ABSTRACT

MOSCICKI, DAVID JAMES. Multi-scale Assessment of Wild Turkey Ecology in North Carolina. (Under the direction of Dr. Christopher E. Moorman and Dr. Krishna Pacifici).

Eastern wild turkey (*Meleagris gallopavo silvestris*) populations have declined in many portions of the eastern United States. Evidence indicates that population declines are driven by low reproductive success, but the underlying mechanisms of the change are uncertain. Thus, we conducted a study to document state specific female survival, nest site selection, nest success, and nesting and gobbling chronology across North Carolinas 3 ecoregions (Coastal plain, Piedmont, and Mountain). The results will provide a foundation on which future hunter harvest and habitat management actions can be based.

We investigated the spatial and temporal factors that affected female survival across the 4 behavioral states (non-breeding [NBS], pre-nesting [PNS], incubation [INS], and brood rearing [BRS]) that females may reside in across their annual cycle. We radio-tracked 370 female turkeys from 2020 to 2022, and we documented mortalities of 48%, 56%, and 31% of the females monitored in the Mountain, Piedmont, and Coastal plain ecoregions, respectively. Female survival in the PNS and NBS increased with greater average daily distance traveled. No land cover covariate influenced survival estimates within any behavior state. Daily survival rates were lowest for the INS and highest during the PNS and BRS. Mean derived annual survival was greatest in the Coastal plain and lowest in the Piedmont across all years.

We conducted a multi-scale assessment of the relationships between nest site selection and nest success in each of the 3 ecoregions. During the 2020 – 2022 reproductive periods, we monitored 420 nests from 305 female wild turkeys equipped with VHF-GPS transmitters to: (1) develop scale-specific predictive models for vegetation characteristics selected at nest sites, and (2) describe the effects of female behaviors and vegetation conditions on nest survival. We used

24 land cover covariates at 2 scales – (1) the nest site (15-m radius) and (2) the incubation range (50% utilization distribution) – to determine if vegetation characteristics influenced nest site selection and nest survival. Wild turkeys selected nest sites that had greater forb and woody understory cover and greater visual obstruction than paired random locations. Wild turkeys selected for patches with greater shrubland and herbaceous land cover within the incubation range than at random locations. Nest survival decreased with the increase of bare ground cover at the nest site and increased with greater amounts of edge and shrubland cover in the incubation range. An increase of 1 additional daily recess movement by the incubating female increased the risk of nest failure by 12.9%. Female turkeys selected nest sites with concealing vegetation cover and nearby vegetation types that likely provided additional high quality nesting cover.

The timing of the wild turkey hunting season must include sufficient gobbling to ensure hunter satisfaction while minimizing risks to reproductive success that could occur if the hunting season begins before the peak of nest initiation. We documented gobbling and nesting chronology in each of the 3 ecoregions in North Carolina from 2020-2022. We recorded gobbling activity using autonomous recording units and determined nesting chronology based on 420 nests from 305 female wild turkeys monitored during the 2020─2022 reproductive periods. Gobbling chronology did not vary regionally but did vary daily and annually within each ecoregion. Nest incubation initiation dates were similar among years and across regions, indicating that photoperiod was the main driver of nesting chronology. Gobbling activity was not bimodal or consistent in relation to nesting activity across years and regions. We identified 2 relatively consistent time lag relationships between gobbling and nesting activity. However, the lack of variation in nesting chronology across the large elevation gradient covered by our study

sites indicates uniform opening dates for hunting within a similar latitudinal zone are appropriate.

Multi-scale Assessment of Wild Turkey Ecology in North Carolina

by
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DEDICATION

I dedicate this to my loving family who has supported me through every endeavor and to all those who have influenced my life–you continue to do so in so many ways. Thank you for giving me the courage to pursue my passion.

And to Katie, no words can express the gratitude I have for you and all you have done for me.

BIOGRAPHY

David J. Moscicki, born in Binghamton, New York, grew up spending his summers camping throughout upstate New York. After graduating High school, he spent several years exploring and photographing the United States, achieving his dream of exploring faraway places such as Alaska and Hawaii. In 2004, he attended community college with the goal of transferring into film school. In 2006 he transferred to the Seattle Film Institute and by 2008 was working on a grip and lighting crew in Los Angeles, California. Although he had a passion for his work, he always wanted to work on nature documentaries. Eventually David returned to school to get a background in wildlife ecology and pursue his passion of providing knowledgeable films on the wildlife of North America. At the California State University at Long Beach, David learned firsthand about the scientific method, how to collect data and at this point learned he had a true passion for research. David transferred to the University of Nebraska-Lincoln (UNL) in 2012 where as an undergraduate he worked on several research projects regarding the remediation of lakes. After graduating from UNL, David would take a position with Nebraska Cooperative Fish and Wildlife Research Unit working on a Ringed-necked Pheasant project in western Nebraska. Garnering a passion for upland game bird research, he accepted a master’s position in Louisiana State Universities School of Renewable Natural Resources focusing on wild turkeys. Upon completion of his master’s degree, David began a PhD program in Fisheries, Wildlife, and Conservation Biology Program at North Carolina State University in 2019 continuing his research on wild turkeys. Currently, as he completes his Ph.D. in Fisheries, Wildlife, and Conservation Biology David began work at the Arkansas Game and Fish Commission as the Wild Turkey program Coordinator.

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I am forever grateful to all the homeowners who granted us permission and access to their properties to look for turkeys, their nest, or to find mortalities, or to just locate a signal from their tags. Were it not for the homeowners, we would not have had a project – all of our work was on private property! I cannot thank you all one by one but know that all of you were instrumental collaborators that made this project a success.

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CHAPTER 1: Spatial and temporal variation in survival of female wild turkeys

ABSTRACT

Female survival often is the vital rate that contributes most to population growth of upland gamebirds such as wild turkey (*Meleagris gallopavo*). Female wild turkey survival may vary spatially and temporally, for example in relation to land cover and the individual's behavioral state, so investigation of the factors that affect female survival is critical to direct long-term management. We radio-tracked 370 female turkeys from 2020 to 2022 to determine spatial and temporal factors that influenced survival across study areas in each of the 3 major ecoregions in North Carolina. We constructed a Bayesian hierarchical model, parameterized using covariates likely to influence survival – year, age-class, mean daily distance traveled, land cover type and edge density in the individual's home range, and ecoregion (Coastal plain, Piedmont, or Mountain) – for 4 behavioral states (non-breeding [NBS], pre-nesting [PNS], incubation [INS], and brood rearing [BRS]). We recorded 59 (48% of monitored individuals) mortalities in the Mountain ecoregion, 64 (56%) mortalities in the Piedmont ecoregion, and 41 (31%) mortalities in the Coastal plain ecoregion. Female survival in the PNS and NBS increased with greater average daily distance traveled. No land cover covariate influenced survival estimates within any behavior state. Overall, daily survival rates were lowest for the INS (0.993 [SD = 0.003]) and highest during the PNS and BRS (0.999 [SD = 0.002] and 0.999 [SD = 0.001], respectively). Mean estimated annual survival was consistently greatest in the Coastal plain ecoregion (0.77) and lowest in the Piedmont ecoregion (0.66) across all years. Because mortality risk was greatest during the incubation state, managers may indirectly increase female survival by increasing the amount of high-quality nesting cover on the landscape.

INTRODUCTION

Individual survival is an important demographic parameter, relevant to understanding patterns in the distribution and abundance of wildlife populations (Martin 2002, Collier et al. 2009). Temporal and spatial factors act synergistically to influence survival, and many studies have attempted to quantify the influence of one or more related factors on survival (Murray and Patterson 2006, Collier et al. 2009, Blomberg et al. 2013). Predator abundance, food availability, interspecific and intraspecific competition, and the composition and structure of vegetation may affect survival locally (Royle and Dubovsky 2001, Devries et al. 2003). Additionally, certain time periods are associated with greater risk of mortality, such as during hunting seasons (Fleskes et al. 2007, Yetter et al. 2018) and breeding seasons (Kirby and Cowardin 1986, Arnold and Howerter 2012). Survival tends to be more difficult to estimate than other demographic parameters (e.g., reproduction) for free-ranging animals, which often leads to problems in the quality of survival estimates in ecological studies (Murray and Patterson 2006). Therefore, to appropriately inform management actions, researchers must apply robust methodologies that incorporate influential biotic and abiotic factors to effectively quantify the spatial and temporal variation in individual survival.

Eastern wild turkey (*Meleagris gallopavo silvestris*; hereafter wild turkey) is a widely distributed galliform species that exhibits multiple behavioral states that are often repeated across the annual cycle. Survival for wild turkeys is especially linked to reproductive activities, during which females are particularly susceptible to mortality risk due to lengthy incubation periods, exposure to ground-dwelling predators, and reliance on crypsis (Deeming 2002, Blomberg et al. 2013, Lohr et al. 2020, Londe et al.2023). For wild turkeys, incubation and brood rearing are female-only endeavors, meaning females are the sex most vulnerable to predation (Lack 1968, Cockburn 2006, Londe et al. 2023). Therefore, female survival estimates are needed for each behavior state in the reproductive process (e.g., nesting to brood rearing; Poulin et al. 1992, Crawford et al. 2021). Additionally, identifying which factors influence female survival in each behavioral state is critical to inform drivers of population dynamics of wild turkey (Ghalambor and Martin 2001, Collier et al. 2009, Crawford et al. 2021).

Estimates of wild turkey survival vary widely across studies, and survival studies have long failed to incorporate variation across well-defined behavioral states, instead aggregating multiple behavioral activities into broad categories (e.g., reproductive period; Miller et al. 1997, Bakner et al. 2019, Lohr et al. 2020). In general, the contemporary approach to quantify survival is to identify important seasons within the annual cycle (e.g., breeding season), and evaluate mortality risk for annual and seasonal survival (Healy 1992, Wright et al. 1996, Collier et al. 2009, Pollentier et al. 2014). More specifically, the pre-nesting, incubation, and brood rearing seasons (March ─ August; Miller and Conner 2007, Niedzielski and Bowman 2015) are regularly used to estimate survival during a combined reproductive period. This approach lumps multiple mutually exclusive behavioral states, including pre-nesting (Miller and Conner 2007, Conley et al. 2016), laying and incubation (Conley et al. 2015, Bakner et al. 2019, Lohr et al. 2020), renesting (e.g., Keegan and Crawford 1997, Bakner et al. 2019, Lohr et al. 2020), and brood rearing, and includes non-reproductive individuals (Wright et al. 1996, Kane et al. 2007, Collier et al. 2009). Thus, it is plausible that inferences from turkey survival estimates have been overly generalized with respect to management planning and population level conservation efforts.

Few studies comparing wild turkey survival have been large enough to capture variation in localized weather (Boone et al. 2023), harvest strategy (Vangilder and Kurzejeski 1995, Norman and Steffen 2003), or geographic variation in land cover and land use (Fleming and Porter 2015, Little et al. 2016). Small-scale studies may be influenced by unique local scale environmental factors, further complicating extrapolation of results to direct larger-scale conservation actions.

Our objective was to compare female wild turkey survival across 4 behavioral states (pre-nesting, incubation, brood rearing, non-reproductive) in 3 geographically distinct ecoregions, simultaneously accounting for the effects of individual behaviors and movements and regional variations in land cover. Our goal was to identify factors that influence female survival to guide management strategies used to conserve wild turkey populations. We predicted that the incubation and brood-rearing states would have lower average daily survival than the pre-nesting and non-reproductive behavioral states because reproductive females are more vulnerable to predation while incubating and raising broods. We predicted that individuals that have greater mean daily distance traveled would have higher survival (i.e., PNS: female moves in search of alternate nest sites [see Conley et al. 2016], INS, BRS: female moves more while bet-hedging on survival over nest/brood survival [Lohr et al. 2020; Chamberlain et al. 2020], NBS: female forages greater distances in search of food and cover resources [Gonnerman et al. 2023]). We predicted that survival would decrease in areas with greater edge density because of greater predator densities in fragmented landscapes (Thogmartin 1999, Fuller et al. 2013).

STUDY AREA

We monitored female wild turkeys from January 2020 through September 2022 across > 250 privately-owned properties and 8 counties in the Mountain (Madison, McDowell, Mitchell, and Yancey), Piedmont (Moore), and Coastal plain (Bladen, Duplin, and Sampson) ecoregions of North Carolina, USA (Figure 1.1). The combined areas of properties to which we were granted access were 3,040, 3,073, and 2,843 hectares in the Mountain, Piedmont, and Coastal plain ecoregions, respectively. All study sites were on privately-owned land, with a few bordering public properties.

Mountain properties had heterogeneous topography (500–1800 m elevation) with a climate characterized by moderate winters prone to periods of harsh weather, cool summers, and annual precipitation of 130–250 cm/year (Figure 1.1; Gould et al. 2021). Property uses included livestock grazing, haying, and timber production. Forest cover was mixed hardwoods with scattered pine (*Pinus spp*.; Kirk et al. 2012) and mixed pine-hardwood (Mitchell et al. 2002), often with dense ericaceous shrub understory (*Kalmia latifolia, Rhododendron maximum*). The Piedmont properties were in the Piedmont and Sandhills physiographic regions (Figure 1.1). Elevations ranged from 75 to 180 m and the climate was characterized by mild winters, warm-temperate, humid summers, and annual precipitation averaging 120 cm/year (Sorrie et al. 2006). Land uses included timber production, row-crop agriculture, and commercial poultry or swine farms. Forest cover mostly was managed loblolly pine (*Pinus taeda*) plantations with mixed hardwood forest along riparian areas. Crop rotations were corn, soybeans, and winter wheat, although some tobacco crops were present. The Coastal plain properties (Figure 1.1) had homogonous topography (0–30 m elevation) with a climate characterized by mild winters, warm-temperate, humid summers, and annual precipitation averaging 160 cm/year (Palmquist et al. 2015). Most properties were primarily used for commercial poultry and swine production. Row-crops consisted primarily of corn, soybeans, and winter wheat rotation. Forests had mixed hardwood or pine-hardwood overstory, with common species including red maple (*Acer rubrum*), oak (*Quercus* spp.), and American sweetgum (Liquidambar styraciflua); the forest understory and midstory often were dense and commonly contained brambles (*Rubus* spp.), greenbrier (*Smilax spp.*), gallberry (*Ilex coriacea*), and swamp redbay (*Persea palustris*).

METHODS

Capture and Monitoring

We captured female wild turkeys between January and March 2020–2022 using rocket nets at sites baited with cracked corn. Individuals were classified as adult or subadult based on the presence of barring on the ninth and tenth primaries (Pelham and Dickson 1992). We fitted captured individuals with a uniquely numbered aluminum rivet leg band (National Band and Tag Company, Newport, Kentucky, Butler et al. 2011) and a GPS–VHF backpack style transmitter (Biotrack Ltd., Wareham, Dorset, UK, Guthrie et al. 2011). We programmed units to record 1 location at 07:00:00, 09:00:00, 11:00:00, 12:00:00, 13:00:00, 14:00:00, 16:00:00, 18:00:00, 19:00:00 daily and one roost location at night (23:59:58) between 1 March and 31 August (reproductive period), and units recorded a single roost location for all days outside the reproductive period (Cohen et al. 2018). The unit ran until the battery died or the unit was recovered via mortality or recapture. We released turkeys immediately at the capture location following processing. Wild turkey capture and handling protocols were approved by the Animal Care and Use Committee at North Carolina State University (Permit #19-739-01, 19-739-02, 19-739-04 as amended).

We monitored live-dead status ≥2 times per week during the reproductive period (mid-March to 31 July) and ≥1 time per month outside the reproductive period using a Biotracker receiver (Biotrack Ltd., Wareham, Dorset, U.K.) and handheld Yagi antenna. We downloaded GPS locations ≥2 times per month via a VHF/UHF handheld command unit receiver (Biotrack Ltd., Wareham, Dorset, U.K.), or we downloaded GPS data from units recovered via recapture or mortality (Guthrie et al. 2011). We derived date of mortality from VHF tracking and spatio-temporal GPS locational data (Guthrie et al. 2011, Conley et al. 2015). We censored the first 14 days post capture from analysis, which ensured that we removed any potential capture-related effects (Nenno and Healy 1979, Wright et al. 1996, Morellet et al. 2009).

Based on contemporary knowledge of wild turkey behaviors, we defined the annual cycle as a suite of 4 distinct, identifiable behavioral states that were specific to each individual (Conley et al. 2015, 2016, Bakner et al. 2019, Moscicki et al. 2023). First, we defined the pre-nesting state (PNS) as the period from the initiation of the breeding season (15 Mar) until incubation began, or in the case of a failed nesting attempt (whether it be during pre-nesting, incubation, or brooding), the period from the day after the failure of the previous attempt until the start of an individual's subsequent incubation state within that year. The PNS incorporates movements prior to and during egg laying. Second, we defined the incubation state (INS) as the day the female began incubating, which we identified using VHF tracking and GPS data, noting the date when the first nightly roost location was at the nest site (Conley et al. 2016, Yeldell et al. 2017). The INS lasted until either nest abandonment, nest failure, female death, or hatch (Conley et al. 2016, Yeldell et al. 2017). We visually identified each incubation attempt based on VHF tracking and GPS data (Conley et al. 2016, Bakner et al. 2019), and we located each nest via homing to determine nest fate (Yeldell et al. 2017, White et al. 2019). We defined the brood rearing state (BRS) as the period a female was actively brooding based on repeated brood surveys for each GPS-tagged female that successfully hatched; we monitored brooding activity for up to the first 28 days after hatch (Chamberlain et al. 2020, Moscicki et al. 2023). Lastly, we defined the non-breeding state (NBS) as the remainder of the year, when individuals were not involved in reproductive activities. All non-reproductive individuals resided within the NBS year-round. For reproductively active individuals, the NBS began on the first day after the last recorded day of reproductive activity and lasted until the onset of the next reproductive period or mortality (Collier et al. 2009, Moscicki et al. 2023). We used telemetry data to help confirm start and end dates for each identified behavioral state.

Behavior state analysis

For each behavioral state that was identified for each individual, we estimated the state-specific home range size (95% Utilization Distribution) using autocorrelated kernel density estimation (AKDE) and Continuous Time Movement Modeling (ctmm; Fleming and Calabrese 2017). To ensure our home range estimates were not overestimated, individuals that had <9 locations collected during a behavior state was censured. We performed all AKDE using R package ctmm (version 4.2.1, Calabrese et al. 2016) in program R (version 4.2.2, R Core Team 2023). To quantify the influence of land cover on survival within each behavioral state, we estimated the percent cover of 5 land cover types within each individual's range. Furthermore, we estimated edge density within each range. We acquired land cover from the 2021 National Land Cover Data (NLCD, Dewitz 2021), a 30-m raster layer of land cover types. We simplified the number of land cover types (Sullivan et al. 2022) and increased the data accuracy from NLCD (Wickham et al. 2013) by reclassifying 15 land cover types into 5 types – open vegetation (Grassland/Herbaceous, Pasture/Hay), shrubland (Shrub/Scrub), forest (Deciduous Forest, Evergreen Forest, Mixed Forest, and Woody Wetlands), crop (Cultivated Crops), and developed (Barren Land, Developed: Open Space, Developed: Low Intensity, Medium Intensity, and High Intensity). Additionally, we estimated the average daily distance traveled (m) by each individual within each behavioral state.

Female survival model

We constructed a Bayesian hierarchical survival model (Ch. 11 in Royle and Dorazio 2008) using the R2jags package (Su & Yajima 2015) in program R (R Core Team, 2023) to estimate behavioral state specific female survival. We parameterized models using covariates likely to influence survival, including average daily distance traveled, state-specific range size, duration (days) in each behavioral state (additive for multiple behavioral states in a single annual cycle), edge density, and percent cover of each of 5 land cover types (Wiebe and Martin 1997, Lehman et al. 2008, Bakner et al. 2019). To examine collinearity, we calculated Pearson correlations (*r*) for all pairs of predictor variables. We developed 95% credible intervals to evaluate the support for specific covariates influencing daily survival. If a credible interval overlapped 0, we assumed there was no biological effect.

Following Royle and Dorazio (2008), we treated female fate between successive days as the sampling unit. We designated individual female *i* on a given day, *j*, in behavioral state, *s,* as 1 for alive and 0 for a female that had been depredated. The probability of female survival from day *j* to day *j + 1* was modeled using a Bernoulli distribution. Our study included wild turkeys monitored across multiple study sites (hereafter ecoregions: Mountain, Piedmont, Coastal plain) and years and we included these as fixed effects in the model. We used uninformative priors for all coefficients. The full model is specified as:

$$\begin{aligned} logit(\phi_{i,j}) = {} & \beta_0[s_{i,j}] + \beta_1[s_{i,j}] * distance_{i,j-1} + \beta_2[s_{i,j}] * duration_{i,j} + \beta_3[s_{i,j}] * edge_{i,s[i,j]} \\ & + \beta_4[s_{i,j}] * forest_{i,s[i,j]} + \beta_5[s_{i,j}] * shrubland_{i,s[i,j]} + \beta_6[s_{i,j}] * open_{i,s[i,j]} \\ & + \beta_7[s_{i,j}] * developed_{i,s[i,j]} + \beta_8[s_{i,j}] * crop_{i,s[i,j]} + \beta_9[s_{i,j}] * range\ size_{i,s[i,j]} \\ & + \beta_{10} * age_i + \beta_{11} * year_i + \beta_{12} * region.mtn_i + \beta_{13} * region.coast_i \end{aligned}$$

Where $\beta_0[s_{i,j}]$ is a behavioral state specific intercept for each individual, $\beta_1[s_{i,j}]$ is the behavioral state specific effect of daily distance traveled for each individual on the previous day (*j*-1), $\beta_3[s_{i,j}], \beta_4[s_{i,j}], \beta_5[s_{i,j}], \beta_6[s_{i,j}], \beta_7[s_{i,j}]$, and $\beta_8[s_{i,j}]$ are the behavioral state specific effects of edge density, % forest, % shrubland, % open, % developed and % crop land for each individual *i* in state $s[i,j]$, $\beta_9[s_{i,j}]$ is the behavioral state specific effect of home range size for each individual *i* in state $s[i,j]$, β_{10} is the effect of age for each individual, β_{11} is the effect of year, and β_{12} and β_{13} are the ecoregion effects of the Mountain and Coast with Piedmont as the baseline.

To better understand the cumulative survival probabilities within a behavioral state we calculated derived estimates of average daily survival and period specific survival across years and regions based on the posterior distributions of $\phi_{i,j}$. We fit the model using Markov chain Monte Carlo (MCMC) to estimate posterior distributions of the model parameters with 3 chains, 100,000 iterations, a burn in value of 20,000 and a thinning rate of 5 (Gelman and Rubin 1992). We used visual inspection of the trace plots and R-hat values <1.1 to assess convergence (Gelman et al. 2004). We reported posterior means and 95% credible intervals.

RESULTS

We monitored 370 females distributed across North Carolina in the Mountain (*n*=100 A, 22 J), Piedmont (*n*=87 A, 27 J), and Coastal plain (*n*=111 A, 23 J) ecoregions. We recorded mortalities for 59 of the 122 individuals (48%) monitored in the Mountain ecoregion, 64 of the 114 individuals (56%) monitored in the Piedmont ecoregion, and 41 of the 134 individuals (31%) monitored in the Coastal plain ecoregion (Table 1.1). For all ecoregions and years, the majority of mortalities occurred during the NBS (92 mortalities), followed by the INS (46), BRS (14), and PNS (12; Table 1.1). We assigned the causes of mortality as predation (124 individuals), harvest [3, (1 illegal)], vehicle collision (4), or unknown causes (33; Table 1). We calculated the range (95% AKDE) of 1479 individual behavioral states – PNS (420), INS (407), BRS (62), and the

NBS (590; Table 1.2). Females were documented for the longest duration in the NBS with an average of 153 days in both the Mountain and Piedmont ecoregion, and 138 days in the Coastal plain (Table 1.2). Female turkey daily movements were greatest during the PNS, and mean daily distances traveled in the PNS were lower in the Mountain ecoregion (1,198 ±37 m) than in the Piedmont ecoregion (1,563 ±81 m). Mean daily distances traveled in the INS and NBS were similar across all ecoregions and ranged between 232─307 m and 1,262─1,331 m, respectively (Table 1.2). Home range size varied among behavior states, with the largest average home ranges occurring in the NBS for all ecoregions ($\bar{x}_{min}$=235 ha [Mountain], $\bar{x}_{max}$=329 ha [Piedmont]), and the smallest average home ranges occurring in the INS ($\bar{x}_{min}$= 1.09 ha [Coastal plain], $\bar{x}_{max}$=1.84 ha [Mountain]; Table 1.2). Because of the constraints on home ranges during the INS, the average edge density was low during this behavior state $\bar{x}_{max}$=15.5 m/ha [Piedmont], $\bar{x}_{min}$=13.6 m/ha [Coastal plain]; Table 1.2). Average edge density within the BRS was lowest in the Piedmont ecoregion (147.8 m/ha) and greatest in the Mountain ecoregion (174.1 m/ha; Table 1.2). Home ranges across all behavior states were primarily forested; the Coastal plain consistently had the lowest mean percent forest cover in each behavior state (58% [PNS], 51% [INS], 58% [BRS], 59% [NBP), whereas the Piedmont and Mountain ecoregions were similar across behavior states.

