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Use of pine-dominated forests by female eastern wild turkeys immediately after prescribed fire

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ABSTRACT

Prescribed fire is used in southeastern pine forests to maintain desirable forest conditions and provides herbaceous understory plant communities for wildlife. However, it is unclear how time-since-fire affects the short-term response of wild turkeys (*Meleagris gallopavo*) to prescribed fire. We examined use of recently burned pine stands by female eastern wild turkeys (*M. g. silvestris*) immediately following prescribed fire in a pine-dominated landscape managed with frequent fire. We developed several models to best predict the influence of time-since-fire and month of fire application on turkey use of burned areas. We also assessed the spatial behavior of turkeys when using recent burns to determine if distance to escape cover affected turkey use of recently burned areas. Female turkeys used burned areas immediately after fire and probability of use increased until 141 days post-fire and then declined until 250 days post-fire when data collection stopped. Response of turkeys to recent burns depended on the month of prescribed fire application; probability of use was greater for areas burned in February and during the growing season (April and May). Turkey use of space within burned areas declined as distance to surrounding unburned areas increased, suggesting that turkeys favor the edge of burned and unburned areas which could serve as escape cover. However, the effect of distance to the perimeter of burned stand decreased as time-since-fire increased. Our findings suggest that turkeys are less likely to use areas burned in early winter (e.g., December) than late winter (e.g., February), and are more likely to use space near edges of burned areas than the interior. We recommend managers in southeastern pine-dominated ecosystems apply dormant season fires in late winter and apply early spring growing season fires as needed to meet forest management objectives. Turkeys used burned areas immediately following prescribed fire, but traded-off exploitation of foraging opportunities by using space near escape cover. Applying prescribed fire on smaller patches in checkerboard fashion may enhance turkey use of the entirety of a burn unit, and future research should seek to delineate other variables influencing how turkeys use recently burned areas. We recommend applying prescribed fire to patches smaller than those burned on our study sites at frequent (2–3) year fire-return intervals to increase usable space for female turkeys throughout the reproductive period.

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1. Introduction

Management of longleaf pine (*Pinus palustris*) forests necessitates frequent (e.g. 1–3 years) fire return intervals to limit midstory encroachment by fire impeding hardwood species and maintain open canopy (Kirkman et al., 2004). Repeated, low-intensity fires limit accumulation of fuels, resulting in top-killing of ground-cover forbs, shrubs, and sapling hardwoods which resprout from underground storage organs the following growing season (Drewa et al., 2002). Understory interactions with fire are highly dynamic; variation in timing of fire and fuel load can alter fire intensity and influence survival of understory plants, germination of herbaceous plants, and future vegetation conditions (Thaxton and Platt, 2006; Ellair and Platt, 2013; Wiggers et al., 2013). Reduction of midstory plants and variations in fire intensity promote diversity in understory plant growth, woody plant stem density, germination of legumes and grasses, and vertical and

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horizontal structure (Brockway and Lewis, 1997; Thaxton and Platt, 2006, Grady and Hoffmann, 2012). However, these changes can be ephemeral because reduction in fire frequency allows hardwoods to increase in the midstory and overstory (Provencher et al., 2001; Beckage et al., 2009; Haywood, 2012), decreasing the prominence of herbs and grasses and reducing structural heterogeneity in the understory (Kush et al., 2000; Varner et al., 2000).

The timing of prescribed fire affects composition of vegetation communities (Haywood et al., 2001; Glitzenstein et al., 2003; Haywood, 2012). Application of fire during the dormant season promotes growth of herbaceous forbs and resprouting of shrubs and hardwood species (Brockway and Lewis, 1997; Sparks et al., 1998; Haywood, 2012; Cronan et al., 2015). However, vegetation regrowth is initially slower for vegetation experiencing dormant season prescribed fire, meaning bare ground can be present for longer durations when compared to growing season burns (Sparks et al., 1998). Fire application during the growing season promotes regrowth of grasses (Sparks et al., 1998; Haywood, 2010; Shepherd et al., 2012), but reduces resprouting of woody plants (Drewa et al., 2002; Robertson and Hmielowski, 2014). These differences in vegetation are most dramatic during the first growing season after fire; vegetation communities converge as time-since-fire increases (Varner et al., 2000; Provencher et al., 2001; Beckage et al., 2009).

The eastern wild turkey (*Meleagris gallopavo silvestris*; hereafter, turkey) inhabits pine (*Pinus* spp.)-dominated ecosystems in the southeastern United States that are frequently managed with prescribed fire. Prescribed fire in pine forests occurs prior to and during the reproductive period of turkeys and may immediately affect habitat quality. Herbaceous vegetation comprises a substantial component of turkey diets (Exum et al., 1987; Hurst, 1992) and improved access to food items remaining after fire disturbance may increase attractiveness of burned stands to turkeys (Martin et al., 2012; Kilburg et al., 2014). Likewise, increases in ground cover vegetation (Wiggers et al., 2013), herbaceous plants (Ellair and Platt, 2013), and invertebrates (New, 2014) may increase concealment and forage availability (Campo et al., 1989; Burk et al., 1990; Sisson et al., 1990; Still and Bauman, 1990). However, the sparse understory immediately after prescribed fire but before plant regrowth (Lavoie et al., 2010), coupled with decreases in midstory structure may increase search efficiency of avian predators (Andersson et al., 2009), and remove possible escape cover. These changes in forage availability and predation risk suggest habitat quality may differ within a burned stand. For example, turkeys may use recently burned areas, but may exploit areas closest to escape cover to reduce predation risk until understory vegetation regrowth provides visual concealment from predators.

