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Annual survival and resource selection of juvenile male wild turkeys in central Tennessee

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Abstract

Documenting juvenile male wild turkey (*Meleagris gallopavo*) resource selection, survival, and harvest is important to better manage this life stage, which is the direct source for harvestable adult male wild turkeys. To better understand the relationship between resource selection and survival and how harvest impacts survival rates, we trapped and attached backpack very high frequency (VHF) radio transmitters to juvenile males ($n = 136$) in 5 counties of south-central Tennessee, 2017–2021. We modeled resource selection using case-controlled conditional logistic regression and fit known-fate survival models to estimate annual survival. We calculated landscape metrics and land cover proportions associated with each turkey's home range using the National Land Cover Database to determine if landscape characteristics were related to resource selection and annual survival. We also analyzed state-reported hunter harvest data using a generalized linear model to determine if changing harvest regulations affected harvest of juvenile males during the spring hunting season. Juvenile male wild turkeys selected smaller row crop fields, less mature forest interior (≥120 m from patch edge), and lower proportions of developed land and young forest. Mean annual survival was 0.73 (95% CI = 0.65–0.81) with a harvest rate of 0.03 (95% CI = 0.01–0.09). Survival increased as hay and pasture interior increased in the home range, but this positive effect was reduced as the interspersion of young forest increased. Survival decreased as the interspersion of developed land increased in the home range, but this negative effect was reduced as the percentage of deciduous forest increased. The proportion of juvenile males in the spring harvest decreased from 14.1% to 13.7% to 8.9% as the male bag limit decreased from 4 to 3 to 2. Our results suggest that young forest, which represents dense woody cover, may reduce survival as a result of increased cover and ambush opportunities for wild turkey predators, whereas increased proportions of cover types that provide enhanced visibility and food resources benefit juvenile male wild turkey survival. Given a relatively robust survival rate, regulatory restrictions on the harvest of juvenile male turkeys could increase the adult male population and likely increase turkey hunter satisfaction.

KEYWORDS

harvest, juvenile male, *Meleagris gallopavo*, mortality, resource selection, survival, Tennessee, wild turkey

Eastern wild turkey (*Meleagris gallopavo silvestris*) population and harvest estimates have declined in much of the eastern United States since 2000 (Tapley et al. 2011, Chamberlain et al. 2022). Concomitant with population declines, wild turkey productivity in these states has declined (Byrne et al. 2015). In Tennessee, the poult-per-female ratio has declined since 2000 (Shields 2024). A recent (2018–2022) study reported poult survival estimates lower than many historical estimates (Quehl et al. 2025), and the relative abundance of wild turkeys has decreased by 37% from 2013 to 2022 according to the North American Breeding Bird Survey (United States Geological Survey 2022). Reported wild turkey harvest has declined in some counties of south-central Tennessee since 2005 (Buehler and Harper 2024), but the statewide harvest has remained relatively stable (Shields 2024). Collectively, these data suggest turkey harvest does not correlate precisely with turkey population trends, and therefore, these potential declines merit further investigation (United States Geological Survey 2022, Shields 2024).

Exact causes of declining wild turkey populations and harvest are unclear, but declines likely are influenced by various factors (Casalena et al. 2015, Chamberlain et al. 2022, Londe et al. 2023). Land-use change leading to an increase of human-developed areas has resulted in an increase of more than 3 million hectares of developed land in the southeastern United States from 1997 to 2017, which is a 26% increase over that 20-year period (United States Department of Agriculture 2020, World Population Review 2025). An increase in meso-mammalian predator abundance in the southeastern United States since the 1980s is another factor likely contributing to declining wild turkey populations (Roberts and Crimmins 2010, Casalena et al. 2015, Bragina et al. 2019, Wang et al. 2023). The effect of increased predator populations on wild turkeys likely has been amplified by concomitant increased urbanization and increased forest cover across the southeastern United States, which favors meso-mammalian predators and provides less visibility for wild turkeys (Kunkel 1997, Whittingham and Evans 2004, Pollentier et al. 2014, Ivey et al. 2024, Wang et al. 2025). Lastly, it has been hypothesized that more liberal hunting regulations following successful restoration in the 1970s and 1980s, such as increased bag limits, fall harvest of adult female turkeys, and lengthened spring hunting seasons that start too early and disrupt breeding, may be contributing to population declines (Tapley et al. 2000, Norman et al. 2004, Londe et al. 2023, Quehl et al. 2024*a*). However, more conservative harvest frameworks, such as reducing bag limits and delaying the spring hunting season by as much as 14 days so as not to interfere with reproduction, had no effect on wild turkey productivity in Tennessee, USA (Quehl et al. 2024*a*). Survival of juvenile males represents an important linkage between wild turkey reproduction and the availability of adult males for harvest (Palumbo et al. 2014). Obtaining survival and harvest estimates of juvenile male turkeys is important because these estimates enable state wildlife agencies to manage this cohort and influence subsequent availability of adult males (Humberg et al. 2009, Israelsen et al. 2020, Wightman et al. 2024).

In theory, juvenile male turkey survival and harvest rates should be inversely related unless harvest is strictly compensatory (Moore et al. 2008, Sandercock et al. 2011). Research from Georgia, Kentucky, Louisiana, Mississippi, Missouri, North Carolina, South Carolina, Virginia, and West Virginia, USA, indicates a generally inverse relationship: as juvenile male harvest increases, the survival rate generally decreases (Hubbard and Vangilder 2007, Wright and Vangilder 2007, Norman et al. 2022, Wightman et al. 2024). Given recent changes in bag limits in Tennessee, documentation of harvest and survival rates of juvenile male turkeys is warranted to further advance science-based harvest regulations.

Beyond just survival rates, little is known about resource selection and factors influencing survival for the juvenile male life stage. Investigation of home range and factors affecting resource selection and survival would provide wildlife managers with better information on how habitat management might help improve survival during this life stage. We conducted a radio telemetry study over 5 years in 5 counties of south-central Tennessee to study resource selection and how juvenile male survival is influenced by land cover type and other landscape metrics. Our research objectives were to 1) document juvenile male wild turkey resource selection of specific land cover types, 2) determine if juvenile male wild turkey survival is related to land cover type and other landscape metrics, and 3) document juvenile male wild turkey harvest proportions for our focal counties and determine if a delayed hunting season start date and changes in bag limit affected juvenile male harvest. We hypothesized juvenile male wild turkeys would select land cover types that may provide greater potential for food and cover and less potential for predation risk, and juvenile males would avoid land cover types less likely to provide sufficient food and cover resources. We predicted turkeys would select smaller land cover patches if those patches were cover types that provide food or cover. We predicted juvenile male wild turkey survival would be positively related to home ranges with a greater interspersion and juxtaposition index of row crop and hay or pasture because of increased visibility and potential food resource availability. We further predicted that survival would be negatively related to the proportion of developed land and land cover types with limited visibility for turkeys, which may cause increased predation risk. Finally, we hypothesized the wild turkey hunting season framework would affect juvenile wild turkey harvest. We predicted a lower proportion of juvenile males would be harvested with a lower bag limit because more hunters would choose not to harvest a juvenile bird so as not to fill their seasonal bag limit before they harvest an adult. However, we predicted a 14-day delay in the spring hunting season would not affect juvenile male harvest.

STUDY AREA

We conducted research in Bedford, Giles, Lawrence, Maury, and Wayne counties in south-central Tennessee, 2017–2021. We chose these 5 counties as a result of growing concern for wild turkey population declines in south-central Tennessee. These declines were supported by a 60% reduction in harvest from 2005–2015 in Giles, Lawrence, and Wayne counties in conjunction with poult-per-female declines across the state (Buehler and Harper 2024, Quehl et al. 2024*a*, Shields 2024). We established north and south study sites within each county for trapping and monitoring turkeys (Figure 1). Two of the 10 study sites were on public land, Tie Camp Wildlife Management Area (WMA; 1,325 ha) in Wayne County and Yanahli WMA (5,200 ha) in Maury County, whereas the remaining 8

