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# SHORT-TERM EFFECTS OF FIRE ON BREEDING BIRDS IN SOUTHERN APPALACHIAN UPLAND FORESTS

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ABSTRACT.—We investigated how variation in fire severity (control or no fire; low, medium, and high severity fires) and interval (1–2 years vs. 3–6 years after fires) affected habitat and avian abundance, species diversity, richness, and evenness in the southern Appalachian Mountains. Fire severity and interval had significant implications for both habitat and avian communities. Species richness within 2 years of fires was on average 26% higher in areas receiving medium and high severity treatments than in unburned control units. Species diversity and species richness were markedly greater 3–6 years after fires within high severity treatments (12 and 44%, respectively), compared to unburned controls. Relative abundance and species evenness did not vary with fire severity or time since fire. The short-term effects of low severity fires, or high severity fires with short rotation periods (≤2 years) may have limited positive effects on avian communities. Facilitation of disturbance regimes including mid to high severity fires, which foster uneven-aged forests, can be an effective conservation tool for restoring avian communities. *Received 30 June 2009. Accepted 1 March 2010.*

Disturbance is a fundamental ecological process that has had a role in structuring and maintaining diversity within many ecological communities (Loucks 1970, Elliott et al. 1999, Brawn et al. 2001, Bond and Keeley 2005, Bond et al. 2005). Generally, disturbance increases diversity by creating a mosaic of habitats or successional stages within a landscape (Askins 2001, Brawn et al. 2001). Fire is one form of disturbance that has had a large part in structuring the ecological communities of the southern Appalachian Mountains (Lorimer 1980, Van Lear and Waldrop 1989, Waldrop et al. 1992). Suppression of fire on public lands during the past century has likely reduced diversity and structure of animal and plant communities (Abrams 1992, Lorimer 2001, Artman et al. 2005). Several federal land management agencies, in an effort to restore diversity and ecological function, now plan for increased use of prescribed fire in the southern Appalachian Mountains. However, effects of restoring fire on wildlife are largely unknown in these mostly hardwood forest systems. In particular, effects of varying fire severity and interval on wildlife are largely unknown.

Many bird species associated with early succession habitats and pine (*Pinus* spp.) savannas would likely benefit from return of fire to the southern Appalachian Mountains. Species of concern include: Bachman's Sparrow (*Aimophila aestivalis*), Northern Bobwhite (*Colinus virginianus*), Red-cockaded Woodpecker (*Picoides borealis*), Prairie Warbler (*Dendroica discolor*), and Golden-winged Warbler (*Vermivora chrysoptera*) (Brewster 1886, Burleigh 1958, Stupka 1963, Hunter et al. 2001, Klaus 2004). Measured responses for other bird species may not be positive (Lang et al. 2002, Artman and Downhower 2003, Tomcho et al. 2006), and the benefits of fire restoration may not integrate similarly across all members of avian communities, or in all habitats (Artman et al. 2001, Saab and Powell 2005, Tomcho et al. 2006, Greenberg et al. 2007). Thus, reintroduction of fire should be based on desired ecological condition.

The historical suppression of fire and changes in agricultural practices within the eastern United States have been implicated in loss of early successional habitat (Askins 2001). Loss of this habitat type has had a significant impact on avian communities. Early succession songbirds in the southern Appalachians have the strongest declines of any group of birds (Hunter et al. 1999, Sauer et al. 2005). Many of the species that require mature forest for nesting also use early succession habitat as fledglings and during molt (Anders et al. 1998, Vega Rivera et al. 1999, Marshall et al. 2003, Rush and Stutchbury 2008). Restoration of early successional habitat may be a key feature of policies directed at conservation of many avian species (Dettmers 2003, Bulluck and Buehler 2006, Buehler et al. 2007).

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Prescribed fire is often cited as a likely tool for restoring and providing suitable habitat for many avian species (Partners in Flight Working Group 2002), but our current understanding of the appropriate application of fire in shaping forest ecosystems of the southern Appalachian Mountains remains limited. We currently know of only a few studies that have examined the effects of prescribed fire on songbirds in hardwood forests of the eastern United States (Aquilani et al. 2000; Artman et al. 2001, 2005; Greenberg et al. 2007); only one of these studies occurred in the southern Appalachians. Our objectives were to document how breeding season distributions of birds changed with variation in fire severity and time since fire in the southern Appalachians.

## METHODS

*Study Area.*—This study was conducted within the Brasstown and Tallulah ranger districts of the Chattahoochee-Oconee National Forest (CNF), Murray County, Georgia, USA. U.S. Forest Service (USFS) personnel were consulted within the CNF and 22 potential study sites were identified at elevations from 600 to 1,500 m. All burn units were >200 ha and had burned in the last 8 years, either as a prescribed fire or as part of a wildfire. Vegetation sampling sites were placed into one of three fire severity groups on the basis of the extent of canopy mortality: low, medium, or high. Low severity burns were typical of most 'fuel reduction' prescribed fires in the southern Appalachians. Flame lengths were generally less than 1 m, resulting in <5% canopy mortality throughout the burn unit and low to moderate midstory mortality. Moderate to severe midstory and 5 to 20% canopy mortality characterized medium severity burns and flame lengths ranged from <0.5 m in mesic sites to 4 m along dry ridge tops, leaving a heterogeneous result. High severity burns were characterized by 20 to 50% canopy mortality, mostly along ridge tops, and severe to total midstory mortality except in ravines.

We selected 12 of the 22 burn units, four of each treatment, based on similarity of forest type, elevation, and average aspect. All chosen burn units had been burned ≤6 years earlier. Half the 12 burn units selected (2 of each treatment) were in sites that were burned <2 years previously, and two were in sites that were burned 3–6 years previously. Forest types consisted primarily of mixed pine (*Pinus* spp.)-hardwoods and drier oak-hickory (*Quercus-Carya*), although ridge tops occasionally included small stands of *P. taeda*, *P. virginiana*, *P. rigida*, and *P. pungens*. Four control units were also identified with the aid of USFS personnel. Control units were similar in forest type, elevation, and average aspect but had not burned in ≥20 years.

