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Abstract.—Due to fire suppression and land use changes, Missouri glade habitats have undergone long-term declines in area and function leading to consequent declines in many bird species that rely on these habitats. We examined breeding bird species composition and vegetation community composition on three glade sites undergoing restoration with prescribed fire and compared them to three unburned glade sites and three unburned forest sites. Although we documented subtle changes in vegetation characteristics in response to prescribed fire, important structural characteristics, such as canopy cover (>55% at all study sites) and grass cover (<10% at all study sites) remain outside ranges used to characterize glades. Despite this, bird community structure shifted towards grass-shrubland (glade) birds (*e.g.*, prairie warbler (*Dendroica discolor*), blue-winged warbler (*Vermivora pinus*), yellow-breasted chat (*Icteria virens*)) in glades that had been managed with prescribed fire. Using canonical correspondence analyses and stepwise forward logistic regression, we found that grass-shrubland (glade) birds were associated with habitat characteristics such as high stem density of small (0–6.3 cm diameter at breast height) trees, greater herbaceous cover, greater rock cover and a more open canopy. However, we did not detect any bird species historically associated with glades, such as Bachman's sparrow (*Aimophila aestivalis*) or field sparrow (*Spizella pusilla*) on any study sites but did frequently detect red-eyed vireos (*Vireo olivaceous*) on all sites. Short term application of prescribed fire has not yet produced functionally restored glades. Long term applications of prescribed fire, used in conjunction with mechanical and/or chemical removal of woody overstory, are necessary to achieve restoration at these sites.

Introduction

Midwestern Ozark glades are generally treeless, fire maintained, perennial-C_4 grass dominated openings, often within woodland matrices, in hilly or mountainous areas of the southern Midwestern United States (especially in Missouri and Arkansas) (Ware, 2002). Glade plant community structure and composition was historically maintained by both periodic fires and their physical occurrence on sloping, shallow soils with rocky outcrops that are susceptible to erosion and weathering (Erickson *et al.*, 1942; Kucera and Martin, 1957; Guyette and McGinnis, 1982; Nelson and Ladd, 1983; Baskin and Baskin, 2000; Ware, 2002; Mier, 2004). Frequently experiencing xeric conditions during the growing season (Ware, 2002), understory vegetation is typified by prairie grasses such as little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardii*) and Indiangrass (*Sorghastrum nutans*), but oaks (*Quercus* spp.) and shortleaf pines (*Pinus echinata*) may occur in characteristically sparse (<30%) overstory, while eastern red cedars (*Juniperus virginianus*)

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typically occur on the periphery of Ozark glades (Nelson and Ladd, 1982; Cole, 1986; Baskin and Baskin, 2000).

Most glades are considered fragmented and commonly persist within a larger structural mosaic of interspersed woodlands, referred to as ''glade-woodland complexes.'' Although Ozark glades were not historically large (<200 ha; average 1–3 ha; Ware, 2002), fire exclusion and suppression furthered physical and functional fragmentation of extant glades, via encroachment and eventual replacement of glade-prairie plant communities by fire-intolerant woody species (Kucera and Martin, 1957; Ware, 2002). Estimates vary, but the areal extent of Ozark glades has declined nearly 60% (Ladd and Nelson, 1982), the result of a greater than five-fold increase in fire return intervals since 1870, from one every 4 y (Guyette and McGinnis, 1982; Guyette and Cutter, 1991; Templeton *et al.*, 2001) to one every 22 (Guyette and McGinnis, 1982) or 24 y (Cutter and Guyette, 1994).

The Missouri Ozarks occur within the Central Hardwood Bird Conservation Region (CHBCR) (Fitzgerald *et al.*, 2003), where aforementioned elongation of fire return intervals, fragmentation and subsequent woody plant invasion have contributed to substantial regional declines of grass-shrubland avifauna (Fitzgerald *et al.*, 2003; Sauer *et al.*, 2005; Fink *et al.*, 2006). Focal grass-shrubland species historically associated with glades, such as Bachman's sparrow (*Aimophila aestivalis*), prairie warbler (*Dendroica discolor*) and field sparrow (*Spizella pusilla*) (*see* Probasco, 1978; Hardin *et al.*, 1982; Thompson and DeGraaf, 2001), are Tier I species of conservation priority in the CHBCR (Fitzgerald *et al.*, 2003). Other early successional forested (including glade) habitat associated species, such as blue-winged warbler (*Vermivora pinus*), cerulean warbler (*D. cerulea*), Kentucky warbler (*Oporornis formosus*), white-eyed vireo (*Vireo griseus*) and yellow-breasted chat (*Icteria virens*) are also Tier I species within the CHBCR (Fitzgerald *et al.*, 2003). As such, restoration of these glade-early successional woodland complexes and their associated avifauna is a regional priority (Fitzgerald *et al.*, 2003; Rich *et al.*, 2004).

