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Northern Bobwhite (Colinus virginianus) resource selection and survival on Quail Focal Areas in Tennessee

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To the Graduate Council:

I am submitting herewith a thesis written by Elizabeth Faye Burken entitled "Northern Bobwhite (Colinus virginianus) resource selection and survival on Quail Focal Areas in Tennessee." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Wildlife and Fisheries Science.

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DEDICATION

I dedicate this thesis, first and foremost, to my fiancé, Ryan Hofer. He has been there for me throughout my graduate career, supporting me in all ways possible. Ryan helped me with fieldwork, data entry (lots of Excel tips and tricks), and generally kept me sane during the most stressful times. His unwavering support and love have been invaluable to me- I could not have completed my degree without him. I am beyond lucky to have him as my life partner, and I continuously thank God for placing him in my life. I love you so much and cannot wait to marry you this spring!

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PREFACE

We studied northern bobwhite resource selection and survival year-round from January 2021 to October 2023 on three quail focal areas located on wildlife management areas in Tennessee. Chapter 1 contains background material about northern bobwhite and Tennessee's historical conservation methods. Chapter 2 contains resource selection models across different scales of selection (macro and micro) for the breeding and non-breeding seasons. Chapter 3 contains survival models of the breeding and non-breeding seasons relating survival to habitat characteristics (macro and micro), management practices, and predator indices. Chapter 4 contains a combined synthesis of management recommendations from Chapter 2 and Chapter 3. Chapter 2 and Chapter 3 are formatted as stand-alone chapters prepared for publication in the Journal of Wildlife Management.

ABSTRACT

Northern bobwhite (*Colinus virginianus*) populations have experienced steep declines across the eastern United States, primarily because of habitat loss, fragmentation, and changing land use. In Tennessee, the Tennessee Wildlife Resources Agency implemented intensive habitat management on three Quail Focal Areas to investigate whether focused efforts could boost bobwhite populations. This study aimed to document resource selection and survival at the macro and micro scales during the breeding (Apr–Sep) and non-breeding (Oct–Mar) seasons, assess site-specific differences, evaluate the influence of management practices on resource selection and survival, and document meso-mammalian predator relationships with seasonal survival. From 2021 to 2023, 312 bobwhites were captured and radio-tagged with VHF transmitters. Individuals were monitored 3–5 times weekly, and habitat characteristics were measured through vegetation sampling and remote spatial metrics in ArcGIS Pro. General linear models and Program RMark were used to evaluate resource selection and survival. Bobwhite consistently selected early successional vegetation types and avoided closed-canopy forests. Management practices influenced resource selection. During the breeding season, spot-spraying and disking enhanced herbaceous cover and vegetation structure, whereas recent burns (<11 months) promoted food resources and reduced litter. Smaller management units (<5 ha) were favored during summer, likely because of increased proximity of food and cover resources. Non-breeding season selection emphasized areas with shrub cover, increased midstory stem density, and visual obstruction, which provided thermal and escape cover. Bobwhite avoided areas treated with spot-spray herbicide applications from the previous summer during the non-breeding season, likely because of reduced woody cover. Survival differed by season (37.0% breeding and 58.8% non-breeding seasons, respectively). Survival was negatively related to management unit size and increased midstory stem density during the breeding season whereas non-breeding season survival was positively related to increased ground cover and prescribed burns within the past year. Predation by meso-mammals is negatively related to survival. We recommend implementing small-scale disturbances (<6 ha) using frequent prescribed fire (1–2-year intervals) and disking to enhance nesting and brooding cover. Maintaining escape and thermal cover during non-breeding seasons may require less-frequent burns (3-year intervals). Continued focused habitat management is necessary for maintaining bobwhite populations on the focal areas.

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CHAPTER 1. INTRODUCTION

The northern bobwhite (*Colinus virginianus*; hereafter, bobwhite) is the most common native quail species in North America. Bobwhite was once the premier game bird in North America and quail hunting once provided a sizeable economic benefit to the state of Tennessee. Bobwhite also have aesthetic value and are treasured for their attractive appearance and characteristic call (Tennessee Wildlife Resources Agency 2021). Bobwhite population declines have occurred over the past 90 years, with declines in Tennessee being greater than the national average (Sauer et al. 2017, Tennessee Wildlife Resources Agency 2021). Declines have been attributed to land use change, habitat loss, and fragmentation (Brennan 1991, Guthery 1997, Brady et al. 1998, Veech 2006). The National Bobwhite and Grasslands Conservation Initiative, and its organization predecessors, have been focused on conservation of bobwhite populations since 2001 (National Bobwhite and Grasslands Conservation Initiative 2022). However, bobwhite populations have continued to decline across much of its range. The Tennessee Wildlife Resource Agency (TWRA) established the bobwhite as a species of conservation concern in 1987. Quail hunting once provided a sizable economic benefit to the state. In 1980, an estimated 80,000 quail hunters in Tennessee harvested >2 million birds. The number of quail hunters in Tennessee declined to <5,000 by 2020, with very few birds being harvested as a result (Burger et al. 1999, Tennessee Wildlife Resources Agency 2021). If the bobwhite is to continue to provide significant cultural, economic, and intrinsic value to Tennessee, more focus is needed to conserve the species for future generations.

From 1936 to 1957, bobwhite conservation in Tennessee largely focused on the release of pen-reared birds (Marcum 1975, Tennessee Wildlife Resources Agency 2021). These efforts were not successful because of the high mortality rates of pen-reared birds (Buechner 1950). Beginning in the 1950s, conservation efforts then shifted to the planting and establishing of plant species associated with bobwhite food and cover. Some of these species included non-native, invasive plants, such as bicolor (*Lespedeza bicolor*) and sericea lespedeza (*Lespedeza cuneata*; Davison 1945, Rosene 1956). Biologists soon realized bicolor could spread into unintended areas, and sericea seed was so hard that the birds could not digest them, with the plants outcompeting more desirable native species (Dimmick 1971, Eddy and Moore 1998, Brooke et al. 2015). Recent attempts at bobwhite conservation involve removing non-native species, restoring native plant communities (Estes 2016), and reintroducing disturbance regimes to the landscape (Harper et al. 2016, Carroll et al. 2017). In 2013, TWRA designated four wildlife management areas (WMAs), where remaining bobwhite populations existed, as "anchor reserves." Anchor reserves are areas where management efforts are focused on maximizing habitat quality and quantity for bobwhite and to serve as a source of bobwhite for a larger Quail Focal Area (QFA) that extends beyond the WMA (Tennessee Wildlife Resources Agency 2021). Each anchor area was selected by TWRA staff based on the perceived opportunity for populations to expand into surrounding public and private land. Wildlife management staff recorded spring male calling counts annually to record bobwhite population trends for each focal area.

The bobwhite has been extensively studied across its range, but much of that research has been focused on regions and habitat conditions not representative of Tennessee. Most bobwhite research has been performed in areas dominated by longleaf or loblolly pine woodlands and savannas in the upper and lower coastal plain, arid shrublands in Texas and Oklahoma, and agricultural landscapes along the coastal plain and in the Midwest. Several research projects have studied bobwhite in Tennessee, but few focused on bobwhite resource selection in early successional communities, and none focused on scale of resource selection (Dimmick 1971, Eubanks and Dimmick 1974, McRae and Dimmick 1982, Minser and Dimmick 1988, Seckinger et al. 2008). Additionally, no study has assessed the effectiveness of Tennessee's QFAs, which is essential for identifying limiting factors and shaping future management goals for bobwhite populations. This project aims to provide critical information on population size (**Figure A.1**), resource selection and survival on three QFAs to assist the TWRA in effectively managing bobwhite within these focal areas, ultimately contributing to the sustainability of this vital wildlife resource in the state.

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APPENDIX A

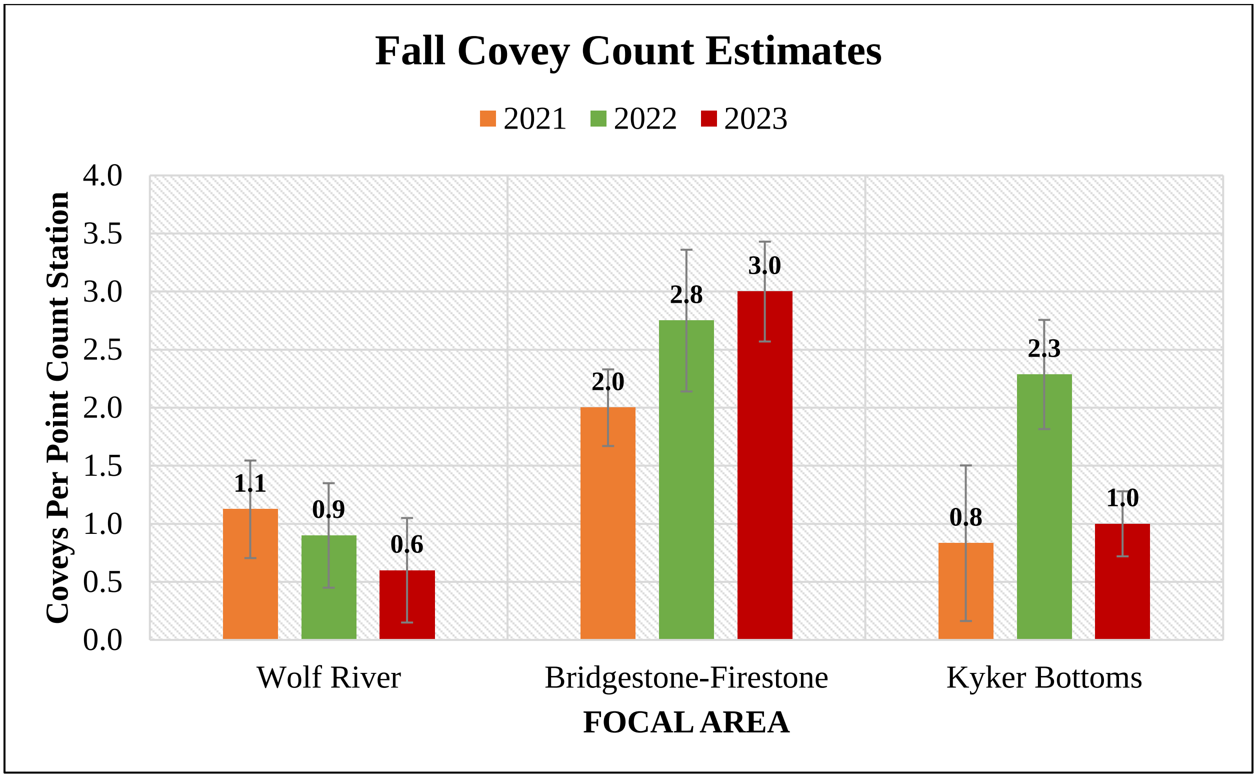

Figure A.1. Average number of birds heard per observer point during maximum fall covey count across Wolf River, Bridgestone-Firestone, and Kyker Bottoms focal areas, TN, 2021–2023.

CHAPTER 2. NORTHERN BOBWHITE RESOURCE SELECTION IN RESPONSE TO HABITAT MANAGEMENT ON QUAIL FOCAL AREAS IN TENNESSEE

ABSTRACT

Northern bobwhite (*Colinus virginianus*) populations have declined precipitously throughout most of the eastern US, largely because of changing land use, habitat loss, and habitat fragmentation. In response to this decline, the Tennessee Wildlife Resources Agency implemented intensive bobwhite habitat management on three wildlife management areas designated as Quail Focal Areas to determine if focused management could increase bobwhite populations on these areas. Our objectives were to 1) document resource selection at macro (across each focal area) and micro (within bobwhite home ranges) scales during the breeding and non-breeding seasons on each focal area, 2) assess differences in resource selection between focal areas, and 3) assess the influence of habitat management (burning, disking, herbicide use) on resource selection. We captured and radio-tagged 312 bobwhites with VHF transmitters, 2021–2023. We monitored tagged bobwhites 3–5 times weekly during breeding (Apr–Sep) and non-breeding (Oct–Mar) seasons and used general linear models to assess bobwhite resource selection for 136 individuals (breeding season) and 27 coveys (non-breeding season). We characterized habitat at the macro-scale by sampling landscape metrics on each QFA along with a 175-m buffer using ArcGIS Pro. We characterized habitat at the micro-scale by sampling vegetation at telemetry locations and comparing them with vegetation measured at random locations. Resource selection differed between Quail Focal Areas at the macro-scale, but not at the micro-scale. During the breeding season, at the macro-scale, early successional vegetation types were positively selected for whereas deciduous forests were selected against, suggesting that bobwhite avoided closed-canopy forests. Management unit size (ha) was negatively related to selection during the summer, as bobwhite selected smaller management units (<5 ha). Bobwhite selected areas that had been spot-sprayed (applied the same season) during summer as

herbaceous cover and vegetation structure increased at ground level. Similarly, bobwhite selected disked areas (disked the prior spring) as disking increased openness at ground level and likely improved foraging opportunities. Bobwhite also selected areas burned in the previous 0–11 months as these areas provided herbaceous cover and food resources and maintained sparse litter layers. During the non-breeding season, at the macro-scale, coveys selected for early successional vegetation types and woodlands, indicating bobwhite continued to select early seral stages. Coveys selected for increased distance from management unit edges (i.e., firebreaks or roads), indicating bobwhite were using the interiors of management units more than edges. Coveys selected areas with increased midstory stem density and increased visual obstruction 0.26–0.50 m above ground during the non-breeding season. Bobwhite selected against areas that had been spot-sprayed (applied the previous summer) during the non-breeding season apparently because of decreased escape and thermal cover through the elimination of woody cover. Bobwhite were located close to shrub cover (breeding = 20.9 m ± 1.50 SE; non-breeding = 15.5 m ± 1.48 SE) during both seasons. During the non-breeding seasons, areas burned in the previous year were positively related to use, suggesting bobwhite continued to select areas dominated by forbs and grasses after prescribed burning. We recommend managers implement regular disturbance such that 33–50% of the management area is disturbed annually, but management units should be relatively small (<6 ha) to avoid bobwhite displacement and ensure food and cover resources are in close proximity during all seasons of the year. We recommend frequent disturbance through prescribed burns every 1–2 years and annual disking as they increase herbaceous cover and promote an open structure at ground level that allows for poult mobility during the summer.

KEY WORDS *Colinus virginianus,* disturbance, early succession, habitat, northern bobwhite, quail, resource selection, scale of management

Northern bobwhite (*Colinus virginianus*; hereafter bobwhite) populations have declined precipitously throughout most of the eastern US, mainly because of disturbance suppression and land use changes (Brennan 1991, Guthery 1997, Brady et al. 1998, Veech 2006). In Tennessee, bobwhite habitat generally consists of early successional plant communities, including old-fields, oak/pine savannas, and open oak/pine woodlands (Burger 2001, Tennessee Wildlife Resources Agency 2021, Brennan et al. 2020). However, these vegetation communities have diminished over time, largely as a result of landscape change driven by agricultural expansion and urban development. Consequently, quail habitat in Tennessee has declined over time and the remaining bobwhite populations are scattered and isolated across the landscape (Brennan 1991, Guthery 1997, Noss et al. 1995, Noss 2013). In response to decreased and fragmented quail habitat and declining quail populations, the Tennessee Wildlife Resources Agency (TWRA) designated certain wildlife management areas (WMAs) across the state as Quail Focal Areas (QFAs). Management of these areas is focused on providing resources required by bobwhite to ultimately increase bobwhite populations on these and surrounding areas.

Resource selection by bobwhite occurs at multiple scales (Johnson 1980, Brennan et al. 2020). Evaluating and comparing resource selection across these scales can assist management by providing a comprehensive view of bobwhite resource selection across the landscape. Traditionally, resource selection was determined via on-the-ground observation, but increased availability of remote sensing data allows a landscape-level assessment of resource selection. Also, modeling resource selection at the management area level can help bobwhite managers understand how the surrounding landscape affects bobwhite selection. Understanding the surrounding landscape is especially important in regions such as Tennessee, where bobwhite populations are confined to isolated patches of habitat, surrounded in some cases by largely hostile land cover. Fragmented habitat leads to increased mortality and reduced immigration rates, emphasizing the need to account for landscape effects (Fies et al. 2002, Terhune et al. 2010). Wildlife managers can use this information to ensure the spatial configuration of vegetation types and early successional stages aligns with bobwhite requirements. Managers should first focus on a broader landscape context when considering bobwhite management, and then fine-tune vegetation structure and composition on a finer scale to enhance habitat quality. Evaluating bobwhite resource selection is important because limiting factors can be identified and management priorities redirected if necessary.

Many studies have documented the necessity for landscape-scale management for bobwhite and the importance of focusing efforts where bobwhite populations are intact and habitat improvement is possible (Roseberry and Sudkamp 1998, Williams et al. 2004, Veech 2006, Riddle et al. 2008, Miller et al. 2019). In our analysis, we defined macro-scale selection as resource selection at the home range scale within the context of the management area and surrounding area (Johnson 1980, Tanner et al. 2012, Brennan et al. 2020). A macro-scale analysis evaluates vegetation characteristics through remote sensing, and may include vegetation type composition, distance to features of interest across the landscape, the amount and characteristics of edge, and interspersion. Management prescriptions can alter the configuration of vegetation types, patch size, edge, and interspersion on the landscape and alter bobwhite habitat use at the macro scale.

Micro-scale selection refers to resource selection at the location of an individual bird and represents vegetation characteristics measured on the ground where an individual bird occurred

(Tanner et al. 2012, Brennan et al. 2020). Analyzing the response of bobwhite to specific habitat management practices can better inform managers how to best manage bobwhite habitat at the micro scale and positively influence resource selection. Bobwhite management of micro-scale characteristics involves developing and maintaining early successional vegetation communities (Rosene 1969, Wilson et al. 1995, Gruchy et al. 2014). Prescribed fire, disking, and herbicide applications are commonly used to maintain early seral stages in the eastern US where precipitation is adequate to promote vegetation communities dominated by woody species within a few years without disturbance. Moreover, the timing, frequency, and scale of disturbance may influence resource selection. At the micro scale, management can alter vegetation structure and composition, but bobwhite response may vary depending on the scale of selection (Harper 2007, Wellendorf and Palmer 2009, Martin 2010, Gruchy and Harper 2014, Kamp 2015).

The scale (size and shape) at which managed disturbance should occur across wildlife management areas to benefit bobwhite remains largely unexplored in studies of bobwhite resource selection. Wellendorf and Palmer (2009) reported bobwhite mortality increased, density decreased, and nesting success decreased on large-scale burn units (~8 ha) compared with small-scale (~2 ha) units. Additional research investigating the effects of different management practices and the most appropriate scale of management for bobwhite is crucial to develop optimal habitat management strategies, especially in highly fragmented areas. Increasing and enhancing bobwhite habitat on quail focal areas will presumably increase the sustainability of these important populations and demonstrate successful management strategies for public and private land managers.

We conducted a radio-telemetry study at three quail focal areas located across Tennessee from Jan 2021 to Oct 2023. Our objectives were to document bobwhite resource selection during the breeding and non-breeding seasons, compare resource selection at the macro and micro scales, and assess how management influenced resource selection. We hypothesized that resource availability would differ across the three focal areas because they differed in bird densities, and that the difference in resource availability would influence patterns of resource selection. We predicted that Bridgestone Firestone, our study site with the greatest bobwhite densities, would have the greatest quality habitat (and greatest overall relative probabilities of use). We hypothesized that bobwhite resource selection would differ between nonbreeding and breeding seasons. We predicted greater use of herbaceous cover during the breeding season related to nesting and brood-rearing cover requirements, and greater use of woody/shrub cover during the non-breeding season related to use of escape cover for survival. We hypothesized resource selection would be influenced by the management practices applied at each management area. We predicted greater use of areas burned or disked in the growing season following application because lower overall vegetation height and improved openness at ground level would facilitate movement and foraging. We also predicted greater use of small disturbance management unit sizes (e.g., 2 ha) over large disturbance management unit sizes (e.g., 8 ha) as large disturbances may alter too much of a bobwhite's core area, causing displacement into unfamiliar areas.

STUDY AREA

We conducted our study on three wildlife management areas owned and managed by the Tennessee Wildlife Resources Agency (**Figure B.1**). At each property, TWRA had designated a portion of the WMA as an "anchor reserve" where management efforts were focused on maximizing habitat quality and quantity for bobwhite and to serve as a source of bobwhite for a larger Quail Focal Area (QFA) that extended beyond the WMA (Tennessee Wildlife Resources

Agency 2021). Each anchor area was selected by TWRA staff based on the documented presence of bobwhite and the perceived opportunity for quail management and for populations to expand into surrounding public and private land.

Wolf River WMA, located in Fayette County, TN, USA, was 1,714 ha and consisted of bottomland hardwood forests and fields along the Wolf River. The Wolf River QFA (hereafter WR) consisted of 535 ha of interspersed fields and forested tracts. Prior to ownership by TWRA in1996, fields at WR were used for row cropping cotton (*Gossypium herbaceum*) and soybeans (*Glycine max*), and for pasture for cattle (B. Gilbert, TWRA, personal communication). Soils at WR consisted of various silt loams (i.e. Calloway silt loam) and sandy loams (Collins fine sandy loam; Soil Survey Staff Natural Resources Conservation Service 2024). Elevations vary from 113 m to 131 m. Lands surrounding WR consisted of bottomland hardwood forest, row crops, and human-developed land use and cover types.

Bridgestone-Firestone WMA, located in White County, TN, USA, consisted of 4,047 ha on the Cumberland Plateau, spanning the Caney Fork River. Most of the area consisted of hardwood forests, but the Bridgestone-Firestone QFA (hereafter BF) was a contiguous, 308-ha tract comprised of fields, scattered pine-hardwood woodlands, and hardwood forests. Throughout BF, soils consisted of Lonewood loam and Ramsey-Lily complex (Soil Survey Staff Natural Resources Conservation Service 2024). Elevations vary from 500 m to 536 m. Prior to TWRA ownership in 1998, land use at BF was pasture and hay production associated with a cattle operation (A. Deck, TWRA, personal communication). Lands surrounding BF consisted of hardwood forest and a mixture of pasture, woodlands, and human-developed land use and cover types.

Kyker Bottoms WMA, located in Blount County, TN, USA, was 262 ha, with 227 ha of that in the Kyker Bottoms QFA (hereafter KB), which included 144 ha of upland fields and woodlands managed for bobwhite. The remaining acreage consisted of hardwood forest and wetlands managed for waterfowl, which were available to bobwhite only during the breeding season when the waterfowl units were not flooded. Prior to TWRA purchase in 1997, the land was used for hay production and pasture (W. Smith, TWRA, personal communication). Soils at KB consisted of various silt loams (i.e. Dandridge silt loam), sandy loams (i.e. Holston fine sandy loam), and silty clay loams (i.e. Sequatchie silt loam; Soil Survey Staff Natural Resources Conservation Service 2024). Elevation varied from 259 m to 335 m. Land surrounding KB consisted of hardwood forest, pasture, hayfields, and human-developed land use and cover types.

Management to maintain early successional plant communities for bobwhite on all areas included prescribed fire, disking, and broadcast and spot-spray herbicide applications. Management units were delineated by wildlife management staff and were defined as contiguous areas in which consistent management practices occurred delineated by natural (e.g., forest edge, creek) or manmade features (e.g., field road, firebreaks). Management units that contained early successional vegetation types typically were between 8 and 24 ha. Management units could change seasonally depending on the management practices implemented.

METHODS

Bobwhite capture and monitoring

We trapped bobwhites during the non-breeding season (September–April) in standard funnel traps (Stoddard 1931) baited with scratch grains (cracked corn, milo, whole oats) or mixed songbird seed. Each trap was lined with hardware cloth, covered with burlap, and then covered with vegetation to minimize bird injury and stress and to lower visibility to predators. Typically, we checked traps once in the evening during ideal weather (0–23.9°C). We checked traps in the late afternoon when daily temperatures were <0°C and late morning and late afternoon when temperatures were >23.9°C. We did not deploy traps during extreme weather events (storms, extreme temperatures, etc.) to prevent bird injuries. We typically deployed 30 traps per night per focal area, centered around historical and current covey locations, with the intention to trap as many coveys as possible. Our target was to maintain a sample size of ≥30 radio-tagged birds each year on each focal area. We attached a very high frequency (VHF) necklace-style transmitter (5.0-6.5 g; model number AWE-QLL, 11-mo battery life, American Wildlife Enterprises, Monticello, FL, USA) to each individual bird weighing ≥130 g. We attached aluminum leg bands (number 7 butt end style, National Band and Tag Company, Newport, KY, USA) to individuals to ensure identification of the bird during recapture events, regardless of radio-tag life and retention. We determined sex by evaluating the color of the supercilium, cap, auricular, and throat (Petrides and Nestler 1943, Petrides and Nestler 1952). We determined age by the presence of buffy tips (juveniles) on the primary coverts, along with the muddy coloration of facial markings (Petrides and Nestler 1943, Petrides and Nestler 1952, Rosene 1969). We recorded mass with a Medio-Line spring scale (300-g; Pesola, Schindellegi, Switzerland), measuring to the nearest gram. Capture and handling protocols were approved by the Institutional Animal Care and Use Committee at the University of Tennessee-Knoxville (No. 0561-0720).