*Bird Surveys.*—Surveys were conducted by USFS and Georgia Department of Natural Resources staff. Participants received several weeks of spring training on bird identification and point-count techniques prior to surveys. All participants had conducted bird surveys for several years prior to this study. Two transects were placed for each survey within each burn unit. Transects followed contours and were at least 200 m apart. All surveys were conducted between 0630 and 1100 hrs, 17 May–10 June 2004, following protocols established by Hamel et al. (1996), except that counts were conducted for 10 min and distance bands of 0–10, 11–25, 26–50, 51–100, and >100 m were used. Ten point counts were conducted on each survey transect, 20 per burn unit. Locations of individual point counts were: (1) separated by at least 200 m, (2) at least 100 m inside the burn unit, and (3) placed in upland mixed pine hardwood stands or oak stands. Ravines, road edges, and other cover types were avoided. Four replications of each treatment were surveyed for a total of 80 points per treatment.

*Habitat Measurements.*—We conducted variable-radius vegetation surveys within each burn unit centered on each point count location. We measured the basal area using a 10-factor prism of live trees >25 cm diameter breast height (DBH); this metric is referred to as BASAL AREA. We visually estimated average canopy (CANOPY COVER) and herbaceous cover (HERBACEOUS COVER) to the nearest 10% for a 25-m radius around each plot center. We also measured shrubs (woody plants 1 to 7 m tall and <12 cm DBH) within a 3-m radius around the plot center by counting all stems (SHRUB DENSITY) and measuring average shrub height (SHRUB HEIGHT) to the nearest decimeter. Each burn unit was categorized based on known fire histories into one of three fire histories: (1) control [not burned within the last ≥20 years], (2) burned within 1–2 years of surveys, and (3) burned within 3–6 years of surveys.

*Data Analysis.*—We restricted our analysis to limit the repeated counting of the same individual at two adjacent survey sites and to include only those birds detected within 100 m of each survey point. The relative abundance of each species for each treatment was calculated as the average number of individuals detected/ha. We restricted each point-count survey to counts of individuals detected per distance band during each time interval for conservative estimates of relative abundance of each species. Detections of the same species in the same distance band but in different time intervals were treated as a possible recount of the same individual and were excluded from further analysis. All bird species observed at each survey point along each transect were used in calculations of bird species diversity, species richness, and species evenness. Species diversity was calculated as the Shannon-Weaver Diversity Index ($H'$) (Shannon and Weaver 1963). Species richness was calculated as the number of individual species observed per point during each point count, and species evenness was calculated as $H'$ divided by the natural log of species richness (Magurran 1988).

We used linear, mixed-effects models (*lme*) in R (Version 2.7.1; R Development Core Team 2008) to compare habitat measurements, diversity, species evenness, and species richness between treatments using the burn unit as the experimental unit. Mixed-effects models are appropriate for this data structure because they partition information into multi-level components. The data recommends level-1 (survey point), level-2 (survey transect), and level-3 (burn unit) components in our case. Each component is estimated with the appropriate degrees of freedom, and the standard errors of other parameter estimates are appropriately adjusted (Raudenbush and Bryk 2002). Transect and burn unit effects were accounted for as random variables, and treatment as a fixed effect. We used q-q plots prior to analysis to examine the normality of each habitat metric. We log transformed BASAL AREA, SHRUB DENSITY, SHRUB HEIGHT, and HERBACEOUS COVER and arcsine square-root transformed CANOPY COVER to improve normality and homoscedasticity. We used conditional *t*-tests for each *lme* to ascertain whether covariates were significantly different from zero (Pinheiro and Bates 2000). We also developed a series of orthogonal contrasts to compare means between the different levels of burn severity and times since fire.

We used canonical correspondence analysis (CCA) of data collected at each of the survey points to examine the relationship between bird community structure and measured environmental variables (McCune and Grace 2002). This technique was used to produce graphical presentations depicting relationships among abundance of individual species, treatments, and measured environmental gradients. Habitat variables explaining a significant amount of variation ($P \leq 0.10$), as calculated by Monte Carlo permutation tests (1,000 random permutations of samples in the species data; package Vegan in R) (R Development Core Team 2008), were included in the CCA analyses. The means of these variables are represented by the origin in the resulting diagram. We constrained our analysis for clarity in presentation of bird assemblages to include only those species that were detected at ≥20% of all survey points. We conducted two separate analyses to facilitate comparisons, one comparing habitat and bird assemblage between control and treatments 1–2 years after fires, and a separate analysis with similar comparisons for control and treatments sampled 3–6 years after fires. We log transformed BASAL AREA, SHRUB DENSITY, SHRUB HEIGHT, and HERBACEOUS COVER and arcsine square-root transformed CANOPY COVER prior to using them in the CCA.

## RESULTS

*Fire and Habitat.*—Fire severity affected habitat structure. Comparisons of treatments and unburned controls revealed CANOPY COVER and SHRUB DENSITY differed among treatments ($F_{6,9} = 19.1$, $P < 0.001$; $F_{6,9} = 4.0$, $P = 0.03$, respectively), (Fig. 1). High severity treatments had significantly less CANOPY COVER than control units both 1–2 years ($t = 6.8$, df = 9, $P < 0.001$), and 3–6 years after fires ($t = 7.9$, df = 9, $P < 0.001$). CANOPY COVER did not differ relative to the number of years since fires ($t = 1.0$, df = 9, $P = 0.33$) but, SHRUB DENSITY was significantly lower among high severity treatments 1–2 years after fires than 3–6 years after fires ($t = -4.4$, df = 9, $P = 0.002$).