Reintroduction of fire, deployed at historic return intervals, is assumed to eventually achieve recovery of historical (primarily non-woody) vegetative (*see* Blake and Scheutte, 2000; Duncan *et al.*, 2008) and avian community structure in glades (*see* Davis *et al.*, 2000). To prevent further deterioration and initiate restoration of extant and historic Ozark glades, the Missouri Department of Conservation and the U.S. Forest Service reintroduced fire at several historic glade sites in the Mark Twain National Forest (MTNF) in southeastern Missouri from 1992 through 2004 via human-ignited prescribed burns. Of approximately 200,000 ha of glade habitats occurring in Missouri, >28,000 ha exist in the MTNF (Kimmel and Probasco, 1980; Nelson, 1985). Although few studies have focused upon bird and vegetative community response(s) to regional restoration attempts (*see* Davis *et al.*, 2000; Blake, 2005; Au *et al.*, 2008), such approaches are critical to assessing restoration and conservation success and for refining restoration strategies (Blake, 2005). Therefore, the objectives of this research were to evaluate the impacts of prescribed fire on vegetative and breeding bird species composition among burned and unburned glades and nearby unburned forest sites in the MTNF. We hypothesized that vegetative structure and bird composition would be similar among unburned glade/forest sites. Conversely, we hypothesized that burned glade sites would more closely resemble desired conditions than either unburned glades or forested sites, as indicated by bird species composition and relationships to assumed relevant vegetative features. We assumed that presence of aforementioned focal grass-shrubland birds in burned glades indicated some relative level of restoration success.

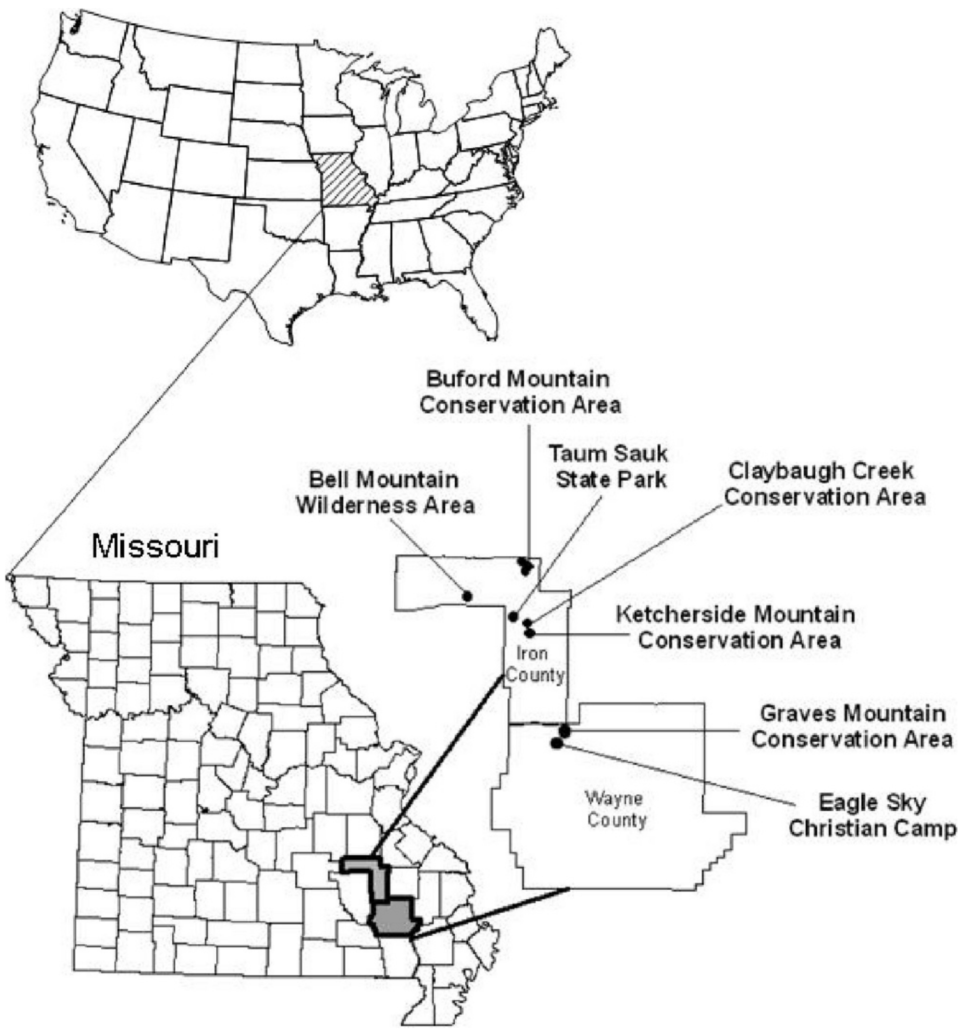

FIG. 1.—Locations of study sites used to quantify breeding bird and vegetative community composition in southeastern Missouri, May–Jul. 2005 and 2006