The recent development of GPS-equipped transmitters for use with wild turkeys has enhanced our ability to describe behavior, particularly space use and movement ecology (Collier and Chamberlain, 2010; Guthrie et al., 2011; Gross et al., 2015; Cohen et al., 2015). Although previous research with VHF-transmitters has suggested turkeys may avoid burned areas within 10-days after fire (Perez, 2013), and probability of use may peak 250 days after fire (Martin et al., 2012), changes in use of recently burned areas may be more subtle. The timing of application of prescribed fire and the availability of other vegetation communities to provide escape cover likely both affect how turkeys immediately respond. Because shifts in habitat quality may alter fitness of turkey populations in fire-influenced pine forests, we sought to examine turkey use of burned pine stands following prescribed fire application. Our objectives were to examine female turkey use of pine stands treated with prescribed fire and describe patterns of use within 1 year following fire application. Particularly, we examined how timing of prescribed fire application and distance to cover affected turkey use of recently burned pine stands.

2. Materials and methods

2.1. Study area

We conducted research on Kisatchie National Forest (KNF) and Fort Polk Wildlife Management Area (WMA) in west-central Louisiana. The KNF was owned and managed by the United States Forest Service (USFS) and was divided into 5 Ranger Districts. We conducted research on the Kisatchie Ranger District, Winn Ranger District, and the Vernon Unit of the Calcasieu Ranger District located in Natchitoches, Winn, and Vernon Parishes, respectively. Fort Polk WMA was jointly owned by the USFS and the United States Army. The northern portion of Fort Polk WMA owned by the US Army was within the Fort Polk Joint Readiness Training Center, whereas the southern portion lied within the Vernon Unit of KNF. Environmental conditions and forest management practices were similar on the Vernon Unit and Fort Polk WMA, hence we considered these areas as a single study site. The spatial extents of Kisatchie Ranger District, Winn Ranger District, and the Vernon/Fort Polk area were approximately 41,453 ha, 67,408 ha, and 61,202 ha, respectively. The area was composed of pine-dominated forests, hardwood riparian zones, and forested wetlands, with forest openings, utility right-of-ways, and forest roads distributed throughout. Overstory trees included longleaf pine, loblolly pine (*P. taeda*), shortleaf pine (*P. echinata*), slash pine (*P. elliottii*), sweetgum (*Liquidambar styraciflua*), oaks (*Quercus* spp.), hickories (*Carya* spp.) and red maple (*Acer rubrum*). Understory plants included yaupon (*Ilex vomitoria*), American beautyberry (*Callicarpa americana*), blackberry (*Rubus* spp.), greenbrier (*Smilax* spp.), wild grape (*Vitis* spp.), broomsedge (*Andropogon virginicus*), woodoats (*Chasmanthium* spp.), and panic grasses (*Panicum* spp. and *Dichanthelium* spp.). Privately owned land within and surrounding KNF were also available to turkeys. Much of this land was used for industrial timber production and was comprised of even-aged stands of loblolly pine and recent clearcuts $\leq$4 years old.

Land managers on KNF used prescribed fire to promote growth of longleaf pine, inhibit growth of undesirable hardwood species, and reduce fuel loads (Haywood, 2012). Prescribed fire was primarily applied to mesic upland sites containing pine-dominated and mixed pine-hardwood stands. Prescribed fire was applied in both dormant seasons (December-March) and growing seasons (April-July), with most fires (71.3% of total area burned) applied in dormant seasons. The average size of burn patches on KNF was 484.93 ha (SD = 295.33) but ranged from 7.28 to 1567.35 ha. The proportion of public land within the study area burned annually was 23.2% and 19.2% in 2014 and 2015, respectively. Most upland pine stands were burned on a 3–4 year rotation, although some areas had no recent burn history at the time of this study. Prescribed burning was uncommon on private lands within the boundary of and surrounding KNF.

2.2. Animal capture and GPS relocations

We captured female turkeys using rocket nets during January-March of 2014 and 2015. We classified each turkey as adult or subadult based on presence of barring on the ninth and tenth primary feathers (Pelham and Dickson, 1992). We fitted all turkeys with a serially numbered, butt-end style or riveted aluminum tarsal band. We also fitted each turkey with a backpack-style GPS transmitter equipped with a VHF beacon and mortality sensor weighing approximately 88 g (Lotek Minitrack Backpack L; Lotek Wireless Inc., Newmarket, Ontario, Canada). We programmed GPS transmitters to record hourly locations from 0600 to 2000 each day and one nightly roost location at midnight. All birds were released on site immediately after processing. We used a hand-held, 3-element

Yagi antenna and R2000 receiver (Advanced Telemetry Systems, Inc., Isanti, MN) to locate and monitor status of radio-marked individuals ≥1 time per week from mid-February to mid-August. Turkey capture, handling, and marking procedures were approved by the Institutional Animal Care and Use Committee at the University of Georgia (AUP #A3437-01).

2.3. Prescribed fire and stand delineation

We obtained spatial data from USFS, the US Army Environmental and Natural Resources Division, and local forest product companies which detailed areas and dates of prescribed fire applications during the study period. We used these data to create a map of fire events which occurred during the study period and 4 years prior to the beginning of each year of our study. We defined a recently burned area as a pine-dominated stand burned between October prior to turkey capture and June following turkey capture. In cases in which adjacent stands were burned on the same day, we considered the units as a single unique burn compartment. We also developed a 30 m resolution land cover map of major plant communities throughout our study area (see Yeldell et al., 2017a, in press-b). Briefly, we classified forest stands as pine, mixed-pine hardwoods, hardwood, open, and wetland based on stand inventory data. This information provided us with vegetation communities which were not recently burned within our study area.

