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Changes in Avian Diversity Post-Wildfire in a Southeastern Deciduous Forest: Flipper Bend Woods, Signal Mountain, Tennessee

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Abstract - In eastern deciduous forests, fire-disturbance and its ecological implications haven't been heavily studied. In Tennessee, an intensely burned plot of forest (2016) presented a unique opportunity to analyze successional habitat regrowth 2–3 years after a wildfire occurred. To examine post-fire recovery, we observed the diversity of avian species in 1 burned site (1-km transect) and 1 unburned site (690-m transect) during 2018–2019. We used line-transects to examine avian diversity and performed a vegetation analysis to compare the sites. Our results showed that though the unburned site was higher in avian diversity (mean Shannon diversity: 2.844 in unburned vs. 2.521 in burned), the burned site appeared to be suitable habitat for multiple disturbance-dependent avian species. Bird species associated with low to medium vegetation heights and overstory heights and low residual basal areas in early successional forests, such as *Setophaga discolor* (Prairie Warbler)*, Passerina cyanea* (Indigo Bunting)*,* and *Icteria virens* (Yellow-breasted Chat), were found only in the burned site, suggesting the fire created suitable habitat for these species, with its average canopy height of 3.55 m and canopy coverage of 18.75%.This study supports the need for greater fire research in Eastern deciduous forests. The results suggest regular fires could create patches of habitats that benefit struggling species of disturbance-dependent birds in this region.

Introduction

Within many eastern North American temperate forests, fire historically influenced ecosystem development (Flatley et al. 2013, Lorimer 2001, Nowacki and Abrams 2008). Fires were primarily low to moderate severity and decreased fuel accumulation, thereby diminishing the likelihood of severe fires that caused gross mortality of the standing vegetation (Flatley et al. 2013, Wimberly and Reilly 2007). These frequent fires maintained disturbance-dependent ecosystems, such as *Quercus* (oak)–*Pinus* (pine) and oak–*Castanea* (chestnut) forests and pine savannas (Adams 2013, Delcourt and Delcourt 1997, Flatley et al. 2013, Nowacki and Abrams 2008). However, since the mid-20th century, burns (natural, controlled, or accidental) have been rare due to the implementation of a policy of fire suppression by the US Forest Service (Flatley et al. 2013). Fire-maintained ecosystems and their associated species have declined (Flatley et al. 2013, Glasgow and Matlack 2007, Lorimer 2001). Biotic homogenization has been documented in fire-suppressed habitats, likely due to low ecological disturbances (Flatley et al. 2015, Mero et al. 2015). These changes resulted in a shift in species composition (flora and fauna)

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within ecosystems previously associated with burns and led to a loss in species richness (Fei et al. 2011, Flatley et al. 2015, Glasgow and Matlack 2007, Nowacki and Abrams 2008). Specifically, fire suppression has led to the decline of avian species (Freeman et al. 2017).

When an ecosystem is disturbed through various fire-severity ranges, it can create a multi-layered habitat used by diverse groups of animals (Doherty et al. 2017, Steel et al. 2021). Studies suggest that to have effective conservation efforts, protected habitats should not be spared from historically ecologically significant events such as fires (Brawn et al. 2001, Freeman et al. 2017, Kelly et al. 2015). Reviews of forest-management techniques have found that a combination of fire-severity exposures could be necessary to maintain diversity and species richness of fire-sensitive taxa (Fontaine and Kennedy 2012, Glasgow and Matlack 2007). Some avian species may be better adapted to high-intensity vs. low-intensity fires or vice versa (Adams 2013, Brawn et al. 2001, Freeman et al. 2017). In eastern deciduous forests, pyrodiversity (varying levels of fire intensity) has been shown to increase disturbance-dependent avian species for a period of time (1–20 years in most cases; Rose and Simons 2016), and bird communities slowly shift back to disturbance-intolerant species as the flora of the ecosystem returns (Smucker et al. 2005, Tingley et al. 2016). In areas of fire suppression in central hardwood forests in North Carolina, low-severity fires were not found to have a detectable effect on species composition, but high-severity fires did (Greenberg et al. 2023). This result suggests it is necessary to study the level of fire severity to manage for certain disturbance-dependent avian communities (Rose and Simons 2016, Smucker et al. 2005, Steel et al. 2021).