*Effects on Avian Diversity and Communities.*—Sixty-three species were detected among the four treatments (Table 1). Species richness differed among several treatments ($F_{6,9} = 4.9$, $P = 0.02$) and was significantly higher 1–2 years after fires relative to the low severity burn units. It did not differ among medium and high severity burn units ($t = -2.5$, df = 9, $P = 0.03$, $t = -2.3$, df = 9, $P = 0.05$) (Fig. 2). Species richness 3–6 years

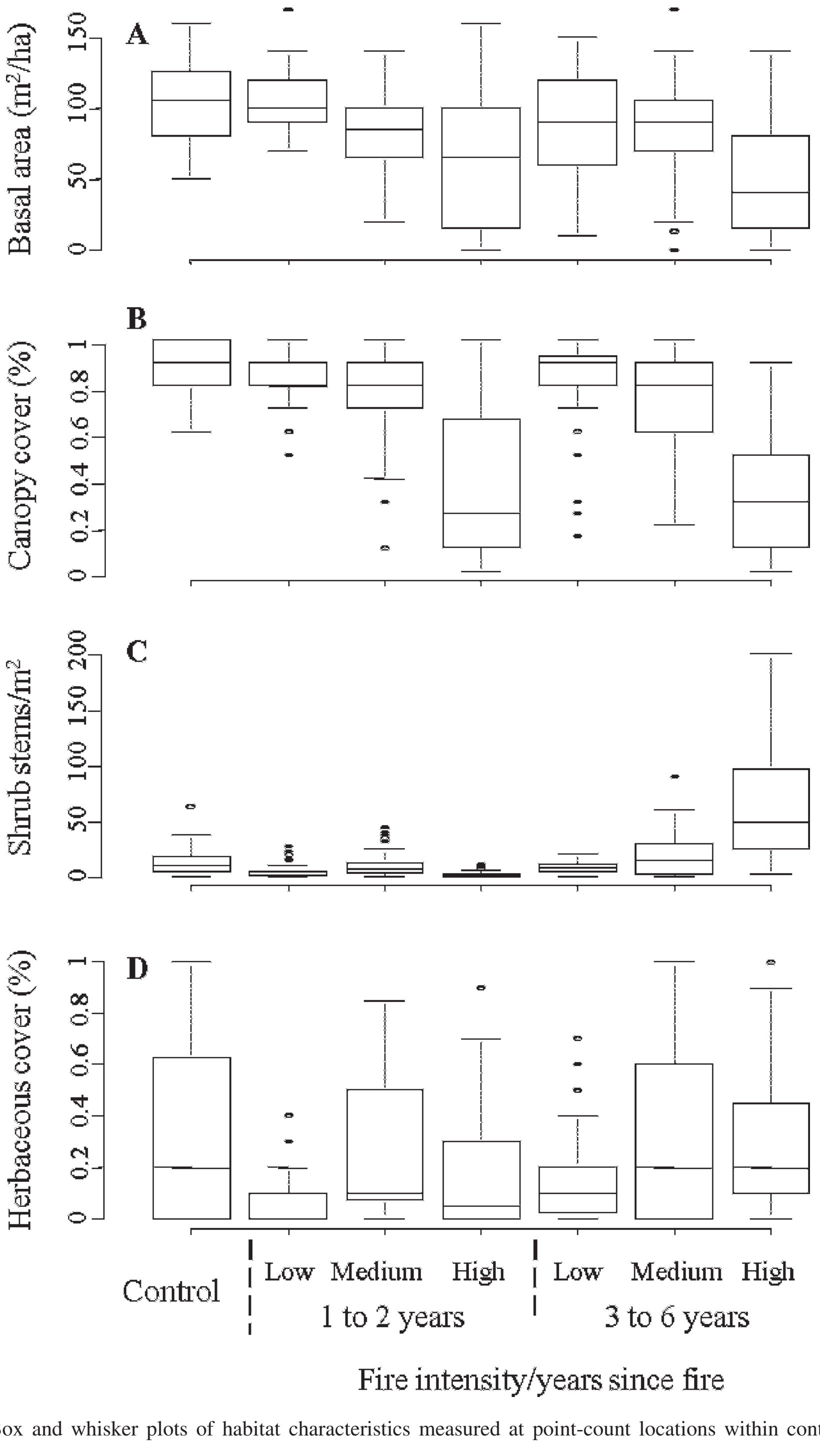


FIG. 1. Box and whisker plots of habitat characteristics measured at point-count locations within control and burn treatments. Whiskers represent maximum and minimum observations while boxes represent the 25 and 75% quartiles.

TABLE 1. Relative abundance of species detected during surveys in the southern Appalachian Mountains. Estimates are individuals/10ha ($\bar{x} \pm$ SE). Missing values indicate species not detected.

| | | Treatment (years after fires) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Low | | Medium | | High | |
| Species<br>Scientific name | Control | 1–2 | 3–6 | 1–2 | 3–6 | 1–2 | 3–6 |
| Ruffed Grouse<br>*Bonasa umbellus* | | 0.1 ± 0.1 | | | | | |
| Wild Turkey<br>*Meleagris gallopavo* | | 0.2 ± 0.1 | | | | | 0.1 ± 0.1 |
| Black Vulture<br>*Coragyps atratus* | | | | | | | 0.2 ± 0.2 |
| Turkey Vulture<br>*Cathartes aura* | | | | 0.2 ± 0.2 | | | 0.3 ± 0.2 |
| Sharp-shinned Hawk<br>*Accipiter striatus* | | | 0.2 ± 0.2 | | | | |
| Broad-winged Hawk<br>*Buteo platypterus* | | 0.3 ± 0.2 | 0.2 ± 0.2 | 0.1 ± 0.1 | | 0.1 ± 0.1 | |
| Red-tailed Hawk<br>*B. jamaicensis* | | | | | 0.2 ± 0.1 | | |
| Mourning Dove<br>*Zenaida macroura* | 0.1 ± 0.1 | 0.3 ± 0.2 | 0.3 ± 0.2 | 0.2 ± 0.1 | 0.6 ± 0.2 | 0.7 ± 0.2 | 1.0 ± 0.3 |
| Yellow-billed Cuckoo<br>*Coccyzus americanus* | | | 0.3 ± 0.2 | 0.2 ± 0.1 | 0.5 ± 0.2 | 0.3 ± 0.2 | 0.5 ± 0.2 |
| Barred Owl<br>*Strix varia* | 0.1 ± 0.1 | | | | | | |
| Chimney Swift<br>*Chaetura pelagica* | 0.1 ± 0.1 | | 0.3 ± 0.2 | 0.6 ± 0.2 | 0.2 ± 0.2 | 1.2 ± 0.4 | 0.6 ± 0.3 |
| Ruby-throated Hummingbird<br>*Archilochus colubris* | | | 0.1 ± 0.1 | | 0.1 ± 0.1 | | 0.1 ± 0.1 |
| Red-bellied Woodpecker<br>*Melanerpes carolinus* | | | | | | 0.1 ± 0.1 | |
| Downy Woodpecker<br>*Picoides pubescens* | | | 0.1 ± 0.1 | 0.2 ± 0.1 | 0.2 ± 0.1 | 0.1 ± 0.1 | 0.1 ± 0.1 |
| Hairy Woodpecker<br>*P. villosus* | 0.2 ± 0.1 | 0.1 ± 0.1 | 0.2 ± 0.1 | 0.6 ± 0.2 | 0.1 ± 0.1 | 1.2 ± 0.3 | 0.6 ± 0.2 |
| Northern Flicker<br>*Colaptes auratus* | | | 0.2 ± 0.1 | 0.1 ± 0.1 | 0.1 ± 0.1 | 0.7 ± 0.3 | 0.4 ± 0.2 |
| Pileated Woodpecker<br>*Dryocopus pileatus* | 0.9 ± 0.3 | 1.6 ± 0.3 | 1.1 ± 0.2 | 1.5 ± 0.4 | 1.6 ± 0.3 | 1.3 ± 0.3 | 1.5 ± 0.3 |
| Eastern Wood-Pewee<br>*Contopus virens* | | | | 0.7 ± 0.2 | 0.2 ± 0.2 | 1.4 ± 0.3 | 2.4 ± 0.4 |
| Eastern Phoebe<br>*Sayornis phoebe* | | | 0.1 ± 0.1 | | 0.1 ± 0.1 | 0.2 ± 0.1 | |
| Great Crested Flycatcher<br>*Myiarchus crinitus* | 0.1 ± 0.1 | 0.1 ± 0.1 | 0.1 ± 0.1 | 0.2 ± 0.1 | 0.2 ± 0.1 | 0.5 ± 0.2 | 0.6 ± 0.2 |

