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Habitat Selection of Wild Turkeys in Burned Longleaf Pine Savannas

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Abstract

Frequent prescribed fire (≤3 yr) and selective harvest of off-site hardwoods are the primary restoration and management tools for pine (*Pinus* spp.) savannas in the southeastern United States. However, a knowledge gap exists in our understanding of eastern wild turkey (*Meleagris gallopavo silvestris*) habitat selection in longleaf pine savannas and research is warranted to direct our future management decisions. Therefore, we investigated habitat selection of female turkeys in 2 longleaf pine savanna systems managed by frequent fire in southwestern Georgia during 2011–2013. We observed differential habitat selection across 2 scales (study area and seasonal area of use) and 3 seasons (fall-winter: 1 Oct–30 Jan; pre-breeding: 1 Feb–19 Apr; and summer: 16 Jun–30 Sep). During fall-winter, turkeys selected mature pine, mixed pine-hardwoods, hardwoods, and young pine stands, albeit at different scales. During pre-breeding, turkeys selected for mature pine, mixed pine-hardwoods, hardwoods, young pine, and shrub-scrub, although at different scales. During summer, turkeys also demonstrated scale-specific selection but generally selected for mature pine, hardwoods, and shrub-scrub. Days-since-fire did not influence selection of stands managed by frequent fire (≤3 yr). In cases where female turkeys used pine-dominated stands (i.e., mature pine, young pine, and mixed pine–hardwoods), selection was not influenced by days-since-fire; however, these results are at least partially due to a lack of longer burn rotations (>3 yr) on our study areas. We suggest land managers consider scale of selection by turkeys when developing habitat management strategies. In addition to creating early successional habitat conditions by using prescribed fire, we recommend managers retain hardwoods and recognize the importance of shrub-scrub cover to management of turkey populations in longleaf pine savannas.

Keywords Georgia, habitat use, *Meleagris gallopavo silvestris*, pine savannas, *Pinus palustris*, prescribed fire, radiotelemetry

Longleaf pine (*Pinus palustris*) savannas are one of the most biologically diverse systems in North America and commonly support hundreds of species of flora and fauna (Alavalapati et al. 2002). This ecosystem historically occupied over 30 million ha in the southeastern United States (Brockway et al. 2005, Van Lear et al. 2005) and was maintained by fire ignited by natural and anthropogenic sources, but today the ecosystem is commonly managed by prescribed fire (Komarek 1964, Pyne 1982, Robbins and Myers 1992). Frequent fire events are critically important to many species found in this ecosystem. For example, wiregrass (*Aristida* spp.) is one of the most common plant species found in longleaf pine savannas and the lifecycle of this species requires frequent fire to induce flowering and propagation (Mulligan and Kirkman 2002, Fill et al. 2012). Researchers have documented >40 plant species/m^2 in this system with many of these species endemic to longleaf pine savannas (Peet and Allard 1993). Today, approximately 1.2 million ha of longleaf pine savannas exist in isolated patches (Van Lear et al. 2005); this fragmentation is primarily due to land use change (e.g., conversion to agriculture and establishment of intensively managed pine plantations were the primary goal is timber production) and government policies that encouraged landowners to exclude fire from their properties (Alavalapati et al. 2002). Over 30 plant and animal species endemic to longleaf pine savannas are now considered to be threatened or endangered (Landers et al. 1995).

For managing longleaf pine savannas, fire is the primary management tool and can increase understory plant species richness, diversity, and evenness (Brockway and Lewis 1997). Without fire disturbance, longleaf pine savannas are replaced by hardwoods and other pine species (Landers et al. 1995, Glitzenstein et al. 2012). Fire is also beneficial to fauna found in a fire-maintained system because it promotes availability of nesting and brood-rearing cover for ground-nesting birds (Dickson 1981, Hurst 1981, Landers 1981) and maintains open, park-like conditions needed by species including the endangered red-cockaded woodpecker (*Picoides borealis*; Alavalapati et al. 2002). Land managers commonly apply prescribed fire every 1–3 years in longleaf pine savannas to balance objectives of managing for species that rely on frequent fire regimes and for other wildlife species that prefer early successional habitat conditions (e.g., northern bobwhite quail [*Colinus virginianus*]).

Wild turkeys (*Meleagris gallopavo*) prefer fire-maintained pine systems because of the creation of early successional habitat (Miller et al. 2000, Miller and Conner 2007, Martin et al. 2012); however, information is needed to fill this knowledge gap in our understanding of wild turkey habitat selection in pine savannas to direct our future management decisions. Martin et al. (2012) reported female turkeys preferred pine savannas burned within 1.4 years and attributed avoidance of stands with longer burn rotations to inability of females to effectively find food resources beginning at about

500 days post-fire. Palmer and Hurst (1998) also noted that longer burning rotations resulted in most upland pine stands being unsuitable to female turkeys during spring, which corresponds to nesting and brood-rearing seasons. However, previous research in pine-dominated systems has recommended longer burn intervals ranging from 3 to 7 years to aid in development of concealment cover to reduce impacts of predation for wild turkeys and other ground-nesting birds (Stoddard 1963, Miller et al. 2000, Miller and Conner 2007). Therefore, research is warranted to better understand influence of prescribed fire on habitat selection by turkeys in a forested system managed by frequent fire.