Daily survival varied among years (β_{Year} = 0.003, 95% CrI = 0.002, 0.005; Table 1.3). During the PNS and INS, daily survival estimates were negatively influenced by the duration (days) spent in each behavior state ($\beta_{duration, PNS}$ = -0.062, 95% CrI = -0.095, -0.029, $\beta_{duration, INS}$ = -0.050, 95% CrI = -0.081, -0.019; Table 1.3, Figure A.1, A.2). However, the duration (days) spent in the NBS had a positive influence on daily survival ($\beta_{duration, NBS}$ = 0.002, 95% CrI = 0.001, 0.004; Table 1.3, Figure A.3). The average daily distance traveled was the only covariate to influence daily survival for the PNS and NBS. As mean daily distance traveled increased, daily survival increased in the PNS ([m]; $\beta_{\text{Distance, PNS}}$ = 0.0016, 95% CrI = 0.0008, 0.0025; Table 1.3, Figure A.4) and in the NBS ($\beta_{\text{Distance, NBS}}$ = 0.0008, 95% CrI = 0.0005, 0.0011; Table 1.3, Figure A.5). Ten of the 13 variables included in the model, including edge density and land cover metrics, were not predictors of daily survival (Table 1.3).

Derived estimates of daily survival for wild turkeys statewide during the PNS were 0.999 (SD = 0.002), during the INS were 0.993 (SD = 0.003), during the BRS were 0.999 (SD = 0.001), and during the NBS were 0.998 (SD = 0.002; Table 1.4). Daily survival during the PNS (0.998, SD = 0.002) and INS (0.992, SD = 0.004) were lowest in the Mountain ecoregion, and daily survival during the BRS (0.998, SD = 0.002) and NBS (0.997, SD = 0.003) were lowest in the Piedmont ecoregion (Table 1.4).

Estimated period survival rates for wild turkeys statewide during the PNS were 0.96 (SD = 0.09), during the INS were 0.84 (SD = 0.12), during the BRS were 0.97 (SD = 0.04), and during the NBS were 0.78 (SD = 0.18; Table 1.4). Period survival during the PNS was lowest in the Mountain ecoregion (0.94, SD = 0.01), lowest during the INS in the Mountain ecoregion (0.82, SD = 0.15), lowest during the BRS in the Piedmont ecoregion (0.95, SD = 0.05), and lowest during the NBS in the Piedmont ecoregion (0.69, SD = 0.02; Table 1.4). Period survival during the PNS was highest in the Piedmont ecoregion (0.98, SD = 0.05), highest during the INS in the Coastal plain (0.87, SD = 0.10), highest during the BRS in the Mountain ecoregion (0.98, SD = 0.02), and highest during the NBS in the Coastal plain (0.85, SD = 0.13; Table 1.4). Statewide, across all years, estimated annual survival was consistently the highest in the Coastal plain ecoregion (0.73 [2020], 0.76 [2021], 0.81 [2022]) and consistently lowest in the Piedmont ecoregion (0.63 [2020], 0.66 [2021], 0.68 [2022]; Table 1.5).

DISCUSSION

Average daily survival was lower during the INS than for the other behavioral states, which highlights the vulnerabilities of female wild turkeys while incubating. To place our statewide estimated average daily survival (0.993) and period survival (0.84) in the context of previous studies, Lohr et al. (2020) reported average daily and period female survival rate during incubation across South Carolina, Georgia, and Louisiana as 0.99 and 0.78, respectively, whereas Carpenter et al. (2023) reported that average daily survival rates during incubation in Florida were 0.91─0.99. The high mortality risk during incubation may lead some individual female turkeys to bet-hedge, either by not initiating a nest in some years or by spending more time away from the nest during the incubation state. Moscicki et al (in prep), documented that an increase of 1 additional daily recess movement by the incubating hen increased the risk of nest failure by 12.9%, which indicates that less time incubating may increase the female's survival probability while concurrently increasing the chance of nest failure.

Though there was indication of regional variation for some daily and period survival estimates, the differences were not statistically significant. However, the biological relevance of even a minor decline in survival, especially in a long duration behavior state like NBS, may contribute to lower overall annual survival rates as was the case in the Piedmont relative to the other 2 ecoregions. Furthermore, lower daily survival rates in the Mountain region during the PNS and INS may be a result of mechanisms likely to influence local populations. Different rates of disease prevalence (Kunkel et al. 2022), greater predator abundance (Chamberlain et al. 1995), or weather variation (Boone et al. 2023) may influence these state-specific survival estimates. Kreh and Palamar (2022) reported greater lymphoproliferative disease virus (LPDV) prevalence in the Mountain ecoregion and the lowest prevalence in the Coastal plain of North

Carolina. However, disease dynamics in wildlife populations can be complex and there is limited data addressing the relationship between disease and survival of wild turkeys. Regional differences in predator communities, possibly linked to land cover characteristics, may lead to higher risk of mortality, especially during incubation. However, land cover characteristics were not important predictors of survival in our study. Conversely, regional differences may have resulted from more extreme weather and temperature in the Mountain ecoregion, including late spring cold snaps with frozen precipitation, which occurred at several mountain sites at higher elevations in 2020, relative to the same period in the Piedmont or Coastal plain ecoregions. It is unlikely these short but extreme periods of weather effected local populations (Moscicki et al. (2022). However, for early nesting females, precipitation has been related to the depredation of nest, inevitably negatively affecting nest success at the local scale (Palmer et al. 1993, Roberts et al. 1995, Roberts and Porter 1998, Boone et al. 2024).

Several mechanisms may have contributed to the variation in daily survival across years (Table B.1). Fluctuations in predator populations, including nest predators (Speake 1980, Kurzejeski et al. 1987, Roberts et al. 1995, Pollentier et al. 2014), may have contributed to annual variation. Annual variation in weather, including precipitation and temperature (Roberts and Porter 1998, Kilburg et al. 2014, Keever et al. 2023), also may influence annual survival. Furthermore, these factors can have both direct (i.e., mortality from severe storms) and indirect consequences (i.e., warmer weather can reduce metabolic stress) on female survival. Similarly, the wet hen hypothesis suggests prolonged wet periods are likely to elevate a predator’s ability to locate incubating turkeys, thereby reducing survival rates (Rubolini et al. 2003).

Land cover characteristics were not important predictors of average daily survival for any behavior state, which further supports that predation is a largely random event not easily linked to spatial predictors (Chamberlain et al. 1995, Fleming and Porter 2015). It remains widely accepted that different behavior states are likely to have varying degrees of dependence on specific land cover types to likely increase survival (e.g., nest site selection, brood rearing cover; Conley et al. 2016, Chamberlain et al. 2020). However, individuals are likely occupying areas of their home range that should already optimize their survival no matter their behavior state. Thus, we may not expect to identify specific landcover attributes important to wild turkeys unless the individuals are on the fringe of their range or occupying less favorable areas (e.g. suburban-urban gradient, Spohr et al. 2004). Finally, the NLCD land cover information is relatively coarse and therefore may have limited our ability to appropriately measure land cover conditions and predict their influence on survival.

Female movement, specifically average daily distance traveled, was a positive predictor of survival during the PNS and NBS but not during the INS and BRS, which indicates that the importance of female movements may vary seasonally. During the PNS, individual females leave winter flocks in search of nesting sites, future brood rearing areas, and potential mates, often traveling great distances (Conley et al. 2016). During the NBS, females may move long distances in search of seasonally available foods, especially acorns and other sources of mast during the fall and winter periods (Gonnerman et al. 2022). It may be that the females that cover greater distances daily during these 2 periods have greater survival rates because they are better able to locate appropriate food and cover resources or because the movements somehow indirectly reduce predator efficiency (Conley et al 2016, Chamberlain et al. 2020).

MANAGEMENT IMPLICATIONS

More detailed understanding of how individual female wild turkey behaviors influence survival is needed to better predict wild turkey population dynamics across space and time. However, we identified few consistent predictors of female survival probability, and no land cover characteristic predicted survival during any state. The relatively low survival during the incubation state across regions and years highlighted the importance of this period to wild turkey population dynamics. It is possible that increasing the prevalence of high-quality nesting cover on the landscape may increase incubating hen survival, but the lack of relationship between survival and land cover characteristics, including during incubation, does not support this premise. Additional research is needed to evaluate the effects of finer-scale land cover metrics, the health of the individual (e.g., disease prevalence), and local predator densities on female survival.

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Table 1.1. Number of mortalities by behavior state and cause for radio-marked female wild turkeys (*Meleagris gallopavo*) for each ecoregion and year (North Carolina, 2020─2022).

		Behavior State				Cause of Mortality				
Ecoregion	Year	Pre-nesting	Incubation	Brood Rearing	Non-breeding	Predation	Harvest	Vehicle	Unknown	Total
Mountain	2020	1	10	1	11	21	1	0	1	23
	2021	3	5	1	12	16	0	0	5	21
	2022	3	4	1	7	9	1	1	4	15
	Cumulative	7	19	3	30	46	2	1	10	59
Piedmont	2020	0	7	3	22	28	0	0	4	32
	2021	1	4	2	15	13	0	1	7	21
	2022	0	4	1	5	4	0	1	6	11
	Cumulative	1	15	6	42	45	0	2	17	64
Coastal Plain	2020	0	2	1	13	15	0	0	1	16
	2021	0	6	3	6	9	1	1	4	15
	2022	4	4	1	1	9	0	0	1	10
	Cumulative	4	12	5	20	33	1	1	6	41
Statewide	2020	1	19	5	46	64	1	0	6	71
	2021	4	15	6	33	38	1	2	16	57
	2022	7	12	3	13	22	1	2	11	36
	Cumulative	12	46	14	92	124	3[1]	4	33	164

[1] 1 illegal harvests in Mountain ecoregion 2020

Table 1.2. Mean, SE, and range of covariate values used to predict female wild turkey survival for each ecoregion and behavior state. The value (n) is how many individuals were monitored and the count value is the number of ranges estimated in that state (North Carolina, 2020–2022).

		Ecoregion															
		Mountain				Piedmont				Coastal plain				Statewide			
		PNS	INS	BRS	NBS	PNS	INS	BRS	NBS	PNS	INS	BRS	NBS	PNS	INS	BRS	NBS
	n	89	80	23	122	69	64	16	114	96	90	22	134	254	234	61	370
	Count	161 152	158 152	24	193	106	105 181	16	177	153	144 148	22	220	420 589	407 310	62	590 589
Cumulative days in behavior state	mean	28	23	20	153	21	22	22	153	25	20	19	138	25	22	20	147
	$\widehat{S.E.}$	2	2	2	16	2	1	2	13	2	1	2	10	1	1	1	8
	Range	6-101	3-29	7-28	6-833	3-82	3-29	7-28	16-723	7-107	1-29	7-28	13-495	3-107	1-29	7-34	6-833
Mean daily distance traveled (m)	mean	1,198	307	735	1,262	1,563	240	814	1,331	1,512	232	947	1,330	1,413	262	831	1,308
	$\widehat{S.E.}$	37	16	74	51	81	14	101	61	55	13	66	54	33	9	46	32
	Range	53-2,462	35-798	39-1,430	26-5,414	15-7,061	3-508	88-1,464	3-5,414	174-4,277	1-622	351-1,588	74-9,941	15-7,061	1-798	39-1,588	3-9,941
Area (ha)	mean	81.65	1.84	35.33	235.44	124.89	1.19	25.27	328.63	115.05	1.09	36.54	283.34	106.13	1.37	33.13	281.50
	$\widehat{S.E.}$	5.78	0.19	4.85	12.29	8.31	0.15	4.80	18.30	7.51	0.15	5.38	13.85	4.30	0.10	2.96	8.76
	Range	18-401	0-9	7-94	49-891	32-334	0-5	7-69	1-891	21-414	0-7	7-95	53-930	18-414	0-9	7-95	1-930
Edge Density (m/ha)	mean	144.7	14.0	174.1	145.4	128.6	15.5	147.8	134.5	152.0	13.6	161.7	151.4	143.1	14.3	162.8	144.2
	$\widehat{S.E.}$	7.2	1.8	15.1	5.0	6.1	2.4	11.8	3.4	4	2	13	3	3.4	1.1	8.0	2.3
	Range	0-276	0-73	46-362	29-248	34-235	0-88	75-250	54-272	42-241	0-69	88-298	64-246	0-276	0-88	46-362	29-272
Developed	mean	0.067	0.072	0.078	0.081	0.025	0.028	0.039	0.033	0.024	0.034	0.031	0.031	0.04	0.05	0.05	0.05
	$\widehat{S.E.}$	0.008	0.014	0.012	0.005	0.003	0.009	0.006	0.002	0.002	0.014	0.006	0.002	0.003	0.01	0.01	0.002
	Range	0-0.57	0-0.51	0-0.3	0-0.3	0-0.09	0-0.46	0-0.08	0-0.09	0-0.11	0-0.9	0-0.09	0-0.12	0-0.57	0-0.9	0-0.09	0-0.3
Forest	mean	0.743	0.691	0.700	0.716	0.740	0.616	0.704	0.741	0.577	0.506	0.584	0.594	0.68	0.66	0.60	0.68
	$\widehat{S.E.}$	0.020	0.038	0.039	0.013	0.016	0.045	0.042	0.009	0.013	0.040	0.026	0.008	0.01	0.02	0.02	0.01
	Range	0.35-1	0-1	0.2-0.9	0.37-1	0.32-1	0-1	0.23-1	0.52-1	0.16-0.9	0-1	0.39-0.8	0.35-0.9	0.16-1	0-1	0.2-1	0.35-1
Shrubland	mean	0.006	0.015	0.006	0.014	0.064	0.123	0.030	0.071	0.044	0.081	0.035	0.046	0.04	0.07	0.02	0.04
	$\widehat{S.E.}$	0.001	0.008	0.003	0.001	0.008	0.031	0.009	0.005	0.004	0.020	0.006	0.002	0.003	0.01	0.004	0.002
	Range	0-0.08	0-0.6	0-0.06	0-0.05	0-0.27	0-1	0-0.12	0-0.27	0-0.16	0-1	0-0.1	0-0.2	0-0.08	0-1	0-0.06	0-0.05
Herbaceous	mean	0.006	0.021	0.004	0.010	0.079	0.201	0.036	0.063	0.045	0.085	0.033	0.036	0.04	0.09	0.02	0.04
	$\widehat{S.E.}$	0.001	0.007	0.001	0.001	0.011	0.038	0.008	0.005	0.007	0.023	0.014	0.003	0.004	0.01	0.01	0.002
	Range	0-0.06	0-0.4	0-0.02	0-0.04	0-0.44	0-1	0-0.11	0-0.21	0-0.35	0-1	0-0.32	0-0.21	0-0.06	0-1	0-0.02	0-0.04

Table 1.2. (continued)

Cropland	mean	0.176	0.203	0.207	0.173	0.082	0.030	0.183	0.084	0.299	0.286	0.308	0.283	0.20	0.19	0.24	0.19
	$\widehat{S.E.}$	0.016	0.032	0.033	0.011	0.008	0.010	0.049	0.005	0.012	0.039	0.026	0.008	0.01	0.02	0.02	0.01
	Range	0-0.6	0-1	0-0.5	0-0.4	0-0.3	0-0.4	0-0.8	0-0.2	0-0.6	0-1	0-0.6	0.1-0.6	0-0.3	0-1	0-0.05	0-0.2

Table 1.3. Posterior means and 95% credible intervals for covariates used to model average daily survival for female wild turkey (*Meleagris gallopavo*). Credible intervals not overlapping 0 suggest support for specific covariates influencing survival (North Carolina, 2020-2022).

Survival Covariates	State	Mean	SD	0.025	0.975
Intercept	PNS	0.654	1.562	-2.304	3.944
	INS	-0.502	1.378	-3.323	2.162
	BRS	-0.013	1.656	-3.336	3.327
	NBS	-0.042	1.419	-2.901	2.781
Year		0.003	0.001	0.002	0.005
Age		0.086	0.231	-0.350	0.553
Mountain [a]		0.373	0.226	-0.072	0.818
Coastal plain [a]		0.452	0.255	-0.046	0.955
Duration in behavior state[b]	PNS	-0.062	0.017	-0.095	-0.029
	INS	-0.050	0.016	-0.081	-0.019
	BRS	-0.146	0.102	-0.359	0.044
	NBS	0.002	0.001	0.001	0.004
Range size (ha)	PNS	0.001	0.007	-0.012	0.017
	INS	-0.015	0.119	-0.322	0.142
	BRS	-0.015	0.033	-0.075	0.055
	NBS	0.000	0.001	-0.001	0.001
Daily distance traveled (m)	PNS	0.0016	0.0004	0.0008	0.0025
	INS	-0.0002	0.0002	-0.0006	0.0002
	BRS	0.0017	0.0016	-0.0010	0.0053
	NBS	0.0008	0.0002	0.0005	0.0011
Edge density (m/ha)	PNS	-0.012	0.008	-0.027	0.004
	INS	-0.012	0.010	-0.032	0.009
	BRS	0.012	0.014	-0.012	0.043
	NBS	-0.006	0.003	-0.013	0.000
Forest (%)	PNS	-0.444	1.853	-4.050	3.226
	INS	-0.920	1.273	-3.413	1.580
	BRS	0.577	2.467	-4.210	5.473
	NBS	-1.769	1.430	-4.510	1.090
Shrubland (%)	PNS	2.012	2.947	-3.722	7.852
	INS	-0.359	1.452	-3.151	2.550
	BRS	0.160	3.147	-5.988	6.348
	NBS	-1.981	2.138	-6.155	2.232
Open (%)	PNS	2.272	2.860	-3.238	7.966
	INS	1.522	1.568	-1.451	4.711
	BRS	0.341	3.127	-5.753	6.513
	NBS	1.705	2.309	-2.777	6.253
Developed (%)	PNS	-1.280	2.603	-6.244	3.949
	INS	-0.773	1.610	-3.838	2.484
	BRS	0.268	3.145	-5.903	6.423
	NBS	0.368	2.417	-4.321	5.153

Table 1.3. (continued)

Cropland (%)	PNS	-0.292	2.280	-4.738	4.176
	INS	-1.162	1.301	-3.707	1.409
	BRS	-1.204	2.633	-6.265	4.056
	NBS	1.030	1.621	-2.132	4.225

[a] Comparison of differences between Piedmont ecoregion and ecoregion of interest.

[b] Additive for multiple behavioral states in a single annual cycle.

Table 1.4. Derived estimates of cumulative period survival and estimated average daily survival for female wild turkeys for each behavior state and ecoregion (North Carolina, 2020─2022).

Ecoregion	Behavior State	Period Survival Probability	SD	Daily Survival Probability	SD
Mountain	Pre-nesting (PNS)	0.94	0.10	0.998	0.002
	Incubation (INS)	0.82	0.15	0.992	0.004
	Brood rearing (BRS)	0.98	0.02	0.999	0.001
	Non-breeding (NBS)	0.78	0.19	0.998	0.001
Piedmont	Pre-nesting (PNS)	0.98	0.05	0.999	0.001
	Incubation (INS)	0.84	0.11	0.993	0.004
	Brood rearing (BRS)	0.95	0.05	0.998	0.002
	Non-breeding (NBS)	0.69	0.20	0.997	0.003
Coastal plain	Pre-nesting (PNS)	0.96	0.10	0.999	0.002
	Incubation (INS)	0.87	0.10	0.994	0.003
	Brood rearing (BRS)	0.97	0.04	0.999	0.002
	Non-breeding (NBS)	0.85	0.13	0.999	0.001
Statewide	Pre-nesting (PNS)	0.96	0.09	0.999	0.002
	Incubation (INS)	0.84	0.12	0.993	0.003
	Brood rearing (BRS)	0.97	0.04	0.999	0.001
	Non-breeding (NBS)	0.78	0.18	0.998	0.002

Table 1.5. Derived estimates of annual and cumulative survival of female wild turkeys for each of the 3 ecoregions of North Carolina, (2020–2022).

Year	Ecoregion	Survival	SD
2020	Mountain	0.70	0.17
	Piedmont	0.63	0.18
	Coastal plain	0.73	0.13
	Statewide	0.69	0.16
2021	Mountain	0.70	0.18
	Piedmont	0.66	0.17
	Coastal plain	0.76	0.15
	Statewide	0.71	0.17
2022	Mountain	0.73	0.14
	Piedmont	0.68	0.14
	Coastal plain	0.81	0.10
	Statewide	0.74	0.13
Cumulative Years	Mountain	0.71	0.16
	Piedmont	0.66	0.16
	Coastal plain	0.77	0.13
	Statewide	0.71	0.15

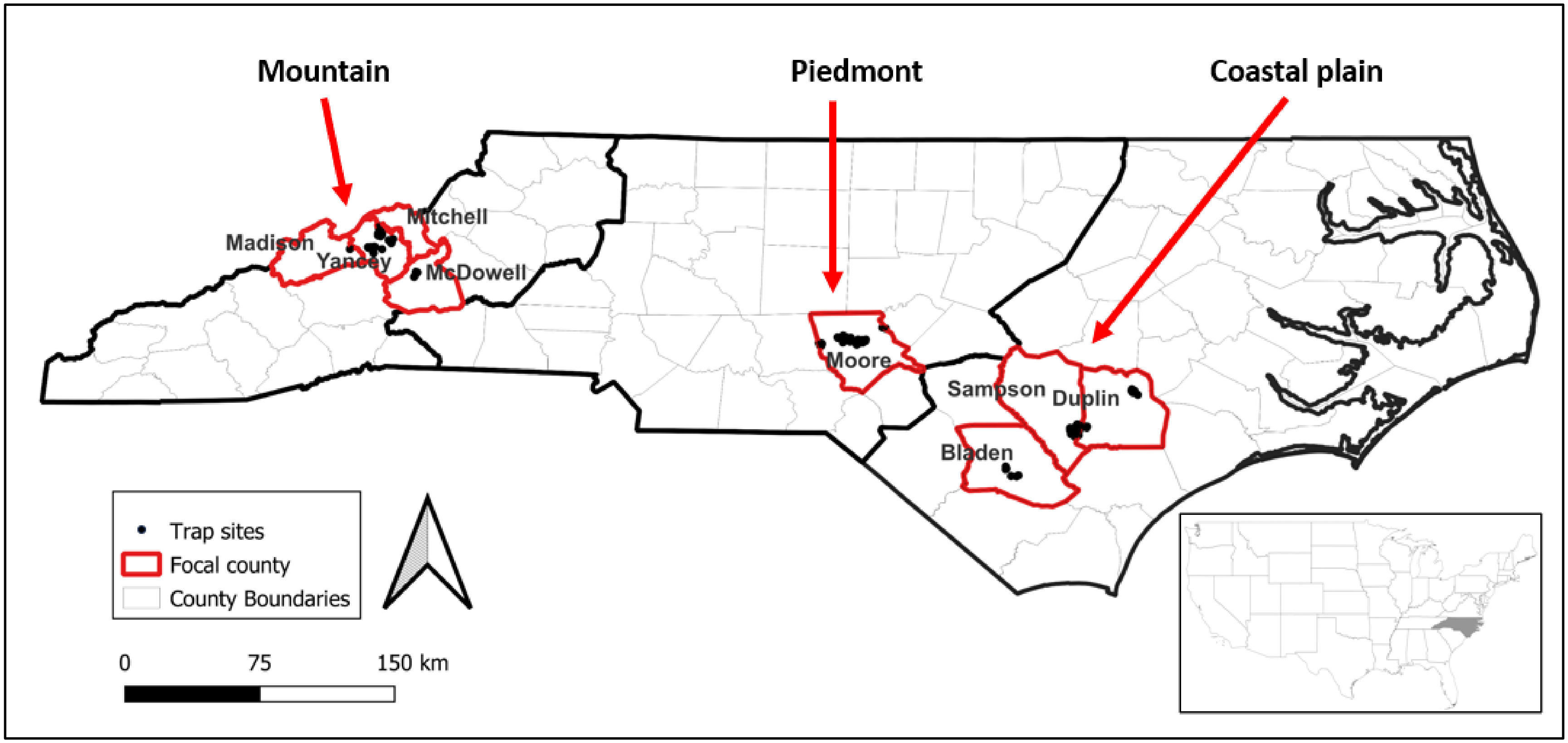

Figure 1.1. Locations of 30 field sites across the 3 ecoregions of North Carolina, United States, where we monitored 370 wild turkey, 2020–2022.

CHAPTER 2: Multi-scale evaluation of eastern wild turkey nest site selection and nest survival

ABSTRACT

The relationship between nest site selection and nest success remains unclear for many avian species, and discrepancies among results may be driven by the localized conditions of study sites being evaluated at a single scale. Thus, we monitored eastern wild turkey (*Meleagris gallopavo silvestris*) nests across 3 study areas to: (1) develop scale-specific predictive models for vegetation characteristics selected at nest sites, and (2) describe the effects of female behaviors and vegetation conditions on nest survival. We monitored 370 female eastern wild turkeys and evaluated nest site selection and the relationship with nest survival at 2 spatial scales across 3 ecoregion-specific study areas in North Carolina during the 2020 – 2022 reproductive periods. We used generalized linear modeling and an information-theoretic approach to determine if vegetation characteristics around the nest site (15-m radius) and landscape features in the incubation range (50% nesting period utilization distribution) influenced nest site selection at 407 nests across the 3 ecoregions. We used a Cox proportional hazard model to calculate baseline hazards and associated effects of covariates from the nest selection model. Wild turkeys selected nest sites that had greater forb and woody understory cover and greater visual obstruction than paired random locations. Within the incubation range, wild turkeys selected for patches with greater shrubland and herbaceous land cover than at random locations. Nest survival decreased by 2.3% for every 1% increase of bare ground cover at the nest site, increased by <1.0% for every 100 m/ha increase in the amount of edge in the incubation range, and increased by 5.8% for every 10% increase in shrubland cover in the incubation range. An increase of 1 additional daily recess movement by the incubating female increased the risk of nest failure by 12.9%. Female turkeys selected nest sites with concealing vegetation cover and

nearby vegetation types that likely provided additional high quality nesting cover. Thus, management practices (e.g., forest thinning and prescribed burning) that foster understory vegetation within forest and woodlands intermixed with shrubland and herbaceous vegetation types are critical to maximize high quality nesting cover for female wild turkeys.