TABLE 1. Continued.

| Species<br>Scientific name | | Treatment (years after fires) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Low | | Medium | | High | |
| | Control | 1–2 | 3–6 | 1–2 | 3–6 | 1–2 | 3–6 |
| Yellow-throated Vireo<br>*Vireo flavifrons* | | | | 0.2 ± 0.1 | | | 0.4 ± 0.2 |
| Blue-headed Vireo<br>*V. solitarius* | 0.6 ± 0.2 | 0.1 ± 0.1 | 1.0 ± 0.3 | 0.7 ± 0.2 | 0.7 ± 0.2 | 1.3 ± 0.3 | 0.7 ± 0.2 |
| Red-eyed Vireo<br>*V. olivaceus* | 5.6 ± 0.4 | 4.0 ± 0.5 | 4.4 ± 0.5 | 4.0 ± 0.5 | 5.8 ± 0.5 | 3.5 ± 0.6 | 5.4 ± 0.5 |
| Blue Jay<br>*Cyanocitta cristata* | 0.9 ± 0.3 | 0.6 ± 0.2 | 0.9 ± 0.3 | 0.9 ± 0.3 | 0.6 ± 0.2 | 0.6 ± 0.2 | 0.8 ± 0.3 |
| American Crow<br>*Corvus brachyrhynchos* | 1.5 ± 0.3 | 4.6 ± 0.6 | 3.7 ± 0.4 | 1.3 ± 0.3 | 1.4 ± 0.3 | 1.3 ± 0.3 | 2.7 ± 0.4 |
| Carolina Chickadee<br>*Poecile carolinensis* | | 0.3 ± 0.2 | 0.5 ± 0.2 | 0.2 ± 0.1 | 0.7 ± 0.3 | 0.1 ± 0.1 | 0.4 ± 0.2 |
| Tufted Titmouse<br>*Baeolophus bicolor* | 1.0 ± 0.2 | 1.4 ± 0.2 | 2.5 ± 0.4 | 1.7 ± 0.3 | 1.6 ± 0.3 | 0.6 ± 0.3 | 2.1 ± 0.3 |
| White-breasted Nuthatch<br>*Sitta carolinensis* | 0.5 ± 0.2 | 0.2 ± 0.1 | 0.4 ± 0.2 | 0.4 ± 0.2 | 0.5 ± 0.3 | 0.6 ± 0.3 | 0.5 ± 0.2 |
| Carolina Wren<br>*Thryothorus ludovicianus* | 0.2 ± 0.1 | 0.3 ± 0.2 | 0.2 ± 0.1 | 0.6 ± 0.2 | 0.4 ± 0.2 | 1.3 ± 0.3 | 1.4 ± 0.3 |
| Blue-gray Gnatcatcher<br>*Polioptila caerulea* | 0.1 ± 0.1 | | | 0.2 ± 0.1 | 0.1 ± 0.1 | | 0.6 ± 0.3 |
| Wood Thrush<br>*Hylocichla mustelina* | 0.1 ± 0.1 | 0.6 ± 0.3 | 0.2 ± 0.1 | 0.2 ± 0.1 | 0.6 ± 0.3 | 0.4 ± 0.2 | 0.3 ± 0.2 |
| Brown Thrasher<br>*Toxostoma rufum* | | | | | 0.1 ± 0.1 | 0.1 ± 0.1 | 0.1 ± 0.1 |
| Cedar Waxwing<br>*Bombycilla cedrorum* | | | | 0.1 ± 0.1 | | 0.9 ± 0.5 | 0.2 ± 0.2 |
| Golden-winged Warbler<br>*Vermivora chrysoptera* | | | | | 0.2 ± 0.2 | | |
| Northern Parula<br>*Parula americana* | | | | 4.0 ± 0.4 | | | 0.1 ± 0.1 |
| Chestnut-sided Warbler<br>*Dendroica pensylvanica* | 0.4 ± 0.2 | | 0.2 ± 0.2 | 1.4 ± 0.4 | 0.8 ± 0.2 | 1.5 ± 0.4 | 6.6 ± 0.5 |
| Black-throated Blue Warbler<br>*D. caerulescens* | | | 0.6 ± 0.3 | 1.0 ± 0.3 | | | |
| Black-throated Green Warbler<br>*D. virens* | 1.1 ± 0.3 | 1.2 ± 0.3 | 1.7 ± 0.4 | 1.4 ± 0.3 | 3.5 ± 0.5 | 0.8 ± 0.2 | 1.0 ± 0.3 |
| Blackburnian Warbler<br>*D. fusca* | 0.4 ± 0.2 | | | 0.9 ± 0.3 | 0.3 ± 0.2 | | 0.4 ± 0.2 |
| Yellow-throated Warbler<br>*D. dominica* | 0.1 ± 0.1 | 0.1 ± 0.1 | 0.9 ± 0.3 | | 0.2 ± 0.1 | | 0.8 ± 0.3 |

