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Canopy reduction and fire seasonality effects on deer and turkey habitat in upland hardwoods

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ABSTRACT

Understory conditions strongly influence the value of upland hardwood forests for white-tailed deer (*Odocoileus virginianus*) and wild turkey (*Meleagris gallopavo*). Canopy reduction can be paired with low-intensity prescribed fire to increase forage and cover. Most fire in these systems is applied during the dormant season, but there may be benefits to burning during different seasons to provide different resources throughout the year. We implemented a shelterwood harvest with reserves in four upland hardwood stands in east Tennessee in 2010, then applied fire during the early-growing season (EGS) and late-growing season (LGS) to different treatment units on approximately a 2.2-year return interval from 2012–2023. We recorded vegetation composition, measured vegetation structure, calculated deer forage availability, and tallied wildlife detections via camera traps in summer 2023 to evaluate our treatments relative to an unharvested and unburned control. We found canopy reduction and fire during either season resulted in greater understory coverage of plants, with tree and bramble coverage greatest following LGS fire, which was lower intensity on average than EGS fire. Vegetation structure following EGS fire was more open, which is typically selected by brooding turkeys. The taller structure following LGS fire provided conditions typically selected for bedding or fawning by deer and nesting for turkeys. Deer forage biomass in July was increased by both EGS and LGS relative to control, but forage of sufficient quality to support a lactating doe was increased only in EGS because of increased nutrition of recently resprouting vegetation. Deer and turkey detections were greater in EGS than control or LGS during May–June. Turkey detections remained greater in EGS during July–August, but deer use was similar between EGS and LGS during July–August. Our results indicate burning during different seasons following canopy reduction can promote different food and cover resources which are important for deer and turkeys during different times of the year.

1. Introduction

Forest management strongly influences understory characteristics which provide resources for many wildlife species in upland hardwood forests (DeGraaf et al., 1991; Lashley et al., 2011; Greenberg et al., 2013). Management practices that allow approximately 30% sunlight increase understory vegetation and generally provide increased forage and cover for wildlife (McCord et al., 2014; Turner et al., 2020). Commercial harvest techniques, such as various thinnings, shelterwood harvests, and group selection harvests, often are used to increase understory sunlight and influence regeneration composition and herbaceous groundcover (Kelty and Nyland, 1983; Peitz et al., 1999; Grayson et al., 2012; McNab and Oprean, 2021). Noncommercial techniques employing various Forest Stand Improvement (FSI) practices also are used to improve overstory species composition and increase sunlight to the understory to influence groundcover (Rankin and Perlut, 2015; Harper, 2020; Turner et al., 2021b). Several wildlife species, including white-tailed deer (*Odocoileus virginianus*; hereafter, deer) and wild turkeys (*Meleagris gallopavo*; hereafter, turkeys), benefit from the structure and food resources available soon after canopy reduction following both commercial and noncommercial practices.

Deer and turkeys benefit from diverse understory conditions that result from forest management. Deer body size, antler growth, and productivity all benefit from increased nutritional carrying capacity (NCC), which is provided by understory plants (Verme, 1969; Harmel et al., 1989; Edwards et al., 2004; Michel et al., 2016). Understory vegetation also may increase visual obstruction below 2 m, which provides bedding and fawning cover for deer (Huegel et al., 1986; DePerno et al., 2003; Lashley et al., 2015b; Cherry et al., 2017). Turkey productivity has declined in many areas of the southeastern US, and there

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has been increased interest in improving turkey nesting and brooding cover (Byrne et al., 2015, Chamberlain et al., 2022, Johnson et al., 2022). Turkeys select to nest in areas with greater visual obstruction from 0.5–1.5 m (Keever et al., 2022), and improved nesting cover may increase nest survival (Kilburg et al., 2014, Little et al., 2016, Johnson et al., 2022). Hens with broods select sites with visual obstruction from 0–0.5-m, but with open structure underneath the plant canopy, and relatively good visibility above 0.5-m to allow for predator detection (Wood et al., 2018; Nelson et al., 2022). Brooding cover also improves with increased understory herbaceous plant coverage, with forbs especially important (Campo et al., 1989; Johnson, 2019; Nelson et al., 2022). Thus, both understory structure and composition are important for deer and turkeys, and management is necessary to maintain these conditions in upland hardwoods following canopy reduction (Lashley et al., 2011; McCord et al., 2014).

Prescribed fire is one of the most important tools to maintain structure and forage for deer and turkeys in upland hardwood forests (Harper et al., 2016). Fire historically was present in upland hardwood systems, and many tree species are adapted to frequent, low-intensity fire (Brose and Van Lear, 1999; Marschall et al., 2014; Keyser et al., 2018). When paired with canopy reduction, fire can be used to promote herbaceous understory plants which provide forage and cover for deer and turkeys (Lashley et al., 2011; McCord et al., 2014; Vander Yacht et al., 2017a). Frequent fire can promote deer forage availability and cover for turkey hens raising a brood, whereas fire on a slightly longer return-interval (i.e. 3–5 years) can promote turkey nesting and deer bedding and fawning cover (Lashley et al., 2015b; Harper et al., 2016; Wood et al., 2018; Glow et al., 2019). Other factors, especially fire intensity and seasonality, interact with frequency to shape understory conditions important for deer and turkeys (Vander Yacht et al., 2017b).

Understory composition and structure may vary based on the seasonality of fire. Fire in upland hardwoods is most commonly applied during the dormant season, yet there is increased interest in burning during other periods of the year (Knapp et al., 2009; Harper et al., 2016). Growing-season fire may be used to promote herbaceous plants while reducing woody coverage, but timing of fire during the growing season may or may not influence composition (Holcomb et al., 2014; Vander Yacht et al., 2017a; Nanney et al., 2018; Resop et al., 2023). Early-growing season (i.e., April–May; hereafter, EGS) fire is used commonly in upland hardwoods, but the effects of late-growing season (i.e., August–October; hereafter, LGS) are not well-understood (Lewis et al., 1964; Sparks et al., 1998; Lashley et al., 2011; Vaughan et al., 2022). There often are suitable burn days during the LGS, and fire during that time may promote forbs while controlling understory tree sprouts (Gruchy et al., 2009; Vander Yacht et al., 2017b). Understory structure also may be influenced by seasonality, as vegetation burned during the EGS has less time to respond by early summer than vegetation burned the prior LGS. Changes to both composition and structure based on fire seasonality may have strong implications for wildlife habitat in upland hardwoods.