INTRODUCTION

Considerable effort has focused on determining the relative importance of environmental conditions, including vegetation, to nest site selection by eastern wild turkey (*Meleagris gallopavo silvestris*). Previous studies investigated the effects of the availability of resources during incubation (Bakner et al. 2019, Lohr et al. 2020) and conditions that mitigate risk of predation (Martin and Roper 1988, Little et al. 2016, Yeldell et al. 2017*a*). The landscape surrounding a nest site likely influences nest predation risk (Crawford et al. 2021, Ulrey et al. 2022). Habitat fragmentation reduces patch sizes and increases edge density, which can promote high densities of nest predators (Prugh et al. 2009, Beasley et al. 2011). However, Chamberlain et al. (2002) suggested that an increase in landscape heterogeneity may reduce predator foraging efficiency due to an increase in the number of potential nest site locations, often denoted as unoccupied prey sites (Martin 1993, Conley et al. 2016, Ulrey et al. 2022). Furthermore, the increase in vegetation complexity near edges may improve nest concealment, which impedes or limits predation (Badyaev 1995, Fuller et al. 2013, Crawford et al. 2021).

For ground-nesting bird species such as eastern wild turkey, understanding the factors that influence nest success is important because reproduction is a key component of population trajectories (Roberts and Porter 1996, Pollentier et al. 2014, Tyl et al. 2020, Boone et al. 2023). Previous research measured the effect of intrinsic (e.g., age) and extrinsic factors on wild turkey reproduction, including weather and climate (Collier et al. 2009, Boone et al. 2023), female age

(Roberts et al. 1995, Vangilder and Kurzejeski 1995, Isabelle et al. 2016), the timing of nest initiation during the reproductive season (Yeldell et al. 2017*a*, *b*, Wood et al. 2019), and the vegetation characteristics at the nest site (Badyaev et al. 1996, Nguyen et al. 2004, Fuller et al. 2013, Isabelle et al. 2016) and throughout the incubation range (Conley et al. 2015). Wild turkey nest sites are often described as having greater ground cover and understory vegetation structure (Bowman and Harris 1980, Badyaev 1995, Moore et al. 2010), indicating that both the nest and incubating female benefit from dense vegetation at the nest (Lazarus and Porter 1985, Isabelle et al. 2016) as its likely aids in concealment and mitigates both predation risk (Lehman et al. 2008) or nest scavenging.

Although wild turkeys have been shown to select concealing vegetation at the nest site, few relationships between vegetation conditions and nest survival have been documented (Little et al. 2014, Crawford et al. 2021, Keever et al. 2023, Boone et al. 2023). However, the lack of documented relationships between nest site vegetation and nest success may be a consequence of short-term, limited geographic scope (single ecoregion, local scale) of studies that under-represented the broad range of vegetation conditions that may influence nest selection and success (however see; Crawford et al 2021, Keever et al. 2023, Boone et al. 2023). Nest site selection, especially for a wide-ranging species like eastern wild turkey, is a complex multi-scale process, likely dependent on the availability of fine-scale nest-concealing vegetation (nest site) and broad-scale resources (incubation range) influenced by land cover composition (Thogmartin 1999). Hence, it is necessary to consider multiple spatial scales in investigations of nest site selection (Orians and Wittenberger 1991).

We monitored nesting female wild turkeys across 3 ecoregion-specific study areas in North Carolina during the 2020–2022 reproductive periods. We had 2 objectives: (1) develop scale-specific predictive models for vegetation characteristics selected at nest sites and use cross-validation to evaluate their predictive performance; and (2) describe the consequences of female behaviors (e.g., nest recess) and both nest site and incubation range vegetation conditions on nest survival. As selection is presumably a hierarchical process (Johnson 1980), we hypothesized that the nest site model (4th order of selection) would be a better predictor of nest site selection than the incubation range model (3rd order). Likewise, we predicted that nest sites with lower visual obstruction would have lower survival rates because of lower concealability from nest predators. Because nest predator densities can be associated with landscape fragmentation (Fleming and Porter 2015), we predicted that nest sites with a greater edge density would have an increased risk of nest failure. Finally, we predicted lower survival for nests incubated by less attentive females that took more and longer recess movements (Lohr et al. 2020).

STUDY AREA

We monitored female wild turkeys from January 2020 through September 2022 across > 250 privately-owned properties in 8 counties within the mountain (Madison, McDowell, Mitchel, and Yancey), Piedmont (Moore), and Coastal plain (Bladen, Duplin, and Sampson) physiographic ecoregions of North Carolina, USA (Figure 2.1). We were granted access to 3,040, 3,073, and 2,843 hectares in the mountain, Piedmont, and Coastal plain ecoregions, respectively. Although all study sites were on privately-owned land, a few bordered public properties.

Mountain properties had heterogeneous topography (500–1800 m elevation) with a climate characterized by moderate winters prone to periods of harsh weather, cool summers, and annual precipitation of 130–250 cm/year (Figure 2.1; Gould et al. 2021). Land uses included livestock grazing, haying, and timber production. Forest cover was mixed hardwoods with scattered pine (*Pinus spp*.; Kirk et al. 2012) and pine-hardwood (Mitchell et al. 2002), often with dense ericaceous shrub understory (e.g., *Kalmia latifolia, Rhododendron maximum*). The Piedmont properties were in the Piedmont and Sandhills physiographic regions (Figure 2.1). Elevations ranged from 75 to 180 m and the climate was characterized by mild winters, warm-temperate, humid summers, and annual precipitation averaging 120 cm/year (Sorrie et al. 2006). Primary land uses were timber production, row-crop agriculture, and commercial poultry or swine farms. Forest cover mostly was managed loblolly pine (*Pinus taeda*) plantations with mixed hardwood forest along riparian areas. Crop rotations were corn, soybeans, and winter wheat, although some tobacco crops were present. The Coastal plain properties (Figure 2.1) had homogonous topography (0–30 m elevation) with a climate characterized by mild winters, warm-temperate, humid summers, and annual precipitation averaging 160 cm/year (Palmquist et al. 2015). Most coastal properties were primarily used for commercial poultry and swine production. Row-crops consisted primarily of corn, soybeans, and winter wheat rotation. Forests had mixed hardwood or pine-hardwood overstory, with common species including red maple (*Acer rubrum*), oak (*Quercus* spp.), and American sweetgum (*Liquidambar styraciflua*). The forest understory and midstory often was dense, with blackberry (*Rubus* spp.), greenbrier (*Smilax spp.*), gallberry (*Ilex coriacea*), and swamp redbay (*Persea palustris*).

METHODS

Capture and Monitoring

We captured female wild turkeys between January and March 2020–2022 using rocket nets at sites baited with cracked corn. We classified individuals as adult or subadult based on the presence of barring on the ninth and tenth primaries (Pelham and Dickson 1992). We fitted captured individuals with a uniquely numbered aluminum rivet leg band (National Band and Tag Company, Newport, Kentucky, Butler et al. 2011) and a GPS–VHF backpack style transmitter

(Biotrack Ltd., Wareham, Dorset, UK, Guthrie et al. 2011). We programmed units to record 9 locations at 07:00:00, 09:00:00, 11:00:00, 12:00:00, 13:00:00, 14:00:00, 16:00:00, 18:00:00, 19:00:00, and one roost location at night (23:59:58) daily between 1 March and 31 August (reproductive period), then a single roost location at night (23:59:58) for all days outside the reproductive period (Cohen et al. 2018). Data collection continued until the GPS unit battery died or the unit was recovered via mortality or recapture. We released turkeys immediately at the capture location following processing. Wild turkey capture and handling protocols were approved by the Animal Care and Use Committee at North Carolina State University (Permit No. 19-739-01, 19-739-02, 19-739-04 as amended).

We monitored live-dead status ≥2 times per week during the reproductive period (mid-March to 31 July) and ≥1 per month outside the reproductive period using a Biotracker receiver (Biotrack Ltd., Wareham, Dorset, U.K.) and handheld Yagi antenna. We downloaded GPS locations ≥2 times per month via a VHF/UHF handheld command unit receiver (Biotrack Ltd., Wareham, Dorset, U.K.), or we downloaded GPS data from units recovered via recapture or mortality (Guthrie et al. 2011). We reviewed GPS locations and considered a female to be incubating when locations became concentrated over a single point for multiple days (Yeldell et al. 2017*a*, *b*). When a female was considered to be laying or incubating a nest, we monitored its location using VHF telemetry and GPS locations until nest termination (female was no longer tending the nest). We considered a nest as successful after we visually identified pipped eggs at the nest bowl, or we observed ≥1 poult during an initial brood flush survey post-incubation (Conley et al. 2016, Yeldell et al. 2017*a, b*, Chamberlain et al. 2020). A nest was considered abandoned if a female left the nest prior to 28 days of incubation and if only intact eggs were in the nest bowl (Conley et al. 2016; Yeldell et al. 2017*a*, *b*). We deemed a nest as depredated when no eggs or only eggshell fragments were detected in and around the nest bowl, and no poults were identified with the female during the initial brood flush survey post-incubation (Conley et al. 2016; Yeldell et al. 2017*a*, *b*).

We determined nest initiation dates by backdating from the nest incubation initiation date, where the nest initiation start date was documented as the earliest date we first documented a GPS location for that hen that fell within a 27-m buffer (mean distance of error; Guthrie et al. 2011, Bakner et al. 2019) around the nest. Following White et al. (2020), we defined nesting rate as the proportion of females alive at the start of the breeding season (15 March) that attempted a first nest. Renest rates were the proportion of females available for a renesting attempt (i.e., not brooding and still alive) that nested a second or third time (Everett et al., 1980).

Nest Site Characteristics

Using methods detailed by Streich et al. (2015), Yeldell et al. (2017*a*), and White et al. (2020), we evaluated vegetation characteristics within a 15-m radius circular plot surrounding the nest. We measured nest site vegetation within approximately one week after the predicted (failed nests) or actual (successful nests) hatch date. All measurements were taken at the nest site and at a paired location in a random direction and a random distance within 100 to 200 m of the nest site. We assumed the paired random location was a site that the female could have selected as an alternative nest location (Argabright et al. 2023).

At each nest site and paired random location, we recorded tree density, canopy cover, ground cover ([%] woody, grass, forb, vine, fern, bare ground), understory vegetation height (cm), and visual obstruction (cm). We measured tree density by counting all trees >10.16 cm diameter at breast height within the 15-m radius plot. We measured canopy cover using a convex spherical densiometer, once above the nest bowl and at locations 15 m in each of the 4 cardinal directions (Concave Model C, Forestry Suppliers, Lemmon 1956); we held the densiometer 1 m from the ground, which approximated the height of a female wild turkey (Pelham and Dickson 1992). We averaged the 5 readings to provide a single value. We viewed a 1-m^2 Daubenmire frame (Daubenmire 1959) from directly overhead and estimated percent ground cover centered on the nest bowl and at locations 15 m from the nest bowl in the 4 cardinal directions. We averaged the value from all 5 frames. We used a 2-m Robel pole (Robel et al. 1970) to estimate average and maximum understory vegetation height and horizontal visual obstruction (i.e., the lowest point on the pole where the pole was completely obstructed by vegetation). We placed the Robel pole in the nest bowl and took readings from 15 m in each cardinal direction following Yeldell et al. (2017*a*). We estimated the visual obstruction, average height, and maximum height of understory vegetation by viewing the pole from a height of 1 m above the ground. We then used the average of the 4 readings to estimate the average and maximum vegetation height and visual obstruction.

Incubation Range Characteristics

For each nest, we evaluated third-order selection (Johnson 1980) using a 50% utilization distribution (hereafter incubation range) with autocorrelated kernel density estimation (AKDE). We performed all AKDE using R package ctmm (version 4.2.1, Calabrese et al. 2016) in program R (version 4.2.2, R Core Team 2023). The incubation range was analogous to the core area used during the incubation period described in Moscicki et al. (2023). For each incubation range, we randomly selected a paired location within the female's home range (95% AKDE), which we estimated using all locations collected for the duration of the female’s monitoring period (Moscicki et al. 2023). We presumed that the home range encompassed all possible nesting areas available to the female. Based on the average area (ha) of all estimated incubation ranges (1.48 ha), we created a 109-m radius (i.e., radius of a 1.48-ha circular range) paired range centered at a random location within the home range.

Within each paired nest and random range, we measured edge density and percent cover of land cover types based on the 2019 National Land Cover Data (NLCD, Dewitz 2021), a 30-m raster layer. We simplified the number of land cover types (Sullivan et al. 2022) and increased the data accuracy (Wickham et al. 2013) by reclassifying 15 land cover types into 7 types – herbaceous (Grassland/Herbaceous), shrubland (Shrub/Scrub), forest (Deciduous Forest, Evergreen Forest, Mixed Forest, and Woody Wetlands), crop (Cultivated Crops), pasture (Pasture/Hay), water (Open Water and Emergent Herbaceous Wetlands), and developed (Barren Land, Developed: Open Space, Developed: Low Intensity, Medium Intensity, and High Intensity). Additionally, using data on state-maintained roads from the North Carolina Department of Transportation website (NCDOT 2023, Conner et al. 2003), we measured the straight-line distance from the center of the incubation range or random range to the nearest road and to the nearest of each of the 7 land cover types using the R package sp (Bivand et al. 2013).

We retrieved enhanced vegetation index (EVI) values derived from the 16-day composite MOD13Q1 Terra Vegetation Indices (version 6) data to estimate the EVI within each nest and random range (Crawford et al. 2021). The EVI correlates accurately with vegetation biomass and has been used as a proxy for vegetation conditions in various wildlife research applications (Pettorelli et al. 2005, 2011). Application of EVI improves sensitivity in dense vegetation conditions compared to the NDVI by minimizing canopy-soil reflectance in normalized difference vegetation index imagery (Didan, 2015). We collected EVI data within a single Moderate Resolution Imaging Spectroradiometer (MODIS) 250-m^2 tile that overlapped each nest and random range center. For both the incubation range and paired random range, we ensured

EVI values were specific to the dates of the nesting period for each female by collecting 16-day composite average EVI values beginning on the first day of nest incubation and ending on the date of hatch or failure. We then used the estimated average daily maximum EVI score recorded during each nest attempt.

Analysis of Nest Site Selection

To determine what characteristics affected nest site selection, we developed 2 global models, 1 each for the nest site and incubation range, and assumed predictor variables were statistically significant at an $\alpha = 0.05$. The covariates in the nest site model were canopy cover, average and maximum understory vegetation height, visual obstruction, and the percent ground cover metrics. The covariates in the incubation range model were EVI, edge density, the percentage of 7 land cover types, and the distances to the nearest road and to each of the 7 land cover types from the nest. We added a year, age, (adult or juvenile), and ecoregion covariate to both models. We included renesting attempts in all analyses and assumed they were independent of the initial nesting attempt (Locke et al. 2013, Yeldell et al. 2017*a*, Johnson et al. 2022). We assessed variable collinearity using Pearson's correlation coefficient prior to analysis and retained the variable that presented the simplest biological interpretation (Yeldell et al. 2017*a*). We ran generalized linear models with a logit link in program R (Bates et al. 2015), where known nests were given a response variable of 1 and the random sites a 0. We tested the independent variables for multicollinearity and dropped variables with variance inflation factor (VIF) values higher than 5.0 (Tabachnick et al. 2013). We then used backward selection to identify the variables influencing nest site selection based on Akaike's information criterion accounting for small sample size (AICc) and considered models with ΔAICc values ≤ 2 to be competing models (Akaike 1973, Burnham and Anderson 2002). To determine the predictive performance of the models, we used repeated k-fold cross-validation using 5 folds to estimate the performance of all competing models. 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 training and testing (Sullivan et al. 2022).

Modeling of Nest Survival

We explored the effect of both nest site and incubation range covariates on nest survival (success or fail) using R package survival (Therneau and Lumley 2016). Cox proportional hazards models provide hazard ratios for each covariate term included in the model. Hazard ratios >1.0 indicate increasing probability of an event (e.g., nest failure) with increasing values for the covariate, whereas hazard ratios <1.0 indicate a decreasing probability of an event (e.g., nest failure) with increasing values for the covariate. Before data analysis, we assessed the proportional hazards assumption for the models.

Covariates in the nest survival model were ecoregion, female age, canopy cover, average and maximum understory vegetation height, visual obstruction, percent ground cover metrics, EVI, edge density, the percentage of 7 land cover types, and the distances to the nearest road and to each of the 7 land cover types from the nest. Additionally, we included incubation initiation date (ordinal date when incubation began) because early nest initiation has been correlated with greater nest success (Keever et al. 2023). Female wild turkey recess movements to and from nests may increase predation risk (Wiebe and Martin 1997, Martin 2002). Thus, following Lohr et al. (2020), we quantified incubation recess behaviors – daily distances traveled and number of daily recess movements away from the nest. We isolated pre- and post-nesting movements from incubation by censoring the first and last days of incubation (Conley et al. 2015). To remove potential GPS error and short movements away from the nest that did not constitute recess movements, we defined a recess movement as ≥1 GPS location >27.5 m from the nest (Bakner et al. 2019, Lohr et al. 2020). Our location schedule was more limited than Bakner et al. (2019) and Lohr et al. (2020), which may have led to missed recess movements or reduced estimates of distances traveled. However, Bakner et al. (2019) reported that 47% of recess movements occurred between 1000 and 1500, for which our location schedule recorded hourly locations between 1100–1400, likely capturing the majority of recess movement. We determined the minimum number of recess movements as the number of GPS locations that fell outside of the 27.5-m nest buffer each day. Similarly, we estimated the daily distance traveled for each recess movement and averaged the values for the duration of the nest attempt.

RESULTS

We monitored 370 individual females, of which 305 nested (*n* = 97 adults, 12 juveniles [Mountain]; *n* = 74 adults, 9 juveniles [Piedmont]; *n* = 101 adults, 12 juveniles [Coastal plain]) during 2020 – 2022. Nesting rates for adults and juveniles in the mountain, Piedmont, and Coastal plain were 73, 61, and 73% and 50, 32, and 40%, respectively (Table 2.1). The renesting rates for adults and juveniles in the mountain, Piedmont, and Coastal plain were 54, 38, and 36% and 22, 11, and 17%, respectively (Table 2.1). Of 420 nests monitored, 315 (75%) failed, including 73% (*n* = 221) of 305 first nests, 83% (*n* = 80) of 96 second nests, and 74% (*n* = 14) of 19 third nests (Table 2.1). We censored 13 nests from further analysis because of restricted access to private properties (*n*=7) and transmitter failure (*n*=6). Statewide average annual nest success was 25% (18 – 30% range across ecoregions; Table 2.2).

Nest Site Selection

According to NLCD 2021, nest sites were located in forest ($n = 118$, 75% [Mountain]; $n = 57$, 56% [Piedmont]; $n = 84$, 57% [Coastal plain]), herbaceous land cover ($n = 4$, 3% [Mountain]; $n = 28$, 28% [Piedmont]; $n = 21$, 14% [Coastal plain]), pasture ($n = 32$, 20% [Mountain]; $n = 4$, 4% [Piedmont]; $n = 3$, 2% [Coastal plain]), shrubland ($n = 4$, 3% [Mountain]; $n = 12$, 12% [Piedmont]; $n = 20$, 14% [Coastal plain]), and cropland ($n = 0$, 0% [Mountain]; $n = 0$, 0% [Piedmont]; $n = 20$, 14% [Coastal plain]; Table 2.3).

Average understory vegetation height at nest sites was correlated with visual obstruction ($r = 0.78$) and maximum understory vegetation height ($r = 0.67$), so we excluded both visual obstruction and maximum vegetation height from models. For the nest site scale, backward stepwise regression identified 4 competitive models based on AICc values (Table 2.4). The *k*-fold cross-validation accuracy values for all 4 models were similar, ranging between 71.0 – 71.6% (Table 2.4). Therefore, we selected the simplest model that included 4 covariates; wild turkeys selected for nest sites with greater average understory vegetation height ($\hat{\beta} = 0.019$, $\widehat{SE} = 0.002$, $p \leq 0.001$), greater percent woody understory, and greater percent forb cover ($\hat{\beta} = 0.022$, $\widehat{SE} = 0.007$, $p = 0.003$; $\hat{\beta} = 0.014$, $\widehat{SE} = 0.005$, $p = 0.003$, respectively) than at random sites. The covariate percent vine ground cover included in the top model was not statistically significant (Table 2.4).

For the incubation range model, distance to the nearest developed land cover was correlated with the distance to the nearest road ($r = 0.782$), so we excluded the distance to the nearest developed land cover from analysis. Backward stepwise regression identified 3 competitive models based on AICc values (Table 2.4). The *k*-fold cross-validation performance for all 3 models was similar, ranging between 53.9 – 54.8% (Table 2.4), and we selected the simplest incubation range model. The top model included 4 covariates, which indicated wild turkeys selected for incubation ranges with greater percent herbaceous and shrubland land cover ($\hat{\beta}$ = 0.017, $\widehat{SE}$ = 0.004, $p \leq 0.001$; $\hat{\beta}$ = 0.011, $\widehat{SE}$ = 0.004, $p \leq 0.001$, respectively). The other covariates (EVI, distance to the nearest road; Table 2.4) included in the top model were not statistically significant.

Nest Survival

Only 1 nest site covariate was a predictor of nest survival – percent bare ground cover ($\hat{\beta}$ =0.023, $\widehat{SE}$ = 0.008; hazard ratio = 1.023; p = 0.004; Table 2.5; Figure C.1). Nest survival decreased 2.3% for every additional percent of bare ground (Table 2.5). Two of the incubation range covariates, edge density ($\hat{\beta}$ = -0.007, $\widehat{SE}$ = 0.002, hazard ratio = 0.993, p =0.001; Table 2.5; Figure C.2) and percent shrubland cover ($\hat{\beta}$ = -0.871, $\widehat{SE}$ =0.357; hazard ratio = 0.4185; p =0.015, Table 2.5; Figure C.3), were significant predictors of nest survival. Although both incubation range covariates were statistically significant, edge density had a weak statistical effect on nest survival; more specifically, there was <1% increase in nest survival for every additional 100 m/ha of edge within the incubation range (Table 2.3). Conversely, shrubland cover around the nest had a strong effect on nest survival – with every 10% increase in shrubland cover, nest survival increased by 5.8%. Two female behavior covariates were significant predictors of nest survival – the average minimum number of daily recess movements ($\hat{\beta}$ =0.125, $\widehat{SE}$ = 0.021, hazard ratio = 1.134, $p \leq 0.001$; Figure C.4; Table 2.5) and the average daily distance of travel ($\hat{\beta}$ =0.009, $\widehat{SE}$ = 0.002, hazard ratio = 1.009, $p \leq 0.001$; Figure C.5; Table 2.5). The average minimum number of daily recess movements had a strong effect on nest survival with the addition of one recess bout increasing the risk of nest failure by 13.4% (Table 2.3). There was an estimated 0.9% increase in the risk of nest failure for every additional meter to the average daily recess distance traveled. Twenty-six of the 31 variables included in the nest survival model, including the timing of incubation initiation, were not predictors for nest survival.

DISCUSSION

We demonstrated that wild turkeys selected nest sites with vegetation characteristics, particularly understory cover, that provided concealment. Many previous studies have reported a selection for greater cover or density of understory vegetation (Badyaev 1995, Byrne and Chamberlin 2013, Little et al. 2016, Yeldell et al. 2017*a*, *b*, Wood et al. 2019). As a ground nesting bird, wild turkey should logically select nests sites with optimal concealing cover that minimizes predation risk (Martin 1993, Wood et al. 2019). Concealing vegetation surrounding nests sites may reduce transmission of olfactory and visual cues for potential nest predators and hinder the foraging efficiency of predators (Lehman et al. 2008, Little et al. 2016). Though vegetation at the nest site may reduce predation risk, predation may be more closely related to the vegetative characteristics at larger scales (e.g., patch, stand) than at the nest site (Kilburg et al. 2014, Yeldell et al. 2017*a*). However, metrics measured at larger spatial scales were less predictive of where female turkeys established nest sites in our study, demonstrating the importance of concurrently evaluating selection at multiple scales.

Numerous studies have identified nest site and landscape characteristics associated with the nest site selection process (Byrne and Chamberlain et al. 2013, Yeldell et al. 2017*a*, Crawford et al. 2021, Keever et al. 2023), but there has been little support that vegetation characteristics at any scale influence nest success (Thogmartin 1999, Fuller et al. 2013, Yeldell et al. 2017*a*, Wood et al. 2019, Crawford et al. 2021). We hypothesized that nests with lower visual obstruction would have greater rates of nest failure due to lower concealability from nest predators, but the nest survival model did not directly support this. However, related factors –

bare ground cover at the nest site, edge density in the incubation range, and the percent of shrubland cover in the incubation range – did influence the likelihood of nest failure. Increased bare ground likely resulted in decreased concealment, which increased the probability of nest failure due to predation (Davis 2005, Spears et al. 2007, Byrne and Chamberlain 2013). We predicted that greater edge density in the incubation range would increase the risk of nest failure because nest predator densities are positively associated with fragmented landscapes (Chamberlain et al. 1995, Thogmartin and Schaeffer 2000, Fleming and Porter 2015), but greater edge density actually decreased predation risk. The mean distance to the nearest edge for all nests was 19.9 m, with 94% of nests within <100 m of forested edges. Greater edge density surrounding nests may represent an increase in alternate nest sites because understory vegetation typically is more prominent along edges than in forest interior (Murcia 1995); hence, greater edge density around nests may have reduced predator efficiency because of the increase in alternate nesting locations along edges (Moorman et al. 2002). Finally, nest survival was greater for nests surrounded by more shrubland, and some nests were actually located within shrubland patches. It is possible that nests isolated from areas of shrubland were more likely to be detected by predators because they were not in areas that matched the search image, or predator densities increased further away from shrubland patches (Chamberlain et al. 2002, Ulrey et al. 2022).