TABLE 1. Continued.

| Species<br>Scientific name | Control | Treatment (years after fires)<br>Low 1–2 | Low 3–6 | Medium 1–2 | Medium 3–6 | High 1–2 | High 3–6 |
|---|---|---|---|---|---|---|---|
| Pine Warbler<br>*D. pinus* | 0.2 ± 0.1 | | 0.2 ± 0.1 | | | 0.3 ± 0.1 | 0.2 ± 0.1 |
| Prairie Warbler<br>*D. discolor* | | | | | | 0.1 ± 0.1 | 1.0 ± 0.3 |
| Cerulean Warbler<br>*D. cerulea* | | | | | | | 0.2 ± 0.2 |
| Black-and-white Warbler<br>*Mniotilta varia* | 1.8 ± 0.3 | 0.6 ± 0.2 | 1.4 ± 0.3 | 1.5 ± 0.3 | 1.3 ± 0.3 | 1.0 ± 0.2 | 0.9 ± 0.3 |
| American Redstart<br>*Setophaga ruticilla* | 0.1 ± 0.1 | | | | 0.1 ± 0.1 | | 0.6 ± 0.2 |
| Worm-eating Warbler<br>*Helmitheros vermivorum* | 0.6 ± 0.2 | 0.3 ± 0.2 | 0.3 ± 0.2 | 0.1 ± 0.1 | 0.5 ± 0.2 | | 0.2 ± 0.2 |
| Ovenbird<br>*Seiurus aurocapilla* | 4.7 ± 0.5 | 1.1 ± 0.3 | 2.3 ± 0.5 | | 2.9 ± 0.4 | 1.2 ± 0.3 | 0.2 ± 0.2 |
| Kentucky Warbler<br>*Oporornis formosus* | 0.2 ± 0.1 | 0.1 ± 0.1 | 0.1 ± 0.1 | 0.1 ± 0.1 | 0.2 ± 0.1 | | 0.1 ± 0.1 |
| Common Yellowthroat<br>*Geothlypis trichas* | | | | | | | 0.1 ± 0.1 |
| Hooded Warbler<br>*Wilsonia citrina* | 0.9 ± 0.3 | 1.8 ± 0.3 | 2.5 ± 0.4 | 0.6 ± 0.2 | 1.3 ± 0.3 | | 1.4 ± 0.4 |
| Canada Warbler<br>*W. canadensis* | | | | 0.2 ± 0.1 | | | |
| Yellow-breasted Chat<br>*Icteria vireos* | 0.2 ± 0.2 | | | | 0.1 ± 0.1 | | 2.9 ± 0.5 |
| Eastern Towhee<br>*Pipilo erythrophthalmus* | 0.5 ± 0.2 | 0.4 ± 0.2 | 1.4 ± 0.4 | 0.8 ± 0.2 | 0.9 ± 0.3 | 4.2 ± 0.5 | 4.0 ± 0.5 |
| Chipping Sparrow<br>*Spizella passerina* | | | | | | 1.2 ± 0.4 | 0.2 ± 0.1 |
| Field Sparrow<br>*S. pusilla* | | | | | | | 0.1 ± 0.1 |
| Song Sparrow<br>*Melospiza melodia* | | | | | | | 0.1 ± 0.1 |
| Dark-eyed Junco<br>*Junco hyemalis* | | | 0.1 ± 0.1 | 0.2 ± 0.1 | | | |
| Scarlet Tanager<br>*Piranga olivacea* | 1.2 ± 0.3 | 1.4 ± 0.3 | 2.4 ± 0.5 | 1.9 ± 0.3 | 2.4 ± 0.4 | 2.6 ± 0.4 | 2.3 ± 0.4 |
| Northern Cardinal<br>*Cardinalis cardinalis* | 0.1 ± 0.1 | 0.3 ± 0.2 | 0.8 ± 0.2 | | 0.1 ± 0.1 | 0.1 ± 0.1 | 0.6 ± 0.2 |
| Rose-breasted Grosbeak<br>*Pheucticus ludovicianus* | 0.2 ± 0.1 | | | 0.4 ± 0.2 | 0.3 ± 0.2 | | 0.6 ± 0.2 |

TABLE 1. Continued.

| Species<br>Scientific name | Control | Treatment (years after fires) Low 1–2 | Low 3–6 | Medium 1–2 | Medium 3–6 | High 1–2 | High 3–6 |
|---|---|---|---|---|---|---|---|
| Blue Grosbeak<br>*Passerina caerulea* | | | | 0.4 ± 0.2 | | | |
| Indigo Bunting<br>*P. cyanea* | 1.0 ± 0.3 | 0.7 ± 0.3 | 2.5 ± 0.5 | 2.6 ± 0.4 | 2.1 ± 0.3 | 4.0 ± 0.4 | 5.3 ± 0.6 |
| American Goldfinch<br>*Spinus tristis* | | | | 0.1 ± 0.1 | 0.1 ± 0.1 | 1.0 ± 0.3 | 0.6 ± 0.3 |

after fires, relative to all other treatments, was significantly higher among the high severity burn units (Fig. 2). Generally, species diversity ($H'$) did not differ among treatments or relative to time since fire ($F_{6,9} = 2.4$, $P = 0.12$). However, species diversity was significantly greater in the high severity burn units 3–6 years after fires in contrast with the controls ($t = -3.0$, df $= 9$, $P = 0.1$) (Table 2). Species evenness did not differ among treatments ($F_{6,9} = 0.43$, $P = 0.84$) (Fig. 2).