In pine-dominated forests of the southeastern United States, female turkeys typically use hardwood forests during fall and winter and move into upland pine or pine-hardwood forests prior to nesting season (Speake et al. 1975, Kennamer et al. 1980, Miller and Conner 2007, Martin et al. 2012). Forests selected during spring are typically characterized by relatively dense ground cover presumably used for nesting and brood-rearing (Hillestad 1970, Speake et al. 1975, Streich et al. 2015). Knowledge of habitat selection by turkeys in longleaf pine savannas will enable land managers to balance management objectives for wild turkeys with those of threatened and endangered species endemic to longleaf pine savannas. Therefore, our objectives were to evaluate seasonal habitat selection of female turkeys in longleaf pine savannas, and assess effects of prescribed fire on turkey habitat selection.

Study Area

Our study was conducted on the 11,735-ha Joseph W. Jones Ecological Research Center at Ichauway (hereafter, Jones Center) located in Baker County, Georgia, USA and the 3,900-ha Silver Lake Wildlife Management Area owned by the Georgia Department of Natural Resources located in Decatur County, Georgia (hereafter, Silver Lake WMA). The Jones Center contains a diverse array of habitats including a variety of forest types such as longleaf pine, loblolly pine (*Pinus taeda*), slash pine (*Pinus elliottii*), mixed pine and hardwood forests, oak barrens, lowland hardwood hammocks, and cypress-gum (*Taxodium ascendens-Nyssa biflora*) limesink ponds (Boring 2001). The Ichawaynochaway Creek bisects the property and the Flint River borders the property to the southeast. The Jones Center was historically managed as a northern bobwhite quail hunting plantation. Today, the Jones Center is an ecological research site and also serves as a quail hunting plantation. The Jones Center was comprised of approximately 39% mature pine (>20 yr old), 24% mixed pine-hardwoods, 11% agriculture or food plot (hereafter, agriculture), 8% young pine (≤20 yr old), 7% hardwoods, 4% scrub-shrub, 3% wetland, 3% open water, and 1% urban or barren. Wiregrass and old-field grasses (e.g., *Andropogon* spp.) were the dominant understory plants in pine and mixed pine-hardwoods stands (Goebel et al. 1997). However, >1,000 vascular plant species occurred on the site (Drew et al. 1998).

Silver Lake WMA is located about 42 km southwest of the Jones Center and has similar ecological conditions. It is managed for endangered and threatened species including the endangered red-cockaded woodpecker and game species (e.g., bobwhite quail, white-tailed deer [*Odocoileus virginianus*], and wild turkey). Lake Seminole borders Silver Lake WMA to the south. Silver Lake WMA was comprised of approximately 56% mature pine (>20 yr old), 22% young pine (≤20 yr old), 10% open water, 9% mixed pine–hardwoods, 1% shrub-scrub, 1% hardwoods, 1% urban or barren, and <1% wetlands and agriculture. The Georgia Department of Natural Resources provided all habitat classification data for Silver Lake WMA, which we used to create similar habitat classes across both study sites.

We classified stands as pine if they consisted of loblolly, longleaf, slash, and shortleaf (*Pinus echinata*) pine with >90% pine. We classified stands as mature pine if trees were >20 years old and were in large pole (12.6–25.4 cm) or saw timber (>25.4 cm) size classes; these stands had an average basal area of 4.9 m^2 (range: 0.2–12.6 m^2). We classified stands as young pine if trees were ≤20 years old and fell in seedling-sapling (0–12.7 cm) or small pole timber (12.7–25.4 cm) size classes; these stands had an average basal area of 2.0 m^2 (range: 0–10.43 m^2).

Mixed pine-hardwood stands contained a variety of species (e.g., loblolly, longleaf, slash pine, southern red oak [*Quercus falcata*], turkey oak [*Q. laevis*], live oak [*Q. virginiana*], laurel oak [*Q. laurifolia*], and sweetgum [*Liquidambar styraciflua*]). We classified stands as mixed pine-hardwoods if they were 50–80% hardwoods or pine. Within these stands, tree sizes ranged from seedling-sapling through saw timber; however, most (>90%) were in the pole to saw timber classes. Average basal area was 2.8 m^2 (range: 0–8.8 m^2) for pine and 3.2 m^2 (range: 0–20.8 m^2) for hardwoods.

Hardwood stands consisted of a variety of species (e.g., southern red, turkey, live, laurel oaks, and sweetgum) with tree sizes ranging from seedling-sapling to saw timber; however, most (>90%) were in the pole to saw timber classes. Average basal area was 9.8 m^2 (range: 2.9–30.1 m^2) and stands consisted of >90% hardwoods. Agriculture stands consisted of cropland, pasture land, wildlife food plots, and horticultural crops (e.g., pecan orchard). Shrub-scrub stands consisted of abandoned agricultural fields and pastures, clear-cuts, grassland, and shrubby areas.

To successfully restore and maintain longleaf pine savannas on our study sites, land managers used prescribed fire and mechanical hardwood removal. Fire was applied to mature pine, young pine, mixed pine-hardwoods, and shrub-scrub stands. Prescribed fire was conducted throughout the year with

>95% of burns conducted during January–October. Prescribed fire application occurred in a mosaic fashion, which promoted landscape diversity. Average patch size burned at the Jones Center was 21.41 ha_0.83 (SE; range: 0.02–240.57 ha), whereas average patch size burned at Silver Lake WMA was 14.41 ha ± 0.58 (range: 0.66–88.27 ha). Fire return interval typically ranged from 1 to 3 years, but most (≥95%) fires applied to our study sites occurred ≤2 years before the study (38.4% 0 yr, 34.9% 1 yr, 21.7% 2 yr, and 4.9% of stands 3 yr since fire). Land managers often used mechanical removal to remove large off-site hardwoods (e.g., water oak [*Q. nigra*]) from within mature pine stands.