Comparable to Lohr et al. (2020), our results indicate that increased cumulative distance traveled per day and greater number of recess movements decrease nest survival for wild turkeys. Females that make more recess movements over longer distances may be bet hedging on their own survival over survival of their nest to ensure future reproductive opportunities (Bakner et al. 2019, Lohr et al. 2020). Moreover, shorter recess distances may relate to a nest guarding tactic, whereas longer distance recesses may reflect a lack of resources near the nest (Lohr et al.

2020), but there is little understanding of the mechanisms for these behaviors. Further research into activities during recess movement and resource selection will likely be informative for management actions (Bakner et al. 2024). Hence, linking the mechanisms for these behavioral strategies is an important step in identifying possible management actions to increase nest success.

Female wild turkeys demonstrated selection for nest site characteristics at multiple scales. The k-fold cross-validation accuracy assessment for the top models was 71.6% and 54.6% for the nest site and incubation range selection models, respectively. Although these values indicated that both top models were useful in predicting nest site selection, the predictive performance of the nest site model was most accurate. Multi-scale analyses are critical because they address the potential for targeted management solutions at multiple scales. Additionally, ecological conditions and processes often operate at multiple spatial scales to affect population trends of species like wild turkey (Steen and Haydon 2000, White et al. 2005, Melbourne and Chesson 2006, O’Donnell et al. 2019). In our study, wild turkeys selected nest sites with greater concealment at the nest site scale and greater shrubland and herbaceous cover at the incubation range. However, management outcomes are difficult to monitor at scales as small as what we defined as a nest site (i.e., 15-m radius), so management for shrubland and herbaceous cover at the scale of the incubation range may be more practical and should still ensure that concealing nest site vegetation is widely available.

MANAGEMENT IMPLICATIONS

The availability of nesting cover may be a limiting factor for wild turkey populations, and the creation and maintenance of nesting cover is regularly identified as a management tool to conserve wild turkey populations. Our results confirmed the relative importance of nest-concealing vegetation and nearby shrubland and herbaceous vegetation that may provide alternative nesting cover or brooding cover, respectively. Nest site selection did not vary across ecoregions in North Carolina, which indicates habitat management for wild turkeys can target a similar vegetation condition across a broad geographic scale in the eastern US. More specifically, managers should create and maintain a mosaic of landcover types, with emphasis on communities dominated by herbaceous and low woody vegetation that provides concealing cover. Nesting cover can be provided in forest and woodlands by thinning and prescribed burning to maintain understory. However, the response by predators to these management actions and the resulting influence on nest survival needs more study.

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Table 2.1. Reproductive parameters (% (*n*)) for 370 female wild turkeys monitored across 3 ecoregions (Coastal plain [CP], Piedmont [PIE], Mountain [MNT]) of North Carolina, United States, 2020─2022. Nest rate=attempt/available, where the value (*n*) is how many individuals were being monitored. Renest rate= count of renesting hens/count of available hens to renest, where the value (*n*) is the count of hens that had already nested and was available to renest. Nest success=hatched (at least 1 egg)/total count of located nests, where the value (*n*) is the total count of nests located. Hen success=hatched (at least 1 egg)/count of monitored females, where the value (*n*) is how many individuals were being monitored.

		2020				2021				2022				
	Age	CP	PIE	MNT	State	CP	PIE	MNT	State	CP	PIE	MNT	State	Total
Nest rate	Cumulative	68 (31)	48 (52)	60 (53)	57 (136)	81 (48)	60 (57)	74 (54)	71 (159)	59 (90)	60 (40)	74 (50)	63 (180)	64 (475)
	Juvenile	33 (6)	8 (12)	47 (15)	30 (33)	25 (4)	50 (10)	67 (3)	47 (17)	45 (20)	50 (6)	50 (6)	47 (32)	40 (82)
	Adult	76 (25)	60 (40)	66 (38)	66 (103)	86 (44)	62 (47)	75 (51)	74 (142)	63 (70)	62 (34)	77 (44)	67 (148)	69 (393)
Renest rate	Cumulative	42 (19)	53 (17)	50 (22)	48 (58)	20 (45)	29 (34)	58 (40)	35 (119)	43 (53)	29 (24)	44 (34)	41 (111)	40 (288)
	Juvenile	50 (2)	0 (1)	0 (4)	14 (7)	0 (1)	0 (5)	0 (2)	0 (8)	11 (9)	33 (3)	67 (3)	27 (15)	17 (30)
	Adult	41 (17)	56 (16)	61 (18)	53 (51)	20 (44)	34 (29)	61 (38)	38 (111)	50 (44)	29 (21)	42 (31)	43 (96)	43 (258)
Nest success	Cumulative	7 (29)	18 (34)	26 (43)	18 (106)	35 (48)	36 (44)	22 (63)	30 (155)	24 (76)	26 (31)	25 (52)	25 (159)	25 (420)
	Juvenile	0 (3)	0 (1)	43 (7)	27 (11)	100 (1)	80 (5)	50 (2)	75 (8)	20 (10)	0 (4)	0 (5)	11 (19)	29 (38)
	Adult	8 (26)	18 (33)	22 (36)	17 (95)	34 (47)	31 (39)	21 (61)	28 (147)	24 (66)	30 (27)	28 (47)	26 (140)	25 (382)
Hen success	Cumulative	6 (31)	12 (52)	21 (53)	14 (136)	35 (48)	28 (57)	26 (54)	30 (159)	20 (90)	20 (40)	26 (50)	22 (180)	22 (475)
	Juvenile	0 (6)	0 (12)	20 (15)	9 (33)	25 (4)	40 (10)	33 (3)	35 (17)	10 (20)	0 (6)	0 (6)	6 (32)	13 (82)
	Adult	8 (25)	15 (40)	21 (38)	16 (103)	36 (44)	26 (47)	27 (51)	29 (142)	23 (70)	24 (34)	30 (44)	25 (148)	24 (393)

Table 2.2. Mean nest success (%) for 305 female wild turkeys (*n* = 420 nests) monitored across 3 ecoregions of North Carolina, United States, 2020–2022.

		Annual nest success %	
Site	$n_{(\text{nest})}$	$\bar{x}$	S.E.
Mountain	158	0.24	0.01
Piedmont	109	0.28	0.05
Coastal plain	153	0.24	0.08
Statewide	420	0.25	0.04

Table 2.3. Characteristics of wild turkey nests at the nest site (15-m radius buffer) and incubation range (50% U.D., *n* = 407) for 303 female wild turkeys monitored across 3 ecoregions of North Carolina, United States, 2020–2022.

	Unsuccessful		Successful	
Variable	$\bar{x}$	S.E.	$\bar{x}$	S.E.
Nest site covariates				
% Canopy Cover	53.7	1.9	53.0	3.7
% Woody	15.1	0.76	17.2	1.6
% Grass	20.6	1.1	23.1	2.6
% Forb	16.0	0.92	14.3	1.6
% Vine	4.2	0.54	3.0	0.69
% Fern	1.4	0.23	1.2	0.35
% Bare ground	6.0	0.48	5.0	0.84
Avg. vegetation height (cm)	140.1	2.6	142.5	4.0
Incubation range covariates				
EVI[a]	48.0	0.6	50.0	1.0
Edge density (m/ha)	2,898.4	159.8	3,995.5	330.4
% Water	0.4	0.2	0.5	0.5
% Herbaceous	9.0	1.0	9.0	3.0
% Shrubland	8.0	1.0	12.0	3.0
% Forest	62.0	2.0	61.0	2.0
% Cropland	8.0	1.0	11.0	3.0
% Pasture	8.0	1.0	5.0	2.0
% Developed	3.0	0.5	5.0	2.0
Water[b] (m)	181.0	8.2	157.3	15.0
Herbaceous[b] (m)	429.2	25.3	408.1	54.5
Shrubland[b] (m)	326.2	18.6	364.1	43.4
Forest[b] (m)	21.0	2.5	16.1	4.5
Road[b] (m)	465.1	19.9	484.9	42.3
Cropland[b] (m)	544.3	67.4	755.1	152.9
Pasture[b] (m)	381.0	21.9	457.4	61.9

[a] Average maximum enhanced vegetation index collected from a 250-m^2 sampling tile surrounding the nest during the nesting period.

[b] Straight-line distance to nearest land cover class.

Table 2.4. Model selection and predictive performance results of nest site selection using k-fold cross validation for both the nest site and incubation range models for 407 nests monitored across 3 ecoregions of North Carolina, United States, 2020─2022. We evaluated support using Akaike's Information Criterion for small sample sizes (AICc) for environmental covariates measured at 2 spatial extents around nests. We used the 2019 National Land Cover Database to classify land cover into 7 common classes. All models at the nest site and incubation range extents included day as a fixed effect. K indicates the number of fixed effects in each model and weight represents relative model weight for models within each spatial extent.

	Model selection					*k*-fold cross validation			
Model	*K*	AICc	ΔAICc	Weight	Cum. Wt	Accuracy	Kappa	Accuracy SD	Kappa SD
Nest site model									
Avg. vegetation height + Woody cover + Forb cover + Vine cover	5	983.55	0.00	0.35	0.35	0.716	0.433	0.032	0.064
Avg. vegetation height + Woody cover + Forb cover + Vine cover + Canopy cover	6	984.11	0.56	0.26	0.61	0.711	0.423	0.032	0.065
Avg. vegetation height + Woody cover + Forb cover + Vine cover + Grass cover + Canopy cover	7	984.44	0.89	0.22	0.84	0.710	0.420	0.032	0.065
Avg. vegetation height + Woody cover + Forb cover + Vine cover + Grass cover + Fern cover + Canopy cover	8	985.13	1.58	0.16	1.00	0.710	0.419	0.032	0.064
Incubation range model									
EVI + Herbaceous + Shrubland + Distance to the nearest road	5	1107.83	0.00	0.49	0.49	0.539	0.078	0.033	0.069
EVI + Herbaceous + Shrubland + Distance to the nearest road + Distance to the nearest pasture	6	1108.82	0.99	0.30	0.78	0.548	0.096	0.034	0.068
EVI + Crop + Herbaceous + Shrubland + Distance to the nearest road + Distance to the nearest pasture	7	1109.44	1.61	0.22	1.00	0.543	0.086	0.034	0.068

Table 2.5. Results of Cox proportional hazards models of risk of failure for 407 wild turkey nests monitored across 3 ecoregions of North Carolina, United States, 2020─2022.

					Hazard ratio CI	
	$\hat{\beta}$	$\widehat{S.E.}$	p	Hazard ratio	Lower 95%	Upper 95%
Female behavior covariates						
Region	-0.006	0.115	0.958	0.9939	0.7926	1.2464
Age	0.143	0.211	0.498	1.1535	0.7631	1.7436
Avg. daily recess	0.125	0.021	0.000	1.1336	1.0881	1.1809
Ordinal date	0.006	0.004	0.118	1.0056	0.9986	1.0127
Avg. daily distance traveled	0.009	0.002	0.0001	1.0088	1.0044	1.0132
Year	-0.076	0.080	0.340	0.9264	0.7918	1.0840
Nest site covariates						
Canopy cover	0.002	0.002	0.257	1.0022	0.9984	1.0060
Avg. vegetation height	-0.002	0.001	0.191	0.9983	0.9958	1.0008
Woody cover (%)	0.001	0.005	0.915	1.0005	0.9908	1.0103
Grass cover (%)	-0.003	0.004	0.463	0.9973	0.9900	1.0046
Forb cover (%)	0.003	0.004	0.466	1.0033	0.9945	1.0121
Vine cover (%)	0.008	0.007	0.265	1.0079	0.9940	1.0220
Fern cover (%)	0.011	0.017	0.497	1.0114	0.9789	1.0450
Bare ground (%)	0.023	0.008	0.004	1.0228	1.0071	1.0388
Incubation range covariates						
EVI	0.141	0.590	0.811	1.1512	0.3622	3.6591
Edge density	-0.007	0.002	0.001	0.9933	0.9894	0.9972
Water (%)	-0.780	1.851	0.673	0.4583	0.0122	17.255
Herbaceous (%)	-0.161	0.356	0.651	0.8512	0.4233	1.7117
Shrubland (%)	-0.871	0.357	0.015	0.4185	0.2077	0.8431
Forest (%)	-0.153	0.295	0.604	0.8583	0.4818	1.5292
Cropland (%)	-0.481	0.381	0.207	0.6184	0.2932	1.3042
Pasture (%)	-0.225	0.379	0.553	0.7986	0.3799	1.6789
Developed (%)	-0.821	0.593	0.166	0.4400	0.1377	1.4061
Distance to the nearest water	0.003	0.061	0.967	1.0025	0.8891	1.1304
Distance to the nearest herbaceous	0.007	0.080	0.933	1.0068	0.8609	1.1774
Distance to the nearest shrubland	-0.143	0.081	0.077	0.8664	0.7392	1.0155
Distance to the nearest forest	0.077	0.057	0.177	1.0806	0.9655	1.2094
Distance to the nearest road	0.027	0.068	0.691	1.0273	0.8995	1.1733
Distance to the nearest pasture	-0.140	0.101	0.166	0.8689	0.7122	1.0602

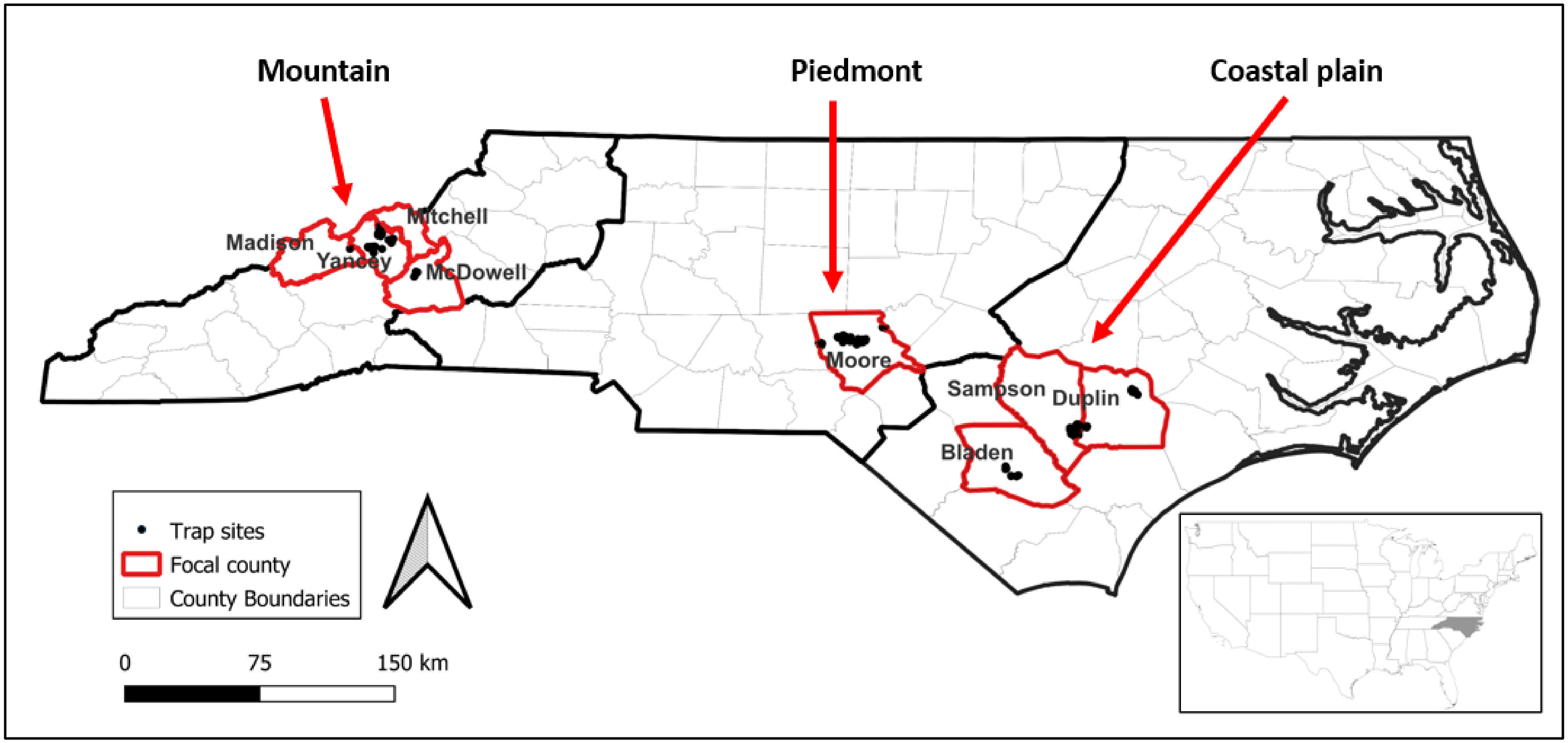

Figure 2.1. Locations of 30 wild turkey trap sites in 8 counties across the 3 ecoregions of North Carolina, United States, where we monitored 420 wild turkey nests, 2020–2022.

CHAPTER 3: Geographical variation in male eastern wild turkey gobbling activity relative to female nesting chronology

ABSTRACT

Wild turkey (*Meleagris gallopavo*) gobbling is a key aspect of hunter satisfaction and has been traditionally used to determine the timing of spring wild turkey hunting seasons. However, to minimize effects on reproductive success, the hunting season should not begin before the peak of nest initiation. Thus, it’s important to understand the timing of gobbling and nesting to appropriately structure the hunting season such that hunter satisfaction is maximized while not reducing nesting success. We conducted a study to determine if gobbling and nesting chronology and the relative overlap in timing varied temporally and spatially across a large elevational gradient. We collected gobbling chronology data using autonomous recording units and determined nesting chronology of 305 female eastern wild turkeys (*M.g. silvestris*) monitored with Global Positioning System transmitters across 3 distinct physiographic ecoregions of in North Carolina, USA, during 2020─2022. We recorded 63,456 gobbles and located 420 nests and determined that gobbling chronology did not vary regionally but did vary daily and annually within each region. Nest incubation initiation dates were similar among years and across regions, supporting photoperiod as the main driver of nesting chronology. Gobbling activity was not bimodal or consistent in relation to nesting activity across years and regions; for example, gobbling activity declined following the onset of incubation in some regions and years but continued at relatively high rates during incubation in other years and regions. We identified 2 relatively consistent time lag relationships between gobbling and nesting activity. The lack of variation in nesting chronology across the large elevation gradient indicates uniform opening dates for hunting within a similar latitudinal zone (e.g., North Carolina ecoregions) are appropriate.

INTRODUCTION

Wild turkey (*Meleagris gallopavo*) populations may be affected by the timing of the spring hunting season, which generally coincides with the start of the reproductive season. Unlike most other gamebirds in the contiguous United States, wild turkeys are primarily hunted during the height of reproductive activities (Chamberlain et al. 2018). Reproductive success (i.e., nesting rate, nest success) influences population change in wild turkeys, and hunting activities may negatively influence reproduction (Chamberlain et al. 2018, Wightman et al. 2019). Consequently, managers are challenged with setting hunting seasons that limit negative effects to reproduction while maximizing hunter satisfaction (Healy and Powell 1999, Casalena et al. 2015, Wightman et al. 2019, Wakefield et al. 2020). With mounting evidence of declines in wild turkey reproduction indices across much of the southeastern (Byrne et al. 2014, Londe et al. 2023), mid-Atlantic (Casalena et al. 2015), and midwestern regions (Parent et al. 2016) of the United States, there is an impetus to evaluate harvest management strategies using the most current and biologically relevant data available.

It is important to understand the relationship between gobbling and nesting chronology to maximize hunter satisfaction without diminishing reproductive output. Gobbling activity is an important determinant of hunter satisfaction (Kurzejeski and Vangilder et al 1992, Little et al. 2000, Wightman et al. 2019), so wildlife managers use the perceived peaks (local maxima) in gobbling activity as a key determinant in setting hunting season dates (Wightman et al. 2019). The traditional approach has been to begin the hunting season after the initial peak in gobbling activity, at which point females have initiated nesting and should be less vulnerable to harvest or hunter activity, while males are more apt to gobble and move across the landscape in search of additional breeding opportunities. The timing of the spring hunting season has the potential to result in a negative effect to either hunter satisfaction (i.e., season starts after gobbling activity declines) or wild turkey reproduction (i.e., season starts before breeding and nest initiation has occurred; Healy and Powell 1999, Casalena et al. 2016, Gonnerman et al. 2022). Furthermore, any long-term declines in wild turkey abundance resulting from harvest mismanagement is likely to reduce future hunter satisfaction (Healy and Powell 1999, Whitaker et al. 2005, Wightman et al. 2019).

Few studies have concurrently evaluated nesting and gobbling chronology, and those that have were conducted at a single location (Chamberlain et al. 2018, Wightman et al. 2019, 2022, Wakefield et al. 2020). Nesting chronology and gobbling chronology vary with latitude, with both beginning later further north (Whitaker et al. 2005, Gonnerman et al. 2022). However, less is known about variation in gobbling and nesting chronology across elevation change within a similar latitude, where the timing of the spring green-up would be earlier at lower elevations. Prior research in North Carolina indicated that elevation has relatively little effect on gobbling or nesting chronology, but those studies did not monitor the two behaviors concurrently (Kreh et al. 2023, Boone et al. 2024, Moscicki et al. in prep). Additionally, concurrent monitoring of nesting and gobbling is needed to document the relative timing of the behaviors (i.e., the degree of overlap) across space (e.g., elevation gradient) and time (e.g., multiple years). Studies that concurrently document gobbling and nesting chronology, especially across a broad spatial extant, can inform whether there should be variation in the timing of wild turkey hunting seasons across regions (Whitaker et al. 2005, Pollentier et al. 2014, Palumbo et al. 2019).

Our objectives were to document the timing of gobbling and nesting during 3 reproductive seasons (2020-2022) across a large elevational gradient that spanned the 3 dominant ecoregions of North Carolina, USA. We predicted that nesting and gobbling chronology, generally thought to be driven by photoperiod, would not vary spatially across the study area because latitudinal variation was low. Hence, we predicted that an identifiable lag in the timing of nest initiation following peak gobbling activity (i.e., the amount of time between peak gobbling and nest initiation) would occur consistently across regions and years.

STUDY AREA

We monitored female wild turkeys from January through August 2020─2022 on privately-owned properties across 8 counties in the Mountain (Madison, McDowell, Mitchel, and Yancey), Piedmont (Moore), and southeastern Coastal plain (Bladen, Duplin, and Sampson) physiographic ecoregions of North Carolina, USA (Figure 3.1). Mountain properties had heterogeneous topography (500–1800 m elevation) with a climate characterized by moderate winters with periods of harsh weather, cool summers, and annual precipitation of ≥130 cm/year (Figure 3.1; Gould et al. 2021). Properties were used for timber production, livestock grazing, and hay production. Forest cover was primarily mixed pine-hardwood (Mitchell et al. 2002), often with dense shrub understory (e.g., *Kalmia latifolia*). Properties in the Piedmont physiographic region included a portion of the Sandhills ecoregion (Figure 3.1). Elevations ranged from 75 to 180 m and the climate was characterized by mild winters and warm-temperate, humid summers, with annual precipitation averaging 120 cm/year (Sorrie et al. 2006). Land use included timber production and row-crop agriculture (e.g., corn, soybeans, winter wheat). Forest cover primarily was managed pine (*Pinus* spp.) plantations and mixed pine-hardwood forest. The Coastal plain properties (Figure 3.1) had relatively homogonous topography (0–30 m elevation) with a climate characterized by mild winters, warm-temperate, humid summers, and annual precipitation averaging 160 cm/year (Palmquist et al. 2015). Most of the properties were used for commercial poultry and swine production. Row-crops consisted primarily of corn, soybeans, and winter wheat rotation. Forests had mixed hardwood or pine-hardwood overstory (e.g., *Acer rubrum, Quercus* spp., *Liquidambar styraciflua*) with dense midstory of the same species. All properties were regularly hunted during both the youth and regular harvest season. The youth season consistently opened on the first Saturday of April; the regular season consistently opened on the second Saturday in April and closed on the fifth Saturday thereafter.

METHODS

We captured female wild turkeys between January and March 2020–2022 using rocket nets at site baited with cracked corn. Based on the presence of barring on the ninth and tenth primaries, we classified individuals as adult or subadult (Pelham and Dickson 1992). We fitted captured individuals with a uniquely numbered aluminum rivet leg band (National Band and Tag Company, Newport, Kentucky, Butler et al. 2011) and a backpack style GPS-VHF transmitter (Biotrack Ltd., Wareham, Dorset, UK, Guthrie et al. 2011). We programmed units to record 9 locations at 07:00:00, 09:00:00, 11:00:00, 12:00:00, 13:00:00, 14:00:00, 16:00:00, 18:00:00, 19:00:00, and one roost location at night (23:59:58) daily between 1 March and 31 August (reproductive period), then a single roost location at night (23:59:58) for all days outside the reproductive period (Chamberlain et al. 2018). The unit ran until the battery died or the unit was recovered via mortality or recapture. We released turkeys at the capture location immediately following processing. All captures and handling protocols were approved by the Animal Care and Use Committee at North Carolina State University (Permit #19-739-01, 19-739-02, 19-739-04 as amended).