Studies on avian response to eastern deciduous fires generally report that fire created suitable habitats for disturbance-dependent species (Akresh et al. 2015, Greenburg et al. 2023, Klaus et al. 2010, Rose and Simons 2016, Rush et al. 2012). However, despite the historical occurrence of fires in the southeastern United States and the more frequent use of fire as a management tool (Aldrich et al. 2014, Flatley et al. 2015, Lafon and Quiring 2012), fire studies on avian diversity appear to be sparse. Our study focused on avian diversity in burned and unburned sites in an eastern deciduous forest in Tennessee to help fill in the gaps in existing literature. The goal was to examine whether a burned eastern deciduous forest in southeastern Tennessee could provide suitable habitat for disturbance-dependent avian species as compared to a nearby unburned forest. Specifically, we aimed to assess the overall avian species diversity, evenness, and richness within the burned site and unburned site.

We hypothesized that, at the successional stage of the land at 2 years of regrowth when this study began, we would find a greater amount of disturbance-dependent birds, such as the *Setophaga discolor* (Vieillot) (Prairie Warbler), *Spizella pusilla* (Wilson) (Field Sparrow), *Spinus tristis* (L.) (American Goldfinch), *Geothlypis trichas* L. (Common Yellowthroat), *Setophaga pensylvanica* (L.) (Chestnut-sided Warbler), and *Icteria virens* (L.) (Yellow-breasted Chat), within the burned site. We expect to find these species either in higher quantities or only within the burned site when compared to the unburned site.

Methodology

Study area

In 2016, a fire burned the Flipper Bend region of the North Chickamauga Creek Conservancy, a 2870-ha natural area located in Hamilton and Sequatchie counties, TN (Fig. 1). The region consists of sandstone plateaus, bluffs, a large gorge, and steep slopes with a mix of mesophytic vegetation interspersed with formerly logged pine stands.

We conducted the study from April 2018 to June 2019. The unburned site (230 ha) ran alongside the heavily trafficked North Chickamauga Creek access (35°14'10.3"N 85°14'00.1"W). It was an older second-growth forest with a thick undergrowth primarily comprised of *Kalmia latiforia* L. (Mountain Laurel), *Polystichum acrostichoides* (Michx.) Schott (Christmas Fern), *Toxicodendron radicans* (L.) Kuntze (Poison Ivy), and herbaceous plants such as flowering perennials. The standing vegetation was a mesophytic mix including *Quercus alba* L. (White Oak), *Quercus velutina* Lam. (Black Oak), *Fagus grandifolia* Ehrh. (American Beech), *Liriodendron tulipifera* L. (Tulip Poplar), *Cornus florida* L. (Flowering Dogwood), *Acer saccharum* Marshall (Sugar Maple), *Aesculus glabra* Willd. (Ohio Buckeye), and *Tsuga canadensis* (L.) Carrière (Eastern Hemlock).

The burned site was located in the "intensely burned" portion and was roughly 221 ha (35°15'28.8"N 85°15'00.3"W). The burned site was higher up on the ridge and was only accessible via old logging roads that ran through stands of *Pinus* sp.