Methods

Turkey Capture and Monitoring

We captured female turkeys using rocket nets baited with corn during December–March of 2011–2013 and June–August of 2011–2012. We fitted all captured females with serially numbered, butt-end (left leg), and riveted (right leg) aluminum leg bands (National Band and Tag Co., Newport, KY). We also affixed a backpack-style very high frequency (VHF) radio transmitter, weighing approximately 60 g, (Sirtrack, Havelock North, New Zealand; and Telenax, Playa del Carmen, México) to all females. We released all birds at the capture site immediately after processing. The Institutional Animal Care and Use Committee at the University of Georgia approved all turkey capture, handling, and marking procedures (Protocol no. A2013 05-034-Y1-A0). We used a hand-held, 3-element Yagi antenna and Wildlife Materials TRX 2000S receiver (Wildlife Materials, Murphysboro, IL) to locate radio-marked females ≥2 times per week from mid-July to mid-March and ≥1 time per day from mid-March to mid-July. We located females by triangulation and recorded locations using a mobile phone containing Location Of A Signal-SD software (LOAS™ [2010; Version 4.0.3.8] Ecological Software Solutions, Hegymagas, Hungary) and a Bluetooth global positioning system unit. We obtained azimuths within a 15-minute time period to reduce error caused by animal movement. We evaluated telemetry error by randomly assigning dummy VHF radio-transmitters (n = 8) throughout the Jones Center. Each observer (n = 5) triangulated each dummy radio but did not know the exact location of dummy radios during testing. We then calculated average telemetry error among observers using LOAS-SD (observer error: $\bar{x}$ = 1.1 ± 0.3 ha). We assumed the telemetry error was similar across study areas. We attempted to further minimize error and standardize our telemetry data by eliminating any locations if observer distances were determined to be ≥800 m from the estimated turkey locations by LOAS-SD.

Habitat Selection Analysis

To investigate wild turkey habitat selection, we examined selection at 2 scales: study area and seasonal areas of use. We determined study area habitat availability by calculating a 100% minimum convex polygon (MCP) that surrounded all turkey locations at each study site. To develop seasonal areas of use, we delineated biologically meaningful seasons based on reproductive chronology of turkeys on our study areas and previous research (Miller et al. 1999; Miller and Conner 2005, 2007). We used median nest initiation date to define start of a 2-month nesting season (20 Apr–15 Jun; Little et al. 2014). Information on female habitat selection during nesting season on our study sites is provided by Streich et al. (2015). For our seasonal habitat selection analysis, we defined summer as 16 June–30 September, fall-winter as 1 October–31 January, and pre-breeding as 1 February–19 April. We calculated 95% MCP in the adehabitat package (Calenge 2006) for program R version 3.1.3 (R Core Team, Vienna, Austria). We required each turkey to have ≥10 locations/season to calculate seasonal areas (SAUs) of use similar to Miller and Conner (2007). We acknowledge this is a low number of locations to estimate range size; however, our goal was simply to estimate a seasonal area of use rather than defining a home range (Miller and Conner 2007).

To quantify habitat selection, we used a geographic information system (ArcGIS® 10.2, Environmental Systems Research Institute Inc., Redlands, CA) to create a vector layer of habitat classes available on our study areas. We converted the vector layer to a 30-m raster layer and used the Euclidean distance tool in ArcGIS® 10.2 to calculate distance (m) from every 30-m pixel to the nearest patch of each habitat. We used a distance-based approach because distance-based metrics are not restricted to linear or point habitat features, require no explicit error handling, and permit extraction of more information than classification-based analyses such as compositional analysis (Conner et al. 2003). At the study area scale, we evaluated non-random habitat selection each season with a ratio of 1 turkey location to 5 available locations to characterize available habitat at a larger extent (Northrup et al. 2013). At the seasonal area of use scale, we characterized available habitat each season using a ratio of 1 turkey location to 3 available locations because of the smaller spatial extent. We extracted all distance values to used and available locations using ArcGIS® 10.2.

We modeled habitat selection at each scale and season (fall–winter, pre-breeding, and summer) using a generalized linear mixed-effects model (GLMM) implemented in program R and a use versus availability habitat selection approach to evaluate non-random habitat selection (Manly et al. 2002). We compared used (i.e., turkey locations) to available (i.e., random locations) in a logistic regression framework where turkey locations were represented as a binary response (1 = turkey location; 0 = random location).

We included season (fall-winter, pre-breeding, and summer) as an interaction term with each stand type in the model to evaluate whether habitat selection differed across seasons. We considered fall-winter as the reference group for the interaction. Additionally, we included study site as a fixed effect in the model to account for variation across study areas; however, we were not interested in evaluating differences in selection across sites. We also included turkey identification as a random effect to account for an unbalanced design and variability among individual turkeys (Gillies et al. 2006).