METHODS

This research was conducted in the western portion of the CHBCR, in southeastern Missouri. Specifically, nine study sites were located in Iron and Wayne counties (Fig. 1) within the MTNF. Study sites were classified using a combination of ecological land types (ELT; Nigh and Schroeder, 2002) and fire history. Three sites were glade-woodland complexes (Taum Sauk State Park, Ketcherside Mountain Conservation Area and Graves Mountain Conservation Area; Fig. 1) defined using ELT ($<$30% canopy cover; Nigh and Schroeder, 2002) subjected to prescribed fire between 1992 and 2004 (hereafter referred to as burned glades; Table 1). Another three sites were also historically glade-woodland complexes (Buford Mountain Conservation Area, Bell Mountain Wilderness Area and Eagle

TABLE 1.—Community type, name, size, location and burn history (1994–2002) for nine study sites used for breeding bird and vegetation assessment in southeastern Missouri, May–Jul. 2005 and 2006

Name	Size (ha)	County	Burn history
Burned glade sites			
Taum Sauk State Park	37.5	Iron	Winter 1992, Spring 1994, Spring 2001
Ketcherside Mtn. Conservation Area	25	Iron	Spring 1995, Spring 2001
Graves Mtn. Conservation Area	25	Wayne	Spring 1997, Spring 2000, Spring 2002
Unburned glade sites			
Buford Mtn. Conservation Area (1)	25	Iron	None
Bell's Mountain Wilderness Area	25	Iron	None
Eagle Sky Christian Camp	37.5	Wayne	None
Forest sites			
Claybaugh Crk. Conservation Area	37.5	Iron	None
Buford Mtn. Conservation Area (2)	25	Iron	None
Buford Mtn. Conservation Area (3)	37.5	Iron	None

Sky Christian Camp; Fig. 1), defined using ELT (<30% canopy cover; Nigh and Schroeder, 2002) but had not been burned in 75 y (hereafter referred to as unburned glades; Table 1). The remaining three sites were forest sites (Claybaugh Creek Conservation Area, Buford Mountain Conservation Area; Fig. 1) with no record of ever being glades defined using ELT (>80% canopy cover; Nigh and Schroeder, 2002) and had not been burned in >75 y (Table 1). No timber harvest had occurred on any sites within 75 y.

AVIAN COMMUNITY ASSESSMENT

At each study site, we systematically established 10 point count stations on a grid pattern approximately 250 m apart (Dawson *et al.*, 1995; Ralph *et al.*, 1995). All stations were visited three times per year during the breeding season from 15 May–4 Jul. 2005 and 2006. At each station, we recorded all birds observed visually or audibly within a 50-m radius during a 10 min period. To reduce bias, all point counts were conducted between 0600 and 0930 CST, by the same observer (A. Bell) and only during weather conditions favorable for bird activity (*i.e.*, low winds, no precipitation; Ralph *et al.*, 1995).

VEGETATION MEASUREMENTS

We measured vegetative species and structural composition in 2005 and 2006, following a modified B-BIRD Field Protocol (Martin *et al.*, 1997) similar to Shugart and James (1973). We established a vegetation measurement plot at each point count station (10 plots per study site) and an associated plot, located 35 m in a random direction (10 plots per study site). At each plot, we established three nested subplots: a 1 m^2 ground cover subplot, a 5 m radius understory subplot and an 11.3 m radius overstory subplot. We used the Daubenmire canopy-coverage technique to quantify percent cover of all plant species in the 1 m^2 subplots (Daubenmire, 1959). Plant species were grouped into functional group (*i.e.*, grass, forb and woody) categories for analyses (sensu Fuhlendorf *et al.*, 2006). Within the 5 m radius subplot, we counted all woody stems <20.3 cm diameter at breast height (DBH) by species and assigned them to categories by DBH: small (<6.3 cm) and medium (6.4–20.2 cm). We also estimated ground cover (%) in the following categories: rock, vegetation, bare ground, leaf litter (leaf litter and bare ground in 2006 only). We recorded litter depth on the perimeter of the subplot at each cardinal direction and measured slope (%) using a clinometer. On the 11.3 m radius overstory plot, we recorded species and DBH for all woody stems (live or dead) >20.3 cm DBH. We also recorded canopy cover with a spherical densiometer at the four cardinal directions along the perimeter of the subplot. Mean canopy height was estimated by averaging the heights of the three tallest trees within the plot.