We monitored turkeys ≥2 times per week from March through August using a Biotracker receiver (Biotrack Ltd., Wareham, Dorset, U.K.) and handheld Yagi antenna. We downloaded spatial data ≥2 times per month via a VHF/UHF handheld command unit receiver (Biotrack Ltd., Wareham, Dorset, U.K.; Guthrie et al. 2011) to document nesting activities of females. We determined the onset of incubation by viewing GPS locations, and we considered females to be incubating when locations for several days did not deviate from a central location (Healy 1992, Yeldell et al. 2017). Each female was monitored daily at the start of incubation. If locations denoted the female was absent from the nest longer than 48hrs, we located the nest and classified it as successful (≥1 egg; Conley et al. 2016) or failed (presence of egg fragments, missing eggs, or mortality). We continuously monitored females for renest attempts throughout the summer, which comprised the entire period we monitored gobbling activity. Nest initiation (when laying began) dates were determined by backdating from each confirmed nest's incubation initiation date using the date that the first GPS location fell within a 27-m buffer (mean distance of error; Guthrie et al. 2011, Bakner et al. 2019) around the nest location.

We quantified gobbling activity during the reproductive season (1 Mar─31 May) using 51 autonomous recording units (ARUs; Song meter model SM3: Wildlife Acoustics, MA, USA; 17/ecoregion) deployed at locations across the 3 ecoregions of North Carolina, USA. Based on Kreh et al. (2023), ARUs were separated by ≥500m to avoid double counting males on multiple ARUs. The ARUs were distributed in areas where we observed turkey activity within ranges maintained by monitored females (Chamberlain et al. 2018, Wightman et al. 2019). We programmed ARUs to record for 2.5hrs daily starting 30 minutes before sunrise from 1 March to 31 May (Kreh et al. 2023, Wightman et al 2019). Each ARU was placed in a metal security box and bolted to a tree ≥2m above the ground.

We used Raven Pro 1.6 (Cornell Laboratory of Ornithology, Ithaca, NY, USA) to search for potential gobbles in ARU recordings via a Band Limited Energy Detector (BLED). Following Kreh et al. (2023), we used the following settings: 775–1050 Hz, minimum duration

0.49806 seconds, maximum duration 1.18769 seconds, minimum separation 0.26819 seconds, minimum occupancy 40%, signal to noise threshold 10 dB, block size 5.01894 seconds, hop size 1.99225 seconds, percentile 20, screen resolution 1225; remaining parameters for the BLED settings were unchanged from default settings or not used. Using the above parameters, the BLED detected and stored selections identified as gobbles by either of each ARU's external microphones. We verified gobbles by examining each selected sound visually and auditorily, and then categorized them as either a true positive (i.e., gobbles) or false positive (e.g., woodpecker). Using a similar process, the North Carolina Wildlife Resources Commission (2021) reported 33.8% of all gobbles contained in the recordings were detected via automated review process, which was sufficient to identify patterns in gobbling activity.

To evaluate the lagged correlation between timing of gobbling activity and nest initiation (first date of laying), we used cross-correlation analysis in package "forecast" (Hyndman 2017). Cross-correlation analysis produces autocorrelation functions that depict lagged correlations between paired observations (e.g., daily gobbling activity and nest initiation) and provides a measure of similarity between 2 times series. We used the package "dynlm" to fit a lagged regression to evaluate the magnitude and direction of the temporal relationship between gobbling activity and nest initiation (Venables and Ripley 2002, Zeileis 2016, Chamberlain et al. 2018). We considered $p \geq 0.05$ to be statistically significant and conducted all analyses in Program R version 3.4.3 (R Core Team 2023).

RESULTS

We captured and marked 370 female wild turkeys, of which 305 nested (n = 109 [Mountain]; n = 83 [Piedmont]; n = 113 [Coastal plain]) during the 2020 – 2022 reproductive seasons. Overall, we located 420 nests. In 2020, mean date of onset of initiation (i.e., egg laying) of first nest attempts was 11-April in the Mountain, 13-April in the Piedmont, and 14-April in the Coastal plain (Table 3.1). In 2021, mean date of onset of initiation of first nest attempts was 13-April in the Mountain, 9-April in the Piedmont, and 12-April in the Coastal plain (Table 3.1). In 2022, mean date of onset of initiation of first nest attempts was 12-April in the Mountain, 9-April in the Piedmont, and 11-April in the Coastal plain (Table 3.1). Overall, the timing of nest incubation initiation was similar among regions and years; mean incubation initiation dates for first nests varied by only 6 days (i.e., earliest was 21 April and latest was 27 April) across all regions and years of the study (Table 3.1).

Across the 3 physiographic regions, we collected 33,312 hours of ambient sound during 2020─2022. We identified and evaluated 407,200 potential gobbles and positively identified 63,456 gobbles (Table 3.2). Gobbling activity was highly variable across all years and ecoregions, though the initiation and termination dates for most gobbling activity were relatively consistent across space and time (Figures 3.2─3.4). An autocorrelation analysis of gobbling activity revealed little evidence of lags in gobbling activity, suggesting that gobbling activity at time t had little influence on gobbling activity at t > lag0 (i.e., gobbling on one day was not related to gobbling the following day; Figures 3.5─3.7).

We observed no consistent relationship between daily gobbling activity and the onset of nest incubation among years or ecoregions (Figures 3.2─3.4). For example, during 2020, gobbling activity declined as incubation activity increased in the Piedmont and Coastal plain, with a peak in gobbling prior to the start of incubation (Figure 3.2). However, in the Mountain region, gobbling remained consistent into late May and during a substantial portion of the incubation activity (Figure 3.2). There was substantial variability in gobbling activity from day to day across most years and regions, though activity was least variable during incubation in

2020 in the Piedmont and Coastal plain regions (Figure 3.2). The total numbers of gobbles detected varied annually in the Mountain and Coastal plain, especially in 2022 when gobbling activity increased dramatically in both regions (Table 3.2). We detected the fewest gobbles in 2020 in all 3 regions (Table 3.2). Gobbling activity spiked later in the season in several cases (e.g., Mountain in 2021, Piedmont 2021 and 2022, and Coastal plain in 2022), possibly coinciding with an increase in reproductive females after failed initial nesting attempts.

In 2020 and 2022, cross-correlation analysis between gobbling and nesting activity indicated 1 significant cross-correlation each in the Mountain and Piedmont regions and 2 in the Coastal plain at lags -15, -3, -9, and -40 for 2020, and at lags -5, -11, -3, and -42 in 2022, respectively (Figures 3.8, 3.10, Table 3.3). In 2021, each region had 2 significant cross-correlations – lags at -4 and -35 in the Mountain, lags at -6 and -38 in the Piedmont, and lags at -3 and -39 in the Coastal plain (Figure 3.9, Table 3.3). As an example of how to interpret these relationships, an above average number of gobbles 15 days prior in the Mountain in 2020 led to an above average number of females initiating nests approximately 15 days later (Figure 3.8, Table 3.3). Conversely, in the Coastal plain in 2022, an above average number of gobbles 42 days prior lead to a below average number of females initiating nests approximately 42 days later (Figure 3.10, Table 3.3). After we rescaled the data to account for any observed lags, we noted that the times-series data sets were similar at all lags (Table 3.3), further supporting the relevance of the observed lags.

DISCUSSION

Consistency in female reproductive activity across years and regions indicated that photoperiod was a key driver in female reproductive phenology, despite the extreme range of elevation change (0─2037m) and differences in timing of spring green-up. More specifically, green-up in the Mountain region was approximately 2 weeks later than the Piedmont and coastal region each year of the study (Table D.1.). Photoperiod influences hormonal changes that govern the timing of ovulation, mating behavior, and gestation in wild turkeys (Healy 1992). Even across diverse elevation changes and different timings of green-up, the consistent timing of reproductive activity indicates that photoperiod was the dominant signal for female wild turkeys to initiate reproductive processes in our study (Wakefield et al. 2020). However, snow persistence delayed nest initiation in several populations of wild turkey in Ontario, Canada, so additional study in more northern regions, where weather may override photoperiod, is warranted (Lavoie et al. 2017).

Gobbling chronology was highly variable across both space and time, likely because of weather and other local scale factors. In fact, previous studies have demonstrated that gobbling activity was influenced by temperature (Vangilder et al.1987, Hoffman 1990, Wightman et al. 2022), wind velocity and dewpoint (Miller et al. 1997, Wightman et al. 2022), rainfall (Wightman et al. 2022), and barometric pressure (Wellendorf et al. 2004, Wightman et al. 2022). Wightman et al. (2022) suggested that rain, high wind speed, and high temperatures suppressed gobbling activity, whereas greater barometric pressure led to increased gobbling activity. Some of these factors also likely influence an ARUs ability to detect gobbles. Gobbling activity declined at both the Piedmont and Coastal plain sites in 2020 after early April, but gobbling activity in 2021 and 2022 was more variable with several upticks in gobbling even after most reproductively active females had initiated nests. This variation in gobbling activity could be a result of the varying number of unreceptive (non-reproductive) females on the landscape or females that failed nest attempts in the early season. However, nesting rates were relatively consistent across space and time (~65% overall) and weather conditions varied. For example, the

2020 nesting period was characterized by warm and wet conditions, and the 2021 and 2022 nesting periods had above average temperatures and drier conditions (Frankson et al. 2022). Therefore, we believe that variation in weather most contributed to the differences in gobbling activity among years.

Because there were no consistent peaks in gobbling activity across years and ecoregions, gobbling likely is not an appropriate guide for the timing of hunting seasons. Although gobbling activity was temporally and spatially variable, the reproductive timing for female wild turkeys was spatially and temporally consistent and likely linked with photoperiod. Thus, the mean or median nest initiation or nest incubation initiation dates are more appropriate indicators for setting season timing than gobbling activity. Gobbling activity often continued at relatively high rates even after females were on nests and throughout the regular harvest season statewide (Table E.1., Figure E.1.). Although the use of gobbling activity in the regulatory decision-making process is important, it should be used with caution, with less emphasis on identifying peaks of gobbling suggested by earlier studies (Bevill 1973, 1975, Hoffman1990, Lehman et al. 2005) and instead more focus on examining the occurrence of gobbling prior, during, and after harvest seasons. In fact, we documented that 15 and 45% of all gobbling across North Carolina occurred within the 7-day special youth season and 29-day regular season window, respectively (youth season opens the first Saturday of April, and the regular season opens on the second Saturday of April and closes on the fifth Saturday), and 26 and 14% of recorded gobbling occurred prior to and after the hunting season, respectively (Table E.1.). Notably, gobbling activity in our study was ~60% lower than documented by Kreh et al. (2023) in non-hunted sites in the 3 ecoregion of North Carolina during the same 29-day regular season window. However, nearly half of the gobbling occurred prior to the hunting season and nearly half during the hunting season (Kreh et al. 2023). Although the variation in gobbling activity within and across years in our study could have been related to hunter activity, we were not able to measure this potential effect.

We identified 2 relatively consistent time lag relationships between gobbling and nesting activity. First, with an increase in gobbling activity on average 38.6 days prior there were fewer females initiating nests ~38.6 days later. One explanation for this relationship is that male reproductive activity begins earlier than for females, which are more focused on flock dynamics and less on breeding as early gobbling activity begins (Healy 1992). The second relationship was that above average gobbling activity on average 6.5 days prior was associated with greater number of females initiating nest ~6.5 days later. Although female turkeys can store sperm for extended periods, it is plausible that males that copulate immediately prior to egg laying may be an attempt to navigate around sperm competition and increase individual fitness over another conspecific (Birkhead and Moller 1992, Khillare et al. 2018). Chamberlain et al. (2018) posited that females achieve maximum sperm storage immediately prior to egg production, and thus as males perceive females to be nearing egg production, male competition and related gobbling activity would increase. Finally, our research across multiple study sites with variable biotic and abiotic conditions identified two lag periods quite similar to Chamberlain et al. (2018), which indicates a wide-spread and relatively consistent temporal relationship between gobbling activity and nest initiation.

MANAGEMENT IMPLICATIONS

Because gobbling activity generally was not bimodal or consistent in relation to nesting activity across years and regions, our study does not support gobbling chronology as a dependable metric for directing the timing of spring hunting seasons. Instead, we recommend nesting chronology as a better guide for timing hunting seasons. Moreover, the lack of regional variation in nesting chronology indicates uniform opening dates for hunting across North Carolina, and possibly other areas within similar latitudes, are appropriate. We recommend research on how hunter activity directly influences gobbling activity and whether there are indirect effects of modified gobbling activity on female reproductive behavior.

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Table 3.2. Number of nests monitored (*n*), range and mean values of nest and renesting initiation, incubation initiation, and hatch dates by year for 420 wild turkey nests located across the 3 ecoregions of North Carolina, United States, 2020–2022.

				Initiation		Incubation Initiation		Hatch	
Attempt	Region	Year	*n*	Range	Mean	Range	Mean	Range	Mean
First Nest	Mountain	2020	32	26 Mar-5 May	11-Apr	10 Apr-19 May	23-Apr	8 May-16 Jun	21-May
	Piedmont		25	28 Mar-16 May	13-Apr	9 Apr-27 May	25-Apr	7 May-24 Jun	23-May
	Coastal plain		21	1 Apr-2 May	14-Apr	12 Apr-12 May	26-Apr	10 May-9 Jun	24-May
	Statewide		78	26 Mar-16 May	13-Apr	9 Apr-27 May	24-Apr	7 May-24 Jun	22-May
Renest	Mountain		11	28 Apr-5 Jun	14-May	13 May-16 Jun	28-May	9 Jun- 14 Jul	23-Jun
	Piedmont		9	18 Apr-23 May	8-May	2 May-6 Jun	22-May	30 May-29 Jun	13-Jun
	Coastal plain		8	4 May-23 May	17-May	12 May-14 Jun	28-May	9 Jun-12 Jul	25-Jun
	Statewide		28	18 Apr-5 Jun	13-May	2 May-16 Jun	27-May	30 May-14 Jul	20-Jun
First Nest	Mountain	2021	40	23 Mar-5 May	13-Apr	7 Apr-19 May	24-Apr	8 May-8 Jun	23-May
	Piedmont		34	25 Mar-25 Apr	9-Apr	9 Apr-8 May	23-Apr	5 May-29 May	17-May
	Coastal plain		39	26 Mar-30 Apr	12-Apr	8 Apr-12 May	24-Apr	14 May-11 Jun	28-May
	Statewide		113	23 Mar-5 May	11-Apr	7 Apr-19 May	24-Apr	5 May-11 Jun	22-May
Renest	Mountain		23	20 Apr-30 May	10-May	5 May-8 Jun	22-May	3 Jun-8 Jun	5-Jun
	Piedmont		10	9 Apr-21 May	30-Apr	21 Apr-31 May	11-May	19 May-28 May	23-May
	Coastal plain		9	20 Apr-22 May	6-May	2 May-2 Jun	17-May	2 Jun-11 Jul	6-Jun
	Statewide		42	9 Apr-30 May	5-May	21 Apr-8 Jun	19-May	19 May-11 Jul	1-Jun
First Nest	Mountain	2022	37	22 Mar-4 May	11-Apr	3 Apr-15 May	25-Apr	10 May-31 May	16-May
	Piedmont		24	25 Mar-29 Apr	9-Apr	4 Apr-8 May	21-Apr	12 May-31 May	17-May
	Coastal plain		53	29 Mar-15 May	12-Apr	10 Apr-25 May	27-Apr	13 May-12 Jun	23-May
	Statewide		114	22 Mar-15 May	11-Apr	3 Apr-25 May	26-Apr	10 May-12 Jun	18-May
Renest	Mountain		15	20 Apr-10 Jun	13-May	5 May-20 Jun	22-May	8 Jun-29 Jun	20-Jun
	Piedmont		7	9 Apr-22 May	3-May	21 Apr-2 Jun	14-May	11 Jun-12 Jul	26-Jun
	Coastal plain		23	18 Apr-1 Jun	10-May	30 Apr-16 Jun	19-May	26 May-27 Jun	9-Jun
	Statewide		45	9 Apr-10 Jun	8-May	21 Apr-20 Jun	21-May	26 May-12 July	18-Jun

Table 3.3. Number of autonomous recording units (*n*), hours of recorded sound, number of potential wild turkey gobbles, and true positives detected with a band limited energy detector in Raven Pro 1.6 software. Sound was recorded across North Carolina's 3 physiographic regions during 2020–2022.

Region	Year	*n*	Hours of ambient sound recorded	Potential Gobbles	Gobbles Identified
Mountain[a]	2020	16	3,640	52,690	6,702
	2021	15	3,413	48,896	7,741
	2022	16	3,640	61,153	9,887
Piedmont	2020	17	3,868	43,525	4,663
	2021	17	3,690	44,414	5,837
	2022	17	3,868	38,258	5,456
Coastal plain	2020	17	3,795	32,305	5,827
	2021	17	3,813	49,248	8,319
	2022	17	3,585	36,711	9,024

[a] 1 ARU unit failed each year of the study, and 1 additional ARU unit failed in 2021.

Table 3.4. Results of the lagged regression to evaluate the magnitude and direction of the temporal relationship between gobbling activity and nest initiation of turkeys monitored across 3 ecoregions of North Carolina, United States, 2020–2022. The plus sign (+) represents an increase in the parameter (e.g., increase in the number of gobbles or number of incubating females), whereas the negative sign (-) denotes a decrease in the parameter (e.g., decrease in the number of incubating females), and NA denotes no lag was identified.

		First identified lag					Second identified lag				
Year	Physiographic Region	Lag days	$\hat{\beta}$	$\widehat{S.E.}$	p	Direction of effect Gobbles/Inc. hen	Lag Days	$\hat{\beta}$	$\widehat{S.E.}$	p	Direction of effect Gobbles/Inc. hen
2020	Mountain	-15	-0.217	0.138	0.119	+/+	NA	NA	NA	NA	NA
	Piedmont	-3	-0.070	0.114	0.543	+/+	NA	NA	NA	NA	NA
	Coastal plain	-9	0.075	0.126	0.554	+/+	-40	-0.152	0.147	0.306	+/-
2021	Mountain	-4	0.152	0.111	0.175	+/+	-35	-0.220	0.142	0.125	+/-
	Piedmont	-6	0.056	0.115	0.627	+/+	-38	-0.154	0.185	0.407	+/-
	Coastal plain	-3	0.058	0.105	0.582	+/+	-39	0.099	0.132	0.457	+/-
2022	Mountain	-5	0.163	0.111	0.146	+/+	NA	NA	NA	NA	NA
	Piedmont	-11	-0.073	0.121	0.545	+/+	NA	NA	NA	NA	NA
	Coastal plain	-3	0.069	0.104	0.509	+/+	-42	0.099	0.182	0.589	+/-

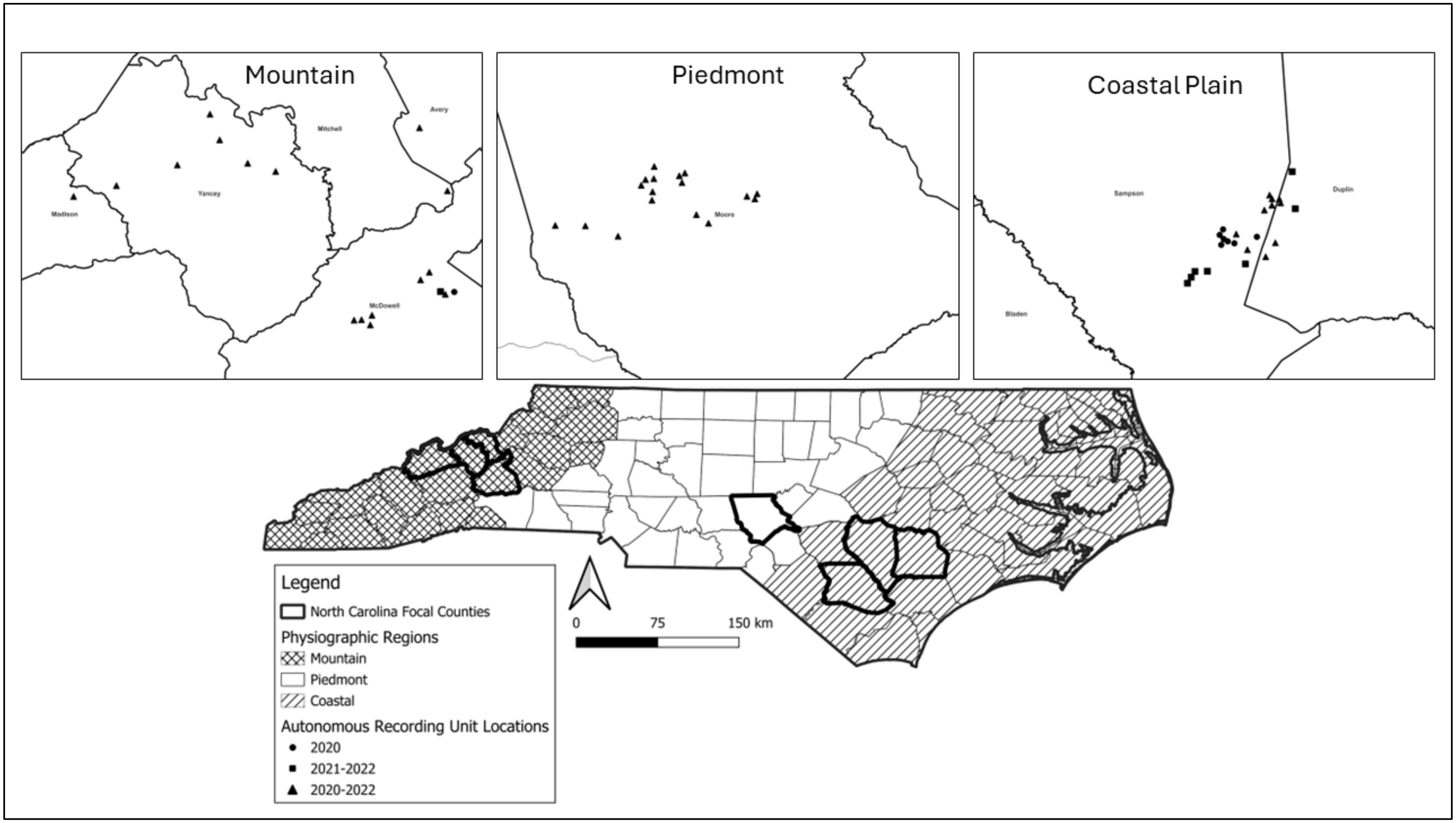


Figure 3.1. Locations of 51 autonomous recording units deployed across the 3 physiographic regions of North Carolina, United States, 2020–2022.

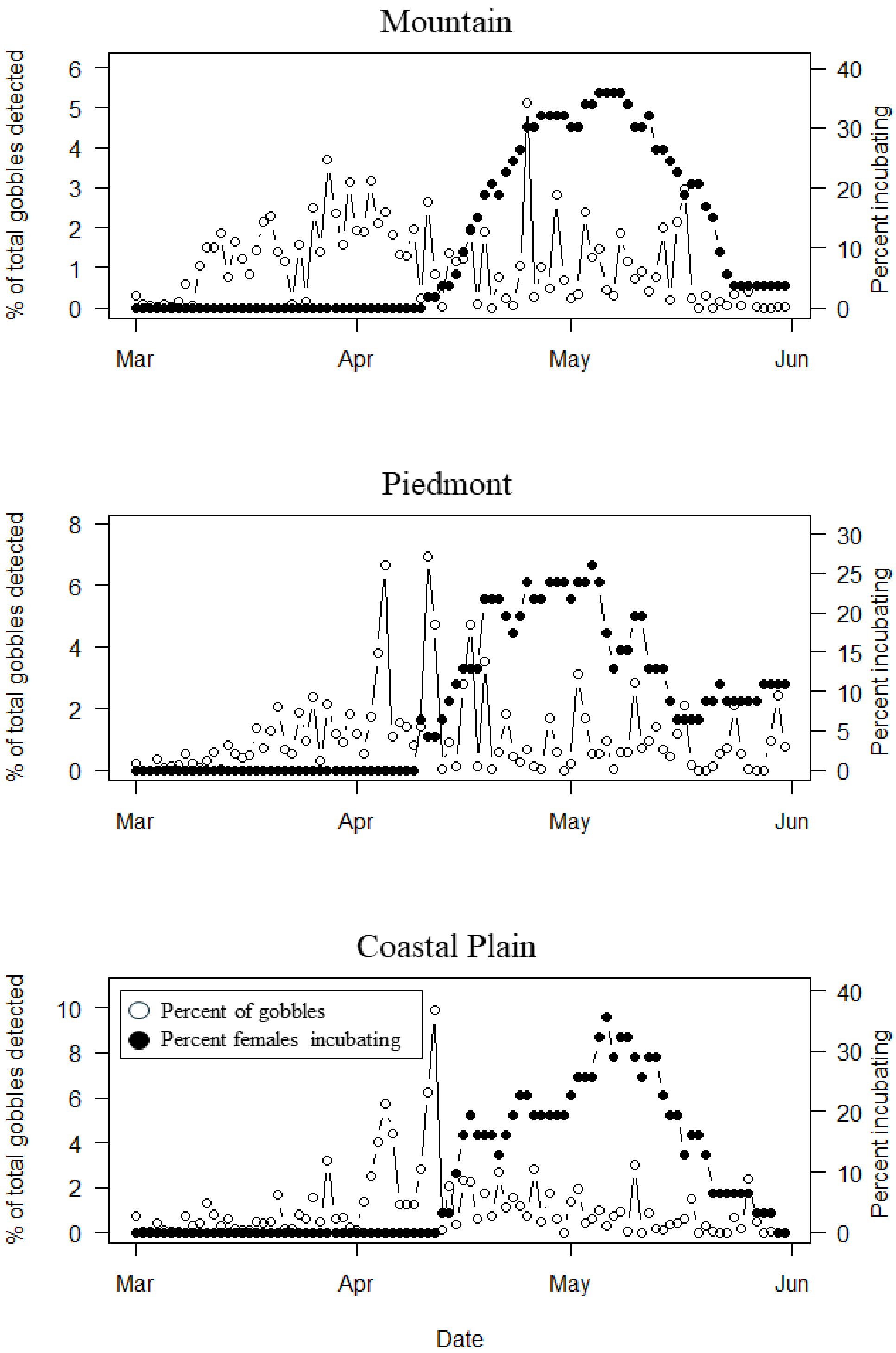


Figure 3.2. Daily numbers of gobbles recorded relative to percent of all monitored (Global Positioning System (GPS)-marked) female eastern wild turkeys incubating in the Mountain, Piedmont, and Coastal plain physiographic regions of North Carolina, USA, during 2020.