Canonical correspondence analysis for bird species assemblages and habitat measured 1–2 years after fires indicated the overall relationship between species and environmental variables (all canonical axes) differed significantly from those derived randomly (Table 2). The primary axis (horizontal axis, Fig. 3) indicated strong positive relationships with BASAL AREA, SHRUB DENSITY, and CANOPY COVER, a moderate positive effect with SHRUB HEIGHT, and a moderate negative effect with HERBACEOUS COVER (Table 2). The secondary axis (vertical axis, Fig. 3), indicated a strong negative relationship with SHRUB HEIGHT and weaker relationships with SHRUB DENSITY, CANOPY COVER, and BASAL AREA. The habitat in high severity burn units 1–2 years after fires was best characterized by reduced CANOPY COVER and BASAL AREA (Fig. 3).

The avian community associated with high severity burn units 1–2 years after fires was largely represented by early successional species including American Goldfinch (scientific names are in Table 1), Eastern Towhee, Indigo Bunting, and Eastern Wood-Pewee. These species were along the negative side of the primary axis. Ovenbirds, a species most closely associated with habitat characterized by higher CANOPY COVER, BASAL AREA, and HERBACEOUS COVER tended to be in a positive position relative to both the primary and secondary axes. Treatment ellipses overlapped among other species indicating that habitat metrics and species pools were similar among treatments (Fig. 3).

Relationships between species and habitat 3–6 years after fires were significantly different for all variables except SHRUB HEIGHT (Table 2). This metric was omitted from further analysis. The primary axis of the CCA had a strong negative relationship with BASAL AREA and CANOPY COVER, and a strong positive relationship with SHRUB DENSITY. The secondary axis had a strong negative relationship with HERBACEOUS COVER. High severity burn units were best characterized by habitat with less CANOPY COVER, lower BASAL AREA, and higher SHRUB DENSITY. Several species along the primary axis were depicted farthest from the centroid and included Yellow-breasted Chat, Chestnut-sided Warbler, Indigo Bunting, and Eastern Towhee (Fig. 4). Species such as Hooded, Black-and-White, and Black-throated Green warblers were mapped highest on the vertical axis (Fig. 4).

## DISCUSSION

The effects of fire severity can vary between species and across avian communities. Our results indicated both species richness and diversity increased relative to fire severity and time since fire. Relative abundance did not change considerably among treatments or with time since fire (Table 1, Fig. 2); this may have been a bias from our conservative analysis of repeat observations. Species evenness also remained stable among treatments.

The species most negatively affected by fire was the Ovenbird, which is associated with closed

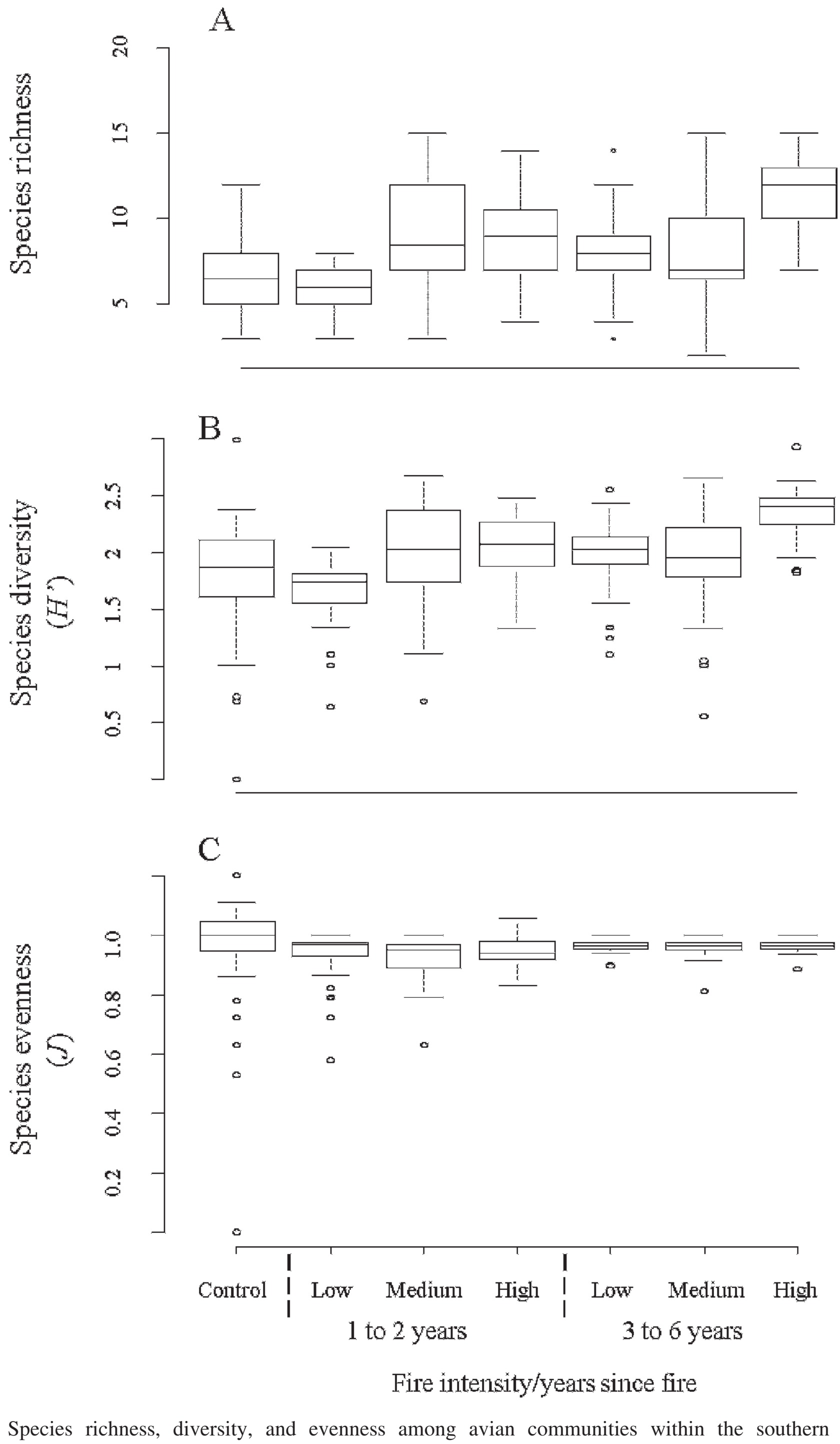


FIG. 2. Species richness, diversity, and evenness among avian communities within the southern Appalachian Mountains. Surveys were conducted at sites which received one of four levels of fire severity <2 years since fire or 3–6 years after fire.