Prior to data analysis, we scaled all distance values for used and available locations by dividing the linear distance by 200m to reduce model convergence issues. We evaluated pairwise correlations between explanatory variables at each scale using Pearson correlation. We considered any variables that were highly correlated ($|r|>0.7$) and retained the variable that provided the simplest biological interpretation (Dormann et al. 2013). We then evaluated variance inflation factors of all variables to assess the extent of any remaining collinearity. All variables contained a variance inflation factor ≤ 2.1, which suggested that collinearity was not likely an issue (Zuur et al. 2009). We constructed a full model for each scale and season. We made inference to only those variables that were statistically significant ($\alpha = 0.05$). For easier interpretation, we calculated scaled odds ratios (OR) and associated 95% confidence intervals for parameter estimates. We only considered parameter estimates with 95% confidence intervals that excluded 0 to be informative (Miller and Conner 2007).

Model assessment is important when developing predictive models because it provides evidence that the model is robust and applicable to data other than the model data (Boyce et al. 2002). We validated our study area and home range models by using k-fold cross-validation (k = 10 folds; Boyce et al. 2002). K-fold cross-validation is based on partitioning data into k equal-sized subsamples and performing k iterations of training and validation in which a different bin of the data is held out for validation, and the remaining $k - 1$ bins are used for the training set. The advantage of k-fold cross-validation is that all observations are eventually used for both training and testing.

Habitat Selection in Relation to Prescribed Fire

To evaluate effects of prescribed fire on turkey habitat selection, we used a subset of our radio-telemetry data that included only those turkey locations occurring on our study areas and in stands that received frequent fire (i.e., mature pine, young pine, and mixed pine-hardwoods) from 1 February to 12 October, which corresponded to >95% of prescribed fire applications. We used only locations within our study area boundaries because days-since-fire data were not available outside of our study areas. We used the union tool in ArcGIS® 10.2 to create a days-since-fire (no. days) map for each study area. We placed a buffer (394-m radius) around each used telemetry location to serve as the available habitat. We determined the radius of the buffer by calculating a 50% pre-breeding season (1 Feb–20 Apr) MCP core area of use in the adehabitat package (Calenge 2006) for program R. Within each buffer, we generated 3 random points that intersected with the days-since-fire map. We calculated a days-since fire value for each used and random location by subtracting the day we obtained the location from the day the fire occurred for that patch.

We modeled effect of days-since-fire on habitat selection by turkeys using a generalized linear mixed-effects model (GLMM) implemented in program R. We compared used to available in a logistic regression framework where turkey locations were represented as a binary response (1 = turkey location; 0 = random location). We included study site as a fixed effect in the model to account for variation across study areas; however, we were not interested in evaluating differences in selection across sites. We included turkey identification as a random effect to account for an unbalanced design and variability among individual turkeys (Gillies et al. 2006).

Results

We monitored 86 wild turkeys during 2011–2013 across both study sites (**Table 1**). During the study period, 16.5% of turkey locations occurred off our study sites. We constructed 141 SAUs from our final data set. We found no highly correlated variables at study area or seasonal area of use scales; therefore, we retained all variables in our modeling efforts. During the fall-winter reference season at the study area scale, turkeys were closer to mature pine (β = –0.359, P < 0.001) and farther from young pine (β = 0.120, P < 0.001) and shrub-scrub (β = 0.070, P = 0.037); whereas, we found no difference in selection of mixed pine-hardwoods (β = –0.057, P = 0.054), hardwoods (β = –0.043, P = 0.115), and agriculture (β = –0.001, P = 0.906). During pre-breeding, turkeys were farther from mature pine (β = 0.117, P = 0.044) and agriculture (β = 0.068, P < 0.001) and closer to young pine (β = –0.118, P < 0.001) and shrub-scrub (β = –0.343, P < 0.001) relative to fall-winter selection. Selection of mixed pine-hardwoods (β = 0.022, P = 0.484) and hardwoods (β = 0.004, P = 0.882) during pre-breeding was similar to fall-winter selection. During summer, turkeys were farther from mature pine (β = 0.230, P < 0.001) and agriculture (β = 0.088, P < 0.001) and closer to hardwoods (β = –0.138, P < 0.001), young pine (β = –0.099, P = 0.001), and shrub-scrub (β = –0.308, P < 0.001) relative to their fall-winter locations. Selection of mixed pine-hardwoods (β = 0.044, P = 0.188) during summer was similar to fall–winter selection.

Table 1. Number of radio-marked female eastern wild turkeys (*n*) and mean number (and SE) of radio-telemetry locations/turkey by season at the Joseph W. Jones Ecological Research Center and Silver Lake Wildlife Management Area (WMA), southwestern Georgia, USA, 2011–2013.

Site	*Season*[a]	*n*	$\bar{x}$ *locations/turkey*	*SE*
Jones Center	Fall-winter	11	29.4	5.3
	Pre-breeding	40	47.2	5.2
	Summer	26	42.7	6.9
Silver Lake WMA	Fall-winter	13	23.8	3.0
	Pre-breeding	29	60.4	4.7
	Summer	22	38.0	3.6

a. Season: Fall-winter (1 Oct–30 Jan), pre-breeding (1 Feb–19 Apr), and summer (16 Jun–30 Sep).

