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Research Article

Spatial Scale and Shape of Prescribed Fires Influence Use by Wild Turkeys

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ABSTRACT In recent years, there have been increasing efforts to understand effects of prescribed fire on population dynamics of wild turkeys (*Meleagris gallopavo*; turkeys) in pine (*Pinus* spp.) forests. Although distribution of turkeys is not limited to pine forests, these forests provide nesting and brood-rearing habitat throughout the southeastern United States. Previous studies have investigated direct (e.g., nest loss to fire) and indirect (e.g., nest- and brood-site selection) effects of prescribed fire, but little is known about how turkeys are influenced by the spatial scale and shape of prescribed fire. We constructed an individual-based model (IBM) with landscapes of 2 burn unit shapes and 17 spatial scales. We used telemetry data obtained from global positioning system-marked female turkeys to replicate movement behaviors of turkeys within the model. We hypothesized that use of units burned during the current year (<1 yr) would decrease as scale of fires increased, and that shape of burn units would influence use by turkeys. Spatial scale most influenced turkey use; the greatest use was in burned stands of approximately 23 ha in size, whereas least use was associated with burned stands >1,269 ha. At a spatial scale of 23 ha, the daily percent use of rectangular burn units was 7% greater than square-shaped burn units. Likewise, daily percent use of rectangular burn units was 34% greater than square-shaped burn units at a spatial scale of 1,269 ha. When burn units were rectangular-shaped, daily percent use decreased by 48% as the spatial extent of the fires increased from 23 ha to 203 ha. Likewise, when burn units were square-shaped, turkey use decreased by 49% as spatial extent of fires increased from 23 ha to 203 ha. Our findings suggest the importance of managing forested landscapes with prescribed fires not exceeding approximately 200 ha if wild turkeys are a management concern.

KEY WORDS fire return interval, *Meleagris gallopavo*, prescribed fire, spatial extent, spatial scale, wild turkey.

Natural mechanisms of disturbance (e.g., wildland fire, stochastic events) have been anthropogenically limited, thereby reducing diversity of vegetation types across many landscapes (Culver and Buzas 1995, Pickett and Rogers 1997). Hence, land managers use various forms of disturbance to encourage early successional vegetation communities and enhance growth and survival of wildlife populations (Andren 1995, Lashley et al. 2015). Pine forests in the southeastern United States provide an example of landscapes managed by disturbance, and demonstrate the role various forms of disturbances (e.g., distribution, frequency, size, severity; Pickett and White 1985) play in maintaining early successional vegetation communities in these forests. Pine forests across the southeastern United States are fire-maintained systems that developed with lightning and anthropogenic fires (Komarek 1964, Pyne 1982, Rorig and Ferguson 1999, Block et al. 2016). Therefore, resource managers use prescribed fire to attempt to maintain vegetation communities beneficial to various wildlife species that inhabit fire-maintained pine forests (Alavalapti et al. 2002, Lashley et al. 2015).

Recently, there have been increasing efforts to understand effects of prescribed fire on population dynamics of wild turkeys (*Meleagris gallopavo*; turkey) in pine forests managed with fire (Little et al. 2015; Yeldell et al. 2017*a*, *b*, *c*; Wood et al. 2018). The relative influence of fire on turkey reproductive success can be affected by scale (size of fire), timing (dormant vs. growing season), and fire return interval (Martin et al. 2012, Kilburg et al. 2014, Yeldell et al. 2017*a*). Previous researchers have investigated direct (e.g., nest loss to fire) and indirect (e.g., nest- and brood-site selection) effects of prescribed fire (Sisson et al. 1990, Martin et al. 2012, Little et al. 2016, Wood et al. 2018), but little is known about how turkeys are influenced by the spatial scale and shape of prescribed fires (Wann et al. 2019).

The spatial scale of prescribed fire management units (i.e., burn units) varies across lands managed by state and federal

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agencies. Contemporary literature has noted that average size of burn units on public lands can range from 26 ha (Wood et al. 2018) to approximately 485 ha (Yeldell et al. 2017*a*, *b*, *c*), but scaling of burn units may continue to expand as management agencies increase reliance on aerial ignition and address federally mandated fuel load reductions (Stephens et al. 2016). Expanding the scale of burn units may influence population dynamics of turkeys because vegetative communities could be influenced by scaling of fires (Thaxton and Platt 2006, Knapp et al. 2009, Lashley et al. 2014). Increasing the spatial scale of fires beyond some extent would presumably replace numerous smaller burn units with fewer larger ones (Beckage et al. 2005, Lashley et al. 2014, Holland et al. 2017). Likewise, shape of a burn unit can affect a species' ability to traverse and occupy patches because of the relationship between perimeter-area ratios and core areas (Helzer and Jelinski 1999). For species like turkeys, burn units with increased perimeter-area ratios provide a greater number of unburned areas juxtaposed to burned areas if the area of burned units is similar, thereby reducing movements necessary to reach escape cover during or after fires (Andersson et al. 2009, Lavoie et al. 2010) and during recolonization of burned areas immediately following fire (Yeldell et al. 2017*c*). Hence, altering burn unit shape to increase perimeter-area ratio may enhance the ability of turkeys to move to unburned patches juxtaposed to burned areas, increasing use of recently burned units (Lima and Dill 1990, Fischhoff et al. 2007).

Researchers have not detailed how scale and shape of burn units influence use of the landscape by turkeys (Wann et al. 2019). Previous studies on other species have used individual-based models (IBM; also known as agent-based models) to assess system-level mechanisms responsible for influencing population dynamics (DeAngelis and Gross 1992, Van Winkle et al. 1993, Huse et al. 2002). Individual-based models are simulation models that can be used to assess how system-level properties emerge from individual behavior, while also assessing system-level effects on individuals (Grimm et al. 2006, Railsback and Grimm 2012). System-level mechanisms emerging from IBM simulations at the individual-level are typically responsible for influencing population dynamics (e.g., survival and growth) of a species; hence, IBMs may be useful tools in decision-making regarding population and community-level management. Wild turkeys residing in pine forests managed with fire could be influenced by scale and shape of prescribed fires, so IBMs inherently provide a suitable framework to assess the influence of spatial scale and shape of prescribed fire on use by turkeys.

