	0.0± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1398	0.3407	0.7682
		1.1± 1.1	0.0 ± 0.0	4.0 ± 4.0	0.0 ± 0.0			
		0.0± 0.0	0.0 ± 0.0	1.4 ± 1.4	0.0 ± 0.0			
OVEN	W/G	6.8± 2.8	1.1 ± 1.1	4.3 ± 1.4	8.0 ± 3.9	0.2353	0.2779	0.0551
		11.4± 2.5	3.4 ± 1.4	0.0 ± 0.0	3.4 ± 1.4			
		3.4± 2.3	1.4 ± 1.4	0.0 ± 0.0	4.6 ± 2.8			

Continued

Table 3. Continued.

Species[b,c]	Guilds[d] Hab/Nest	Density (no./10 ha)				RM MIXED ANOVA		
		C	OSW	SW	B	P_{trt}	P_{yr}	P_{trtXyr}
		$\bar{x}$ ± SE	$\bar{x}$ ± SE	$\bar{x}$ ± SE	$\bar{x}$ ± SE	df = 3,15	df = 2,30	df = 6,30
RBWO	W/C	2.3 ± 1.4	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3635	0.6334	0.6771
		1.1 ± 1.1	0.0 ± 0.0	1.4 ± 1.4	1.1 ± 1.1			
		3.4 ± 2.3	1.1 ± 1.1	0.0 ± 0.0	1.1 ± 1.1			
REVI	W/T	8.0 ± 2.3	12.5 ± 1.1	2.9 ± 1.6	8.0 ± 2.9	0.7388	0.7272	0.5109
		6.6 ± 2.1	8.0 ± 3.4	9.1 ± 2.9	4.6 ± 2.1			
		5.7 ± 1.8	5.7 ± 1.8	6.4 ± 4.7	6.8 ± 3.3			
SCTA	W/T	2.3 ± 1.4	5.7 ± 1.8	1.4 ± 1.4	0.0 ± 0.0	0.0349	0.7186	0.1682
		3.4 ± 2.3	2.3 ± 1.4	2.9 ± 1.6	2.3 ± 1.4			
		0.0 ± 0.0	8.0 ± 1.4	4.5 ± 2.8	2.3 ± 1.4			
NOFL	W/C	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1519	0.1692	0.0233
		0.0 ± 0.0	0.0 ± 0.0	1.6 ± 1.0	1.1 ± 1.1			
		0.0 ± 0.0	0.0 ± 0.0	3.1 ± 1.8	0.0 ± 0.0			

[a] Means and SEs are from raw data and do not represent lsmeans output from the statistical model.

[b] ACFL=Acadian Flycatcher (*Empidonax virescens*); AMCR=American Crow (*Corvus brachyrhynchos*); AMGO= American Goldfinch (*Carduelis tristis*); AMRO=American Robin (*Turdus migratorius*); BGGN = Blue-gray Gnatcatcher (*Polioptila caerulea*); BHVI=Blue-headed Vireo (*Vireo solitarius*); BLBW=Blackburnian Warbler (*Setophaga fusca*); BLJA=Blue Jay (*Cyanocitta cristata*); BRCR=Brown Creeper (*Certhia americana*); BTBW=Black-throated Blue Warbler (*Setophaga caerulescens*); BTNW=Black-throated Green Warbler (*Setophaga virens*); BWWA=Black-and-white Warbler (*Mniotilta varia*); CACH=Carolina Chickadee (*Poecile carolinensis*); CAWR=Carolina Wren (*Thyrothorus ludovicianus*); CSWA=Chestnut-sided Warbler (*Setophaga pensylvanica*); DOWO=Downy Woodpecker (*Picoides pubescens*); EATO=Eastern Towhee (*Pipilo erythrophthalmus*); EAWP=Eastern Wood-pewee (*Contopus virens*); ETTI=Tufted Titmouse (*Baeolophus bicolor*); HAWO=Hairy Woodpecker (*Picoides villosus*); HOWA=Hooded Warbler (*Wilsonia citrina*); INBU=Indigo Bunting (*Passerina cyanea*); MODO=Mourning Dove (*Zenaida macroura*); NOCA=Northern Cardinal (*Cardinalis cardinalis*); NOPA=Northern Parula (*Parula americana*); OVEN=Ovenbird (*Seiurus aurocapilla*); PIWO=Pileated Woodpecker (*Dryocopus pileatus*); RBGR=Rose-breasted Grosbeak (*Pheucticus ludovicianus*); REVI=Red-eyed Vireo (*Vireo olivaceus*); RTHA=Red-tailed Hawk (*Buteo jamaicensis*); SCJU=Slate-colored Junco (J*unco hyemalis*); SCTA=Scarlet Tanager (*Piranga olivacea*); WBNU=White-breasted Nuthatch (*Sitta carolinensis*); WEWA=Worm-eating Warbler (*Helmitheros vermivorus*); WITU=Wild Turkey (*Meleagris gallopavo*); WOTH=Wood Thrush (*Hylocichla mustelina*); YBCU=Yellow-billed Cuckoo (*Coccyzus americanus*); NOFL= Northern Flicker (*Colaptes auratus*).