Because of differences in seasonal habitat selection at the study area scale, we developed 3 separate seasonal models (fall-winter, pre-breeding, and summer) and provided season-specific parameter estimates (**Table 2**; **Fig. 1**, A–F). During fall-winter, turkeys were closer to mature pine (β = –0.322, SE = 0.055, OR = 0.724), mixed pine-hardwoods (β = –0.101, SE = 0.032, OR = 0.904), and hardwoods (β = –0.108, SE = 0.031, OR = 0.898) and farther from young pine (β = 0.143, SE = 0.027, OR = 1.154). Selection of agriculture and shrub-scrub were not statistically different (P > 0.05; Table 2). During pre-breeding, turkeys were closer to mature pine (β = –0.256,SE = 0.023, OR = 0.774), mixed pine-hardwoods (β = –0.022, SE = 0.011, OR = 0.978), and shrub-scrub (β = –0.258, SE = 0.017, OR = 0.773) and farther from agriculture (β = 0.073, SE = 0.006, OR = 1.076). Selection of hardwoods and young pine were not statistically different (P > 0.05; Table 2). During summer, turkeys were closer to mature pine (β = –0.115, SE = 0.027, OR = 0.891), hardwoods (β = –0.203, SE = 0.018, OR = 0.816), and shrub-scrub (β = –0.251, SE = 0.024, OR = 0.778) and farther from agriculture (β = 0.075, SE = 0.008, OR = 1.077). Selection of mixed pine-hardwoods and young pine were not statistically significant (P > 0.05; Table 2).

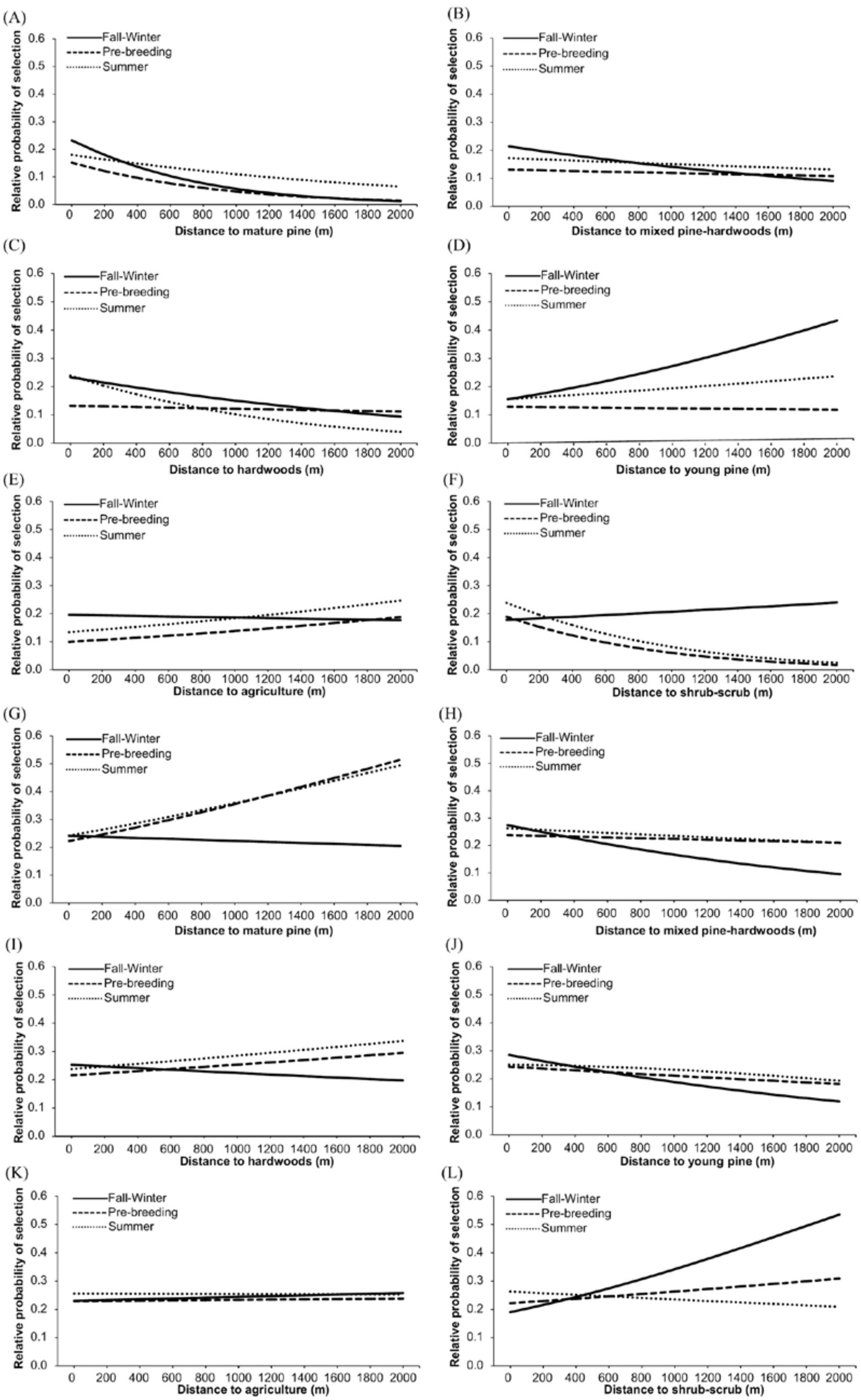
During the fall-winter reference season at the seasonal area of use scale, turkeys were closer to mixed pine-hardwoods (β = –0.128, P < 0.001) and young pine (β = –0.109, P < 0.001) and farther from shrub-scrub (β = 0.160, P < 0.001); whereas, we found no difference in selection of mature pine (β = –0.022, P = 0.758), hardwoods (β = –0.028, P = 0.377), or agriculture (β = 0.016, P = 0.212). During pre-breeding, turkeys were located farther from mature pine (β = 0.159, P = 0.047), mixed pine-hardwoods (β = 0.111, P = 0.005), and young pine (β = 0.077, P = 0.010) and closer to shrub-scrub (β = –0.119, P = 0.004) relative to fall-winter selection. Selection of hardwoods (β

Table 2. Probability of seasonal habitat selection for female eastern wild turkeys based on distance metrics (m) at the study area (100% minimum convex polygon) spatial scale (scalar = 200-m), Joseph W. Jones Ecological Research Center and Silver Lake Wildlife Management Area, southwestern Georgia, USA, 2011–2013.