Deer and turkey habitat quality and use vary following fire during different times of the year. For example, deer benefit from increased forage quality in resprouting woody plants relatively soon after fire occurs during the EGS (Nichols et al., 2021). Conversely, areas burned the previous year during the LGS may provide increased cover because more time has passed since fire was applied (Lashley et al., 2015b). Most work on deer response to fire seasonality has been conducted in pine forests, and there may be different responses in upland hardwoods with greater understory woody plant coverage (Lashley et al., 2015b; Nichols et al., 2021). Turkey use increases following fire applied during the dormant season in pine forests (Yeldell et al., 2017a; Yeldell et al., 2017b), but turkey response to growing-season fire in the literature is primarily limited to concerns about nest destruction during EGS (Kilburg et al., 2014; Wood et al., 2018; Wann et al., 2020). We believe increasing our understanding of deer and turkey response to fire during EGS versus LGS in upland hardwoods could provide an opportunity to burn during additional times of the year while improving understory conditions for these species.

Given the importance of understory structure and composition to deer and turkeys, we designed an experiment to quantify vegetation and wildlife response to fire during the EGS and LGS following canopy reduction. Specifically, we wanted to compare stands that had been burned multiple times during the EGS or LGS, along with stands where canopy reduction and fire had not been implemented. We hypothesized understory composition and structure would vary by treatment. We predicted greater understory plant coverage in treated stands, and greatest visual obstruction following LGS fire because of the increased time to respond the following growing season. We hypothesized deer NCC would vary by treatment and predicted greatest NCC following EGS fire because vegetation following EGS would be younger and more nutritious than the relatively older plant material following LGS the previous year. Finally, we hypothesized deer and turkey detections would vary based vegetation structure as influenced by fire intensity and time since fire. We predicted greatest deer use in the EGS treatment during early summer because of greater plant digestibility and nutrition, but deer use would be similar between EGS and LGS treatments during late summer as the relative age of plant leaf material would be mature and similar in nutrition. We predicted turkey use would be greatest in EGS treatment, at least hens with broods through spring and early summer, because of increased visibility above 0.5 m.

2. Methods

2.1. Study area

We conducted our study on four upland hardwood stands located in different watersheds of the Chuck Swan State Forest and Wildlife Management Area (hereafter, CSF) located in Union and Campbell Counties, Tennessee, USA. The four stands were Big Springs Picnic, Big Springs Y, Crumley Loop, and Long Hollow. Average annual temperature on CSF was 13.1 °C and average annual precipitation was 128.5 cm (National Oceanic and Atmospheric Administration NOAA, 2023). Stands were located on south to west facing slopes, and overstory species composition included white oak (*Quercus alba*), northern red oak (*Quercus rubra*), southern red oak (*Quercus falcata*), yellow-poplar (*Liriodendron tulipifera*), red maple (*Acer rubrum*), hickory (*Carya* spp.), and blackgum (*Nyssa sylvatica*). The Big Springs Y and Long Hollow replicates had predominately Clarksville cherty silt loam soils, the Big Springs Picnic replicate had predominately Fullerton gravelly silt loam soils, and the Crumley Loop stand had predominately Fullerton and Bodine gravelly silt loam soils (Natural Resource Conservation Service NRCS, 2023). Based on time since the last known clearcut, Big Springs Picnic was approximately 100 years old, Big Springs Y was approximately 140 years old, Crumley Loop was approximately 70 years old, and Long Hollow was approximately 120 years old.

2.2. Treatments

We divided each stand into three equal treatment units which were approximately 1.6 ha each. We then randomly assigned one of the following treatments to each unit: control (CON), cut + burn during the early-growing season (EGS), and cut + burn during the late-growing season (LGS). We did not burn or cut trees in the CON unit during any time after the study began, and no management had occurred in the stands since they were regenerated naturally. In fall 2010, a shelterwood with reserves harvest was implemented in the EGS and LGS units. Our objective with the harvest was to allow approximately 30% sunlight to the understory by reducing basal area to approximately 13 m^2/ha. Additionally, we wanted to primarily retain oaks and select soft mast producers, such as persimmon (*Diospyros virginiana*), black cherry (*Prunus serotina*), and blackgum, which are important food sources for deer and turkeys.

We began burning the EGS and LGS treatment units approximately two years after the overstory harvest. Our objective was to maintain approximately a 2-year fire-return interval, and to burn the EGS treatment the spring immediately after the LGS treatment was burned to keep both treatments in sequence with the following growing seasons. We burned LGS treatments six times for an average of a 2.2-year fire-return interval, with fires occurring in 2012, 2014, 2016, 2017, 2019, and 2022. We burned EGS treatments six times for an average of a 2.2-year fire-return interval, with fires occurring in 2013, 2015, 2017, 2018, 2020, and 2023. All fires for a particular seasonality were implemented on the same day to ensure fire weather and timing were similar across units. EGS burns were conducted in April–early May after leaf-out. We applied LGS fires prior to leaf drop in September–October, except for 2017 when LGS burns were conducted in November because conditions and schedules did not allow burning in September/October of that year. We chose to burn in 2017 because the LGS burns in 2016 were particularly low-intensity with > 80% of each unit unburned.

We used a combination of low-intensity backing, flanking, and strip-heading fires in both treatments. We removed slash from the base of trees to reduce damage to the tree bole (Brose and Van Lear, 1999), and we maintained average flame lengths < 1-m. Weather conditions during burns included temperatures between 16–27 ℃, relative humidity between 20–50%, in-stand wind speed between 1.6–6.4 km/hour, and mixing height between 1000–2100 m. Average estimated burn coverage for LGS burns was 65%, whereas average estimated burn coverage for EGS was 95%.

2.3. Data collection

We randomly placed four points in each treatment unit to collect fire temperature, vegetation transect, deer forage, and vegetation structure data. Prior to the 2022 LGS and 2023 EGS prescribed burns, we placed a ceramic tile with ten Tempilaq® heat-sensitive indicator paints (Tempil, Elk Grove Village, IL, USA) at each point. We used paints which melted at 107, 135, 149, 163, 191, 246, 316, 343, 371, and 399 ℃ to measure relative temperature of each fire. We wrapped the tile in foil to prevent charring, and recorded the highest temperature of paint which was melted after each burn.

We evaluated plant coverage in July 2023 along a 30-m point-intercept transect which was centered on each of the four random points in each treatment and oriented to the east and west. We placed an additional 15-m point-intercept transect to the north of the point. We documented all species < 1.4-m tall present at each meter-mark, and combined data from the 15- and 30-m long transects for a total of 45 transect readings at each point. Following collection, we calculated the coverage of understory grasses, forbs, brambles (*Rubus* and *Smilax* spp.), vines, shrubs, and trees at each point. We evaluated visual obstruction at each point using a 2-m vegetation profile board (Nudds, 1977). The board had alternating 0.5-m white and orange sections, and we evaluated each on a scale of 1–5 based on the percent of the section obstructed by vegetation, whereby 1 = 0–19%, 2 = 20–39%, 3 = 40–59%, 4 = 60–79%, and 5 = 80–100%. A kneeling observer took three obstruction readings from the center point, with the board placed 10-m from plot center to the east, west, and north.