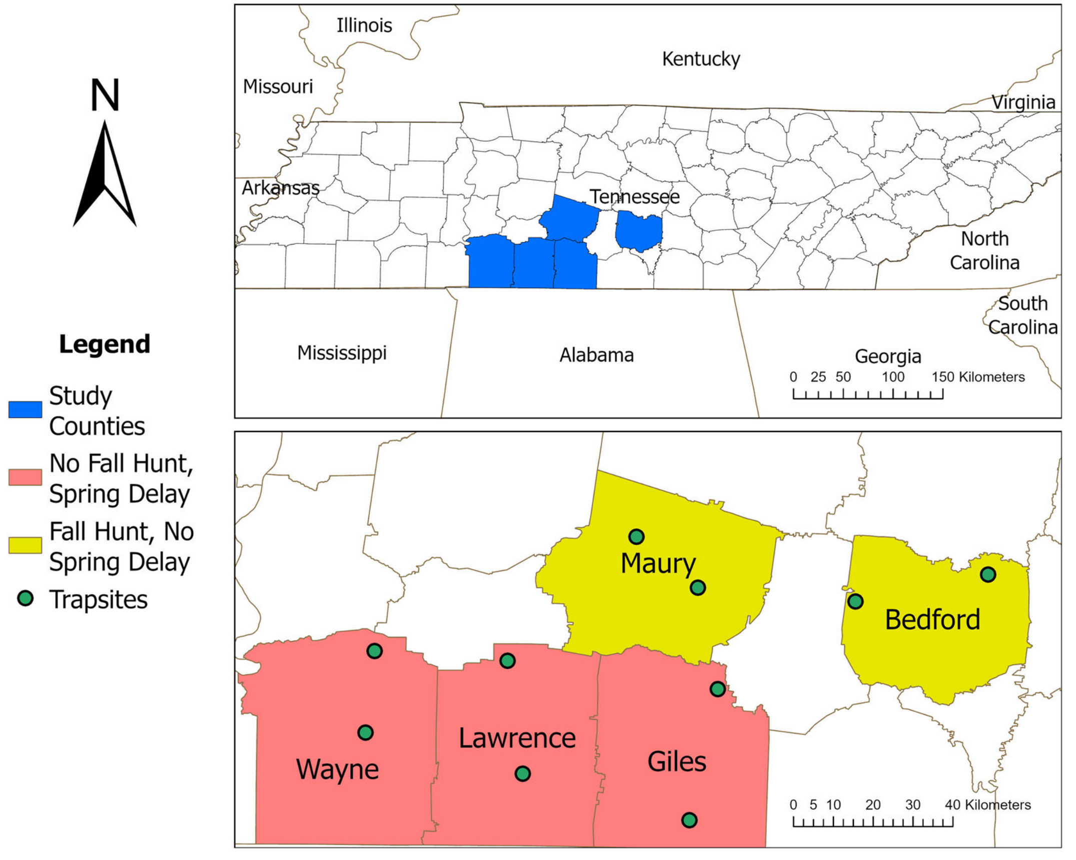

FIGURE 1 Our 5 study counties and associated northern and southern trap sites for juvenile male wild turkeys, south-central Tennessee, USA, 2017–2021. Counties are separated by whether an experimental 14-day spring hunting season delay was present in the county from 2021–2022 and whether the county had a fall turkey season.

sites were on private land. Private land sites totaled >29,000 ha and included >380 individual landowners. The study sites were comprised of mature deciduous and coniferous forest, young forest (<10 years old), early successional plant communities, hayfields, pastures, row crops, and human-developed areas. The primary soil types for the study area were Bodine cherty silt loam and gravelly silt, Gladeville rock outcrop, Ashwood, Brandon silt loam, Biffle gravelly silt loam, and Frankstone cherty silt loam (United States Department of Agriculture 2019). All 5 study counties were similar in topography, elevation range, weather, and predator communities. Land cover proportions were similar between counties, except Wayne County had a larger proportion of coniferous forest because of an increased number of commercial pine plantations. Since 1989, the spring wild turkey season opened on the Saturday closest to 1 April (including 29–31 March), was 6 weeks in duration, and had a bag limit of 4 bearded birds. In 2021–2022, the spring turkey season was delayed 14 days (thereby shortened by 2 weeks) in Giles, Lawrence, and Wayne counties, and the bag limit was reduced to 3 bearded birds, of which only one could be a juvenile male. In 2023–2024, the season was delayed 14 days statewide but lengthened at the end of the season by 2 weeks for a total duration of 6 weeks, and the bag limit was reduced to 2 bearded birds, of which only one could be a juvenile male. Additionally, Giles, Lawrence, and Wayne counties were closed to fall turkey hunting starting in 2014, whereas Bedford and Maury counties have had a fall hunting season with a bag limit of 1 bearded turkey per county since 2016.

METHODS

Field methods

We trapped wild turkeys during winter, 2017–2021, using box-set rocket nets (Delahunt et al. 2011). We baited trap sites with shelled corn every other day to attract turkey flocks. We used trail cameras to monitor wild turkey visitation patterns, sex and age ratios, and flock sizes (model MCG13202, Moultrie, Birmingham, AL, USA). We established a goal of maintaining a sample of 100 male turkeys each year across all 5 focal counties (10 males at each of the 10 sites, 5 adults and 5 juveniles). We excluded adult males from this study because we were interested in research questions specific to the juvenile cohort. We aged turkeys as juveniles based on uneven tail fan margins, primary feather barring, and leg spur length according to Pelham and Dickson (1992). We fitted each trapped juvenile male with a $75 reward aluminum leg band (style 1242FR8A, National Band and Tag Company, Newport, KY, USA), assuming such a reward would encourage a greater return rate (Diefenbach et al. 2000). We attached a very high frequency (VHF) transmitter to each juvenile male (Series A1500, ~80 g, life expectancy of 5.7 years; Advanced Telemetry Systems, Isanti, MN, USA). We recorded each male's weight, beard length, spur length, tarsus length, and body condition score (scoring the amount of fat and muscle found on the bird's keel; Gregory and Robins 1998). After processing, we immediately released each turkey at the trap site. We radio-tracked wild turkeys weekly to monitor mortality status and triangulated their location during each tracking event. When a turkey entered mortality mode (i.e., lack of activity for >8 hours), we retrieved the transmitter and investigated the cause and location of death as quickly as possible. We investigated the majority of turkey mortalities within 2 days after mortality, unless we were unable to obtain permission to access private property. Direct observation of the cause of tagged turkey mortality is rarely possible; therefore, we used evidence at the kill site to infer the probable cause of mortality as accurately as possible. We inferred great-horned owl (*Bubo virginianus*) predation by the removal of the head and breast muscle (Thogmartin and Schaeffer 2000, Little et al. 2016), bobcat (*Lynx rufus*) predation by a cached or covered carcass (Thogmartin and Schaeffer 2000), and coyote (*Canis latrans*) predation by broken bones, scattering of remains, and presence of coyote scat and hair (Thogmartin and Schaeffer 2000). If mammalian predation was apparent, but we did not have enough evidence to attribute the mortality to a specific species, we categorized the mortality as an unknown mammal. Poaching was identified by cleanly cut transmitter straps with no evidence of predation. All harvested birds were reported via reward leg bands. All remaining mortalities were classified as unknown. We acknowledge that the land cover classification associated with mortality may not be completely accurate, as some carcasses could have been moved from the site of mortality to a different cover type.

Home range analysis

We calculated triangulated locations in the program LOAS using 3 intersecting bearings defined during VHF transmitter tracking events (Sallee 2005). We tracked turkeys weekly on average during all months of the year. We calculated our location error in LOAS using a 95% confidence interval ellipse polygon. We removed all locations from home range analysis whose error polygon was >10 ha, which resulted in a mean error of 1.4 ha/location. We created 90% minimum convex polygon (MCP) annual home ranges for turkeys using the adehabitatHR (version 0.4.22) package (Calenge 2006) in R version 4.4.1 (R Core Team 2026). We created home ranges for turkeys with ≥20 locations from their capture date to 12 months after capture. We excluded any individuals that had <20 locations or did not survive for the entire year from home range analysis. Even though this number of locations per bird may not capture the full extent of the home range of each turkey, a minimum of 20 locations was necessary to provide a large enough sample size for calculation. Furthermore, we only used the average home range size across all years of the study (2017–2021) in subsequent survival analysis, so basing the home range analysis on a minimum of 20 locations had little if any influence on our results.

Resource selection analysis

We analyzed resource selection of juvenile male wild turkeys using case-controlled conditional logistic regression with a use versus availability framework to investigate which land cover types and other landscape metrics turkeys were selecting compared to what was available on the landscape (Johnson 1980, Manly et al. 2004). Locations of all turkeys were used regardless of how long they lived. This approach may not represent even distribution of selection over the year because approximately 25% of individuals died before completing the juvenile life stage. We also acknowledge that analyzing resource selection using locations derived from VHF telemetry instead of a global positioning system (GPS) limited the frequency of obtaining locations to approximately weekly per individual rather than multiple daily locations and introduced greater location error, which can limit our inference and potentially introduce some bias because there are fewer locations for each individual (Hebblewhite and Haydon 2010, Latham et al. 2015). However, because VHF radio-tags are less expensive per unit and have much greater battery life compared to GPS units, our sample size of individual turkeys and the length of our study were greater than many GPS studies, enabling more robust population-level inferences about selection (Hebblewhite and Haydon 2010, Latham et al. 2015). We buffered each triangulated location by 138 m to create a 6-ha polygon around each used location using ArcGIS Pro version 3.3.1 (Esri, Redlands, CA, USA). We obtained an average of approximately 30 locations per turkey for resource selection. We chose a 6-ha buffer size because it enabled us to assess the composition of the land cover types they were using as opposed to the cover type they were located in at the time of the location. The buffer size also was larger than the average location error (1.4 ha; Erickson et al. 1998), which allowed the location estimate and its error buffer to shift in any direction by a radius length of the error polygon while remaining inside the 6-ha buffer. This buffer size was slightly larger than the average size of all cover type patches (5.5 ha), which enabled our scale of selection to match the landscape and facilitate inference at a patch scale. We clipped the land cover types for each polygon from the United States Geological Survey (USGS) National Land Cover Database (NLCD; 2017–2021) 30-m spatial resolution Landsat land cover maps of North America using ArcGIS Pro (United States Geological Survey 2024). We then calculated landscape metrics associated with individual locations for the resource selection analyses using the landscapemetrics (version 2.2.1) package (Hesselbarth et al. 2019) in R version 4.4.1 (R Core Team 2026). These metrics included forest edge density, mean patch size, percentage of land cover by type, and percentage cover type interior (≥120 m from patch edge, see below). We created available, non-overlapping polygons identical in size to the associated use polygons by randomly locating 10 points 0–3,000 m from the center of each use polygon in accordance with the design III protocol reported in Manly et al. (2004). We chose a 1:10 used-to-available ratio to align with sample sizes used in other studies that implemented conditional logistic regression in a similar framework, while also maintaining practical data storage and analysis of large raster datasets (Matthews and Spooner 2014, Lehman et al. 2016, Cain et al. 2024, Green et al. 2025). We defined the area for placement of these available buffers based on a distance of 3,000 m, which represented the average daily travel distance for a male turkey from other recent studies (Gross 2015, Chamberlain et al. 2018, Cohen et al. 2022). We chose to use a 3,000-m extent instead of our average home range size to better characterize what was available to the turkeys because home ranges may underestimate what was truly available (Walter et al. 2015, Niedzielski and Bowman 2016, Skupien et al. 2016, Cohen et al. 2018). Although we cannot know what was truly available for each turkey, this approach defined a broad landscape that individual turkeys could use given their daily movements. We then calculated the same 4 landscape metrics for each available polygon that were applied to the used polygons and averaged the values for the 10 random polygons associated with a single-use polygon (Figure 2).