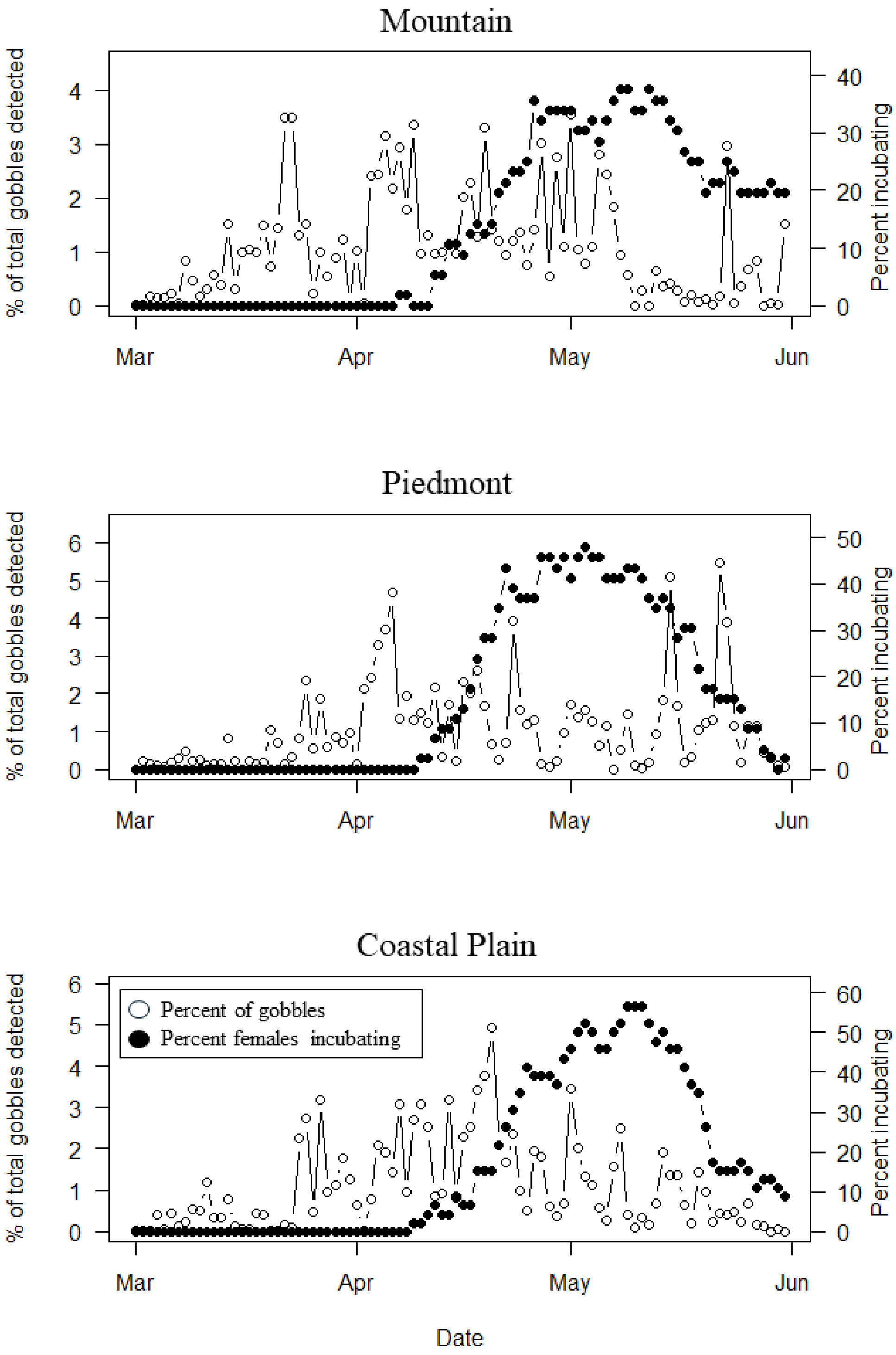


Figure 3.3. Daily numbers of gobbles recorded relative to percent of all monitored (Global Positioning System (GPS)-marked) female eastern wild turkeys incubating in the Mountain, Piedmont, and Coastal plain physiographic regions of North Carolina, USA, during 2021.

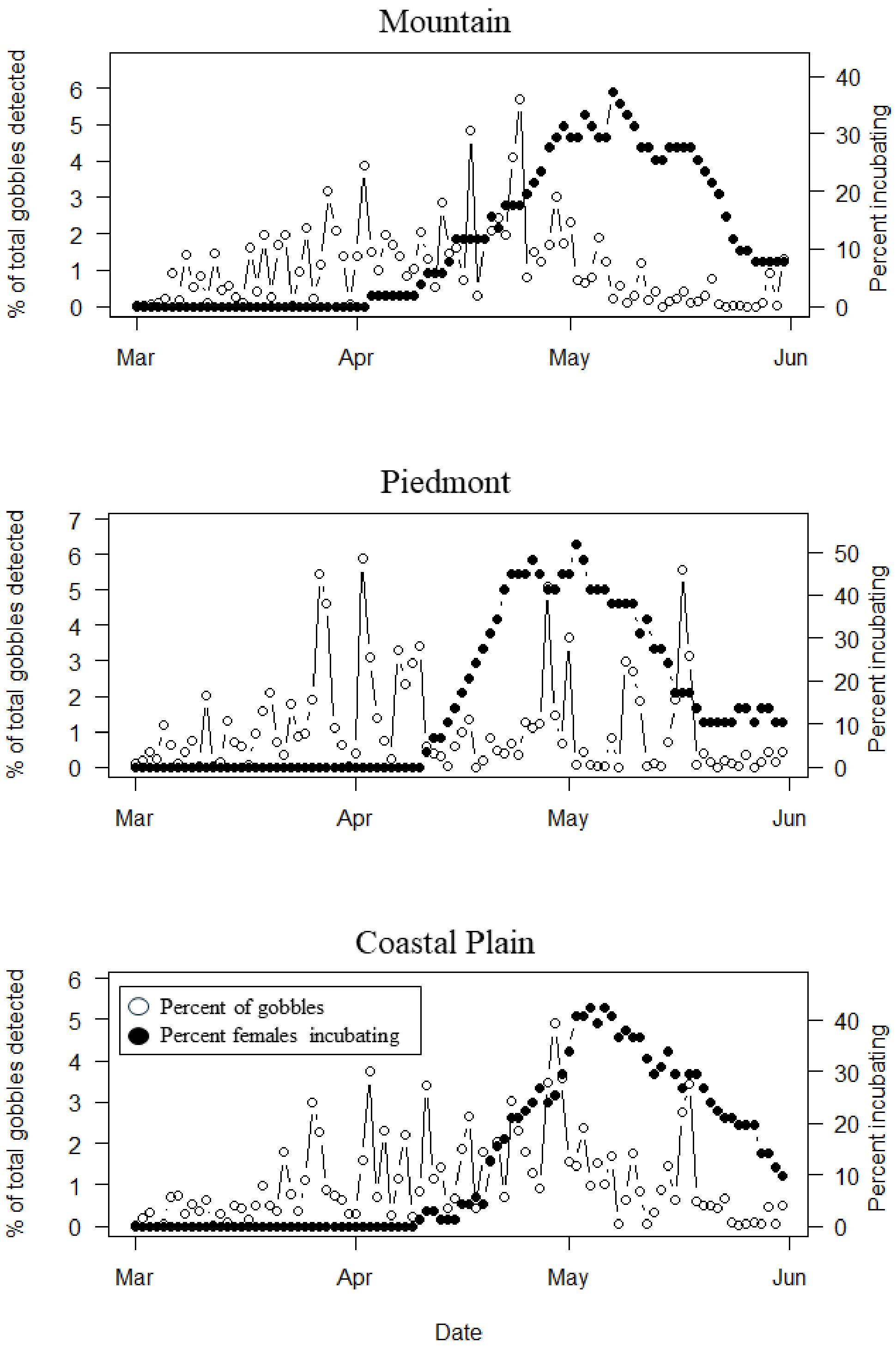
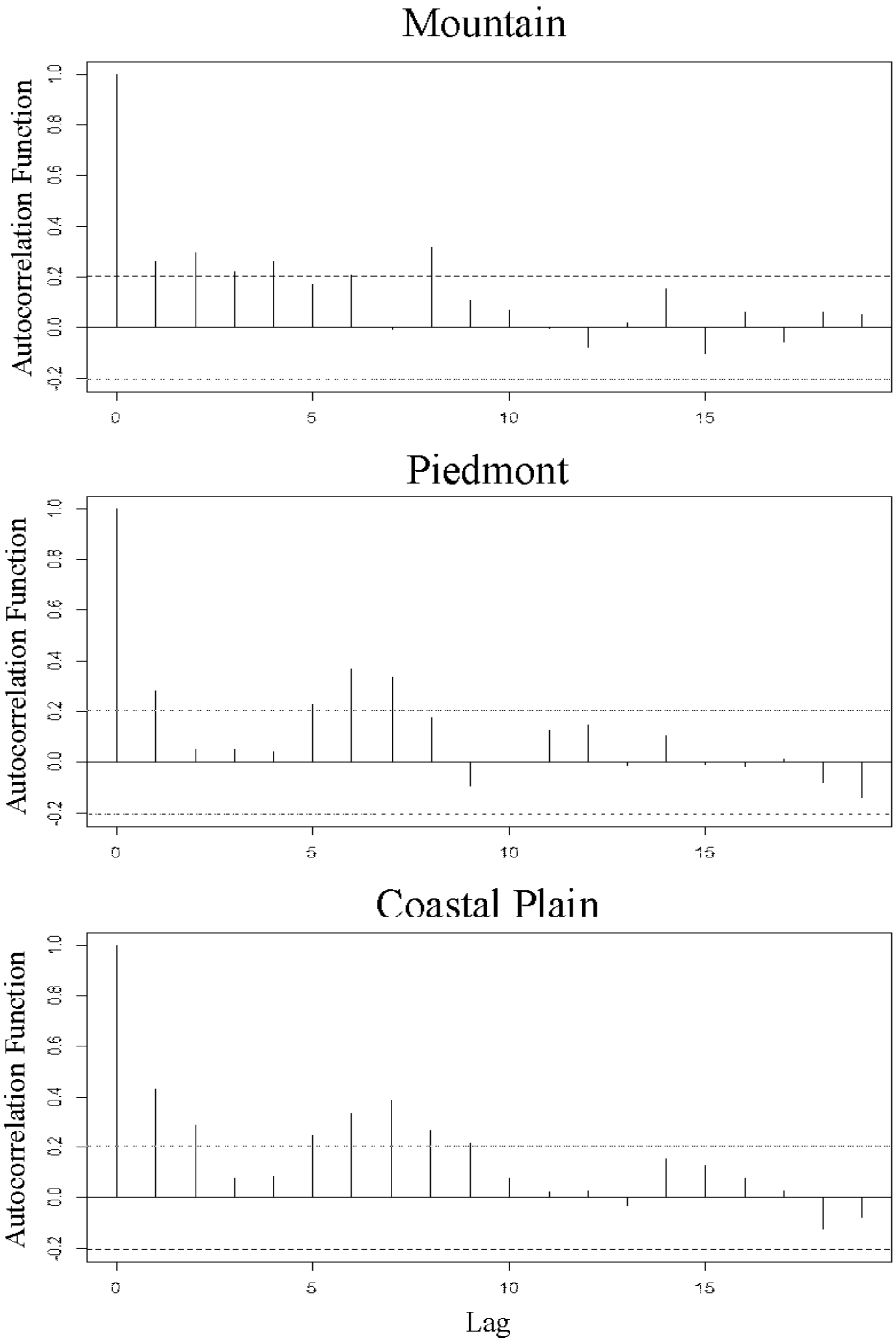


Figure 3.4. Daily numbers of gobbles recorded relative to percent of all monitored (Global Positioning System (GPS)-marked) female eastern wild turkeys incubating in the Mountain, Piedmont, and Coastal plain physiographic regions of North Carolina, USA, during 2022.


Mountain

Piedmont

Coastal Plain

Figure 3.5. Autocorrelation plot for daily time series of daily gobbling activity showing weak correlation (significance noted by dashed lines) between gobbling activity for one day relative to subsequent days by male eastern wild turkeys in the Mountain, Piedmont, and Coastal plain physiographic regions of North Carolina, USA, during 2020.

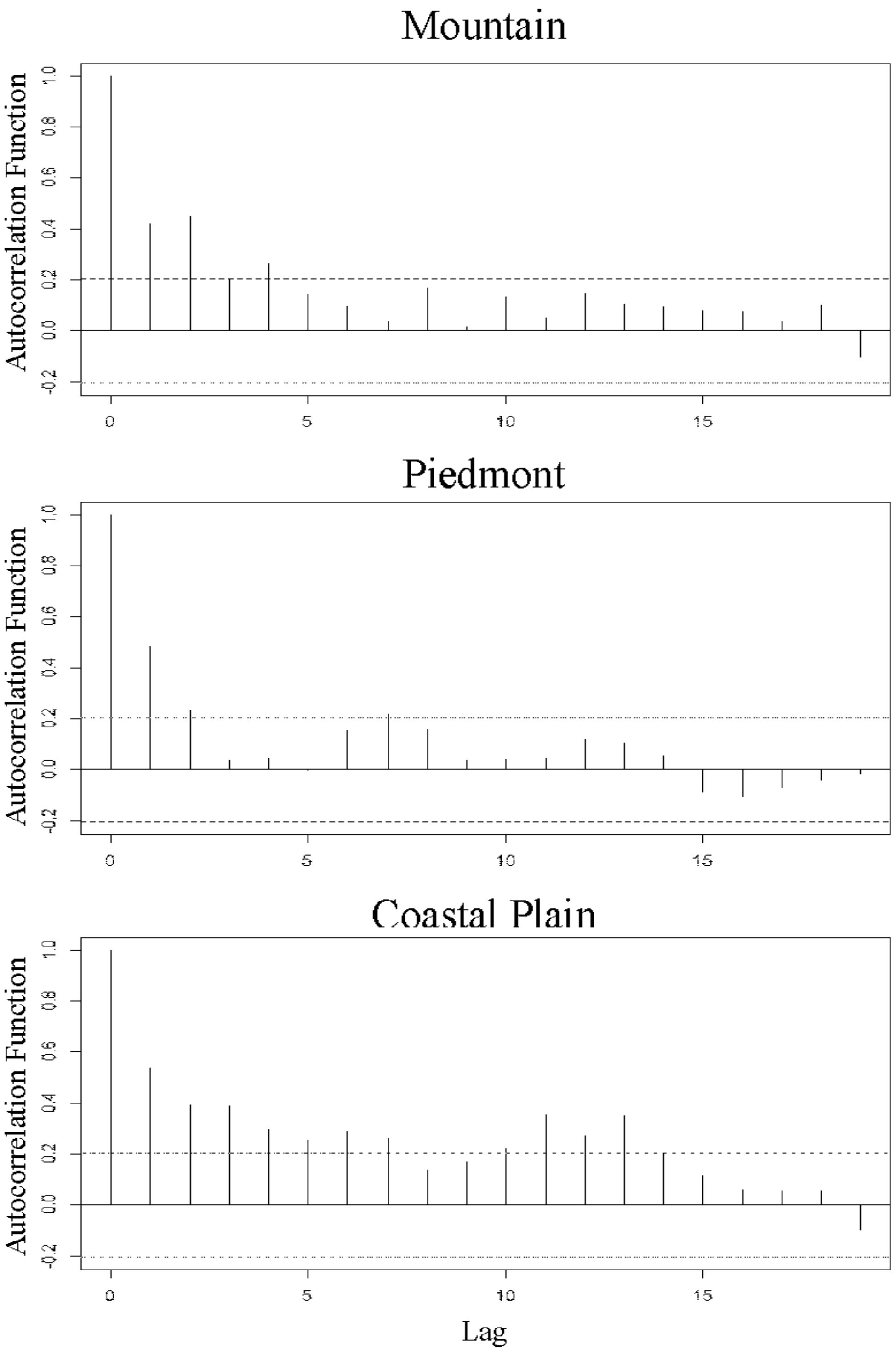


Figure 3.6. Autocorrelation plot for daily time series of daily gobbling activity showing weak correlation (significance noted by dashed lines) between gobbling activity for one day relative to subsequent days by male eastern wild turkeys in the Mountain, Piedmont, and Coastal plain physiographic regions of North Carolina, USA, during 2021.

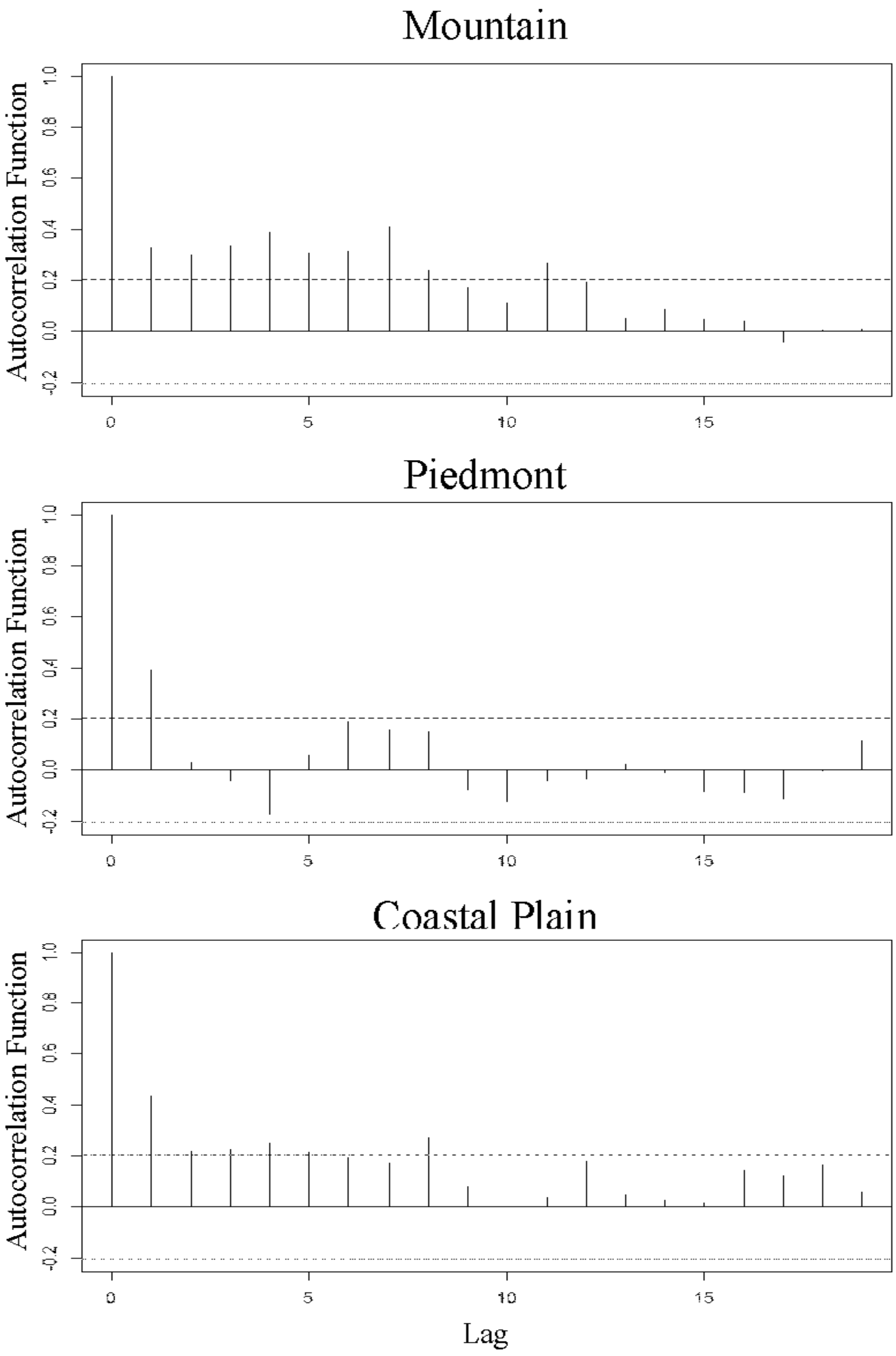
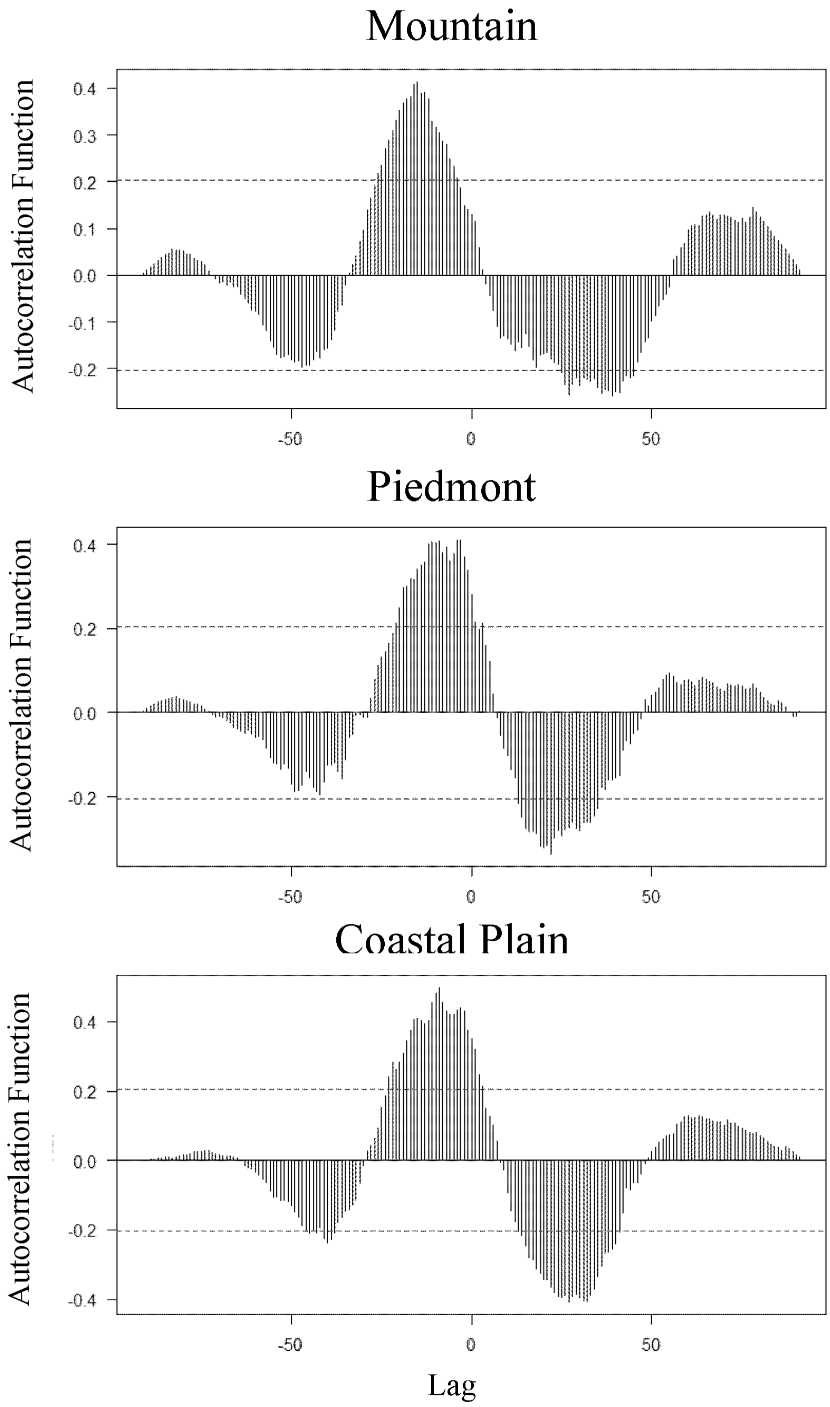


Figure 3.7. Autocorrelation plot for daily time series of daily gobbling activity showing weak correlation (significance noted by dashed lines) between gobbling activity for one day relative to subsequent days by male eastern wild turkeys in the Mountain, Piedmont, and Coastal plain physiographic regions of North Carolina, USA, during 2022.


Mountain

Piedmont

Coastal Plain

Figure 3.8. Autocorrelation plot depicting average correlation between time series of daily gobbling activity and nest initiation as a function of time lags between them by eastern wild turkeys in the Mountain, Piedmont, and Coastal plain physiographic regions of North Carolina, USA, during 2020. We noted 4 distinct lags (noted by dashed lines) in gobbling activity prior to nest initiation in 2020.