We tracked bobwhite movement and survival during the non-breeding (Oct. 1–Mar. 31) and breeding (Apr. 1–Sep. 30) seasons using a 3-element Yagi antenna and a receiver (receiver model R410, Advanced Telemetry Systems, Isanti, MN, USA). We used the homing method to approach individual birds within 30–50 m (White and Garrott 1990) without flushing them. We calculated bobwhite locations in Excel using the observer location (recorded by GPS), and the estimated azimuth and distance to the bird. We recorded the vegetation type (**Table B.A**) where the bird was located and varied locations by time of day and day of week to balance potential temporal bias. We monitored individual bobwhite ≥3 times per week during the non-breeding season and ≥5 times per week during the breeding season to better determine reproductive activity. Mortality signals occurred after a 12-hr period of inactivity, which we promptly investigated and recovered to note the fate of individual birds.

Home range analysis

We used home range analysis to determine the average home range to define the area of use of bobwhite during the breeding and non-breeding seasons. The breeding season home range was determined individually whereas the non-breeding season home range was determined on a covey basis, with ≥20 locations per individual or covey per season (DeVos and Mueller 1993, Taylor et al. 1999). We calculated the minimum convex polygon (MCP) of all locations using the adehabitat package in Program R (Calenge 2006). To ensure a robust sample size, we combined home range estimates across years by season. Home ranges were averaged across 2021, 2022, and 2023 breeding seasons and across 2020-2021, 2021-2022, and 2022–2023 non-breeding seasons, respectively.

Macro-scale characterization

We characterized a suite of macro-scale covariates to determine how resource selection was related to landscape structure and composition (**Table B.2**). For each bobwhite, we sampled five randomly selected points within the study sites and an adjacent buffer extending 175 m onto adjacent properties to represent what was available to the bird for each location. We selected 175 m for the buffer because that was an average estimate of daily movement of bobwhite over a 1-

year period (Brooke et al. 2015). During the breeding season, we only selected individuals that were not actively nesting or brooding-rearing because our objective was to assess resource selection during the breeding season that was not directly associated with nest sites or brood locations.

We characterized vegetation type based on delineation from satellite imagery with ground-truthing using ArcGIS Pro (ESRI 2023; **Table B.1**). We identified 12 vegetation types: deciduous forest, coniferous forest, young forest, woodland, savanna, early succession, early succession woody, open pine row, food plot, row crop, pasture/hayfield, and other (water and manmade structures). We defined forest as areas with >80% canopy cover (deciduous and coniferous). We defined areas dominated by regenerating trees <11.4 cm in diameter and <10 years old as young forest. Savannas and woodlands were areas with scattered trees and an understory dominated by herbaceous plants. Savannas had 10–30% tree canopy cover, whereas woodlands had 30–80% tree canopy cover. We defined open pine rows as conifers planted in 12-18 m-wide rows. We defined early succession as plant growth consisting of shade-intolerant forbs and grasses, with scattered shrubs and trees that did not comprise >50% of species composition. Early succession woody was defined as woody species comprising >50% but <80% of species composition. We defined food plots as areas planted for wildlife food, comprised of crops such as corn, sunflowers, sorghum, or millet. We defined pastures as areas either being grazed by livestock or being managed for hay production, and generally dominated by non-native grasses (*Festuca arundinacea*, *Paspalum dilatatum, Cynodon dactylon*). We defined row crop as areas comprised of planted crops such as (*Zea mays*) and soybeans (*Glycine max*) intended for agricultural production. We defined areas as ‘other’ if they were altered by manmade structures (e.g. firebreaks, roads, houses, lawns) or ponds or wetlands.

For each season (breeding and non-breeding) and year (2021, 2022, and 2023), we separately delineated vegetation types to account for temporal variation in vegetation on the landscape. We created vegetation type rasters with 10- x 10-m cell dimensions. We calculated the percentage of each vegetation type within a 100- x 100-m (1 ha) neighborhood around each pixel where locations and available points were located using the Focal Statistics tool in ArcGIS Pro. We chose the 100- x 100-m (1 ha) analysis neighborhood because we believed it was a biologically relevant scale for resource selection by bobwhite (Wiens 1989). Although we identified 12 vegetation types in the cover type classification, we used only 5 types that were either most influential to bobwhite use and/or prevalent across all focal areas (i.e., percent deciduous forest, percent early succession, percent early succession woody, percent young forest, and percent woodland; Roseberry and Sudkamp 1998).

We calculated an interspersion index for each cell using the Focal Statistics tool in ArcGIS Pro, which calculated the intermixing of units of vegetation types within a 100- x 100-m neighborhood around each cell. The index ranged from 1 to 8, with higher values indicating greater intermixing and lower values indicating less intermixing. The 10-m pixel for vegetation type mapping was consistent with telemetry location error based on homing to within 30–50 m of an individual or covey.

TWRA staff reported and mapped seasonal management practices at each focal area for each year. We measured the distance (m) to the edge of the management unit defined by roads, firebreaks, or other natural vegetation breaks using a laser rangefinder. We defined management unit size to be the area (ha) in which wildlife managers apply disturbance to clearly delineated portions of the study area (by natural or manmade breaks). We mapped management units with ArcGIS Pro and estimated the associated area (ha).

Micro-scale characterization

We documented vegetation at a random sample of bird locations and random points to characterize micro-scale vegetation during the breeding and non-breeding seasons. We selected random points based on a randomly selected distance (30–175 m) and azimuth from the bird location. We selected 175 m as the maximum distance because that was the average daily movement of bobwhite over a 1-year period (Brooke et al. 2015). Once we choose random points, we navigated to the location using a handheld GPS unit (Garmin eTrex 10, Olathe, KS, USA). Individuals during the non-breeding season do not move independently of one another because of covey association (Janke 2011). Therefore, during the non-breeding season, we selected covey locations randomly and sampled them during the same timeframe each year (October–March). We conducted all sampling within 2 weeks of use to minimize potential changes in vegetation associated with selected locations.

For the breeding season micro-scale characterization, we measured vegetation composition and structure along a 30-m point-intercept transect, centered over location coordinates with 15 m to either side, placed following a randomly selected bearing (Bonham 1989). We noted all plant species present at each 1-m mark along the transect. We grouped species into plant types (**Table B.2**) and calculated percent coverage by dividing the total number of points with detections by the total number of sampling points on the transect (n = 30). Plant types during the breeding season included forb, warm-season grass, cool-season grass, sedges and rushes, semi-woody (briars, vines), shrub, tree, bare ground (no vegetation present), and other (leaf litter and coarse woody debris). Non-breeding season plant types included herbaceous (grasses and forbs), semi-woody, woody (shrubs and trees), bare ground, and other (leaf litter and coarse woody debris). We defined leaf litter as senescent vegetation from the previous year at ground level. We measured litter depth (ruler, cm) and ground-sighting distance at four intervals along the transect (0 m, 10 m, 20 m, 30 m). We measured ground-sighting distance as openness at ground level using a horizontal PVC tube (diameter of 3.8 cm) mounted 15.2 cm above the ground, representative of bobwhite height (Gruchy and Harper 2014). One observer looked through the tube while a second observer moved a brightly colored pole (bottom 15.2 cm colored, remainder white) perpendicularly away from the observer until the observer could not see the colored portion of the pole and recorded the distance (nearest 0.1 m). We took vertical obstruction readings using a modified Nudd's (1977) board. The board consisted of four strata: 0.00–0.25 m (first stratum), 0.26–0.50 m (second stratum), 0.51–1.00 m (third stratum), and 1.01–2.00 m (fourth stratum). The first stratum (0.00–0.25 m) represented visual obstruction at the level where bobwhite occurred (Powell 2022). The second stratum (0.26–0.50 m) represented visual obstruction important for brooding cover (Taylor et al. 1999). The third stratum (0.51–1.00 m) represented visual obstruction important for cover from mesomammalian predators (Yoho and Dimmick 1972, Roseberry and Klimstra 1984). The fourth stratum (1.01–2.00 m) represented visual obstruction for cover from avian predators (Yoho and Dimmick 1972, Roseberry and Klimstra 1984). Standing at the location point-center, we viewed the Nudd's board from 5 m in each cardinal direction. We then estimated the percentage of each stratum that was covered by vegetation and assigned a value to 1 of 5 cover classes (1 = 0–20%, 2 = 21–40%, 3 = 41–60%, 4 = 61–80%, and 5 = 81–100%). We designated patches of escape cover as any area >15 m^2 with dense shrubby/semi-woody cover that provided thermal cover or cover from predators. We measured distance (m) to nearest escape cover from bird locations and random points via laser rangefinder (+/- 1 m). We recorded tree basal area using a 2.5-m^2/ha prism and identified trees to species. We counted woody stems >1.37 m tall and <11.4 cm diameter by species within a 5-m radius of bird and random point locations. We also grouped woody stems into two diameter classes (<5.1 cm and 5.1–11.44 cm).

During the non-breeding season, we measured visual obstruction (Nudds board), vegetation cover, and average vegetation height 5 m from the bird and random point in each cardinal direction. We measured vegetation composition by recording the species present at the base of the Nudd's board (where the first strata contacted the ground). We measured average vegetation height to the nearest 1 cm.

Data analysis

We used general linear binomial models with a logit link function to determine seasonal resource selection across macro- and micro scales and to assess potential effects of various management practices. We tested for differences in vegetation type availability between focal areas with a chi-squared test. Results were deemed significant if $\alpha < 0.05$. We determined macro-scale selection using a discrete-choice function to determine resource selection, with a use vs. availability framework (Cooper and Millspaugh 1999). Discrete choice assumes selection based on individual choice over time (Cooper and Millspaugh 1999, Hoffman et al. 2010). We modeled micro-scale selection with case-controlled logistic regression. We tested covariates for correlation using Pearson's correlation coefficient with a threshold of 0.7. If covariates were correlated, we excluded the covariate with less apparent biological or management relevance (Shrestha 2020, Rosche et al. 2021). We retained all the Nudd's board measurements despite their correlations because of their potential importance in resource selection but correlated strata were not run within the same model to avoid potential collinearity problems (Graham 2003, Dormann et al. 2013, Brooke et al. 2015).

Macro-scale covariates included percent vegetation type and an interspersion index (**Table B.C**). We used interspersion to measure the intermixing of vegetation types around bird locations. Micro-scale covariates included vegetation composition, stem density, basal area, distance to nearest woody cover, visual obstruction score, average vegetation height (only for non-breeding season), litter depth (only for breeding season), and ground sighting distance score (only for breeding season; **Table B.C**). We standardized all continuous covariates by subtracting the mean from each covariate and then dividing the new centered value by the standard deviation; thus, each covariate had a mean of 0 and a standard deviation of 1 (Quinn and Keough 2002, Zuur et al. 2007).

We used generalized linear binomial models with a logit link function. For the macro-scale models, we used the general stats package in R (R Core Team 2023). For micro-scale selection, we used the survival package in R to model generalized linear equations with a clogit function to structure a case-controlled dataset. We first tested each covariate individually to determine potential significance. We retained covariates with $P < 0.25$ and tested combinations of multivariate models that were biologically reasonable. We used Akaike's Information Criterion (AICc) to determine model selection (Akaike 1976; Burhnam and Anderson 1998) and we considered models with ΔAIC_C scores <2.0 to have strong support and worthy of interpretation. After identifying our top models, we evaluated quadratic terms of covariates included in the best-supported model to test for non-linear relationships. Site was tested and considered a significant covariate if it lowered the ΔAIC_C value of the best-supported model by >2.0. If site was supported, we used the package "emmeans" (Lenth 2018) to compare means between sites using Tukey's Honest Significant Difference (HSD) *P*-value adjustment. We used a significance level of $\alpha = 0.05$ for contrast.

We also created and evaluated models with management covariates to test for relationships between resource selection and different management practices. To address the timing of response to management, we only used data from the study areas (excluded used and available locations in the 175-m buffer surrounding study sites) and we only used data from 2022 (response to 2021 management) and 2023 (response to 2022 management). Management covariates included distance to edge of management unit, management unit size, and type/timing of management prescription. We categorized burning as a binary covariate (1 = burned, 0 = unburned) and assigned one of three categories based on time since burn: 1 year (0–11 months), 2 years (12–23 months), and >2 years. We also used binary covariates for disking and herbicide applications, which we only considered relevant if the disked or sprayed unit was used within ≤1 year of application.

RESULTS

Trapping and telemetry

We captured 365 birds (WR = 113, BF = 169, KB = 83) and collared 312 (WR = 103, BF = 130, KB = 79) individuals from January 2021 to May 2023. We monitored 42 coveys (2021 = 12, 2022 = 18, 2023 = 16). We captured 155 females, 199 males, and 13 individuals of indeterminate sex. We caught 211 adults, 150 juveniles, and 4 individuals of indeterminate age. We calculated an average home range of 33.4 ha (± 2.4 SE) during the breeding season and 19.1 ha (± 2.7 SE) during the non-breeding season.

We used data from 121 individuals (WR = 32, BF = 56, KB = 32) and 27 coveys (WR = 7, BF = 12, KB = 8) for the macro-scale resource selection analyses. On average, individuals had 50.1 locations (SE = 1.8) and coveys had 54.3 locations (SE = 4.0). We used 6,302 individual and 1,466 covey locations during the breeding and non-breeding seasons, respectively, along with 31,522 and 7,335 corresponding random points for the macro-scale analyses. For micro-scale selection analyses, we included 343 pairs of used and random locations (n = 91 individuals) during the breeding season and 226 pairs of used and random locations (n = 21 coveys) during the non-breeding season. We did not detect any differences between sex in resource selection at macro and micro scales during the breeding season, so we pooled data across sexes.

Breeding season

Macro-scale selection: We evaluated 90 models for macro-scale resource selection during the breeding season, including a null model, 7 univariate models, and 82 models with combinations of covariates (**Table D.1**). We had 2 competing best-supported models (<2 ΔAIC_C score; **Table D.1**). The most-supported model included vegetation types (4 different types), distance to linear manmade structure, and an interspersion index (**Table B.3**). Site had an additive effect on selection at the macro scale as it lowered the ΔAIC_C value by >2 (**Table D.1**), supported by the fact that vegetation type availability differed across sites ($\chi^2 = 54.72$, $P < 0.001$). For example, BF was comprised of a large quantity of early succession (48.3%), whereas WR and KB had much less early succession (23.2% and 22.5%, respectively), indicating a large difference in availability of a preferred vegetation type (**Table B.4**). A post-hoc Tukey test indicated the BF-KB and BF-WR relationships differed ($P < 0.001$), but the KB-WR relationship did not ($P = 0.875$; **Figure B.2**). On average, BF had the greatest predicted probability of selection across the entire focal area (average probability of selection = 0.128), followed by WR (average probability of selection = 0.123) and KB (average probability of selection = 0.120; **Figure B.7**, **B.8**, and **B.9**).

Vegetation types that were related to selection included deciduous forest, early succession, early succession woody, and young forest. Deciduous forest was negatively related to bobwhite use (β = -0.017, 95% CI = -0.018–-0.015; **Table B.3** and **Figure B.3**). Nine percent (± 0.3 SE) of the 1-ha area surrounding bobwhite locations contained deciduous forest, whereas 35.8% (± 0.2 SE) of the area surrounding random locations was deciduous forest (**Table D.2**). Early succession and early succession woody vegetation types were positively associated with use (β = 0.009, 95% CI = 0.008–0.011, and β = 0.008, 95% CI = 0.006–0.009, respectively; **Table B.3** and **Figure B.3**). On average, 49.1% (± 0.4 SE) of the area surrounding bobwhite locations was early succession, whereas 33.8% (± 0.2 SE) of the area surrounding random locations contained early succession (**Table D.2**). Early succession woody comprised 15.2% (± 0.3) of the area surrounding bobwhite locations, whereas 9.7% (± 0.1) of the area surrounding random locations was early succession woody (**Table D.2**). Young forest also exhibited a positive association with bobwhite use (β = 0.016, 95% CI = 0.014–0.017; **Table B.3** and **Figure B.3**). On average, 6.4% (± 0.3 SE) of the area surrounding bobwhite locations was young forest whereas only 2.3% (± 0.1 SE) of the area surrounding random points was young forest (**Table D.2**). Interspersion was positively related to bobwhite use (β = 0.278, 95% CI = 0.248–0.308; **Table B.3** and **Figure B.3**). On average, bobwhite locations were associated with 27% greater interspersion values (3.3 ± 0.02 SE) compared with interspersion values associated with random locations (2.6 ± 0.01 SE; **Table D.2**).

We developed 39 models based on management covariates, with 2 competing best-supported models (<2 $\Delta\text{AIC}_\text{C}$ score; **Table D.3**). The best-supported model included management unit size and its quadratic term, distance to edge of management unit and its quadratic term, within one year since burning, within one year since disking, spot-spraying herbicide application, and site (**Table B.5**). Within the best-supported model, spot-spraying included a β estimate that barely crossed 0, indicating a weak positive relationship with resource selection (95% CI = -0.006–0.263; **Table B.5**). On average, bobwhite were located in areas that were spot-sprayed within one year 17% whereas random locations were in areas that were spot-sprayed within one year only 9% of the time (**Figure B.4**). One-year since burn was positively related to use (β = 0.238, 95% CI = 0.156–0.320; **Table B.5**). On average, bobwhite were located in areas that had been burned within one year 23% of the time, whereas random locations were in areas that had been burned within one year 14% of the time (**Figure B.4**). Disking was positively related to bobwhite use (β = 0.230, 95% CI = 0.141–0.318; **Table B.5**). On average, bobwhite were located in areas that had been disked within one year 7% of the time, whereas random locations were in areas that had been disked within one year only 3% of the time (**Figure B.4**).

Management unit size had a negative relationship with use (β = -0.497, 95% CI = -0.626–-0.369) and the quadratic term was positive (β = 0.341, 95% CI = 0.213–0.468, **Table B.5** and **Figure B.5**), suggesting a non-linear relationship. The mean management unit size at bobwhite locations was 5.4 ha (± 0.06 SE); the mean management unit size for random locations was 5.9 ha (± 0.03 SE; **Table D.2**). The distance to the edge of the management units had a positive relationship (β = 0.132, 95% CI = 0.016–0.251), and the quadratic term was negative (β = -0.450, 95% CI = -0.611–-0.298), suggesting another non-linear relationship (**Table B.5** and **Figure B.5**). Bobwhite locations were on average 22.3 m (± 0.3 SE) from the edge of the management unit whereas random locations were 27.5 m (± 0.2 SE; **Table D.2**).

Micro-scale selection: We fit 58 models to evaluate micro-scale resource selection during the breeding season, including a null model, 19 univariate models, and 37 models representing a combination of covariates (**Table D.7**). We had 17 competing top models (<2 ΔAIC_C score; **Table D.6**). Site did not influence micro-scale selection.

Our best-supported model included distance to nearest woody cover, quadratic distance to nearest woody cover, basal area, and visual obstruction between 0.26–0.50 m (**Table B.6**). Bobwhite use was negatively related to distance from woody cover, indicating that bobwhite selection decreased as distance from woody cover increased (β = -0.718, 95% CI = -1.113–-0.322) with a positive quadratic term, indicating a non-linear relationship (β = -0.453, 95% CI = 0.093–0.812; **Table B.6** and **Figure B.6**). The mean distance from woody cover for bobwhite locations was 20.8 m (± 1.5 SE), whereas the mean distance from random locations was 26.3 m (± 1.5 SE; **Table D.7**). Basal area had a negative relationship with use (β = -0.236, 95% CI = -0.433–-0.038; **Table B.6** and **Figure B.6**). The mean basal area for bird locations was 1.2 m^2/ha (± 0.3 SE), whereas random locations was 4.6 m^2/ha (± 0.4 SE; **Table D.7**). Visual obstruction between 0.26–0.50 m included a β estimate that included 0, indicating no relationship with resource selection (**Table B.6**).

Non-breeding season

Macro-scale selection: Our model set for the non-breeding season macro-scale resource selection analysis included a null model, 7 univariate models, and 18 models with combinations of covariates (**Table D.5**). Two models had strong support (<2 ΔAIC_C score; **Table D.5**). The best-supported model included vegetation types (4 different categories) and an interspersion index (**Table B.3**). Site had an additive effect on selection at the macro-scale as it lowered the ΔAIC_C value by >2 (**Table D.1** and **D.5**). For example, BF was comprised of a small quantity of deciduous forest (27.1%), whereas WR and KB had >40% greater quantities (38.5% and 43.0%, respectively; **Table B.4**). A post-hoc Tukey test indicated the BF-KB and BF-WR relationships differed ($P \leq 0.001$), whereas the KB-WR relationship did not differ (P = 0.162; **Figure B.2**). On average, BF had the greatest predicted probability of selection across the entirety of the focal area (average probability of selection = 0.128), followed by WR (average probability of selection = 0.113) and KB (average probability of selection = 0.104; **Figure B.7**, **B.8**, and **B.9**).

Vegetation types that were selected for in the model included early succession, early succession woody, young forest, and woodland. Early succession and early succession woody were positively related to selection (β = 0.024, 95% CI = 0.022–0.027, and β = 0.033, 95% CI = 0.031–0.036, respectively; **Table B.3** and **Figure B.3**). On average, 40.2% (± 0.9 SE) of the area surrounding bobwhite locations was early succession, whereas the area surrounding random locations contained 31.7% (± 0.4 SE) early succession (**Table D.2**). Early succession woody comprised 21.5% ± 0.8 SE) of the 1-ha area surrounding bobwhite locations, whereas random locations contained 9.6% (± 0.2 SE, **Table D.2**). Young forest and woodland also were positively related to selection (β = 0.039, 95% CI = 0.036–0.042, and β = 0.028, 95% CI = 0.025–0.032, respectively; **Table B.3** and **Figure B.3**). On average, the percentage of the 1-ha area surrounding bobwhite locations for young forest and woodland was 11.1% (± 0.7 SE) and 9.3% (± 0.5 SE), respectively, whereas random locations contained 2.8% (± 0.2 SE) and 5.4% (± 0.2 SE, **Table D.2**). Interspersion was positively related to bobwhite use (β = 0.197, 95% CI = 0.144–0.250), indicating that greater interspersion of vegetation types was selected for by bobwhite (**Table B.3** and **Figure B.3**). On average, the 1-ha area surrounding bobwhite locations had 18% greater interspersion values (3.2 ± 0.03 SE) compared with interspersion around random locations (2.7 ± 0.02 SE, **Table D.2**).

To evaluate management covariates, we fit 39 multivariate models that produced 2 models with ΔAIC_C scores <2 (**Table D.5**). Our best-supported model included management unit size and its quadratic term, distance to edge of management unit, one-year since burn, spot-spraying herbicide application, and site (**Table B.6**). Within the best-supported model, management unit size and its quadratic term included β estimates that crossed 0, indicating no relationship with the predictor covariates, 95% CI = -0.429–0.109 and 95% CI = -0.220–0.306, respectively; **Table B.5**). The percent of the area in one-year since burns were positively related with bobwhite use (β = 0.700, 95% CI = 0.547–0.854; **Table B.5**). On average, 30% of bobwhite locations had been burned in the previous year, whereas only 12% of random locations had been burned in the previous year (**Figure B.4**). Areas treated with spot-spray herbicide applications were negatively related to use (β = -1.382, 95% CI = -2.212–-0.688), with bobwhite located in spot-sprayed areas on average 0.5% of the time, whereas random locations were in spot-sprayed areas 0.9% of the time (**Table B.5** and **Figure B.4**). The distance to the edge of the management unit had a positive relationship (β = 0.136, 95% CI = 0.053–0.854; **Table B.5** and **Figure B.5**). Bobwhite locations were on average 27.6 m (± 0.6 SE) from the nearest edge of the management unit whereas random locations were 26.2 m (± 0.4 SE) from the edge (**Table B.6** and **Figure B.6**).

Micro-scale selection: Our model set for non-breeding season micro-scale resource selection included a null and 15 additional multivariate models: 3 models had strong support (<2 ΔAIC$_C$ score; **Table D.8**). Our best-supported model included distance to nearest woody cover, average vegetation height, herbaceous plant coverage, visual obstruction in the 0.25 m to 0.50 m strata, and small midstory woody stem totals (**Table B.6**). Within the best-supported model, average vegetation height and herbaceous plant coverage had β estimates that included 0, indicating no relationships with the predictor covariates (**Table B.6**). Significant covariates included distance to woody cover, visual obstruction (0.26–0.50 m), and small midstory stems (≤5.1 cm dbh; **Table B.6**). Site was not related to micro-scale selection.