DATA ANALYSIS

We assessed differences in avian species composition among community types using a variety of statistical and graphical techniques. We calculated overall breeding bird species diversity (Simpson's index) and richness for each study site and community type. We used analysis of variance (ANOVA) to examine differences in bird species diversity among community types (*i.e.*, burned glade, unburned glade and forest). Chi-square goodness-of-fit tests were used to examine differences in bird species richness among community types. Vegetative data collected as class values (*e.g.,* all coverage data from 1 m^2 subplots) were converted to class midpoints and arcsine transformed prior to analysis (Jenkins and Jenkins, 2006). We used ANOVA to examine differences in vegetation characteristics among community types, with both years (*i.e.*, 2005 and 2006) combined. Student-Newman-Keuls tests (SNK) were used if differences ($P < 0.05$) occurred in ANOVAs (SAS Institute, Cary, NC, 2003).

Further bird analyses focused upon a subset of commonly detected species with highest conservation status according to Partners in Flight in the CHBCR (Rich *et al.*, 2004; Table 2). Subsequent analyses examining bird-habitat relationships were constrained to this subset of focal bird species (Table 2). To quantify the direction and magnitude of relationships among structural (vegetative) characteristics and bird community composition, among study sites, we performed canonical correspondence analyses (CCA) using PC-ORD (McCune and Mefford, 1999). We used this approach to allow interpretation of potentially relevant combinations of characteristics in a multidimensional setting. We calculated occurrence (%) of each focal species within each study site (10 point count locations/study site) and used this as the primary data matrix. Vegetative characteristics [*e.g.,* herbaceous, woody, grass, rock and litter percent cover, height, canopy cover, litter depth and stem density of small (<6.3 cm), medium (6.4–20.2 cm) and large (>20.3) trees] within each study site formed the secondary data matrix. Because the habitat data were collected at different scales and used different area-units, we performed two CCA analyses. The first included the stem density data only (for three size classes), as these data were collected on the 5 m subplot and extrapolated to stems/ha. The second CCA included the remaining habitat variables expressed on a plot basis. We felt this was a conservative approach that allowed the identification of more potentially significant variables while preserving the integrity of the data structure. We used the default (rescaled axis) function to maintain correspondence among the first two axes, and restricted our interpretation of CCA axis structure and corresponding eigenvalues to only these axes (McCune and Meffort, 1999).

To explore and clarify the relationship(s) among bird species occurrence and vegetative community structure, we followed CCA with stepwise logistic regression analyses. These analyses were performed to (a) identify the functional relationship(s) among avian species presence/absence and vegetative characteristics at specific point count locations (Hinsley *et al.*, 1995; Manel *et al.*, 1999) and (b) develop predictive models of bird species presence based upon measured vegetation characteristics (Hinsley *et al.*, 1995; Villard *et al.*, 1999). We

TABLE 2.—Common and scientific names, American Ornithologist's Union species code, and conservation status for bird species of concern in the Central Hardwoods Bird Conservation Region (Rich *et al.*, 2004) detected in glade and forested sites in southeastern Missouri, May–Jul. 2005 and 2006

Common name	Scientific name	Code	Status
Yellow-billed cuckoo	*Coccyzus americanus*	YBCU	RMA[1]
Eastern towhee	*Pipilo erythrophthalmus*	EATO	RMA
Carolina chickadee	*Poecile carolinensis*	CACH	RS[2]
Cerulean warbler	*Dendroica cerulea*	CEWA	CIMA[3]
Prairie warbler	*Dendroica discolor*	PRAW	CMA[4]
Worm-eating warbler	*Helmitheros vermivorum*	WEWA	CMA
Yellow-breasted chat	*Icteria virens*	YBCH	RMA
Black-and-white warbler	*Mniotilta varia*	BAWW	
Kentucky warbler	*Oporornis formosus*	KEWA	CMA
Ovenbird	*Seiurus aurocapilla*	OVEN	
Blue-winged warbler	*Vermivora pinus*	BWWA	CMA
Hooded warbler	*Wilsonia citrina*	HOWA	
White-breasted nuthatch	*Sitta carolinensis*	WBNU	
Blue-gray gnatcatcher	*Polioptila caerulea*	BGGN	RMA
Summer tanager	*Piranga rubra*	SUTA	RS
Wood thrush	*Hylocichla mustelina*	WOTH	CMA
Eastern wood-peewee	*Contopus virens*	EWPE	RMA
Acadian flycatcher	*Empidonax virescens*	ACFL	RS and CS[5]
White-eyed vireo	*Vireo griseus*	WEVI	RMA

[1] Management attention regionally
[2] Regional stewardship
[3] Immediate management attention at the continental scale
[4] Management attention at the continental scale
[5] Continental stewardship

defined presence at a point as at least one observation (in any of six visits over the duration of the study) of the species at a given point. Independent variables were community type, density of small, medium and large woody stems, percent cover of rock, plant, bare ground and litter, average height, canopy cover and mean litter depth. A Chi-Square Likelihood Ratio was used for each species' model P-value, where variables were included in a model if they explained a significant ($\alpha = 0.1$) portion of the overall variance.