We calculated landscape metrics based on composition and structural features we thought could be important to turkey resource selection based on the hypotheses we were testing and the associated literature. Forest edge density was defined as the meters of forest edge (where forest and another cover type meet) per ha within a 6-ha buffer (McGarigal 1995). Mean patch size was defined as the sum of the areas of all patches of a given patch type within a given buffer, divided by the number of patches of the same type. Because calculating patch size using a

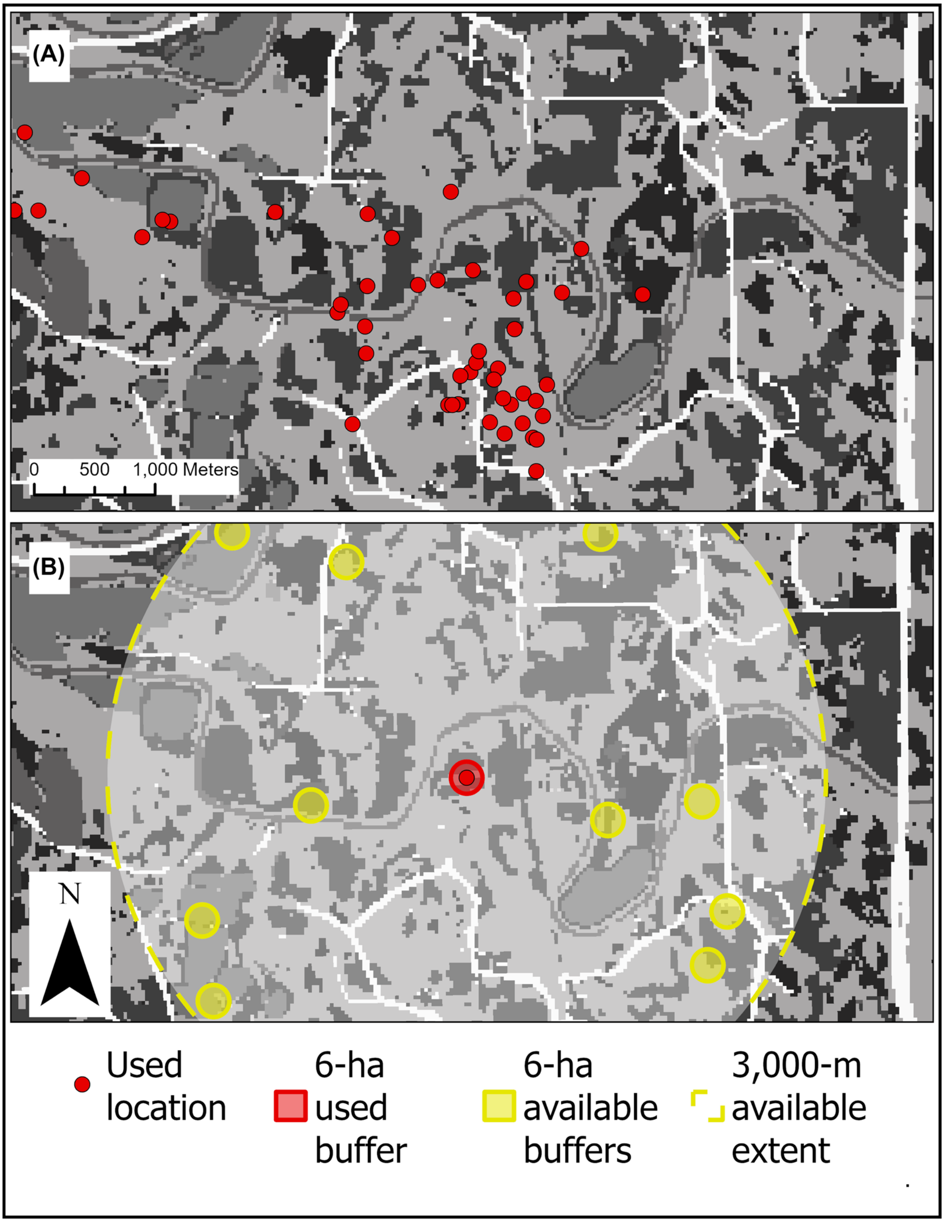

FIGURE 2 Resource selection framework for juvenile male wild turkeys in south-central Tennessee, USA, 2017–2021. (A) Example of used annual locations for one turkey. (B) Example of one used location and its 6-ha buffer surrounded by its associated 10 random available buffers within the 3,000-m extent.

6-ha buffer would truncate some patches that extended beyond the boundaries of the buffer, we included all patches that were fully within or intersected the buffer. Thus, we considered the full size of all patches even if they extended beyond the limits of the 6-ha buffer. We calculated the percentage of land cover by type by dividing the number of pixels of a given land cover type by the total number of pixels within the 6-ha buffer. The percentage of cover type interior was defined as the square meters of a particular land cover type that were ≥120 m in all 4 cardinal directions from a patch edge, divided by the total buffer area (McGarigal 1995). We chose 120 m to align with previous studies and to represent a maximum preferred foraging distance from edges (Schroeder 1985, Glennon and Porter 1999, Fleming and Porter 2000). The formula used to calculate cover type interior was:

$$CPLAND = \left(\frac{\sum_{j=1}^{n} a_{ij}^{core}}{A}\right) \times 100, \quad (1)$$

where a_{ij}^{core} was the cover type interior in square meters, and A was the total landscape area in square meters. When calculating cover type interior for a 6-ha buffer, we applied an additional 120 m outside the buffer to ensure the boundary of the 6-ha buffer was not artificially considered an edge. This method enabled proper identification of the entire 6-ha buffer as eligible for cover type interior consideration (Figure 3). We calculated all landscape metrics from land cover types defined by the NLCD map, which included open water, coniferous forest, deciduous forest, young forest, early succession, hay or pasture, row crop, woody wetland, emergent herbaceous wetland, developed land, and barren land. We combined open water, wetland, and barren land into a singular land cover type called nonhabitat. The developed land cover type was represented by roads, individual residential homes, and farmsteads.

We used the proportion of the 6-ha buffer composed of deciduous forest, coniferous forest, all mature forest, young forest, early succession, hay or pasture, row crop, developed land, and nonhabitat as covariates in the resource selection analysis (Table 1). We included all forested and open land cover proportion covariates in the analysis to determine if turkeys selected different cover types or if they behaved as generalists, as documented in previous studies (Hurst 1992, Marable et al. 2012, Pollentier et al. 2017). We included developed land and nonhabitat proportions to determine if turkeys would avoid areas that provided little food and cover and possibly presented a mortality risk. For edge density, we only calculated this metric for mature forest land cover (combined deciduous and coniferous forest) to specifically test if turkeys selected areas directly adjacent to forest edges to be closer to different cover types that provide food and cover (Davis et al. 2018, Pollentier et al. 2021; Table 1) To determine if turkeys were avoiding larger patches of discrete and managed land cover, we calculated the mean patch size for row crop and coniferous cover types. We used a subset of the data for this landscape metric by ignoring any instances when a turkey did not use one of these particular land cover types because we were interested in the mean patch size only when a turkey specifically used a row crop or coniferous patch. We specifically chose the patch size metric for row crop and coniferous cover types because they are most often spatially discrete and isolated, so that patch size reflected the true spatial extent of that cover type. Mature forest and hay or pasture were the most abundant cover types in the landscape matrix of south-central Tennessee (Rodewald 2003, Driscoll et al. 2013). We used the cover type interior metric rather than patch size for mature forest and hay or pasture because these cover types are frequently connected by narrow corridors, resulting in patches perforated by edges with an inflated patch size that does not properly represent a larger uninterrupted management unit (Hargis et al. 1998; Table 1). We did not calculate land cover metrics related to size or interior structure for cover types such as early succession, young forest, nonhabitat, and developed land because these cover types were consistently represented by small patches and attempting to calculate size or interior would be uninformative. We evaluated the inclusion of interactions between county and land cover covariates to assess spatial heterogeneity of land cover relationships with resource selection across the study area. We evaluated multicollinearity among continuous covariates using the variance inflation factor (VIF) from the car (version 3.1-3) package (Fox and Weisberg 2019) in R version 4.4.1 by using a threshold of 5 and removing any models that exceeded that threshold (Shrestha 2020, R Core Team 2026). We standardized all continuous covariates by z-transforming each to enable direct comparison of beta coefficient effect sizes (Quinn and