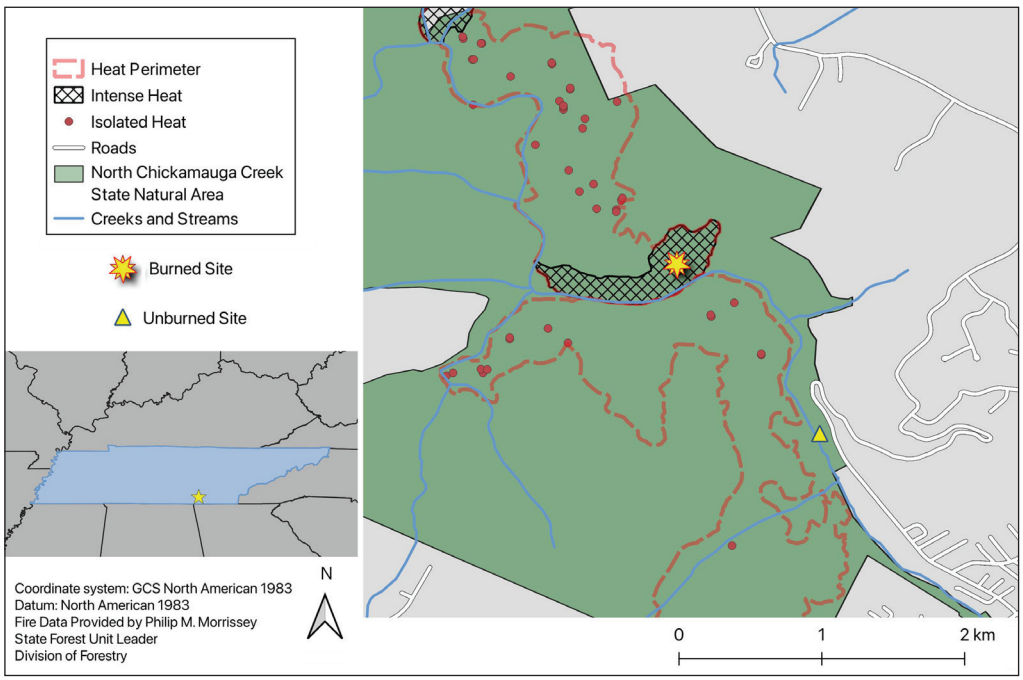

Figure 1. Location of field site and fire locations within Flipper Bend and Walden ridge of Signal Mountain, TN. The site is located near Soddy Daisy, TN, and is part of the North Chickamauga Creek Conservancy. GIS parcels were acquired from the US Forest Service.

The pre-burned ecosystem was unknown due to lack of records. Based on standing vegetation near the burned site, it likely was also a mixed mesophytic forest such as oak–hickory and oak–pine with species such as White Oak, Black Oak, *Quercus rubra* L. (Northern Red Oak), American Beech, and *Carya ovata* (Mill.) K. Koch (Shagbark Hickory).

The fire, deemed arson, occurred from 5 November to 29 November 2016, burning roughly 400 ha. It ran underground past control lines, through mineral rich soil, and spread across the forest causing mortalities to standing vegetation and rare hardwood crown-fires (J. Dale, Assistant District Forester, Cookeville, TN, pers. comm.). The study took place within a 222-ha (548-ac) "intense heat" region identified by the USFS IR mapping (P.M. Morrissey, State Forest Unit leader, Tennessee Department of Agriculture,Nashville, TN, pers. comm.). Due to the large portion of the burned site being on inaccessible slopes, we located the transect site via GIS analysis close to the middle of the largest part of the intensely burned site (away from the edges, sandstone bluffs, and intact forest). We noted that the burn was near-complete with medium- and large-sized trees dead and either still standing or fallen. Of the large- and medium-sized trees, few live ones were interspersed in the intensely burned region in or around the transect. Most living trees were closer to the edges of slopes and appeared to be *Quercus* sp. At the perimeter, where the forest remained intact, we observed living standing trees with large burn scars.

Line transects and vegetation analysis

To evaluate avian diversity, we performed line transects up to 5 times per season. We located 1 transect within the intensely burned area (1 km) and a second in the unburned site (690 m). The same researchers walked both transects at a 30-minute pace. We recorded all birds seen and heard within 50 m on either side of the transects.

We conducted vegetation analysis in the transects during May 2019. At the start, and at each 100-m interval, we collected data on vegetation density, canopy cover, canopy height, and percent ground cover 20 m from the edge on either side. For foliage density, we used a vegetation-profile board similar to that described by Nudds (1977). The profile board consisted of a 0.50 m x 1.22 m board painted in 5 alternating segments of black and white (35 cm each, total height = 1.75 m). We visually estimated foliage to the nearest 5% by the percent of each board segment covered. We took readings with eye level at a height of 1 m starting with the bottom segment and moving to the top (Mitchell and Hughes 1995). We estimated canopy cover using a densiometer and visually estimated canopy height. We estimated ground cover using a 1 m x 1 m quadrant laid down 20 m from the edge on either side.

Data analysis

We split data into seasons: spring = March, April, May, and early June; summer = late June, July, and August; fall = September, October, and November; and winter = December, January, and February. We used Shannon–Weiner diversity index to analyze richness and evenness differences between the seasons and to

compare the burned and unburned sites. We used Jaccard's index to calculate community similarity between burned and unburned sites for each season. We ran two-way ANOVA's , with site and season as the main effects, and used Holm–Sidak post-hoc tests if there were any significant differences. Analyses were completed using Excel (v. 16; Microsoft Corp., Redmond, WA) and SPSS (v. 26.0; IBM Corp., Armonk, NY).

Results

Vegetation analysis

The burned site had a higher density of vegetation and a higher percentage of vegetation coverage. The unburned site had lower density but greater canopy height and coverage (Table 1). While we did not perform an extensive vegetation identification, with the help of a local botanist (J. Shelton), we noted that prominent species included *Rubus* sp., *Andropogon virginicus* L. (Broomsedge Bluestem), young Red Maple trees, grasses, and perennials such as *Solidago altissima* L. (Goldenrod) and *Oxalis*, *Liatris*, *Eupatorium*, *Penstemon*, and *Hypericum* spp. No sign of invasive plants such as *Lonicera* or *Ligustrum* spp. were noted, but we found some invasives such as *Albizia julibrissin* Durazz (Mimosa) and *Lespedeza cuneata* (Dum. Cours.) G. Don (Bush Clover).