RESULTS

We detected 39 bird species over both breeding seasons in this study, including 19 focal species of concern in Missouri (Table 3). The same species were detected in 2005 and 2006, where species richness was similar among community types (burned glade richness = 34 both years; unburned glade richness = 28 (2005) and 32 (2006); forest richness = 24 (2005) and 28 (2006)) in both 2005 ($\chi^2 = 1.19$, P = 0.550, df = 2) and 2006 ($\chi^2 = 0.59$, P = 0.740, df = 2). Simpson's diversity indices were also similar among community types (range: 0.85–0.88) and did not vary among community types in either 2005 (F = 1.92, P = 0.168, df = 2) or 2006 (F = 0.07, P = 0.94, df = 2). Several focal species were only, or predominantly, detected in burned glade sites (Table 3). Sparrows typically associated with glades (*i.e.*, Bachman's and field sparrow) were not detected on any sites; however, prairie warblers and yellow-breasted chats were detected only in burned glade sites. Indigo buntings (*Passerina*

TABLE 3.—Numbers (*n*) of individuals detected using fixed radius point counts for bird species of concern in the Central Hardwoods Bird Conservation Region (Rich *et al.*, 2004) in glade and forested sites in southeastern Missouri, May–Jul., 2005–2006

	Burned glade		Unburned glade		Forest	
Species	2005	2006	2005	2006	2005	2006
Yellow-billed cuckoo	4	5	8	4	13	11
Eastern towhee	25	27	0	0	1	0
Carolina chickadee	7	6	4	9	5	8
Cerulean warbler	6	5	0	0	0	0
Prairie warbler	13	18	0	0	0	0
Worm-eating warbler	2	0	5	4	10	12
Yellow-breasted chat	39	35	0	0	0	0
Black-and-white warbler	14	4	14	17	10	6
Kentucky warbler	24	14	1	1	0	0
Ovenbird	7	3	15	12	37	25
Blue-winged warbler	14	9	0	0	0	0
Hooded warbler	8	6	0	0	0	0
White-breasted nuthatch	11	18	7	19	16	10
Blue-gray gnatcatcher	19	9	26	9	30	19
Summer tanager	39	35	31	29	45	29
Wood thrush	1	4	0	2	0	3
Eastern wood-peewee	44	25	26	29	38	30
Acadian flycatcher	27	11	6	11	31	30
White-eyed vireo	22	37	0	1	0	0

cyanea), an early successional species often associated with prairie warblers and yellow-breasted chats, have no heightened conservation status within the CHBCR but were commonly encountered in both burned and unburned glade habitats. Finally, red-eyed vireo (*Vireo olivaceus*), not considered a glade-woodland complex species, was frequently detected in all community type and year combinations.

Vegetative characteristics generally varied ($P < 0.05$) among community types, although large structural elements, such as woody stem densities, were similar ($P > 0.05$) (Table 4). Burned glades tended to have more small stems, and fewer medium and large woody stems than either the unburned or forest types (Table 4). Burned and unburned glades tended to group together, as both had similar amount of rock, herbaceous and canopy cover, while forest sites had the greatest litter and canopy cover (Table 4).

The first two axes of the initial CCA accounted for 56.5% of the variance in the bird data, where axis 1 and 2 had eigenvalues of 0.471 and 0.046 respectively (Fig. 2). Canonical coefficients between CCA Axis 1 and stem densities were driven by strong negative ($r > -0.70$) correlations with densities of small (0–6.3 cm) woody stems (Fig. 2). Several glade-early successional focal species [yellow-breasted chat, prairie warbler, eastern towhee (*Pipilo erythrophthalmus*), white-eyed vireo, Kentucky warbler] were associated with sites (*e.g.,* Ketcherside Mountain Conservation Area) containing the greatest small stem densities (Fig. 2). Some focal forest species such as ovenbirds (*Seiurus aurocapilla*) were associated with sites (*e.g.,* Claybaugh Creek Conservation Area) with high densities of large (>20 cm) trees, and other forest species [*e.g.,* wood thrush (*Hylocichla mustelina*), Acadian flycatcher (*Empidonax virescens*)] were associated with sites (Buford Mountain Conservation Area) containing increasing densities of medium (6.3–20 cm) trees (Fig. 2). The first two axes of

TABLE 4.—Means ($\bar{x}$), Standard Errors (SE), and F and P values resulting from analysis of variance for vegetative structural characteristics among three community types in southeastern Missouri, May–Jul. 2005 and 2006