Bobwhite use was negatively associated with distance to woody cover (β = -0.300, 95% CI = -0.577–-0.023; **Table B.6** and **Figure B.6**), with bobwhite 15.5 m (± 1.5 SE) from woody cover on average, whereas random locations were 19.4 m (± 1.3 SE) on average from woody cover (**Table D.7**). Visual obstruction in the 0.26 to 0.50-m strata had a positive relationship with use (β = 1.714, 95% CI = 0.662–2.765; **Table B.6** and **Figure B.6**). The mean visual obstruction score for bobwhite locations was 61% (± 0.03 SE), whereas the mean score for random locations was 47% (± 0.02 SE, **Table D.7**). Bobwhite use was positively related to midstory stem counts with diameters $\leq$5.1 cm at breast height (β = 0.528, 95% CI = 0.077–0.979; **Table B.6 and Figure B.6**). The mean midstory stem count for bobwhite locations was 31.1 stems/ha (± 4.6 SE), whereas the random locations had stem counts that averaged 21.9 stems/ha (± 1.8 SE, **Table D.7**).

DISCUSSION

Bobwhite resource selection differed by study site at the macro scale because vegetation type availability differed across the three QFAs, supporting our hypothesis. There was greater availability of early successional vegetation types at BF, and so the greatest probability of use was at BF, whereas WR and KB had lesser availability of preferred vegetation types and thus lesser probability of use. Resource selection did not differ at the micro scale among sites, thus bobwhite on all QFAs were able to locate micro-sites with appropriate structure to support their life history requirements during the breeding and non-breeding season. Although we expected bobwhite to select for greater herbaceous cover during the breeding season because of nesting and brood-rearing, this hypothesis was not supported. If we had documented actual nest sites and brood use, the relationship with herbaceous cover likely may have been more evident. Resource selection also was related to several management practices. Most importantly, areas burned during the previous year were positively related to use, consistent with what we predicted, whereas areas burned less frequently were not selected. Apparently, areas burned annually were selected because burning increased herbaceous food plants with more open vegetation structure at ground-level, allowing for better mobility. We also found support for our prediction that smaller disturbance sizes (management unit size) positively influenced bobwhite resource selection during the breeding season.

Vegetation type was related to bobwhite probability of use at the macro-scale in both seasons, consistent with expected life history requirements. Early succession and early succession woody vegetation types were positively related to use, consistent with bobwhite requirements of open areas for food resources including seeds, insects, and green vegetation (Rosene 1969, Eubanks and Dimmick 1974). Woodlands can also provide quail habitat, but an open canopy that allows sufficient sunlight to support an understory dominated by relatively shade-intolerant herbaceous species is requisite. Crosby et al. (2015) reported bobwhite occupancy declined from 100% at 30% canopy cover to 0% when canopy cover reached 60%, the range of canopy cover typically associated with woodlands (Grossman et al 1998). In Ohio, Janke and Gates (2013) reported bobwhite used disturbed woodlands with open canopy cover and an herbaceous understory but avoided woodlands with more canopy closure. Therefore, open woodlands allowing ≥50% sunlight with frequent fire (every 1–2 years) that maintains an herbaceous understory can provide nesting, brood-rearing, and escape cover (Brockway and Lewis 1997, Brennan et al. 1998, Sparks et al. 1998, Hiers et al. 2000, Bowling et al. 2013). Savannas also provide these habitat elements, but we were unable to include savannas in our modelling because of general lack of occurrence on the QFAs.

Bobwhite avoided forested areas during summer, likely because of a lack of food and cover available, as well as to lessen predation risk from bobcats, raccoons, and raptors (Brennan 1991, Dijak and Thompson 2000, Byrne and Chamberlain 2011, Veech 2006, Nolan et al. 2024). Lohr et al. (2011) reported how closed-canopy forests do not support the seed-bearing plants that provide common bobwhite foods. Our breeding-season results were consistent with results reported in Kentucky (Brooke et al. 2015) and Ohio (Janke and Gates 2013), where bobwhite selection increased as distance from forests increased.

The negative relationship between distance to woody cover and bobwhite use during both the breeding and non-breeding seasons was expected because of the need for thermoregulation in both seasons and proximity to escape cover in the non-breeding season. Our research supports similar findings in the Southeast and Midwest, reinforcing the designation of bobwhite as ‘shrubland obligates’ (Crosby et al. 2013, Janke and Gates 2013, Brooke et al. 2015, Thompson et al. 2022). Low woody cover, including shrubs and young resprouting trees, provides multiple resources for bobwhite during breeding and non-breeding seasons, such as thermal cover from extreme weather (heat and cold), escape cover from predators, and perch locations for calling males (Johnson et al. 1990, Hiller and Guthery 2005). Selection for low woody cover also was represented by a positive relationship with the percentage of young forest around bobwhite locations. The positive relationship between midstory stems (0–5.1 cm) and bobwhite use during the non-breeding season also demonstrated selection for escape cover (Rosche et al. 2019, Mosloff et al. 2021). These results support our hypothesis that bobwhite are dependent on woody cover during all seasons, but this dependence may be most critical during the non-breeding season. A 3-year fire-return interval can be used to maintain patches of resprouting woody stems <5.1 cm that serve as escape cover for the non-breeding season, though specific selection for this management regime was not evident in the modeling, perhaps because of its limited availability on the QFAs.

We predicted that bobwhite would select for forbs and grasses during the breeding season and woody plant species during the non-breeding season, but our results did not support these predictions. Forbs have been shown elsewhere to be critical during the breeding season as they provide bobwhite cover and attract insects (Cross 1956, Hurst 1972, DeVos and Mueller 1993). Grasses provide additional structure for nesting but can become dense and prohibit use by bobwhite (Scott and Klimstra 1954, Kiel 1976, Jackson 1969, Unger et al. 2015, Mosloff et al. 2021). Many of our bobwhite and random locations had similar averages for plant coverage, indicating little support for selection. Given our sampling approach of locating random points within 175 m of bobwhite locations, random point locations typically were in the same vegetation type as the bobwhite locations (53% in breeding season and 62% in non-breeding season; **Table D.9**). This approach may have limited our ability to detect the influence of coverage of various plant types on bobwhite selection. Although we did not find support for woody plant coverage with bobwhite non-breeding season selection, we did document the importance of woody vegetation through other metrics, such as midstory stem density and distance to woody escape cover.

Bobwhite habitat management is complex because bobwhite response to a given management practice may be dependent on spatial extent, season, and time since management (Burger 2001). For example, areas burned during the previous year were positively related to bobwhite use at the macro-scale regardless of season, as burning stimulated germination of herbaceous plants from the seedbank, reduced litter, and promoted open structure at ground level (Zuckerberg and Vickery 2006, Harper et al. 2015, Powell et al. 2022). Although three-year-after burns were not in our best-supported models, relatively small three-year burns well-dispersed throughout a management area can maintain resprouting of woody stems <5.1 cm that provide escape and thermal cover. The effect of spot-spray applications (within 1 year of application) in open areas (early succession and early succession woody) had differential relationships with bobwhite use by season (breeding season positive, non-breeding season negative). Across our study sites, spot-spraying generally was used to reduce undesirable sprouting of shrubs and trees. Therefore, bobwhite likely selected these areas during summer because spot-spraying increased herbaceous cover and enhanced vegetation structure at the ground level, and reduced woody cover (McComb and Hurst 1987, Witt et al. 1993, GeFellers 2020, Powell et al. 2021, Harper et al. 2021). Even though our beta estimates crossed 0 during the non-breeding season, bobwhite likely selected against spot-spraying applications because woody stems were removed and therefore reduced escape or thermal cover.

Disking increases forb cover and openness at ground level, which provides accessible foraging opportunities and increased insect abundance (Greenfield 2005, Brooke at al. 2015, Palmer and Sisson 2017). During the breeding season, bobwhite responded positively to disked areas, likely because of the change in vegetation structure and composition, in spite of the very infrequent use of disking by QFA managers. On average, disking disturbed <15% of the focal areas annually (WR = 3%, BF = 14%, KB = <1%). Brooke et al. (2015) reported similar results on the importance of disking, and suggested disking on two-year intervals to control nuisance species, such as sericea lespedeza.

Scale of management also was related to bobwhite resource selection. Our management unit sizes ranged from 0.1 to 20.4 ha. As management unit size increased from 2.5 to 10 ha, the probability of use decreased linearly by 7%, but the relationship leveled off thereafter (**Figure**

B.5). The non-linear portion of the graph (from 10-20 ha), suggesting that the probability of use increases with unit size is likely because we had small sample sizes of large management units. Bobwhite home ranges typically span 19–33 ha, with core areas (the central 50% of locations) ranging from 5–10 ha, helping further highlight their selection for smaller management units. Relatively large management units may be more efficient with regard to management effort (i.e., it may be more efficient to burn one 100-ha unit than ten 10-ha units) but are likely less beneficial for bobwhite. Burning, spraying, or disking relatively large areas may temporarily displace bobwhite outside their core-use area, increase predation risk, and decrease survival as coveys or individuals move into unfamiliar areas (Wellendorf and Palmer 2009, McGrath et al. 2017). Anecdotally, a covey at BF was displaced after a 50-ha winter burn, and all radio-tagged individuals died within 4 weeks of displacement.

Concentrated use of the interior of management units was related to the size of management units on the QFAs. Bobwhite typically were within 25 m of the edge of a management unit, regardless of size, and the interior of larger units were used less than the interior of smaller units during the non-breeding season. Size of management units as well as land use has led some people to consider the bobwhite an "edge species" (Guthery and Bingham 1992, Masters et al. 2017). Historically, bobwhite were studied and observed in agricultural settings where the vegetation along the edge of the agricultural fields provided cover for nesting, foraging, or escape (Stoddard 1931, Rosene 1969). Although edges are used by bobwhite if the correct vegetation structure and composition are present, any affinity to the edge may indicate that the interior of one or both of the adjacent vegetation patches provide poor cover or a lack of food resources. Although management of field edges is a critical consideration for bobwhite and other species in agricultural settings (Burger et al. 2006, Bowling et al. 2013, Janke et al. 2015), if the site is managed specifically for bobwhite, then the structure and composition of the interior of the management unit should allow just as much use as the edge of the unit. If properly managed for both food and cover resources, the interior of management units may be more beneficial than edges which feature elevated predation risk (Andren 1995). Optimal management unit size and configuration may be towards smaller sizes (i.e., <5 ha) with reduced edge and less irregular in shape (Vergara and Hahn 2009, Masters et al. 2017).

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APPENDIX B

Table B.1. Description of vegetation types used in macro-scale analysis during the breeding and non-breeding season across Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2021–2023.

Vegetation type	Acronym	Description
Deciduous forest[a]	DEC	>80% canopy cover; consists of deciduous trees.
Coniferous forest	CON	>80% canopy cover; consists of coniferous trees.
Early succession[a]	ES	plant growth consisting of shade-intolerant forbs and grasses, with scattered shrubs, and trees; woody species <u>DO NOT</u> comprise more than 50% of species composition.
Early succession woody[a]	ESW	plant growth consisting of shade-intolerant forbs and grasses, with scattered shrubs, and trees; woody species <u>DO</u> comprise more than 50% of species composition but <u>DO NOT</u> comprise more than 80% of species.
Savanna	SAV	10-30% canopy cover with a dominant herbaceous understory.
Young forest[a]	YGF	comprised of regenerating trees <11.43 cm; trees are typically between 4-10 years old and are forming a developing canopy
Woodland[a]	WOOD	30-80% canopy cover with a dominant herbaceous understory.
Open pine row	PIN	coniferous trees planted in 12-18 m wide rows.
Food plot	FP	plots actively planted for wildlife food; comprised of crops such as corn, sunflowers, sorghum, millet, etc.
Row crop	ROW	comprised of planted crops such as corn and soybeans.
Pasture/hayfield	PAS	landscape that is activity being grazed by livestock or being groomed for a hayfield; can consist of a variety of forbs and grasses.
Other	OTH	landscape altered by manmade influences; includes roads, firebreaks, structures, lawns, etc.; also includes wetland areas that are flooded at least part of the year

*** Bold** indicates that the vegetation type was only found on surrounding private land, not on the wildlife management area.

[a] indicates the vegetation types used in the macro-scale analysis. Types were selected if they were biologically relevant and/or well-represented across all study sites.

Table B.2. Description of micro and macro-scale covariates used in breeding and non-breeding season resource selection analysis across Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2021–2023.

Covariate	Description	Acronym	Scale	Season
Litter	Average litter depth (cm)	Litter	Micro	B
Sight	Average sight tube measurement (m)	Ground	Micro	B
Height	Average vegetation height (cm)	Height	Micro	NB
N1-N4[a]	Visual obstruction reading, 4 covariates (1 for each stratum; %)		Micro	B, NB
Small stems	Number of midstory stems between 0-5.08 cm diameter (stems/ha)	SmallStem	Micro	B, NB
Mid stems	Number of midstory stems between 5.08-11.43 cm diameter (stems/ha)	MidStem	Micro	B, NB
Forb	Groundcover comprised of broadleaf herbaceous species (%)	FRB	Micro	B
Warm-season grass	Groundcover comprised of warm-season grass species (%)	WSG	Micro	B
Cool-season grass	Groundcover comprised of cool-season grass species (%)	CSG	Micro	B
Herbaceous	Groundcover comprised forb and grass species (%)	HRB	Micro	NB
Sedge & rush	Groundcover comprised of sedge and rush species (%)	SDR	Micro	B
Semi-woody	Groundcover comprised of bramble and vine species (%)	SEM	Micro	B, NB
Shrub	Groundcover comprised of shrub species (%)	SHR	Micro	B
Tree	Groundcover comprised of tree species (%)	TRE	Micro	B
Woody	Groundcover comprised of woody species (%)	WOO	Micro	NB
Bare	Amount of bare ground with no overhead vegetation (%)	BARE	Micro	B, NB
Other	Coverage of bare ground, coarse woody debris, and leaf litter (%)	OTH	Micro	B, NB
Basal area	Average amount of area occupied by tree stems (m^2/ha)	BasalArea	Micro	B, NB
Woody cover	Distance to nearest woody cover (m)	WoodDist	Micro	B, NB
Vegetation type[b]	Vegetation type		Macro	B, NB
Manmade distance	Distance to nearest manmade structure (road, firebreak, etc.; m)	ManDist	Macro	B, NB
Management unit size	Size of management unit (ha)	MSize	Macro	B, NB

Table B.2. Continued.

Covariate	Description	Acronym	Scale	Season
Management unit edge	Distance to edge of management unit (m)	UnitDist	Macro	B, NB
Burn[c]	Does the location fall in a burned area (1 or 0)		Macro	B, NB
Disk	Does the location fall in disked area (1 or 0)	Disk	Macro	B, NB
Herbicide broadcast	Does the location fall in broadcast sprayed area (1 or 0)	HerbBC	Macro	B, NB
Herbicide spot-spray	Does the location fall in spot-sprayed area (1 or 0)	HerbSS	Macro	B, NB

[a] Nudds strata separated into 4 categories: N1 = 0.00–0.25 m, N2 = 0.26–0.50 m, N3 = 0.51–1.00 m, and N4 = 1.01–2.00 m.

[b] Vegetation types separated into twelve categories (reference Table B.1); only five categories used in resource selection analysis.

[c] Burns were separated into three categories based on time elapsed since fire: OneBurn = 1–11 months, TwoBurn = 12–23 months, and ThreeBurn = 24+ months.

Table B.3. Model coefficients, standard errors, confidence intervals, and model rank for covariates in best-supported model for macro-scale resource selection analysis across Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2021–2023.

Covariate	**Estimate**	**SE**	**95% CL**		***P***
Breeding season					
ES	0.009	0.001	0.008	0.011	8.60E-44
ESW	0.008	0.001	0.006	0.009	8.71E-23
DEC	-0.017	0.001	-0.018	-0.015	1.65E-81
YGF	0.016	0.001	0.014	0.017	5.56E-57
Int	0.278	0.015	0.248	0.308	2.20E-72
ManDist	-0.162	0.030	-0.220	-0.104	5.51E-08
Non-breeding season					
ES	0.024	0.001	0.022	0.027	9.88E-76
ESW	0.033	0.001	0.031	0.036	2.09E-121
YGF	0.039	0.002	0.036	0.042	1.42E-114
WOOD	0.028	0.002	0.025	0.032	1.28E-53
Int	0.197	0.027	0.144	0.250	2.80E-13

* ES = early succession, ESW = early succession woody, DEC = deciduous forest, YGF = young forest, WOOD = woodland, Int = interspersion index, and ManDist = distance (m) to nearest linear manmade structure.

Table B.4. Vegetation types available for northern bobwhite on Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, from 2021 to 2023. Includes entire study area (focal area and surrounding 175 m buffer). B Use refers to use of vegetation type during the breeding season and NB Use refers to use of vegetation type during the non-breeding season.

Vegetation type (%)	**Wolf River**			**Bridgestone-Firestone**			**Kyker Bottoms**		
	Available	**B Use**	**NB Use**	**Available**	**B Use**	**NB Use**	**Available**	**B Use**	**NB Use**
Coniferous forest	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0
Deciduous forest	38.5	12.1	11.3	27.1	0.7	5.8	43.0	19.2	11.6
Early succession	23.2	33.2	33.6	48.3	71.7	57.3	22.5 (12.5)	33.3	27.9
Early succession woody	6.2	27.4	28.0	9.6	16.2	24.9	12.0 (9.4)	12.5	17.6
Food plot	1.2	1.0	1.1	1.0	2.2	0.1	0.5 (0.0)	0.8	0.0
Open pine row	1.5	2.6	0.8	0.0	0.0	0.0	0.0	0.0	0.0
Pasture	0.0	0.0	0.0	1.6	0.0	0.0	3.8	4.1	0.7
Row crop	8.6	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Savanna	1.8	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Young forest	4.9	6.0	13.5	0.0	0.0	0.0	3.5	16.5	26.6
Woodland	5.4	7.2	7.0	5.5	4.9	8.9	4.1	7.1	9.8
Other	9.1	7.6	4.7	6.9	4.3	3.0	9.6 (22.6)	6.5	5.7

* ( ) indicate the winter season at Kyker Bottoms in which water units are flooded for waterfowl management and vegetation type percentage changes.

Table B.5. Model coefficients, standard errors, confidence intervals, and model rank for covariates in management resource selection analysis across Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2021–2023.

Covariate	Estimate	SE	95% CL		*P*
Breeding season					
MSize	-0.497	0.066	-0.626	-0.369	3.48E-14
MSize^2	0.341	0.065	0.213	0.468	1.53E-07
UnitDist	0.132	0.060	0.016	0.251	0.028
UnitDist^2	-0.450	0.080	-0.611	-0.298	1.72E-08
OneBurn	0.238	0.042	0.156	0.320	1.26E-08
Disk	0.230	0.045	0.141	0.318	3.16E-07
HerbSS	0.129	0.068	-0.006	0.263	0.059
Non-breeding season					
MSize	-0.160	0.137	-0.429	0.109	0.244
MSize^2	0.045	0.134	-0.220	0.306	0.740
UnitDist	0.136	0.042	0.053	0.218	0.001
OneBurn	0.700	0.078	0.547	0.854	3.87E-19
HerbSS	-1.382	0.384	-2.212	-0.688	3.17E-04

* MSize = management unit size (ha), MSize^2 = management unit size quadratically, UnitDist = distance (m) to management unit edge, UnitDist^2 = distance (m) to management unit edge quadratically, OneBurn = location falls in burn 0-11 months, Disk = location falls in disked area, and HerbSS = location falls in area that was spot-sprayed.

Table B.6. Model coefficients, standard errors, confidence intervals, and model rank for covariates in best-supported model for micro-scale resource selection analysis across Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2021–2023.

Covariate	**Estimate**	**SE**	**95% CL**		***P***
Breeding season					
WoodDist	-0.718	0.202	-1.113	-0.322	0.000
WoodDist^2	0.453	0.183	0.093	0.812	0.014
BasalArea	-0.236	0.101	-0.433	-0.038	0.019
N2	0.727	0.451	-0.157	1.612	0.107
Non-breeding season					
WoodDist	-0.300	0.141	-0.577	-0.023	0.034
Height	0.237	0.147	-0.051	0.526	0.107
HRB	0.505	0.458	-0.392	1.403	0.270
N2	1.714	0.536	0.662	2.765	0.001
SmallStem	0.528	0.23	0.077	0.979	0.022

* Basal = basal area, WoodDist = distance (m) to nearest woody cover, WoodDist^2 = quadratic distance (m^2) to nearest woody cover, Height = average vegetation height (cm), HRB = coverage (%) of herbaceous (forbs and grasses) plants, and SmallStem = Pooled number of stems within 0-5.08 cm diameter, and N2 = visual obstruction from 0.26–0.50 m.

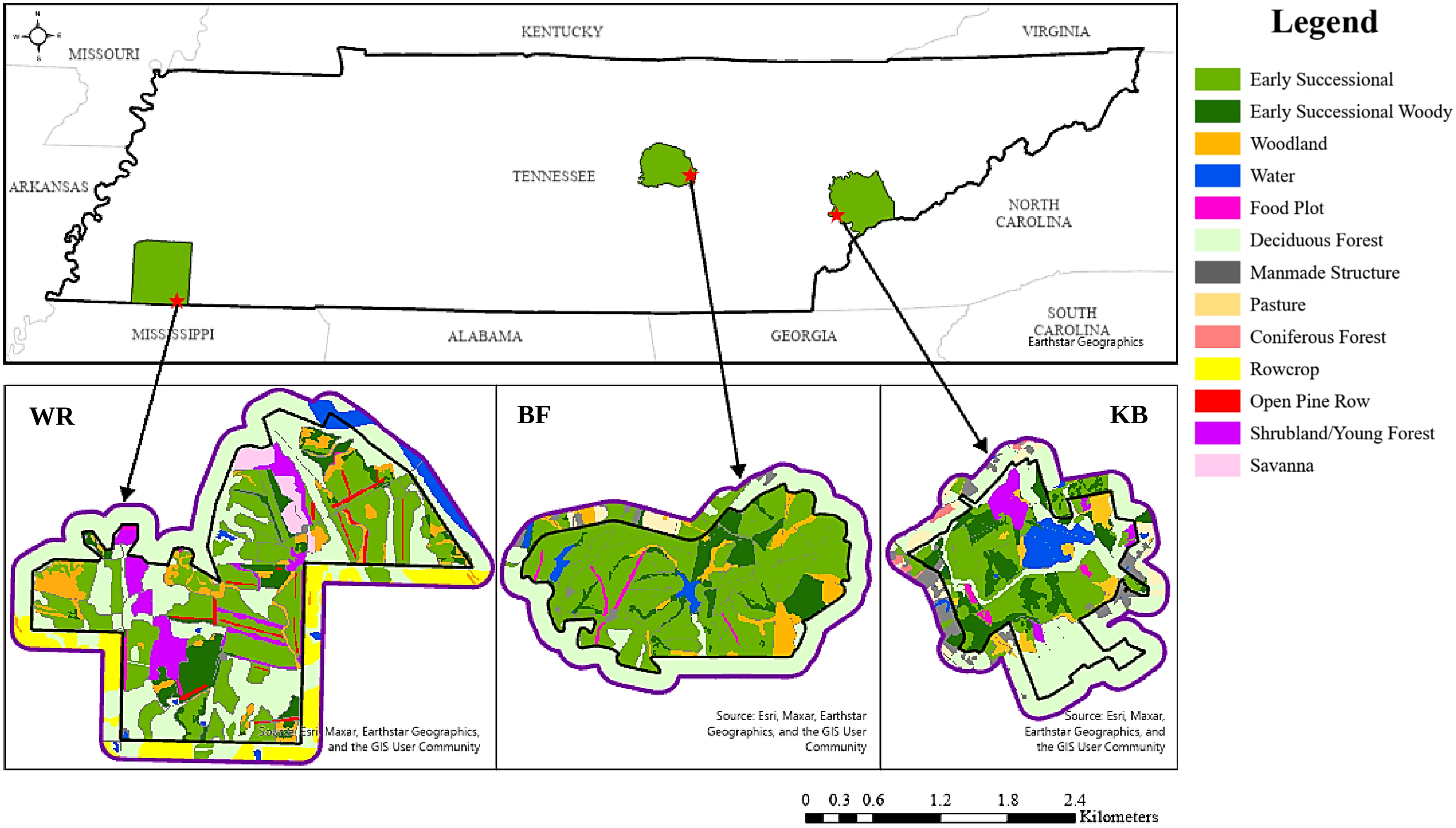

Figure B.1. Map of study areas and associated vegetation types at Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2021–2023. Study area (focal area and 175 m buffer) is outlined in dark purple, focal area is outlined in black.