[c] Other species (guilds) occurring within transects that were not common enough for valid statistical analyses (<3 per 10 ha, post-treatment years) are: ACFL (W/T), AMCR (W/T), AMGO (S/S), BGGN (W/T), BLJA (U/T), BRCR (W/C), DOWO (W/C), HOWA (W/S), NOCA (S/S), NOPA (W/T), PIWO (W/C), RBGR (W/T), RTHA (W/T), SCJU (W/G), WBNU (W/C), WEWA (W/G), WITU (W/G), WOTH (W/S), YBCU (W/C).

NOTE: See footnote b for species key

[d] First letter denotes primary breeding habitat guild: woodland (W), early successional-scrub (S) and generalist (G); second letter denotes nest location: cavity (C), tree (T), shrub (S), or ground (G).

ments. Flickers are associated with open woodlands and edges and often forage on the ground (Hamel 1992), and may have been attracted to SW by its open canopy and disturbed leaf litter.

In our study, the ground-nesting guild, including Ovenbirds, disappeared from the SW treatment for the two breeding seasons post-harvest (but statistically, densities differed marginally only from C), but did not change following treatments in B or OSW. Ground-nesting Black-and-white Warblers showed a marginally significant lower abundance in all three treatments compared to C, but no interaction between

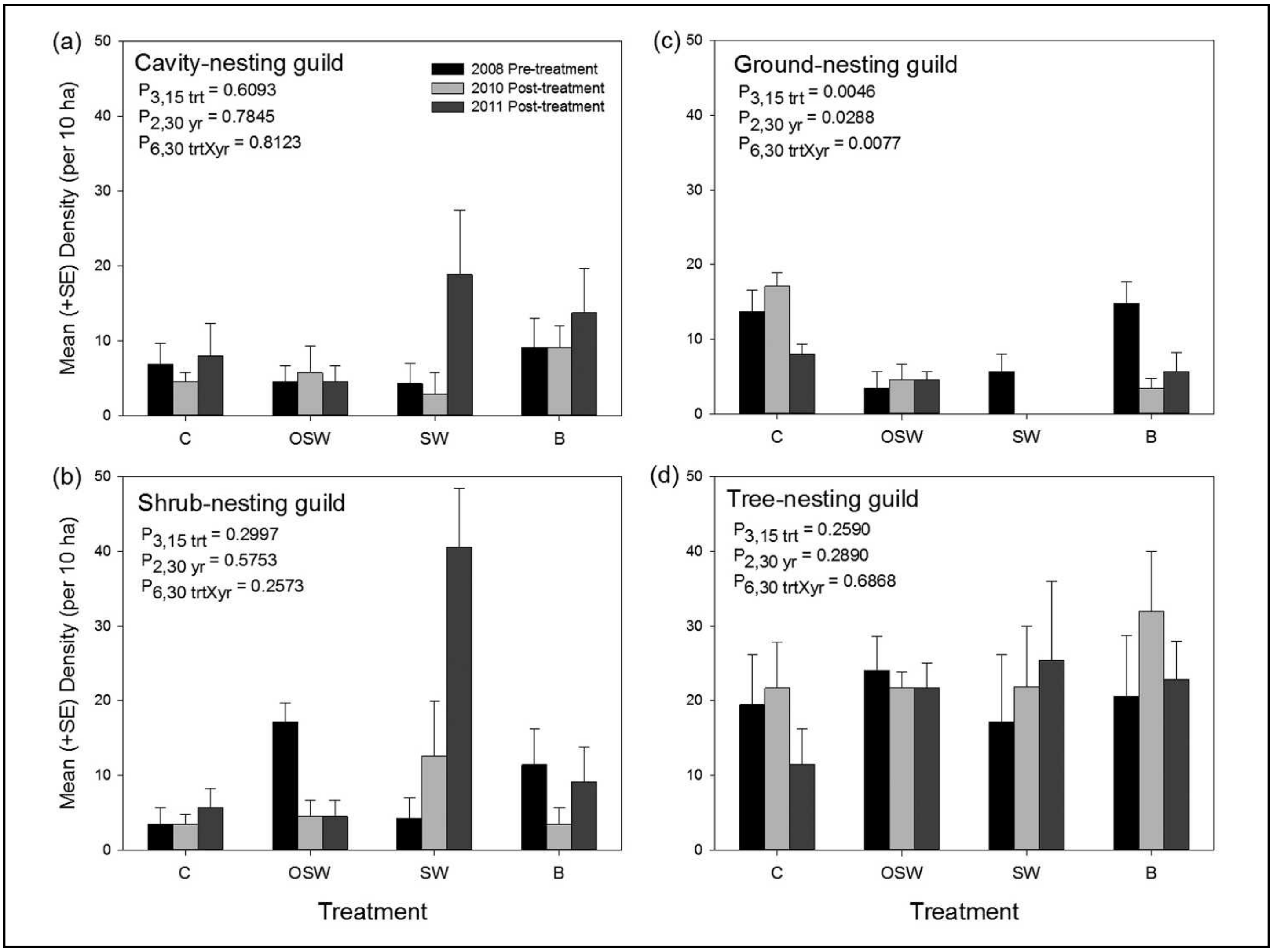

Figure 3. Mean (+SE) density (number per 10 ha) of breeding birds in (a) cavity-, (b) shrub-, (c) ground-, and (d) tree-nesting guilds pre-treatment (2008) and post-treatment (2010 and 2011) oak regeneration treatments on Cold Mountain Game Land, Haywood County, NC. Treatments were control (C), oak shelterwood (OSW), shelterwood harvest (SW), and a single prescribed burn (B). *P*-values are results of repeated measures ANOVAs comparing treatment, years, and treatment x year interaction effects.

treatment and year (pre- to post-harvest). Decreased abundance of ground-nesters in recent SW harvests (Vanderwel et al. 2007; Newell and Rodewald 2012) has been reported by others and is likely associated with reduced leaf litter cover that they use for nest concealment, and reduced canopy cover in shelterwood harvests that may increase visibility and the risk of predation. Several studies report short-term declines in some ground-nesting species after single, low-intensity winter burns with little tree mortality (Aquilani et al. 2000; Artman et al. 2001; Greenberg et al. 2007) or understory reduction treatments (Wilson et al. 1995; Rodewald and Smith 1998). Among ground-nesting species, decreased Ovenbird abundance after low-intensity prescribed burns (Aquilani et al. 2000; Artman et al. 2001) or mechanical understory reductions is commonly reported (Wilson et al. 1995; Rodewald and Smith 1998), but response by other ground-nesting species is not consistent among studies. Differences in reported response to prescribed burns by ground-nesting species are likely due to low or no treatment replication, too few detections, and differences in patchiness of burns and rates of leaf litter or shrub recovery over time. Additionally, many birds forage within burned sites despite a paucity of suitable nesting substrate (Artman et al. 2001).