	Burned glade		Unburned glade		Forest			
Vegetative character	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	F	P
Forbs (%)[1]	10 a[3]	10	9 a	16	7 a	8	0.92	0.402
Grass (%)[1]	5 a	7	3 a	3	3 a	2	1.42	0.248
Woody (%)[1]	22 a	15	19 a	18	13 a	9	2.61	0.079
Bare ground (%)[1,2]	2 a	1	3 a	1	2 a	1	0.32	0.725
Litter (%)[1,2]	39 b	4	39 b	4	65 a	3	19.32	<0.001
Vegetation (%)	40 a	3	37 a	3	28 b	2	4.70	0.010
Rock (%)	16 a	2	19 a	2	7 b	1	8.82	<0.001
Litter depth (cm)	3 b	<1	5 a	<1	4 a	<1	6.16	0.003
Small stems ha^{-1}	2345 a	380	2041 a	181	2270 a	176	0.36	0.698
Medium stems ha^{-1}	1231 a	148	1396 a	143	1479 a	115	0.85	0.428
Large stems ha^{-1}	154 a	12	180 a	15	190 a	11	2.15	0.120
Canopy (%)	77 b	3	77 b	2	85 a	1	6.04	0.003
Height (m)	12 a	1	11 a	1	9 b	1	4.76	0.009

[1] Percent cover as measured in 1 m^2 plots. Other estimates are from 5 m and 11.3 m radius plots. All data for each community type within each year were measured in 20 plots per individual study site (60 plots/community type/y)
[2] Percent cover for bare ground and litter were measured in 2006 only
[3] Means followed by the same letter within a row are not different ($P > 0.05$)

the second CCA accounted for 52.4% of the variance in the bird data, where axis 1 and 2 had eigenvalues of 0.405 and 0.074 respectively (Fig. 3). Canonical coefficients between CCA Axis 1 and habitat features in this CCA were driven by strong positive ($r > 0.70$) correlations with canopy cover, and negative ($r > -0.20$) correlations with herbaceous cover and canopy height (Fig. 3). Forest focal species such as wood thrush, ovenbirds and Acadian flycatchers were associated with sites (*e.g.,* Claybaugh Conservation Area and Buford Conservation Area) with taller and more closed forest canopy (Fig. 3). Conversely, the glade-early successional focal species (yellow-breasted chat, prairie warbler, cerulean warbler, eastern towhee, white-eyed vireo, Kentucky warbler) were associated with sites (*e.g.,* Ketcherside Mountain Conservation Area) containing more coverage of herbaceous plants and short canopy heights (Fig. 3).

Logistic regression models generally supported the CCA results for eight of 19 focal species (Table 5). The habitat variables we measured did not explain variation ($P > 0.1$) in presence of the remaining 11 species. Logistic regression models for glade-early successional focal species (yellow breasted chat, white-eyed vireo, Kentucky warbler, Eastern towhee and blue-winged warbler) all shared a positive relationship with small (0–6.3 cm) stem densities (Table 5). Yellow-breasted chat presence was best described by this single variable and other models for these species included percent plant cover, density of medium stems and canopy characteristics. Variation in prairie warbler presence was not related to small stem densities; rather, its presence was most influenced by a negative relationship with canopy cover (Table 5). Conversely, ovenbirds and worm-eating warblers were negatively associated with small stem densities, although regression models predicting presence of these two forest birds performed poorly, as neither model explained >29% of the total variation (Table 5).

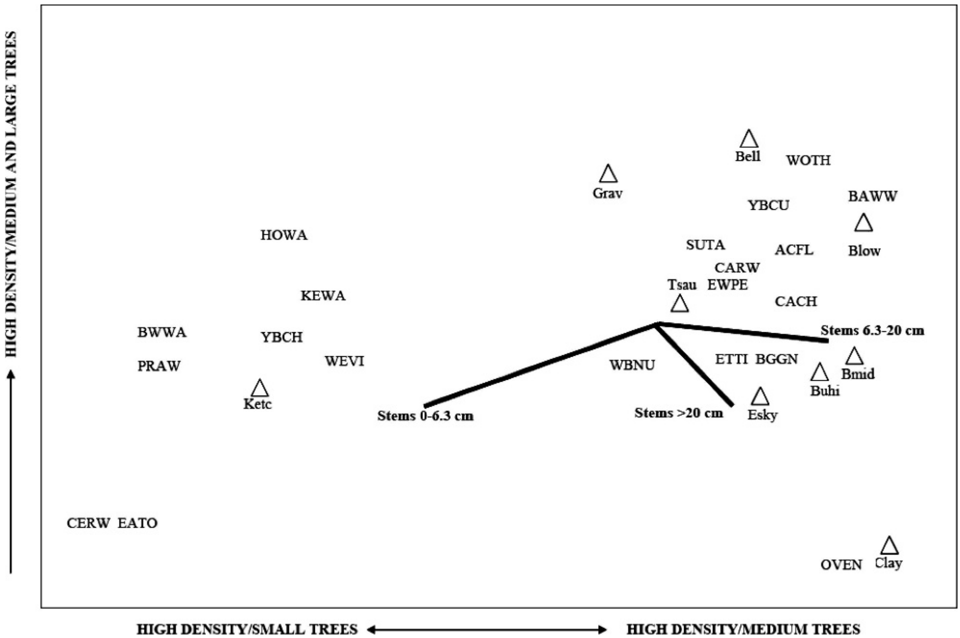

FIG. 2.—Plots of the first two axes of the Canonical Correspondence Analysis (CCA) for focal bird species of concern and vegetative structural characteristics (small (0–6.3 cm), medium (6.4–20.3 cm) and large (>20.3 cm) woody stem densities) in (un)burned glade and forest sites in southeastern Missouri, May–Jul., 2005–2006

Although rock cover is an important characteristic of many glade habitats, it provided partial explanatory power for presence of only one species (blue-winged warbler) (Table 5).