We evaluated overstory basal area and canopy coverage with timber cruise plots and ceptometer readings at each of the four random points. We measured all overstory trees > 11.4 cm diameter at breast height (DBH) within a 0.04-ha plot centered on each sampling point in July 2023. In August 2023, we collected paired ceptometer readings to measure photosynthetically active radiation (PAR) using an AccuPAR® LP-80 PAR/LAI ceptometer (Decagon Devices, Inc., Pullman, WA). Fifteen readings were taken at a height of 1.4 m along a transect oriented east to west at 1-m intervals at each of the four random points. Simultaneous readings were taken in full sunlight in an opening close to the stand, and we calculated the percent PAR in the understory by dividing the in-stand readings by the full sunlight readings (McCord et al., 2014; Turner et al., 2020).

We collected selected deer forages in early July 2023 to evaluate forage availability between treatments. Our collection time corresponded with peak milk production for lactating does (Robbins and Moen, 1975; Diefenbach and Shea, 2011). At each transect point, we collected all selected forage present in 0.5-m^2 frames placed at the 5- and 25-m marks of the east/west transect. We collected species identified as selected by deer in the literature (Miller and Miller, 2005; Harper, 2019), and collected young and old tissues separately as there may be nutritional differences based on tissue age (Lashley et al., 2014; Turner et al., 2021a). We collected smaller leaves closer to the stem tip as younger tissue, and considered larger leaves farther down the stem older tissue based on Lashley et al. (2014).

Following collection, we dried all forages at 50 °C for 72 h and weighed them with a digital scale. We ground samples to a homogenous powder and sent at least 5 g to the Agricultural Services Laboratory at Clemson University for nutritional analysis for each species/age that was present in either CON, LGS, or EGS. We combined samples from across the four units in each treatment for nutritional analysis, as we were more interested in nutritional differences based on treatment than small differences in nutrient content based on site fertility or other factors (Turner et al., 2021a). The Agricultural Services Laboratory used wet-chemistry methods to determine nitrogen content, which we multiplied by 6.25 to estimate crude protein (Robbins et al., 1987). We then used a mixed-diet approach to estimate nutritional carrying capacity (NCC) for each treatment unit (Hobbs and Swift, 1985), using a 14% crude protein nutritional constraint and 2.4 kg/day intake of a 50-kg doe. The 14% crude protein constraint corresponds to the peak demand of a lactating doe with one fawn and commonly is used in the literature to estimate growing-season forage availability for deer (NRC 2007, Jones et al., 2009, Iglay et al., 2010, Lashley et al., 2011, Harper et al., 2021). We also considered the total biomass of selected forages to evaluate differences in overall forage availability based on treatments. Finally, we considered the biomass of forbs, semiwoody plants, and woody plants which were selected deer forages to compare whether treatments influenced various forage classes differently.

We placed camera traps at three of the four transect points to monitor deer and turkey use during the growing season. We randomly selected which points were to receive a camera and placed a Browning Strike Force® (Prometheus Group, Birmingham, AL, USA) camera on a t-post 1-m above ground facing the tree closest to each selected transect point. Cameras were placed 10-m from the tree and were set to take one picture with a one-minute delay between pictures. We cleared vegetation between the tree and camera to ensure detection probability was equal among treatment units. We placed cameras in the stands 18 May 2023, checked them 5 July 2023, and removed cameras 17 August 2023.

We separated the camera trap deployment into two periods: early summer (mid-May–June) and late summer (July–mid-August). This separation was based on possible differences in nutritional availability and life-history needs between early and late summer. We counted all adult and neonate deer, and adult turkeys and poults, present in each picture. Although forage and cover requirements of male, female, and young differ for deer and turkeys, they are similar enough during the period we were investigating to allow for grouping within a species to provide meaningful results on their response to various treatments (Chance et al., 2020). We then summed the detections within each treatment unit for each species and divided by the number of days in each sampling period to calculate the detections per day.

2.4. Analysis

We conducted all analysis in Program R (R Core Team, 2023). We used a linear mixed-effect model with stand as a random effect to evaluate whether the relative maximum fire temperature differed between LGS and EGS. We also used linear mixed-effect models to evaluate whether coverage of forbs, grasses, brambles, vines, shrubs, and trees differed based on treatment. We tested each plant growth form separately and included stand and point as random effects. We also used linear mixed-effect models with stand and point as random effects to test for differences in visual obstruction, basal area, and understory sunlight.

We used linear mixed-effect models with stand as a random effect to evaluate differences in NCC, total forage biomass, selected forb biomass, selected semiwoody biomass, and selected woody biomass between treatments. We also used linear mixed-effect models to determine whether deer or turkey detections differed based on treatments during May–June or July–August. We analyzed each species and period separately and included stand and point as random effects in the analysis (Gomes, 2022; Oberpriller et al., 2022). We used a square-root transformation on all forage and camera data before analyzing to meet normality assumptions. We used the Tukey procedure to determine which treatments differed significantly and set $\alpha = 0.05$ for all statistical tests. Although some analyses were conducted on transformed data, all results are presented with untransformed means and standard errors to allow for easier interpretation.

3. Results

Relative maximum temperature was 156.8 °C in EGS, which was greater than the relative maximum of 85.5 °C in LGS ($p = 0.042$). Understory sunlight was greater in EGS ($p < 0.001$) and LGS ($p < 0.001$) compared to CON, whereas overstory BA was greater in CON than EGS ($p = 0.001$) or LGS ($p < 0.001$; Table 1). Coverage of forbs ($p < 0.001$), grasses ($p < 0.001$), brambles ($p < 0.001$), and shrubs ($p < 0.001$) was greater in EGS than CON, whereas coverage of forbs ($p = 0.003$), grasses ($p = 0.001$), brambles ($p < 0.001$), shrubs ($p < 0.001$), and trees ($p = 0.006$) was greater in LGS than CON. Coverage of brambles ($p = 0.047$) and trees ($p = 0.003$) was greater in LGS than EGS, but was similar with all other plant classes (Fig. 1). Visual obstruction from 0–0.5-m was greater in LGS ($p < 0.001$) and EGS ($p < 0.001$) than CON, whereas visual obstruction from 0.5–1-m was greater in LGS than EGS ($p < 0.001$), LGS than CON ($p < 0.001$), and EGS than CON ($p = 0.046$). Obstruction from 1–1.5-m was greater in LGS than CON ($p = 0.006$) and EGS ($p = 0.001$), and visual obstruction from 1.5–2-m was greater in CON than EGS ($p = 0.025$; Fig. 2).