2.4. Availability and use

To determine availability of burned areas to radio-marked turkeys, we generated a 100% minimum convex polygon (MCP) around all recorded GPS locations of each turkey and identified all turkeys whose MCP intersected ≥1 burned area. We assumed that any burned area within a turkey MCP was available to that individual. For every GPS location, we generated 3 random locations within the MCP for each individual turkey. These 3 random locations shared the same time-stamp as the known GPS location. This provided us with an initial ratio of 3:1 known to random locations across an individual's MCP. To examine use of recently burned areas, we then selected only used (known) and available (random) locations falling within recently burned areas. In other words, we excluded locations that fell outside of recently burned areas. We also excluded locations falling within recently burned areas when time-stamps indicated they occurred prior to application of prescribed fire. This provided us with a different ratio (i.e., no longer a constant 3:1 ratio) of used to available locations within recently burned areas for every time-stamp for each individual in our study. We then calculated the associated time-since-fire value for all used and available locations as the time (days) lapsed between the date of the location's associated time-stamp and the prescribed fire application. This allowed us to analyze the influence of time-since-fire on probability of use based on time-stamps associated with used and random locations. Because we were interested in the response of turkeys immediately following fire, we excluded any used or random location with a time-since-fire value >250 days.

2.5. Statistical analyses–probability of use of recently burned areas

We used generalized linear models (GLM) within the package 'lme4' (Bates et al., 2015) implemented in R version 3.1.1 (R Core Team, 2013) to evaluate influence of time-since-fire on probability of turkey use of recently burned areas. We modeled probability of use by selecting time-since-fire as a continuous predictor variable and used (known turkey locations) and available (random locations) locations as a binary response variable. We assumed a binomial distribution and treated known turkey locations as a 1 and random locations as a 0. We treated time-since-fire at each location as a fixed effect on probability of use. Timing of fire application affects vegetation communities and vigor of plant growth immediately following fire (Robertson and Hmielowski, 2014) which may affect turkey's response to a recently burned area. Therefore, for each used and available location we extracted the month prescribed fire was applied based on the burn date of the stand the location fell within. We treated month of fire application as a fixed effect. We scaled our time-since-fire predictor variable by a factor of 50 to improve model convergence. We developed three models to predict probability of use of burned areas as a function of time-since-fire and month during which fire occurred, then used an information-theoretic approach to select the most parsimonious model (Table 1). Our first model predicted turkey use of burned areas would increase linearly as time-since-fire increased and that use would be influenced by the month during which fire was applied. Our second model also included month of fire application, but assumed a quadratic relationship between time-since-fire and turkey use of burned areas, in that turkeys would increase their selection of recently burned areas until a point in time where recently burned areas lost some of their perceived value, and probability of use would decline. Our third model included month of fire application as a lone predictor of use. Lastly, to ensure our variables were informative, we created a null model which included no predictor variables. We used second-order Akaike's Information Criteria (AIC*c*) to determine the weight of evidence in support of each model (Burnham and Anderson, 2002). We calculated adjusted Akaike's weights (w_i) for each model to select the most parsimonious model from the candidate set. We selected the most parsimonious model based on the lowest AIC_c value and examined parameter estimates of fixed effects from that model. We used these parameter estimates to predict the effect of time-since-fire on probability of use of a burned stand. We assessed goodnesss-of-fit for these models using the Hosmer-Lemeshow statistic, where p-values >0.05 suggest adequate goodness-of-fit (Hosmer and Lemeshow, 1980). We then evaluated each model's predictive power by calculating area-under-the-receiver-operating-characteristic-curve (AUROC) values. Area-under-the-receiver-operating-characteristic-curve values close to 0.50 indicate no predictive power whereas those close to 1.00 indicate excellent predictive power.

2.6. Statistical analyses – distribution of use in recently burned areas

Because prescribed fire immediately opens understory structure, which may decrease available escape cover, we sought to examine if turkeys used certain areas within recent burns. In particular, we examined if distance to escape cover influenced the spatial distribution of turkey locations within recently burned areas. We considered escape cover to be any vegetation community that was not recently burned. For each turkey that used a burned area following fire application, we counted number of used locations within an individual burn compartment following fire application and generated 3 random locations within the same burn compartment. This provided a ratio of 3 random to 1 used location. Each random location was associated with a single used location and therefore shared the same time-since-fire value. For turkeys that used multiple burned areas, we generated separate sets of random locations within each unique burn compartment used. For each random and used location, we then calculated the distance to the nearest vegetation community not recently burned.

Similar to our analysis above, we used GLM to evaluate influence of distance to unburned vegetation on probability of turkey space use within recently burned areas. We modeled probability of use by treating distance to escape cover and time-since-fire as continuous predictor variables and used (known turkey locations) and available (random locations) locations as a binary response

Table 1
Models used to predict use of recently burned forested areas by female eastern wild turkeys at Kisatchie National Forest, west-central Louisiana, USA, 2014 and 2015. Models used logistic regression where time-since-fire was a linear covariate and month of fire application was a categorical covariate.

Model[a]	K[b]	AICc[c]	ΔAICc[d]	Adjusted w_i[e]	Goodness-of-fit[f]	AUROC[g]
TSF (polynomial) + month	8	96855.3	0.00	1.00	0.43	0.79
TSF (linear) + month	7	96937.5	82.13	0.00	0.15	0.61
Month	6	97142.7	287.40	0.00	0.12	0.60
Null	1	97418.4	563.09	0.00	0.00	0.50

[a] Covariates within models included time-since-fire (TSF) and month of fire application (month).
[b] Number of model parameters (*K*).
[c] Second-order Akaike's Information Criterion (AIC*c*).
[d] Difference between candidate model and top performing model.
[e] Adjusted Akaike weight of evidence (w_i) in support of model.
[f] P-values for Hosmer-Lemeshow goodnesss-of-fit test to evaluate general model fit. Smaller values are indicative of poorer fit.
[g] Area-under-the-receiver-operating-characteristic-curve scores estimating the predictive performance of each candidate model. Values of 0.50 are considered to have no predictive power. Predictive power of model is considered to be stronger as values approach 1.00.