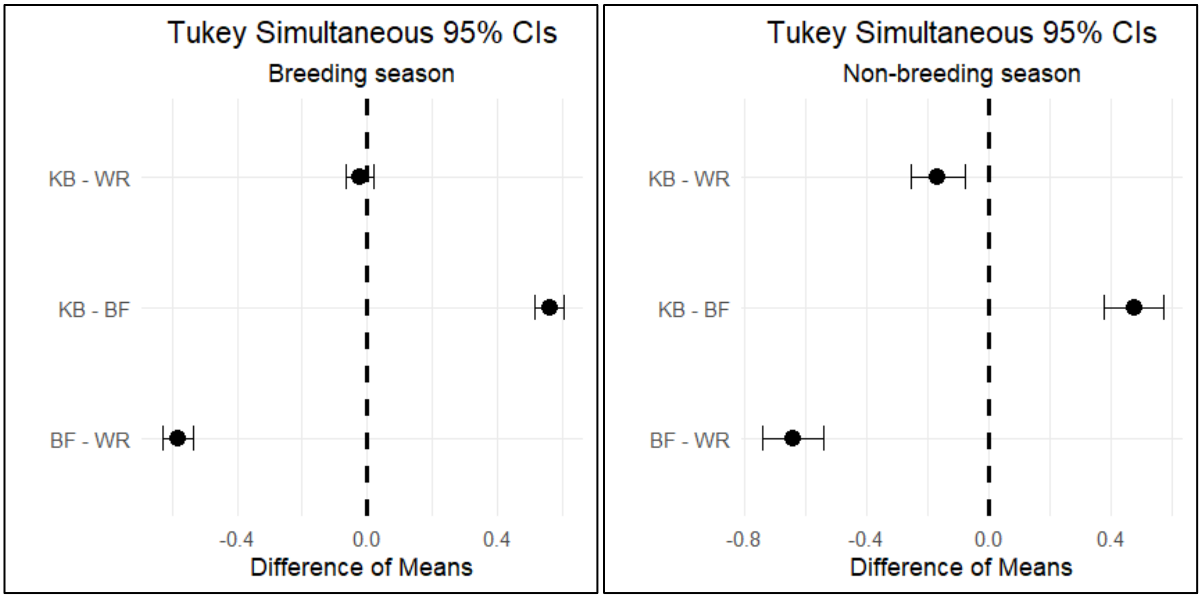

Figure B.2. Tukey Simultaneous 95% Confidence Intervals (CIs) for pairwise comparisons of resource selection means between Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2021–2023. The dashed vertical line at zero indicates no difference in means. Comparisons whose confidence intervals do not cross zero are statistically significant.

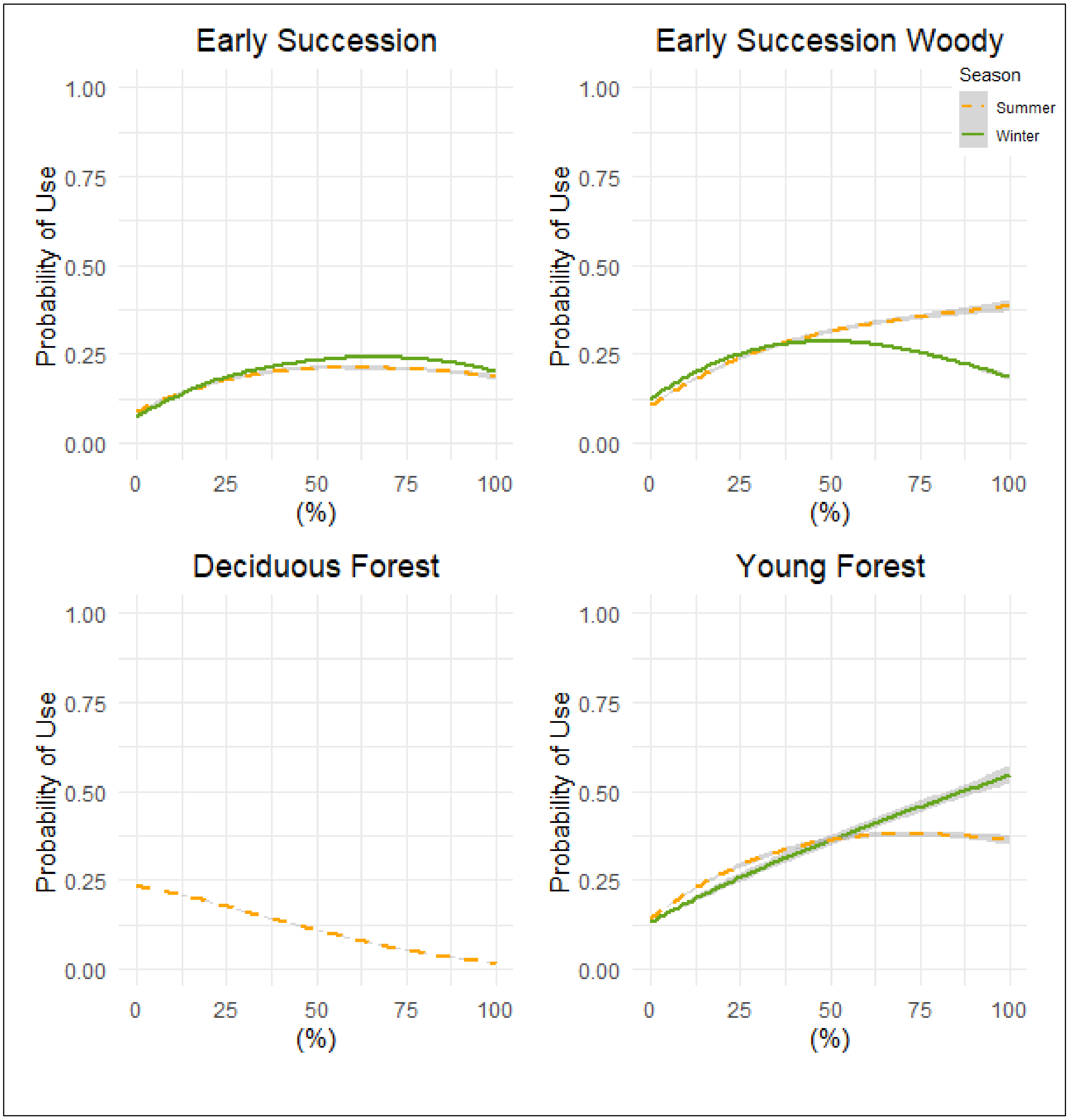

Figure B.3. Probability of use by macro-scale covariates on Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2021–2023. Vegetation type was calculated based on the percentage of each vegetation type in the surrounding ha for each location. Int = interspersion.

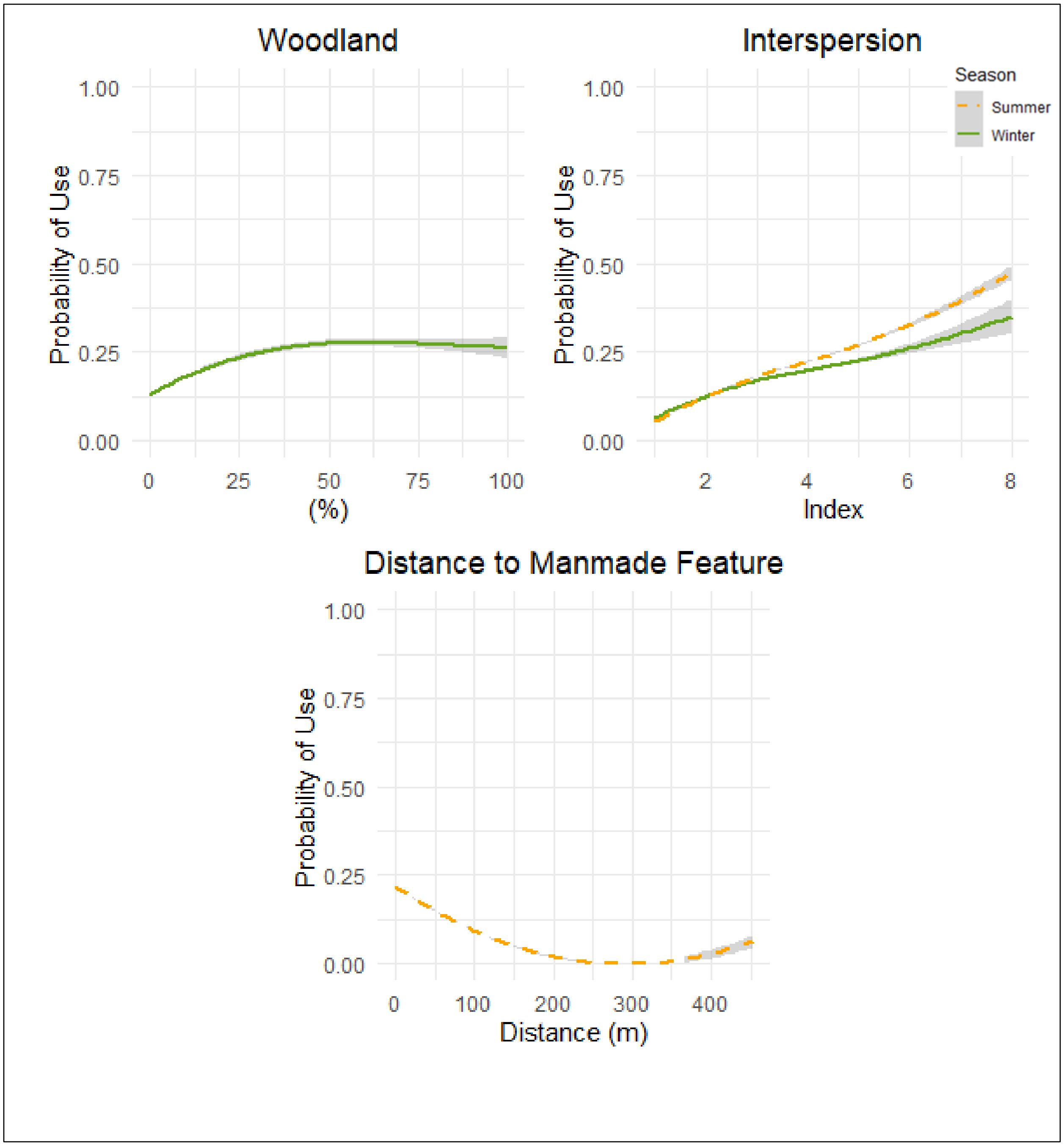

Figure B.3. Continued.

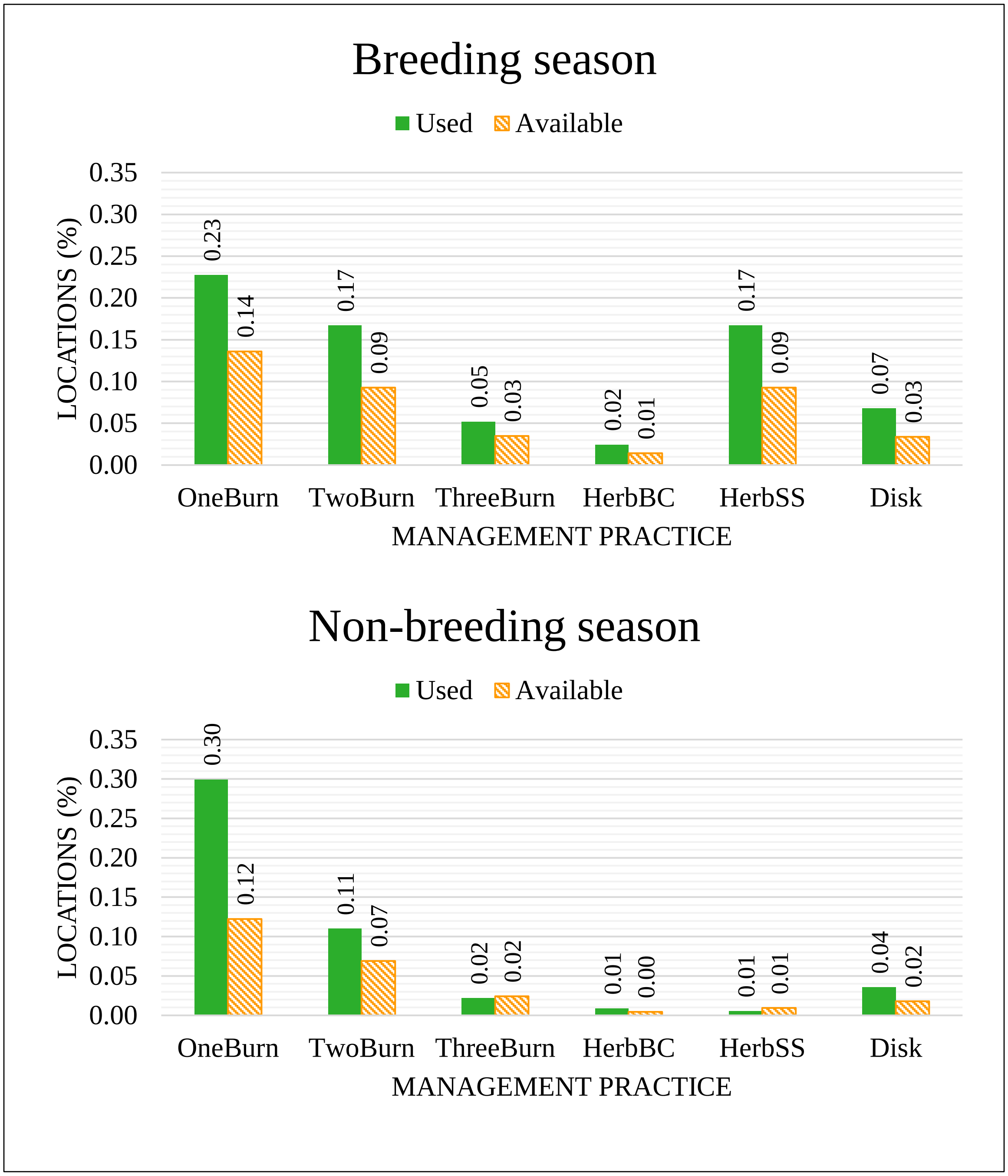

Figure B.4. Percentage of locations per management practice for used and available points during the breeding and non-breeding season for Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2021–2023. OneBurn = location falls in burn 0-11 months, TwoBurn = location falls in burn 12-23 months, ThreeBurn = location falls in burn 24+ months, HerbBC = location falls in broadcast herbicide application, HerbSS = location falls in spot-sprayed herbicide application, and Disk = location falls in disked area.

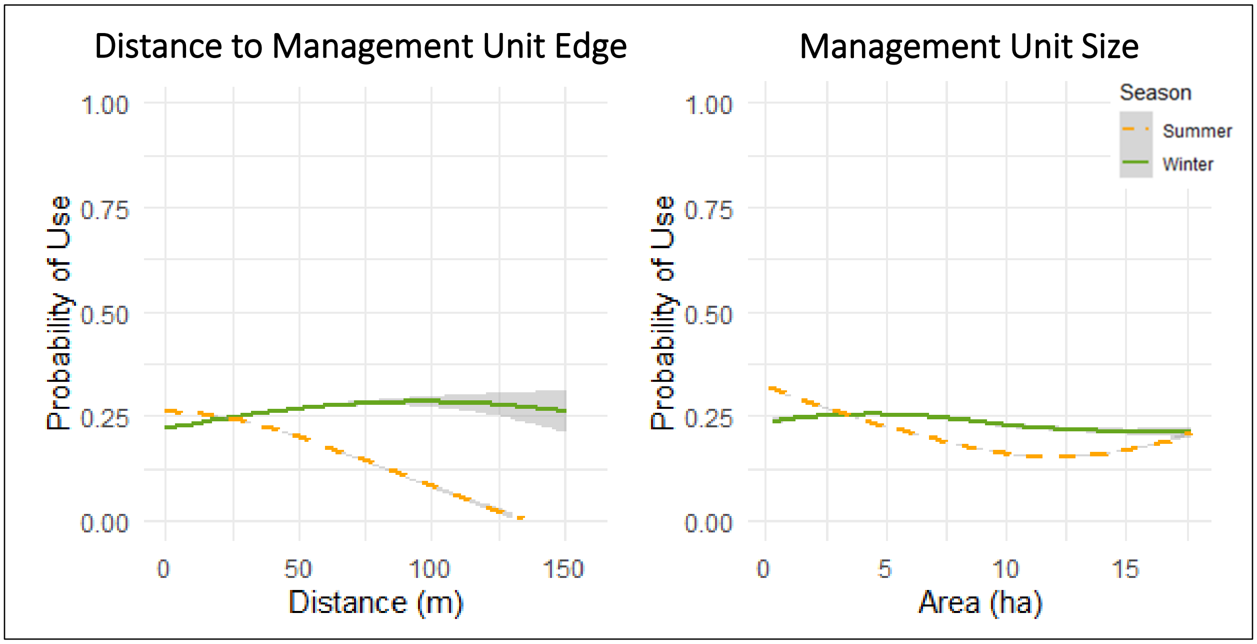

Figure B.5. Influence of management covariates on probability of use from the best-supported model from resource selection on Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2021–2023. Beta estimates for management unit size during the winter crossed 0, indicating little relationship with the predictor covariate.

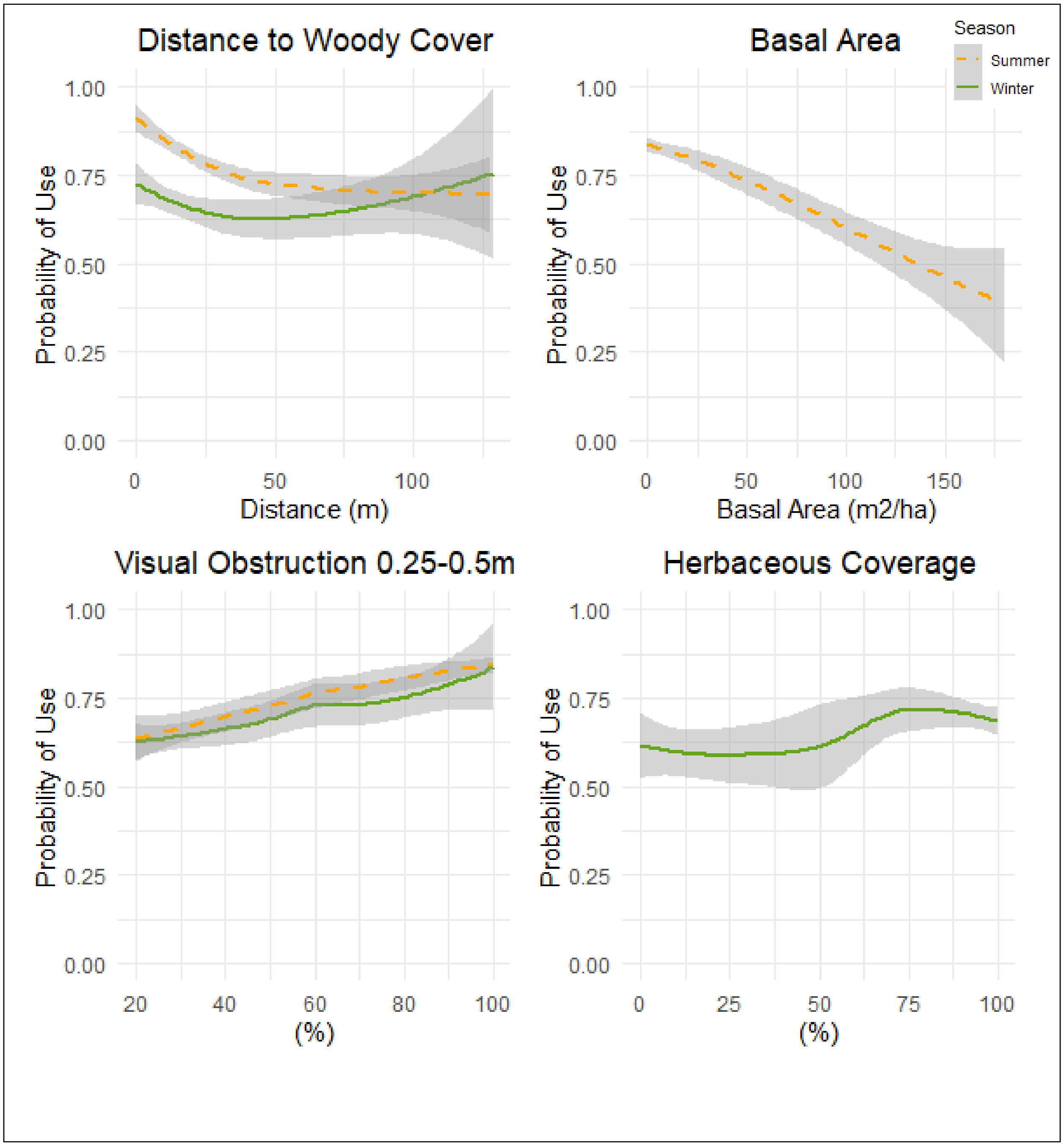

Figure B.6. Influence of micro-scale covariates on probability of use from the best-supported model. Model represents the breeding and non-breeding seasonal selection on Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2021–2023. Beta estimates for breeding season visual obstruction, non-breeding season vegetation height, and non-breeding season herbaceous cover crossed 0, indicating little relationship with the predictor covariates.

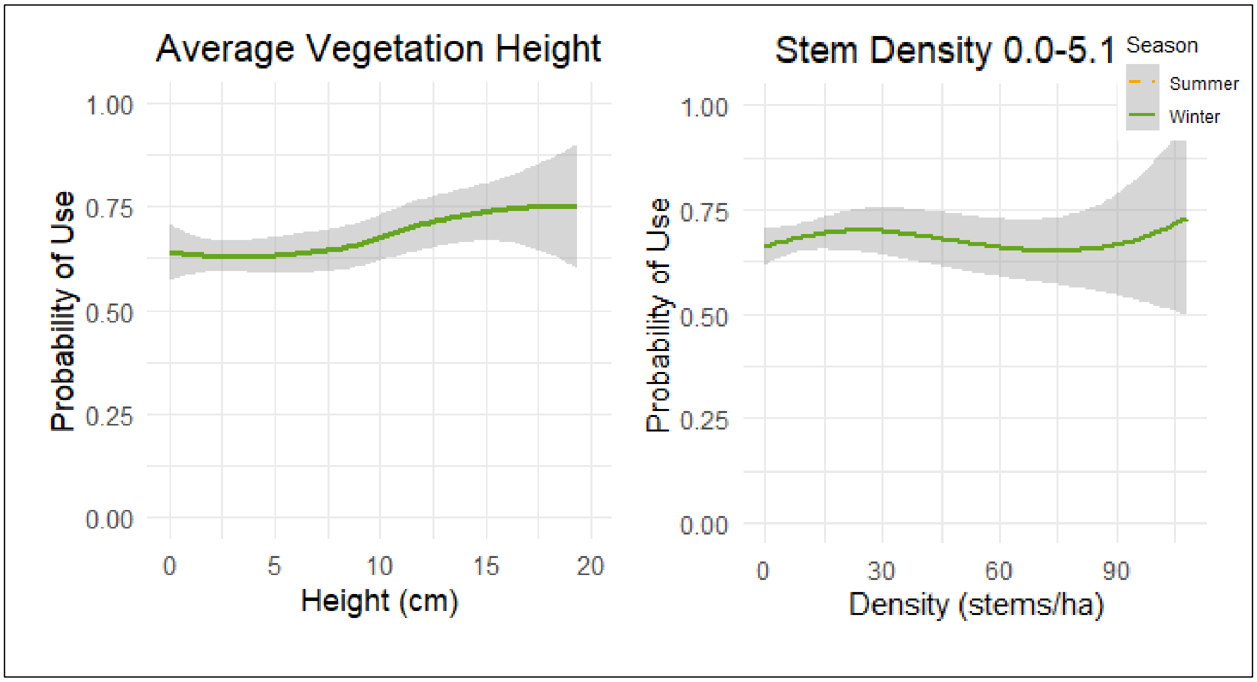

Figure B.6. Continued.

