Research Article

Short-Term Effects of Fire and Other Fuel Reduction Treatments on Breeding Birds in a Southern Appalachian Upland Hardwood Forest

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ABSTRACT We compared the effects of 3 fuel reduction techniques and a control on breeding birds during 2001–2005 using 50-m point counts. Four experimental units, each >14 ha, were contained within each of 3 replicate blocks at the Green River Game Land, Polk County, North Carolina, USA. Treatments were 1) prescribed burn, 2) mechanical understory reduction (chainsaw-felling of shrubs and small trees), 3) mechanical + burn, and 4) controls. We conducted mechanical treatments in winter 2001–2002 and prescribed burns in spring 2003. Tall shrub cover was substantially reduced in all treatments compared to controls. Tree mortality and canopy openness was highest in the mechanical + burn treatment after burning, likely due to higher fuel loading and hotter burns; tree mortality increased with time. Many bird species did not detectably decrease or increase in response to treatments. Species richness, total bird density, and some species, including indigo buntings (*Passerina cyanea*) and eastern bluebirds (*Sialia sialis*), increased in the mechanical + burn treatment after a 1-year to 2-year delay; eastern wood-pewees (*Contopus virens*) increased immediately after treatment. Hooded warblers (*Wilsonia citrina*), black-and-white warblers (*Mniotilta varia*), and worm-eating warblers (*Helmitheros vermivorus*) declined temporarily in some or all treatments, likely in response to understory and (or) leaf litter depth reductions. Densities of most species affected by treatments varied with shrub cover, tree or snag density, or leaf litter depth. High snag availability, open conditions, and a higher density of flying insects in the mechanical + burn treatment likely contributed to increased bird density and species richness. In our study, fuel reduction treatments that left the canopy intact, such as low-intensity prescribed fire or mechanical understory removal, had few detectable effects on breeding birds compared to the mechanical + burn treatment. High-intensity burning with heavy tree-kill, as occurred in our mechanical + burn treatment, can be used as a management tool to increase densities of birds associated with open habitat while retaining many forest and generalist species, but may have short-term adverse effects on some species that are associated with the ground- or shrub-strata for nesting and foraging. (JOURNAL OF WILDLIFE MANAGEMENT 71(6):1906–1916; 2007)

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Vegetation structure, including both vertical strata (MacArthur and MacArthur 1961) and horizontal distribution on the landscape (Mauer et al. 1981), has a strong impact on the diversity and composition of bird communities. Disturbance can enhance diversity at stand and landscape scales by creating a mosaic of habitats or successional stages (Askins 2000, Brawn et al. 2001). Several studies report higher bird species richness, diversity, and density in sites that were disturbed by management activities compared to mature undisturbed forest (Annand and Thompson 1997, Baker and Lacki 1997). In addition, a number of bird species require habitat that has been recently disturbed by fire or by large-scale, high-intensity disturbance (Klaus et al. 2005). However, species differ in their habitat requirements, and each may respond differently to changes in habitat attributes that are created by natural disturbance or forest management activities.

Fire frequencies and intensities in southern Appalachian forests prior to human influence are largely unknown. Lightning-caused fires are infrequent (Harmon 1982), but their frequency varies with topography and associated forest types (Delcourt and Delcourt 1997). However, widespread, frequent burning was historically used by Native Americans and (later) by European settlers to maintain an open understory and improve conditions for travel and game or livestock (Lorimer 1993, Brose et al. 2001).

In the 1930s, forest fires began to be viewed as destructive and were suppressed or excluded where possible (Lorimer 1993). Fire exclusion led to higher mid- and understory densities of shade-tolerant trees and shrubs, especially on mesic upland sites (Brose et al. 2001). Today, prescribed burning and silvicultural treatments, such as mechanical understory reductions, are forest management tools used to reduce fuels and the risk of wildfire (Graham et al. 2004), and for ecosystem restoration, oak (*Quercus* spp.) regeneration, understory control, and wildlife conservation (Brawn et al. 2001). Yet the effects of fuel reduction by prescribed burning and (or) mechanical understory reduction on

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breeding birds is poorly known, especially in the southern Appalachians, USA.

The effect of various fuel reduction treatments on bird communities is likely to correspond with the type and intensity of disturbance and associated changes in habitat attributes. Most fuel reduction treatments reduce understory shrubs and small trees. However, high-intensity disturbances, such as burns that kill trees and shrubs, could increase light, thereby promoting growth of new, succulent vegetation and plant flowering, leading to higher flying and foliar insect densities (Whitehead 2003) and fruit production (Blake and Hoppes 1986, Greenberg et al. 2007). Prescribed fire differs from mechanical understory reduction by burning the leaf litter layer and creating snags that benefit cavity nesters such as woodpeckers (Picidae; Lanham and Guynn 1996, Giese and Cuthbert 2003, Saab et al. 2004).

Land managers need to know how different fuel reduction methods affect breeding birds to better manage populations and communities in conjunction with wildfire risk management or other forest management objectives. As part of the multidisciplinary National Fire and Fire Surrogate Study (Youngblood et al. 2005), we assessed experimentally how breeding bird communities and individual species responded to fuel reduction by prescribed burning, mechanical understory reduction, or mechanical understory reduction followed by burning. Specifically, we examined changes in densities of individual species, total birds, and species richness among the 3 fuel reduction treatments and untreated controls in the southern Appalachians for one breeding season before treatments, one breeding season after mechanical treatments (only) had been implemented, and for 3 breeding seasons after all 3 treatments had been fully implemented.

STUDY AREA

We conducted our study on the 5,841-ha Green River Game Land (35°17′9″N, 82°19′42″W, blocks 1 and 2; 35°15′42″N, 82°17′27″W, block 3) in Polk County, North Carolina, USA. The Game Land was in the mountainous Blue Ridge Physiographic Province of western North Carolina. Soils were primarily of the Evard series (fine-loamy, oxidic, mesic, Typic Hapludults), which are very deep (>1 m) and well drained in mountain uplands (U.S. Department of Agriculture Natural Resources Conservation Service 1998). There were also areas of rocky outcrops in steeper terrain. The upland hardwood forest was composed mainly of oaks and hickories (*Carya* spp.). Shortleaf (*Pinus echinata*) and Virginia (*P. virginiana*) pines were found on ridgetops, and white pine (*P. strobus*) occurred in moist coves. Forest age within experimental units varied from 80 years to 120 years. Predominant shrubs were mountain laurel (*Kalmia latifolia*) along ridgetops and on upper southwest-facing slopes and rhododendron (*Rhododendron maximum*) in mesic areas. Elevation ranged from approximately 366 m to 793 m. None of the sites had been thinned or burned for at least 50 years (D. Simon, North Carolina Wildlife Resources Commission, personal communication).