We hypothesized that wild turkey use of burn units would be influenced by the scale and shape of prescribed fires. Our objective was to assess and quantify these relationships. We predicted that use of recently burned (<1 yr) units would decrease as spatial scale of prescribed fire increased. We also predicted that shape of burn units would influence turkey use, with shapes offering more area juxtaposed to unburned stands being used more.

STUDY AREA

We conducted modeling partially using data collected on 5 study sites across the southeastern United States dominated by pine (*Pinus* spp.)-hardwood forest communities managed with dormant and growing season prescribed fire to manage understory vegetation communities. Those study sites included Kisatchie National Forest and Fort Polk Wildlife Management Area (WMA) in west-central Louisiana, Lake Seminole and Silver Lake WMAs in southwest Georgia, and the Webb WMA Complex in South Carolina, USA. Detailed descriptions of the study sites can be found in Yeldell et al. (2017*a*, *b*, *c*), Wood et al. (2018), and Wightman et al. (2019).

METHODS

We developed an IBM to assess the influence of spatial scale and shape of prescribed fire on use of burned stands by turkeys. Turkey movement was the only process in the model, and the use of recently burned units by turkeys was an emergent property of the model. The model outcome recorded daily percent use of burned units for the length of each model run. We built the model using the program NetLogo (Wilensky 1999) and an overview, design concepts, and details (ODD) protocol (Grimm et al. 2006, 2010), and have included more detailed descriptions of model processes and assumption, along with a summary of the model and some of the naming conventions associated with NetLogo (ODD protocol available online in Supporting Information). We followed recommendations provided in Grimm et al. (2006, 2010) for construction and reporting details in the ODD protocol.

We created 2 artificial landscapes composed of rectangular- or square-shaped burn units. The landscapes were composed of 225-m^2 squares (patches), which we used to create a repetitive pattern of burn units ranging in scale from 23–1,269 ha across the landscape (Fig. 1). Both landscapes were approximately 20,306 ha, and the size of burn units we evaluated was dictated by the shape of patches in each landscape. The square-shaped landscape consisted of 950×950, 225-m^2 patches, whereas the rectangular-shaped landscape consisted of $1{,}444 \times 625$, 225-m^2 patches. Each burn unit was equally distributed across the landscape creating a checkered pattern, with every fourth burn unit designated as a unit burned <1 year prior (i.e., recently burned). The remaining 3 burn units represented >1 but <3 years post-burn. This helped establish spacing between burn units, assuming a fire return interval of 3 years, which is common across multiple study sites that use fire to manage forest conditions (Kilburg et al. 2014; Yeldell et al. 2017*a*, *b*, *c*; Wood et al. 2018). Because previous researchers have already explored how timing of fire influences turkey response (Little et al. 2016; Yeldell et al. 2017*a*, *b*, *c*; Wood et al. 2018), we constructed our model to focus solely on issues relative to spatial scale and shape of prescribed fires. Thus, we programmed the model so that all recently burned units across the landscape were burned at a single time, so that we could evaluate how turkeys would respond