NCC was greater in EGS than CON ($p = 0.01$) but was similar between EGS and LGS ($p = 0.168$; Fig. 3a). NCC in LGS did not differ significantly from CON ($p = 0.118$). Total biomass of selected forages was greater in EGS ($p = 0.02$) and LGS ($p = 0.005$) compared to CON, but EGS and LGS did not differ significantly ($p = 0.444$; Fig. 3b). Biomass of selected forbs was greater in EGS than CON ($p = 0.008$), marginally greater in LGS than CON ($p = 0.056$), and similar between LGS and EGS ($p = 0.266$; Fig. 4a). Biomass of selected semiwoody plants was greater in EGS ($p = 0.005$) and LGS ($p < 0.001$) than CON, and marginally greater in LGS than EGS ($p = 0.053$; Fig. 4b). Biomass of selected woody plants was greater in LGS than CON ($p = 0.046$), but was similar between EGS and CON ($p = 0.203$) as well as LGS and EGS ($p = 0.504$; Fig. 4c).

During May–June, deer detections were 488% greater in EGS than LGS ($p = 0.013$), 600% greater in EGS than CON ($p < 0.001$), and 229% greater in LGS than CON ($p = 0.041$; Fig. 5). Turkey detections were 510% greater in EGS than LGS ($p < 0.001$), and 725% greater in EGS than CON ($p = 0.008$; Fig. 6). Deer detections during July–August were 305% greater in LGS ($p = 0.002$) than CON, 320% greater in EGS ($p = 0.002$) than CON, and did not differ between LGS and EGS ($p = 0.995$). Turkey detections were 1961% greater in EGS than LGS ($p = 0.004$), but EGS and CON did not differ ($p = 0.087$).

Table 1
Average percent understory sunlight (PAR) and m^2/ha overstory basal area (BA) in forest stands on Chuck Swan State Forest and Wildlife Management Area, Tennessee in 2023 across three treatments: control (CON), shelterwood + early-growing season fire (EGS), and shelterwood + late-growing season fire (LGS). SE represent standard error, and different letters indicate significant differences between treatments ($p < 0.05$).

Treatment	PAR	SE	BA	SE
CON	3.17 A	1.2	25.5 B	6.2
EGS	27.3 B	6.8	13.9 A	4.5
LGS	38.1 B	12.4	12.5 A	4.2

4. Discussion

Canopy reduction paired with fire during LGS or EGS increased understory sunlight and plant coverage relative to the control. Fire intensity was greater within EGS than LGS, which influenced plant composition and structure and thereby food and cover resources for deer and turkeys. Visual obstruction from 0–1 m was greater in EGS and LGS than control, and obstruction from 0.5–1.5 m was greater in LGS than EGS or control. EGS and LGS increased deer forage biomass relative to the control, but only EGS significantly increased NCC. Both deer and turkey detections were greatest in EGS during May–June. Deer detections were similar between EGS and LGS during July/August, whereas turkey detections remained greatest in EGS.

Prescribed fire during different portions of the growing season was effective at increasing herbaceous vegetation in upland hardwoods following canopy reduction. We did not test fire seasonality alone, but paired fire with canopy reduction given the lack of low-intensity fire effects on the understory in closed-canopy systems (Shaw et al., 2010). EGS and LGS both were effective at promoting herbaceous plants following canopy reduction, with more than 15 times greater forb coverage on average in treatment units compared to the control. However, after six fires, we still only recorded approximately 15–20% coverage of forbs or grasses. Frequent fire is required to maintain herbaceous understory conditions following canopy reduction (Vander Yacht et al., 2017a), but levels of sunlight greater than 27–38% may be necessary to achieve additional coverage of early successional plants.

We did not document major differences in understory composition between EGS and LGS. Some have reported changes in plant composition based on seasonality, such as differences in forb coverage (Gruchy et al., 2009; Resop et al., 2023), whereas others have noted little difference in composition based on fire seasonality (Nanney et al., 2018; Vander Yacht et al., 2017b; Vander Yacht et al., 2020). The only differences we detected were greater tree and bramble coverage in LGS, which were related to fire intensity. Burn coverage and maximum temperature detected on fire tiles was greater in EGS than LGS, which likely resulted in many tree saplings and brambles not being top-killed during each LGS fire, increasing in coverage over time, and suppressing coverage of forbs and grasses. Similar results were reported by Vander Yacht et al. (2017a). The difference in time after fire also may have influenced understory plant coverage, as brambles and trees had more time to grow and expand in LGS because they were not set-back after spring green-up as they were in EGS. Nonetheless, the use of fire during various portions of the growing season may promote different resources for wildlife even if composition does not change.

Both EGS and LGS increased understory structure relative to the control, and structure varied based on fire seasonality (Fig. 7). Understory structure was relatively open in the control, but canopy reduction and fire promoted greater visual obstruction from 0–1 m, which is important for many wildlife species (McCord et al., 2014; Turner et al., 2020). During the growing season immediately after fire, EGS promoted more open structure from 0.5–2 m, likely because of decreased time-since-fire (Wann et al., 2020). These areas provided structure similar to what turkeys select for brooding, with visual obstruction from 0–0.5-m and more open structure above (Wood et al., 2018; Nelson et al., 2022). Conversely, more dense structure was present in LGS from 0.5–2 m compared to EGS, as greater time-since-fire combined with increased bramble and tree coverage provided taller structure. The structure in LGS was similar to what is reported as turkey nesting cover,