METHODS

Experimental Design

Our experimental design was a randomized block design with repeated measures over years. We selected 3 study areas (blocks) within the Game Land. Perennial streams border and (or) traverse all 3 replicate blocks. We selected blocks based on size (on the basis of their capacity to accommodate 4 experimental units each), forest age, cover type, and management history to ensure consistency in baseline conditions among the treatments. Minimum size of experimental units (4 within each block) was 14 ha to accommodate 10-ha core areas, with 20-m buffers around each. Dirt roads or fire lines separated some of the experimental units but did not traverse any of them, and wooded trails traversed some experimental units.

We randomly assigned 3 treatments and an untreated control (C) within each of the 3 study blocks, for a total of 12 experimental units. Fuel reduction treatments were 1) mechanical understory reduction (M), 2) prescribed burn (B), and 3) mechanical + burn (MB). We conducted mechanical treatments during winter 2001–2002. We reduced the understory using chainsaws (with no heavy equipment), and included all mountain laurel, rhododendron, and other shrubs and trees >1.8 m tall and <10.0 cm diameter at breast height. We left cut fuels scattered on-site, resulting in little or no vertical structure. We conducted prescribed burns in B and MB treatments on 12 or 13 March 2003. We burned one block by hand-ignition, using spot fire and strip-headfire techniques. We ignited the other blocks by helicopter, using a plastic sphere dispenser and a spot fire technique. Our objectives for prescribed burns were to remove the shrub layer and create a few snags.

Fire intensities varied within and among sites but were generally moderate to high. Flame lengths of 1 m to 2 m (214–965 kW/m by Byram's flame length index; Brown and Davis 1973) occurred throughout all burn units, but flame lengths reached up to 5 m (7,073 kW/m) in localized spots where topography or intersecting flame fronts contributed to erratic fire behavior. Measured temperatures were generally <120° C on B sites, but they often exceeded 800° C in MB sites due to a combination of higher fine woody fuel loading, lower fuel moisture, and topography in MB. Phillips et al. (2006) give a detailed description of fire behavior in this study.

Breeding Bird Surveys

We surveyed bird communities using 3 50-m radius (0.785-ha area) point counts spaced 200 m apart in each experimental unit (Ralph et al. 1993). We surveyed each point for 10 minutes during 3 separate visits between 15 May and 30 June 2001–2005. Over the 5-year study period, 3 total observers conducted the bird surveys, with the same one or two surveying them each year. We conducted point counts within 4 hours of sunrise. We recorded all birds that we saw or heard within 50 m. We rotated the times for point counts among the 3 visits to each experimental unit to avoid time-of-day biases. We did not estimate detectability of different bird species and assumed that we detected all birds within each 50-m radius point count area without error. We calculated bird density for each experimental unit by averaging across the 3 surveys and 3 point counts for each year, and extrapolating the average number per point count to number per 10 ha. Species richness represented the total number of species detected during all 3 visits and point counts in each experimental unit each year.

Habitat Sampling

We measured pretreatment (2001) habitat variables in all experimental units. We remeasured these variables during the growing season immediately posttreatment (2002 for M, and 2003 for C, B, and MB) and 2 years posttreatment (2004 for M, and 2005 for C, B, and MB). We measured density of trees and snags (≥10 cm dbh), and percent cover of tall (≥1.4-m ht) shrubs within 10 0.05-ha (10 × 50-m) plots that we spaced systematically within each experimental unit. We estimated percent cover of low (<1.4-m ht) shrubs in 20 1-m^2 quadrats placed systematically within each of the 10 larger plots. We measured leaf litter depth using a meter stick at 3 locations along each of 3 randomly oriented, 15-m transects originating at grid points that we spaced at 50-m intervals throughout each experimental unit. We obtained a measure of percent canopy openness beginning in 2002 (prior to canopy disturbance) at 2 randomly selected points within each experimental unit during summer (leaf on) using a concave spherical densiometer held at breast height (1.4 m). We used the average of all habitat measurements for each experimental unit in our statistical analyses ($n = 3$/treatment or control).

Statistical Analyses

Because we initiated treatments incrementally in different years, we treated our study as 3 separate phases, and we performed separate statistical analyses on each. For phase 1, we tested whether mechanical understory reduction affected breeding birds, and we included data from 2001, prior to any fuel reduction treatments, and 2002, when we conducted a mechanical understory reduction treatment in half of the experimental units. For phase 2, we compared effects of prescribed burns in experimental units that were untreated the year prior, prescribed burns in units that had undergone mechanical treatment the year prior, units that had undergone mechanical treatment the year prior and had no additional treatments, and untreated units. For phase 2, we included data from 2002, when half of the experimental units had undergone mechanical treatment and half were untreated, and 2003, when we had conducted prescribed burns in half of the untreated units and in half of the units that had undergone mechanical treatment. For phase 3, we included data from 2003 to 2005, after all treatments had been implemented, and tested whether any of the 3 fuel reduction treatments (B, M, and MB) or controls (C) affected breeding birds over the 3-year period. We analyzed density for only those species sufficiently common (>2.0/10 ha in any treatment) during the years covered by each phase.

Phases 1 and 2: incremental application of fuel reduction treatments.—We performed separate analyses of variance (ANOVAs) for phases 1 and 2, each of which used data from 2 consecutive years to test for differential effects of treatments implemented between the 2 years. For each ANOVA, we first natural-log transformed each density estimate or species richness to reduce possible heteroscedasticity. For each experimental unit, we subtracted the estimate for the first year from the second year. The difference represents the relative change in density (or species richness) between the 2 years. We analyzed these differences using 1-way ANOVA followed by a Tukey multiple comparison procedure.

For the phase 1 ANOVA, we used data from 2001 (all pretreatment) and 2002 (mechanical treatment in 2 of the 4 units in each block), and thus the only comparison of interest is whether units that received mechanical treatment (C–M) responded differently than those that remained as controls (C–C). In our analyses, we considered the 2 experimental units per block (2 C–C and 2 C–M in each of the 3 blocks, in 2002) to be independent replicates because we assigned treatments randomly and breeding bird territories are relatively stable. Although some bird movement among experimental units was likely, we assumed the error was consistent. For the phase 2 ANOVA, we used data from 2002 and 2003 and 4 treatments were involved: was C and remained C (C–C), was M and remained M (M–M), was C and changed to B (C–B), and was M and changed to MB (M–MB).

Phase 3: comparison of 3 fuel reduction treatments and controls, 2003–2005.—We used a 2-way ANOVA with repeated measures on posttreatment data (2003–2005) to compare bird species richness and density estimates of total birds and each bird species among treatments and years, and we tested for treatment × year interactions. We used the Type III sum of squares and associated mean squares as the error term for treatment effects. We interpreted either a significant treatment effect and (or) a treatment × year interaction effect as evidence of a treatment effect, indicating that changes among years differed among the treatments. We performed post hoc tests using a Tukey multiple comparison procedure.