variable. We assumed a binomial distribution and treated known turkey locations as a 1 and random locations as a 0. We scaled our distance to escape cover and time-since-fire predictor variables by a factor of 100 to improve model convergence. We developed 3 models to predict probability of use within burned areas as a function of distance to escape cover and days since the fire occurred, and then used an information-theoretic approach to select the most parsimonious model (Table 2). Our first model predicted turkey use within burned areas would decrease as distance to escape cover increased. Because vegetation cover is lowest immediately following a burn, but increases with time (Jones et al., 2013), time-since-fire may affect how important turkeys perceive escape cover to be. Therefore, because we hypothesized that time-since-fire would influence the spatial distribution of turkey locations within burns, our second model examined the interaction between distance to escape cover and time-since-fire on the spatial distribution of turkeys in a recently burned area. Our third model was a null model which included no predictor variables. We used AIC*c* to determine the weight of evidence in support of each model (Burnham and Anderson, 2002) and calculated adjusted Akaike's weights (w_i) for each model as an estimate of the probability of that model being the most parsimonious. We selected the most parsimonious model based on the lowest AIC*c* value and calculated parameter estimates of fixed effects from that model. Again, we used Hosmer-Lemeshow goodness-of-fit test to evaluate general model fit and calculated AUROC values for each candidate model.

3. Results

We based our results on 48 female turkeys captured and radio-marked during the winters of 2014 and 2015. We observed no direct mortalities of turkeys attributable to fires. No turkey nests failed during our study due to prescribed fire burning the nesting area or nest bowl (Yeldell et al., 2017a). One nest was exposed to fire after initiation, but the female returned to the nest the following day to continue egg deposition (Yeldell et al., 2017a). Forty-two females had MCPs that intersected a recent burn, whereas 6 females did not. Turkey use of recent burns was associated with 23 unique burns applied from 08 December to 30 May ($\bar{x}$ = 09 March) and ranged in size from 32.3 to 1668.5 ha ($\bar{x}$ = 618.8, SD = 412.0). Nineteen females maintained an area of use that included 1 unique recent burn, 16 maintained areas of use that included 2 burns, and 3 maintained areas of use that contained 3 burns. We recorded locations of 10 females inside a burn compartment on the day of fire application; two females remained in the burn compartment the entire day it was burned. Female #60274 remained within a burn compartment as it was burned and continued to use the area for at least 1 week after, at which time we lost contact with the transmitter (Fig. 1). Similarly, Female #60343 remained within a burn compartment as it was burned, then returned to a nest location within the burn compartment the following day and resumed nesting activity (Fig. 2).

Three females were located within burn compartments during peak times of fuel consumption, but left the area later in the day. For example, Female #52 was located within a burn compartment as it was ignited and left the area at approximately 1700, but continued to use the area during daylight hours in the following weeks (Fig. 3). Two females were outside of burn compartments during ignition, but entered the burned areas immediately afterward. For example, Female #64 was not located inside a burn compartment in the 13 days prior to fire, but entered the burn compartment only hours after ignition and continued to use the area for approximately 1 month (Fig. 4). Two females exited a burn compartment the morning fire was applied, then returned later in the day (presumably after most fuel consumption). One female exited a burn compartment on the morning of fire application (04 May) and did not return to use the area, but instead used another area burned on 03 May throughout May and early June.

Probability of use of a recently burned area was best predicted by the relationship between time-since-fire and month of fire application, with our quadratic model being the most parsimonious (w_i = 1.00; Hosmer-Lemeshow = 0.43; AUC-ROC = 0.79; Table 1). This model suggested probability of turkey use of recently burned areas peaked at 141 days post-fire application (Fig. 5) and decreased to 250 days post-fire, when data collection stopped. Probability of use tended to increase if application of prescribed fire occurred later during the calendar year. For example, probability of use was lowest in areas burned during December and highest in areas burned during April (Table 3).

We used data from 38 individuals who had locations within recently burned areas to determine if probability of use within recently burned areas was best predicted by distance to escape cover and time-since-fire. We found that the interaction model, in which distance to escape cover interacted with time-since-fire, was the most parsimonious (w_i = 1.00; Hosmer-Lemeshow = 0.38; AUC-ROC = 0.76; Table 2). As distance to escape cover increased, probability of use within a recently burned area decreased (Table 4). However, as time-since-fire increased, distance-to-escape cover was less predictive of probability of use within a recently burned area (Table 4).

4. Discussion

Prescribed fire immediately alters vegetation communities and may influence habitat availability for female wild turkeys (Palmer and Hurst, 1998; Martin et al., 2012; Little et al., 2016; Yeldell et al., 2017b). Because prescribed fire events occur concurrent with turkey reproductive season (Yeldell et al., 2017a), understanding

Table 2
Models used to predict space use within recently burned forested areas by female eastern wild turkeys at Kisatchie National Forest, west-central Louisiana, USA, 2014 and 2015. Models used logistic regression where distance to surrounding unburned areas and time-since-fire were linear variables.

Model[a]	K[b]	AICc[c]	ΔAICc[d]	Adjusted w_i[e]	Goodness-of-fit[f]	AUROC[g]
Distance to cover * TSF	4	105920.8	0.00	1.0	0.38	0.76
Distance to cover	2	106038.0	117.21	0.0	0.19	0.63
Null	1	106306.1	385.27	0.0	0.00	0.50

[a] Covariates within models included distance to unburned vegetation communities and time-since-fire (TSF).
[b] Number of model parameters (K).
[c] Second-order Akaike's Information Criterion (AICc).
[d] Difference between candidate model and top performing model.
[e] Adjusted Akaike weight of evidence (w_i) in support of model.
[f] P-values for Hosmer-Lemeshow goodnesss-of-fit test to evaluate general model fit. Smaller values are indicative of poorer fit.
[g] Area-under-the-receiver-operating-characteristic-curve scores estimating the predictive performance of each candidate model. Values of 0.50 are considered to have no predictive power. Predictive power of model is considered to be stronger as values approach 1.00.