DISCUSSION

Comparison of avian community and vegetation data among (un)burned glades and forest sites suggests that glade communities have been neither completely restored nor created by simply reintroducing fire. However, we observed measureable differences that were indicative of potentially successful glade restoration. The primary goals of prescribed fire in these habitats are to reduce canopy cover and woody stem density and increase grass and herbaceous cover, leading to an open, savannah-like community with widely dispersed woody cover (Nelson and Ladd, 1982; Baskin and Baskin, 2000). Although prescribed fire has not completely created these conditions, and habitat data were mixed relative to these goals, we observed greater numbers of bird species typical of early-successional glade complexes in the burned glades than in other community types.

Although differences in vegetation structure were fairly subtle, they were generally consistent with the goals of glade restoration (*e.g.,* lower woody stem density, increased herbaceous cover). We did not observe the dramatic changes in small stem density or cover of prairie grasses that were observed in other studies of prescribed fire in glade habitats (Jenkins and Jenkins, 2006). All community types had canopy coverage (>75%) and woody stem densities that were inconsistent with glade characteristics (*see* Table 4). The burned

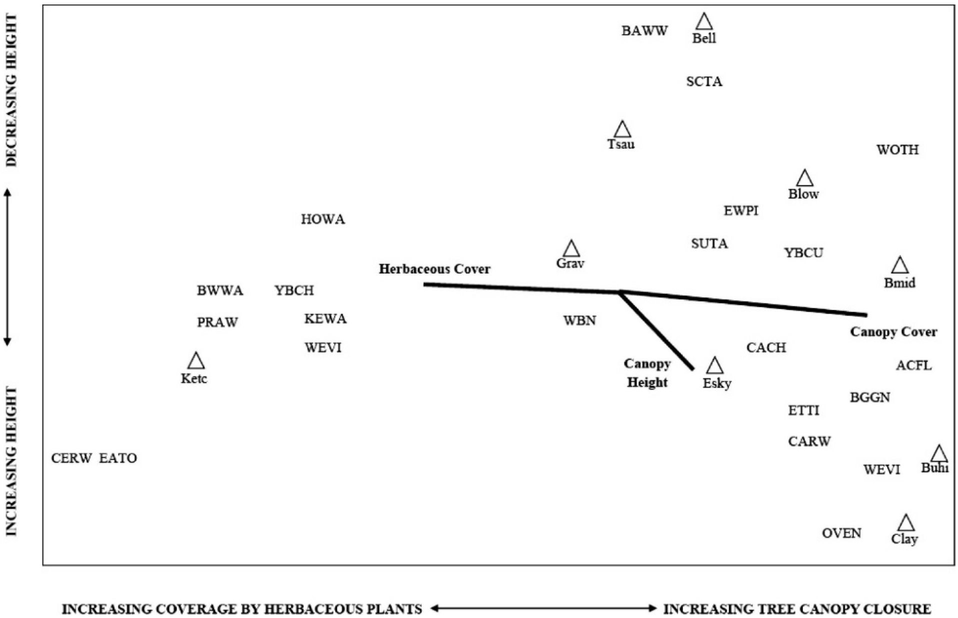

FIG. 3.—Plots of the first two axes of the Canonical Correspondence Analysis (DCA) for focal bird species of concern and vegetative structural characteristics (herbaceous cover (%), canopy height and cover) in (un)burned glade and forest sites in southeastern Missouri, May–Jul., 2005–2006

glade sites in this study were subjected to winter or spring (*i.e.*, non-growing season) prescribed fires; thus, tree mortality on most sites was minimal and canopy cover was largely unaffected. The exception to this was the Ketcherside Mountain site, where the 2001 burn was fairly intense and produced extensive tree mortality. However, even this site maintained

TABLE 5.—Logistic regression equations, parameter estimates and maximum rescaled R^2 estimates for presence of nine focal species of conservation concern in the Central Hardwoods Bird Conservation Region (Rich *et al.*, 2004) detected at (un)burned glade and forest sites in southeastern Missouri, May–Jul., 2005–2006