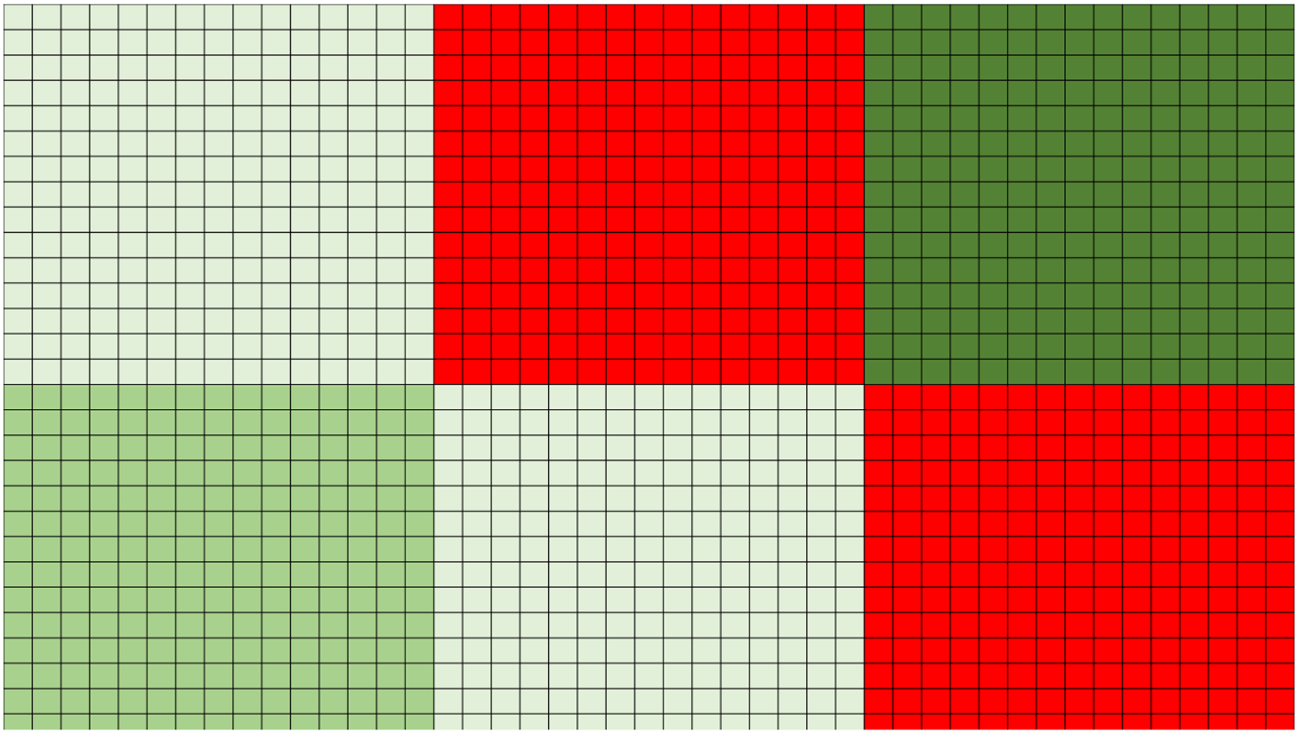

Figure 1. Example of simulated landscape composed of 4 burn units created by 225-m^2 squares (patches). We used repetitive patches to create landscapes with rectangular- and square-shaped burn units. Rectangular-shaped landscapes (1,444 × 625, 225-m^2 patches) and square-shaped landscapes (950 × 950, 225-m^2 patches) included 20,306 ha. Time since prescribed fire is represented by color of collective patches. Red indicates prescribed fire <1 year, light green indicates fire >1 year and <2 years, green indicates fire >2 years and <3 years, dark green indicates fire ≥3 years.

to fire solely as a function of spatial scale and shape. This approach reduced potential noise in the model because recently burned areas were considered such for the entire year.

We programmed the model to randomly distribute 40 turkeys (mobile agents) to unburned units (units burned >1 yr prior) across the landscape when the model was initiated. We initiated turkeys in unburned units because burned units represented the day of the fire when the model initiated, and we assumed turkeys would not be present within burn units the day fires occurred. Recently researchers detailing movements of wild turkeys using global positioning system (GPS)-telemetry have described daily movements using 14 locations collected from sunrise to sunset (Yeldell et al. 2017*b*, Wood et al. 2018); hence, we simulated turkeys in the model to move hourly for 14 hours per day, for 365 days. Turkeys could move in 2 ways, either through walking or foraging-loafing, and each turkey possessed individual tendencies to walk or forage-loaf. We distinguished these 2 movements using distances moved per hour coupled with turning angles between consecutive movements (see below). Each turkey had an individual propensity for walking based on telemetry data (i.e., turkey movements differed across individuals as they did within samples of GPS-marked birds) that was dependent on when the burn unit was burned last (ODD protocol in Supporting Information). This individual propensity for movement created stochasticity in the model.

We calculated estimates of hourly distances moved and turning angles between consecutive locations for walk and foraging-loafing movements using estimates for female wild turkeys reported in Cohen et al. (2019). For the walk movement, we set the distance a turkey walked to a numerical value drawn from a normal distribution with a mean of 241.7 ± 41.1 (SD) m. Walking turn angle was randomly set to right or left, and drawn from a normal distribution with an average of 45.9° ± 6.9°. Similarly, we set the distance moved while foraging-loafing to a value drawn from a normal distribution with a mean of 76.0 ± 11.3 m. Foraging-loafing turn angle was randomly set to right or left, and drawn from a normal distribution with an average 103.1° ± 9.8° (Cohen et al. 2019). Using these values, turkeys evaluated all patches at the given distance and turn angle, and used a probability for movement (based on distance to edge of a burned area) estimated for each patch. If the patch probability was greater than a random value between zero and 1, the turkey moved to one of those patches. If all probabilities were less than the random value, the turkey rotated (based on turning angles as outlined above) and did not move that hour (Fig. 2). This approach to estimate how individual turkeys move assumed they were able to recognize the distance they would walk in an hour, and use that distance to decide where to move within their ranges. We recognize this is likely unrealistic because individual birds are unlikely to move about their ranges through time based on how far they move on average; however, there is no way to know or comprehend minute-by-minute decision-making strategies used by turkeys in response to their environment. Therefore, we validated this assumption by visually comparing individual hourly movements of simulated turkeys in the model to actual GPS

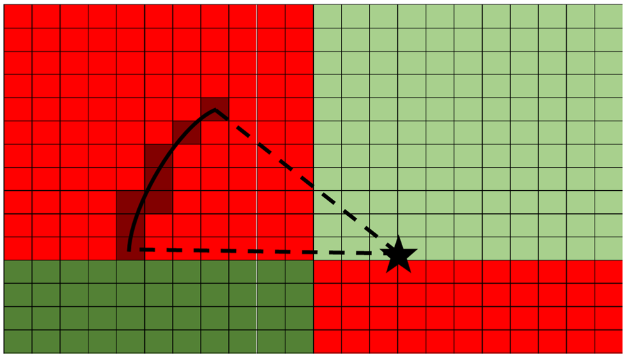

Figure 2. Graphical representation of how a wild turkey moved within the individual-based model. The black star represents the turkey. The dashed black lines represent the distance the turkey would move during that time step (depending on location and movement type). The solid black line represents the turn angle of the turkey, including both left and right turn directions. The red squares represent patches (225 m^2) within recently burned units. The dark red patches are those patches evaluated for potential movement. The probability of movement (based on distance to edge of a burned area) is estimated for each patch, then compared to a random number between 0 and 1. If the patch probability was greater than the random value, the turkey moved to one of those patches. If all probabilities were less than the random value, the turkey rotated (based on turn-angles as outlined above) and did not move that hour.

movement tracks of birds used by Cohen et al. (2019), and determined that predicted movement tracks looked similar to actual movement tracks generated from data on GPS-marked birds, and that birds in model runs avoided the interior of larger burn units as detailed for turkeys in Yeldell et al. (2017*b*). Likewise, the modeling approach we used assumed 100% survival and no predation events, but such parameters could be included in models. Although predator encounters likely vary in relation to spatial extent of fires, we thought including such metrics would over-complicate the model and compromise the ability to focus solely on issues related to scale and shape of prescribed fires.