A steep increase in shrub-nesters was evident but nonsignificant in our SW treatment by 2011. Densities of common shrub-nesting species associated with mature forest, such as Black-throated Blue Warblers (*Setophaga caerulescens* Gmelin), did not differ among treatments, but three shrub-nesting species that are also associated with early successional-scrub for primary breeding habitat – Indigo Buntings, Chestnut-sided Warblers, and Eastern Towhees – were abundant only, or primarily, in SW. Our study focused on relative abundance of breeding birds among treatments and, thus, we could not discern whether any given species used a treatment for nesting, foraging, or for other

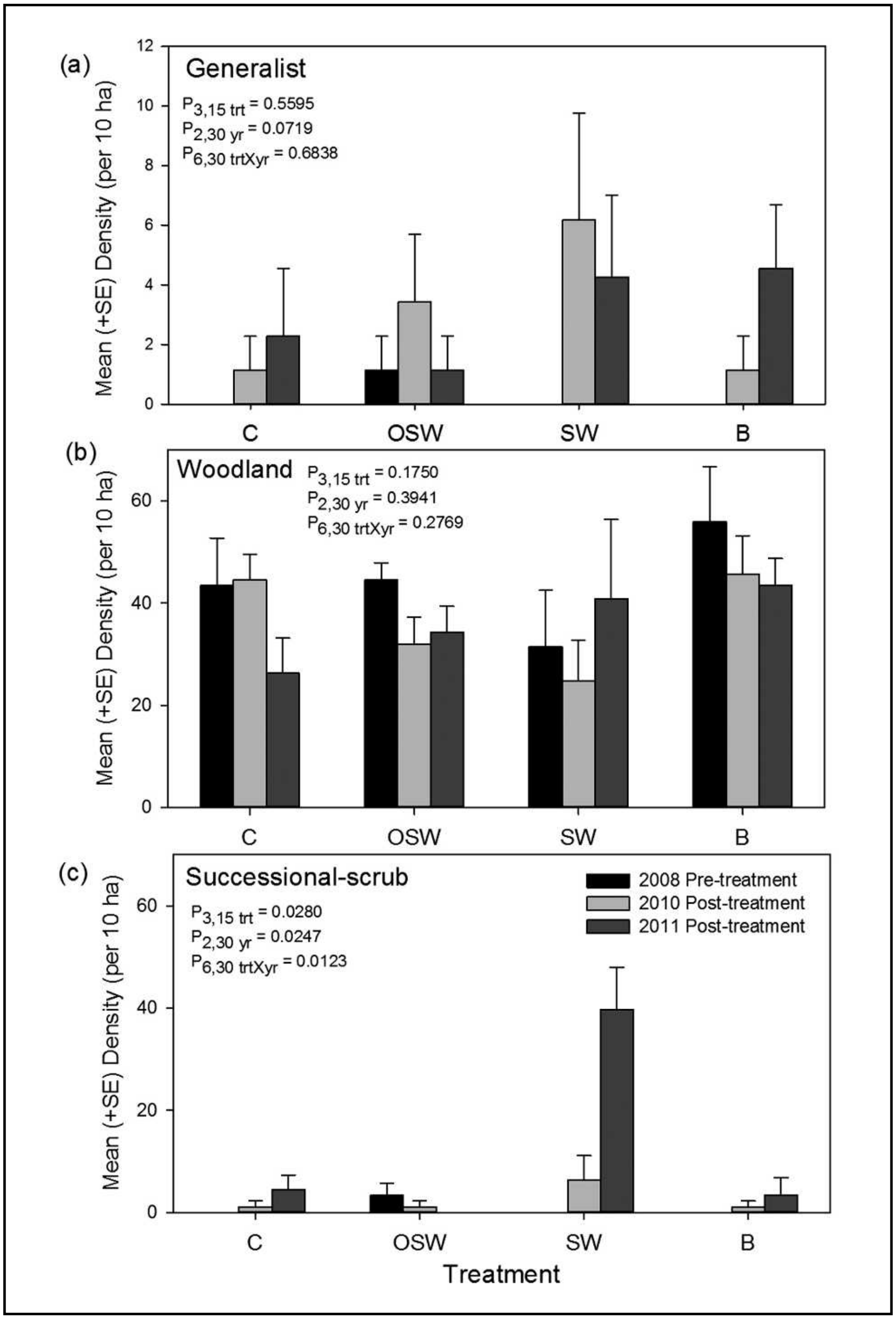

Figure 4. Mean (+SE) density (number per 10 ha) of breeding birds in woodland- and successional-scrub breeding habitat guilds in pre-treatment (2008) and post-treatment (2010 and 2011) oak regeneration treatments on Cold Mountain Game Land, Haywood County, NC. Treatments were control (C), oak shelterwood (OSW), shelterwood harvest (SW), and a single prescribed burn (B). *P*-values are results of repeated measures ANOVAs comparing treatment, years, and treatment x year interaction effects.

purposes. However, our results indicate that a higher density of shrub-nesters in SW was due to increases in species specifically associated with early successional-scrub and use of SW harvests by mature forest species, rather than changes in nest site availability per se. We suggest that unless a nest-searching component is included with bird density estimates, treatment response analyses by nest-placement guild may be less revealing than analysis of individual species response, or primary breeding habitat associations, to examine breeding bird response to forest disturbances.