Variable[a]	*Season*[b]	*β*	*SE*	*Z*[c]	*P*	*Odds ratio*	*Lower 95%*	*Upper 95%*
Mature pine	Fall-winter	–0.322	0.055	–5.892	<0.001	0.724	0.651	0.806
	Pre-breeding	–0.256	0.023	–11.188	<0.001	0.774	0.740	0.809
	Summer	–0.115	0.027	–4.350	<0.001	0.891	0.846	0.939
Mixed pine-hardwoods	Fall-winter	–0.101	0.032	–3.163	0.002	0.904	0.850	0.962
	Pre-breeding	–0.022	0.011	–1.974	0.048	0.978	0.957	1.000
	Summer	–0.032	0.017	–1.911	0.056	0.969	0.938	1.001
Hardwoods	Fall-winter	–0.108	0.031	–3.488	<0.001	0.898	0.845	0.954
	Pre-breeding	–0.019	0.012	–1.549	0.122	0.981	0.958	1.005
	Summer	–0.203	0.018	–10.990	<0.001	0.816	0.787	0.846
Young pine	Fall-winter	0.143	0.027	5.358	<0.001	1.154	1.095	1.215
	Pre-breeding	–0.010	0.013	–0.771	0.441	0.990	0.966	1.015
	Summer	0.032	0.016	1.927	0.054	1.032	0.999	1.066
Agriculture	Fall-winter	–0.013	0.012	–1.031	0.303	0.987	0.964	1.012
	Pre-breeding	0.073	0.006	13.332	<0.001	1.076	1.065	1.088
	Summer	0.075	0.008	8.993	<0.001	1.077	1.060	1.095
Shrub-scrub	Fall-winter	0.038	0.035	1.080	0.280	1.038	0.970	1.112
	Pre-breeding	–0.258	0.017	–15.214	<0.001	0.773	0.747	0.799
	Summer	–0.251	0.024	–10.666	<0.001	0.778	0.743	0.815

a. Distance to nearest habitat patches (m).
b. Season: Fall-winter (1 Oct–31 Jan), pre-breeding (1 Feb–19 Apr), and summer (16 Jun–30 Sep).
c. Standardized coefficient estimates.

Figure 1. [opposite] Predictive probability of seasonal habitat selection for female eastern wild turkeys based on distance metrics (m) at the study area (100% minimum convex polygon) and seasonal area of use (95% minimum convex polygon) spatial scale (scalar = 200-m), Joseph W. Jones Ecological Research Center and Silver Lake Wildlife Management Area, southwestern Georgia, USA, 2011–2013. Seasonal classification was defined as fall-winter (1 Oct–31 Jan), pre-breeding (1 Feb–19 Apr), and summer (16 Jun–30 Sep). Study area scale predictive probability figures: mature pine (**A**), mixed pine-hardwoods (**B**), hardwoods (**C**), young pine (**D**), agriculture (**E**), and shrub-scrub (**F**). Seasonal area of use predictive probability figures: mature pine (**G**), mixed pine-hardwoods (**H**), hardwoods (**I**), young pine (**J**), agriculture (**K**), shrub-scrub (**L**).


(A)
Fall-Winter
Pre-breeding
Summer
Relative probability of selection
Distance to mature pine (m)
(B)
Distance to mixed pine-hardwoods (m)
(C)
Distance to hardwoods (m)
(D)
Distance to young pine (m)
(E)
Distance to agriculture (m)
(F)
Distance to shrub-scrub (m)
(G)
Distance to mature pine (m)
(H)
Distance to mixed pine-hardwoods (m)
(I)
Distance to hardwoods (m)
(J)
Distance to young pine (m)
(K)
Distance to agriculture (m)
(L)
Distance to shrub-scrub (m)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0 200 400 600 800 1000 1200 1400 1600 1800 2000

= 0.064, P = 0.060) and agriculture (β = –0.013, P = 0.333) during pre-breeding was similar to fall-winter selection. During summer, turkeys were farther from mixed pine-hardwoods (β = 0.100, P = 0.017), hardwoods (β = 0.089 P = 0.016), and young pine (β = 0.129, P < 0.001) and closer to shrub-scrub (β = –0.184, P = 0.001) relative to fall-winter selection. Selection of mature pine (β = 0.125, P = 0.128) and agriculture (β = –0.013, P = 0.401) during summer was similar to fall-winter selection.