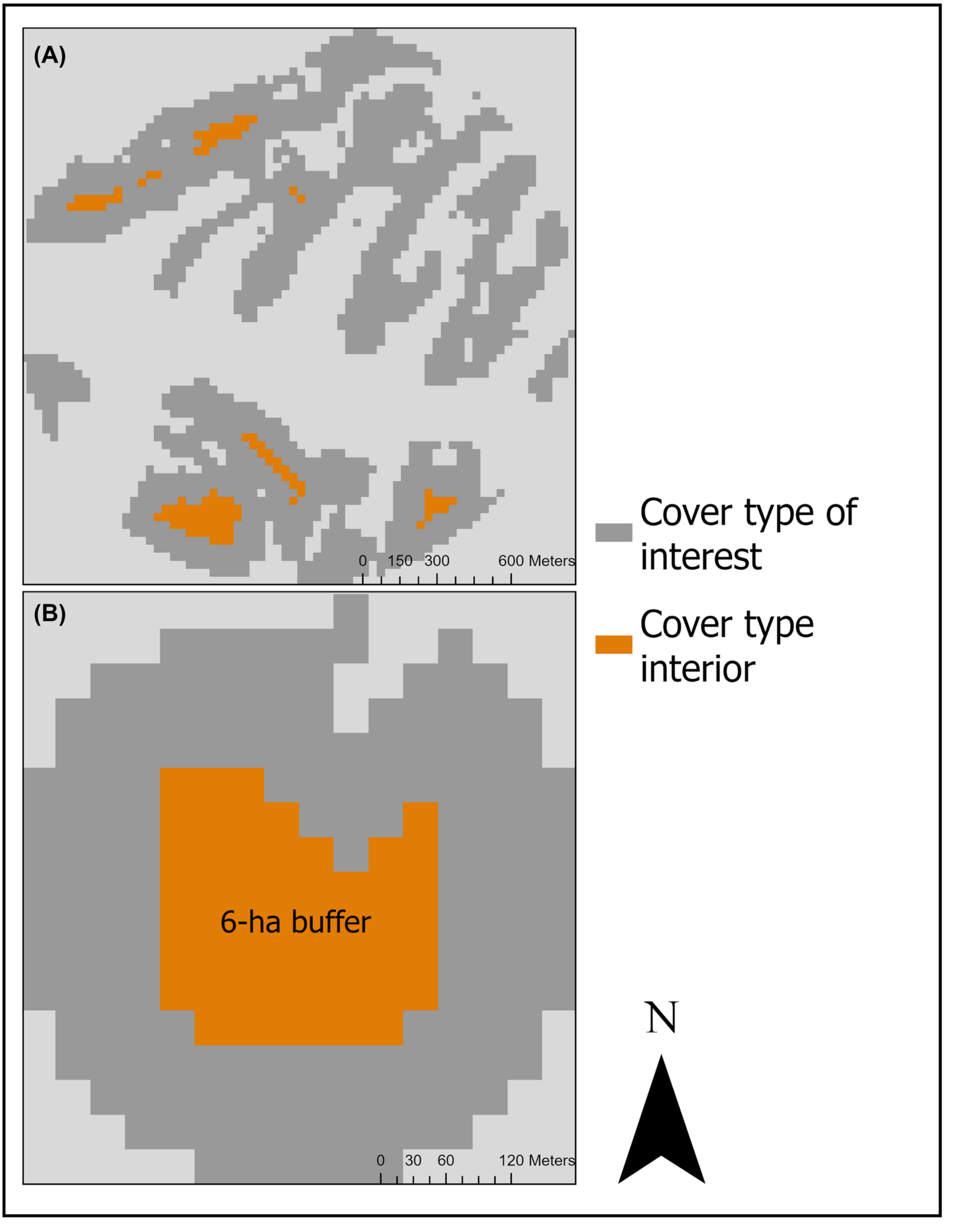

FIGURE 3 Cover type interior metric for juvenile male wild turkey resource selection in south-central Tennessee, USA, 2017–2021. (A) An example of what is considered to be cover type interior for a given cover type within the home range for known-fate survival analysis. (B) An example of what is considered to be cover type interior of a given cover type for a 6-ha buffer for case-controlled resource selection.

TABLE 1 Description of landscape metrics calculated for juvenile male wild turkey resource selection and known-fate survival analyses, south-central Tennessee, USA, 2017–2021.

Metric name	Land cover types used	Definition	Biological question
Resource selection analysis			
Land cover proportion	Deciduous forest, coniferous forest, mature forest, young forest, early succession, hay or pasture, row crop, developed, non-habitat	% of the 6-ha buffer composed of a given land cover type	Do turkeys select specific cover types or are they generalists?
Patch size	Coniferous forest, row crop	Mean patch size (ha) of the given land cover type that is within or intersected by the 6-ha buffer	Do turkeys select smaller patches for a greater interspersion of cover types?
Cover type interior	Mature forest, hay or pasture	% of the 6-ha buffer for a given land cover type that is ≥120 m from a land cover edge	Do turkeys select smaller interiors of open or forested cover for closer proximity to cover?
Edge density	Mature forest	m/ha of edge for a given land cover type within the 6-ha buffer	Do turkeys specifically select forest edges for closer proximity to cover?
Survival analysis			
Land cover proportion	Deciduous forest, coniferous forest, mature forest, young forest, early succession, hay or pasture, row crop, developed, non-habitat	% of the home range composed of a given land cover type	Do cover types affect survival by altering visibility or predator abundance?
Cover type interior	Mature forest, hay or pasture	% of the home range for a given land cover type that is ≥120 m from a land cover edge	Do larger interiors of open or forested cover affect survival by altering visibility?
Edge density	Mature forest	m/ha of edge for a given land cover type within the home range	Do forest edges reduce survival because of decreased visibility along dense edges?
Interspersion and juxtaposition index	Deciduous forest, coniferous forest, mature forest, young forest, early succession, hay or pasture, row crop, developed, non-habitat	Interspersion and juxtaposition of a given land cover type within the home range	Does survival depend on the configuration of cover types that may alter visibility or predator abundance?

Keough 2002, Zuur et al. 2007). We created univariate and multi-covariate case-controlled conditional logistic regression models using the clogit function from the survival (version 3.8-3) package (Therneau et al. 2024) in R version 4.4.1 (Johnson et al. 2022, R Core Team 2026). We paired each use location with its associated 10 available locations by specifying stratification variables within the models. The estimated variance associated with turkey ID was effectively zero ($\theta = 5 \times 10^{-11}$), indicating that inclusion of a turkey-level random intercept was not supported by the data. However, to account for any remaining lack of independence among locations from the same turkey, all models were clustered by turkey ID to calculate robust standard errors (Fieberg et al. 2010, Abernathy et al. 2019, Masto et al. 2024).

To develop the model set, we first tested covariates univariately to examine individual effects on selection and to inform subsequent modeling (Bursac et al. 2008). We developed a model set of univariate and multivariate models that tested our specific hypotheses, based on the literature or developed from our field experience. We used Akaike's Information Criterion corrected for small sample size (AIC_c) to select the best-supported model for the resource selection analysis. We considered all models with $\Delta AIC_c < 2$ as part of our family of best models and interpreted results from these models. The patch size covariate models could not be directly compared with the other resource selection models because patch size models only included data if a given patch type (e.g., row crop and coniferous forest) was present, leading to differential sample sizes. Instead, we evaluated the univariate patch size models independently and determined the results based on effect size and beta coefficient confidence intervals. We considered covariates from both analyses influential if their beta coefficient estimates had 85% confidence intervals that did not include zero, following principles of AIC model selection and multi-model inference (Arnold 2010, Tan and Tan 2010). We emphasize that we used confidence intervals as heuristic filters rather than as formal hypothesis tests. This inferential approach does not imply statistical significance in the traditional null hypothesis-testing framework but rather is interpreted as indicating support for an effect given the data and model structure (Burnham and Anderson 2002).