TABLE 2. Values for the first two axes in canonical correspondence analysis (CCA) and correlations with environmental variables used to constrain the ordination. CCA was based on estimates of relative avian abundance and habitat measured at control (no fire) and varying levels of fire severity treatments within 2 years and 3 to 6 years after fires in the southern Appalachian Mountains.

| | 1–2 years post fire | | | | 3–6 years post fire | | | |
|---|---|---|---|---|---|---|---|---|
| Statistic | CCA Axis I | CCA Axis II | *r* | *P* | CCA Axis I | CCA Axis II | *r* | *P* |
| Eigenvalues | 0.34 | 0.28 | | | 0.33 | 0.16 | | |
| Cumulative variance | 0.18 | 0.33 | | | 0.23 | 0.33 | | |
| Intraset correlations | | | | | | | | |
| BASAL AREA | 0.95 | −0.30 | 0.23 | <0.001 | −1.00 | −0.013 | 0.16 | <0.001 |
| SHRUB HEIGHT | 0.59 | −0.80 | 0.19 | <0.001 | 0.23 | 0.97 | 0.00 | 0.94 |
| SHRUB DENSITY | 0.93 | −0.37 | 0.05 | 0.02 | 0.89 | −0.45 | 0.20 | <0.001 |
| HERBACEOUS COVER | −0.58 | 0.82 | 0.04 | 0.07 | 0.12 | −0.99 | 0.37 | 0.063 |
| CANOPY COVER | 0.96 | −0.28 | 0.25 | <0.001 | −0.99 | 0.11 | 0.04 | <0.001 |

canopy forests with limited understory (Neimi and Hanowski 1984, Smith and Shugart 1987). Availability of this habitat may be reduced for many years following a high severity fire, a relationship governed by increased growth of herbaceous cover and lack of canopy protection (Elliott et al. 1999, Greenberg et al. 2007). Conversely, our results indicated that many

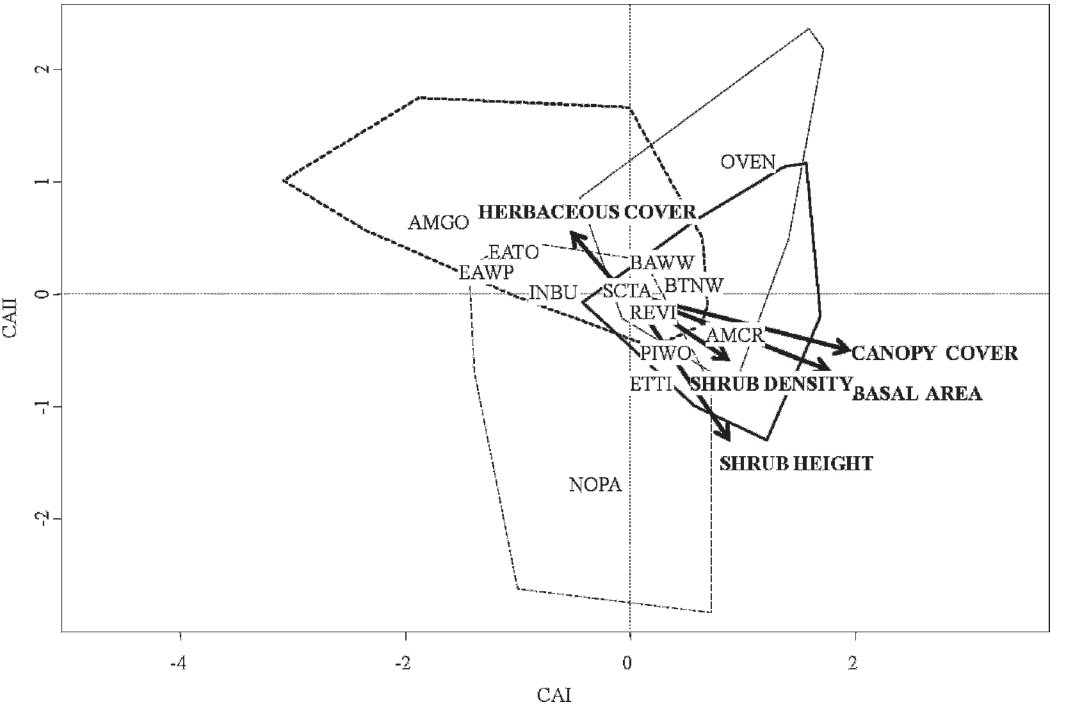


FIG. 3. Habitat associations relative to fire severity for species (AMGO = American Goldfinch, etc.) detected on point-count surveys 1–2 years after fires in northern Georgia. Solid line represents boundary of habitat centroids measured using linear combination scores derived for control units (no fire, thin solid line), low severity (thick solid line), medium severity (thin dashed line), and high severity burn units (thick dashed line). Boxed habitat metrics are mapped with arrows indicating relative locations within the community. The longer the distance between the metric and the community center (axis point 0, 0) the stronger the relationship with the community. Proximity of individual species to habitat metrics indicates strength of association between relative species abundance and habitat metric. Only those species detected on ≥20% of surveys are shown.