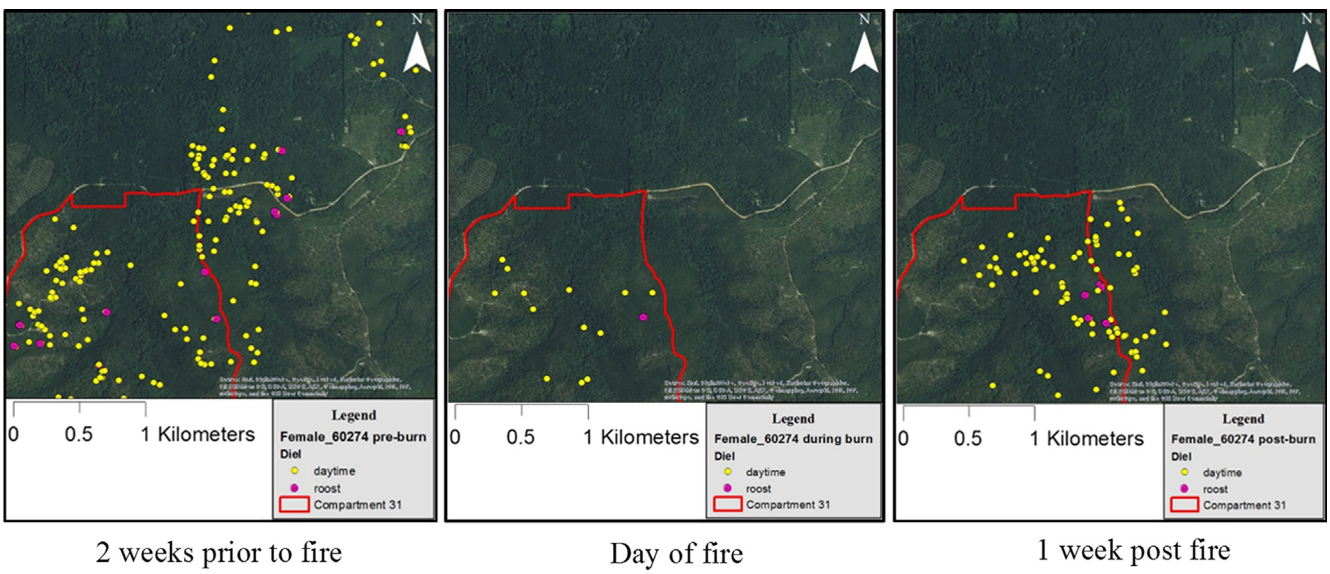

Fig. 1. Locations of adult female eastern wild turkey #60274 relative to an area treated with prescribed fire on 3 May 2015 at Kisatchie National Forest, west-central Louisiana. Red outline depicts outer boundary of burned area. Locations shown depict diurnal activity as yellow circles and nocturnal roost locations as pink circles 2 weeks prior to prescribed fire application, on the day of fire application, and 1 week following fire application. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

how female turkeys use areas immediately after fire is critical for understanding if prescribed fire creates unusable area across a landscape. We observed females using recently burned areas in the days and weeks following fire disturbance, suggesting that low intensity fires do not completely displace turkeys from treated areas. Within recently burned areas, female turkeys increased use of these areas up to 141 days after a fire, at which point use decreased. Month of prescribed fire application also affected probability of using a recently burned area with probability of use tending to increase as month of prescribed fire application advanced from winter to spring. Turkeys preferred to use the area within recent burns that were closer to escape cover; probability of using space within burned areas decreased as distance to surrounding unburned vegetation increased, but the negative effect of distance to escape cover was dampened as time-since-fire increased.

Prescribed fires are often applied prior to and during the turkey reproductive period, hence influence of fire on space use could affect distribution of usable space for nesting and brood-rearing. We found that female turkey use of burned areas was sensitive to time-since-fire, with use increasing following fire and peaking at 141 days before declining. Martin et al. (2012) reported female turkeys avoided vegetation communities that were older than 500 days-since-fire, with selection peaking around 125 days-since-fire in a pine-dominated landscape. Whereas Martin et al., (2012) examined selection of fire-influenced vegetation communities up to 1375 days-since-fire, our study only examined selection of recently burned areas within the first 250 days following fire. Nonetheless, our findings agree with the assertion that female turkeys use of recent burns peaks within 150 days-since-fire. The herbaceous plant community immediately after fire declines after the first growing season on sites similar to KNF (Haywood, 2009, 2010). Also, prevalence of bare ground declines rapidly after prescribed fire application (Jones et al., 2013). Because turkeys feed on a variety of herbaceous plants and foods found in leaf litter (Hurst, 1992), all of which may be exposed after a fire removes litter from the ground, use of recently burned areas may increase foraging opportunities for turkeys (Schoener, 1971). Stands with longer time-since-fire intervals (e.g., 1, 2 years post-fire) may converge in habitat suitability as longer burn interval regimes return primarily to hardwood-shrub communities (Provencher et al., 2001; Beckage et al., 2009) and may limit use by female turkeys.