We described turkey use of landscapes relative to scale and shape of prescribed fires using the daily percent use of burn units, which we defined as the proportion of burned areas used ≥1 time by a turkey within 1 day. This metric allowed us to approximate relative use of recently burned areas compared to surrounding areas, while accounting for the number of recently burned areas in the model run. We then ran the model for 10 simulations per burn unit size and shape (34 total landscapes) to capture variance in daily percent use (Gilbert 2008). We used an analysis of variance (ANOVA) to compare daily percent use of recently burned units across different burned unit areas for rectangular-shaped and square-shaped burn units. Because turkey behavior did not change daily in the model, each day served as a replicate and each model run contained 365 days. Therefore, using 10 simulations per burn unit across 365 days resulted in 3,650 replicates per landscape. This level of replication resulted in measures of variation (e.g., SE) that approached zero. We used Tukey honest significant difference *post hoc* tests to determine significance levels among spatial scales at $\alpha = 0.05$. We also calculated the percentage decrease in daily use of each burn unit size and shape relative to the smallest burn unit of each shape. We calculated the percentage difference in daily percent use between rectangular- and square-shaped burn units as a metric for relative influences of shape on predicted use of stands following burns.

We then binned daily percent use of recently burned units by spatial scales for each burn unit shape in increments of 10% difference starting with the spatial scale with greatest daily percent use. We delineated each bin as a category of high (41–50% use), moderate (31–40% use), minor (21–30% use), low (11–20% use), or very low (0–10%) levels of use for easier interpretation. We visualized our data and performed all analyses using Program R (Wickham 2016, R Core Team 2017).

RESULTS

We observed that daily percent use of recently burned units was greatest at the smallest spatial scale of fire, regardless of shape, and declined as scale increased (Table 1). Differences in daily percent use varied between square- and rectangular-shaped burn units, and ranged from 3% to 34%. Specifically, at the smallest spatial scale of 23 ha, the daily percent use of square-shaped burn units (45.3%) was 7% less than use of rectangular-shaped burn units (48.8%). The daily percent use of square-shaped burn units (8.7%) was 34% less than use of rectangular-shaped burn units (13.2%) at the largest spatial scale (1,269 ha; Table 1).

For landscapes with rectangular-shaped burn units, we observed a 48.8% decrease in daily percent use as the spatial scale increased from 23 ha to the median of 203 ha (Table 1; Fig. 3). Similarly, for landscapes with square-shaped burn units, we observed a 49.4% decrease in daily percent use as the spatial scale increased from 23 ha to 203 ha. At 203 ha, daily percent use fell below 25%, irrespective of burn unit

Table 1. Simulated mean daily percent use of recently (<1 yr) burned units and associated standard deviations (SD) by female wild turkeys across 17 spatial scales and 2 shapes (rectangular- and square-shaped). The percentage decrease (% D) in percent use is for each scale relative to the smallest scale for each shape of burn unit.

Scale of burn unit (ha)	Rectangular-shaped unit			Square-shaped unit		
	$\bar{x}$	SD	% D	$\bar{x}$	SD	% D
23	48.8	7.6	0.0	45.3	7.7	0.0
27	46.5	8.0	4.8	43.8	7.8	3.3
32	42.2	8.0	13.4	39.5	7.7	12.8
40	41.8	7.7	14.3	38.9	7.8	14.1
51	38.2	7.8	21.8	35.8	7.8	20.9
65	35.8	7.5	26.6	33.5	7.2	26.0
90	31.6	7.3	35.3	30.6	7.3	32.4
125	27.4	7.1	43.8	26.7	7.0	41.2
203	24.9	7.0	48.8	22.9	6.9	49.4
248	23.3	6.9	52.2	22.0	6.5	51.4
317	21.4	6.5	56.1	19.8	6.3	56.3
391	20.7	6.7	57.5	19.2	6.3	57.8
507	18.4	5.9	62.4	17.0	6.0	62.6
635	16.2	5.6	66.9	15.1	5.6	66.6
812	13.1	5.5	73.1	12.1	5.1	73.4
1,015	13.3	5.5	72.7	11.3	5.0	75.0
1,269	13.2	4.9	73.0	8.7	4.8	81.0

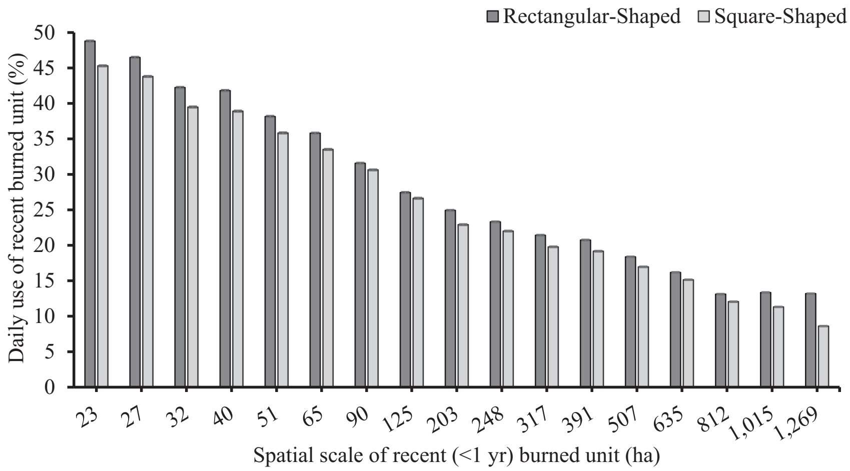

Figure 3. Daily percent use of recent (<1 yr) burned units by wild turkeys for 17 spatial scales of recent burned units (ha) and 2 burn unit shapes (rectangular- and square-shaped). Mean ± 1 standard error. Because of extensive model replication, standard errors approach zero.

shape (Table 1; Fig. 3). Hence, at 203 ha, daily percent use of recently burned units was similar to use of other available units, and as scale increased thereafter, daily percent use of burned units decreased relative to other available units. Results of ANOVAs and *post hoc* tests indicated daily percent use significantly differed across all spatial scales within rectangular- ($F_{16, 62,033} = 13,626$, $P < 0.001$) and square-shaped burn unit landscapes ($F_{16, 62,033} = 11,326$, $P < 0.001$). Because all spatial scales differed and *post hoc* tests did not reveal natural breaks in data, as noted above we binned daily percent use data in increments of 10% difference starting with the spatial scale with greatest daily percent use (23 ha; Fig. 4). For rectangular-shaped burn units, we found that burns not exceeding 40 ha fell within high levels of daily percent use, whereas burns exceeding 507 ha fell within the low levels of daily percent use. No rectangular-shaped burn units produced levels of daily percent use that fell into the lowest category. For square-shaped burn units, we found that burn units not exceeding 27 ha fell within highest levels of daily percent use, whereas burns 317–1,015 ha fell within low levels and burns of 1,269 ha fell within the lowest level.