In the unburned site, the majority of forest floor plants included Christmas Fern, Poison Ivy, *Trillium lancifolium* Raf. (Lanceleaf Wakerobin), and *Lonicera* and *Ligustrum* spp. Standing vegetation was a mesophytic mix including *Quercus* and *Acer* spp., Eastern Hemlock, American Beech, and Flowering Dogwood.

Shannon diversity index

We analyzed transects from the burned site in 2018 and 2019 for each season (excluding spring 2018 due to the site being inaccessible due to road closures; Table 2). Fall had the highest individual count average. Summer had the highest

Table 1. Average density, canopy height, canopy coverage, and vegetation coverage for burned and unburned sites. The unburned site had 16 plots and the burned site had 20.

	Density	Canopy height (m)	Canopy coverage (%)	Vegetation coverage (%)
Unburned	20.75	15.37	83.43	56.31
Burned	22.75	3.55	18.75	94

Table 2. Average Shannon diversity, Hmax, evenness, richness, and individual count for winter, fall, summer, and spring of 2018 and 2019 in the burned region of Flipper Bend, Signal Mountain, TN. * indicates significance.

Season	Shannon average	Hmax	Evenness	Richness	Individual count average
Winter	2.12	2.64	0.81	14.00	69.00
Fall	2.44	2.85	0.86	17.60	88.20
Summer	3.00*	3.24	0.93*	25.67*	60.67
Spring 2018	2.95	3.22	0.91	24.80	64.60
Spring 2019	2.60	2.95	0.88	19.60	54.40

richness, evenness, Shannon average, and Hmax. Winter was the lowest in all categories except individual count average.

We also analyzed unburned transects (excluding spring 2018) for each season (Table 3). We were unable to sample the unburned site in the spring of 2018 as access to the area was closed. Summer 2018 had the highest Shannon diversity index, but spring 2019 was closer to its Hmax, as evidenced by its high evenness. Winter had the highest and species count, whereas summer had the highest richness.

Transect diversity differed regardless of season ($P = 0.019$) and site ($P = 0.024$), and no significant interaction was found between site and season ($P = 0.055$). The unburned site had the highest diversity overall with a mean of 2.844 versus the burned site's 2.521. Summer had a higher average diversity than fall and winter ($P < 0.05$). No significant difference was found between site, seasons, or site x seasons for the Hmax. A *t*-test performed on the burned and unburned spring 2019 data found no significant difference ($P = 0.067$). When compared using the Jaccard's index, 2018 summer season had the highest percentage similar at 33% and 2019 spring had the lowest at 24% (Table 4).

Seasonal community composition

In the burned site during the 2018 summer season, 36 species of birds were detected (transect = 3; Table 5). Out of those, 14 were unique to the burned site. In the unburned region during the summer, 29 species were found (transect = 2) and 7 were unique. During the 2018 fall season, we detected 31 species of which 9] were unique in the burned site and 46 species (transect = 3) of which 24 were unique in the unburned site (Table 5).

In the burned site during the 2018 winter season, 14 species were found (transect = 1) of which 4 were unique to the burned site (Table 5). In the unburned site

Table 3. Average Shannon diversitiy, Hmax, evenness, richness, and individual species count average for winter, fall, and summer 2018, and spring 2019 of the unburned region of North Chickamauga Creek, Signal Mountain, TN. * indicates significance.

Season	Shannon average	Hmax	Evenness	Richness	Individual count average
Winter	2.84	3.05	0.93	21.5	110.5
Fall	2.80	3.04	0.92	22.0	75.0
Summer	2.89*	3.19	0.90	24.5*	87.5
Spring 2019	2.06	2.17	0.95*	9.0	16.0

Table 4. Jaccard's index, species, and count data for unburned and burned sites for winter (transects = 3), fall (transects = 8), and summer of 2018 (transects = 5) and spring of 2019 (transects = 9).