Because of differences in seasonal habitat selection at the seasonal area of use scale, we developed 3 separate seasonal models (fall-winter, pre-breeding, and summer) and provided season-specific coefficient estimates (**Table 3**; Fig. 1, G–L). During fall-winter, turkeys were closer to mixed pine-hardwoods (β = –0.128, SE = 0.038, OR = 0.880) and young pine (β = –0.108, SE = 0.029, OR = 0.897) and farther from shrub-scrub (β = 0.159, SE = 0.038, OR = 1.172). Selection of mature pine, hardwoods, and agriculture were not statistically different (P > 0.05; Table 3). During pre-breeding, turkeys were

Table 3. Probability of seasonal habitat selection for female eastern wild turkey based on distance metrics (m) at the seasonal area of use (95% minimum convex polygon) spatial scale (scalar = 200-m), Joseph W. Jones Ecological Research Center and Silver Lake Wildlife Management Area, southwestern Georgia, USA, 2011–2013.

Variable[a]	*Season*[b]	*β*	*SE*	*Z*[c]	*P*	*Odds ratio*	*Lower 95%*	*Upper 95%*
Mature pine	Fall-winter	–0.021	0.074	–0.277	0.782	0.980	0.847	1.133
	Pre-breeding	0.131	0.033	3.951	<0.001	1.140	1.068	1.217
	Summer	0.112	0.039	2.913	0.004	1.119	1.037	1.207
Mixed pine-hardwoods	Fall-winter	–0.128	0.038	–3.394	0.001	0.880	0.817	0.947
	Pre-breeding	–0.016	0.011	–1.360	0.174	0.985	0.963	1.007
	Summer	–0.030	0.019	–1.566	0.117	0.971	0.935	1.008
Hardwoods	Fall-winter	–0.032	0.041	–0.784	0.433	0.969	0.895	1.049
	Pre-breeding	0.042	0.015	2.855	0.004	1.043	1.013	1.074
	Summer	0.049	0.022	2.259	0.024	1.051	1.007	1.096
Young pine	Fall-winter	–0.108	0.029	–3.770	<0.001	0.897	0.848	0.949
	Pre-breeding	–0.037	0.014	–2.678	0.007	0.963	0.937	0.990
	Summer	0.028	0.019	1.497	0.134	1.029	0.991	1.067
Agriculture	Fall-winter	0.015	0.013	1.162	0.245	1.016	0.989	1.042
	Pre-breeding	0.005	0.006	0.778	0.437	1.005	0.993	1.017
	Summer	–0.002	0.009	–0.256	0.798	0.998	0.979	1.016
Shrub-scrub	Fall-winter	0.159	0.038	4.192	<0.001	1.172	1.088	1.263
	Pre-breeding	0.045	0.020	2.251	0.024	1.046	1.006	1.088
	Summer	–0.030	0.027	–1.129	0.259	0.970	0.921	1.022

a. Distance to nearest habitat patches (m).
b. Season: Fall-winter (1 Oct–31 Jan), pre-breeding (1 Feb–19 Apr), and summer (16 Jun–30 Sep).
c. Standardized coefficient estimates.

closer to young pine (β = –0.037, SE = 0.014, OR = 0.963) and farther from mature pine (β = 0.131, SE = 0.033, OR = 1.140), hardwoods (β = 0.042, SE = 0.015, OR = 1.043), and shrub-scrub (β = 0.045, SE = 0.020, OR = 1.046). Selection of mixed pine-hardwoods and agriculture were not statistically different ($P > 0.05$; Table 3). During summer, turkeys were farther from mature pine (β = 0.112, SE = 0.039, OR = 1.119) and hardwoods (β = 0.049, SE = 0.022, OR = 1.051). Selection of mixed pine-hardwoods, young pine, agriculture, and shrub-scrub were not statistically significant ($P > 0.05$; Table 3). Our k-fold cross-validation correctly classified 83.3%, 83.3%, and 83.3% of the locations for the study area selection models for fall-winter, pre-breeding, and summer, respectively.

Our k-fold cross-validation correctly classified 75.1%, 75.0%, and 75.0% of the locations for the seasonal area of use selection models for fall-winter, pre-breeding, and summer, respectively. Study area and seasonal area of use model performances ranged from fair to good.

Days-since-fire did not influence turkey use of pine stands that received frequent fire (P = 0.254). Females on average used stands 442 ± 6 days after fire, whereas expected use was 435 ± 3 days.

Discussion

Wild turkey habitat selection occurs at multiple scales. Specifically, we found selection of mature pine, mixed pine–hardwoods, hardwoods, young pine, and shrub-scrub differed by scale and season. Days-since-fire did not influence selection of stands managed by frequent fire (≤3 yr). Overall, our findings provide evidence that turkeys require habitat diversity in longleaf pine savannas but can adapt to a system managed by frequent prescribed fire intervals (≤3 yr).

Mature pine was selected by turkeys, especially at the study area scale across all seasons. Our findings are consistent with Miller and Conner's (2007) research in intensively managed pines in Mississippi. They suggested that intensively managed pines were primarily selected because of the availability of early successional habitat created by thinning and burning. Past research has indicated female turkeys prefer open, herbaceous understory vegetation, which can be used for concealment from predators, especially during the reproductive season (Bowman and Harris 1980, Lehman et al., 2008). Martin et al. (2012) reported that female turkey selection of pine stands was primarily a function of time-since-fire, suggesting that turkeys were exploiting potential food resources within 1.4 years post-fire. Our research suggests that selection of mature pine stands may also be a function of their dominance on the landscape. In other words, mature pine was the primary stand type on both study areas (Jones Center: 39% mature pine;

and Silver Lake WMA: 56% mature pine). Therefore, turkeys were likely to encounter mature pine more often than any other stand type. Additional research is needed to better understand the importance of mature pine stands to wild turkeys in frequently burned pine savannas including research evaluating potential food resources available to turkeys.