Timing of fire application affected likelihood of female turkeys using recently burned areas. Female turkeys were less likely to use areas burned earlier in the calendar year, particularly in December and January on our study site. Similarly, Sisson et al. (1990) found that turkeys avoided recently burned pine stands in winter. Conversely, areas burned in April or May were most likely to be used. Vegetation communities are a function of long-term fire

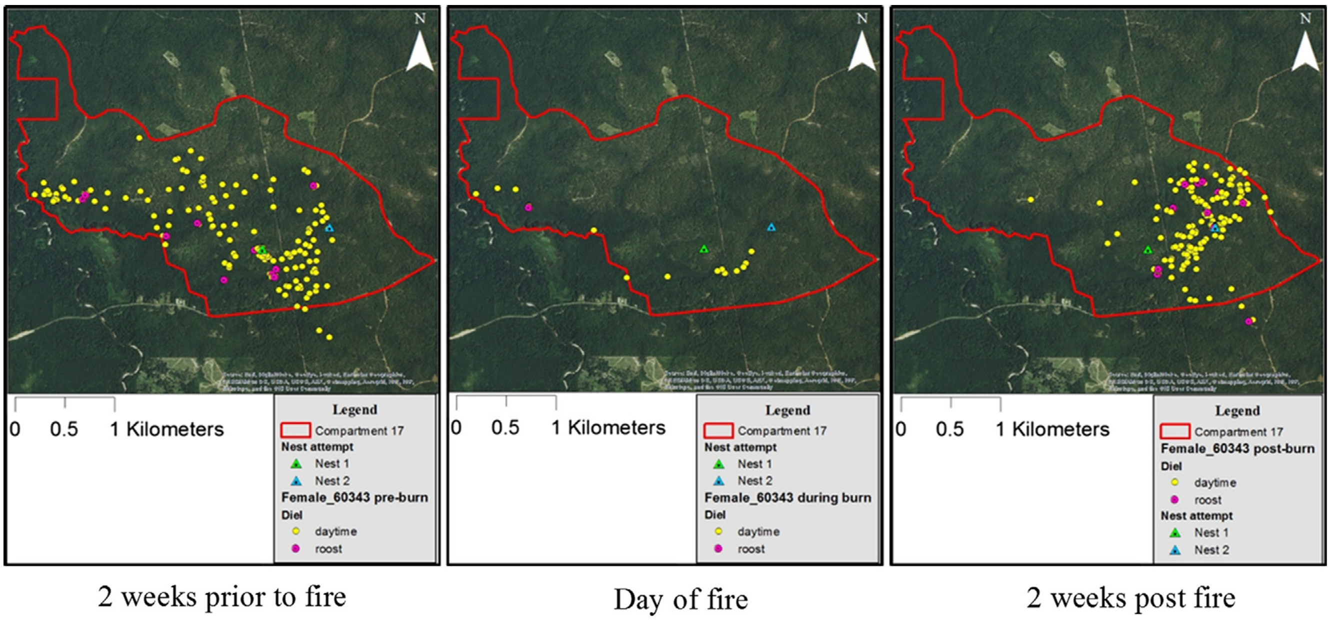

Fig. 2. Locations of subadult female eastern wild turkey #60343 relative to an area treated with prescribed fire on 15 May 2015 at Kisatchie National Forest, west-central Louisiana. Red outline depicts outer boundary of burned area. Locations shown depict diurnal activity (daytime) and nocturnal roost locations (roost) 2 weeks prior to prescribed fire application, on the day of fire application, and 2 weeks following fire application. First nest attempt (green triangle) incubated from 14 April to 26 April. Second nest attempt (blue triangle) initiated on 5 May and incubated from 18 May until hatching on 14 June. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

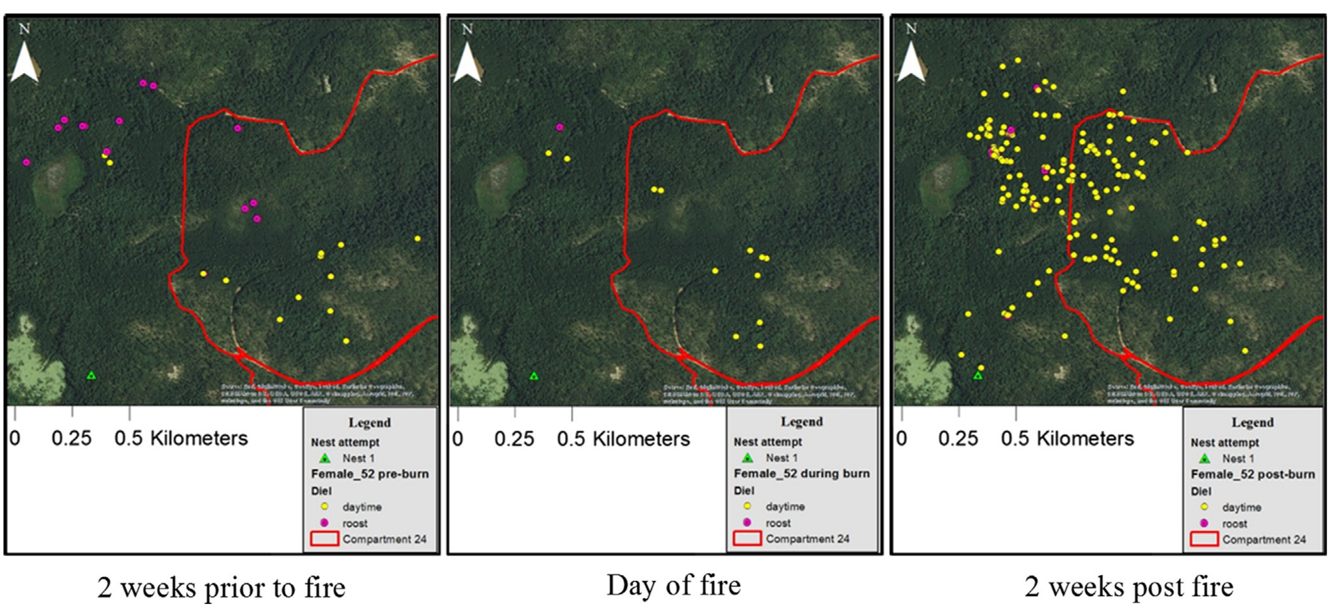

Fig. 3. Locations of adult female eastern wild turkey #52 relative to an area treated with prescribed fire on 16 February 2014 at Kisatchie National Forest, west-central Louisiana. Red outline depicts outer boundary of burned area. Locations shown depict diurnal activity (daytime) and nocturnal roost locations (roost) 2 weeks prior to prescribed fire application), on the day of fire application, and 2 weeks following fire application. First nest attempt (green triangle) incubated from 22 May to 24 May 2014. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