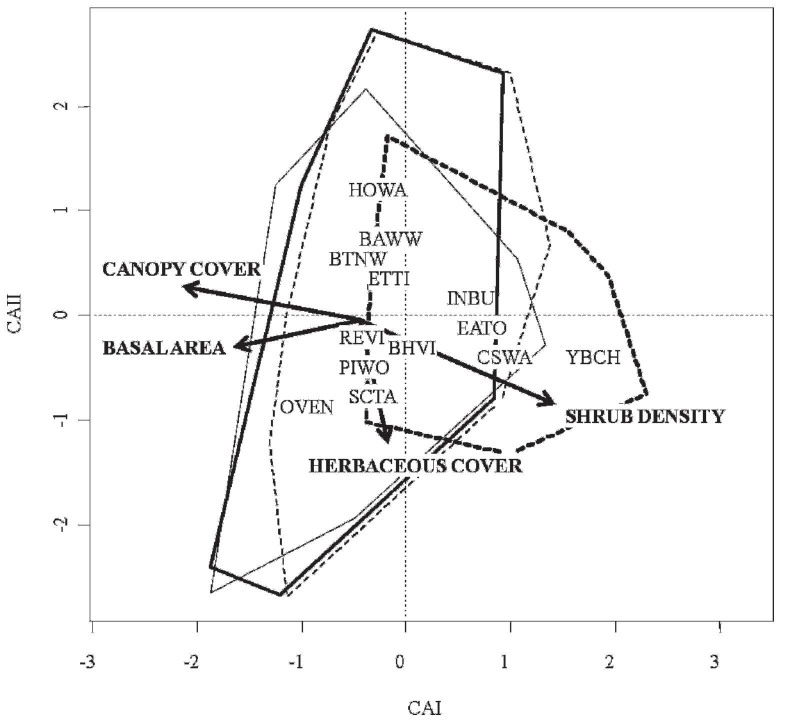


FIG. 4. Habitat associations relative to fire severity for species (BAWW = Black and White Warbler, etc.) detected on point-count surveys conducted 3–6 years after fires in northern Georgia. Community mapped using Canonical Correspondence Analysis (CCA) with habitat centroids based on linear combination scores derived from habitat measured at control units (thin solid line), low severity (thick solid line), medium severity (thin dashed line), and high severity (thick dashed line). Boxed habitat metrics are mapped with arrows indicating relative locations within the community. The longer the distance between the metric and the community center (axis point 0, 0) the stronger the relationship with the community. Proximity of individual species to habitat metrics indicates strength of association between relative abundance and habitat metric. Only those species detected on ≥20% of surveys are shown.

species associated with disturbance and early successional habitat responded positively to fire severity.

Species that responded positively to increased fire severity included American Goldfinch, Chestnut-sided Warbler, Eastern Towhee, Indigo Bunting, Prairie Warbler, and Yellow-breasted Chat. Most of these species had higher abundance 3–6 years after fires, tracking decreased canopy cover and released growth of shrubs relating to increased shrub density. Also included among these species were Golden-winged and Cerulean warblers, species that are both endangered in Georgia. Both species were encountered once and were found exclusively in either medium (Golden-winged Warbler) or high severity (Cerulean Warbler) treatments (Table 1).

The physiognomic properties of habitats continued 3–6 years after high severity fires. Continued canopy openness related positively with abundance of several woodpecker species; Hairy Woodpeckers and Northern Flickers had highest abundance in high severity treatments. Species characteristic of forests with more-open canopy, such as Yellow-billed Cuckoo, Eastern Wood-Pewee, and Blue-gray Gnatcatchers increased relative to fire severity, responses that may relate to suppressed understory, more-open conditions, higher insect abundance, and improved foraging habitat (Greenberg et al. 2007).

Mid-story nesting species are thought to be relatively flexible in habitat selection and may not respond to fire-driven habitat change (Artman et al. 2005). Our results indicated density of several of these mid-story nesting species including Wood Thrush, Blue-headed Vireo, and Red-eyed Vireo did not differ relative to either fire severity or time since fire. However, American Redstart, a species that forages and nests in shrubs and vines, appeared to be absent from treatment burn units during the first 2 years after fires. This association may reflect the temporary reduction of vertical structure during the first few years after a fire (Waldrop et al. 2007).

Uneven-age forests may represent natural historical conditions within the southern Appalachian Mountains (Lorimer 1980). Our results indicated that returning a fire regime to these forests may be an effective conservation tool for restoring avian diversity (Artman et al. 2005, Greenberg et al. 2007). However, effectiveness of fire restoration can vary (Artman et al. 2005). Continued fire suppression, or frequent application of low severity fires, may lead to forest maturation, have limited effects on species diversity, and can lead to declines in some species (Artman et al. 2005, Klaus et al. 2005). Application of high severity fires corresponding with short rotation periods may not allow habitat regeneration and can lead to decreased diversity. Application of higher severity fires over broader time intervals may be more effective in managing uneven-age forests.

Changes in relative abundance of a particular species may not equate directly with habitat quality or persistence (Johnson 2007). We did not examine the effects of treatment on reproductive success, survival, or other demographic measures and cannot provide predictions relating treatments to these population metrics. Our results reflect acute numerical relationships among individual species and across avian communities. Longer-term studies focused on addressing variation in population demographics through several seasons after different fire severity treatments would greatly benefit our understanding of avian communities.

## CONSERVATION IMPLICATIONS

Management directed at conservation of avian species should balance restoration of early successional habitat with conservation of mature forest (Dettmers 2003, Artman et al. 2005, Bulluck and Buehler 2006, Buehler et al. 2007). Our results, and those of others (Artman et al. 2005, Greenberg et al. 2007), indicate conservation activities that foster avian diversity within the southern Appalachian Mountains may benefit from occasional high severity fires and a fire return interval of $3 \leq 10$ years. We are not suggesting all burns should be of high severity, only that the full range of fire severity be used through time and space.

Fire may be most beneficial to avian conservation when it is used over relatively large spatial scales (Artman et al. 2005, Greenberg et al. 2007). Managed fires will help develop a matrix of habitats and successional stages, and minimize the isolation of populations (Askins 2001, Brawn et al. 2001). A rationale against prescription of smaller-scale fires is that larger fires may be more easily controlled in habitat characterized by terrain similar to that in the Chattahoochee-Oconee National Forest. Larger burn units can make use of creeks and roads for fire breaks helping avoid undue disturbance such as plowing, which may be a vector for invasion of exotic species (Merriam et al. 2006). Our study did not examine the cumulative impacts of repeated low intensity burns, or combinations of burn intensities. However, our results suggest that medium and high intensity fires can have positive effects on bird communities and should be considered a valuable land management tool.

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