Survival analysis

From 2017–2021, we monitored the weekly mortality status of each of the juvenile male wild turkeys until they either died, were recruited to the adult age class, or we lost contact with their radio signal. We recorded the land cover type at the mortality site for each carcass and the apparent cause of death for each mortality. We considered juvenile turkeys to be any male that was in juvenile plumage at capture during their first winter until 23 March of the subsequent year. We chose 23 March as the end date of this age class because it was the earliest opening date of the spring youth turkey hunt in any year of the study. We acknowledge that our classification of juveniles includes a time period after each turkey's second autumn when juveniles transition to the adult age class according to feather molting patterns (Pelham and Dickson 1992). However, because they are not harvested as an adult male until at least the following March, extending the length of this age class helps answer crucial questions about turkey survival before the probability of mortality from harvest substantially increases and will better describe annual survival by including all months of the year. We estimated survival using the Kaplan-Meier known-fate survival model calculated using the RMark (version 3.0.0) package (Laake 2013) in R version 4.4.1 (Kaplan and Meier 1958, Pollock et al. 1989, White and Burnham 1999, R Core Team 2026). We used a staggered-entry design to allow for additional turkeys to be added to the analysis after the study had begun (Pollock et al. 1989). We removed individuals from the study with mortalities within 14 days of capture to avoid including turkeys that may have experienced capture myopathy (Nicholson et al. 2000). We right-censored all turkeys that we could not detect with telemetry after the last successful tracking occasion. We defined tracking occasions as biweekly because the average time between telemetry location attempts was one week. We raised the biweekly survival estimate, averaged across the entire year, to the 26th power to calculate annual survival estimates. We calculated the harvest rate by right-censoring all non-harvest mortalities and subtracting the resulting survival rate from 1 (Norman et al. 2022). We included multiple covariates in the survival model to evaluate the influence of different land cover types and landscape metrics on juvenile male wild turkey survival. We removed all birds whose mortality was attributed to hunter harvest from models investigating the influence of landscape metrics on survival to isolate the effect of landscape on non-harvest mortality. The first set of models included the discrete factor variables year and county. The second set of models included landscape covariates calculated using the landscapemetrics (version 2.2.1) package (Hesselbarth et al. 2019) in R version 4.4.1 for all turkeys by using identical circular polygons equal to the mean annual home range size of all turkeys that lived ≥12 months, placed over the centroid of each turkey's estimated locations (R Core Team 2026). We chose to use average home range polygons to extract each turkey's landscape covariates because only a subset of turkeys that lived at least 12 months would have an MCP home range produced. To justify the use of average home ranges, we created a generalized linear mixed-effects model with a Gaussian error distribution using the glmmTMB function from the glmmTMB (version 1.1.14) package (Brooks et al. 2017) in R version 4.4.1 to show that there was no significant difference between the landscape covariates for MCP and average home ranges ($Z = -0.05$, $P = 0.96$; R Core Team 2026). We used different buffer sizes for the survival analysis compared to resource selection because we wanted to model survival at the home-range scale to understand how used land cover influenced survival, whereas a 3,000-m buffer in the resource selection analysis represented the full extent of available land cover. We included the proportion of the home range comprised of deciduous forest, coniferous forest, all mature forest combined, young forest, early succession, hay or pasture, row crop, developed land, and nonhabitat in the survival models to determine how different amounts of land cover were related to survival probability as it related to visibility or predator abundance (Miller and Leopold 1992, Whittingham and Evans 2004). Mature forest edge density was included to determine if the total length of woody edges was related to survival by increasing predator success as a result of decreased visibility along forest edges (Šálek et al. 2010, Wang et al. 2025; Table 1). We included the percentage of mature forest and hay or pasture interior, consistent with the resource selection analysis, to determine if large uninterrupted areas of open or forested cover would be related to survival by affecting visibility for wild turkeys (Table 1). Lastly, we included the IJI of deciduous forest, coniferous forest, young forest, early succession, hay or pasture, row crop, nonhabitat, and developed land to determine if the impact of land cover was more dependent on the configuration and distribution in the home range instead of the total amount present (Mimet et al. 2016, Gengler et al. 2024; Table 1). The IJI was defined as the observed interspersion of land cover type classes over the maximum possible interspersion for the given number of land cover type classes (McGarigal 1995). The equation used to calculate IJI for each land cover type was:

$$IJI = \frac{-\sum_{k=1}^{m}\left[\left(\frac{e_{ik}}{\sum_{k=1}^{m} e_{ik}}\right)\ln\left(\frac{e_{ik}}{\sum_{k=1}^{m} e_{ik}}\right)\right]}{\ln(m-1)} \times 100, \tag{2}$$

where e_{ik} are the unique adjacencies of a particular land cover type class in meters, and m is the number of all classes present (McGarigal 1995). Values of IJI are defined between 0 and 100, with a lower value indicating a landscape with land cover types that are more poorly interspersed (McGarigal 1995). We evaluated the inclusion of interactions between county and land cover covariates to assess spatial heterogeneity of land cover relationships with survival across the study area We z-transformed all covariates and tested them for multicollinearity using VIF, similar to the resource selection analysis. We developed a model set for evaluation by first testing covariates univariately to examine individual effects on survival and to inform subsequent modeling (Bursac et al. 2008). We then created multivariate models by including covariates that tested specific hypotheses based on the literature or developed from field experience. We obtained beta coefficient estimates from all models with $\Delta AIC_c < 2$. We used an 85% confidence interval threshold for beta coefficients to determine influential covariates similar to the resource selection analysis (Arnold 2010, Tan and Tan 2010). However, to remain consistent and comparable to the literature, we report estimates of means—annual survival, annual harvest, and home range size—with 95% confidence intervals and associated standard errors.

Harvest analysis

Because radio-tracking and trapping of juvenile male wild turkeys ceased in 2022, we were unable to analyze the effect that changes in harvest regulations after 2021 had on our survival or harvest. We obtained spring harvest data from the Tennessee Wildlife Resources Agency (R. Shields, unpublished data) for Bedford, Giles, Lawrence, Maury, and Wayne counties for 2017–2024 to assess the impact of regulation changes on juvenile male turkeys. We calculated the total reported spring season harvest of juvenile and adult males from the annual harvest data by county and year. We then used the glm function with a binomial error distribution and logit link function in the R version 4.4.1 stats package to create generalized linear models to determine if the proportion of juvenile male turkeys in the harvest differed by county and year (R Core Team 2026). We created 2 sets of models, one with year and county variables and one with harvest regulation variables (spring delay, bag limit). We used AIC_c to select the best-fitted model for each model set. We used the Anova function from the car package to perform likelihood ratio (LR) chi-square tests to detect the overall effect of year and county variables on harvest proportion. We used the summary function from the stats package to perform Wald z-tests to detect the individual effect of the changes in bag limit and 14-day delay. We used the plot function from the stats package to inspect the residuals versus fitted values, verify that the deviance residuals were normally distributed, and identify influential observations. For this analysis, we set $\alpha = 0.05$ for interpretation of results and used odds ratios (OR) to explain the effect size.

RESULTS

Trapping and home ranges

We trapped and banded 173 juvenile male turkeys from 2017–2021 across all 5 focal counties. We radio-tagged 148 juvenile male turkeys with backpack VHF transmitters. We included 136 turkeys in the resource selection and survival analysis (Wayne = 12, Lawrence = 30, Maury = 40, Bedford = 20, Giles = 34). Of the 136 turkeys monitored, 74 produced enough locations to create MCP home ranges. The mean number of locations per home range was 44.1 (±1.7 SE, 95% CI = 40.8, 47.4). We excluded 431 locations from the resource selection analysis because they had error polygons >10 ha. The mean annual home range size was 352.3 ha (±27.3 SE, 95% CI = 297.8, 404.7).

Resource selection

Our monitoring protocol produced 3,860 used locations with a mean of 28.4 locations per individual (±1.4 SE; 95% CI = 25.8–31.2) and 38,600 random available locations (10 random locations for each used location), well exceeding the 10,000 sample threshold often recommended for proper characterization of availability on the landscape (Northrup et al. 2013). We created 14 univariate and 41 multivariate models. There was no evidence of significant interactions between land cover covariates and counties, indicating that covariate relationships on resource selection applied across the 5-county study area.

The best-supported model contained the proportion of developed land, young forest, and mature forest interior (Table 2). All other models in the model set had values of $\Delta AIC_c > 2$ and therefore were not considered. Based on the best-supported model, turkeys selected lower proportions of developed land ($\beta = -0.43$; 85% CI = [−0.55, −0.31]; Figure 4), such that a 10% increase in developed land decreased the odds of use by 48%. Turkeys selected lower proportions of mature forest interior ($\beta = -0.35$; 85% CI = [−0.42, −0.28]; Figure 4), such that a 10% increase in mature forest interior decreased the odds of use by 41%. Turkeys selected lower proportions of young forest ($\beta = -0.20$; 85% CI = [−0.37, −0.04]; Figure 4), such that a 10% increase in young forest decreased the odds of use by 50%. Out of the 2 separate models using the mean patch size data sets, only the model containing the mean patch size of row crop showed a relationship with selection ($\beta = -0.31$; 85% CI = [−0.55, −0.07]; Figure 4), indicating turkeys were selecting smaller patches of row crops. For each 50-ha increase in the mean patch size of row crops, the odds of use decreased by 37%.

TABLE 2 Model selection results (top 10 models) for juvenile male wild turkey case-controlled resource selection analysis, south-central Tennessee, USA, 2017–2021. We present the number of parameters (K), corrected Akaike's Information Criterion (AIC_c), the difference between model rankings (ΔAIC_c), AIC_c model weight (w_i), and model deviance (Dev).

Model[a]	K	AIC_c	ΔAIC_c	w_i	Dev
Developed + young forest + forest interior	3	4,934.89	0.00	1.00	4,928.89
Developed + forest interior + hay	3	4,950.98	16.09	0.00	4,944.98
Developed + forest interior	2	4,972.65	37.76	0.00	4,968.65
Developed + edge + forest interior	3	4,973.40	38.51	0.00	4,967.40
Deciduous + developed + young forest + hay	4	4,990.02	55.13	0.00	4,982.02
Deciduous + developed + hay	3	5,005.42	70.53	0.00	4,999.41
Forest + developed	2	5,025.64	90.75	0.00	5,021.64
Deciduous + developed + edge	3	5,062.69	127.80	0.00	5,056.69
Deciduous + developed + young forest	3	5,064.59	129.70	0.00	5,058.59
Developed + young forest + edge	3	5,067.89	133.00	0.00	5,061.88

[a]Deciduous = proportion of deciduous forest, young forest = proportion of young forest, developed = proportion of developed land, edge = forest edge density, forest interior = proportion of forest interior, hay = proportion of hay or pasture.

Survival

We documented 32 total mortalities of 136 juvenile males monitored (24%). Probable causes of mortality based on field sign included coyote (n = 15, 47% of mortalities), bobcat (n = 1, 3%), unknown mammal (n = 7, 22%), harvest (n = 3, 9%), poaching (n = 2, 6%), and unknown (n = 4, 13%). Although we used all possible evidence to identify the predator species, some of the mortality assigned to certain species, of course, may not be accurate. Regardless, we attributed 23 of 32 mortalities (72%) to mammalian predators. Of the 29 non-harvest mortalities, 25 carcass recovery locations were in deciduous forest (89%) and 3 were in hay or pasture (11%). We were unable to gain access to the private land location of one mortality.