	Winter 2018	Fall 2018	Summer 2018	Spring 2019
Jaccard's	0.25	0.28	0.33	0.24
Percentage	25	28	33	24
Total species	40	77	65	72
Same species	21	22	22	17
Burned count	14	31	36	48
Unburned count	26	46	29	24

Table 5. Species found at unburned and burned sites during the summer (Su) of 2018 (transects = 2 and 3, respectively), fall (F) of 2018 (transects = 3 and 5), winter (W) of 2018/2019 (transects = 2 and 3), and spring (Sp) of 2019 (transects = 4 and 7). [Table continued on following page.]

Species	Unburned	Burned
Empidonax virescens (Vieillot) (Acadian Flycatcher)	Sp	
American Crow	Su, F, W, Sp	Su, F, Sp
American Goldfinch	W	Su, F, W, Sp
Falco sparverius L. (American Kestrel)		F
Setophaga ruticilla (L.) (American Redstart)	F	
American Robin	Su, F, W	Sp, Su, F, W
Haliaeetus leucocephalus (L.) (Bald Eagle)	Sp	
Hirundo rustica L. (Barn Swallow)		Su
Megaceryle alcyon (L.) (Belted Kingfisher)	Su, F, W	
Black-and-white Warbler	Su, F	Su, Sp
Black-throated Green Warbler	F, Sp	Sp
Passerina caerulea (L.) (Blue Grosbeak)		Sp
Blue Jay	Su, F, W, Sp	Su, F, W, Sp
Blue-gray Gnatcatcher	Su, F	Su, Sp
Buteo platypterus (Vieillot) (Broad-winged Hawk)	Sp	Su
Taxostoma rufum (L.) (Brown Thrasher)	F, W	Sp
Molothrus ater (Boddaert) (Brown-headed Cowbird)	Su, F	F
Sitta pusilla Latham (Brown-headed Nuthatch)		F
Cardellina canadensis (L.) (Canada Warbler)	F	
Poecile carolinensis (Audubon) (Carolina Chickadee)	Su, F, W, Sp	Su, F, W, Sp
Thryothorus ludovicianus (Latham) (Carolina Wren)	Su, F, W, Sp	Su, F, Sp
Bombycilla cedrorum Vieillot (Cedar Waxwing)	F	F, Sp
Chaetura pelagica (L.) (Chimney Swift)	Su, F	Su, Sp
Spizella passerina (Bechstein) (Chipping Sparrow)		Sp
Quiscalus quiscula (L.) (Common Grackle)	W	Sp
Accipiter cooperii (Bonaparte) (Cooper's Hawk)	F	F, W, Sp
Junco hyemalis (L.) (Dark-eyed Junco)	W	W, Sp
Dryobates pubescens (L.) (Downy Woodpecker)	Su, F, W, Sp	Su, F, Sp
Sialia sialis (L.) (Eastern Bluebird)		Su, F, W, Sp
Sayornis phoebe (Latham) (Eastern Phoebe)	F, W, Sp	Su, F, Sp
Pipilo erythrophthalmus (L.) (Eastern Towhee)	Su, F, W, Sp	Su, F, Sp
Eastern Wood Pewee	Su, F	Sp
Field Sparrow		Su, Sp
Regulus satrapa Lichtenstein, MHC (Golden-crowned Kinglet)	F, W	F, W, Sp
Dumetella carolinensis (L.) (Gray Catbird)	Su, F	Sp
Myiarchus crinitus (L.) (Great Crested Flycatcher)	F	
Leuconotopicus villosus (L.) (Hairy Woodpecker)	Sp	Su, F, W, Sp
Catharus guttatus (Pallas) (Hermit Thrush)	F, W	F
Setophaga citrina Boddaert (Hooded Warbler)	Su, F, Sp	Su, Sp
Troglodytes aedon Vieillot (House Wren)		Sp
Indigo Bunting		Su, Sp
Geothlypis formosa (A. Wilson) (Kentucky Warbler)	F	
Parkesia motacilla (Vieillot) (Louisiana Waterthrush)	Sp	
Setophaga magnolia (A. Wilson) (Magnolia Warbler)	F	
Zenaida macroura (L.) (Mourning Dove)	F, W, Sp	Su, Sp
Cardinalis cardinalis (L.) (Northern Cardinal)	Su, F, W, Sp	Su, F, W, Sp
Colaptes auratus (L.) (Northern Flicker)		Su, F, Sp
Ovenbird	Su, F	Su

during that winter, 26 species were found (transect = 2) of which 16 were unique. During the 2019 spring season, we found 48 species (transect = 7) of which 31 were unique in the burned site and 24 species (transect = 4) of which 7 were unique in the unburned site (Table 5).