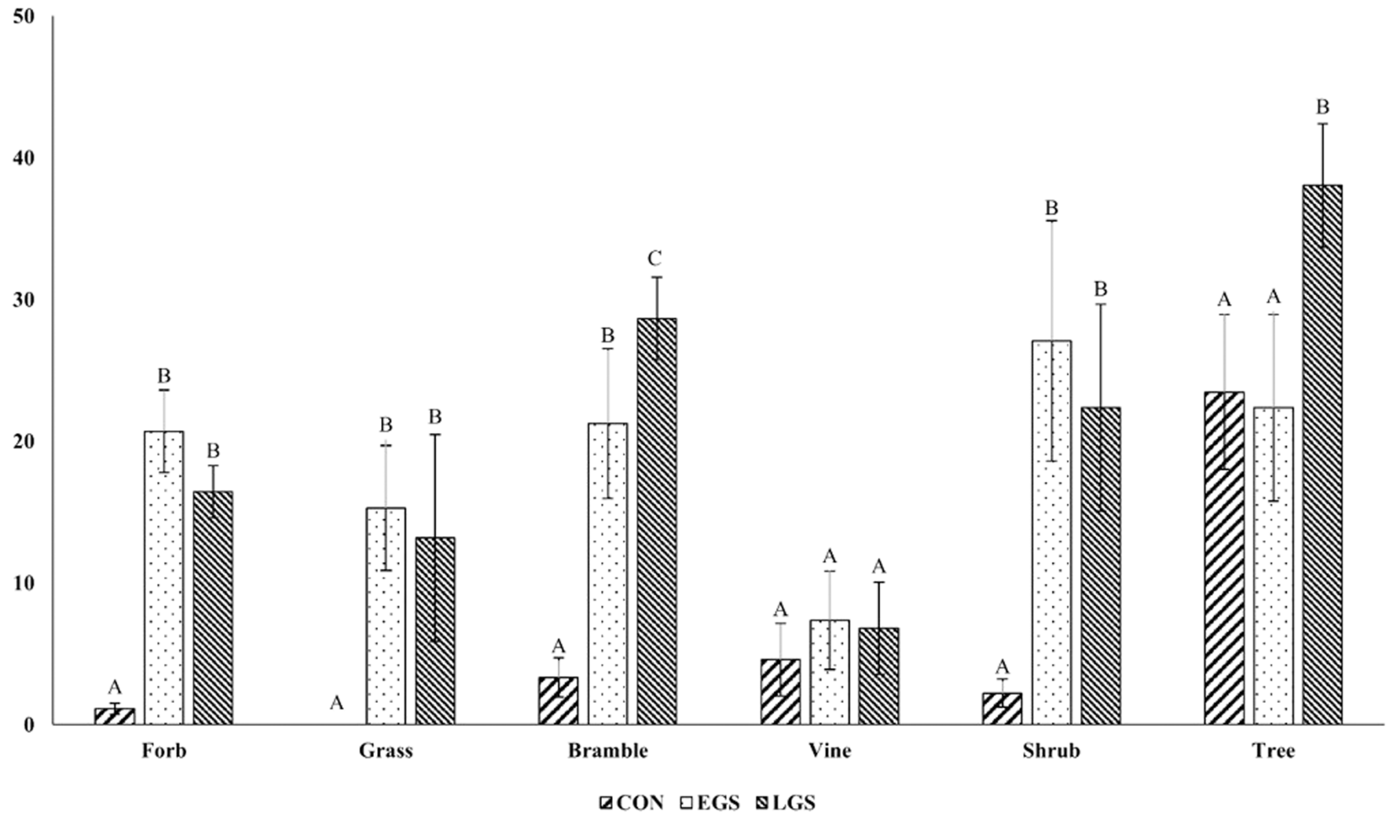

Fig. 1. Average coverage of understory forbs, grasses, brambles (*Rubus* and *Smilax* spp.), vines, shrubs, and trees in forest stands on Chuck Swan State Forest and Wildlife Management Area, Tennessee in July 2023 across three treatments: control (CON), shelterwood + early-growing season fire (EGS), and shelterwood + late-growing season fire (LGS). Different letters within a plant class indicate significant differences between treatments ($p < 0.05$).

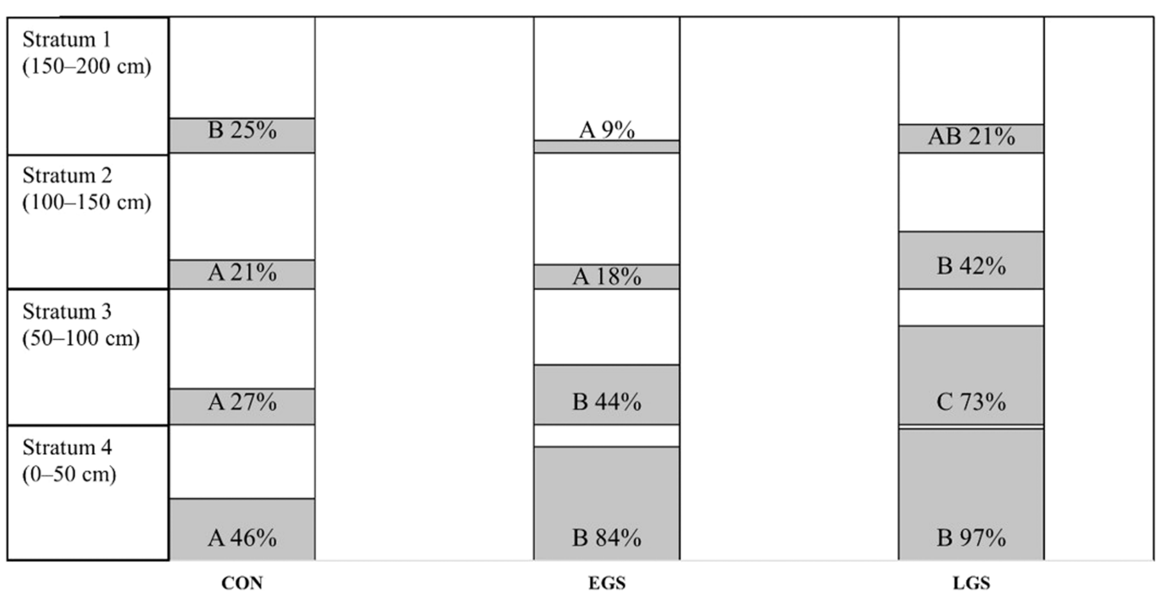

Fig. 2. Visual obstruction from 0–0.5, 0.5–1, 1–1.5, and 1.5–2-m above ground in forest stands on Chuck Swan State Forest and Wildlife Management Area, Tennessee in July 2023 across three treatments: control (CON), shelterwood + early-growing season fire (EGS), and shelterwood + late-growing season fire (LGS). Different letters within a stratum indicate significant differences between treatments ($p < 0.05$).

with greater visual obstruction between 1–1.5-m (Kilburg et al., 2014; Little et al., 2016; Johnson et al., 2022). LGS treatments also provided bedding and fawning cover for deer, with relatively dense structure from 0–1.5-m (Huegel et al., 1986; DePerno et al., 2003; Chitwood et al., 2017). Differences in structure have strong implications on wildlife use, and fire prescriptions should promote diverse understory structure for species that require different conditions during various life stages (Lashley et al., 2015a; Chance et al., 2020).