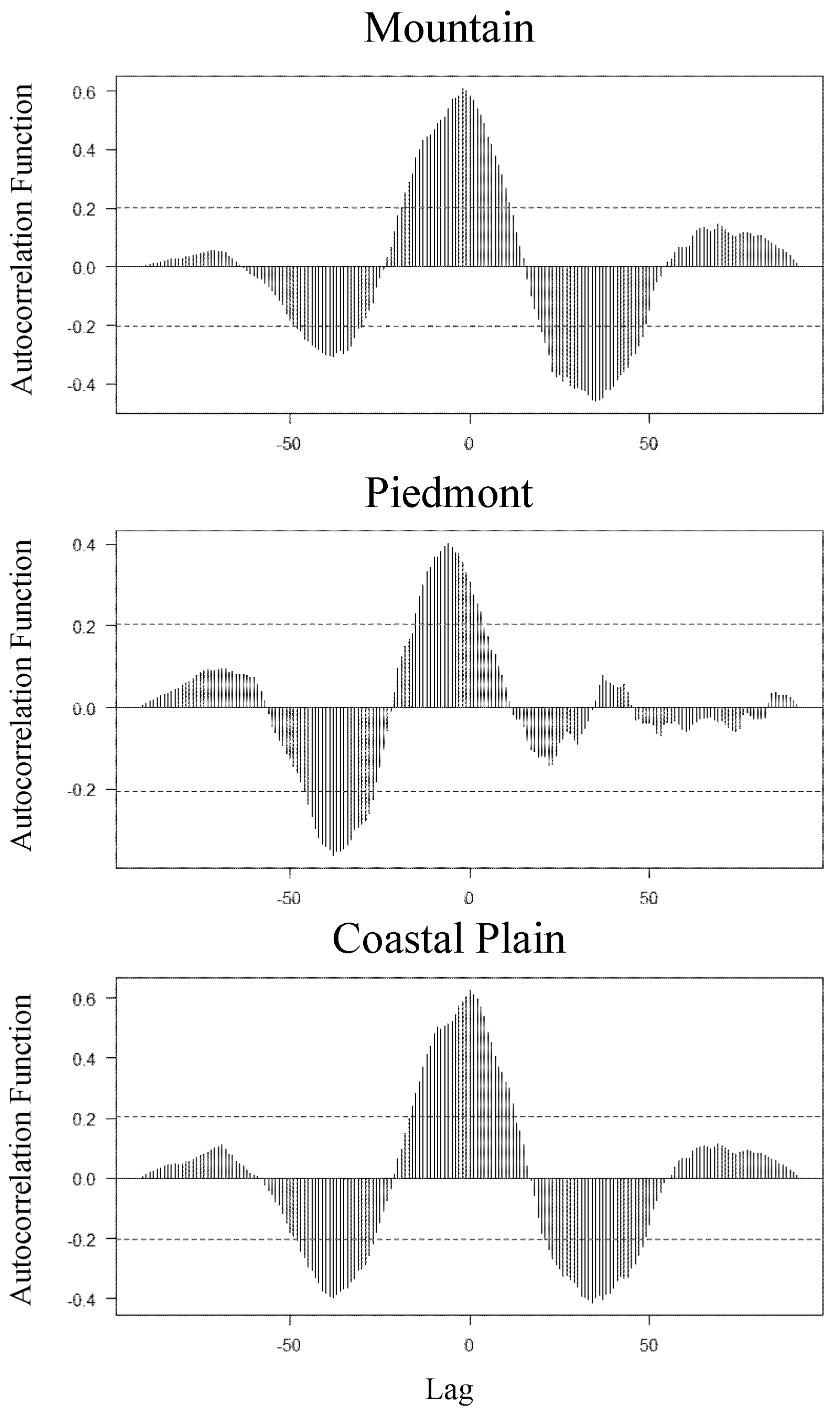


Figure 3.9. Autocorrelation plot depicting average correlation between time series of daily gobbling activity and nest initiation as a function of time lags between them by eastern wild turkeys in the Mountain, Piedmont, and Coastal plain physiographic regions of North Carolina, USA, during 2021. We noted 6 distinct lags (noted by dashed lines) in gobbling activity prior to nest initiation in 2021.

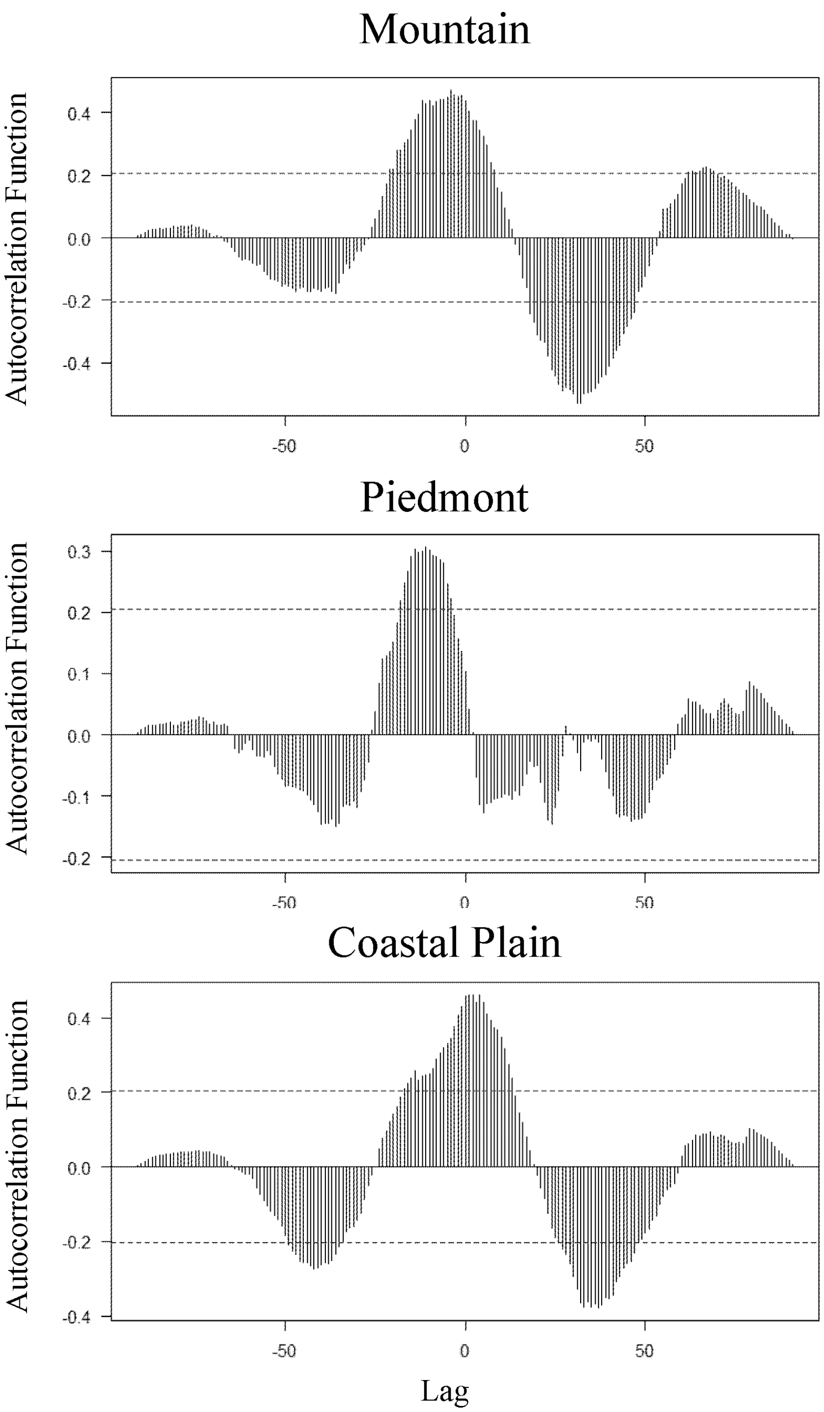


Figure 3.10. Autocorrelation plot depicting average correlation between time series of daily gobbling activity and nest initiation as a function of time lags between them by eastern wild turkeys in the Mountain, Piedmont, and Coastal plain physiographic regions of North Carolina, USA, during 2022. We noted 4 distinct lags (noted by dashed lines) in gobbling activity prior to nest initiation in 2022.

APPENDICES

Appendix A

Posterior Distributions of Survival Estimates by Year

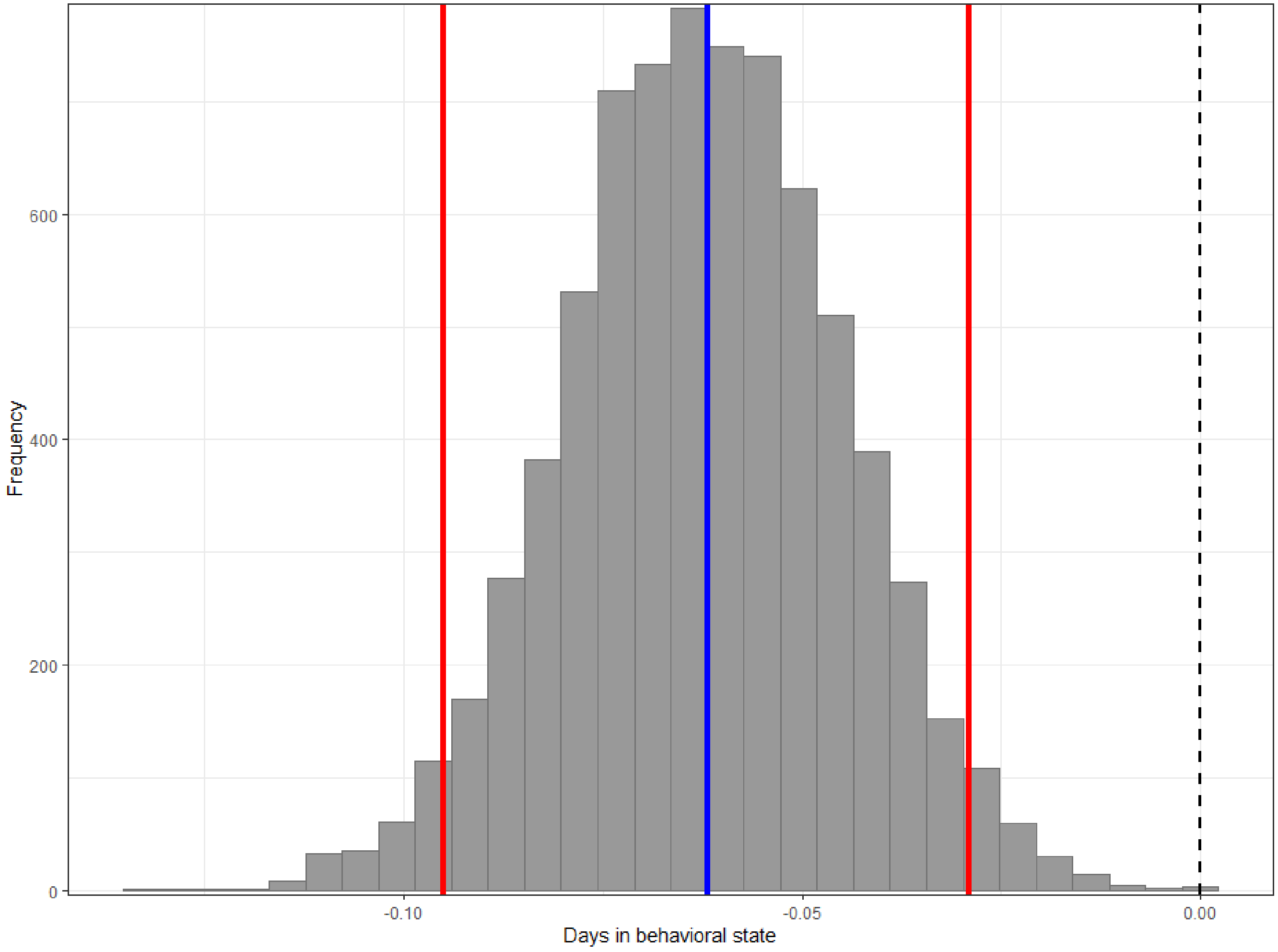


Figure A.1. Posterior distributions for covariates used to model daily survival for female wild turkeys (*Meleagris gallopavo*) during the pre-nesting state. Solid blue lines denote posterior means, red lines represent 95% credible intervals, and dashed black lines indicate 0.

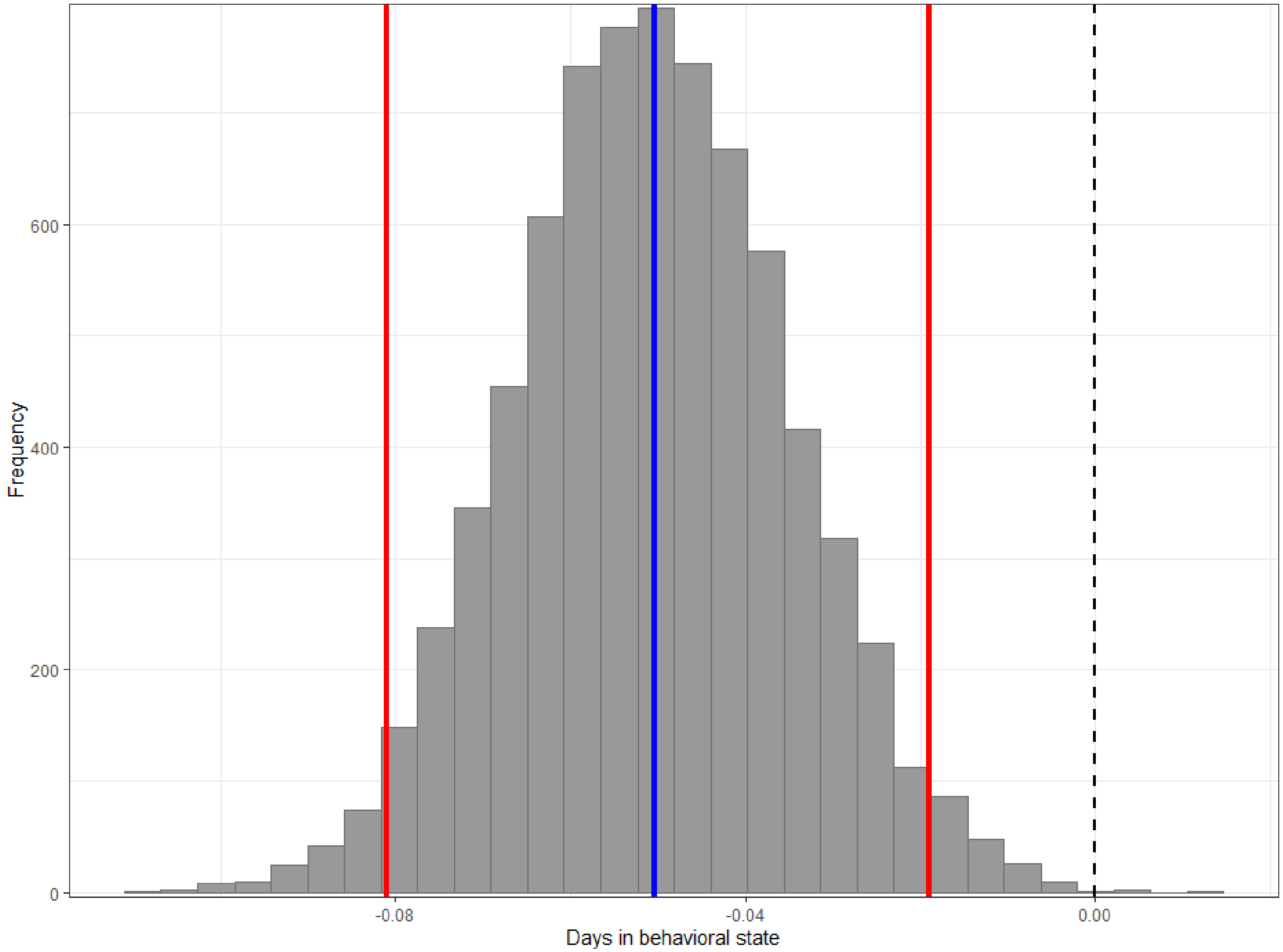


Figure A.2. Posterior distributions for covariates used to model daily survival for female wild turkeys (*Meleagris gallopavo*) during the incubation state. Solid blue lines denote posterior means, red lines represent 95% credible intervals, and dashed black lines indicate 0.

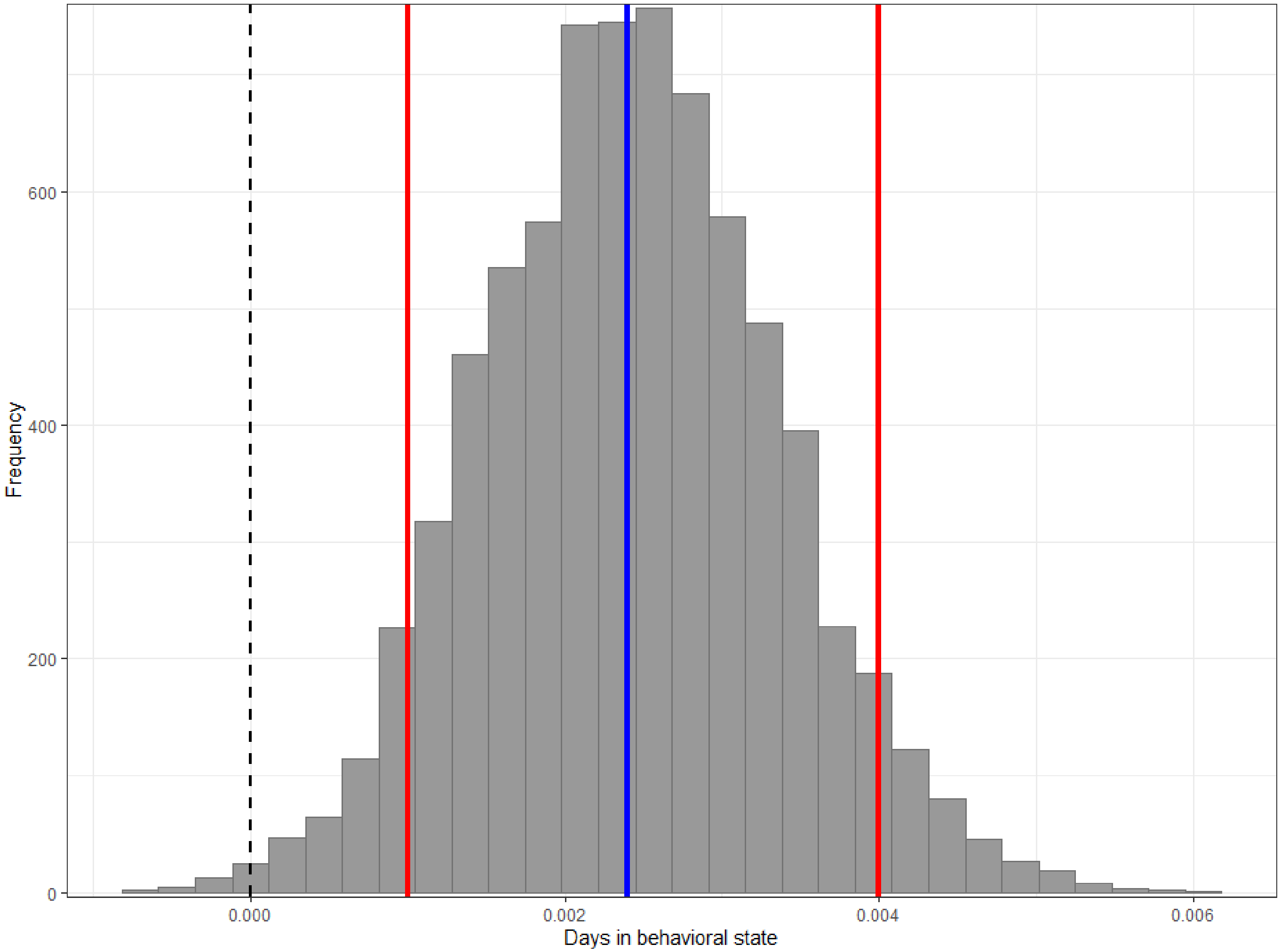


Figure A.3. Posterior distributions for covariates used to model daily survival for female wild turkeys (*Meleagris gallopavo*) during the non-breeding state. Solid blue lines denote posterior means, red lines represent 95% credible intervals, and dashed black lines indicate 0.

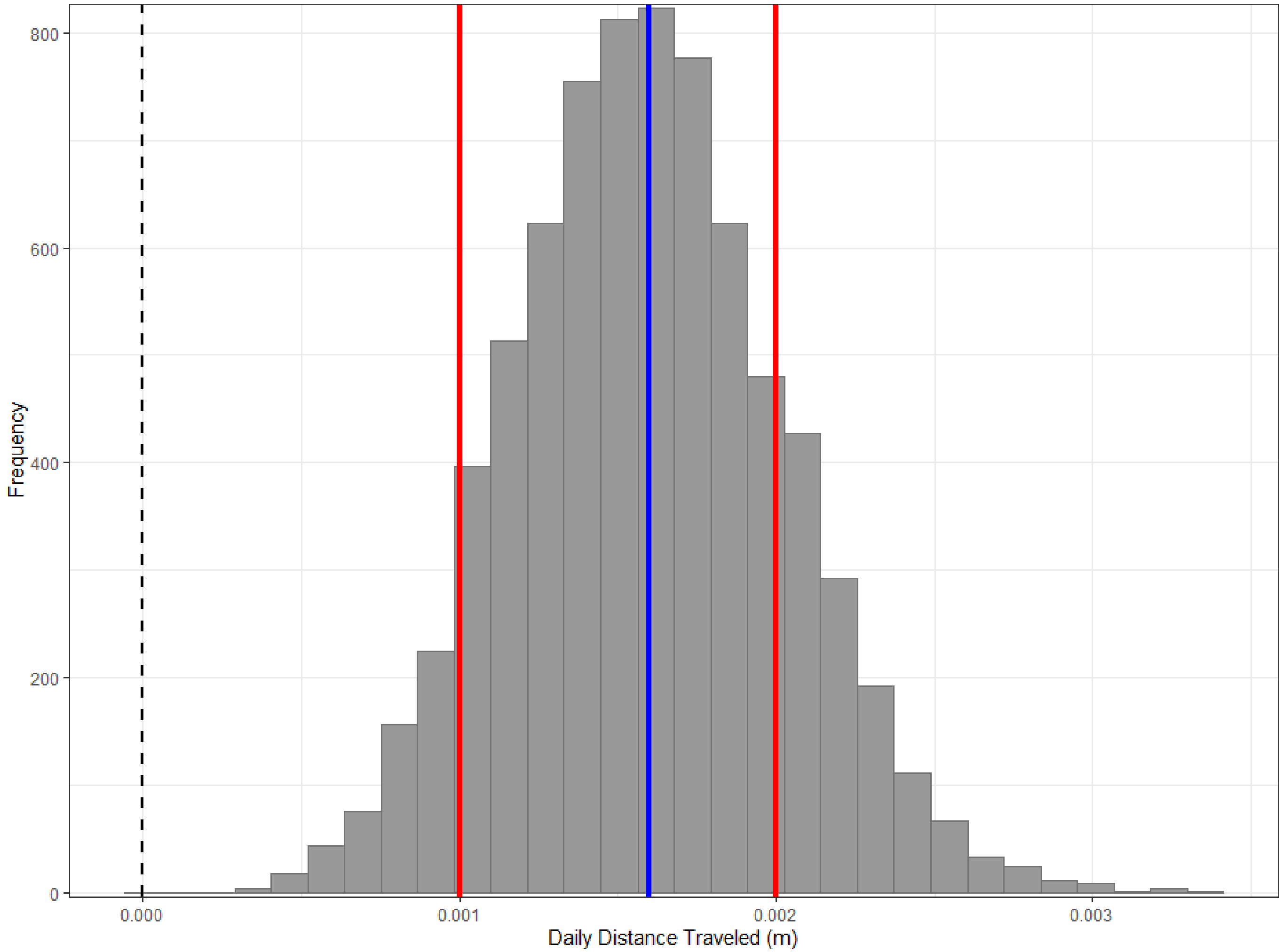


Figure A.4. Posterior distributions for covariates used to model daily survival for female wild turkeys (*Meleagris gallopavo*) during the pre-nesting state. Solid blue lines denote posterior means, red lines represent 95% credible intervals, and dashed black lines indicate 0.