Common disturbance-dependent species

The burned site had many species of disturbance-dependent birds. Our hypothesis was supported as results indicated disturbance-dependent birds utilized the

Table 5, continued.

Species	Unburned	Burned
Dryocopus pileatus (L.) (Pileated Woodpecker)	Su, F, W	Su, F, Sp
Pine Warbler	F, W	F, Sp
Prairie Warbler		Su, Sp
Red-bellied Woodpecker	Su, F, W, Sp	Su, F
Red-breasted Nuthatch		Sp
Vireo olivaceus (L.) (Red-eyed Vireo)	Su, F, Sp	Su, Sp
Red-headed Woodpecker		Su, F, Sp
Buteo lineatus (Gmelin) (Red-shouldered Hawk)	Su	W
Buteo jamaicensis (Gmelin) (Red-tailed Hawk)	F	
Pheucticus ludovicianus (L.) (Rose-breasted Grosbeak)	F	F
Regulus calendula (L.) (Ruby-crowned Kinglet)	F, W, Sp	F, W, Sp
Archilochus colubris (L.) (Ruby-throated Hummingbird)	Su, F	Su, Sp
Piranga olivacea (Gmelin) (Scarlet Tanager)	Su, Sp	Su
Piranga rubra (L.) (Summer Tanager)	Su	
Catharus ustulatus (Nuttall) (Swainson's Thrush)	F	
Leiothlypis peregrina (A. Wilson) (Tennessee Warbler)	F	
Tufted Titmouse	Su, F, W, Sp	Su, F, W, Sp
Sitta carolinensis Latham (White-breasted Nuthatch)	Su, W	Su, F, W, Sp
Vireo griseus (Boddaert) (White-eyed Vireo)	Su, F	Su, F, Sp
Zonotrichia albicollis (Gmelin) (White-throated Sparrow)	F, W	F, Sp
Troglodytes hiemalis Viellot (Winter Wren)		F
Wood Thrush	Su, F, Sp	
Sphyrapicus varius (L.) (Yellow-bellied Sapsucker)	W	
Coccyzus americanus (L.) (Yellow-billed Cuckoo)	Su, Sp	Su, Sp
Yellow-breasted Chat		Su, Sp
Setophaga coronata (L.) (Yellow-rumped Warbler)	F, W	Sp
Vireo flavifrons Vieillot (Yellow-throated Vireo)	F, Sp	Su, Sp

Table 6. Common disturbance-dependent birds at the burned site frequency per transect.

	Average number of individuals		
Species	Spring 2018 (transect = 4, avg = 81 total birds)	Summer 2018 (transect = 3, avg = 66.3 total birds)	Spring 2019 (transect = 4, avg = 65.5 total birds)
Prairie Warbler	5.50	1.30	5.00
Yellow-breasted Chat	9.50	4.00	4.75
Indigo Bunting	6.25	4.60	2.75
Field Sparrow	3.80	3.33	3.40
Red-headed Woodpecker	0.00	2.00	1.60

burned site either in greater numbers or exclusively compared to the unburned site. Five that only occurred at the burned site are the Prairie Warbler, *Passerina cyanea* (L.) (Indigo Bunting), Yellow-breasted Chat, Field Sparrow, and *Melanerpes erythrocephalus* (L.) (Red-headed Woodpecker) (Table 6).

Discussion

Avian diversity and presence

During spring of 2018 and spring and summer of 2019, the burned region had the largest number of disturbance-dependent species of birds. This result supports findings of other studies comparing successional avian communities in disturbed and undisturbed habitats (Akresh et al. 2015, Allen et al. 2006, King et al. 2011, Roberts and King 2017, Sheehan et al. 2014, Thompson and Degraaf 2001, Yahner 2003). While these studies were similar in methodology, most were focused on thinning, clearcutting, and other disturbance. Regardless, they found many of the same disturbance-dependent species of birds this study did, suggesting multiple disturbance types could assist these species.

Studies similar to ours also found an uptick of disturbance-dependent birds post-fire and in addition generally found higher richness and evenness after burning (Annand and Thompson 1997, Greenburg et al. 2023, Klaus et al. 2010, Yahner 2003) In contrast, our study did not find a higher level of richness and evenness in the burned site, and the unburned site had significantly higher diversity. Differences could stem from the unburned site being closer to a creek than the burned site or be due to a lack of opportunity to study the site before it burned. While the pre-burned habitat is unknown, we noted that the burned site was surrounded by relatively intact forest that was a mix of mesophytic flora similar to the unburned site with large trees and an intact canopy. These observations and the presence of standing and fallen large dead trees inside the burned site suggests that it might have been an intact forest with species similar to the unburned site before the fire occurred. Thus, these contrasting results could be attributed to site dependency (Allen et al. 2006) or could be due to high-severity–fire patch size creating declining subsets of edge-community species (Steel et al. 2021).