Deer forage was increased by EGS and LGS relative to the control, but EGS was the only treatment that increased NCC relative to the control. NCC provides an estimate of forage value relative to the nutritional demands of an animal, such as the requirements for a lactating doe

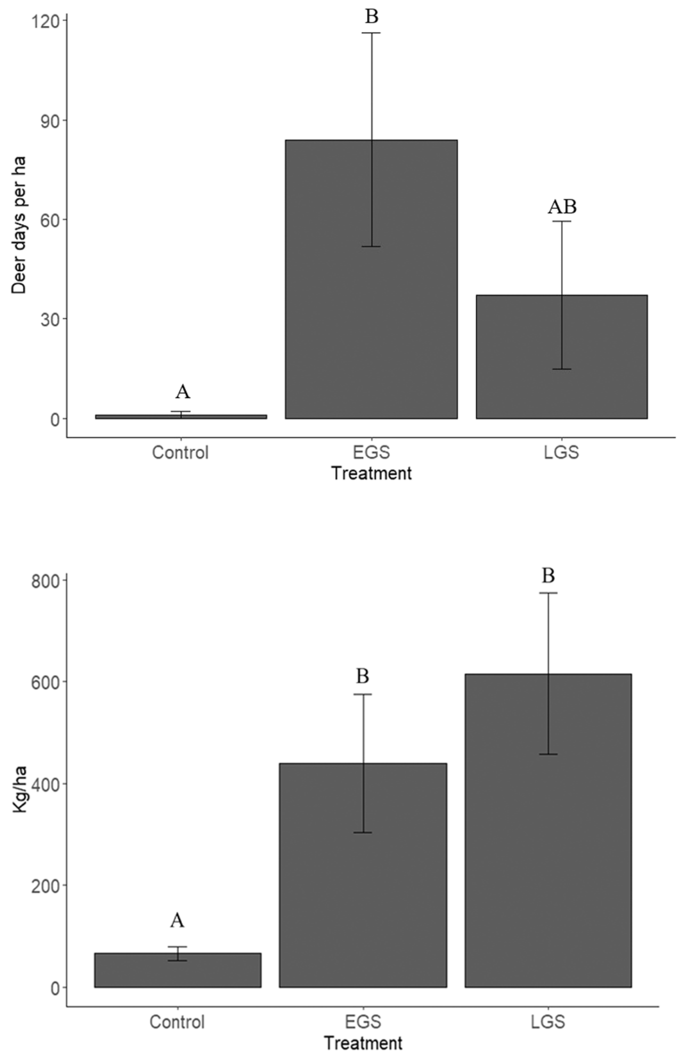

Fig. 3. White-tailed deer (*Odocoileus virginianus*) nutritional carrying capacity (a) and total biomass of selected forages (b) in forest stands on Chuck Swan State Forest and Wildlife Management Area, Tennessee in July 2023 across three treatments: control, shelterwood + early-growing season fire (EGS), and shelterwood + late-growing season fire (LGS). Nutritional carrying capacity calculated based on deer days per hectare using a 14% crude protein nutritional constraint. Different letters indicate significant differences between treatments ($p < 0.05$).

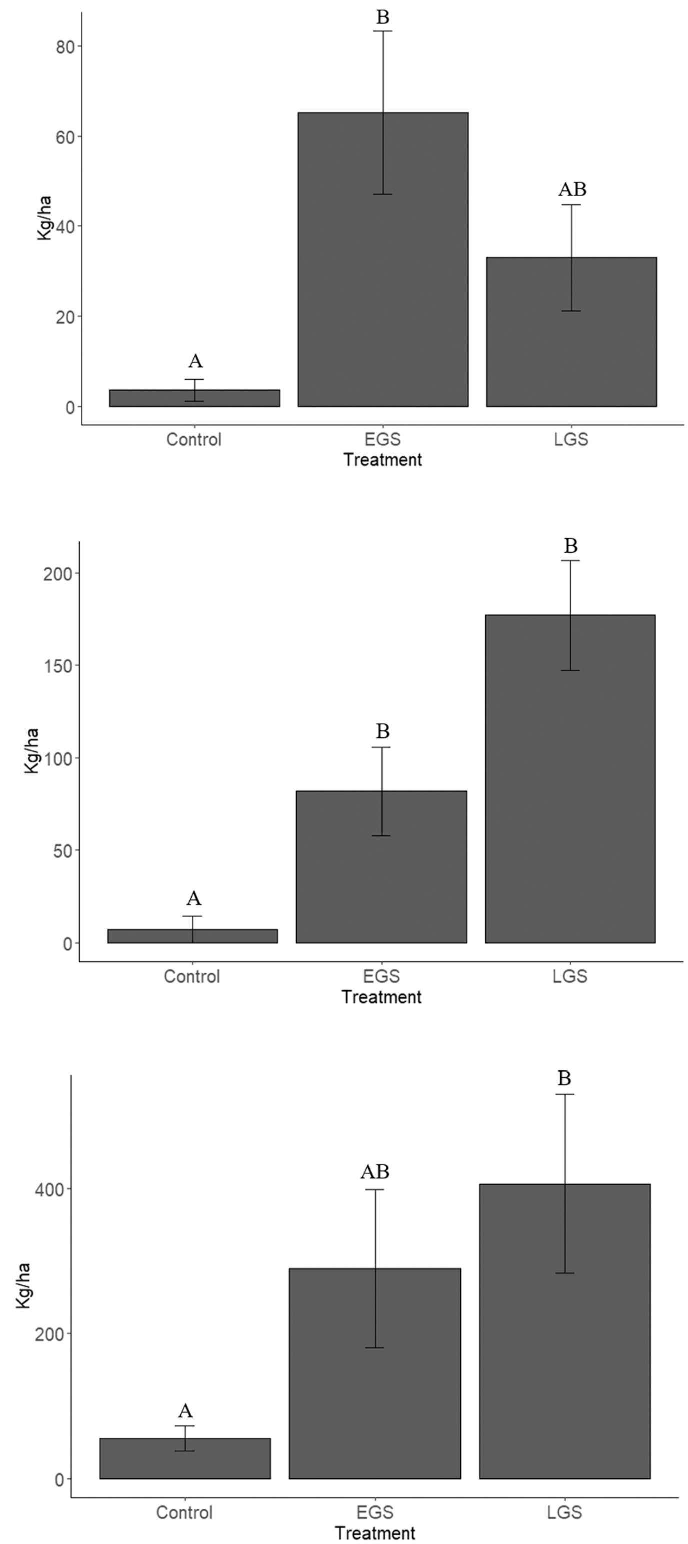

Fig. 4. Biomass of forbs (a), semiwoody (b), and woody (c) plants which are selected white-tailed deer (*Odocoileus virginianus*) forage plants in forest stands on Chuck Swan State Forest and Wildlife Management Area, Tennessee in July 2023 across three treatments: control, shelterwood + early-growing season fire (EGS), and shelterwood + late-growing season fire (LGS). Different letters indicate significant differences between treatments ($p < 0.05$).

(Hobbs and Swift, 1985; Nanney et al., 2018). Forage quality in the South often is limiting more than biomass (Edwards et al., 2004; Mixon et al., 2009), and our data suggest EGS fire promoted increased quality during our sampling in July. The recent fire in EGS promoted fresh resprouting of woody and semiwoody plants, which are more digestible and higher quality than older plant tissue (Lashley et al., 2014; Nichols et al., 2021; Turner et al., 2021a). The improved quality of fresh resprouting plants likely contributed to increased NCC in EGS despite reduced semiwoody plant biomass. We also recorded approximately 30 kg/ha more selected forbs in EGS than LGS, which contributed to the increased NCC because of the higher crude protein content of most forbs (Nanney et al., 2018). We collected forage during July, which corresponds with peak lactation demands in our region (Robbins and Moen, 1975; Diefenbach and Shea, 2011). However, high-quality forages also are required in spring during late gestation for females and antler growth for males (NRC 2007), and it is likely that LGS fire promoted increased high-quality forage earlier in the growing season. Our data indicate both LGS and EGS fire may be used to maintain forage availability throughout the growing season.