Bird–habitat relationships.—We used stepwise multiple regressions on densities of bird species that responded to the fuel reduction treatments, or species that had strong responses to similar treatments in other studies, to further explore the relationship between their densities and select habitat features including live tree density, snag density, percent cover of low and tall shrubs, and leaf litter depth. We included only posttreatment years when habitat and bird data were gathered concurrently (2002 and 2004 measurements for M; 2003 and 2005 measurements for B, C, and MB). We natural-log transformed density data for regressions.

Habitat.—We used separate 1-way ANOVAs to test for among-treatment differences in measured habitat features for pretreatment (2001), immediately posttreatment (2002 measurements for M; 2003 measurements for B, C,

Table 1. Mean (± SE) number and P-values of analyses of variance[a] for pretreatment (2001), <1 year posttreatment, and 2 years posttreatment density of live trees and snags (no./ha), percent tall (≥1.4-m ht) and low (<1.4 m-ht) shrub cover, and percent canopy openness, in 3 treatments: prescribed burn, mechanical understory reduction, mechanical + burn, and controls ($n = 3$ each), Green River Game Land, Polk County, North Carolina, USA, 2001–2005.

		Treatment								
		Control		Burn		Mechanical		Mechanical + burn		
Habitat feature	Measurement	$\bar{x}$	SE	$\bar{x}$	*SE*	$\bar{x}$	SE	$\bar{x}$	SE	P_{trt} (df = 3,6)
Live trees/ha	Pretreatment	566.0	10.6	568.7	29.3	602.0	18.1	506.7	33.8	0.166
	<1 yr posttreatment	550.7	15.0^{A}	539.3	30.0^{A}	588.0	11.0^{A}	379.3	43.5^{B}	0.007
	2 yr posttreatment	552.0	12.5^{A}	505.3	39.1^{A}	594.0	9.5^{A}	277.3	60.2^{B}	0.002
Snags/ha	Pretreatment	74.0	8.3	62.7	6.7	55.3	4.7	67.3	14.1	0.592
	<1 yr posttreatment	68.0	9.0^{AB}	72.7	19.0^{AB}	52.7	4.4^{A}	152.0	25.3^{B}	0.031
	2 yr posttreatment	56.7	14.1^{A}	90.0	33.3^{AB}	60.6	6.7^{A}	212.0	29.0^{B}	0.015
Tall (≥1.4 m) shrub cover (%)	Pretreatment	14.2	4.7	7.6	2.9	15.0	3.9	9.6	3.3	0.544
	<1 yr posttreatment	20.0	3.9^{A}	4.7	2.8^{B}	1.4	0.1^{B}	0.2	0.2^{B}	0.008
	2 yr posttreatment	17.8	4.4^{A}	4.1	2.4^{B}	2.6	0.4^{B}	1.3	0.6^{B}	0.014
Low (<1.4 m) shrub cover (%)	Pretreatment	12.7	2.0	10.4	2.2	14.0	0.4	18.3	3.8	0.288
	<1 yr posttreatment	7.3	0.8^{AB}	3.8	1.0^{B}	14.9	1.6^{A}	6.7	1.8^{B}	0.008
	2 yr posttreatment	9.6	1.3	8.6	2.5	15.6	2.7	18.9	5.6	0.189
Leaf litter depth (cm)	Pretreatment	5.0	0.1	4.8	0.3	5.0	0.2	5.1	0.3	0.896
	<1 yr posttreatment	4.2	0.5^{A}	0.9	0.1^{B}	5.5	0.2^{C}	0.5	0.1^{B}	<0.001
	2 yr posttreatment	4.7	0.2^{AB}	3.9	0.1^{B}	5.9	0.4^{A}	3.3	0.1^{B}	0.003
Canopy openness (%)	Pretreatment	6.8	1.0	6.2	0.3	8.3	1.2	8.5	2.6	0.561
	<1 yr posttreatment	1.6	0.4^{A}	2.6	1.1^{AB}	3.0	0.8^{AB}	12.8	5.0^{B}	0.028
	2 yr posttreatment	6.0	2.7^{A}	8.4	2.5^{AB}	9.0	2.0^{AB}	35.5	13.1^{B}	0.039

[a] Differences among treatments within yr are denoted by different letters within rows.

and MB), and 2 years posttreatment (2004 measurements for M; 2005 measurements for B, C, and MB) data. We also compared canopy openness among treatments for 2002 (before canopy disturbance) and for 2 posttreatment measurements (2003 and 2005). We square-root arcsine transformed percentage data (shrub cover and canopy openness) for ANOVAs. We performed post hoc tests using a Tukey multiple comparison procedure. In all analyses we considered $P < 0.10$ to be statistically significant.

RESULTS

Habitat

Prior to treatment, estimates of the number of live trees and snags per hectare, percent cover of shrubs, and canopy openness did not differ among treatments (Table 1). About 25% of live trees were killed within a few months of prescribed burning in MB, and about 50% were dead within about 2 years; in contrast, 88% of trees survived 2 years after burning in the B treatment. All other treatments had more live trees than MB a few months and 2 years after burns; MB also had more snags than C or M 2 years posttreatment (snag density in B did not differ from other treatments). Correspondingly, canopy openness in MB changed from 8.5% to 35.5% during the 2 years postburn but changed much less in the other treatments; nonetheless, it was higher in MB than in C during both posttreatment measurements, but not in the other 2 fuel reduction treatments due to high variability among experimental units. Immediately post-treatment, and still after 2 years, tall shrub cover was lower in all 3 fuel reduction treatments than in C. Low shrub cover was greater in M than in the other treatments immediately after treatments (C differed from none) but recovered within 2 years (Table 1). After treatments, leaf litter depth was much lower in both burned treatments (B and MB) and highest in M. By 2 years posttreatment, litter depth in B and MB did not differ from C but remained lower than litter depth in M.

Breeding Birds

We detected 48 species 2,760 total times over the 5-year study period. Twenty-one species were sufficiently common to include in analyses for phase 1, 23 species for phase 2, and 27 species for phase 3.

Phases 1 and 2: incremental application of fuel reduction treatments.—Total bird density in all experimental units increased 67% on average between 2001 and 2002, but there was no evidence of an effect of the mechanical treatment ($P = 0.768$; Fig. 1a). From 2002 to 2003, overall bird density decreased 48%, but again there was no evidence of a treatment effect ($P = 0.237$; Fig. 1a). Species richness followed a similar trend, with higher richness in 2002 than in 2001 or 2003, but no evidence of a treatment effect for the mechanical treatment ($P = 0.346$) or among all 4 treatments ($P = 0.295$; Fig. 1b).