Within the unburned site, we found greater occurrences of birds associated with a non-disturbed area with higher canopy coverage and height, such as *Setophaga virens* (Gmelin) (Black-throated Green Warbler), *Seiurus aurocapilla* (L.) (Ovenbird), *Contopus virens* (L.) (Eastern Wood Pewee), and *Hylocichla mustelina* (Gmelin) (Wood Thrush) (Klaus et al. 2010, Sheehan et al. 2014). Wood Thrush, in particular, have been reported in mature sites and fire-suppressed habitats in higher abundance (Allen et al. 2006, Annand and Thompson 1997), which supports our findings as the unburned site had high canopy coverage (83.43%) and canopy height (15.37 m), indicative of a forested habitat with 80–100% canopy coverage (Burger et al. 2016).

Depending on the season, some bird species occurred in both sites such as *Turdus migratorius* L. (American Robin), Tufted Titmouse, and *Polioptila caerulea* (L.) (Blue-gray Gnatcatcher). Tufted Titmice and Blue-gray Gnatcatchers have

been found to not be affected by the level of disturbance and were recorded across multiple habitat types regardless of vegetation cover (Barrioz et al. 2013). Other studies have found that species such as Tufted Titmice, Blue-gray Gnatcatchers, *Corvus brachyrhynchos* C.L. Brehm (American Crow), *Cyanocitta cristata* (L.) (Blue Jay), *Setophaga pinus* (L.) (Pine Warbler), *Melanerpes carolina* (L.) (Red-bellied Woodpecker), and *Mniotilta varia* (L.) (Black-and-white Warbler) are habitat generalists, and their abundance is not significantly impacted by the level of disturbance (Allen et al. 2006, Annand and Thompson 1997), which could explain their presence across both sites. On the other hand, some species were only found during a single season at 1 site versus the other. American Goldfinch were observed in the burned site during spring, summer, fall, and winter yet only observed in the unburned site during winter, which suggests the burned site was ideal for that species only during those seasons. Studies have found that American Goldfinch occur at varying levels within disturbed and undisturbed habitat but were more likely to occur 4 years after fire (Klaus et al. 2010).

Across seasons, sites were never more than 30.33% similar. Spring 2019 was overall the lowest in similarity at 23.61% compared to the other seasons. Though the seasons were not significantly different ($P = 0.055$), the value does approach significance, and the heavy presence of disturbance-dependent birds in the burned site coupled with the low Jaccard's index suggests the results for spring 2019 could be biologically meaningful. This difference in species composition is likely due to different vegetation and canopy structure at each site, as disturbance-dependent birds appear to have a response to fire severity and time (Burger et al. 2016, Greenburg et al. 2023, Rose and Simons 2016).

Conservation implications

It is important to note that studies on introducing fires into ecosystems have been unable to find a single pattern of burning that benefits all species of birds and have stressed the importance of the relationship between time and fire severity (Greenburg et al. 2023, Rose and Simons 2016, Steel et al. 2021). As such, it is crucial to research patterns that benefit disturbance-dependent bird species especially those who have struggling populations. Our study found many disturbance-dependent species only within the burned site who are known to have fluctuating or declining populations according to the Breeding Bird Survey (Sauer et al. 2017). We suggest conservation efforts be focused on Prairie Warblers, Yellow-breasted Chats, Indigo Buntings, Field Sparrows, and Red-headed Woodpeckers because they were found in larger numbers, have struggling populations, and/or show evidence of breeding.

The Prairie Warbler, Field Sparrow, American Goldfinch, and Yellow-breasted Chat are associated with low and medium vegetation heights, low overstory height, and low residual basal area occurring in an early successional forest (Burger et al. 2016, Sheehan et al. 2014). Prairie Warblers are also associated with low, dense, and woody understory and few overstory trees indicative of more-open habitats (King 2011). Our study's findings are in agreement with those studies as Prairie Warblers, Field Sparrows, and Yellow-breasted Chats were only found within the

burned region where the average canopy height was 3.55 m with an average canopy coverage of 18.75%. When comparing the average canopy coverage to other studies on woodlands, prairies, and savannas, our burned site coverage was similar to that found in savannas (Burger et al. 2016), suggesting this level of fire disrupted the ecosystem enough to provide a different kind of habitat than the intact forest surrounding it.