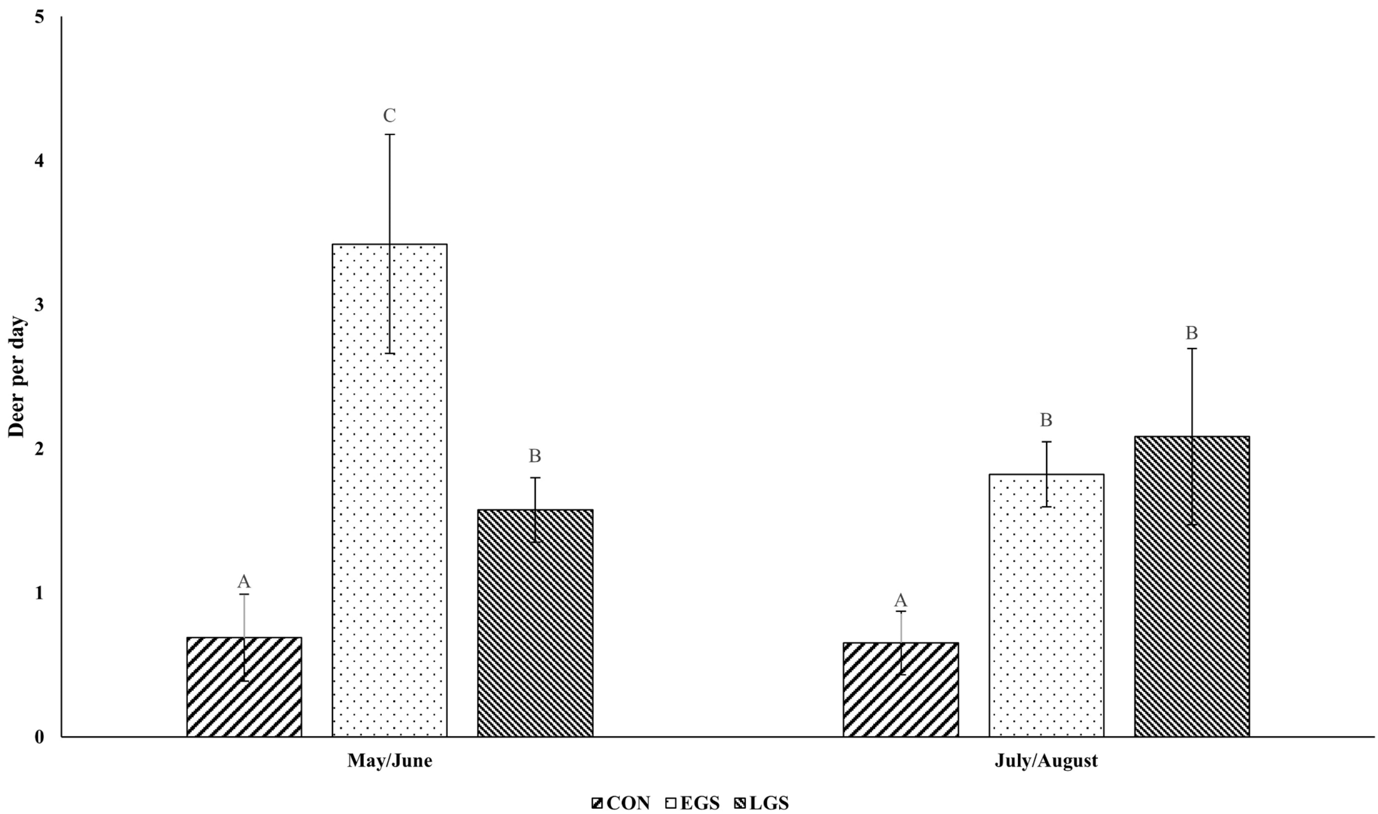

Fig. 5. Average daily detections of white-tailed deer (*Odocoileus virginianus*) in May/June and July/August 2023 in forest stands on Chuck Swan State Forest and Wildlife Management Area, Tennessee in three treatments: control (CON), shelterwood + early-growing season fire (EGS), and shelterwood + late-growing season fire (LGS). Different letters within a sampling period indicate significant differences between treatments ($p < 0.05$).

Deer detections were increased following canopy reduction and burning, with detections during May and June influenced by fire seasonality. The increased structure and forage in both LGS and EGS treatment units likely promoted deer use, as forage and cover were relatively limited in the control stands. Detections in EGS units were greater than LGS units in May– June but were similar in July–August. The difference in detection rates likely is related to increased forage quality 3–8 weeks after implementing the EGS fire. Resprouting woody and semiwoody plants in EGS likely led to increased deer use, as these young plant parts are more nutritious and highly digestible for several weeks following fire (Lewis et al., 1982; Nichols et al., 2021). Our findings contrast those of others who documented deer avoiding freshly burned areas (Lashley et al., 2015b; Cherry et al., 2017), possibly because sufficient cover was maintained in our EGS units and our units were relatively small. By July and August, the difference in forage quality between EGS and LGS would dissipate (Lewis et al., 1982; Eby et al., 2014), resulting in similar use between units. Both EGS and LGS fire treatments received greater use than control, highlighting the strong selection of forage and cover by deer during the growing season.

Turkey detections were greatest in EGS fire treatment units where there was increased structure < 1 m and sufficient visibility above 1 m. Turkeys tend to use areas with relatively open structure from 1–2-m throughout most of the growing season (Yeldell et al., 2017a; Wood et al., 2018). Brooding cover often is limiting for turkeys, and canopy reduction paired with fire promoted obstruction to conceal poults from 0–0.5 m and increased forb coverage (Campo et al., 1989; Johnson, 2019; Nelson et al., 2022). The increased fire intensity of the EGS fire treatment maintained open structure above 0.5-m, which is important to allow hens to detect predators (Metzler and Speake, 1985; Campo et al., 1989). We grouped females, poults, and males together for analysis, but EGS fire treatment units were the only units where we detected hens with poults, and the structure was similar to what hens with broods have been documented to select (Wood et al., 2018). The dominance of semiwoody and woody plants in the understory of the LGS fire treatment units caused reduced visibility > 50 cm. Had our LGS fire treatments been more intensive to prevent increased coverage of understory brambles and trees, turkey use of those units likely would have been similar to the EGS units. We believe these results are among the first to report on turkey use varying with fire during different periods of the growing season, and further research should investigate use throughout the year as related to burning during different seasons of the year.