Other studies also report higher densities of shrub-nesting species in shelterwood harvests than in mature forest, with most of those species also associated with early successional-scrub habitats (McDermott et al. 2009; Newell and Rodewald 2012). Additionally, some report short-term declines in shrub-nester abundance after prescribed burns (Aquilani et al. 2000; Artman et al. 2001; Greenberg et al. 2007) or understory reduction treatments (Rodewald and Smith 1998; Greenberg et al. 2007). In our study, we intentionally selected stands without dense mountain laurel (*Kalmia latifolia* L.) or rhododendron (*Rhododendron maximum* L.) shrub cover that could inhibit oak and other hardwood seedling establishment or treatment response. In addition, none of the oak regeneration treatments in our study significantly reduced shrub cover, including prescribed burns. However, by 2011 shrub recovery and stump sprouting in the SW treatment had created dense shrubby nesting substrate and cover for foraging birds.

We did not examine nest productivity or nestling survival, but other studies have shown that nest success was similar in mature and young forest habitat (e.g., King and DeGraaf 2000; DuGuay et al. 2001; Gram et al. 2003; Newell and Rodewald 2012). Several studies report that densities of Brown-headed Cowbirds (*Molothrus ater* Boddaert) are higher in shelterwood harvests than in mature forests and increase potential for brood parasitism (Annand and Thompson 1997; Rodewald and Smith 1998). We did not detect Brown-headed Cowbirds in our mid-elevation, primarily forested study area, and brood parasitism did not appear to be an issue in our study sites. However, nest parasitism may be a greater issue in young forests near agricultural areas that are suitable for Cowbird foraging (McDermott and Wood 2009).