regimes (Brockway and Lewis, 1997; Glitzenstein et al., 2003; Addington et al., 2015; Cronan et al., 2015) and timing of fire application (Haywood, 2012). On KNF, prescribed fire applied during the growing season increases regrowth of grasses (Haywood, 2012). The preference of wild turkeys to use areas where prescribed fire was applied during the growing season may be a preference for the vegetation community response, or the immediate vigor of plant regrowth which turkeys may forage on (Hurst, 1992). Recent evidence suggests areas burned later in the calendar year does not substantially affect macroarthropod biomass in frequently burned pine-dominated landscapes (Chitwood et al., 2017). Fire immediately removes ground vegetation and leaf litter (Cronan et al., 2015), and application later in the calendar year may increase foraging efficiency for insects which are an important component of the wild turkey's spring and summer diet (Hurst, 1992)

Turkeys were less likely to use space within burned areas as distance to surrounding unburned vegetation increased. We offer that this finding was related to limited cover available to turkeys within

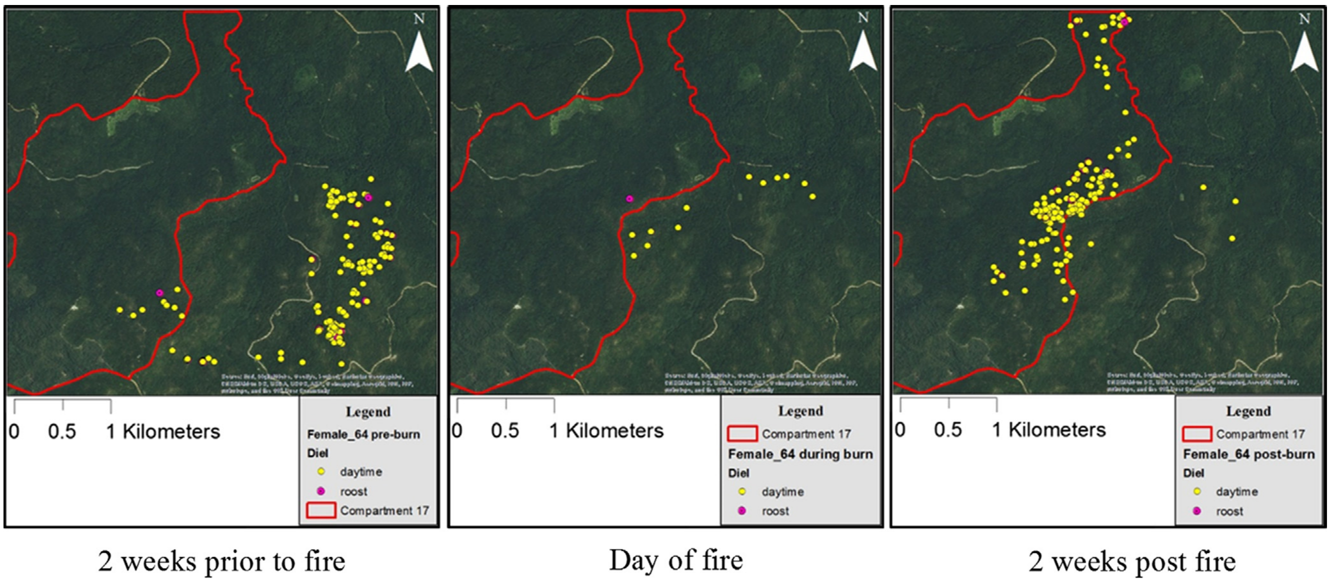

Fig. 4. Locations of adult female eastern wild turkey #64 relative to an area treated with prescribed fire on 28 February 2014 at Kisatchie National Forest, west-central Louisiana. Red outline depicts outer boundary of burned area. Locations shown depict diurnal activity (daytime) and nocturnal roost locations (roost) 2 weeks prior to prescribed fire application, on the day of fire application, and 2 weeks following fire application. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

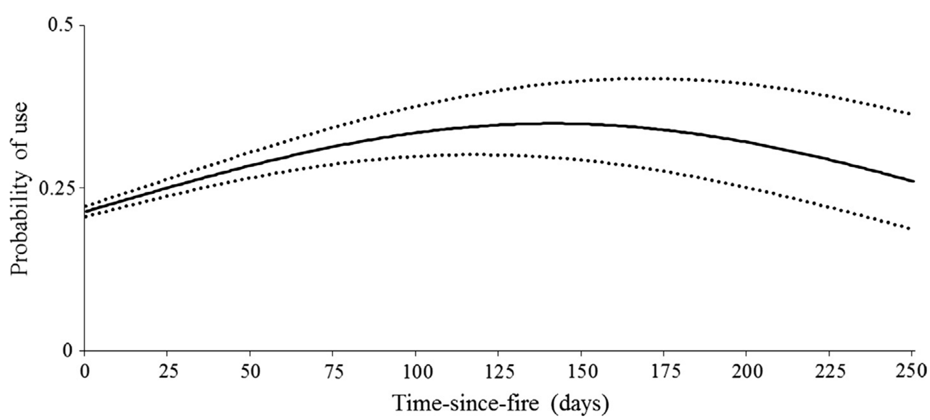

Fig. 5. Predicted probability of use (solid line) ± standard error (dotted line) of recently burned forested areas by female eastern wild turkeys as a function of time-since-fire at Kisatchie National Forest, west-central Louisiana, USA, 2014 and 2015. Probability of use by female wild turkeys peaked at 141 days after application of prescribed fire.