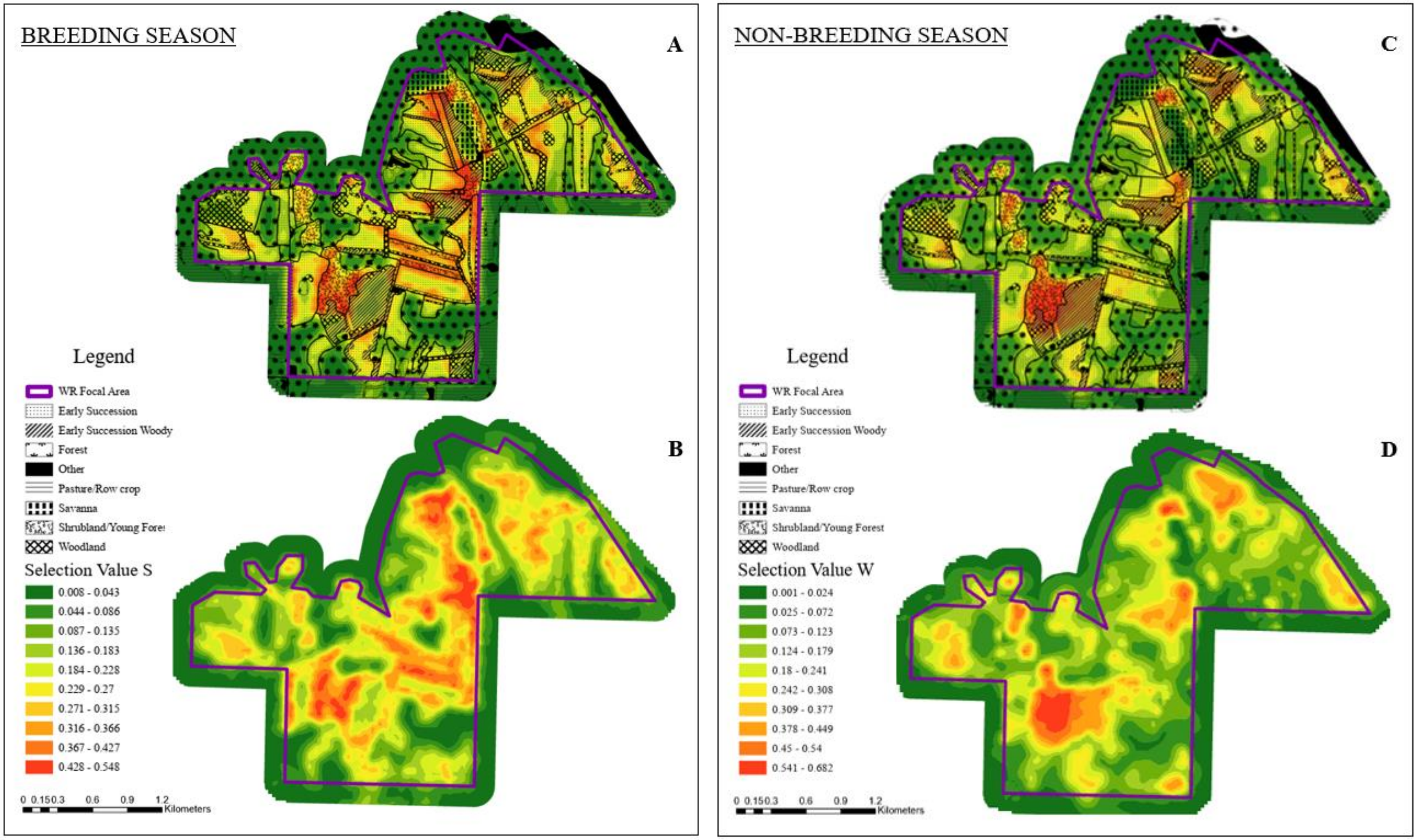

Figure B.7. Vegetation type map and surface predicting probability of use by bobwhite across Wolf River quail focal area, TN, 2021–2023. Predicted surface was created separately for the breeding and non-breeding season using macro-scale characteristics.

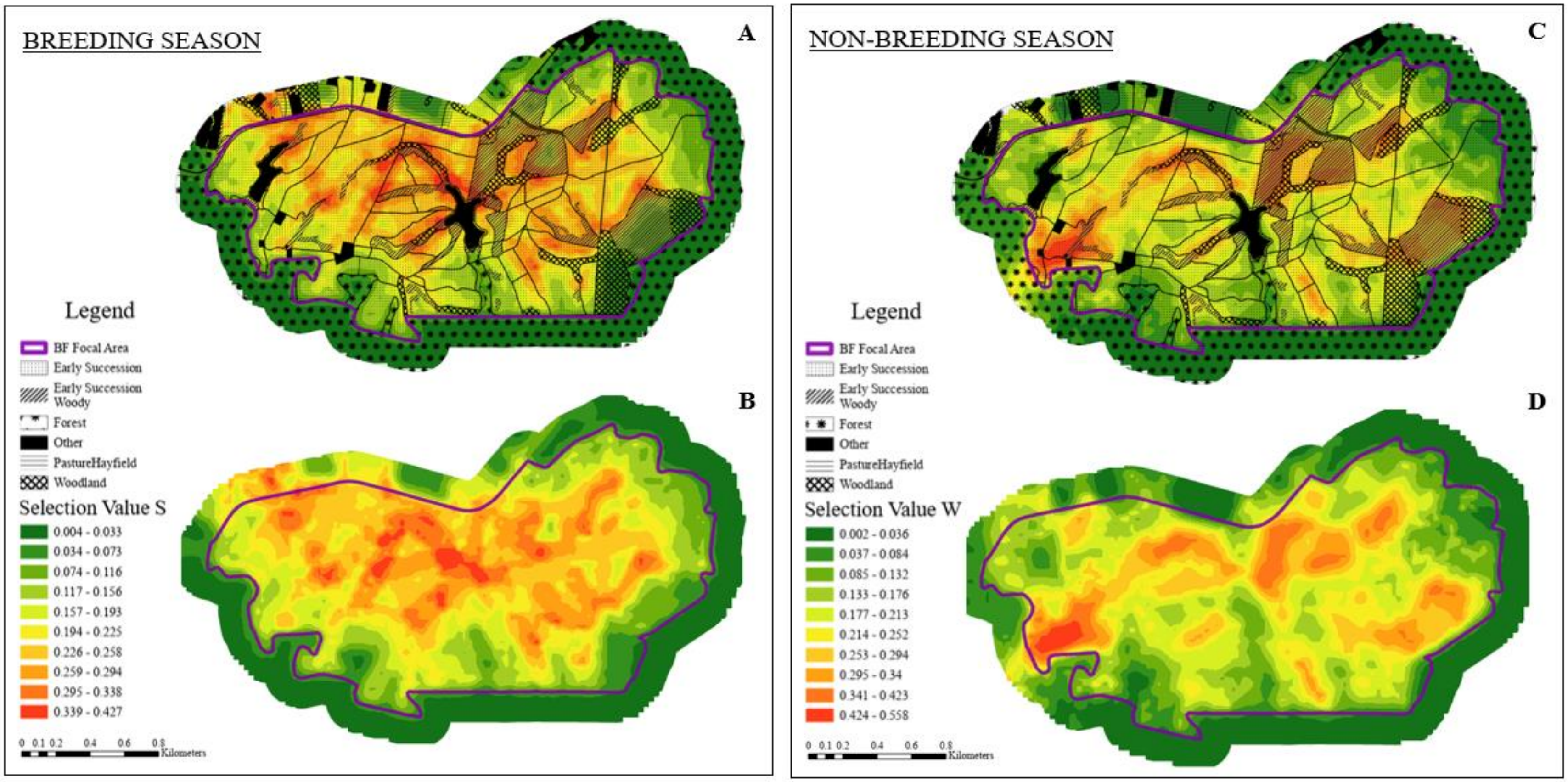

Figure B.8. Vegetation type map and surface predicting probability of use by bobwhite across Bridgestone-Firestone quail focal area, TN, 2021–2023. Predicted surface was created separately for the breeding and non-breeding season using macro-scale characteristics.

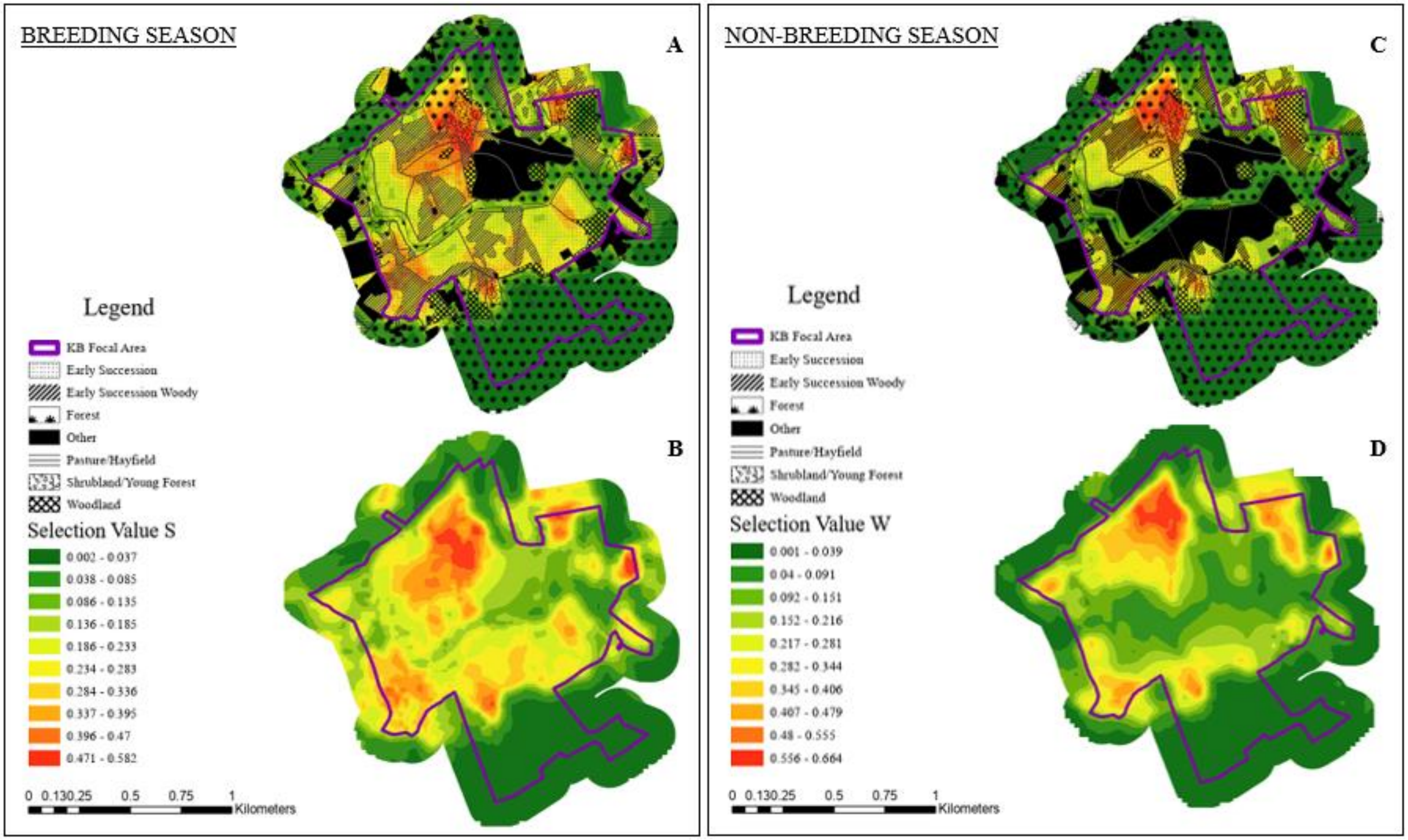

Figure B.9. Vegetation type map and surface predicting probability of use by bobwhite across Kyker Bottoms quail focal area, TN, 2021–2023. Predicted surface was created separately for the breeding and non-breeding season using macro-scale characteristics.

CHAPTER 3. FACTORS AFFECTING NORTHERN BOBWHITE SURVIVAL ON QUAIL FOCAL AREAS IN TENNESSEE

ABSTRACT

The northern bobwhite (*Colinus virginianus*) is an iconic upland gamebird throughout the southeastern United States, but populations have declined largely because of changing land use, habitat loss, and fragmentation. Rising meso-mammalian predator populations also affect bobwhite survival, especially as bobwhite habitat quality and quantity decrease. In response to the declining bobwhite population in Tennessee, the Tennessee Wildlife Resources Agency implemented intensive bobwhite habitat management on three wildlife management areas. To better inform quail management, we monitored adult bobwhite survival during the breeding (Oct–Mar) and non-breeding (Apr–Sep) seasons, assessed the impact of macro- and micro-scale vegetation characteristics on survival, explored the relationship between management practices and survival, and determined the relationship of meso-mammalian predator relative abundance with survival. We captured 312 bobwhites from 2021 to 2023, radio-tagged them with VHF transmitters, and monitored them 3–5 times weekly to document survival. We characterized macro-scale vegetation by characterizing landscape structure and composition from satellite imagery with ArcGIS Pro and we characterized micro-scale vegetation by sampling structure and composition at telemetry locations. We used Program RMark to estimate seasonal survival rates related to biological characteristics (i.e., sex, age), macro-scale vegetation (vegetation type, etc.), micro-scale vegetation (i.e., groundcover composition, midstory stem count, etc.), management practice (i.e., burning, disking, herbicide applications), and predator index covariates using the Kaplan-Meyer known-fate survival model. We used AIC_C model selection in R to select the model that best explained survival. Survival pooled across sites and years was 37.0% (SE = 0.008) and 58.8% (SE = 0.010), during breeding and non-breeding seasons, respectively. Breeding season survival was negatively related to the amount of young forest within the home range. At the micro-scale, survival was negatively related to increased midstory stems, consistent with the macro-scale results. Management unit size (ha) was negatively related to survival during the breeding season, with survival decreasing by 75% as management unit size increased from 3 ha to 6 ha. Meso-mammalian presence was negatively related to bobwhite survival, but less than macro- and micro-scale covariates. During the non-breeding season, survival was negatively related to the amount of bare ground, indicating that increased plant coverage, presumably for concealment, was beneficial for bobwhite survival. Burning in the previous year was positively related to survival, as prescribed burning limited woody regrowth, and forb coverage increased with more open structure at ground level. Overall, we detected a contrast in survival between seasons and sites. Breeding season survival was about average whereas non-breeding season survival was very high compared to other population studies in the region. We recommend managers focus on improving breeding season survival, as it appears to be most limiting population growth among the measured demographic parameters. Managers should implement relatively small-scale (i.e., <6 ha) disturbance using frequent prescribed fire and disking (1–2-year return interval) to promote nesting and brooding cover. Cover for escape and thermoregulation during the non-breeding season can be maintained on smaller well-interspersed areas using a 3-year fire-return interval. Additional predator management in addition to habitat management is likely a pre-requisite for population growth on Kyker Bottoms and Wolf River focal areas, where measured survival rates are inadequate for supporting population growth.

KEYWORDS *Colinus virginianus*, early succession, habitat, meso-mammalian predators, management practices, northern bobwhite survival

The northern bobwhite (*Colinus virginianus*; hereafter bobwhite) has experienced significant population decline throughout its range, with a national decline of 3.5% per year over the past five decades, with a much greater decline in Tennessee (5.9% per year; Sauer et al. 2017, Pardieck et al. 2019). The decline in bobwhite populations is related primarily to land use change and disturbance suppression leading to habitat loss and fragmentation (Brennan 1991, Guthery 1997, Brady et al. 1998, Veech 2006, Tanner et al. 2012). To address these declines, the Tennessee Wildlife Resources Agency (TWRA) established quail focal areas (QFAs) in each of the four major regions of the state (Tennessee Wildlife Resources Agency 2021). QFAs are designated areas where management practices focus on improving bobwhite habitat and increasing resident populations. Management activities include controlled burning, selective timber thinning, disking, and herbicide applications to create and maintain early successional vegetation communities, with the goal of increasing bobwhite survival, reproduction and populations (Tennessee Wildlife Resources Agency 2021). To date, there has been little effort to evaluate the success of the quail focal area management in Tennessee. Such evaluation is critical to gauge progress and develop a rigorous foundation for adaptive management (Gruchy and Harper 2014).

Bobwhite population declines range-wide likely are a consequence of inadequate survival, often during the non-breeding season (Sandercock et al. 2008). Bobwhite survival is related to weather, predators, human influences, and disease, but most importantly, habitat quality and quantity (Stoddard 1931, Roseberry et al. 1979, Roseberry and Klimstra 1984, Brennan 1991). Bobwhite habitat in Tennessee generally consists of early successional plant communities, including old-fields, oak/pine savannas, and open oak/pine woodlands (Seckinger et al. 2008, Tennessee Wildlife Resources Agency 2021). Habitat degradation and fragmentation has isolated bobwhite populations and increased vulnerability to predation across Tennessee and in other parts of their range (Rollins 1999, Rollins and Carroll 2001, Cook 2004, Seckinger et al. 2008). Identifying limiting factors as related to habitat and the influence of predator populations on bobwhite survival on the Tennessee QFAs will inform management going forward.

Predation is the primary cause of mortality for bobwhite (Errington 1934, Stoddard 1938, Carter 1995, Rollins and Carroll 2001). Research documenting predator communities and their influence on bobwhite survival on QFAs can help wildlife managers learn how to mitigate predation risk. A diversity of mammalian, avian, and reptilian species prey on bobwhite during different life stages. Depending on region, avian predators are responsible for about 60% of adult mortality, whereas mammalian predators are responsible for about 30% (Burger et al. 1995, Carter et al. 2002, Cox et al. 2004, Sisson et al. 2009). Managing avian predation is limited to habitat management because of protection of raptors under the Migratory Bird Treaty Act of 1918, but mammalian predation can be directly managed through predator removal (Rollins and Carroll 2001). Primary mammalian predators, such as coyotes (*Canis latrans*), raccoons (*Procyon lotor*), foxes (*Urocyon cinereoargenteus, Vulpes vulpes*), and bobcats (*Lynx rufus*), all opportunistically prey upon bobwhites (Rollins and Carroll 2001, Brennan et al. 2020) and all occur on the Tennessee QFAs. Monitoring bobwhite predator distribution and relative abundance in areas actively being managed for bobwhite may inform managers on the most effective practices for sustaining bobwhite populations in light of pervasive mammalian predator populations.

Studying survival during both the breeding and non-breeding seasons is crucial for wildlife managers to identify when bobwhite are most vulnerable and focus management efforts on the most-limiting factors. Previous research indicates non-breeding season survival often is the most limiting factor for population growth (Sandercock et al. 2008), but inadequate breeding season survival also has been documented in several southeastern populations (Seckinger et al. 2008, Gates et al. 2012, Doggett and Locher 2018, Unger et al. 2012). Studies in Ohio (Gates et al. 2012) and Kentucky (Unger et al. 2012) reported very poor non-breeding season survival rates between 11-28%, whereas Georgia and Florida (Jackson et al. 2022) reported much greater non-breeding season survival rates between 45-63%, indicating a positive relationship between intensive management and survival. Breeding season survival rates were relatively similar across the eastern U.S., including Arkansas (40%; Doggett and Locher 2018), Tennessee (38%; Seckinger et al. 2008), Ohio (29%; Gates et al. 2012), and Kentucky (48%; Unger et al. 2012). Seasonal shifts in home ranges may further influence bobwhite survival, underscoring the importance of understanding these dynamics and the influence of management type, spatial extent, and frequency on survival (Holt et al. 2009, Janke 2011, Peters et al. 2015).

Bobwhite select habitat across multiple spatial scales (see Chapter 1, Johnson 1980, Brooke et al. 2015, Kroeger et al. 2020), and management at different scales may influence survival (Janke et al. 2015, Peters et al. 2015, Brooke et al. 2017). Macro-scale selectivity is identified as habitat selection in the entirety of a local population’s home range (i.e. the management area and adjacent public/private land; Tanner et al. 2012, Brennan et al. 2020). Macro-scale characteristics, such as closed-canopy forest and a lack of patch connectivity, can lead to poor reproduction and poor survival (Burger and Lynch 1999, Seckinger et al. 2010, Miller et al. 2017). Micro-scale selectivity is defined as habitat selection where an individual animal occurs (Tanner et al. 2012, Brennan et al. 2020). Micro-scale features, such as woody stem density and openness at ground level, may influence survival through concealment from predators, mobility, and availability of food resources (Williams et al. 2004, Flock 2006, Tanner

2012, Brooke and Harper 2015, Mosloff et al. 2021). Understanding bobwhite survival at different scales represents a comprehensive foundation for bobwhite management by focusing on the larger-scale distribution of vegetation types as well as finer-scale vegetation characteristics that influence how a given bobwhite uses the resources which are available to it.

We initiated a radio-telemetry study to better inform quail management across three QFAs in Tennessee from 2021 to 2023. Our objectives were to 1) estimate bobwhite survival during the breeding (Oct – Mar) and non-breeding (Apr – Sep) seasons, 2) determine the influence of macro- and micro-scale vegetation characteristics on survival, 3) evaluate the relationship between management practices and survival, and 4) investigate the potential relationship between meso-mammalian predator relative abundance and adult bobwhite survival. We hypothesized survival would differ across the three QFAs because of differences in the availability of preferred vegetation types on the focal areas. We predicted bobwhite in QFAs comprised of less forest would have greater survival because closed-canopy forest generally has less desirable vegetation structure (for concealment) and composition (for food availability; Seckinger et al. 2008). We predicted survival would be lowest during the non-breeding season because of increased predation risk and reduced vegetation cover needed for protection and food resources during the winter (Johnson et al. 1990, Hiller and Guthery 2005). We predicted breeding season survival would be positively related to the prevalence of forbs because of the food resources (seed and insects) and cover that forbs provide (Cross 1956, Rosene 1969, Hurst 1972, DeVos and Mueller 1993). Lastly, we predicted meso-mammalian predator relative abundance would be negatively related to bobwhite survival, more so during the breeding season when individual predation risk may increase without the protection of a covey (Rectenwald et al. 2021).

STUDY AREA

We conducted our study on three wildlife management areas owned and managed by the Tennessee Wildlife Resources Agency (**Figure C.1**). At each property, TWRA had designated a portion of the WMA as an “anchor reserve” where management efforts were focused on maximizing habitat quality and quantity for bobwhite and to serve as a source of bobwhite for a larger Quail Focal Area (QFA) that extended beyond the WMA (Tennessee Wildlife Resources Agency 2021). Each anchor area was selected by TWRA staff based on the documented presence of bobwhite and the perceived opportunity for quail management and for populations to expand into surrounding public and private land.

Wolf River WMA, located in Fayette County, TN, USA, was 1,714 ha and consisted of bottomland hardwood forests and fields along the Wolf River. The Wolf River QFA (hereafter WR) consisted of 535 ha of interspersed fields and forested tracts. Prior to ownership by TWRA in1996, fields at WR were used for row cropping cotton (Gossypium herbaceum) and soybeans (Glycine max), and for pasture for cattle (B. Gilbert, TWRA, personal communication). Soils at WR consisted of various silt loams (i.e. Calloway silt loam) and sandy loams (Collins fine sandy loam; Soil Survey Staff Natural Resources Conservation Service 2024). Elevations vary from 113 m to 131 m. Lands surrounding WR consisted of bottomland hardwood forest, row crops, and human-developed land use and cover types.

Bridgestone-Firestone WMA, located in White County, TN, USA, consisted of 4,047 ha on the Cumberland Plateau, spanning the Caney Fork River. Most of the area consisted of hardwood forests, but the Bridgestone-Firestone QFA (hereafter BF) was a contiguous, 308-ha tract comprised of fields, scattered pine-hardwood woodlands, and hardwood forests. Throughout BF, soils consisted of Lonewood loam and Ramsey-Lily complex (Soil Survey Staff

Natural Resources Conservation Service 2024). Elevations vary from 500 m to 536 m. Prior to TWRA ownership in 1998, land use at BF was pasture and hay production associated with a cattle operation (A. Deck, TWRA, personal communication). Lands surrounding BF consisted of hardwood forest and a mixture of pasture, woodlands, and human-developed land use and cover types.

Kyker Bottoms WMA, located in Blount County, TN, USA, was 262 ha, with 227 ha of that in the Kyker Bottoms QFA (hereafter KB), which included 144 ha of upland fields and woodlands managed for bobwhite. The remaining acreage consisted of hardwood forest and wetlands managed for waterfowl, which were available to bobwhite only during the breeding season when the waterfowl units were not flooded. Prior to TWRA purchase in 1997, the land was used for hay production and pasture (W. Smith, TWRA, personal communication). Soils at KB consisted of various silt loams (i.e. Dandridge silt loam), sandy loams (i.e. Holston fine sandy loam), and silty clay loams (i.e. Sequatchie silt loam; Soil Survey Staff Natural Resources Conservation Service 2024). Elevation varied from 259 m to 335 m. Land surrounding KB consisted of hardwood forest, pasture, hayfields, and human-developed land use and cover types.

Management to maintain early successional plant communities for bobwhite on all areas included prescribed fire, disking, and broadcast and spot-spray herbicide applications. Management units were delineated by wildlife management staff and were defined as contiguous areas in which consistent management practices occurred delineated by natural (e.g., forest edge, creek) or manmade features (e.g., field road, firebreaks). Management units that contained early successional vegetation types typically were between 8 and 24 ha. Management units could change seasonally depending on the management practices implemented.