Black-and-white warblers (*Mniotilta varia*) and hooded warblers (*Wilsonia citrina*; Table 2) decreased in response to the mechanical treatment (2001–2002). After we conducted burns (2002–2003), hooded warbler density decreased in all 3 fuel reduction treatments. Worm-eating warbler (*Helmitheros vermivorus*) density decreased more in M–MB than in C–C or M–M (densities in C–B did not differ from other treatments; Table 2).

Phase 3: comparison of 3 fuel reduction treatments and controls.—Total bird density was highest in MB (but did not statistically differ from B or C; $P_{trt} = 0.004$, $P_{yr} = 0.260$,

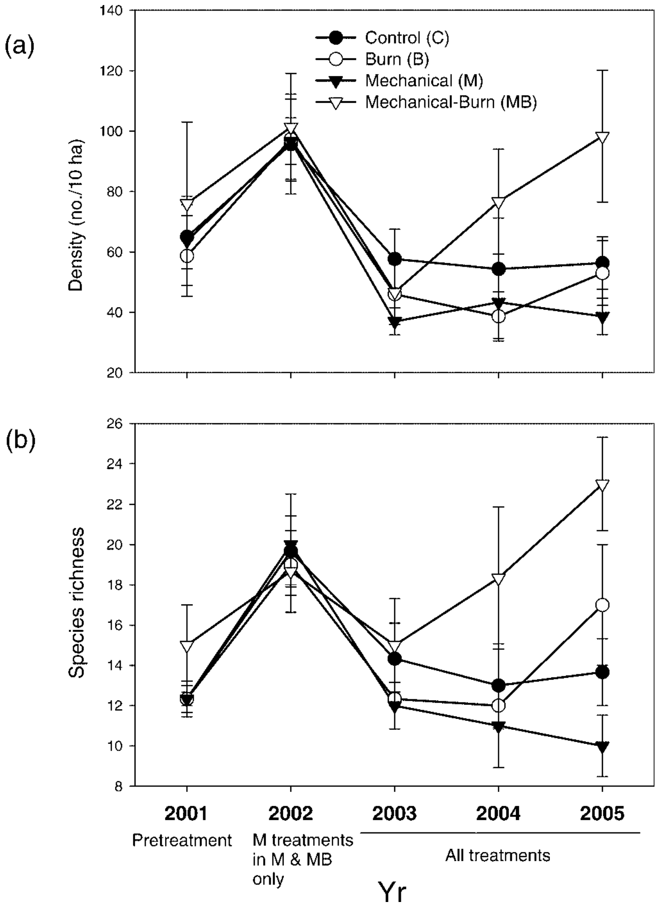

Figure 1. Mean (± SE) total density (no./10 ha; a) and species richness (b) of breeding birds in 3 fuel reduction treatments: prescribed burn (B), mechanical understory reduction (M), mechanical + burn (MB), and controls (C; $n = 3$ each), Green River Game Land, Polk County, North Carolina, USA. Data for 2001 are pretreatment; in 2002 only M treatments had been implemented (in M and MB); 2003–2005 data were collected after all treatments had been implemented.

$P_{trt \times yr} = 0.415$; Fig 1a). Species richness also was highest in MB ($P_{trt} = 0.005$, $P_{yr} = 0.073$, $P_{trt \times yr} = 0.073$; Fig. 1b). Increases in both total density and species richness were evident after a 1-year to 2-year delay; by 2005 they were (on average) twice as high in MB than in the other treatments (Fig. 1).

Many species did not detectably increase or decrease in response to treatments during the 3 posttreatment breeding seasons we analyzed (Table 3). Eastern bluebirds (*Sialia sialis*), eastern wood-pewees (*Contopus virens*), indigo buntings (*Passerina cyannea*), summer tanagers (*Piranga flava*), and cedar waxwings (*Bombycilla cedrorum*) increased in MB (Table 3). This trend was also evident, although not as clear, for Carolina wrens (*Thyrothorus ludovicianus*) and downy woodpeckers (*Picoides pubescens*; lowest densities in M compared to other treatments), and eastern towhees (*Pipilo erythrophthalmus*; lowest densities in B compared to other treatments). In most cases, treatment responses were delayed for 1–2 years (Table 3). Conversely, hooded warblers and worm-eating warblers declined in response to all fuel reduction treatments in the short term (Table 3). Wood thrush (*Hylocichla mustelina*) densities were very low in all treatments and in the untreated control 2003–2005 (Table 3), so their response to treatments was difficult to evaluate.

Densities of most species responding positively to MB also were positively related to snag density (eastern bluebirds) or negatively related to live tree density (eastern wood-pewee, indigo bunting, and summer tanager; Table 4). Of the 2 species that decreased in response to fuel reduction treatments, hooded warbler density was positively related to tall shrub cover and leaf litter depth and worm-eating warbler density was negatively related to leaf litter depth. Ovenbird (*Seiurus aurocapillus*) density was positively related to leaf litter depth and live tree density, and negatively related to tall shrubs. Densities of downy woodpeckers and wood thrushes were not associated with any measured habitat variable (Table 4).

DISCUSSION

Our study indicated that densities of many breeding bird species were not measurably changed fuel reduction treatments, at least in the short term. Hooded warblers and black-and-white warblers were negatively affected in the short term by the mechanical understory reductions. Hooded warbler and worm-eating warbler densities declined in response to burns, especially in units that had been mechanically treated the year prior and burned hotter (MB). In contrast, eastern wood-pewees increased in the MB treatment immediately after burning. In addition, several species, total bird density, and species richness increased in MB 1–2 years after the hotter burns killed substantial numbers of trees and created more open habitat conditions.

Clearly, low treatment replication (n = 3/treatment and control) increased the likelihood that we failed to statistically detect some bird responses that did indeed occur (Type II error). Some response patterns also can be difficult to interpret with insufficient replication. Nonetheless, we detected clear responses by several species to ≥1 fuel reduction treatments (MB in particular), as measured by changes in density. In most cases, bird species responded to treatment-induced changes in forest structure in accordance with what might be expected given their specific habitat requirements. Further, many of our results correspond with those of other studies.