Whereas most other studies compare existing one- or two-year-old silvicultural treatments to unharvested mature forest, our "before-after-control-impact" (BACI) experimental design (Smith 2002) enabled us to detect changes (or not) in breeding bird communities and species densities on the same treatment units, from pre- to post-treatments. Among the three early successional-scrub species showing a response in SW, none were detected in those or other treatment units before treatment implementation. Indigo Buntings increased in SW the first breeding season post-harvest whereas densities of Chestnut-sided Warblers and Eastern Towhees increased the second breeding season (11–18 months) after the shelterwood harvests were complete. Newell and Rodewald (2012) reported higher occurrence and densities of some early successional scrub species in sites that were harvested up to two years prior to their study period, but were unable to address changes in density or occurrence from pre-treatment to immediate post-treatment and subsequent years. Our study indicated that the early successional-scrub guild and individual species did not increase immediately post-harvest, but required one growing season (corresponding with one breeding season) to respond. This delayed response was likely associated with dense thickets of shrubs, stump sprouts, and new seedlings that developed by 2011, providing adequate cover for breeding birds.

We did not measure territory size or boundaries, and, thus, cannot address how patch size, configuration, or proximity of different forest age-classes affected responses by different species with different-sized territories, at a landscape scale. However, our results clearly indicate that many species used the SW stands more than the other treatments, and also suggest that relatively small patches (5 ha, in our study) of successional-scrub habitat can support one to several breeding pairs of some successional-scrub species that would not otherwise commonly occur in a forested landscape.

CONCLUSION

Our results indicate that incomplete canopy-replacing disturbance, such as two-age harvesting, is an important forest management tool that creates habitat for breeding birds associated with both young and mature forests, including several neotropical migrants of conservation concern. In contrast, initial phases of two other oak regeneration methods – low-intensity winter prescribed burning, and oak shelterwood using midstory herbicide – did not create young forest habitat suitable for early successional-scrub birds and had little or no effect on densities of other breeding bird species. The burn and oak shelterwood understory treatments are intended to increase indirect light to promote oak seedling growth for several years by altering understory structure while leaving an intact forest canopy. The initial phases of these oak regeneration methods will eventually conclude in complete overstory removal to release advance regeneration of oak and other hardwood species, resulting in creation of young forest habitat that can benefit successional-scrub breeding birds (Annand and Thompson 1997; Lanham et al. 2002) and that will likely remain suitable for 10–15 years before young trees grow to canopy closure (Loftis et al. 2011; Shifley and Thompson 2011). Structural heterogeneity of forested landscapes can be maintained by creating a temporal and spatial mosaic of different-aged forests through a sustainable rotation of shelterwood harvests or other regeneration harvests (King and DeGraaf 2000; Loftis et al. 2011; Shifley and Thompson 2011) and other disturbances, such as high-intensity burns that kill a large proportion of overstory trees (Greenberg et al. 2007; Greenberg et al. 2013). Differences in species composition of early succession birds between recent SW harvests at our mid-elevation study area and other studies at lower elevations suggests that comprehensive conservation efforts in the southern Appalachians necessitate creating and maintaining young forest habitats across elevation gradients. Our results also suggest that even small patches of young forest habitat are used by more individuals and more species of breeding birds than surrounding closed-canopy forest, and may benefit successional-scrub breeding birds by providing habitat that enables their occurrence in an otherwise forested landscape. Use of different oak regeneration treatments across elevation gradients can create a heterogeneous age class and canopy structure over time, and be an effective tool for conservation of a diverse breeding bird community in upland hardwood forests.

ACKNOWLEDGMENTS

This is a contribution of the Regional Oak Study (ROS). This research was initiated by the USDA Forest Service, Southern Research Station, Upland Hardwood Ecology and Management Research Work Unit (RWU 4157) in partnership with the USFS Northern Research Station, the North Carolina Wildlife Resources Commission (NCWRC), the Stevenson Land Company, and the Mark Twain National Forest. We thank the many individuals who assisted in this study: K. Frick, T. Roof, J. Adams, many other forestry technicians. We thank the many individuals from NCWRC and Haywood Technical College who assisted with the prescribed burns. W.H. McNab, K. Weeks, and an anonymous reviewer provided useful suggestions for improvements to earlier versions of this manuscript.

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