METHODS

Bobwhite capture and monitoring

We trapped bobwhites during the non-breeding season (September–April) in standard funnel traps (Stoddard 1931) baited with scratch grains (cracked corn, milo, whole oats) or songbird seed mixtures. Each trap was lined with hardware cloth, covered with burlap, and then covered with vegetation to minimize bird injury and stress and to lower visibility to predators. We checked traps in the late afternoon when daily temperatures were <0°C and late morning and late afternoon when temperatures were >23.9°C. We did not deploy traps during extreme weather events (storms, temperatures, etc.) to prevent bird injuries. We typically deployed 30 traps per night per focal area, centered around historical and current covey locations, with the intention to trap as many coveys as possible. Our target was to maintain a sample size of ≥30 radio-tagged bobwhite each year on each focal area. We attached an American Wildlife Enterprises very high frequency (VHF) quail transmitter (5.0–6.5 g; model number AWE-QLL) with an expected battery life of 11 months (American Wildlife Enterprises, Monticello, FL, USA) via a necklace collar to each individual bird weighing ≥130 g. We attached aluminum leg bands (number 7 butt end style, National Band and Tag Company, Newport, KY, USA) to individuals to ensure identification of the bird during recapture events, regardless of radio-tag life and retention. We determined sex by evaluating the color of the supercilium, cap, auricular, and throat (Petrides and Nestler 1943, Petrides and Nestler 1952). We determined age by the presence of buffy tips (juveniles) on the primary coverts, along with the muddy coloration of facial markings (Petrides and Nestler 1943, Petrides and Nestler 1952, Rosene 1969). We recorded mass with a Medio-Line spring scale (300-g; Pesola, Schindellegi, Switzerland), measuring to the nearest gram. We evaluated body condition on a ranked scale (numbering 1–4, 1 indicating excellent and 4 indicating poor), based on the development of the breast muscles, injuries suffered to individual, and release performance. Capture and handling protocols were approved by the Institutional Animal Care and Use Committee at the University of Tennessee-Knoxville (No. 0561-0720).

We tracked bobwhite movement and survival during the non-breeding (Oct. 1–Mar. 31) and breeding (Apr. 1–Sep. 30) seasons using a 3-element Yagi antenna and a receiver (receiver model R410, Advanced Telemetry Systems, Isanti, MN, USA). We used the homing method to locate individual birds within 30–50 m (White and Garrott 1990) without flushing them. We calculated bobwhite locations in Excel using the observer location (recorded by GPS), and the estimated azimuth and distance to the bird. We recorded the vegetation type (**Table C.1**) where the bird was located and varied locations by time of day and day of week to balance potential temporal bias. We also noted an association with a covey if applicable. We monitored individual bobwhite ≥3 times per week during the non-breeding season and ≥5 times per week during the breeding season to better determine reproductive activity.

Mortality signals occurred after a 12-hr period of inactivity and were investigated to note the fate of individual birds. If the mortality site showed evidence of predation (damaged transmitter, bird remains, etc.), we assumed predation and determined the predator taxa based on the field sign (Curtis et al. 1988). We assumed avian predation if the transmitter showed signs of scratch marks, the carcass had been plucked, and/or the remains were located near an obvious perch. We assumed mammalian predation if the transmitter and/or remains showed signs of chewing or if the remains were cached in dense vegetation. If the transmitter was undamaged, with no apparent sign of predation, we considered it “dropped” and assumed the individual was alive but with an unknown encounter history beyond that date.

Home range analysis

We used home range analysis to calculate an average seasonal home range to define an area of use for each bobwhite or covey to relate to survival. The breeding season home range was determined individually whereas the non-breeding season home range was determined on a covey basis, with ≥20 locations per individual or covey per season. We calculated the minimum convex polygon (MCP) of all locations using the adehabitat package in Program R (Calenge 2006). To ensure a robust sample size, home ranges were averaged across all bobwhite from 2021, 2022, and 2023 breeding and non-breeding seasons, respectively.

Macro-scale characterization

We used macro-scale characteristics to determine the potential influence of different landscape-level covariates on survival (**Table C.1** and **C.2**). During the breeding season, we only selected individuals that we did not observe actively nesting or brooding-rearing because we were not interested in reproductive behavior. Presumably most of the individuals we monitored during the breeding season were attempting to breed, although our monitoring strategy was focused on documenting survival and resource use, as opposed to locating nests and monitoring broods. Given our monitoring strategy, we documented actual nesting for ≤20% of the females monitored and ≤10% of the males monitored.

We characterized vegetation type based on delineation from satellite imagery using ArcGIS Pro (ESRI 2023, Redlands, CA, USA; **Table C.1**). We ground-truthed areas of each vegetation type to validate our delineations. We classified 12 vegetation types: deciduous forest, coniferous forest, early succession, early succession woody, savanna, young forest, woodland, open pine row, food plot, row crop, pasture/hayfield, and other (composed of water and manmade structures). We defined forest as areas with trees with >80% canopy cover. We defined areas dominated by regenerating trees <11.4 cm in diameter and <10 years old as young forest. We defined savannas as areas with 10–30% canopy cover and woodlands as areas with 30–80% canopy cover. The understory in both woodlands and savannas were dominated by herbaceous plants. We defined open pine rows as coniferous trees planted in 12–18 m wide rows. We defined early succession as plant growth consisting of shade-intolerant forbs and grasses, with scattered shrubs and trees that did not comprise >50% of species composition. Early succession woody differed from early succession with woody species compromising >50–80% of species composition. We defined food plots as areas planted for wildlife food, comprised of crops such as corn (*Zea mays*), sunflowers (*Helianthus annuus*), sorghum (*Sorghum bicolor*), or millet (*Panicum miliaceum*). We defined pastures as areas either being grazed by livestock or being managed as hayfields, and generally dominated by nonnative grasses (*Festuca arundinacea, Paspalum dilatatum, Cynodon dactylon*). We defined row crop as areas comprised of planted crops such as corn and soybeans (*Glycine max*) intended for agricultural production. We defined areas as ‘other’ if they were altered by manmade structures (such as firebreaks, roads, houses, lawns) or ponds or wetlands.

For each season (breeding and non-breeding) and year (2021, 2022, and 2023), we delineated vegetation types to account for temporal variation in vegetation on the landscape. We created vegetation type rasters with 10- x 10-m pixels, consistent with telemetry location error based on homing to within 30–50 m of an individual. We calculated the percentage of vegetation types within individual home ranges. To do so, we first estimated the centroid of an individual’s locations by using the Mean Center tool in ArGIS Pro. We centered a circular buffer, equal to the average seasonal home range size, at the centroid location and calculated the percentage of each vegetation type within the buffer. We limited the survival analysis to inclusion of 5 vegetation types believed to be the most influential to bobwhite survival and that were generally prevalent across most focal areas (percent deciduous forest, percent early succession, percent early succession woody, percent young forest, and percent woodland; Roseberry and Sudkamp 1998).

We calculated an interspersion index for each cell using the Focal Statistics tool in ArcGIS Pro, which calculated the intermixing of units of vegetation types within a 100- x 100-m neighborhood around each cell. The index ranged from 1 to 8, with higher values indicating greater intermixing and lower values indicating less intermixing. We calculated the average interspersion index value within the centered home range, similarly to how we calculated percentage of vegetation types.

We averaged the distance to the nearest manmade structure for any bird locations that fell within the home range. We calculated the distance (m) to the nearest manmade structure (road, firebreak, building, etc.) for bobwhite locations and random locations using the Near tool in ArcGIS Pro.

Micro-scale characterization

We randomly selected individual bobwhite and individual locations for vegetation characterization and sampled during the breeding (May–August) and non-breeding seasons (December–March). Individuals during the non-breeding season do not move independently of one another because of covey association (Janke 2011). Therefore, during the non-breeding season, we selected individual coveys and individual covey locations randomly. Sampling during both breeding and non-breeding seasons occurred within 2 weeks of use to minimize potential changes in vegetation associated with selected locations. Random points were used to characterize availability of the micro-scale vegetation within a bobwhite’s home range. We selected random points based on a randomly selected distance (30–175 m) and azimuth (0–359°)

from the bird location. We selected 175 m as the maximum distance as that was the average daily movement of bobwhite over a 1-year period (Brooke et al. 2015). Once we choose random points, we navigated to the location using a handheld GPS unit (Garmin eTrex 10, Olathe, KS, USA). We also randomly sampled points within each vegetation type to better characterize the micro-scale vegetation characteristics within each type.

During the breeding season, we recorded a total of 19 vegetation characteristics for micro-scale evaluation. We measured vegetation composition and structure along a 30-m point-intercept transect, centered over location coordinates (the tape extended 15 m to either side), placed following a randomly selected bearing (Bonham 1989). We noted all plant species present at each 1-m mark along the transect. We grouped species into plant types (**Table C.2**) and calculated percent coverage by dividing the total number of points with detections by the total number of sampling points on the transect (n = 30). Plant types during the breeding season included forb, warm-season grass, cool-season grass, sedges and rushes, semi-woody (briars and vines), shrub, tree, bare ground (no vegetation present), and other (leaf litter and coarse woody debris). Non-breeding season plant types included herbaceous (grasses and forbs), semi-woody (briars and vines), woody (shrubs and trees), bare ground (no vegetation present), and other (leaf litter and coarse woody debris).

We defined leaf litter as senescent vegetation over a year old at ground level. We sampled litter depth and ground-sighting distance at four intervals along the transect (0 m, 10 m, 20 m, 30 m). We measured litter with a ruler (cm). We measured ground-sighting distance as openness at ground level using a horizontal PVC sighting tube (diameter of 3.8 cm) positioned 15.2 cm above the ground, representative of bobwhite height (Gruchy and Harper 2014). One observer looked through the sighting tube while a second observer moved a brightly colored pole (bottom 15.2 cm colored, remainder white) perpendicularly away from the observer until the observer could not see the colored portion of the pole. We recorded distance from the sighting tube to the pole (nearest 0.1 m). We took vertical obstruction readings using a modified Nudd's (1977) board. The board consisted of four strata: 0.00–0.25 m (first stratum), 0.26–0.50 m (second stratum), 0.51–1.00 m (third stratum), and 1.01–2.00 m (fourth stratum). The first stratum (0.00–0.25 m) represented visual obstruction at the level where bobwhite occurred (Powell 2022). The second stratum (0.26–0.50 m) represented visual obstruction important for brooding cover (Taylor et al. 1999). The third stratum (0.51–1.00 m) represented visual obstruction important for cover from meso-mammalian predators (Yoho and Dimmick 1972, Roseberry and Klimstra 1984). The fourth stratum (1.01–2.00 m) represented visual obstruction for cover from avian predators (Yoho and Dimmick 1972, Roseberry and Klimstra 1984). Standing at the location point-center, we viewed the Nudd's board from 5 m in each cardinal direction. We then estimated the percentage of each stratum that was covered by vegetation and assigned the value to 1 of 5 cover classes (1 = 0–20%, 2 = 21–40%, 3 = 41–60%, 4 = 61–80%, and 5 = 81–100%). We defined escape cover as any area >15 m^2 with dense shrubby/semi-woody cover that provided thermal cover or cover from predators. We measured distance (m) to nearest escape cover from bird locations and random points via laser rangefinder (+/- 1 m). We recorded tree basal area using a 2.5-m^2/ha prism and identified trees to species. We counted woody stems >1.4 m tall and <11.4-cm diameter by species within a 5-m radius of bird and random point locations. We also grouped woody stems into two diameter classes (0.0–5.1 cm and 5.1–11.4 cm).

During the non-breeding season, we measured visual obstruction (Nudds board), vegetation cover, and average vegetation height 5 m from the bird and random point in each cardinal direction. We measured vegetation composition by recording the species present at the base of the Nudd's board (where the first strata contacted the ground). We measured average vegetation height to the nearest 1 cm. For both the breeding and non-breeding seasons, we used the average seasonal home range at the centroid location for each individual bird and averaged the micro-scale vegetation characteristics for any samples (bird locations or random locations) that fell within the home range.

Management practices

TWRA wildlife managers delineated management practices on focal area maps during breeding and non-breeding seasons for each year of the study. Management practices included burning, disking, broadcast herbicide application, and spot-spraying herbicide application. Forest management and woody stem reduction were management practices also used but were not prevalent across all focal areas and therefore we did not include them in our analysis. For each management practice, we calculated the percentage of disturbance within the seasonal home range for each radio-tagged bird in a given year. For bird and random locations, we measured the distance (m) to the edge of the management unit using the Near tool in ArcGIS Pro. Management unit boundaries were defined by roads, firebreaks, or other natural breaks. We mapped management units with ArcGIS Pro and calculated the associated area (ha). For both the breeding and non-breeding seasons, we used the average seasonal home range at the centroid location for each individual bird and averaged distance to edge of management unit and management unit size for any samples (bird locations or random locations) that fell within the home range. We calculated the percent cover of individual management practices within home ranges. To do so, we first estimated the centroid of an individual bobwhite's locations by using the Mean Center tool in ArGIS Pro. We centered a circular buffer, equal to the average seasonal home range size, at the centroid location and calculated the percent cover of each management practice within the buffer.

Predator index

In 2023, to monitor the meso-mammalian predator community, we deployed a camera grid across each focal area, placing each camera (Browning model BTC-6HD-MAX, Birmingham, AL) 500 m apart with 1 camera/25 ha (Jackson et al. 2018, Palmer et al. 2019). We placed cameras along linear features, such as roads or firebreaks, mounted 0.3 m above ground on a t-post (Dickie et al. 2020). Based on this sampling design, we placed 24 cameras at WR, 16 cameras at BF, and 12 cameras at KB. We cleared a 6 x 1.5 m target area in front of each camera and maintained the target area to allow a clear line of sight for the camera. We used our cleared target area as a standard distance to record wildlife observations- anything that was outside of that distance was excluded from analysis. We set cameras to record 3 photos consecutively, 1 sec apart, to ensure the best likelihood of capturing fast-moving predators. After the third consecutive photo, the camera would not trigger again until after a 1–min delay. We placed a fatty acid scent tablet 2.4–3.0 m in front of each camera (Wildlife Control Supplies, Pocatello, ID, USA) to attract raccoon, bobcat, fox, and coyote (Stoddard 1931, Rollins and Carroll 2001, Staller et al. 2005, Jackson et al. 2018). We replaced scent tablets every 2 weeks and swapped camera SD cards every 4 weeks. We also replaced scent tablets immediately after large rain events to avoid scent loss.

We categorized photos by species for each camera, recording the greatest number of individuals of each species present from the 3-photo sequence. We combined all meso-mammalian predator detections by breeding and non-breeding seasons to provide an overview of the predator community. We recorded avian predators occasionally, but we did not include them in our analysis because our camera grid was not optimal for effectively recording avian presence. Meso-mammalian predators recorded included bobcats, coyotes, feral cats (*Felis catus*), gray fox, red fox, raccoons, dogs (*Canis lupus familiaris*), long-tailed weasels (*Mustela frenata*), and American mink (*Neogale vison*). We calculated the predator index (predators/day) by dividing the total number of mammalian predators that visited a camera per breeding or non-breeding season by the total number of days the camera was deployed per season (Jackson et al. 2018).

To assign a predator index value to an individual bird during each season, we averaged the predator index values of the nearest 3 cameras to the centroid of a bobwhite's locations for the breeding and non-breeding seasons. We identified the 3 nearest cameras to individual birds using the Near tool in ArcGIS Pro and averaged the predator index value for the associated cameras. During our predator surveys, management area staff did not trap/remove meso-mammalian predators from focal areas.

DATA ANALYSIS

We analyzed survival using the Kaplan-Meyer known-fate model within R MARK (Kaplan and Meier 1958, Pollock et al. 1989, White and Burnam 1999). We used a post-capture exclusion period of 7 days to negate any potential effects of capture-related myopathy (Guthery and Lusk 2004, Holt et al. 2009). We use a staggered-entry design to allow for inclusion of individuals captured during the season of interest (Pollock et al. 1989). We right-censored individuals that emigrated from the focal area, experienced radio failures, or had unknown fates. Individuals that survived the season of interest until the next season were coded as new individuals in the analysis. We recorded encounter histories in 26 weekly intervals for each season. We assumed birds to be independent of each other, regardless of covey affiliation. We assumed unmarked birds would have similar fates as radio-tagged individuals (White and Garrott 1990).

We used Akaike's Information Criterion (AIC_C) to determine model selection (Akaike 1976, Burhnam and Anderson 1998). Our survival models were analyzed in 5 different sets based on covariate groups: biological, macro-scale vegetation, micro-scale vegetation, management, and predator (**Table C.2**). We grouped seasons (breeding and non-breeding) together during the biological model set as we wanted to compare seasons. Each set of models was assessed to find the best-supported model based on the lowest AIC_C score.

We evaluated all covariates for correlation using Pearson's correlation coefficient with a threshold of 0.7. If covariates were correlated, we removed the covariate with less apparent biological or management relevance from further analyzes (Shrestha 2020, Rosche et al. 2021). We retained all the Nudd's board measurements despite their correlations because of their potential importance in survival but correlated strata were not run within the same model set to avoid potential collinearity problems (Graham 2003, Dormann et al. 2013, Brooke et al. 2015). Management unit size and distance to management unit edge were correlated, so we focused on management unit size.

The biological covariates included sex, age, weight, body condition, year, site, and season. We tested for differences in sex, age, and focal areas with chi-squared tests. We deemed results significant if $\alpha < 0.05$. Macro-scale vegetation covariates included distance to manmade structures, an interspersion index, and percent cover by individual vegetation types (**Table C.1**). Micro-scale covariates included percent cover by plant types, stem density, basal area, distance to nearest woody cover, visual obstruction score, average vegetation height (only for non-breeding season), litter depth (only for breeding season) and ground sighting distance score (only for breeding season; **Table C.2**).

We created management models to assess the effects of different management practices on bobwhite survival. To address the timing of response to management, we only used survival data from 2022 with management covariates recorded from 2021 and survival data from 2023 with management covariates recorded from 2022. Management covariates included management unit size (ha) and type/timing of management practice. We categorized burning into three categories based on timing: burning within the past year (0–11 months), burning that occurred 1-2 years ago (12–23 months), and burning that occurred >2 years ago. We only included disking and herbicide applications (broadcast and spot-spraying) within ≤1 year of application. All management-related covariates were continuous variables.

We created predator models to evaluate the relationship between the predator index and bobwhite survival. We limited the predator-survival analysis to individual bobwhite alive during the two seasons in which we ran the predator camera grid (non-breeding = Dec 2022–Mar 2023, breeding = Apr 2023–Sep 2023).

RESULTS

Trapping and habitat sampling

We captured and banded 365 birds (WR = 113, BF = 169, KB = 83) from January 2021 to May 2023 across all three focal areas, and we monitored 42 coveys (2021 = 12, 2022 = 18, 2023 = 16). We captured 155 females, 199 males, and 13 individuals of indeterminate sex. We caught 211 adults, 150 juveniles, and 4 individuals of indeterminate age. We radio-tagged 312 (WR = 103, BF = 130, KB = 79) individuals and were able to use 254 (WR = 102, BF = 95, KB = 57) individuals in our survival analysis. Birds were censored due to radio failure or emigration from the study area. We calculated an average home range of 33.4 ha (± 2.40 SE) during the breeding season and 19.1 ha (± 2.76 SE) during the non-breeding season.

We measured macro-scale characteristics at 37,817 points (6,301 bird locations and 31,516 random locations) for the breeding season and 8,801 points (1,466 bird locations and 7,335 random locations) for the non-breeding season for the initial habitat-survival analysis. For micro-scale survival analysis, we used 837 vegetation surveys (371 bird locations and 466 random locations) for the breeding season and 521 vegetation surveys (231 covey locations and 290 random locations) to characterize vegetation structure and composition.

We fit 14 models to assess biological relationships with survival, including a null model, 6 univariate models, and 7 multivariate models (**Table D.10**). The best-supported model included site and season as covariates. Site improved model fit as it lowered the AIC_C value >2 (**Table C.3**). Average survival rates by site during the breeding season were BF = 0.46 (± 0.013 SE), WR = 0.33 (± 0.013 SE), and KB = 0.29 (± 0.013 SE; **Table C.3**). Average survival rates by site during the non-breeding season were WR = 0.73 (± 0.017 SE), BF = 0.56 (± 0.015 SE), and KB = 0.47 (± 0.021 SE; **Figure C.2**). Averaged across sites, survival was 0.37 (± 0.008 SE) during the breeding season and 0.59 (± 0.010 SE) during the non-breeding season. Survival increased slightly over time during the breeding (2021 = 0.31 ± 0.015, 2022 = 0.34 ± 0.012, and 2023 = 0.44 ± 0.013) and non-breeding seasons (2021 = 0.51 ± 0.031, 2022 = 0.49 ± 0.020, and 2023 = 0.65 ± 0.013; **Table C.3**). Covariates for sex and age did not improve model fit (did not lower the ΔAIC_C value of the top model by >2) and did not differ ($\chi^2 = 0.044$, P = 0.841 and $\chi^2 = 0.233$, P = 0.675, respectively).

Breeding season survival

In our second suite of models, we fit 26 models to assess the relationship between macro-scale vegetation characteristics and survival, including a null model, 8 univariate models, and 13 multivariate models. We had seven competing top models (<2 score; **Table D.11**). Within the best-supported model, covariates included percent deciduous forest and percent young forest (**Table C.4**). Of those covariates, percent deciduous forest included a beta estimate confidence interval that barely crossed 0, indicating a marginally significant negative relationship with survival (95% CI = -0.030–0.003; **Table C.4**). Bobwhite locations contained, on average, 17% (± 0.2 SE) coverage of deciduous forest within the home range (**Figure D.1**). Bobwhite survival was negatively related to the percentage of young forest within the home range (β = -0.034, 95% CI = -0.059–-0.009; **Table C.4** and **Figure C.3**). Bobwhite locations contained, on average, 7.0% (± 0.8 SE) coverage of young forest within the home range (**Figure D.1**).

In the third suite of models, we fit 95 models to assess the relationship of micro-scale characteristics and survival. Our model set included a null model, 19 univariate models, and 61 multivariate models (**Table D.13**). We had four top models (<2 $\Delta\text{AIC}_\text{C}$ score; **Table D.13**). Within the best-supported model, covariates included forb coverage, midstory stems 0.0–5.1 cm in diameter, and its quadratic term, and midstory stems 5.1–11.4 cm in diameter, and its quadratic term (**Table C.5**). Of those covariates, forb coverage included a beta estimate confidence interval that included 0, indicating little relationship with survival (95% CI = -3.534–0.584; **Table C.5**). Bobwhite survival was negatively related to midstory stems 0.0–5.1 cm in diameter (β = -6.30E-04, 95% CI = -1.06E-03–-1.97E-04) and the relationship was non-linear as the quadratic term indicated a negative relationship (β = 7.35E-04; 95% CI = 1.38E-08–1.33E-07; **Table C.5** and **Figure C.4**). On average, there were 319.7 stems/ha (± 14.9 SE) at bobwhite locations (**Table D.12**). Midstory stems 5.1–11.4 cm DBH also were negatively related to bobwhite survival (β = -2.493, 95% CI = -2.29E-02 to -2.82E-03) and the relationship was non-linear (β = 1.398, 95% CI = 1.16E-05–1.16E-04; **Table C.5** and **Figure C.4**). On average, there were 9.0 stems/ha (± 1.1 SE) where bobwhite were located (**Table D.12**).

In our fourth suite of models, we fit 30 models to assess the relationship between management practices and survival, including a null model, 9 univariate models, and 20 multivariate models. We had two top models (<2 ΔAICC score; **Table D.14**). Within the best-supported model, covariates included management unit size and its quadratic term, and percentage disked (**Table C.6**). Of those covariates, percentage disked included a β estimate confidence interval that barely crossed 0, indicating a marginally significant positive relationship with survival (95% CI = -0.008–0.054; **Table C.6**). Management unit size was negatively related to survival (β = -0.923, 95% CI = -1.595–-0.248), though the quadratic term indicated a non-linear relationship (β = 0.070, 95% CI = 0.016–0.125). The mean management unit size for bobwhite locations was 5.56 ha (± 0.16 SE; **Table D.12**).

In our fifth suite of models, we fit 3 models to assess the relationship between predator indices and survival. None of the three models with predator indices improved the model fit when compared to the best-supported models with macro- or micro-scale covariates (i.e., ΔAIC_C >2.0; **Table D.15**). When viewing predator covariate models univariately, the predator index had a negative relationship with survival (β = -1.502, 95% CI = -2.815–-0.190). KB had the greatest predator index (0.60 predators/camera day ± 0.10), followed by WR (0.47 predators/camera day ± 0.07), and BF (0.24 predators/camera day ± 0.04; **Figure C.7**).

Non-breeding season survival

In our second suite of models, we fit 34 models to assess the relationship between macro-scale covariates and survival, including a null model, 14 univariate models, and 34 multivariate models (**Table D.11**). We had twelve competing top models (<2 ΔAIC_C score; **Table D.11**). Within the best-supported model, survival had a positive relationship with percent deciduous forest. However, percent deciduous forest had a beta estimate confidence interval that barely crossed 0, indicating a marginally significant relationship with survival (95% CI = -0.007–0.038; **Table C.4**). Bobwhite locations contained on average, 15% (± 0.2 SE) coverage of deciduous forest within the home range (**Figure D.1**).

In our third suite of models, we fit 55 models to assess the relationship between micro-scale characteristics and survival. Our micro-scale model set included a null model, 16 univariate models, and 33 multivariate models. We had 21 competing top models (<2 ΔAIC_C score; **Table D.13).** The best-supported model included bare ground (**Table C.5**). Bobwhite survival was negatively related to the amount of bare ground (β = -3.207, 95% CI = -6.336–-0.078; **Table C.5** and **Figure C.4**). On average, bobwhite locations were in areas with approximately 12.6% (± 0.70 SE) bare ground (no vegetation cover; **Table D.12**).