The full set of models included continuous landscape covariates (1 null, 25 univariate, 32 multivariate models; Table 3). There was no evidence of significant interactions between land cover covariates and counties, indicating covariate relationships with mortality applied across the 5-county study area. Of the models we fit, 2 had $\Delta AIC_c < 2$ and were considered part of the family of best models. The best-supported model included hay or pasture interior, the interspersion of young forest, and the interaction between these covariates. This model demonstrated that an increase in hay or pasture interior increased survival (β = 1.47; 85% CI = [0.41, 2.54]) and an increase in the interspersion of young forest reduced survival (β = −0.82; 85% CI = [−1.37, −0.27]). However, the negative interaction between these 2 covariates (β = −1.61; 85% CI = [−2.77, −0.46]; Figure 5) indicated the positive effect hay or pasture interior had on survival was reduced as the interspersion of young forest increased. The second best-supported model included the proportion of deciduous forest, the interspersion of developed land, and the interaction between these covariates. This model demonstrated that an increase in the proportion of deciduous forest (β = −0.44; 85% CI = [−0.81, −0.07]) and an increase in the interspersion of developed land (β = −0.52; 85% CI = [−0.87, −0.16] reduced survival. However, the positive interaction between these 2 covariates indicated the negative effect of developed land on survival was reduced as deciduous forest increased (β = 0.43; 85% CI = [0.10, 0.76]; Figure 5). When fitting models with year and county, the model including county provided the best fit. Annual survival rates varied by county, as survival rates in Bedford and Maury counties were greater than survival rates in

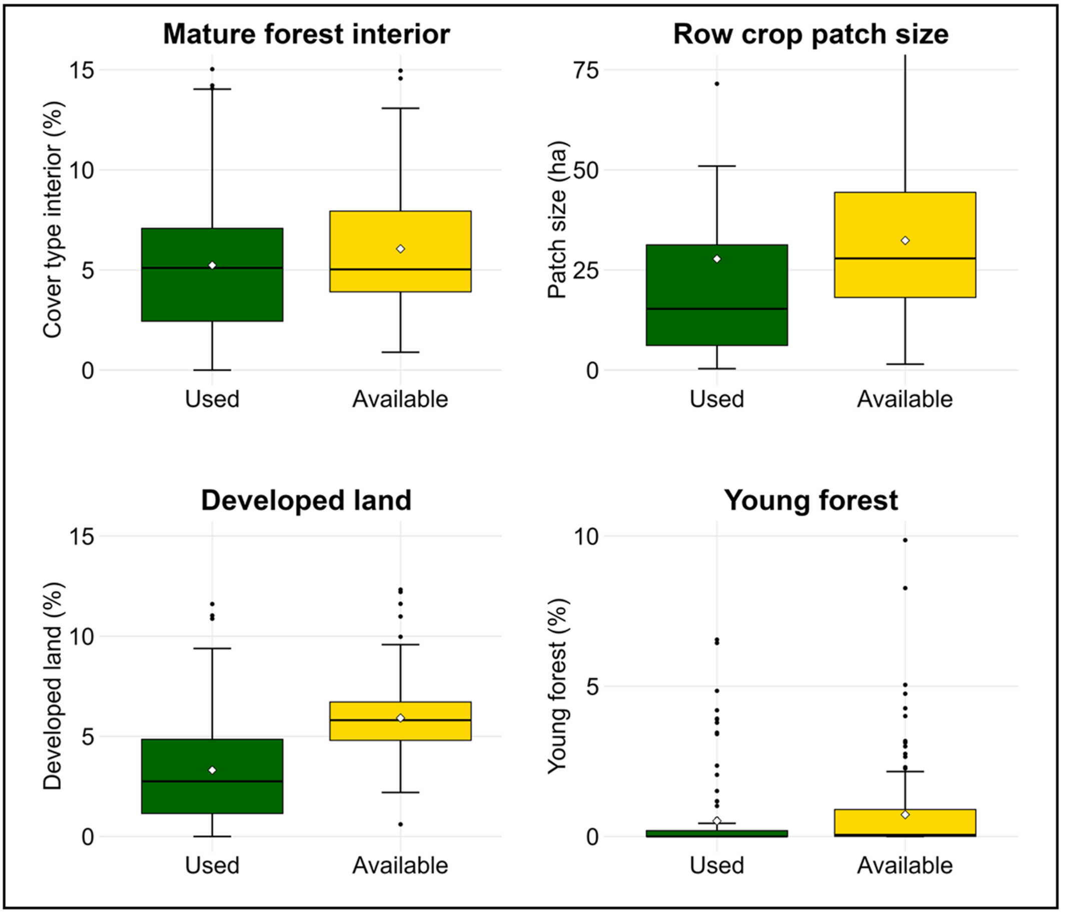

FIGURE 4 Comparison of used versus available mature forest interior, row crop patch size, and the proportion of developed land associated with location buffers for juvenile male wild turkeys, south-central Tennessee, USA, 2017–2021. Box plots display the interquartile range (IQR; box), median (line), mean (diamond), upper and lower limits (1.5 × IQR; whisker limits), and outliers (dots).

Giles, Lawrence, and Wayne counties (Table 4). The null model with no covariates yielded an average annual survival rate of 0.73 (±0.04 SE; 95% CI = 0.65–0.81) with a harvest rate of 0.03 (±0.02 SE; 95% CI = 0.01–0.09).

Harvest

The proportion of juvenile male turkeys in the spring harvest averaged across all years and counties combined was 13.1% (SE = 0.7), with 40 year-county combinations. The proportions varied by year (LR χ^2 = 200.38; df = 7; $P \leq 0.001$; Figure 6) as follows: 16.4% (2017), 10.0% (2018), 14.2% (2019), 15.2% (2020), 11.3% (2021), 16.4% (2022), 10.2% (2023), 7.7% (2024). The proportions varied by county (LR χ^2 = 72.06; df = 4; $P \leq 0.001$) as follows: 11.8% (Bedford), 14.5% (Giles), 17.0% (Lawrence), 12.2% (Maury), 10.0% (Wayne). When comparing the effect of harvest regulations on the proportion of juvenile males in the harvest, the additive model containing the 14-day spring delay and bag limit as covariates had the lowest AIC_c score. In the 5 focal counties, the proportion of spring harvest comprised of juvenile male wild turkeys was 14.1% during a 4-bird bag limit, 13.7% during a 3-bird bag limit, and 8.9% during a 2-bird bag limit. The proportion of

TABLE 3 Model selection results for juvenile male wild turkey known-fate survival analysis, south-central Tennessee, USA, 2017–2021. Only models that outperformed the null(no covariates) are shown. We present the number of parameters (K), corrected Akaike's Information Criterion (AIC_c), the difference between model rankings (ΔAIC_c), AIC_c model weight (w_i), and model deviance (Dev).

Model[a]	K	AIC_c	ΔAIC_c	w_i	Dev
Hay interior × young forest IJI	4	316.64	0.00	0.16	308.62
Deciduous × developed IJI	4	317.34	0.70	0.11	309.33
Developed IJI	2	318.89	2.25	0.05	314.88
Hay interior	2	318.99	2.36	0.05	314.99
Deciduous + developed IJI	3	319.30	2.66	0.04	313.29
Hay interior × developed IJI	4	319.36	2.72	0.04	311.34
Non-habitat + developed IJI	3	319.60	2.96	0.04	313.59
Deciduous + young forest IJI	3	319.87	3.23	0.03	313.86
Hay interior + young forest IJI	3	320.07	3.43	0.03	314.06
Deciduous + hay interior + developed IJI	4	320.11	3.47	0.03	312.10
Deciduous + developed IJI + non-habitat	4	320.14	3.50	0.03	312.13
Young forest IJI + developed IJI	3	320.21	3.58	0.03	314.21
Hay interior + early succession	3	320.32	3.69	0.03	314.32
Deciduous + hay interior	3	320.74	4.10	0.02	314.73
Hay interior + forest	3	320.76	4.12	0.02	314.75
Developed IJI + forest	3	320.83	4.19	0.02	314.82
Non-habitat × developed IJI	4	321.59	4.95	0.01	313.57
Deciduous + young forest IJI + early succession	4	321.65	5.01	0.01	313.63
Young forest IJI × developed IJI	4	321.68	5.05	0.01	313.67
Deciduous × young forest IJI	4	321.83	5.19	0.01	313.82
Hay interior + early succession + young forest IJI	4	321.86	5.22	0.01	313.84
Deciduous + hay interior + early succession	4	321.86	5.23	0.01	313.85
Deciduous	2	321.96	5.32	0.01	317.95
Hay interior × deciduous	4	322.20	5.57	0.01	314.19
Deciduous + early succession	3	322.29	5.66	0.01	316.28
Deciduous + hay interior + early succession + young forest IJI	5	322.37	5.74	0.01	312.35
Null	1	322.45	5.81	0.01	320.45

[a]Deciduous = proportion of deciduous forest, early succession = proportion of early succession, non-habitat = proportion of nonhabitat, forest = proportion of all mature forest, young forest IJI = interspersion and juxtaposition index of young forest, developed IJI = interspersion and juxtaposition index of developed areas, hay interior = proportion of hay or pasture interior.

juveniles did not differ when the bag limit was reduced from 4 birds to 3 birds (OR = 0.92; $Z = -1.47$; $P = 0.141$), but the odds of juvenile harvest decreased by 43% when the bag limit was reduced from 3 birds to 2 birds (OR = 0.57; $Z = -7.34$; $P \leq 0.001$), and the odds also decreased by 48% between the 4-bird and 2-bird bag limits (OR = 0.52; $Z = -6.74$; $P \leq 0.001$). There was a negligible increase in the proportion of juvenile males harvested during the 14-day delay of the spring hunting season (OR = 1.14, $Z = 1.62$; $P = 0.105$).