Table 3
Parameter estimates from the best approximating AICc model predicting use of recently burned forested areas, relative to time since fire application, by female eastern wild turkeys at Kisatchie National Forest, west-central Louisiana, USA, 2014 and 2015. Month of fire application was a categorical covariate with the month of December treated as a baseline category. Positive values for subsequent months represent increased probability of use compared to areas burned in December.

Parameter[a]	Estimate[b]	SE[c]	z-value	p-value	Scaler[d]
TSF	0.35	0.02	13.95	<0.01	50
TSF^2	−0.06	0.01	−9.09	<0.01	50
December	−1.54	0.04	−40.57	<0.01	–
January	0.32	0.04	7.38	<0.01	–
February	0.44	0.03	13.23	<0.01	–
March	0.04	0.05	0.70	0.48	–
April	0.52	0.05	10.44	<0.01	–
May	0.48	0.04	12.36	<0.01	–

[a] Covariates within model included time-since-fire (TSF) and month of fire application (6 levels: December – May).
[b] Parameter estimate on logit scale.
[c] Standard error (SE) of the estimate on logit scale.
[d] Scaler in meters (m).

recently burned areas. Northern bobwhites (*Colinus virginianus*) typically fly <75 m to escape cover, and researchers have advocated for provision of woody escape cover within 100 m to promote predator avoidance (Kassinis and Guthery, 1996). Likewise, a trade-off between high quality foraging opportunities and predation risk influences habitat selection by Himalayan snowcock

Table 4
Parameter estimates from the best approximating AICc model predicting space use within recently burned forested areas, relative to time-since-fire and distance to surrounding unburned vegetation communities, by female eastern wild turkeys at Kisatchie National Forest, west-central Louisiana, USA, 2014 and 2015. Negative values associated with time-since-fire and distance to cover are interpreted as turkeys being less likely to use space farther from unburned vegetation and less likely to use space as time-since-fire increases. A positive value associated with the interaction between distance to cover and time-since-fire is interpreted as a decrease in the effect of distance to cover as time-since-fire increases.

Parameter[a]	Estimate[b]	SE[c]	z-value	p-value	Scaler
Intercept	−0.73	0.02	−31.34	<0.01	–
TSF[d]	−0.25	0.03	−9.45	<0.01	100[e]
Distance to cover	−0.13	0.01	−17.82	<0.01	100[f]
Distance to cover * TSF	0.07	0.01	10.98	<0.01	–

[a] Predictor variables in models included distance from used and random locations within burned areas to unburned vegetation communities and time-since-fire (TSF).
[b] Parameter estimate on logit scale.
[c] Standard error (SE) of the estimate on logit scale.
[d] Time-since-fire (TSF) being the number of days between prescribed fire application and use of the space by a female turkey.
[e] Biologically relevant scaler in days.
[f] Biologically relevant scaler in meters (m).

(*Tetraogallus himalayensis*; Bland and Temple, 1990). Similarly, turkeys may use the interface between burned and unburned areas to balance food availability and proximity to escape cover. Further, remaining closer to unburned vegetation may reflect the availability of other resources outside the burned area such as loafing sites and potential nest sites. Woody cover is an important component of summer covert sites used by northern bobwhites to avoid hyperthermia (Miller and Guthery, 2005), and such cover is more abundant in unburned areas compared to recently burned areas. Remaining near the edge of recent burns may reduce energy expenditures associated with travelling between vegetation communities, thereby optimizing use of a patchy environment (MacArthur and Pianka, 1966). Regardless, our findings suggest that burn patch sizes at KNF tended to create interior space less preferred than space near the perimeter of recent burns. However, our work was not capable of determining the optimal size of burn patches that would increase useable space for turkeys.

5. Conclusions and management implications

Reported decreases in turkey populations across the southeastern United States (Byrne et al., 2015) has raised concerns about the suitability of prescribed fire for turkey management. In particular, timing and scale of prescribed fire application could affect habitat quality for turkeys. We did not document any nest loss directly because of prescribed fire during our study (Yeldell et al., 2017a). Our data suggests dormant season prescribed fire applied in late winter (February) increased likelihood of use by turkeys when compared to earlier months. Stands where prescribed fire was applied in spring (April and May) were most likely to be used, suggesting that spring burning is compatible with wild turkey management. Female turkeys readily used recently burned areas, but were more likely to remain near the perimeter than use interior space. Managers may want to burn in relatively smaller blocks in checkerboard fashion to increase the interface between burned and unburned areas and apply prescribed fire during the late spring to increase likelihood of use by turkeys. Recent evidence suggests turkeys do not select for pine stands ≥3 growing seasons post-burn during any part of their reproductive period (i.e., nesting, brooding, etc.; Martin et al., 2012; Yeldell et al., 2017a, 2017b), and nest survival is lower in stands ≥3 years post-burn (Yeldell et al., 2017a) than stands burned the current year. Managers can maximize useable space for female turkeys by burning on frequent (2–3 year) fire return intervals and maintain vegetation communities which female turkeys select for. Future research should assess the optimal burn patch size and spatial-arrangement of burn patches for turkeys in pine-dominated ecosystems.

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