In our fourth suite of models, we fit 34 models to assess the relationship between management practices and survival, including a null model, 9 univariate models, and 14 multivariate models. We had 11 competing top models (<2 ΔAICC score; **Table D.14**). Within the best-supported model, covariates included percentage spot-sprayed and percentage in areas burned one to two years ago (12–23 months; **Table C.6**). Of those covariates, percentage spot-sprayed included a beta estimate confidence interval that barely crossed 0, indicating a marginally significant positive relationship with survival (95% CI = -0.002–0.016; **Table C.6**). On average, the percentage of a home range located in an area spot-sprayed was 26.9% (± 2.63 SE; **Table C.6**). The percentage of a home range located in an area previously burned within two years showed a positive effect on survival (β = 0.020, 95% CI = 0.001–0.038; **Table C.6** and **Figure C.5**). On average, 18.5% (± 1.6 SE) of a bobwhite home range was located in an area previously burned within 1–2 years (**Table D.16**).

Lastly, in our fifth suite of models, we fit 3 models to assess the relationship between the predator indices and survival. We had a single top model (<2 ΔAIC_C score; **Table D.15**). None of the three models with predator indices improved the model fit when compared to the best-supported models with macro- or micro-scale covariates (i.e., $\Delta AIC_C > 2.0$; **Table D.15**). When viewing predator models univariately, the predator index had a negative relationship with survival (β = -1.624). However, the predator index had a beta estimate confidence interval that included zero (95% CI = -3.489–0.242), indicating no relationship with survival (**Table C.7**). KB had the greatest predator index (0.52 predators/camera day ± 0.15), followed by BF (0.40 predators/camera day ± 0.11), and WR (0.39 predators/camera day ± 0.07; **Figure C.7**).

DISCUSSION

We documented northern bobwhite survival and modeled relationships with biological, macro- and micro-scale vegetation, management, and predator covariates during the breeding and non-breeding seasons across three QFAs in Tennessee. Breeding season survival rates were much lower than non-breeding season rates, contrary to our prediction that winter survival would be a limiting factor. The percentage of young forest and deciduous forest cover across the QFAs were negatively related to breeding season survival, partly supporting our prediction that increasing canopy cover would decrease food resources and increase predator abundance. Management unit size also had a negative relationship with survival, particularly during the breeding season. Larger disturbances may disrupt core-use areas, forcing individuals into unfamiliar areas and increasing vulnerability to predators. This pattern underscores the importance of considering the scale of management when implementing disturbances to maintain early successional plant communities for bobwhite. The positive relationship of areas burned within the previous 1-2 years with non-breeding season survival highlighted the role of regular disturbance in promoting favorable ground cover and food resources. Although meso-mammalian predators were negatively related to bobwhite survival, vegetation characteristics had a stronger relationship, suggesting that improving habitat quality may help mitigate predation risks.

Survival differed among focal areas by year, supporting our prediction that site can be a strong predictor of survival because of the differing habitat characteristics available at each QFA. Vegetation type availability and distribution differed across focal areas. For example, BF was comprised of a small quantity of deciduous forest (27.1%), whereas WR and KB had larger quantities (38.5% and 43.0%, respectively; **Table C.8**). Closed-canopy forests can decrease survival as they provide poor cover and food resources (Brennan 1991, Burger 2001, Veech 2006, Nolan et al. 2024). Furthermore, there were distinct differences in soil drainage patterns between sites (BF = well drained, WR and KB = poorly drained), which drastically affects vegetation structure and the vegetation types present on each QFA. KB contained seasonally flooded wetlands for waterfowl, which decreased bobwhite habitat availability during the non-breeding season. Survival (both breeding and non-breeding) was consistently lowest at the smallest QFA (KB), demonstrating how relatively small QFAs may be affected by a hostile surrounding landscape which may limit the viability of bobwhite populations on these types of areas. Also, the predator index was consistently greatest during both seasons at KB (breeding = 0.60 ± 0.01 and non-breeding = 0.52 ± 0.01), followed by WR (breeding = 0.39 ± 0.02 and non-breeding = 0.47 ± 0.01), and BF (breeding = 0.24 ± 0.01 and non-breeding = 0.40 ± 0.03). Because predation was the primary cause of mortality, greater predator abundances clearly was linked to survival, especially where habitat quantity and quality were deficient. Survival also increased by year, suggesting the ongoing bobwhite habitat management at each site generally was working to improve survival.

Seasonal survival rates can be limiting factors for bobwhite populations, with non-breeding season survival typically most limiting (Sandercock et al. 2008). Contrary to range-wide estimates, survival rates in our study were lesser during the breeding season compared with the non-breeding season. Our pooled (sites and years) breeding season survival rate was 37%, compared to the median of 39% reported by Sandercock et al. (2008) and comparable to other recent studies in the eastern US: Tennessee (38%; Seckinger et al. 2008), Ohio (29%; Gates et al. 2012), Arkansas (40%; Doggett and Locher 2018), Kentucky (48%; Unger et al. 2012), Georgia (32%; Jackson et al. 2022), and Florida (42%; Jackson et al. 2022). Sandercock et al. (2008), however, estimated that a breeding season survival rate of >79% was necessary to produce a stationary population, assuming average mortality rates, average clutch size, average nest success, and average chick survival. If accurate, our observed survival rates during the breeding season appear to be incapable of supporting population growth. Sandercock et al. (2008) also recommended a non-breeding season survival rate of >52%. Our pooled non-breeding season survival rate (59%) exceeded that standard and also greatly exceeded estimates from other studies in the region: Ohio (11%; Gates et al. 2012) and Kentucky (28%; Unger et al. 2012). Our pooled survival rates were closer to those observed from the Gulf coastal plain with intense bobwhite management: Georgia (45%; Jackson et al. 2022) and Florida (63%; Jackson et al. 2022), suggesting the non-breeding season survival we documented was more than sufficient to produce a stable or even increasing population. Our annual rates (21%), however, were about one-half of the estimated annual rate required for stable populations of 41% by Sandercock et al. (2008), highlighting a likely overall cause of bobwhite population declines in Tennessee. Most of the other regional studies reviewed by Sandercock et al. (2008) also failed to meet this standard of annual survival (41%), reflective of the regional decline of the species.

Young forest cover comprised 4.9% (WR), 0.0 % (BF), and 3.5% (KB) of our focal areas, whereas mature forest cover comprised 38.5% (WR), 27.1% (BF), and 43.0% (KB; **Table B.4**). The mature deciduous forest and young regenerating stands were negatively related to bobwhite survival during the breeding season, indicating that later stages of succession may harbor increased predation risk during the breeding season (Brennan 1991, Burger 2001, Veech 2006, Nolan et al. 2024). Crawford (2021) reported similar results with lower survival as young forest cover increased. Herbaceous biomass and diversity decrease with advanced succession, which negatively impacts bobwhite as forbs and grasses provide important food sources (Stoddard 1931, Rosene 1969, Brockway and Lewis 1997, Van Auken 2009). Forests also harbor predators, such as bobcats, coyotes, foxes, raccoons, and raptors, indicating a greater predation risk associated with forest cover (Dijak and Thompson 2000, Byrne and Chamberlain 2011).

Midstory stems can provide protective cover, but once succession advances such that understory herbaceous plants are shaded-out, the cover value is diminished. Decreased breeding season survival related to midstory stem density was unexpected as we thought bobwhite would benefit from the thermoregulation and predator escape cover that woody stems can provide. Desirable woody species for bobwhite in the southeastern US typically include sumacs (*Rhus* spp.), plums (*Prunus* spp.), and elderberries (*Sambucus* spp.). However, mid-successional tree species, such as winged elm (*Ulmus alata*), sweetgum (*Liquidambar styraciflua*), and red maple (*Acre rubrum*), grow taller with a more-open structure underneath the canopy and quickly outcompete desirable understory plants that provide desirable ground cover (Lorimer 2001, Gruchy et al. 2009). Although many studies across the Southeast and Midwest report a positive relationship between woody cover and bobwhite, the relationship is dependent upon species composition, structure, and frequency of disturbance (Janke and Gates 2013, Thompson et al.

2022, Sinnott et al. 2023). Sprouting tree stems in an old-field setting may provide cover for bobwhite, but to maintain the old-field condition, these fields must be disturbed regularly (every 1–3 years), to maintain structure required by bobwhite. Many studies have attempted to quantify the exact amount of woody cover for bobwhite survival, but estimates vary widely across the bobwhite range from 3–100%. Several studies have cited 10–30% as an achievable goal (Jackson 1969, Guthery et al. 2000, DeMaso et al. 2014). It is critical to balance the amount of woody vegetation at the macro- and micro-scales to best meet bobwhite habitat requirements during breeding versus non-breeding seasons, as there are diminishing returns in breeding season survival as woody cover continues to expand across home ranges. In our study, 20-35% low woody cover within the home range would be most compatible with optimizing breeding and non-breeding season survival.

Bobwhite habitat management is complex because bobwhite response to a given management practice may differ seasonally depending on the practice. Bobwhite survival during the breeding season decreased as management unit size increased, likely because bobwhite were more vulnerable during the reproductive season. For example, survival increased >5% as management unit size decreased by 5%. During summer, a larger management unit with relatively low woody cover may negatively impact survival when individuals lack the protection that a covey provides. Relatively large management units may be more effort-efficient to implement, especially for prescribed fire, but our data indicates that larger units are less beneficial for bobwhite survival. Disturbance over relatively large areas can displace bobwhites from their core areas, increasing predation risk, and negatively impacting survival as individuals are forced into unfamiliar areas (Wellendorf and Palmer 2009, McGrath et al. 2017).

Meso-mammalian relative abundance was negatively related to bobwhite survival, consistent with the fact that predation was the leading cause of mortality. Our predator index, however, was less strongly related to survival than macro- and micro-scale vegetation covariates that are linked to multiple habitat features including food, protective cover, and usable space. For example, visual obstruction provided by shrub cover may influence bobwhite survival by providing physical cover that bobwhite use to avoid predators, protection from adverse weather in winter, thermoregulation in summer, and a food resource (seed or soft mast; Taylor et al. 1999, Peters et al. 2015). Importantly, this suggests that addressing documented habitat deficiencies (i.e., too much woody cover) may be as effective at increasing survival as addressing predator populations directly through removals. Meso-mammalian predators are important sources of mortality to bobwhite, but they are not the only threat on the landscape. If avian and reptilian predators were included in a predator index, the influence of such an index likely would be stronger. Jackson et al. (2018) reported removing meso-mammals in areas where habitat resources are not deficient can improve bobwhite reproduction and survival during the summer. They also note that though meso-mammal trap and removal can be effective, it is only effective if implemented annually and used under a wholistic habitat management approach. More habitat management and predator removal field experiments are needed to provide a comprehensive understanding of the spatial relationship between cover type, avian, reptilian, and meso-mammalian predator abundance and survival.

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APPENDIX C

Table C.1 Description of vegetation types used in survival analysis during the breeding and non-breeding season across Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2021–2023.

Vegetation type	**Acronym**	**Description**
Deciduous forest[a]	DEC	>80% canopy cover; consists of deciduous trees.
Coniferous forest	CON	>80% canopy cover; consists of coniferous trees.
Early succession[a]	ES	plant growth consisting of shade-intolerant forbs and grasses, with scattered shrubs, and trees; woody species DO NOT comprise more than 50% of species composition.
Early succession woody[a]	ESW	plant growth consisting of shade-intolerant forbs and grasses, with scattered shrubs, and trees; woody species DO comprise more than 50% of species composition but not more than 80% of species.
Savanna[a]	SAV	10-30% canopy cover with a dominant herbaceous understory.
Young forest[a]	YGF	comprised of regenerating trees <11.43 cm; trees are typically between 4-10 years old and are forming a developing canopy.
Woodland[a]	WOOD	30-80% canopy cover with a dominant herbaceous understory.
Open pine row	PIN	coniferous trees planted in 12-18 m wide rows.
Food plot	FP	plots actively planted for wildlife food; comprised of crops such as corn, sunflowers, sorghum, millet, etc.
Row crop[b]	ROW	comprised of planted crops such as corn and soybeans.
Pasture/hayfield[b]	PAS	landscape that is activity being grazed by livestock or being groomed for a hayfield; can consist of a variety of forbs and grasses.
Other[a]	OTH	landscape altered by manmade influences; includes roads, firebreaks, structures, lawns, etc.; also includes wetland areas that are flooded at least part of the year

[a] indicates that the vegetation type was included in the survival analysis because of biological relevance.

[b] indicates that the vegetation type was only found on surrounding private land, not on the wildlife management area.

Table C.2. Description of covariates groups used in known-fate survival analysis across Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2021–2023. Includes biological, micro, macro, management, and predator covariates.

Covariate	Description	Acronym	Group	Season[d]
Site	Focal area location	Site	Biol	B, NB
Sex	Sex of bird; adult, juvenile, or unknown	Sex	Biol	B, NB
Age	Age of bird; male, female, or unknown	Age	Biol	B, NB
Body condition	Condition index, 1 depicting ideal condition and 4 depicting poor condition	BC	Biol	B, NB
Weight	Weight of bird (g)	Wt	Biol	B, NB
Year	Year; 2021–2023	Yr	Biol	B, NB
Covey	Covey association of bird	Covey	Biol	NB
Litter	Average litter depth (cm)	Litter	Micro	B, NB
Sight	Average sight tube measurement (m)	Ground	Micro	B
Height	Average vegetation height (cm)	Height	Micro	NB
N1-N4[a]	Visual obstruction reading, 4 variables (1 for each stratum %)		Micro	B, NB
SmallStem	Number of midstory stems between 0-5.08 cm diameter (stems/ha)	SmallStem	Micro	B, NB
MidStem	Number of midstory stems between 5.08-11.43 cm diameter (stems/ha)	MidStem	Micro	B, NB
Forb	Coverage of broadleaf species (%)	FRB	Micro	B
Warm-season grass	Coverage of warm-season grass species (%)	WSG	Micro	B
Cool-season grass	Coverage of cool-season grass species (%)	CSG	Micro	B
Herbaceous	Coverage of forb and grass species (%)	HRB	Micro	NB
Sedge & rush	Coverage of sedge and rush species (%)	SDR	Micro	B
Semi-woody	Coverage of bramble and vine species (%)	SEM	Micro	B, NB
Shrub	Coverage of shrub species (%)	SHR	Micro	B
Tree	Coverage of tree species (%)	TRE	Micro	B
Woody	Coverage of tree and shrub species (%)	WDD	Micro	NB
Bare	Coverage of bare ground (%)	BARE	Micro	B, NB
Other	Coverage of coarse woody debris or leaf litter (%)	OTR	Micro	B, NB
Basal area	Average amount of area occupied by tree stems (ft^2/ac)	Basal	Micro	B, NB
Woody cover	Average distance to nearest woody cover (m)	WoodDist	Micro	B, NB

Table C.2. Continued.

Covariate	Description	Acronym	Group	Season[d]
Manmade structure	Average distance to nearest manmade structure (road, firebreak, etc.; m)	ManDist	Micro	B, NB
Vegetation type[b]	Percentage of vegetation type in surrounding home range (%)		Macro	B, NB

[a] Nudds strata separated into 4 categories: N1 = 0.00–0.25 m, N2 = 0.26–0.50 m, N3 = 0.51–1.00 m, and N4 = 1.01–2.00 m.

[b] Vegetation types separated into twelve categories (reference Table C.1).

[c] Burns were separated into three categories based on time elapsed since fire: OneBurn = 1–11 months, TwoBurn = 12–23 months, and ThreeBurn = 24+ months.

[d] Season defines whether the covariate was used in the breeding (B) or non-breeding (NB) season.

Table C.3. Breeding and non-breeding survival estimates (SSR), sample sizes (n), and standard errors (SE) for Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2021–2023. Includes results for sex, age, and pooled survival rates per site; does not include results for unknowns (sample sizes were miniscule).

Site	**Season**	**Male**			**Female**			**Adult**			**Juvenile**			**Pooled**		
		n	**SSR**	**SE**	***n***	**SSR**	**SE**	***n***	**SSR**	**SE**	***n***	**SSR**	**SE**	***n***	**SSR**	**SE**
WR	Breeding	47	0.32	0.015	40	0.35	0.015	57	0.32	0.014	31	0.34	0.015	90	0.33	0.013
	Non-breeding	35	0.78	0.017	35	0.72	0.020	41	0.74	0.019	31	0.72	0.018	74	0.73	0.069
BF	Breeding	45	0.45	0.015	50	0.48	0.015	53	0.46	0.014	42	0.47	0.016	95	0.46	0.013
	Non-breeding	49	0.60	0.018	53	0.51	0.018	59	0.57	0.019	43	0.55	0.018	102	0.56	0.015
KB	Breeding	32	0.27	0.015	27	0.30	0.015	41	0.28	0.014	16	0.29	0.017	61	0.29	0.013
	Non-breeding	27	0.52	0.024	30	0.43	0.024	33	0.48	0.024	23	0.46	0.025	58	0.47	0.021

Table C.4. Model coefficients, standard errors, and confidence intervals for covariates in macro-scale known-fate survival analysis across Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2021–2023.

Covariate	**Estimate**	**SE**	**95% CL**	
Breeding season				
YGF	-0.034	0.013	-0.059	-0.009
DEC	-0.013	0.008	-0.030	0.003
Non-breeding season				
DEC	0.016	0.011	-0.007	0.038

* YGF = home range in young forest (%) and DEC = home range in deciduous forest (%)

Table C.5. Model coefficients, standard errors, and confidence intervals for covariates in micro-scale known-fate survival analysis for the breeding and non-breeding seasons across Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2021–2023.

Covariate	**Estimate**	**SE**	**95% CL**	
Breeding season				
SmallStem	-6.30E-04	2.21E-04	-1.06E-03	-1.97E-04
SmallStem^2	7.35E-08	3.04E-08	1.38E-08	1.33E-07
MidStem	-0.013	5.12E-03	-2.29E-02	-2.82E-03
MidStem^2	6.36E-05	2.65E-05	1.16E-05	1.16E-04
FRB	-1.475	1.050	-3.534	0.584
Non-breeding season				
BAR	-3.207	1.596	-6.336	-0.078

* FRB = forbs, BAR = bare ground, SmallStem = midstory stems between 0.00-5.08 cm, SmallStem^2 = midstory stems between 0-5.08 cm diameter quadratically, MidStem = midstory stems between 5.09-11.43 cm diameter, and MidStem^2 = midstory stems between 5.09-11.43 cm diameter quadratically.

Table C.6. Model coefficients, standard errors, and confidence intervals for covariates in management known-fate survival analysis during the breeding and non-breeding seasons across Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2022–2023.

Covariate	Estimate	SE	95% CL	
Breeding season				
Disk	0.023	0.016	-0.008	0.054
MSize	-0.922	0.344	-1.595	-0.248
MSze^2	0.070	0.028	0.016	0.125
Non-breeding season				
HerbSS	0.007	0.005	-0.002	0.016
TwoBurn	0.020	0.009	0.001	0.038

* MSize = management unit size (ha), MSize^2 = management unit size quadratically, TwoBurn = percentage of home range in burn 12-23 months, Disk = percentage of home range in disked area, and HerbSS = percentage of home range in spot-sprayed herbicide application.

Table C.7. Model coefficients, standard errors, and confidence intervals for covariates in predator known-fate survival analysis during the breeding and non-breeding seasons Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2022–2023.

Covariate	Estimate	SE	95% CL	
Breeding season				
Pred	-1.503	0.670	-2.815	-0.190
Non-breeding season				
Pred	-1.624	0.952	-3.489	0.242

* Pred = predator index.

Table C.8. Vegetation types available for northern bobwhite on Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, from 2021 to 2023. Includes entire study area (focal area and surrounding 175 m buffer).

Vegetation type (%)	**Focal Area**		
	WR	**BF**	**KB**
Coniferous forest	0.0	0.0	1.0
Deciduous forest	38.5	27.1	43.0
Early succession	23.2	48.3	22.5 (12.5)
Early succession woody	6.2	9.6	12.0 (9.4)
Food plot	1.2	1.0	0.5 (0.0)
Open pine row	1.5	0.0	0.0
Pasture	0.0	1.6	3.8
Row crop	8.6	0.0	0.0
Savanna	1.8	0.0	0.0
Shrubland/young forest	4.9	0.0	3.5
Woodland	5.4	5.5	4.1
Other	9.1	6.9	9.6 (22.6)

* ( ) indicate the winter season at Kyker Bottoms in which water units are flooded for waterfowl management and vegetation type percentage changes.

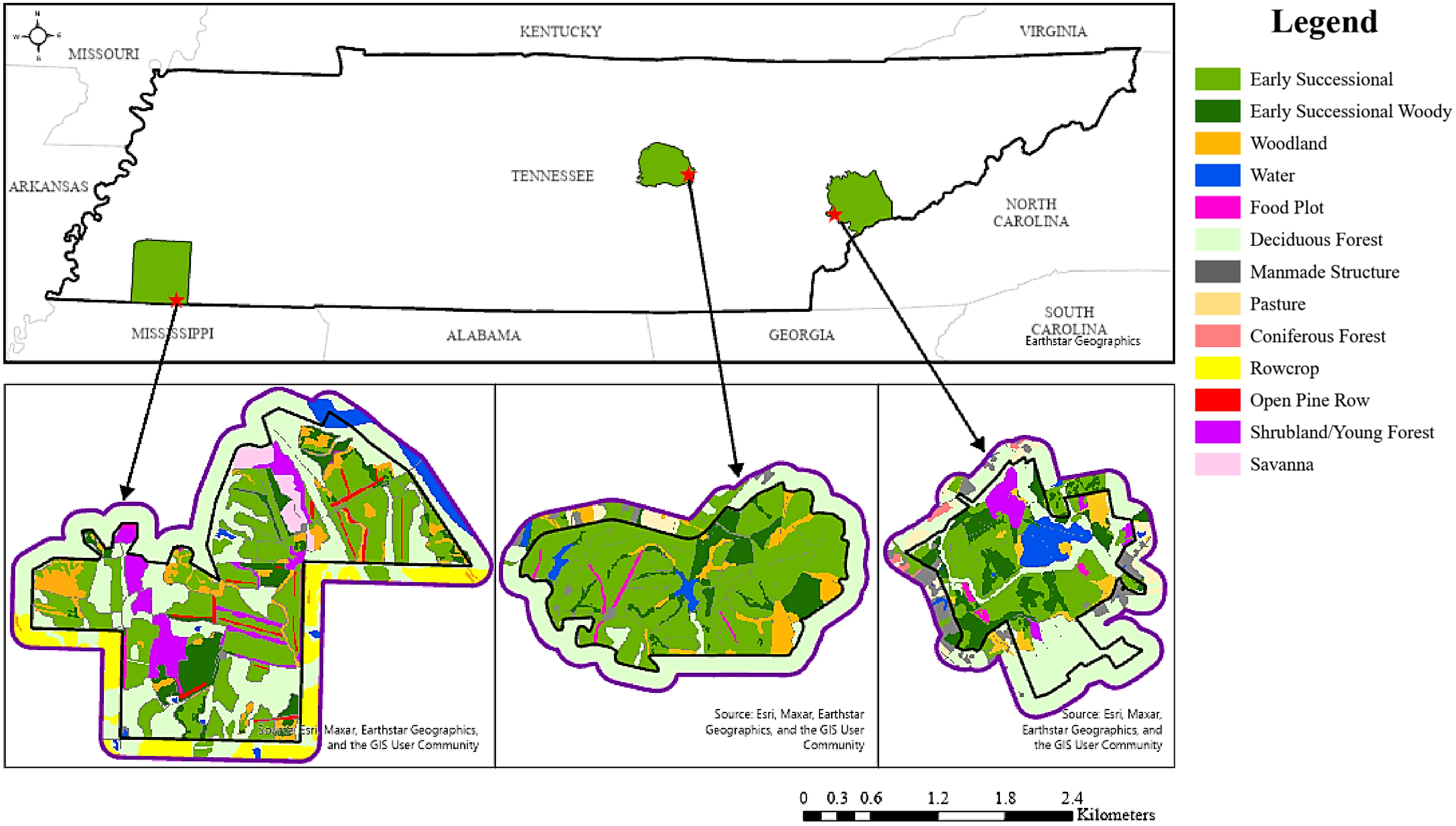

Figure C.1. Map of study areas and associated vegetation types at Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2021–2023. Study area (focal area and 175 m buffer) is outlined in dark purple, focal area is outlined in black.