DISCUSSION

Prescribed fire influences how wild turkeys and other species use portions of the landscape by maintaining patch-level heterogeneity through changes to vegetation structure (Andren 1995, Pickett and Rogers 1997, Lashley et al. 2015, Yeldell et al. 2017*b*). Our findings supported our prediction that use of recently burned units would decrease

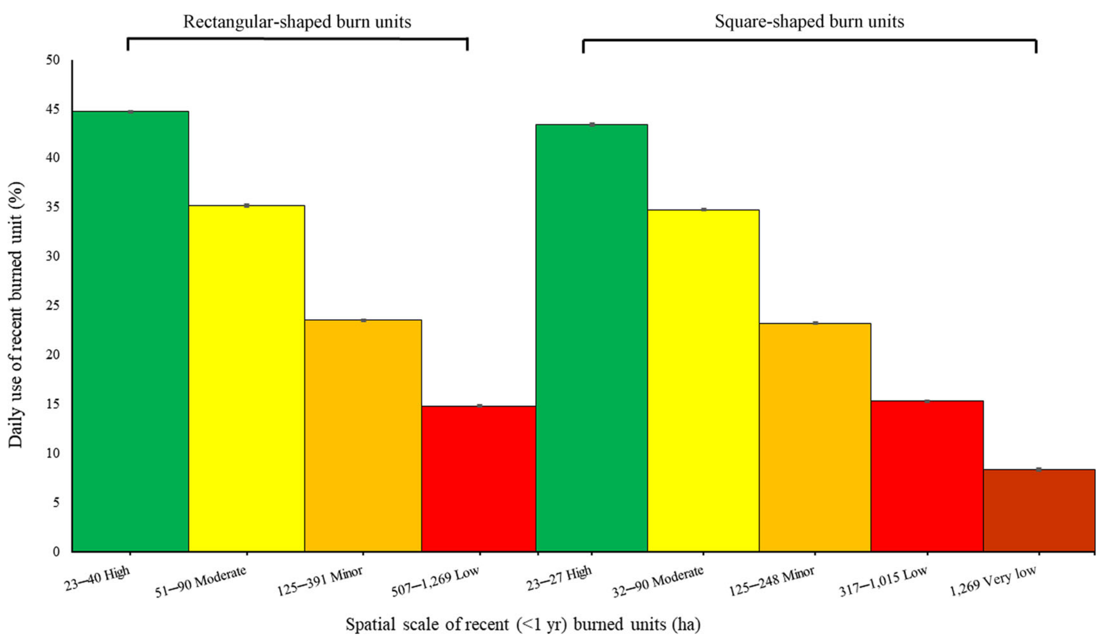

Figure 4. Binned daily percent use of recent (<1 yr) burned units by wild turkeys across 17 spatial scales and 2 shapes (rectangular- and square-shaped). Spatial scales of recent burned units are binned in increments of 10% difference starting with the spatial scale with highest daily use (23 ha), resulting in 4 bins (high, moderate, minor, low) for rectangular-shaped burn units and 5 bins (high, moderate, minor, low, very low) for square-shaped burn units. Because of extensive model replication, standard errors approach zero.

as spatial scale of fires increased. The model outputs suggested a marked and consistent decline in turkey use of recently burned stands with increase in spatial scale of fire. Indeed, turkeys selected recently burned units relative to the other 3 burn units available to them until reaching the median scale of 203 ha. At 203 ha, use of rectangular- and square-shaped burn units fell below 25%, suggesting that at that scale, recently burned areas were used similar to or less than the other 3 areas available to them.

Upland pine forests are commonly managed with disturbance to promote successional vegetation important for maintaining life-history strategies of fire-dependent species (Andren 1995, Conner et al. 2011). Patterns of space use within a species are constrained by body size and metabolic rate (McNab 1963, Harestad and Bunnell 1979), so when the scale of disturbance exceeds the scale at which species use space, habitat conditions (e.g., lack of diversity, structural complexity) within the species' home range can become exceedingly homogenous and unfavorable (Holling 1992, Lashley et al. 2015). Turkey space use is allometrically scaled (Gray 1986, Gray and Prince 1988, Coup and Pekins 1999) and published estimates of space use by wild turkeys in fire-managed landscapes lend support to our finding that prescribed fires at smaller spatial scales are more commensurate with the species' ecology. For example, Yeldell et al. (2017*b*) reported that average core area size of female turkeys was approximately 71 ha during pre-nesting, and Wood et al. (2018) reported pre-nesting home range sizes to be approximately 390 ha. We offer that once fires exceeded the median scale (~200 ha) in our model, such fires would conceivably confront turkeys with habitat and vegetation conditions not congruent with their scaling and space use patterns, particularly during spring reproductive seasons (Martin et al. 2012, Kilburg et al. 2014, Yeldell et al. 2017*b*, Wood et al. 2018, Cohen et al. 2019).

Previous researchers have reported that species maintaining home ranges rarely leave them during disturbance events (Verns and Pope 2001, Bechtoldt and Stouffer 2005, Thompson et al. 2008). Turkeys do not abandon their home ranges even during catastrophic disturbances such as flooding or wildfires (Chamberlain et al. 2013, Oetgen et al. 2015), instead shifting their use to areas not affected during the disturbance if possible, or remaining within the affected ranges. Yeldell et al. (2017*c*) reported that turkeys did not shift their home range in response to prescribed fires, and resumed using burned units almost immediately after fire events. Furthermore, turkeys are gregarious animals that maintain social groups, and their space use is influenced by hierarchical-dominance relationships developed through social hierarchies (Healy 1992). Collectively, findings detailed in earlier literature and our model results suggest that turkeys reasonably respond to prescribed fires by using areas available within their ranges, even when the scale of fires are disproportionate to their ecology.