Mixed pine-hardwoods and hardwood stands were seasonally important to turkeys. Previous research has documented the importance of hardwoods for wild turkeys (Hurst 1992, Minser et al. 1995, Ryan et al. 2004). Wild turkeys readily consume hard mast to accumulate body fat (Hurst 1992). Our research found that hardwoods were important during the fall-winter and summer months. We suggest that hardwood stands may also serve as travel corridors between forage patches and be used as protective cover from summer heat in longleaf pine-dominated landscapes. Previous research has documented the use of riparian areas (containing hardwoods) for travel and foraging throughout the year (Burk et al. 1990). Turkeys may also use these areas because of the availability of potential roost sites (Kilpatrick et al. 1988, Chamberlain et al. 2000), especially during summer when they are with broods (Phalen et al. 1986, Exum et al. 1987, Palmer et al. 1996, Streich et al. 2015).

Shrub-scrub stands were selected by females during prebreeding and summer, which are important for nest site selection on our study areas (Streich et al. 2015). During summer, females commonly renested on both study areas (Little et al. 2014), offering partial explanation for female locations being closer to shrub-scrub habitats. Likewise, prescribed burning regimes and intensive habitat management on our study areas created a mosaic of openings in forested stands across both study sites, thereby providing turkeys with shrub-scrub stands for nest and brood-rearing sites (Streich et al. 2015). Shrub-scrub dominated sites were more open and subsequently had denser understory vegetation. Finally, females may have preferred shrub-scrub habitats because of greater visual obstruction provided by the stand type; visual obstruction is important to broods for foraging and cover from predators (Hillestad and Speake 1970, Hurst and Stringer 1975, Martin and McGinnes 1975, Sisson et al. 1991, Spears et al. 2007).

Our study provides another example of the importance of evaluating habitat selection at multiple scales. We found mature pine, hardwoods, and shrub-scrub were an important component of habitat selection within the study area, but within the seasonal area of use, turkeys avoided these stands. Similar to Conner and Leopold (1996), we suggest that decisions made at one scale are limited and could result in poor management decisions and managers should consider effects of scale on habitat selection. For example, if a land manager was provided with results from the seasonal area of use scale only, and subsequently used those results for landscape-level planning (e.g., restoration of large tracts of longleaf pine), then they may erroneously conclude that hardwoods are not important for wild turkeys. By also examining coefficients at the study area scale, land managers are able to conclude that hardwoods are indeed selected by wild turkeys when establishing their seasonal areas of use on the landscape. Notably, when extent of availability was restricted from the study area boundary to a smaller seasonal area of use boundary, our results indicated that turkeys avoided hardwoods. The advantage of examining multiple scales is that it enables land managers to identify, focus, and potentially monitor the ecological costs and benefits of their management decisions (Ciarniello et al. 2007).

Our models of habitat selection indicated fair to good predictability across both scales and seasons with *k*-fold cross validation accuracy ranging from 75% to 83%. To improve the overall quality of our results, we developed season-specific models to account for variability in habitat selection throughout the year (Boyce et al. 2002). Even with season-specific models, we still only had fair to good predictability. Poorer model validation is common for species with broad resource requirements (Lobo et al. 2008). Wild turkeys are considered a generalist species (Hurst 1992); therefore, we expected to find fair to good model validation. Geographic extent may also influence model validation with improved validation for larger spatial extents (Lobo et al. 2008). Our findings illustrate the potential influence of geographic extent on model validation with improved validation for the study area scale relative to the seasonal area of use scale. Our findings suggest that days-since-fire did not influence turkey habitat selection. However, our results are at least partially due to a lack of stands with longer burn rotations (>3 yr). Previous studies have recommended longer fire return intervals for turkey management in pine-dominated forests. Miller and Conner (2007) recommended 3–7-year fire return intervals to aid in development of concealment cover to reduce impacts of predation. Miller et al. (2000) recommended fire return intervals of 3–4 years for wild turkeys in mature pine forests, and Speake et al. (1975) recommended fire return intervals of 2–4 years to ensure soft fruit production for turkeys. However, longer burn rotations in longleaf pine savannas would be detrimental to endemic flora and fauna that are dependent on frequent fire intervals to create open, park-like conditions (Waldrop et al. 1992, Brockway and Lewis 1997, Glitzenstein et al. 2012).

Management Implications

Longleaf pine savannas are ecologically and economically important to the southeastern United States because of their significant biodiversity, tolerance to frequent fire events, and resistance to pestilences (Alavalapati et al. 2002). Our research provides evidence that mature pine, mixed pine-hardwoods,

hardwoods, young pine, and shrub-scrub stands are selected by wild turkeys within longleaf pine-dominated systems. We suggest land managers maintain scattered site-appropriate hardwoods (Hiers et al. 2014) in longleaf pine savannas and recognize the importance of shrub-scrub stands when managing for wild turkey populations in longleaf pine savannas. Our results suggest that days-since-fire did not influence female turkey habitat selection, but turkeys can coexist with frequent fire (≤ 3 yr) in pine-dominated systems if other stand types are available.

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