Increased density and species richness in MB beginning 1–2 years after burns was partly due to the influx of some species that are typically associated with open habitat, such as chipping sparrows (*Spizella passerina*), eastern bluebirds, brown-headed cowbirds (*Molothrus ater*), indigo buntings, and pine warblers (*Dendroica pinus*), likely in response to the more open, light conditions created by high tree mortality. We also detected several other species in MB (and some in B) after prescribed burning that we did not detect before burning or in either unburned treatment. These included American redstarts (*Setophaga ruticilla*), cedar waxwings, eastern wood-pewees, northern parulas (*Parula americana*), and summer tanagers. Eastern wild turkeys (*Meleagris gallopavo*) also used prescribed burn areas. Recovery of low

Table 2. Mean (± SE) baseline (2001, pretreatment; $n = 12$) density[a] and mean changes in density[b] of common[c] breeding bird species, between 2001 (pretreatment) and 2002 (with one treatment and control),[d] and between 2002 and 2003 (with 3 treatments and control),[e] Green River Game Land, Polk County, North Carolina, USA.

			2001–2002 treatment					2002–2003 treatments[g]								
	Baseline density		C–C		C–M			C–C		M–M		C–B		M–MB		
Species[f]	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	P (df = 1,8)	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	P (df = 3,6)
ACFL	0.3	0.3	2.6	0.8	1.4	1.2	0.245	−2.3	0.7	0.3	0.3	−3.3	1.8	−2.3	2.3	0.485
AMCR	0.6	0.3	1.2	0.8	0.9	1.1	0.724	−1.0	1.0	−1.7	0.7	−1.0	1.5	−3.0	1.7	0.545
AMGO	0.3	0.3	2.8	0.8	1.4	0.7	0.226	−2.0	1.5	−1.0	1.0	0.7	2.0	1.3	2.3	0.980
BAWW	2.0	0.4	1.7	0.9	−0.9	0.8	0.049	−1.3	1.5	−1.0	2.6	−2.7	2.0	−1.0	1.5	0.955
BGGN	1.5	1.0	0.0	0.7	−0.5	1.1	0.338	1.3	0.9	1.0	1.2	1.7	1.2	−1.0	1.0	0.667
BHVI	5.9	1.7	1.7	0.9	4.7	3.2	0.524	−5.7	2.2	−8.3	5.0	−5.7	5.2	−5.0	4.0	0.923
BLJA	0.8	0.3	1.7	0.7	0.5	0.6	0.453	−2.0	1.0	0.3	0.3	−1.3	1.3	0.3	1.8	0.213
BTGN	4.1	1.2	−0.7	1.3	−0.2	1.6	0.589	−2.3	1.2	−3.0	2.0	−1.3	0.9	−1.7	1.2	0.327
CACH	3.3	1.1	0.9	2.2	3.1	3.0	0.107	−7.3	3.0	−2.7	1.7	−0.7	0.3	−7.3	0.3	0.532
CAWR	1.2	0.6	1.9	0.5	2.8	1.0	0.842	−2.7	0.9	−3.3	1.5	−1.0	0.0	−4.7	2.3	0.695
EABL	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	3.7	3.7	0.455
EAWP	0.0	0.0	0.0	0.0	0.0	0.0		0.0^{A}	0.0	0.0^{A}	0.0	0.0^{A}	0.0	2.3^{B}	1.9	0.086
ETTI	3.4	0.9	1.9	0.8	4.2	2.0	0.371	−1.7	2.2	−5.7	3.7	−1.3	2.2	−4.7	4.1	0.595
HOWA	7.9	1.5	4.5	1.5	−3.1	2.0	<0.001	0.0^{A}	3.5	-3.3^{AB}	0.3	-7.7^{AB}	0.3	-7.0^{B}	2.3	0.071
INBU	0.8	0.6	0.7	0.3	0.5	1.1	0.433	−0.7	0.3	−2.0	2.0	−0.3	0.3	−2.0	2.0	0.966
OVEN	3.8	0.8	4.5	1.6	5.0	1.9	0.288	−3.0	1.0	−7.0	3.5	−8.0	3.2	−7.7	4.4	0.797
PIWO	0.0	0.0	3.3	1.0	2.1	0.5	0.978	−2.3	2.7	−1.7	0.7	−1.3	1.3	−1.0	1.2	0.454
PIWA	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.3	0.3	0.3	0.3	3.0	1.7	0.410
REVI	10.3	1.6	−2.4	2.4	−1.2	3.2	0.619	1.0	1.5	−3.7	3.8	−4.0	2.5	−7.0	5.0	0.123
RTHU	2.5	1.8	−1.4	1.4	−2.8	1.1	0.577	1.3	0.9	0.3	0.3	0.7	1.2	−0.3	0.3	
SCTA	3.2	1.9	2.4	1.3	2.6	1.4	0.308	−3.0	2.3	−3.7	1.5	−6.0	2.5	−2.7	1.7	0.709
WBNU	1.1	0.4	0.9	0.9	4.2	2.0	0.778	−2.0	1.0	−1.0	2.9	1.7	3.0	−2.7	2.0	0.291
WOTH	1.7	1.2	2.6	1.1	−1.7	2.3	0.138	−1.3	1.3	−1.3	1.3	−2.3	2.4	0.0	0.0	0.686
WEWA	2.5	0.8	1.9	2.1	0.5	0.9	0.564	-1.3^{A}	1.5	-0.7^{A}	1.2	-2.0^{AB}	1.0	-2.7^{B}	0.9	0.032

[a] Actual values for density (no./10 ha) and species richness are presented, but numbers were natural-log transformed for analyses of variance (ANOVAs).

[b] For ANOVAs, density and richness were first natural-log transformed, and then for each experimental unit we subtracted the estimate for the first yr from the second yr for analysis of the relative change in density or richness between the 2001 and 2002, and between 2002 and 2003.

[c] ≥2/ha per treatment in any yr and (or) treatment (2001–2003).

[d] Treatments: was control (C) and changed to mechanical understory reduction (M; C–M), and was C and remained C (C–C).

[e] Treatments: was C and remained C (C–C), was M and remained M (M–M), was C and changed to prescribed burn (B; C–B), and was M and changed to mechanical + burn (MB; M–MB).

[f] ACFL = Acadian flycatcher (*Empidonax virescens*); AMCR = American crow (*Corvus brachyrhynchos*); AMGO = American goldfinch (*Carduelis tristis*); BAWW = black-and-white warbler; BGGN = blue-gray gnatcatcher (*Polioptila caerulea*); BHVI = blue-headed vireo (*Vireo solitarius*); BLJA = blue jay (*Cyannocitta cristata*); BTGN = black-throated green warbler (*Dendroica virens*); CACH = Carolina chickadee (*Poecile carolinensis*); CAWR = Carolina wren; EABL = eastern bluebird; EAWP = eastern wood-pewee; ETTI = tufted titmouse (*Baeolophus bicolor*); HOWA = hooded warbler; INBU = indigo bunging; OVEN = ovenbird; PIWA = pine warbler; PIWO = pileated woodpecker (*Drycopus pileatus*); REVI = red-eyed vireo (*Vireo olivaceus*); RTHU = ruby-throated hummingbird (*Archilochus colubris*); SCTA = scarlet tanager (*Piranga olivacea*); WBNU = white-breasted nuthatch (*Sitta carolinensis*); WEWA = worm-eating warbler; WOTH = wood thrush.