Our modeling efforts provide a simplified representation of how turkeys would be expected to respond to prescribed fires, and our inferences were constrained relative to how we constructed the model. For instance, our model did not allow adjacent stands to be burned, even at different temporal scales (i.e., during same year but not on same day) because fires were applied in a single day in our model. Clearly, this scenario is not how fires are applied to the landscape, although in many situations, fires are applied in a narrow temporal window when fire conditions allow, and resource agencies often burn adjacent stands during the same year. Nonetheless, previous researchers have already reported how timing of fire influences turkey behavior (Little et al. 2016; Yeldell et al. 2017*a*, *b*, *c*; Wood et al. 2018). Likewise, our model did not account specifically for spatial variations in fire intensity across burn units, although Cohen et al. (2019) detailed influences of fire severity within burn units on turkey movements, and we used those data in our analyses as detailed herein (ODD in Supporting Information). We also recognize our model used landscapes represented by burn units with different fire-return intervals arranged systematically in a checkerboard fashion, rather than randomly distributing fires or otherwise distributing units with different fire-return intervals across the landscape. We did this for simplicity and consistency because attempting to arrange fires more intentionally across the landscape would inevitably introduce our own biases into the model. Lastly, the model assumed that each prescribed fire would prompt similar responses by turkeys on the landscape, which ignores the potential that individual fires produce variable conditions on the landscape; however, accounting for such spatial and temporal variation in fire behavior and resulting effects to the landscape were beyond the scope and capability of our modeling efforts.

At all spatial scales, percent daily use of rectangular burn units exceeded that within square units, although such differences were clearly not as biologically relevant as differences across spatial scales, and were most pronounced only at the largest spatial scales we considered. We offer that inclusion of additional shapes in our modeling approach would have provided opportunity to refine inferences relative to how shape of burn units could influence turkey behavior. Despite the minor differences we observed in predicted daily use by turkeys relative to shape of burn units, previous research suggests that shape of stands managed with fire should logically influence how turkeys respond to burns. For instance, previous works noted that shape of prescribed fire (e.g., elongated burn units) can produce discrete patches with different perimeter-area ratios (Helzer and Jelinski 1999) and edge characteristics (Bradstock et al. 2005, Magrach et al. 2011, Parkins et al. 2018) that influence turkey movements (Thogmartin 1999, Byrne and Chamberlain 2013, Kilburg et al. 2015). Likewise, small-scale and elongated burn units can reduce the distance a turkey must traverse within their home range to unburned areas after fires, thereby lessening energetic demands, reducing predation risks, and increasing the likelihood of survival (Thogmartin and Schaeffer 2000, Little et al. 2016). For example, insects are an important food source for turkeys during spring and summer (Healy and Nenno 1983) but are often limited in the distance they can traverse to recolonize burned areas (Swengel 2001). By creating a patch network of smaller-scale or elongated burn units, insects residing in adjacent unburned areas can rapidly recolonize burned areas, thereby increasing available forage to turkeys (Swengel 2001, Kiss and Magnin 2003, Kim and Holt 2012). Hence, more elongated burn units decrease the total distance across each burn unit, thereby reducing the distance a turkey must traverse to use interior areas of burned stands, and potentially promoting greater use of the burned area. We encourage future research that greatly expands our work to more rigorously detail relationships between shape and juxtaposition of burn units and turkey use.

MANAGEMENT IMPLICATIONS

Managers are faced with balancing requirements to reduce fuel loads across broad areas of public lands with the management of species of economic and social importance. Our results are relevant to managers of public and private lands where prescribed fire is used to manage forest communities and wild turkeys are a species of management interest. Our modeling suggested that predicted percentage of use by wild turkeys declined consistently as spatial scale of fires increased. We suggest that resource agencies managing upland pine forests with prescribed fire conduct burns at spatial scales ≤200 ha when possible. Larger burn units should be managed to create multiple smaller units that once burned would increase spatial heterogeneity and promote diverse vegetative conditions necessary to maintain turkey life-history strategies.

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LITERATURE CITED

Alavalapti, J. R. R., G. A. Stainback, and D. R. Carter. 2002. Restoration of the longleaf pine ecosystem on private lands in the US South: an ecological economic analysis. Ecological Economics 40:411–419.

Andersson, M., J. Wallander, and D. Isaksson. 2009. Predator perches: a visual search perspective. Functional Ecology 23:373–379.

Andren, H. 1995. Effects of landscape composition on predation rates at habitat edges. Pages 225–255 *in* L. Hanson, L. Fahrig, and G. Merriam, editors. Mosaic landscapes and ecological processes. Chapman and Hall, London, United Kingdom.

Bechtoldt, C. L., and P. C. Stouffer. 2005. Home-range size, response to fire, and habitat preferences of wintering Henslow's sparrows. Wilson Bulletin 117:211–326.

Beckage, B., W. J. Platt, and B. Panko. 2005. A climate-based approach to the restoration of fire-dependent ecosystems. Restoration Ecology 13:429–431.

Block, W. M., L. M. Conner, P. A. Brewer, P. Ford, J. Haufler, A. Litt, R. E. Masters, L. R. Mitchell, and J. Park. 2016. Effects of prescribed fire on wildlife and wildlife habitat in selected ecosystems of North America. The Wildlife Society Technical Review 16-01. The Wildlife Society, Bethesda, Maryland, USA.

Bradstock, R., M. Bedward, A. Gill, and J. Cohn. 2005. Which mosaic? A landscape ecological approach for evaluating interactions between fire regimes, habitat and animals. Wildlife Research 32:409–423.

Byrne, M. E., and M. J. Chamberlain. 2013. Nesting ecology of wild turkeys in a bottomland hardwood forest. American Midland Naturalist 170:95–110.