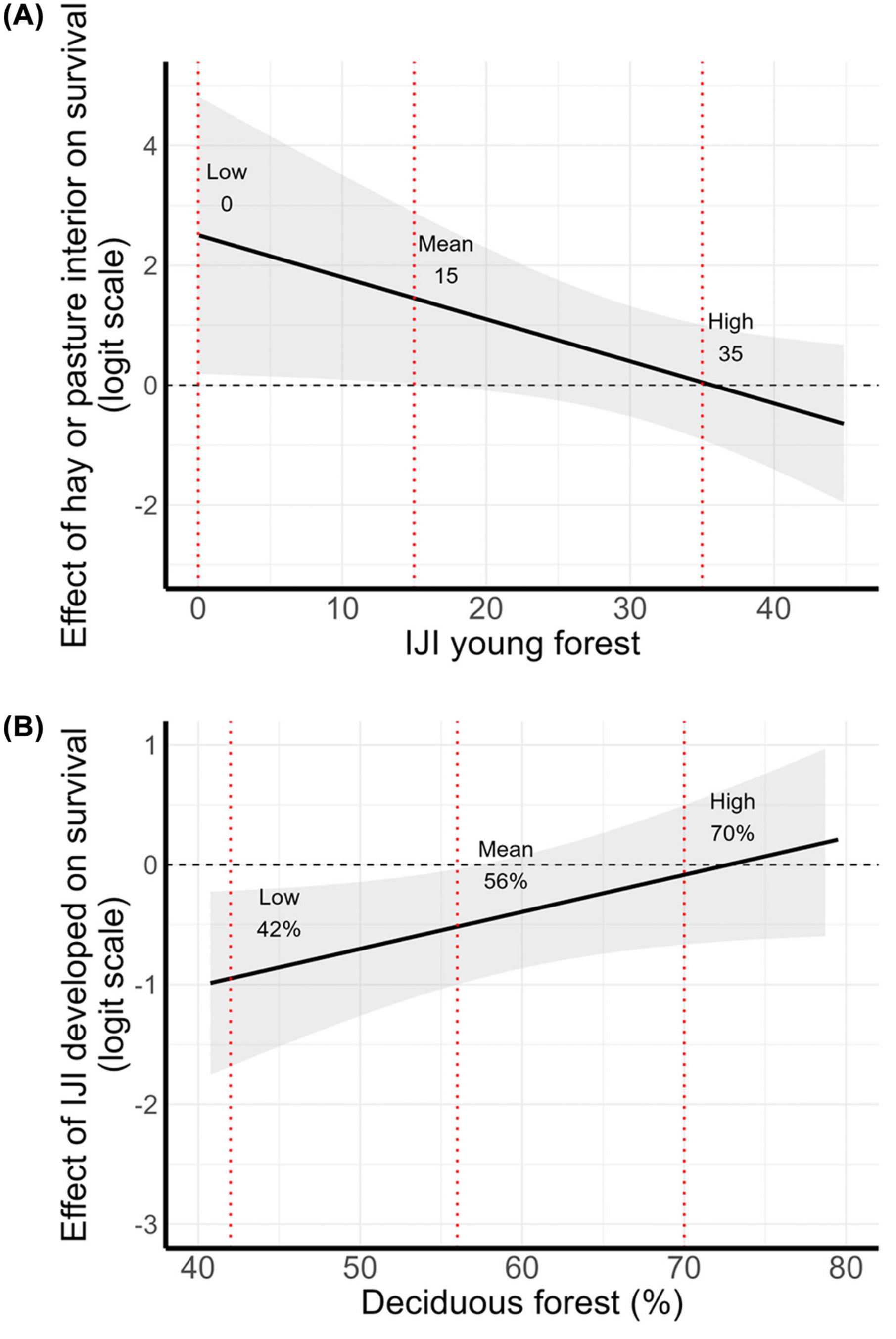

FIGURE 5 Conditional effect plots for juvenile male wild turkey annual survival, south-central Tennessee, USA, 2017–2021. (A) The effect of hay or pasture interior on annual survival across a range of young forest interspersion and juxtaposition index (IJI) values. (B) The effect of the IJI of developed land on annual survival across a range of deciduous forest proportions. The 3 levels indicated by the red dotted lines were determined by setting the middle level to the mean of that covariate and calculating 1 standard deviation below and above the mean for the low and high levels, respectively. The shaded area represents the 95% confidence interval around the conditional effect. Values above the horizontal dotted line represent conditions that increase survival, and those below the line represent conditions that decrease survival.

TABLE 4 Juvenile male wild turkey known-fate annual survival estimates by county, south-central Tennessee, USA, 2017–2021. We present survival rates (*S*), standard errors (SE), 95% confidence intervals (95% CI), and sample sizes (*n*).

County	*S*	SE	95% CI	*n*
Bedford	0.95	0.05	0.70–0.99	20
Maury	0.83	0.06	0.67–0.92	40
Wayne	0.71	0.14	0.40–0.90	12
Lawrence	0.70	0.09	0.49–0.84	30
Giles	0.54	0.09	0.37–0.70	34

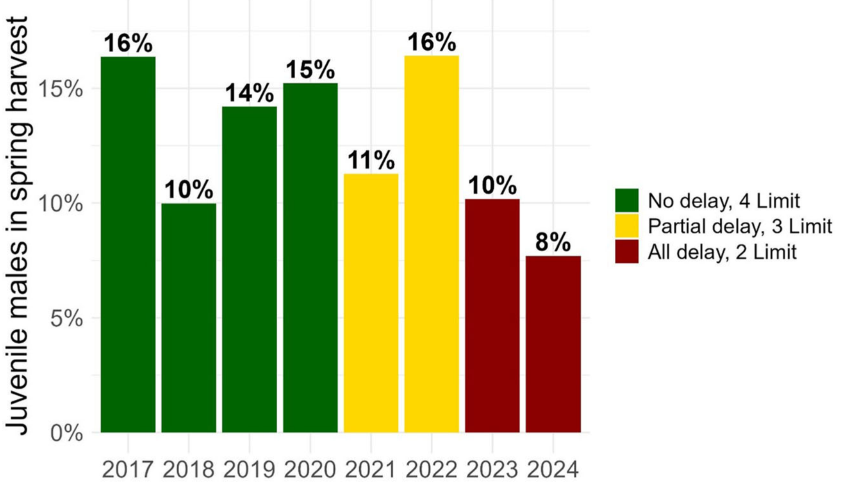

FIGURE 6 The proportion of the spring wild turkey harvest in Bedford, Giles, Lawrence, Maury, and Wayne counties that was made up of juvenile male turkeys, south-central Tennessee, 2017–2021. No delay, 4 Limit = no 14-day spring hunting season delay in any of the 5 counties and a 4-bird bag limit; partial delay, 3 Limit = 14-day spring hunting season delay in Giles, Lawrence, and Wayne counties and a 3-bird bag limit; all delay, 2 Limit = 14-day spring hunting season delay in all 5 counties and a 2-bird bag limit.

DISCUSSION

We documented previously unreported relationships of land cover on resource selection and annual survival and relationships of hunting regulations on juvenile male turkey harvest, which should better inform wild turkey management in Tennessee. Larger patch sizes of row crop, greater mature forest interior, and greater proportions of developed land and young forest were avoided by juvenile males at the home range level. Survival increased as hay or pasture interior increased, but this positive effect was reduced as the interspersion of young forest increased in the home range. Survival decreased as the interspersion of developed land increased, but this negative effect was reduced as the percentage of deciduous forest increased in the home range. These results may be used to adjust land management for wild turkeys, whereby the patch size of forests and fields may be reduced to increase interspersion, and increased frequency of disturbance could reduce patches of dense woody cover that can conceal mammalian predators from turkeys (Gorini et al. 2012, Turner et al. 2024, Bones et al. 2026). Overall, survival of juvenile male turkeys was lower than survival in most contemporary studies in the southeastern United States, but juvenile male survival could increase if regulations did not allow harvest of this age class. The proportion of juvenile males in the harvest approached 20% in some counties. Approximately 3 out of every 4 juvenile males not harvested during their first spring season could survive to increase the adult male population available for hunting the following spring.

The selection for smaller row crop patches by juvenile male wild turkeys supported our first hypothesis and aligns with previous reports that smaller fields dispersed across the landscape provide better interspersion of food and cover (Porter 1992, Glennon and Porter 1999, Kollmann and Schneider 1999, Davis et al. 2018). Wild turkeys use hardwood forests for mast, thermal cover during summer, and roosting (Porter 1992, Steffen et al. 2002), whereas adjacent cropland provides additional food resources, such as invertebrates, agricultural foods, and seeds (Hurst and Dickson 1992, Paisley et al. 1996, Otieno and Frenette 2017, Pollentier et al. 2021). The selection of less forest interior indicates selection for a more interspersed landscape with smaller forest and field patches, which requires less daily movement to acquire necessary resources for survival.