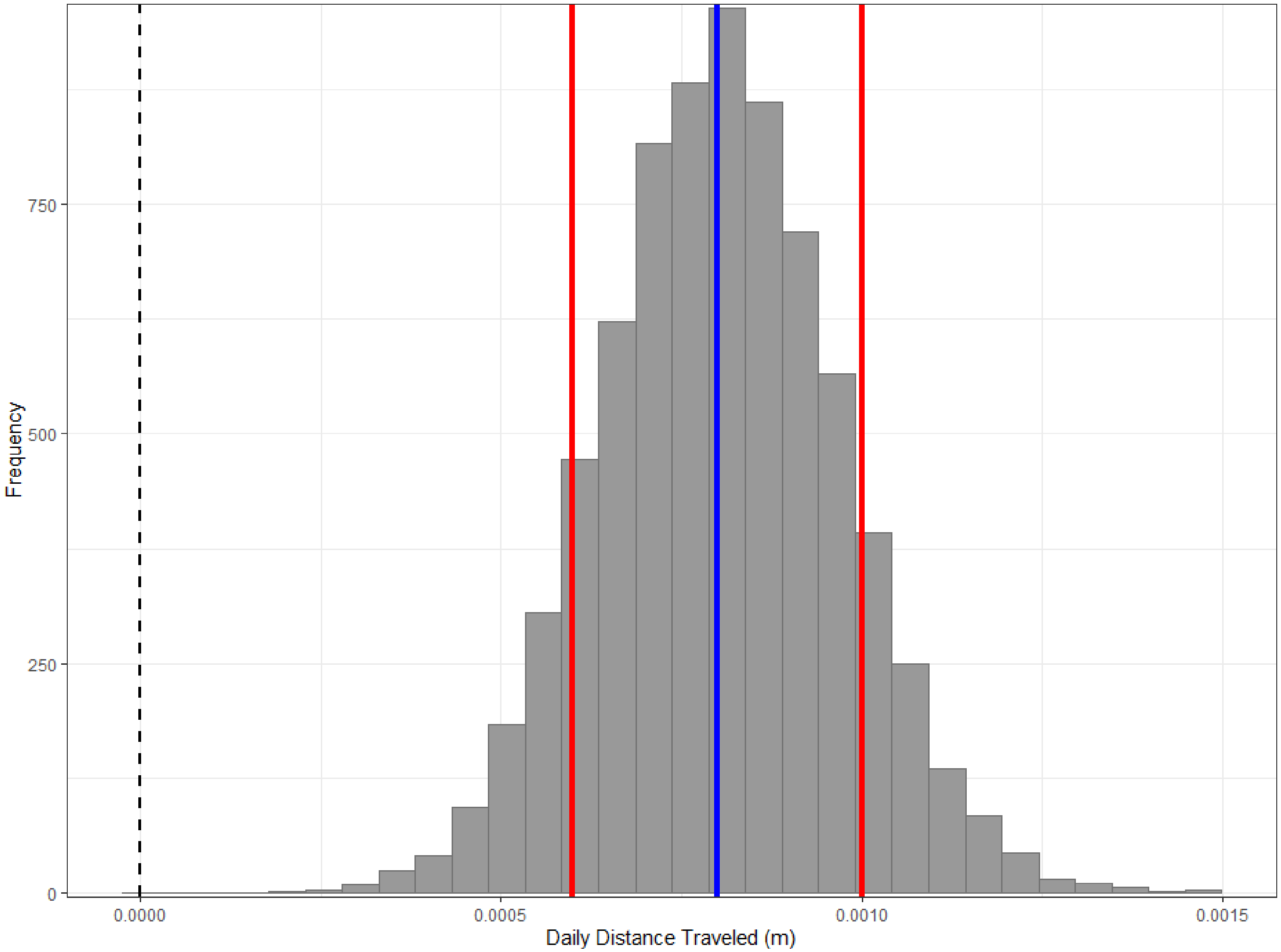


Figure A.5. Posterior distributions for covariates used to model daily survival for female wild turkeys (*Meleagris gallopavo*) during the non-breeding state. Solid blue lines denote posterior means, red lines represent 95% credible intervals, and dashed black lines indicate 0.

Appendix B

Survival Estimates by Ecoregion, Behavior State, and Year

Table B.1. Derived estimates of survival for each behavior state and region by year (North Carolina, 2020─2022).

		2020		2021		2022	
		Survival	SD	Survival	SD	Survival	SD
Age [a]	Cumulative	0.68	0.17	0.71	0.17	0.76	0.13
	Adult	0.66	0.17	0.70	0.17	0.74	0.14
	Juvenile	0.74	0.14	0.73	0.18	0.82	0.08
Ecoregion [a]	Mountain	0.70	0.17	0.70	0.18	0.73	0.14
	Piedmont	0.63	0.18	0.66	0.17	0.68	0.14
	Coastal plain	0.73	0.13	0.76	0.15	0.81	0.10
Behavior State [b]	PNS	0.98	0.03	0.93	0.06	0.93	0.04
	INS	0.89	0.09	0.95	0.05	0.95	0.01
	BRS	0.98	0.01	0.97	0.02	0.96	NA
	NBS	0.72	0.16	0.79	0.14	0.82	0.08
Mountain [c]	PNS	0.98	0.04	0.92	0.04	0.93	0.04
	INS	0.87	0.10	0.95	0.04	0.95	0.01
	BRS	0.99	0.01	0.97	0.02	0.96	NA
	NBS	0.75	0.15	0.77	0.16	0.78	0.07
Piedmont [c]	PNS	0.99	0.02	0.95	0.04	NA	NA
	INS	0.88	0.09	0.93	0.07	NA	NA
	BRS	0.99	NA	0.96	0.01	NA	NA
	NBS	0.66	0.17	0.78	0.14	0.89	0.06
Coastal Plain [c]	PNS	0.98	0.04	0.93	0.11	NA	NA
	INS	0.92	0.07	0.97	0.05	NA	NA
	BRS	0.97	0.01	0.99	NA	NA	NA
	NBS	0.78	0.11	0.85	0.08	NA	NA

[a] Estimated annual survival.
[b] Estimated survival statewide.
[c] Estimated period survival.

Appendix C

Effect Plots for Daily Hazard of Nest Failure

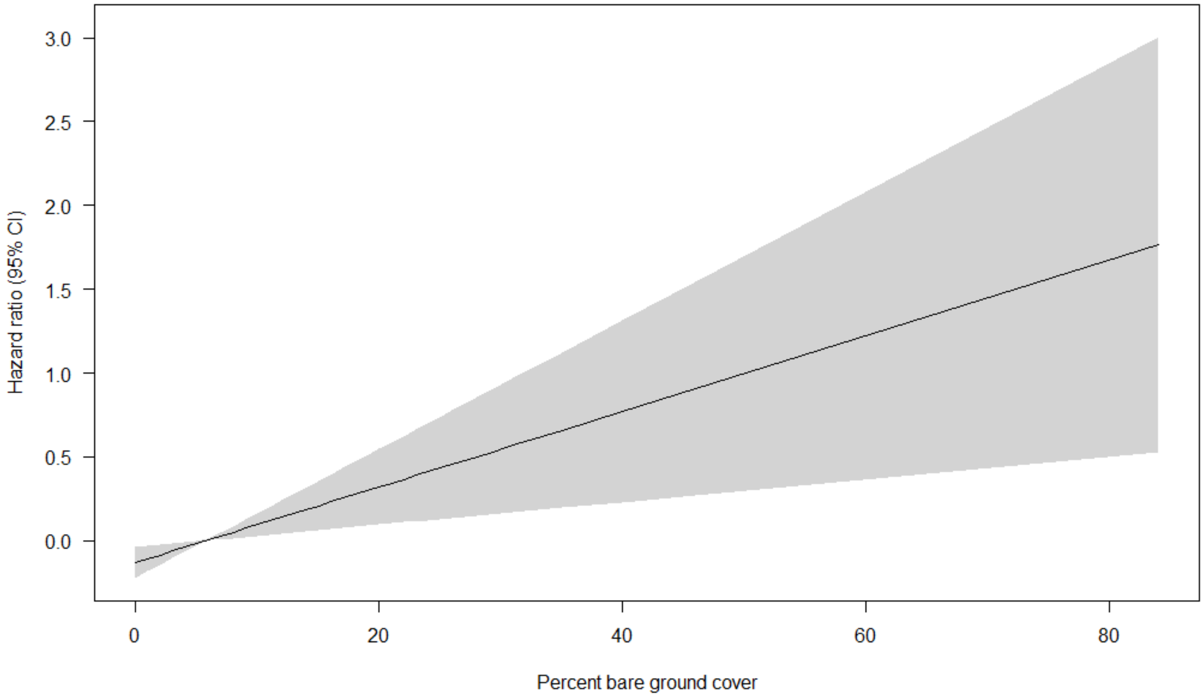


Figure C.1. Effects plot of the influence of bare ground cover (%) on daily hazard of nest failure for 407 nests monitored across 3 ecoregions of North Carolina, United States, 2020─2022. Hazard ratios <1 indicate decreased hazard relative to the reference value. The reference value (mean value) used to estimate hazard ratios for each covariate is indicated by the waist in each graph where y=0. Light gray shading around the line of predicted values represents the 95% confidence interval.

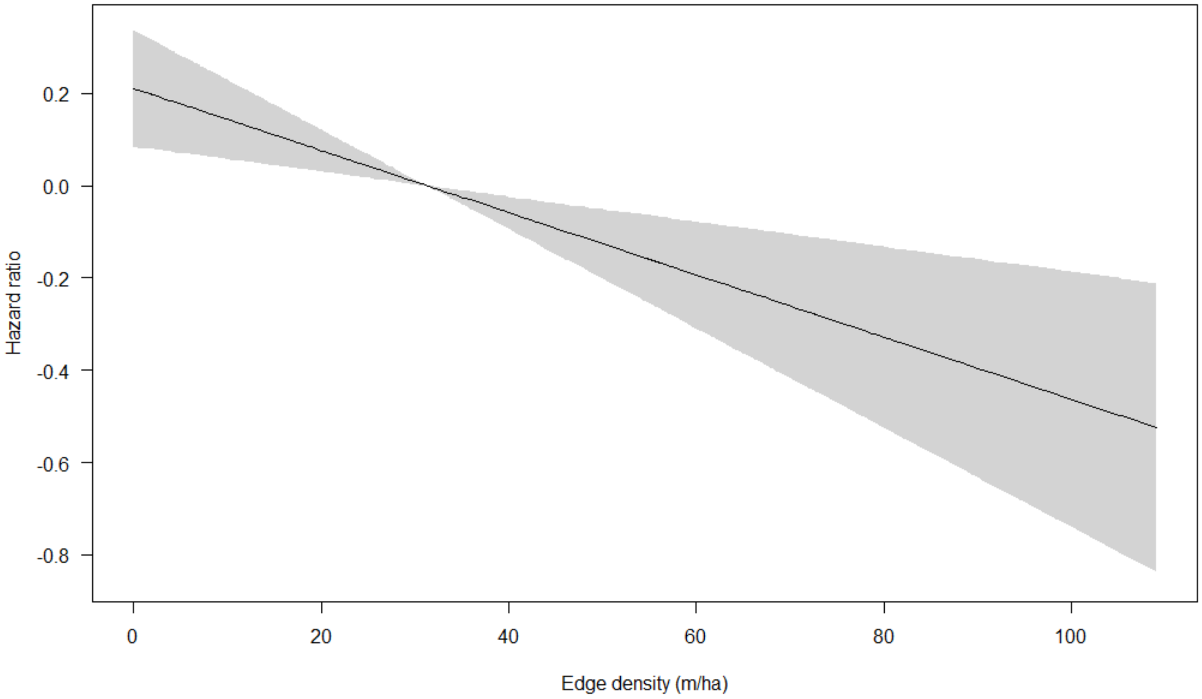


Figure C.2. Effects plot of the influence of edge density (m/ha) on daily hazard of nest failure for 407 nests monitored across 3 ecoregions of North Carolina, United States, 2020–2022. Hazard ratios <1 indicate decreased hazard relative to the reference value. The reference value (mean value) used to estimate hazard ratios for each covariate is indicated by the waist in each graph where y=0. Light gray shading around the line of predicted values represents the 95% confidence interval.

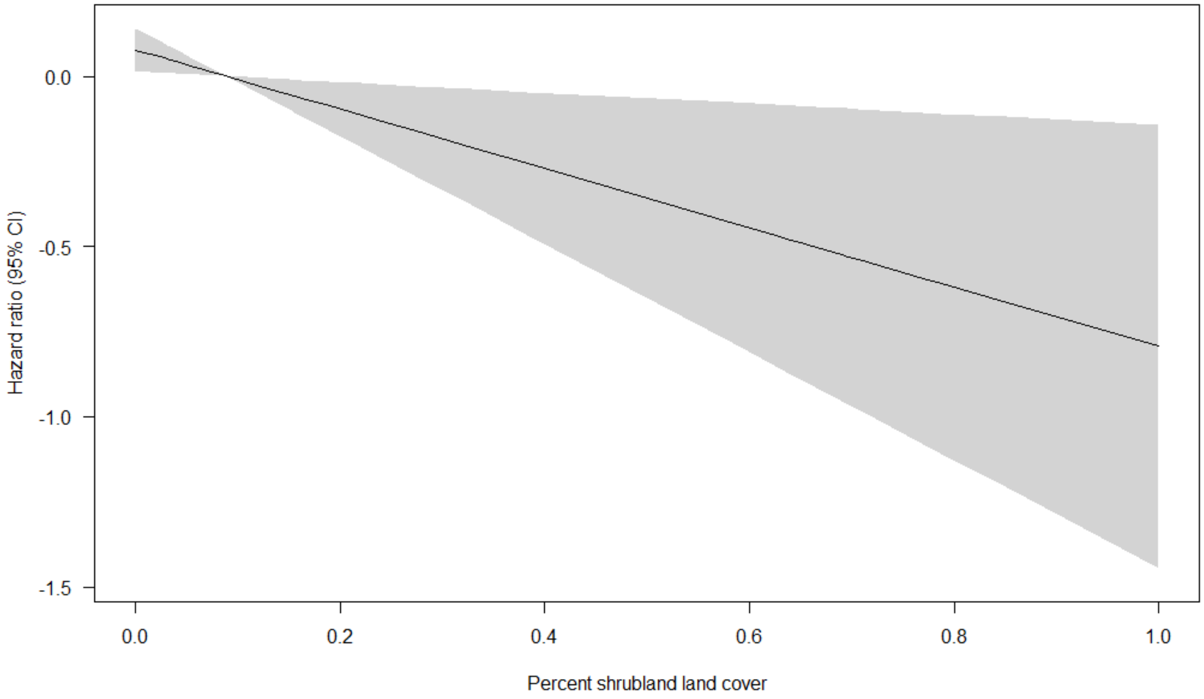


Figure C.3. Effects plot of the influence of shrubland cover (%) on daily hazard of nest failure for 407 nests monitored across 3 ecoregions of North Carolina, United States, 2020─2022. Hazard ratios <1 indicate decreased hazard relative to the reference value. The reference value (mean value) used to estimate hazard ratios for each covariate is indicated by the waist in each graph where y=0. Light gray shading around the line of predicted values represents the 95% confidence interval.

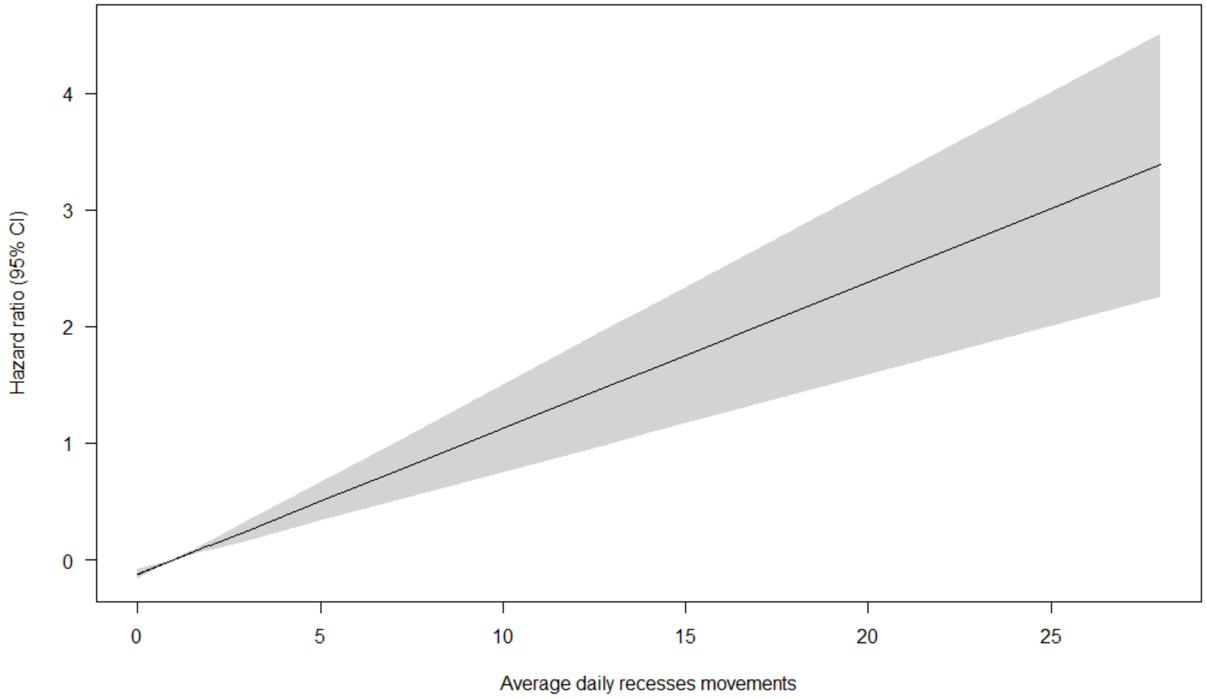


Figure C.4. Effects plot of the influence of average daily recess movements on daily hazard of nest failure for 407 nests monitored across 3 ecoregions of North Carolina, United States, 2020─2022. Hazard ratios <1 indicate decreased hazard relative to the reference value. The reference value (mean value) used to estimate hazard ratios for each covariate is indicated by the waist in each graph where y=0. Light gray shading around the line of predicted values represents the 95% confidence interval.

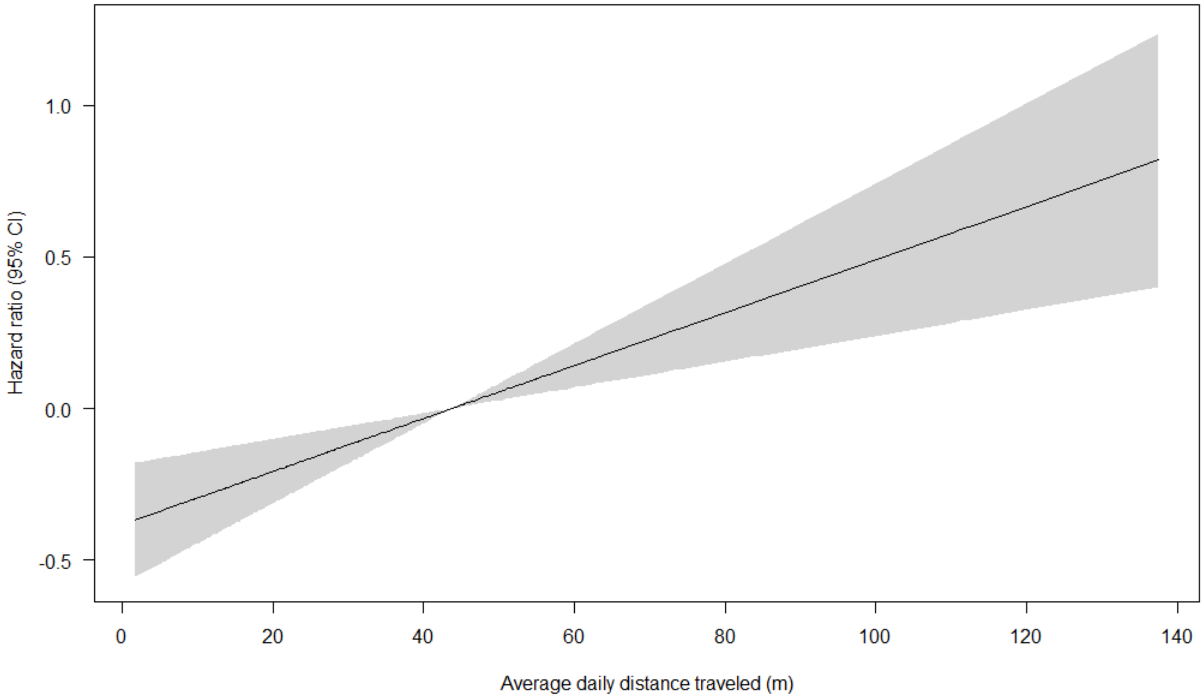


Figure C.5. Effects plots of the influence of average daily distance traveled (m) on daily hazard of nest failure for 407 nests monitored across 3 ecoregions of North Carolina, United States, 2020─2022. Hazard ratios <1 indicate decreased hazard relative to the reference value. The reference value (mean value) used to estimate hazard ratios for each covariate is indicated by the waist in each graph where y=0. Light gray shading around the line of predicted values represents the 95% confidence interval.

APPENDIX D.

Spring Green-up Dates

Table D.1. The day of year that the requirements for the first leaf Spring Index were met. Date of the beginning for green-up across the 3 ecoregions of North Carolina, United States, 2020─2022.

Year	Physiographic Region		
	Mountain (Burnsville, NC)	Piedmont (Eagle Springs, NC)	Coastal plain (Delway, NC)
2020	9-Mar	30-Jan	23-Jan
2021	11-Mar	28-Feb	13-Feb
2022	6-Mar	18-Feb	18-Feb

APPENDIX E

Gobbling Activity in Relation to Hunting Season

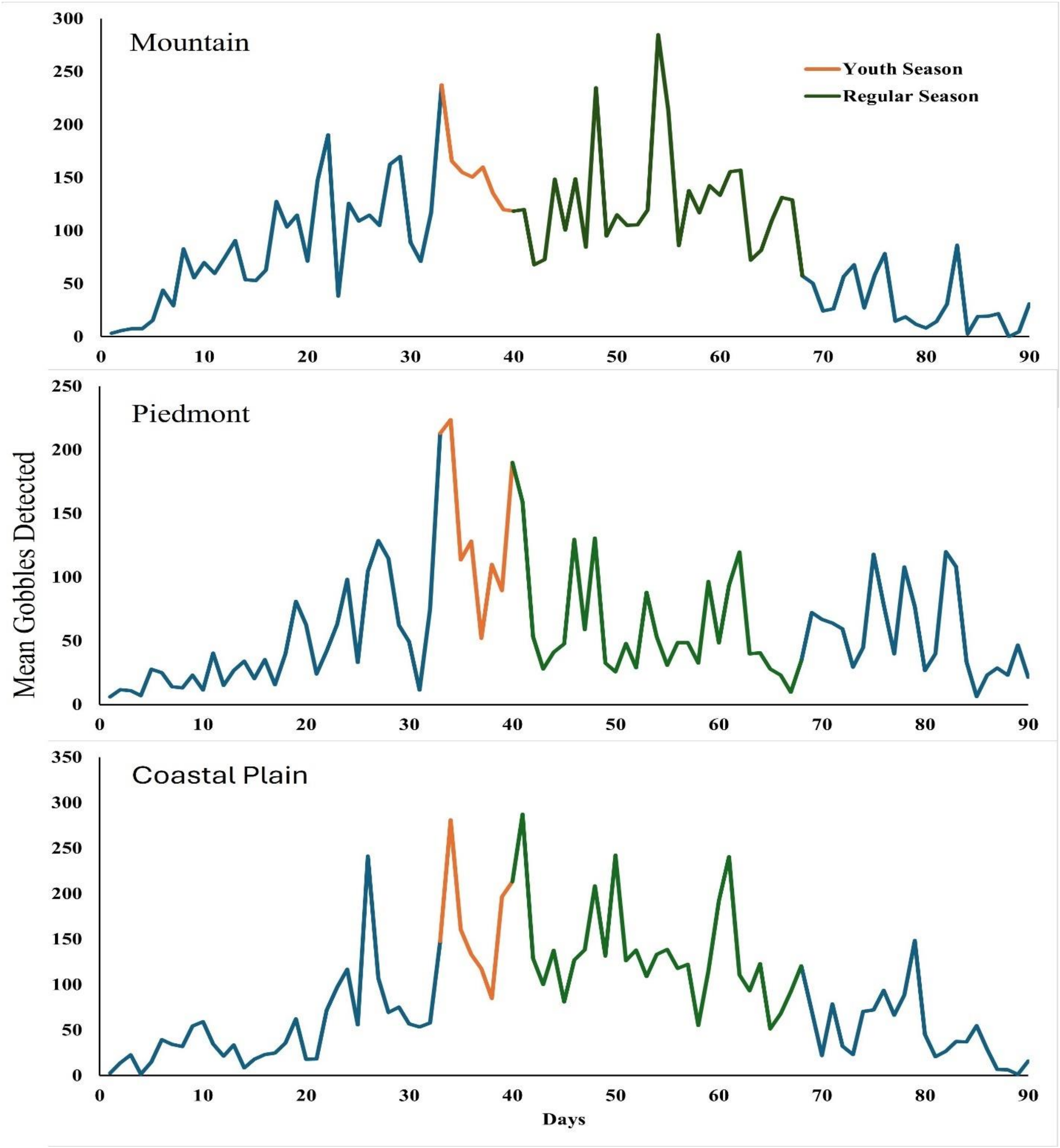


Figure E.1. The average gobbles detected 32 days before, during the 7-day youth season and 29-day of the regular season, and the 22 days after the North Carolinas regular hunting season in each of the 3 ecoregions of North Carolina, United States, 2020─2022. The youth season opened on the first Saturday in April and the regular season consistently opened on the second Saturday in April and closed on the fifth Saturday thereafter.

Table E.1. The percentage of total gobbling that occurred 32 days before, during the 7-day youth season and 29-day of the regular season, and the 22 days after the North Carolinas regular hunting season in each of the 3 ecoregions of North Carolina, United States, 2020─2022. The youth season opened on the first Saturday in April and the regular season consistently opened on the second Saturday in April and closed on the fifth Saturday thereafter.

Physiographic Region	Pre-hunting season (32 days)	Special youth season (7 days)	Regular hunting season (29 days)	Post-hunting season (22 days)
Mountain	32%	14%	45%	8%
Piedmont	25%	18%	34%	23%
Coastal plain	21%	15%	51%	14%
Statewide	26%	15%	45%	14%