[g] Differences among treatments within yr are denoted by different letters within rows.

shrubs in MB likely encouraged recolonization by shrub-associated birds such as hooded warblers. Aging snags and potentially higher abundance of wood-boring arthropods might also have increasingly attracted species that use dead trees for foraging or nesting. Another concurrent study (2003–2004) in the same experimental units found higher densities of flying arthropods in MB (Campbell et al. 2007). Increased visibility (McCarty 1996) and higher flying insect abundance in the MB treatment (Campbell et al. 2007) likely attracted flycatchers (Tyrannidae) and other birds.

Our data support Hejl's (1994) suggestion that bird response to fire varies according to fire severity and the corresponding postburn conditions. We found that low-intensity burns with little subsequent tree mortality had little detectable effect on many species or community parameters. Artman et al. (2001) also reported that total bird densities were similar in a burned and unburned Ohio, USA, mixed-oak forest, where fire intensities were low and did not kill trees. In contrast, we found a strong response by several bird species, total bird density, and species richness to MB where fire intensity and subsequent tree mortality was high. Weakland et al. (2002) also reported that the mosaic of shrub cover and tree mortality created by patchy burns promoted higher bird species richness in West Virginia, USA.

Several species, including indigo buntings, eastern bluebirds, eastern wood-pewees, summer tanagers, and others responded positively to MB. Most of these species did not respond similarly to B, indicating that the response was not to burning per se, but rather to the open conditions and (or) other habitat changes that resulted from heavy tree mortality after the hotter prescribed fire in MB. Further, each of these species was associated with habitat variables indicative of open conditions (negatively with live tree density or

Table 3. Mean posttreatment densities[a] of common[b] breeding bird species in 3 fuel reduction treatments: prescribed burn (B), mechanical understory reduction (M), mechanical + burn (MB), and controls (C; $n = 3$ each), Green River Game Land, Polk County, North Carolina, USA, 2003–2005.

		Density (no./10 ha)											
		C		B		M		MB					
Species[c]	Yr[e]	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	P_{trt} (df = 3,6)	P_{year} (df = 2,16)	$P_{trt \times yr}$ (df = 6,16)	Treatment effects[d]
AMGO	2003	1.3	0.9	3.3	2.0	1.0	1.0	3.3	2.0	0.228	0.158	0.846	
	2004	0.0	0.0	1.0	1.0	0.0	0.0	5.3	3.9				
	2005	0.0	0.0	1.0	1.0	0.3	0.3	2.0	1.0				
BAWW	2003	2.3	0.7	0.3	0.3	1.0	1.0	0.3	0.3	0.286	0.609	0.500	
	2004	1.3	0.9	0.3	0.3	1.3	1.3	0.0	0.0				
	2005	3.0	2.5	1.3	0.9	0.0	0.0	1.3	0.9				
BGGN	2003^{AB}	2.3	1.2	3.0	2.5	1.7	1.2	1.0	1.0	0.893	0.029	0.119	
	2004^{A}	0.3	0.3	0.0	0.0	0.3	0.3	3.3	3.3				
	2005^{B}	1.3	1.3	2.7	1.7	0.3	0.3	3.0	2.0				
BHCO	2003^{A}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.681	0.099	0.841	
	2004^{A}	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3				
	2005^{B}	0.3	0.3	1.0	1.0	0.0	0.0	4.3	4.3				
BHVI	2003	2.7	0.9	3.3	1.8	3.7	1.8	1.7	1.2	0.148	0.293	0.792	
	2004	4.3	1.7	3.3	3.3	6.0	1.5	3.3	1.8				
	2005	5.7	2.2	2.7	2.2	8.3	2.3	5.3	1.2				
BLJA	2003	0.0	0.0	2.3	1.2	1.7	0.7	1.3	0.9	0.243	0.917	0.609	
	2004	1.3	1.3	3.7	2.0	1.0	1.0	0.3	0.3				
	2005	1.7	1.2	1.7	1.2	0.3	0.3	0.7	0.3				
BTGN	2003	1.0	1.0	1.3	1.3	2.3	2.3	1.0	1.0	0.113	0.820	0.753	
	2004	3.0	2.5	1.3	1.3	2.0	2.0	2.0	2.0				
	2005	5.7	3.2	0.3	0.3	1.0	1.0	0.3	0.3				
CACH	2003	0.3	0.3	0.3	0.3	1.0	1.0	0.7	0.3	0.690	0.557	0.968	
	2004	1.7	1.2	2.7	1.3	0.3	0.3	2.0	1.0				
	2005	2.0	2.0	1.3	0.9	1.0	1.0	2.7	2.7				
CAWR	2003	1.7	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.081	0.114	0.053	M^{A} B^{AB} C^{AB} MB^{B}
	2004	0.3	0.3	0.0	0.0	0.3	0.3	1.3	0.9				
	2005	0.3	0.3	2.3	1.9	0.0	0.0	5.0	2.6				
CEDW	2003^{A}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.108	0.024	0.066	
	2004^{A}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				
	2005^{B}	0.0	0.0	0.3	0.3	0.0	0.0	4.3	3.0				
DOWO	2003	1.7	1.2	0.7	0.3	0.0	0.0	1.3	0.9	0.016	0.835	0.762	M^{A} B^{AB} MB^{B} C^{B}
	2004	1.3	0.9	1.3	0.9	0.0	0.0	3.0	2.0				
	2005	2.7	0.9	0.3	0.3	0.3	0.3	1.7	1.2				
EABL	2003	0.0	0.0	0.0	0.0	0.0	0.0	3.7	3.7	0.019	0.720	0.947	C^{A} M^{A} B^{AB} MB^{B}
	2004	0.0	0.0	0.0	0.0	0.0	0.0	3.0	1.7				
	2005	0.0	0.0	1.3	1.3	0.0	0.0	2.7	2.2				
EATO	2003	1.0	1.0	0.0	0.0	0.3	0.3	0.0	0.0	0.058	0.112	0.036	B^{A} C^{AB} M^{AB} MB^{B}
	2004	1.0	1.0	0.0	0.0	1.0	1.0	2.7	2.2				
	2005	0.0	0.0	0.3	0.3	1.0	1.0	7.0	3.8				
EAWP	2003	0.0	0.0	0.0	0.0	0.0	0.0	2.3	1.9	0.001	0.161	0.240	B^{A} C^{A} M^{A} MB^{B}
	2004	0.0	0.0	0.3	0.3	0.3	0.3	0.7	0.3				
	2005	0.0	0.0	0.7	0.3	0.0	0.0	4.0	0.0				
ETTI	2003	3.7	2.0	4.3	2.2	1.3	1.3	4.0	1.0	0.240	0.122	0.895	
	2004	4.0	2.0	3.7	1.8	4.7	2.3	6.7	0.7				
	2005	3.0	0.0	5.0	1.0	2.3	0.7	6.7	3.2				
HOWA	2003	12.3	5.0	2.0	2.0	1.7	1.2	0.0	0.0	0.002	0.158	0.862	MB^{A} B^{A} M^{AB} C^{B}
	2004	7.7	2.7	1.0	1.0	2.7	0.9	0.3	0.3				
	2005	9.3	3.5	4.7	2.4	5.7	2.6	4.0	3.5				
INBU	2003^{A}	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.002	0.001	0.002	C^{A} M^{A} B^{A} MB^{B}
	2004^{B}	0.0	0.0	0.3	0.3	0.0	0.0	6.7	0.7				
	2005^{B}	0.0	0.0	1.0	1.0	0.0	0.0	5.7	2.2				
OVEN	2003	3.0	2.5	0.3	0.3	3.7	1.8	0.3	0.3	0.233	0.735	0.441	
	2004	4.7	3.3	1.3	0.9	4.3	0.9	0.0	0.0				
	2005	3.0	2.5	2.7	1.3	4.7	2.4	0.3	0.3				
PIWA	2003	0.0	0.0	0.3	0.3	0.3	0.3	3.0	1.7	0.129	0.270	0.903	
	2004	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.9				
	2005	0.0	0.0	0.0	0.0	0.3	0.3	2.0	1.0				
REVI	2003	8.3	0.9	4.3	2.0	3.3	1.5	4.3	0.9	0.912	0.570	0.309	
	2004	6.7	3.5	3.3	2.0	4.0	1.7	4.3	0.9				
	2005	4.7	2.3	4.7	1.2	3.7	0.3	3.7	0.3				
RTHU	2003	1.3	0.9	1.3	0.9	0.3	0.3	0.3	0.3	0.665	0.110	0.492	
	2004	1.3	1.3	1.3	1.3	2.3	1.2	3.7	1.8				
	2005	1.7	0.7	1.7	0.7	1.3	0.9	2.7	1.7				