Chamberlain, M. J., M. E. Byrne, N. J. Stafford, K. L. Skow, and B. A. Collier. 2013. Wild turkey movements during flooding after opening of the Morganza Spillway, Louisiana. Southeastern Naturalist 12:93–98.

Cohen, B. S., T. J. Prebyl, B. A. Collier, and M. J. Chamberlain. 2019. Spatiotemporal variability of fire characteristics affect animal responses in pyric landscapes. Fire Ecology 15:article 41. https://doi.org/10.1186/s42408-019-0058-4

Conner, L. M., S. B. Castleberry, and A. M. Derrick. 2011. Effect of mesopredators and prescribed fire on hispid cotton rat survival and cause-specific mortality. Journal of Wildlife Management 75:938–944.

Coup, R. N., and P. J. Pekins. 1999. Field metabolic rate of wild turkeys in winter. Canadian Journal of Zoology 77:1075–1082.

Culver, S. J., and M. A. Buzas. 1995. The effects of anthropogenic habitat disturbance, habitat destruction, and global warming on shallow marine benthic foraminifera. Journal of Foraminiferal Research 25:204–211.

DeAngelis, D. L., and L. J. Gross. 1992. Individual-based models and approaches in ecology. Chapman and Hall, New York, New York, USA.

Fischhoff, I. R., S. R. Sundaresan, J. Cordingley, and D. I. Rubenstein. 2007. Habitat use and movements of plains zebra (*Equus burchelli*) in response to predation danger from lions. Behavioral Ecology 18:725–729.

Gilbert, N. 2008. Agent-based models. Second edition. Sage Publications, Thousand Oaks, California, USA.

Gray, B. T. 1986. Bioenergetics of the wild turkey in Michigan. Thesis, Michigan State University, Lansing, USA.

Gray, B. T., and H. H. Prince. 1988. Basal metabolism and energetic cost of thermoregulation in wild turkeys. Journal of Wildlife Management 52:133–137.

Grimm, V., U. Berger, F. Bastiansen, E. Sigrunn, V. Ginot, J. Giske, J. Goss-Custard, T. Grand, S. K. Heinz, G. Huse, et al. 2006. A standard protocol for describing individual-based and agent-based models. Ecological Modelling 198:115–126.

Grimm, V., U. Berger, D. L. DeAngelis, J. G. Polhill, J. Giske, and S. F. Railsback. 2010. The ODD protocol: a review and first update. Ecological Modelling 221:2760–2768.

Harestad, A. S., and F. C. Bunnell. 1979. Home range and body weight—a re-evaluation. Ecology 60:389–407.

Healy, W. M. 1992. Behavior. Pages 46–65 *in* J. G. Dickson, editor. The wild turkey: biology and management. Stackpole Books, Mechanicsburg, Pennsylvania, USA.

Healy, W. M., and E. S. Nenno. 1983. Minimum maintenance versus intensive management of clearings for wild turkeys. Wildlife Society Bulletin 11:113–120.

Helzer, C. J., and D. E. Jelinski. 1999. The relative importance of patch area and perimeter-area ratio to grassland breeding birds. Ecological Applications 9:1448–1458.

Holland, G. J., M. F. Clarke, and A. F. Bennett. 2017. Prescribed burning consumes key forest structural components: implications for landscape heterogeneity. Ecological Applications 27:845–858.

Holling, C. S. 1992. Cross-scale morphology, geometry, and dynamics of ecosystems. Ecological Monographs 62:447–502.

Huse, G., J. Giske, and A. G. V. Salvanes. 2002. Individual-based modelling. Pages 228–248 *in* P. J. B. Hart and J. Reynolds, editors. Handbook of fish and fisheries. Blackwell, Oxford, United Kingdom.

Kilburg, E. L., C. E. Moorman, C. S. DePerno, D. Cobb, and C. A. Harper. 2014. Wild turkey nest survival and nest-site selection in the presence of growing-season prescribed fire. Journal of Wildlife Management 78:1033–1039.

Kilburg, E. L., C. E. Moorman, C. S. DePerno, D. Cobb, and C. A. Harper. 2015. Wild turkey pre-nesting-resource selection in a landscape managed with frequent prescribed fire. Southeastern Naturalist 14:137–146.

Kim, T. N., and R. D. Holt. 2012. The direct and indirect effects of fire on the assembly of insect herbivore communities: examples from the Florida scrub habitat. Oecologia 168:997–1012.

Kiss, L., and F. Magnin. 2003. The impact of fire on some Mediterranean land snail communities and patterns of post-fire recolonization. Journal of Molluscan Studies 69:43–53.

Knapp, E. E., B. L. Estes, and C. N. Skinner. 2009. Ecological effects of prescribed fire season: a literature review and synthesis for managers. General Technical Report PSW-GTR-224. USDA Forest Service, Pacific Southwest Research Station, Albany, California, USA.

Komarek, E. V. 1964. The natural history of lightning. Tall Timbers Fire Ecology Conference 3:139–183.

Lashley, M. A., M. C. Chitwood, C. A. Harper, C. S. DePerno, and C. E. Moorman. 2015. Variability in fire prescriptions to promote wildlife foods in the longleaf pine ecosystem. Fire Ecology 11:62–79.

Lashley, M. A., M. C. Chitwood, A. Prince, M. E. Elfelt, E. L. Kilburg, C. S. DePerno, and C. E. Moorman. 2014. Subtle effects of a managed fire regime: a case study in the longleaf pine ecosystem. Ecological Indicators 38:212–217.

Lavoie, M., G. Starr, M. C. Mack, T. A. Martin, and H. L. Gholtz. 2010. Effects of a prescribed fire on understory vegetation, carbon pools, and soil nutrients in a longleaf pine-slash pine forest in Florida. Natural Areas Journal 30:82–94.

Lima, S. L., and L. M. Dill. 1990. Behavioral decisions made under the risk of predation: a review and prospectus. Canadian Journal of Zoology 68:619–640.