The lack of importance or selection of forest edge was noteworthy. Amount of edge historically has been considered desirable for various gamebird species (Leopold 1933, Glennon and Porter 1999, Matlack and Litvaitis 1999, Schindler et al. 2020). However, our results highlight how edge, defined by Bolen and Robinson (2002) as the interface of 2 or more vegetation types or seral stages, is not necessarily a determinant of selection or positively related to survival by juvenile male wild turkeys. Instead, resource availability, size and shape of the adjacent vegetation type patches, and the structure of vegetation, which affects visibility, should be considered reasons for selection, as has been demonstrated with other game species such as northern bobwhite (*Colinus virginianus*; Guthery and Bingham 1992, Guthery 1997, Guthery et al. 2001). For example, the edge created by young forest adjoining mature forest could potentially present increased predation risk with reduced visibility for wild turkeys in relatively dense young forest cover. Thus, juvenile male turkeys would not select such areas with young forest-mature forest edges.

The avoidance of developed land where mortality risk is greater and food resources are presumably less abundant was expected and supported our hypothesis. Urbanization is one of several factors that has led to declining wild turkey populations in some areas, including loss of habitat, collisions with vehicles, and increased predation pressure (Stark et al. 2020, United States Department of Agriculture 2020, Cohen et al. 2022, Dawson et al. 2025). When developed land was poorly interspersed in the home range, deciduous forest caused reductions in survival, perhaps as a result of greater predator densities and less visibility (Lagory 1986, Grossman et al. 2008, Gorini et al. 2012, Jones et al. 2022; Figure 5). However, deciduous forest mitigated the negative effect of high interspersion of developed land on survival, most likely as a result of increased usable space with food and cover (Collins et al. 2026; Figure 5). The south-central Tennessee region has developed rapidly over the past 30 years, expanding outward from the Nashville metro area (World Population Review 2025). If the resource selection and survival relationships for juvenile males apply similarly to other wild turkey cohorts, the regional increase in human development likely is contributing to the overall decline of regional wild turkey populations. Increased wild turkey conflicts with humans in recent years have caused some to speculate that turkeys can thrive in developed areas, and it is even proposed that some wildlife species will take refuge near human habitation, which could act as a shield to discourage predators (Gregonis et al. 2010, Gaynor et al. 2025). However, this human shield hypothesis is highly context-dependent, and it has even been demonstrated that 2 of the most common wild turkey predators—coyote and bobcat—actively seek developed areas rather than avoid them because of human interactions (Prugh et al. 2023). Although our study sites were predominantly exurban or rural, wild turkeys that inhabit more urbanized areas still select areas farther from roads and closer to herbaceous cover according to other studies (Collins et al. 2026).

The benefit of hay or pasture interior on juvenile male survival was greatly reduced as the interspersion of young forest cover reached greater levels, which supports our hypothesis related to increased predation risk where visibility for turkeys is limited (Figure 5; Whittingham and Evans 2004, Gorini et al. 2012). Meso-mammalian predators were responsible for most of the wild turkey mortalities we documented, and several species including coyote, bobcat, gray fox (*Urocyon cinereoargenteus*), and red fox (*Vulpes vulpes*) may concentrate their search for prey along the edge of forest cover, which is consistent with the negative effect young forest cover had on survival (Grossman et al. 2008, Deuel et al. 2017, Jones et al. 2022, Webster et al. 2022). The negative effect of deciduous forest on survival when the interspersion of developed land was lower is also supported by the large majority (89%) of mortalities we recorded in deciduous forest when only 57% of the landscape was deciduous forest. These results further support the concept of visibility being a key limiting factor in wild turkey survival, especially as we documented greater survival in home ranges with a greater percentage of hay or pasture interior when the interspersion of young forest was low. However, any benefit of hayfields for juvenile males can have reduced benefit for female turkeys when haying occurs during incubation and leads to nest destruction or abandonment (Tyl et al. 2023).

Our estimated annual survival rate of juvenile male wild turkeys was greater than several rates reported in the eastern and central United States (Wieme 2001, Hubbard and Vangilder 2007, Wright and Vangilder 2007, Norman et al. 2022, Wightman et al. 2024; Table 5). However, most of these rates were from studies that occurred more than 20 years ago, and many of the spring harvest rates were much greater than ours (Table 5). Reported juvenile male survival rates for more contemporary studies in the eastern United States were greater than ours, even with some of those locations having a greater spring harvest of juvenile males (Table 5; Norman et al. 2022, Wightman et al. 2024). Most of the juvenile male mortalities from our study (72%) were attributed to predators compared to 28%, 33%, and 53% of mortalities in 3 other southeastern studies (Wieme 2001, Wright and Vangilder 2007, Wightman et al. 2024). The predator mortality proportions from Mississippi (28%) and Kentucky (33%) were from

TABLE 5 Juvenile male wild turkey survival estimates, harvest estimates, and year of study for various southeastern United States studies.

Study area	Survival estimate	Spring harvest estimate (%)	Years of study	Citation
Georgia	0.96	1	2017–2022	Wightman et al. (2024)
West Louisiana	0.95	5	2013–2022	Wightman et al. (2024)
Mountains North Carolina	0.94	0	2020–2022	Wightman et al. (2024)
East Louisiana	0.90	0	2020–2022	Wightman et al. (2024)
South Carolina	0.82	5	2014–2018	Wightman et al. (2024)
Virginia	0.77	4	2004–2007	Norman et al. (2022)
Coastal North Carolina	0.74	5	2020–2022	Wightman et al. (2024)
South-central Tennessee	0.73	3	2017–2021	Our study
West Virginia	0.70	9	2004–2007	Norman et al. (2022)
Mississippi	0.69	0	1998–2000	Wieme (2001)
Piedmont North Carolina	0.65	0	2020–2022	Wightman et al. (2024)
Missouri Ozarks SSA[a]	0.60	11	1989–2000	Hubbard and Vangilder (2007)
Missouri Ozarks PRCA[b]	0.57	16	1989–2000	Hubbard and Vangilder (2007)
West Kentucky	0.53	N/A	1995–2002	Wright and Vangilder (2007)

[a]South Study Area.

[b]Peck Ranch Conservation Area.

studies that occurred more than 2 decades ago when predator populations likely were much lower and harvest rates for juvenile males were greater (Roberts and Crimmins 2010, Hody and Kays 2018). We documented >7 times greater predation-based mortality than harvest-based mortality (7:1 ratio), which is much greater than ratios reported from several recent southeastern studies (1.5:1 in SC, 4:1 in coastal NC, 1:5 in GA, 1:7 in West LA; Wightman et al. 2024).

The decline in the proportion of juvenile males harvested after a 2-bird bag limit was implemented likely was caused by changes in hunter behavior, in support of our hypothesis. Even though most hunters in the focal counties harvested 0 or 1 bird per season, the lower bag limit likely caused hunters to decide not to harvest a juvenile male bird for fear of filling their seasonal bag limit before they could harvest a second adult male turkey (Quehl et al. 2024*b*). Although there was relatively weak evidence that the proportion of juvenile males in the harvest increased during the 14-day spring delay ($P = 0.105$), the behavioral shift of hunters was more strongly influenced by bag limit than the timing of the hunting season. We were not able to account for changes in reproduction or hunter effort when analyzing the effects of harvest regulations, and we acknowledge those factors also may influence juvenile harvest.

Rather than relying on modest effects of a lower bag limit on reducing the number of juvenile male birds harvested, eliminating the harvest of juvenile males directly could have a greater effect on the availability of adult males. For example, when Mississippi eliminated juvenile male harvest, the average proportion of ≥3-year-old males in the harvest increased from 41% to 48%, and gobbles heard per hour also increased (Leopold and Cummins 2016). The harvest of adult male wild turkeys/100 hours in Arkansas increased by nearly 2.5 times in 2014, the year after a new regulation prohibited harvest of juveniles, and adult harvest has remained 1.5 times greater than the 7-year pre-ban average (Moscicki 2024). Our survival results demonstrate that eliminating juvenile males from harvest could allow 3 out of every 4 juvenile males not harvested during their first spring season to enter the adult age class, which would be available for harvest the following spring. Although the harvest rate of radio-tagged juvenile males on our study sites was low, juvenile males represented ≥10% of the total spring harvest in our study site counties and approached 20% in some years (Figure 6). Therefore, limiting harvest of juveniles likely would lead to increased numbers of adult males available for harvest and ultimately increase hunter satisfaction.

MANAGEMENT IMPLICATIONS

A relatively robust survival rate among juvenile males allows predictable recruitment of adult males into the population the following spring. Any management that increases juvenile male survival should translate directly to an increase in adult male availability the following spring hunting season. Considering the survival rate for juvenile males, we recommend state wildlife agencies consider regulations that limit harvest of juvenile males similar to regulations implemented in Arkansas, Mississippi, South Carolina, and Louisiana. Mammalian predators were responsible for the majority of wild turkey mortality. Habitat management can influence wild turkey survival. We recommend practices that provide more open structure, increase visibility for turkeys, and decrease large homogenous patches of forest cover, including forest clearing and thinning coupled with frequent prescribed fire. Implementing some level of predator control may be warranted where mortality may be limiting fecundity and recruitment into the population. Continued wild turkey habitat loss as a result of human development should be considered when monitoring wild turkey populations in the future. Increased human infrastructure and reduced wild turkey habitat likely will lead to greater predation pressure, further population decline, and lower harvest.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ETHICS STATEMENT

All animals were captured and handled with care and the appropriate permits by trained personnel under University of Tennessee Institutional Animal Care and Use Committee Protocol 0561-0720.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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