Table 3. Continued.

Species[c]	Yr[e]	Density (no./10 ha) C $\bar{x}$	C SE	B $\bar{x}$	B SE	M $\bar{x}$	M SE	MB $\bar{x}$	MB SE	P_{trt} (df = 3,6)	P_{year} (df = 2,16)	$P_{trt \times yr}$ (df = 6,16)	Treatment effects[d]
SCTA	2003	0.3	0.3	1.3	1.3	3.7	1.8	2.3	1.2	0.399	0.529	0.527	
	2004	1.0	0.0	2.3	1.9	0.7	0.3	2.0	1.0				
	2005	2.3	0.7	0.7	0.3	3.0	1.7	4.3	2.0				
SUTA	2003[A]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.070	0.039	0.012	B[A] C[A] M[A] MB[B]
	2004[A]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				
	2005[B]	0.0	0.0	0.0	0.0	0.0	0.0	2.0	1.0				
WBNU	2003	0.0	0.0	4.0	2.0	3.7	1.5	3.0	1.0	0.184	0.204	0.226	
	2004	7.0	4.0	2.3	1.2	6.7	3.3	4.0	1.7				
	2005	4.7	1.9	4.3	0.9	3.0	2.5	9.3	1.2				
WITU	2003	0.0	0.0	0.3	0.3	0.0	0.0	0.3	0.3	0.455	0.418	0.444	
	2004	0.0	0.0	0.0	0.0	0.0	0.0	11.0	11.0				
	2005	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				
WOTH	2003	0.3	0.3	2.3	0.7	0.0	0.0	0.7	0.3	0.027	0.123	0.453	M[A] MB[AB] C[AB] B[B]
	2004	0.3	0.3	0.3	0.3	0.0	0.0	0.3	0.3				
	2005	0.3	0.3	0.3	0.3	0.0	0.0	0.0	0.0				
WEWA	2003	2.7	0.9	1.7	1.2	2.7	0.9	0.0	0.0	0.049	0.600	0.014	MB[A] B[AB] M[B] C[B]
	2004	2.7	1.3	0.3	0.3	3.0	0.0	0.0	0.0				
	2005	1.0	0.0	3.3	2.0	0.3	0.3	3.3	1.8				

[a] Actual values for density (no./10 ha) are presented, but numbers were natural-log transformed for analyses of variance.
[b] >2/10 ha in any yr and (or) treatment, 2003–2005.
[c] See Table 2 for species codes. Codes not included in Table 2: BHCO = brown-headed cowbird; CEDW = cedar waxwing; DOWO = downy woodpecker; EATO = eastern towhee; SUTA = summer tanager; WITU = wild turkey.
[d] Different letters among yr for a species indicate significant differences.
[e] Where treatment effects are significant, treatments are ordered from lowest to highest density; different letters among them indicate significant differences.

positively with snag density). Other studies reported similar responses by indigo buntings to open conditions created by burning or silvicultural treatments (Wilson et al. 1995, Rodewald and Smith 1998). Artman et al. (2001) and Wilson et al. (1995) also found a positive response by eastern wood-pewees to prescribed burns, possibly due to higher flying insect abundance and improved foraging habitat.

Table 4. Results of stepwise multiple regression of bird density with habitat features including live tree density, snag density, low (<1.4-m ht) and tall (≥1.4-m ht) shrub cover, and leaf litter depth, Green River Game Land, Polk County, North Carolina, USA, 2003–2005. Negative and positive relationships are indicated by − or + signs, respectively, before habitat variable.