Maintaining diversity in fire timing may provide resources for deer and turkeys during different periods of the year. Although use tended to be greater following EGS compared to LGS fire, especially for turkeys, this likely relates to our sampling timing. For example, the greater coverage of brambles and trees and increased structure from 0.5–1.5-m following LGS fire likely promoted enhanced nesting cover for turkeys (Little et al., 2016; Johnson et al., 2022). Turkeys also may have used the LGS units readily in the fall immediately after fire because of the open structure and exposed food resources (Yeldell et al., 2017b). Similarly, increased understory tree coverage following LGS fire may provide increased browse for deer during the winter, as well as bedding cover throughout the year (Kroeger et al., 2020). Future work should investigate effects of fire seasonality on wildlife use during other periods of the year. Our results indicate both EGS and LGS fire may be applied in upland hardwoods following canopy reduction, and their use promotes different resources for deer and turkeys.

5. Conclusions

Canopy reduction and fire during EGS or LGS increased understory vegetation relative to CON, with limited compositional differences. However, there were differences in the resulting structure of vegetation as related to fire intensity. Managers can adjust fire intensity to influence

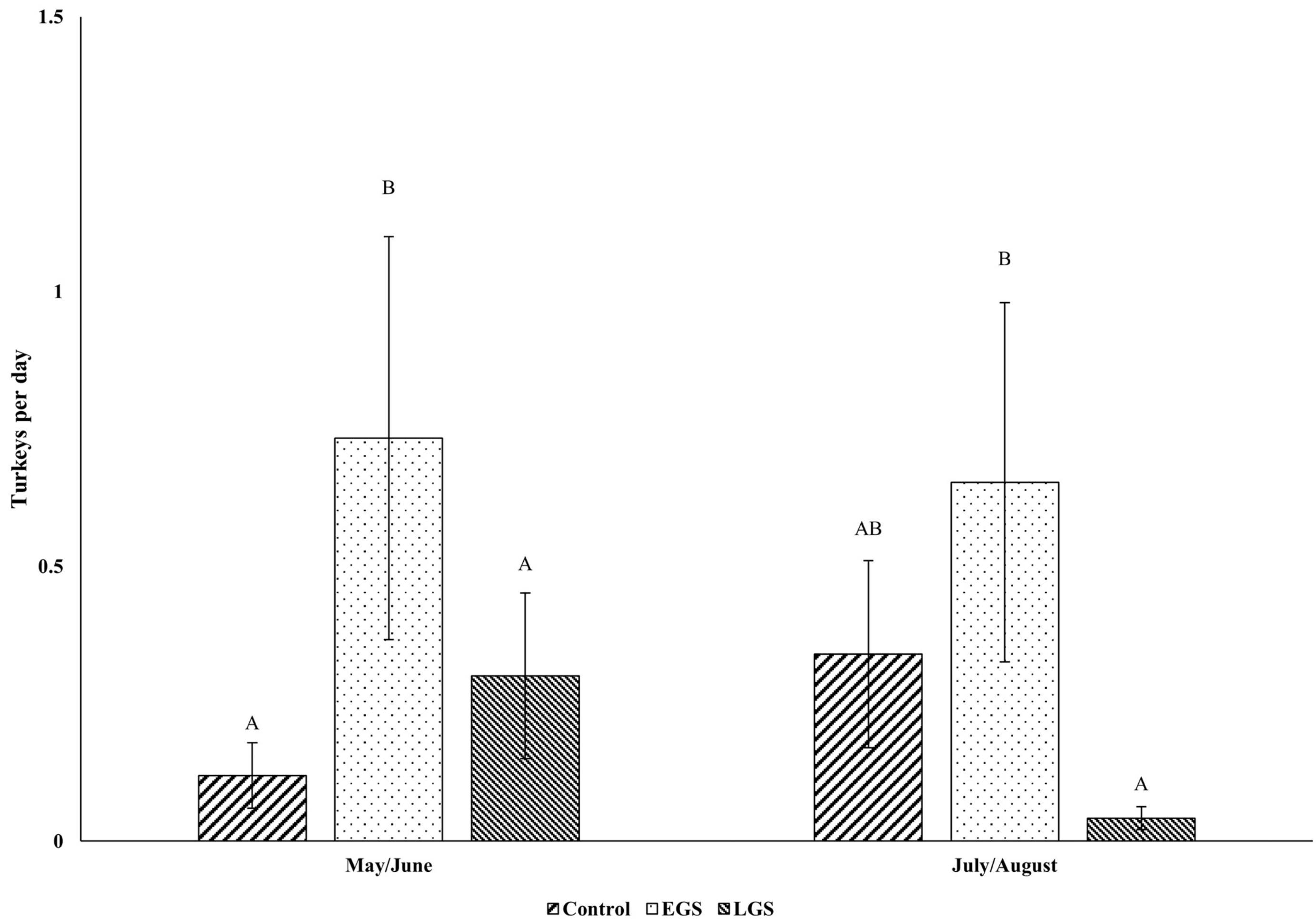

Fig. 6. Average daily detections of wild turkeys (*Meleagris gallopavo*) in May/June and July/August 2023 in forest stands on Chuck Swan State Forest and Wildlife Management Area, Tennessee in three treatments: control (CON), shelterwood + early-growing season fire (EGS), and shelterwood + late-growing season fire (LGS). Different letters within a sampling period indicate significant differences between treatments ($p < 0.05$).

Fig. 7. Upland hardwood stands on Chuck Swan State Forest and Wildlife Management Area, Tennessee following three treatments: Control, shelterwood + early-growing season fire (EGS), and shelterwood + late-growing season fire (LGS).

structure according to objectives and take advantage of burning opportunities during late summer/early fall to better meet fire management goals. Fire during either season promoted deer forage and cover relative to CON, but we only recorded an increase in NCC in July following EGS fire, which had been implemented just several weeks prior to forage sampling. Managers should consider implementing multiple fires from spring through fall across a management area to provide a continual pulse of resprouting vegetation that is highly digestible and nutritious for deer. Turkey use was greater following EGS fire, likely because of the open structure during the time we sampled. Managers should consider burn weather conditions when implementing LGS fire to achieve fire intensity sufficient to top-kill woody saplings and brambles. We recommend managers use fire during different seasons to promote various resources for deer and turkeys throughout the year.

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CRediT authorship contribution statement

Mark A. Turner: Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Visualization, Project administration, Funding acquisition **Jacob T. Bones:** Methodology, Investigation, Data curation, Writing – review & editing. **Spencer G. Marshall:** Methodology, Investigation, Data curation, Writing – review & editing. **Craig A. Harper:** Conceptualization, Methodology, Validation, Investigation, Resources, Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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