Little, A. R., J. F. Benson, M. J. Chamberlain, L. M. Conner, and R. J. Warren. 2016. Survival and cause-specific mortality of female eastern wild turkeys in two frequently-burned longleaf pine savannas. Wildlife Biology 22:238–245.

Little, A. R., N. P. Nibbelink, M. J. Chamberlain, L. M. Conner, and R. J. Warren. 2015. Eastern wild turkey nest site selection in two frequently burned pine savannas. Ecological Processes 5:1–10.

Magrach, A., A. R. Larrinaga, and L. Santamaria. 2011. Changes in patch features may exacerbate or compensate for the effect of habitat loss on forest bird populations. PLoS ONE 6:e21596. https://doi.org/10.1371/journal.pone.0021596

Martin, J. A., W. E. Palmer, S. M. Juhan, Jr., and J. P. Carroll. 2012. Wild turkey habitat use in frequently-burned pine savanna. Forest Ecology and Management 285:179–186.

McNab, B. K. 1963. Bioenergetics and the determination of home range. American Naturalist 97:133–140.

Oetgen, J. G., A. Engeling, A. Dube, M. J. Chamberlain, and B. A. Collier. 2015. Evaluating Rio Grande wild turkey movements post catastrophic wildfire using 2 selection analysis approaches. National Wild Turkey Symposium 11:127–141.

Parkins, K., A. York, and J. Di Stefano. 2018. Edge effects in fire-prone landscapes: ecological importance and implications for fauna. Ecology and Evolution 8:5937–5948.

Pickett, S. T. A., and K. H. Rogers. 1997. Patch dynamics: the transformation of landscape structure and function. Pages 101–127 *in* J. A. Bissonette, editor. Wildlife and landscape Ecology. Springer-Verlag, New York, New York, USA.

Pickett, S. T. A., and P. S. White. 1985. The ecology of natural disturbance and patch dynamics. Academic Press, Orlando, Florida, USA.

Pyne, S. J. 1982. Fire in America: a cultural history of wildland and rural fire. Princeton University Press, Princeton, New Jersey, USA.

R Core Team. 2017. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Railsback, S. F., and V. Grimm. 2012. Agent-based and individual-based modelling. Princeton University Press, Princeton, New Jersey, USA.

Rorig, M. L., and S. A. Ferguson. 1999. Characteristics of lightning and wildlife fire ignition in the Pacific Northwest. Journal of Applied Meteorology 38:1565–1575.

Sisson, D. C., D. W. Speake, and J. L. Buckner. 1990. Effects of prescribed burning on wild turkey habitat preference and nest site selection in south Georgia. National Wild Turkey Symposium 6:44–50.

Stephens, S. L., B. M. Collins, E. Biber, and P. Z. Fule. 2016. U.S. federal fire and forest policy: emphasizing resilience in dry forests. Ecosphere 7:e01584. https://doi.org/10.1002/ecs2.1584

Swengel, A. B. 2001. A literature review of insect responses to fire, compared to other conservation managements of open habitats. Biodiversity and Conservation 10:1141–1169.

Thaxton, J. M., and W. J. Platt. 2006. Small-scale fuel variation alters fire intensity and shrub abundance in a pine savanna. Ecology 87:1331–1337.

Thogmartin, W. E. 1999. Landscape attributes and nest-site selection in wild turkeys. Auk 116:912–923.

Thogmartin, W. E., and B. A. Schaeffer. 2000. Landscape attributes associated with mortality events of wild turkeys in Arkansas. Wildlife Society Bulletin 28:865–874.

Thompson, C. M., D. J. Augustine, and D. M. Mayers. 2008. Swift fox response to prescribed fire in shortgrass steppe. Western North American Naturalist 68:251–256.

Van Winkle, W., K. A. Rose, and R. C. Chambers. 1993. Individual-based approach to fish population dynamics: an overview. Transactions of the American Fisheries Society 122:397–403.

Verns, K., and L. C. Pope. 2001. Stability of nest range, home range, and movement of the northern bettong (*Bettongia tropica*) following moderate-intensity fire in a tropical woodland, north-eastern Queensland. Wildlife Research 28:141–150.

Wann, G. T., J. A. Martin, and M. J. Chamberlain. 2019. The influence of prescribed fire on wild turkeys in the southeastern United States: a review and synthesis. Forest Ecology and Management 455:117661. https://doi.org/10.1016/j.foreco.2019.117661

Wickham, H. 2016. Ggplot2: elegant graphics for data analysis. Springer-Verlag, New York, New York, USA.

Wightman, P. H., J. C. Kilgo, M. Vukovich, J. R. Cantrell, C. R. Ruth, B. S. Cohen, M. J. Chamberlain, and B. A. Collier. 2019. Gobbling chronology of eastern wild turkeys in South Carolina. Journal of Wildlife Management 83:325–333.

Wilensky, U. 1999. NetLogo. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, Illinois, USA.

Wood, J. D., B. S. Cohen, T. J. Prebyl, L. M. Conner, B. A. Collier, and M. J. Chamberlain. 2018. Time-since-fire and stand seral stage affect habitat selection of eastern wild turkeys in a managed longleaf pine ecosystem. Forest Ecology and Management 411:203–212.

Yeldell, N. A., B. S. Cohen, A. R. Little, B. A. Collier, and M. J. Chamberlain. 2017*a*. Nest site selection and nest survival of eastern wild turkeys in a pyric landscape. Journal of Wildlife Management 81:1073–1083.

Yeldell, N. A., B. S. Cohen, T. J. Prebyl, B. A. Collier, and M. J. Chamberlain. 2017*b*. Prescribed fire influences habitat selection of female eastern wild turkeys. Journal of Wildlife Management 81:1287–1297.

Yeldell, N. A., B. S. Cohen, T. J. Prebyl, B. A. Collier, and M. J. Chamberlain. 2017*c*. Use of pine-dominated forests by female eastern wild turkeys immediately after prescribed fire. Forest Ecology and Management 398:226–234.

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