Species[a,b]	Habitat variable	Model summary: Parameter estimate	Parameter SE	$F_{1,22}$	P	Partial r^2	RMSE[c]
BAWW	+ tall shrub cover	0.03539	0.01691	4.38	0.048	0.17	0.67
CAWR	None						
CEDW	− tree density	−0.00356	0.00070	26.20	<0.001	0.54	0.39
	+ low shrub cover	0.03804	0.01146	11.02	0.003	0.16	
DOWO	None						
EABL	+ snag density	0.00798	0.00177	20.36	<0.001	0.48	0.52
EATO	+ low shrub cover	0.05705	0.02234	6.52	0.018	0.23	0.67
EAWP	− tree density	−0.00400	0.00083	22.64	<0.001	0.51	0.47
HOWA	+ tall shrub cover	0.07101	0.01834	16.15	<0.001	0.42	0.81
	+ litter depth	0.55458	0.19947	7.73	0.001	0.16	
INBU	− tree density	−0.00548	0.00103	17.34	<0.001	0.44	0.57
	+ leaf litter depth	0.40531	0.15905	6.49	0.019	0.13	
OVEN	+ leaf litter depth	0.77766	0.18508	19.73	<0.001	0.47	0.59
	+ tree density	0.00267	0.00123	4.68	0.043	0.08	
	− tall shrub cover	−0.04757	0.01577	5.62	0.027	0.11	
SUTA	− tree density	−0.00146	0.00058	9.90	0.005	0.31	0.33
	+ low shrub cover	0.02337	0.01094	4.57	0.045	0.12	
WOTH		none					
WEWA	+ leaf litter depth	0.44868	0.17112	6.87	0.016	0.24	0.62

[a] See Tables 2 and 3 footnotes for species codes.
[b] Species are presented if P_{trt} or $P_{trt \times yr}$ values were <0.10 (Tables 2 or 3) or if they were of special interest (e.g., ovenbirds).
[c] RMSE = root mean-sq error.

All 3 species that decreased in response to ≥1 fuel reduction treatments were closely associated with ground leaf litter and shrubs for nesting and (or) foraging. Hooded warblers, which nest and forage primarily in shrubs (Evans Ogden and Stutchbury 1994), declined in response to all fuel reduction treatments. However, they showed signs of recovery within about 2 years. We found a close, positive relationship between hooded warblers and coverage of tall shrubs. Artman et al. (2001) reported that hooded warblers declined in response to fire and did not recover within 1 year after burns. However, prescribed burning in an Indiana, USA, forest did not appear to adversely affect hooded warblers (Aquilani et al. 2000). Fire intensity, evenness (vs. patchiness), and shrub recovery time likely influenced hooded warbler response and recovery from prescribed burns.

Worm-eating warblers, which forage and nest on the ground and in shrubs (Gale 1995), declined in MB after prescribed burns and a negative trend was evident in B. Our data suggest that short-term declines in density of worm-eating-warblers were due in part to reductions in leaf litter by burning because they did not decline in M where leaf litter remained intact. Further, we found a weak relationship between worm-eating warbler density and leaf litter depth, but none with shrub cover. Aquilani et al. (2000) did not find an adverse effect of burning, but other studies have reported negative effects of prescribed burns (Artman et al. 2001) or understory reduction (Rodewald and Smith 1998) on worm-eating warblers.

Black-and-white warblers, which nest on the ground and forage on tree trunks and branches, decreased temporarily in response to the M treatment, but did not appear to be adversely affected by burns. We found a weak relationship between black-and-white warblers and tall shrub cover. Artman et al. (2001) also reported that prescribed burns did not affect densities of black-and-white warblers. In contrast, Wilson et al. (1995) reported declines in black-and-white warbler populations in response to a combination of prescribed burns and thinning in an Arkansas, USA, oak–pine forest.

We did not detect a response to fuel reduction treatments by ovenbirds, a ground-nesting species that was common in our study. However, they were positively related to leaf litter depth and live tree density and negatively related to tall shrubs, suggesting a negative response to specific habitat conditions that resulted from burning, especially in MB. Other studies have reported ovenbird declines in response to understory reductions by prescribed burns or mechanical removal (Wilson et al. 1995, Rodewald and Smith 1998, Aquilani et al. 2000, Artman et al. 2001).

Nesting or foraging requirements do not necessarily restrict birds to specific habitat conditions. Artman et al. (2001) frequently observed ground-nesting species, including ovenbirds and wood thrushes, foraging within recently burned areas. Woinarski (1990) suggested that fires may actually enhance food resource availability for ground-foraging birds by removing leaf litter and exposing insects and seeds. Because we did not map breeding territories, we were unable to distinguish between visiting and territorial pairs in our density calculations. Some species, such as ovenbirds, may have used burned treatments for foraging despite unsuitable nesting conditions. Alternatively, variability in some habitat conditions among experimental units within B, and especially MB, may have allowed ovenbirds to use select areas or experimental units that were less affected by burning.

Our findings generally correspond with results of other studies in that densities of many breeding bird species were not measurably affected by fuel reduction treatments, but some, especially species that nest or forage primarily on the ground or in shrubs, were negatively affected by prescribed burns (Aquilani et al. 2000, Artman et al. 2001) or understory reductions (Rodewald and Smith 1998), at least in the short term. Other species, such as eastern wood-pewees, increased in response to postburn conditions (Wilson et al. 1995, Artman et al. 2001), perhaps due to higher levels of flying arthropods and greater visibility. We also found a strong positive response by several species, total bird density, and species richness to MB where fire intensity and subsequent tree mortality was high; however, this response was not evident until 1–2 years postburn. Higher bird density does not necessarily indicate better habitat quality (Van Horne 1983). We did not examine possible treatment effects on reproductive success or survival, and thus we cannot address whether treatment areas function as a population source or sink.

Bird response to the MB treatment is likely to change over time as snags fall, shrubs recover further, and other habitat attributes and food resources (e.g., arthropod and fruit abundance) continue to change. Repeated fuel reduction treatments, such as multiple burns, could affect bird responses differently from the short-term effects we reported by further changing important habitat features such as snag and live tree density, canopy cover, shrub cover and height, and leaf litter depth. In order to fully understand how fuel reduction treatments affect breeding birds at the community and species level, both one-time disturbance and repeated disturbance treatments should be studied, and posttreatment(s) surveys of birds and vegetation structure must continue for several years (Raphael et al. 1987).

Our results suggest that fire intensity and pattern, and the habitat conditions that resulted, were important response drivers of some bird species and community parameters. Differing results among studies regarding breeding bird response to prescribed burns or mechanical understory reduction may be in part due to differences in fire intensity and pattern and resulting differences in habitat conditions.

MANAGEMENT IMPLICATIONS

Our results indicate that fuel reduction treatments affecting only the understory, such as low-intensity prescribed fire or mechanical understory removal, have few detectable effects on breeding birds. High-intensity burning with heavy tree-kill, as occurred in MB, can be used as a management tool in the short term to increase densities of birds associated with open habitat, while retaining many generalist species and those that use forested habitat. Retention of snags and some live trees may provide sufficient canopy cover and vertical structure that is required by many bird species that commonly inhabit forests with high canopy cover. However, heavy leaf litter and shrub reductions may adversely affect other bird species that are closely associated with shrub- or ground-strata for nesting and foraging. If >1 burn is planned, allowing sufficient time for recovery of shrubs and leaf litter depth would likely facilitate recovery by ground- and shrub-associated species. Plant recovery and snag longevity are dynamic; therefore, long-term changes in habitat structure and bird communities must be considered.

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