Species	Equation	R^2
Blue-winged warbler	= −2.17 + 3.91 (0–6.3 cm stems) + 0.002 (percent rock) − 0.02 (percent plant cover)	0.594
Eastern towhee	= 2.06 + 2.31 (0–6.3 cm stems) − 0.001 (6.4–20.2 cm stems)	0.636
Hooded warbler	= −27.23 + 0.08 (height)	0.811
Kentucky warbler	= −16.11 + 8.14 (0–6.3 cm stems) − 0.001 (6.4–20.2 cm stems) + 0.34 (height)	0.812
Ovenbird	= 1.14 − 1.12 (0–6.3 cm stems)	0.288
Prairie warbler	= −8.26 − 0.11 (canopy cover)	0.836
White-eyed vireo	= −3.08 + 7.59 (0–6.3 cm stems) − 0.002 (6.4–20.2 cm stems) − 0.07 (canopy cover)	0.788
Worm-eating warbler	= 2.03 − 0.87 (0–6.3 cm stems) + 0.05 (height)	0.194
Yellow-breasted chat	= −1.68 + 4.32 (0–6.3 cm stems)	0.682

mean canopy coverage of 60%, or considerably greater than the 30% canopy cover in typical glade habitat (Nelson and Ladd, 1982).

With the lack of pre-burn vegetation data, it is difficult to determine directly which differences were the results of prescribed fire activity. Some variables, such as percent rock and density of large stems, probably reflected the soils and other characteristics of historic glades rather than the influence of fire *per se*. These variables were similar between burned and unburned glades. Other variables, such as herbaceous cover and litter characteristics most likely reflect the influence of fire, as indicated by differences between the burned glades and all other sites. Although we did not observe any plant species endemic only to glade habitats, several prairie grasses were either more abundant in burned glades (*Schizachyrium scoparium*) or restricted only to burned glade sites (*Panicum virgatum, Sorghastrum nutans*).

Even these relatively minor differences in vegetation community composition were associated with substantial differences in the breeding birds using the sites. These differences were most pronounced for the Ketcherside Mountain site (*see* Figs. 2, 3), but occurred on the other burned sites as well. We did not observe grass-shrubland species historically associated with glades, such as field sparrow or Bachman's sparrow (Probasco, 1978; Hardin *et al.*, 1982) on any of the sites. However, seven species associated with shrublands and glades were observed either exclusively on burned glade sites (blue-winged warbler, hooded warbler, prairie warbler, yellow-breasted chat) or much more frequently on these sites (eastern towhee, Kentucky warbler, white-eyed vireo) (*see* Table 3). In particular, prairie warblers and blue-winged warblers are normally associated with early successional-woodlands and glade habitats (Fink *et al.*, 2006) and were only found on the burned glades.

Although burned glades contained bird species typical of both glade and oak savannah habitats (Callahan, 1996; Fink *et al.*, 2006), it is clear that glade-woodland complexes had not been decisively created at these sites. For example, several forest specialists, such as ovenbirds and Acadian flycatchers, were also detected on burned glade sites. In fact, the most frequently encountered birds on all sites were red-eyed vireos, generally considered a forest canopy species. Studies of true glade habitats have found a predominance of grassland species and very few forest birds (Chambers, 1994). Important habitat features associated with the seven glade-associated species included increased density of small stems and lack of canopy cover. This may have reflected primarily conditions at the Ketcherside Mountain site, where the intense fire resulted in mortality of large trees (and reduced canopy cover) and a dramatic increase in density of small woody stems. That site also had the greatest numbers of all seven glade-associated bird species (*see* Figs. 2, 3). In general, increases in small woody stem density are not a goal of glade restoration, but they may be attractive to generalist early-successional bird species such as yellow-breasted chats, white-eyed vireos and hooded warblers. Habitat characteristics typical of glades (low canopy cover, increased percent rock, decreased vegetation cover) were most important for blue-winged warblers and prairie warblers; these species are also more specifically associated with glade and glade-woodland complex habitats (Fink *et al.*, 2006; Chambers, 1994).

Our results suggest that burning influenced both vegetative and avian communities; however, additional management inputs will be necessary to achieve glade restoration. Changes in breeding bird species composition responded to even subtle changes in vegetation and apparently persisted for at least 5 y following structural changes in habitat. Application of prescribed fire at an interval of 2–3 y is recommended for long-term reduction in woody stems in savannah restoration (Peterson and Reich, 2001), but there is evidence (*see* Au *et al.*, 2008) that prescribed fire alone will not achieve savannah restoration.

For example, dense canopy overstory may be limiting formation of grassy understory even in the presence of fire, as grass cover remained ≤5% in all community types. As lower canopy cover was associated with occurrence of all seven glade-associated birds (*see* Fig. 2) and was included in logistic regression models for prairie warblers and white-eyed vireos, canopy cover remains an important metric for glade restoration success. For sites with closed tree canopies, mechanical and/or chemical treatment of these canopy forming trees will be critical to combine with prescribed fire to achieve desired savanna conditions. Canopy reduction will promote grass and herbaceous cover and, in combination with a regular fire regime, will favor use by glade birds such as Bachman's and field sparrows in addition to the generalist early-successional bird species we observed in this study.

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