Rose and Simons' (2016) models showed Prairie Warblers (noted frequently at our burned site) were found after high-severity fires opened the canopy and could be detected up to 25 years (2016). In North Georgia, Prairie Warblers were detected at higher numbers with increasing disturbance (Klaus et al. 2010). However, they were not found in the site of the most recent fire, suggesting that they are more adapted to later growth (Barrioz et al. 2013, Klaus et al. 2010). This finding supports our detection of Prairie Warblers 2 and 3 years after a high-intensity fire resulting in low canopy coverage (18.75%) and greater ground-vegetation coverage.

Prairie Warblers are more likely to occur in larger patches of disturbed habitat (≥1.1 ha; Akresh et al. 2015, Roberts and King 2017) and have an average territory size of 0.97 ha (Akresh et al. 2015). The entirety of the North Chickamauga Creek Conservancy (that our burned and unburned sites are located in) is roughly 2832 ha, and the high-intensity burned section was ~222.5 ha. Prairie Warblers were found only in the burned site for spring 2019 and spring and summer of 2018, and evidence of breeding (such as nest building) was observed. This knowledge could benefit forest managers who do not have large plots of land. Consistent management of this plot would be ideal to boost the populations of those species. Researchers have found that the "periodic creation" of disturbance in managed plots had a positive influence on the successional bird community and diversity overall (Yahner 2003). For Prairie Warblers, it has been suggested to treat areas adjacent to breeding populations with burning, mowing, and other treatments (Akresh et al. 2015).

Yellow-breasted Chats also appear to prefer heavily burned habitat up to 25 years after fire (Rose et al. 2016). We found them only in the burned site and observed activities such as feeding, nesting, and courting 2 and 3 years post-fire. Another disturbance species, the Indigo Bunting, has been found to be more abundant in various levels of disturbed plots as compared to undisturbed areas (Annand and Thompson 1997). Indigo Buntings are associated with grass cover (Barrioz et al. 2013), which corresponds with our study in which the burned site had an average of 94% ground-vegetation coverage.

Field Sparrows were another frequent disturbance-dependent bird and are declining significantly in population (Sauer et al. 2017). They have been found to be either absent or rare in forests prior to thinning and then increase afterwards (King et al. 2011). One study found Field Sparrows didn't occur after a low or medium fire and only arrived 3–6 years after an intense fire (Klaus et al. 2010). In our study, they were found solely in the burned sections, and evidence of breeding and nesting was noted during the spring.

Lastly, Red-headed Woodpeckers were found in the burned site and can be assisted by fire in other ecosystems (Allen et al. 2006, Rose and Simons 2016). Though they were found at low numbers in our study, their presence suggests that regular fire could benefit their population through management.

In conclusion, this high-severity fire appeared to create habitat suitable for these species. If land managers implement regular disturbance, it could also benefit multiple species that will begin to decline as time passes since the fire.

Limitations and future considerations

During the 2018 spring season, the unburned section of the forest was inaccessible due to road work around the site and caused a lapse in data collection. Another issue involved access to the site via departmental vehicle availability, scheduling conflicts, and inclement weather. These data limitations were mostly confined to the months of January and February 2019. For future fire-disturbance studies in larger plots, increasing the number of transects and number of times a transect is walked during each season could boost results, as detectability of birds can rise and fall across the breeding season (King et al. 2011). Having multiple severity-type burned areas would be ideal to compare the differences in species composition between levels of fire intensity, as studies have found that certain species of birds may only be assisted through high-severity fires (Greenburg et al. 2023, Rush et al. 2012). Through analyzing forests burned with low, medium, and high fire-intensity levels with a control, thorough models could be created that would assist researchers and forest managers.

Another consideration would be to examine the burned and unburned forests and compare the differences across several years. Such a longer-term study could provide valuable information for forest managers regarding the changes in avian diversity as the ecosystem evolves and the canopy returns post fire. Data on differences in diversity across 2, 5, and 10 years would greatly enhance knowledge on the impact of southeastern forest fires. Other studies have gathered such data in northeastern deciduous forests in Massachusetts and Pennsylvania (Akresh et al. 2015, Yahner 2003). Having a greater number of fire-disturbance studies on forests in the southeastern deciduous forest would increase the information available and potentially allow for enhanced conservation of the struggling populations of bird species in that region. This study shows that even in a fairly small area of land, disturbance-dependent species of birds benefited from an uncontrolled burn and could continue to benefit with proper management.

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