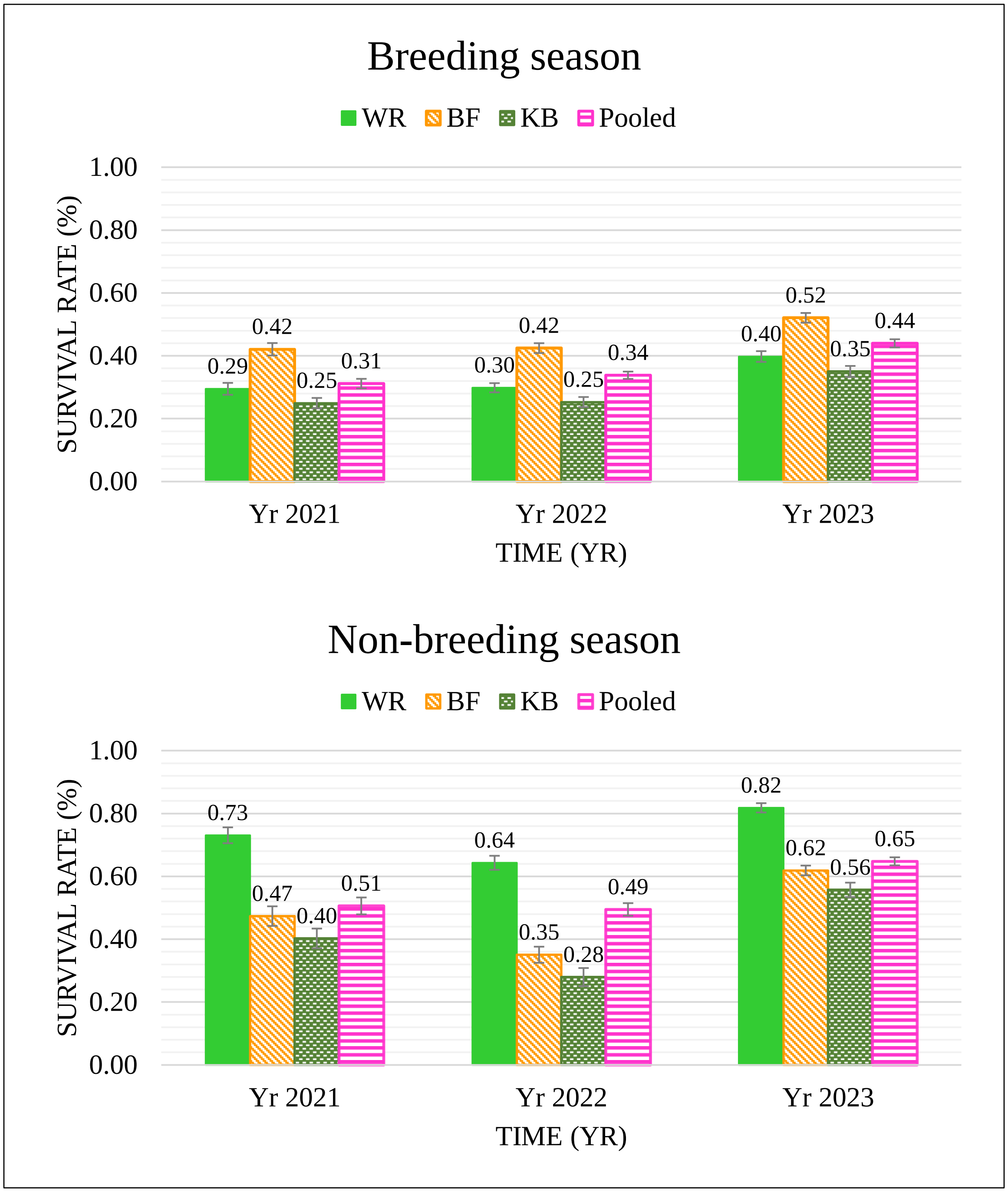

Figure C.2. Seasonal survival rates for Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2021–2023.

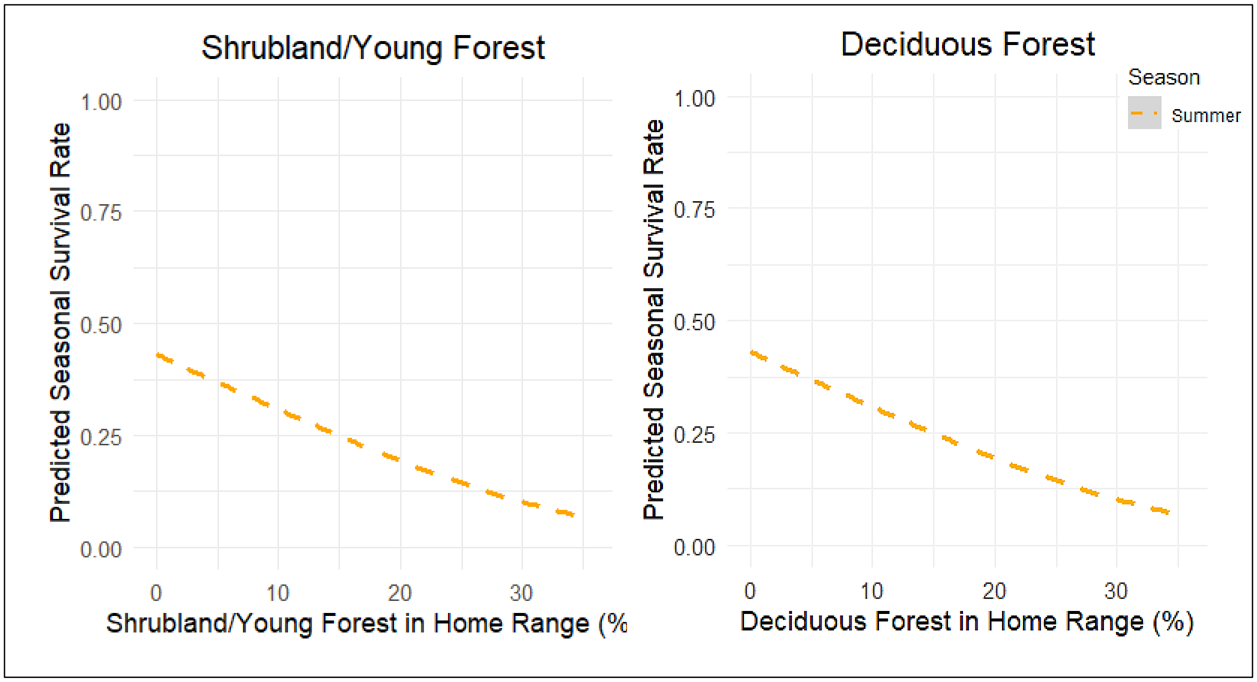

Figure C.3. Influence of macro-scale covariates on predicted survival rates from the top-ranking model. Model represents the breeding season on Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2021–2023. No significant models were supported during the non-breeding season.

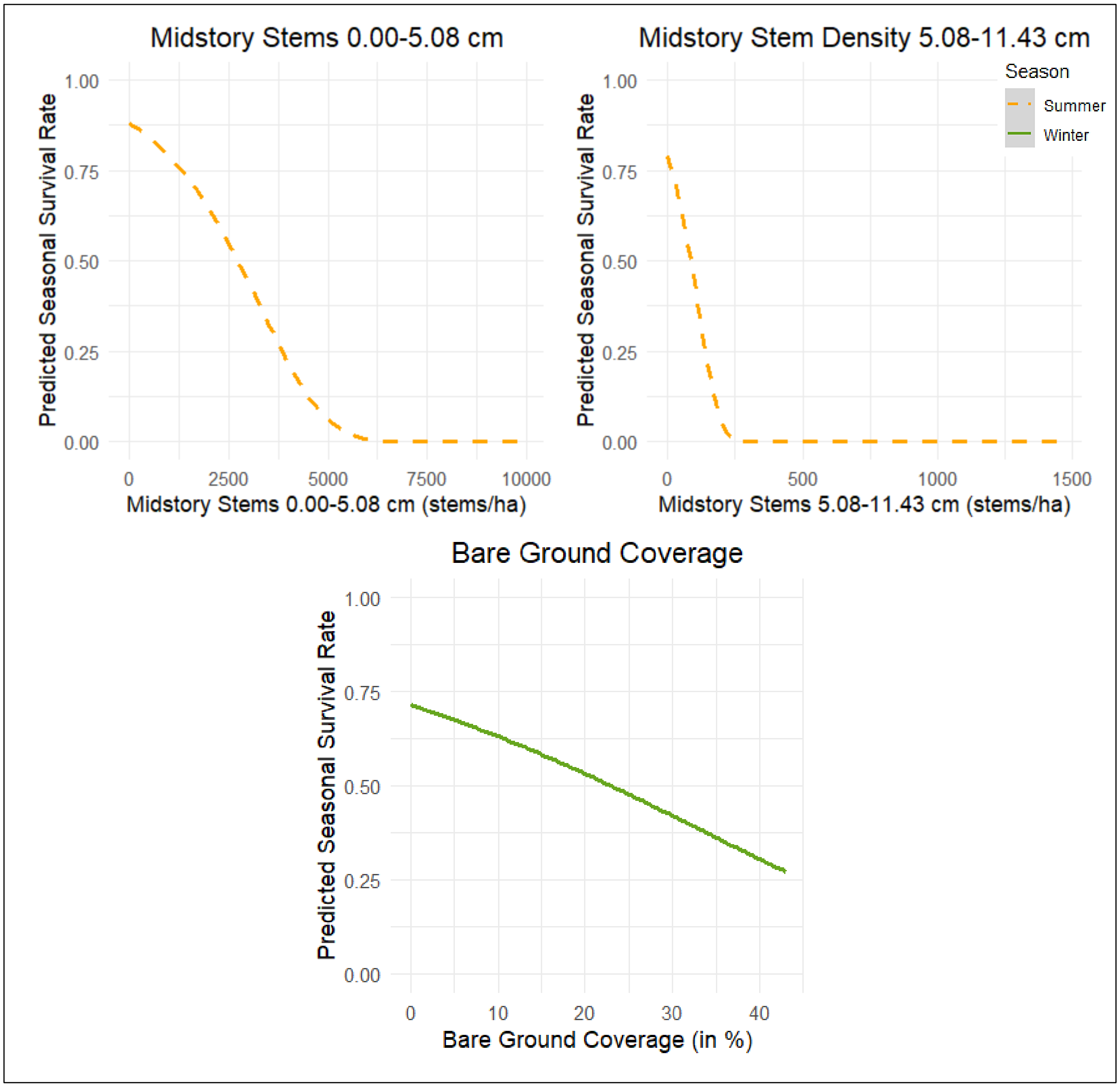

Figure C.4. Influence of micro-scale covariates on predicted survival rates from the top-ranking model. Model represents the breeding season on Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2021–2023.

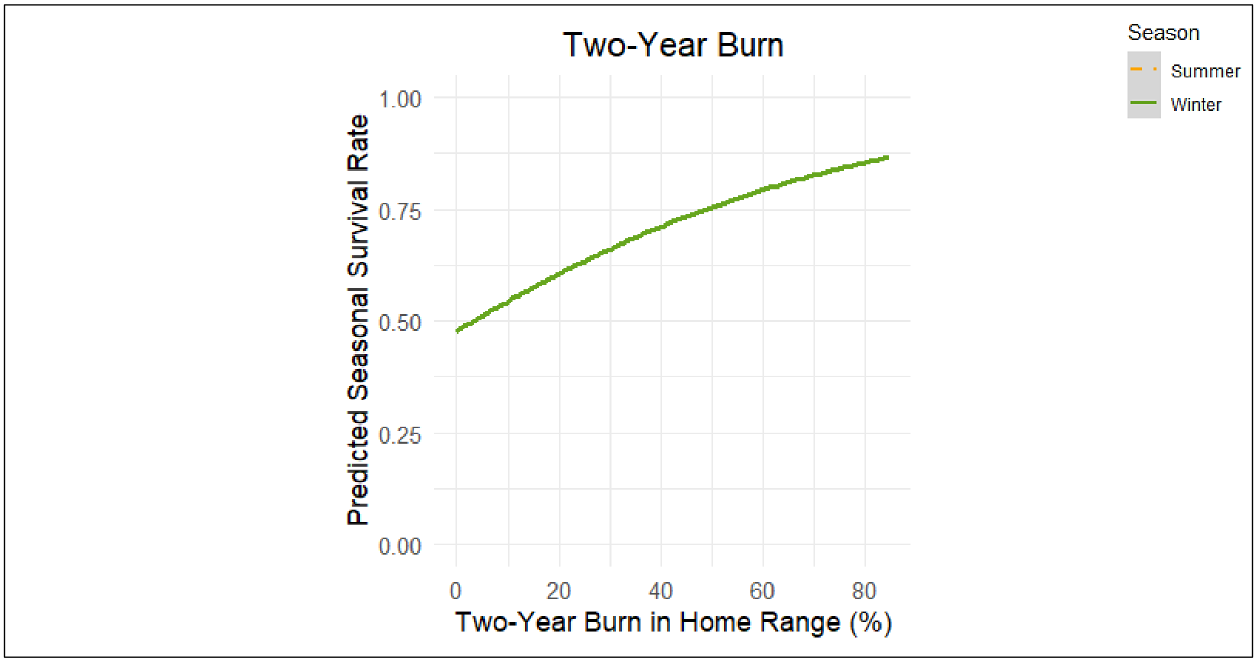

Figure C.5. Influence of management characteristics on predicted survival rates from the top-ranking model. Model represents the breeding season and non-breeding season on Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2022–2023.

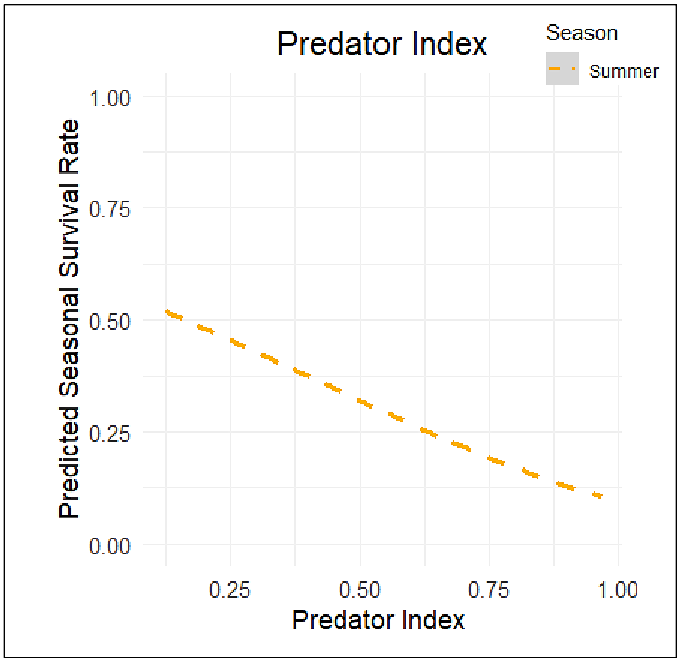

Figure C.6. Influence of predator index on predicted survival rates from the top-ranking model. Model represents the breeding season and non-breeding season on Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2022–2023. The predator index was calculated by dividing the total number of meso-mammalian predators captured by the total number of days the camera was deployed.

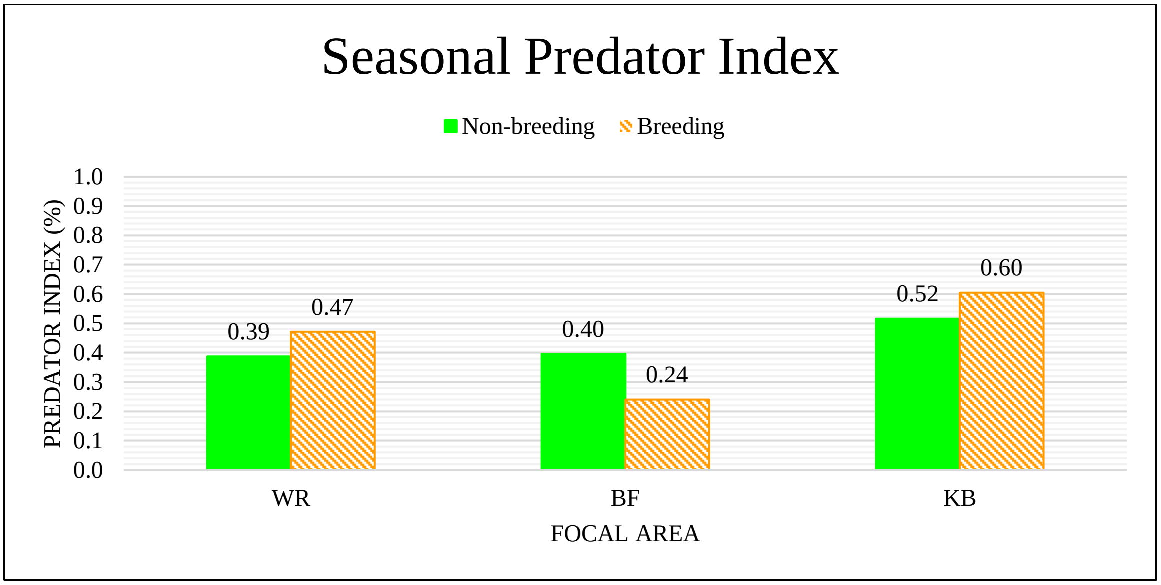

Figure C.7. Predator index during the breeding and non-breeding seasons on Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2022–2023. The predator index was calculated by dividing the total number of meso-mammalian predators captured by the total number of days the camera was deployed. Non-breeding season months included Dec 22, Jan 23, Feb 23, and Mar 23 while breeding season months included Apr 23, May 23, Jun 23, Jul 23, Aug 23, and Sep 23.

CHAPTER 4. MANAGEMENT IMPLICATIONS ON QUAIL FOCAL AREAS IN TENNESSEE

1. Key Finding: Resource selection and survival differed among the three focal areas. Bobwhite resource selection and survival differed across study sites at the landscape scale because of differences in vegetation type availability. Bobwhite consistently selected early successional vegetation types (early succession, early succession woody, open woodlands), which provided vital food resources, such as seeds and insects, as well as sufficient cover to mitigate predation risk. Regular disturbance regimes, such as prescribed burning every 1–2 years, should be implemented to maintain early successional vegetation types, including open woodlands and savannas that allow >50% sunlight, across the focal area. Survival and selection were negatively related to deciduous forests, indicating that food and cover resources are poor and predation likely is high in forested areas. There should be little if any forest of any age class on quail focal areas. Extant forest should be transitioned to early successional vegetation that may include open early successional vegetation, savannas, or open woodlands with >50% sunlight to increase bobwhite habitat quantity and quality. The differences in vegetation type availability and distribution, along with soil drainage, size, and surrounding landscape use, underscore the importance of site-specific management.

Our results indicate quail focal areas should be located in landscapes that are conducive for supporting bobwhite populations. Once quail focal areas are established in suitable areas for bobwhite, managers should tailor habitat management, including prescribed fire, disking, and spot-spraying, to the site's specific soil and vegetation characteristics. For example, the poorly drained soils at Wolf River and Kyker Bottoms would benefit from more frequent (1–2-yr fire-return interval) smaller burns to maintain open structure and limit undesirable species (encroaching bottomland hardwood trees and shrubs) that thrive in the relatively moist conditions. Focusing on site-specific approaches promotes better bobwhite habitat by enhancing the resources specific to each area, specifically at the macro-scale, rather than using a one-size-fits-all prescriptive approach.

2. **Key Finding: Breeding season survival is a key limiting factor for sustaining or growing bobwhite populations, especially at Kyker Bottoms and Wolf River.**

Seasonal survival rates are important determinants of successful bobwhite populations, with non-breeding season survival often identified as the most limiting factor (Sandercock et al. 2008). In contrast to range-wide trends, survival rates in our study were lesser during the breeding season (37%) than during the non-breeding season (59%). Our pooled breeding season survival rate was below the range wide median of 39% reported by Sandercock et al. (2008) and well below the >79% threshold estimated as necessary to maintain a stationary population assuming average reproductive performance. Our results, when put in context with Sandercock et al.'s (2008) models, suggest that breeding season survival, especially at Kyker Bottoms and Wolf River, is insufficient to support population growth.

Each focal area differed in their seasonal survival rates. Kyker Bottoms showed relatively poor survival during both seasons, emphasizing the need for immediate management intervention to boost a marginal population. Wolf River, in contrast, had good survival during the non-breeding season, but poor survival during the breeding season, indicating greater predation risk during summer. Bridgestone-Firestone demonstrated marginally adequate survival during the breeding season and good survival during the non-breeding season. Across all QFAs, management should focus on improving breeding season survival as it is limiting further population growth.

3. **Key Finding: Managers need to reduce woody cover at macro and micro-scales to increase breeding season survival.**

The northern bobwhite is considered a "shrubland obligate," referring to the importance of low woody cover for escape cover and thermal protection. However, woody cover needs must be balanced with requirements for early successional plant communities that provide herbaceous cover requisite for nesting, brood-rearing, and foraging, and generally counters habitat preferences for many bobwhite predators. In the eastern US where precipitation exceeds 100 cm annually, managers must set-back succession with frequent disturbance to establish, maintain, or enhance bobwhite habitat. Prescribed fire and disking on a 1–2-year interval will maintain early successional herbaceous cover, promote an open structure at ground level, limit the advancement of woody species, and also enhance survival. Lengthening the disturbance interval to 3 years on relatively small areas well-interspersed with the more frequently disturbed patches of cover will provide low woody cover required by bobwhite for escape and thermal cover, particularly during the non-breeding season. Spot-spraying areas should be carefully timed and applied to control undesirable woody species without eliminating desirable low woody cover.

4. **Key Finding: Demonstrated positive effects of management on resource selection and survival.**

Survival generally improved on each focal areas with each successive year of the project, highlighting the benefits of continuous, intensive management for bobwhite populations. Management practices that are positively related to resource selection and survival are needed, particularly through the implementation of 1- and 2-year fire-return intervals burns and increased disking.

Larger management units were negatively related to both resource selection and survival, particularly during the breeding season. The negative relationship likely resulted from disruption of core-use areas which increased vulnerability to predation when bobwhites were forced to move into unfamiliar territory after disturbances, such as large-scale burns. Our data indicated that relatively small management units (2–5 ha) were best-suited for bobwhite on these QFAs. A management goal of disturbing 33–50% of a quail focal area annually is required to maintain the early successional vegetation communities requisite for the species. Disturbed management units should be juxtaposed with undisturbed units to prevent large contiguous areas of disturbance.

5. Key Finding: Predation is limiting breeding and non-breeding season survival and thus population levels.

Predators can significantly influence northern bobwhite populations, particularly if cover and food resources are not plentiful and well-interspersed. As expected, we detected a negative relationship between predator abundance and bobwhite survival across the three QFAs, with Kyker Bottoms having the greatest predator index and the lowest survival during both the breeding and non-breeding seasons. Predator indexes were lesser at Bridgestone-Firestone, suggesting fewer predators at this site is directly linked to the greater survival rates and the much greater population level. Meso-mammalian predators, such as raccoons and bobcats, pose substantial risks to bobwhite survival. The negative impacts of predators were especially pronounced in forested areas (all age classes), where bobwhites lacked sufficient escape cover.

Populations at Kyker Bottoms and Wolf River are extremely low (**Figure A.1**), with population estimates at <1 covey per 20 ha (50 acres; **Figure A.1**). Our results indicated that increasing habitat quantity and quality should continue to be the top priority on these focal areas for mitigating predation risk and increasing survival. The key management goal needed to address predation risk to increase survival is reducing the amount and distribution of forest cover (Wolf River, 38.5% of the area and Kyker Bottoms, 43% of the area) through conversion to early successional communities. Predator management, however, is likely needed in addition to habitat management to bolster populations at Wolf River and Kyker Bottoms. Predator management at Bridgestone-Firestone during the breeding season also could enhance the population growth that has already occurred in response to improved habitat management since 2021.

APPENDIX D – Additional information for Chapter 2 and Chapter 3

Table D.1. Model ranking based on AIC scores for discrete choice analysis of macro-scale resource selection during the breeding season across Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2021–2023. Includes both univariate and multivariate models.

Model	AIC	ΔAIC	AICwt	log(L)	df
Int+ES+ESW+DEC+YGF+ManDist+Site	30255.94	0.00	0.57	-15118.97	9
Int+ES+ESW+DEC+YGF+WOOD+ManDist+Site	30256.49	0.54	0.43	-15118.24	10
Int+ES+ESW+DEC+YGF+Site	30284.89	28.94	0.00	-15134.44	8
Int+ES+ESW+DEC+YGF+WOOD+Site	30286.02	30.08	0.00	-15134.01	9
Int+ES+ESW+DEC+YGF+ManDist	30311.20	55.26	0.00	-15148.60	7
Int+ES+ESW+DEC+YGF+WOOD+ManDist	30313.07	57.13	0.00	-15148.53	8
Int+ES+ESW+DEC+YGF	30330.23	74.29	0.00	-15159.12	6
Int+ES+ESW+DEC+YGF+WOOD	30332.19	76.24	0.00	-15159.09	7
Int+ES+DEC+YGF+WOOD+ManDist+Site	30342.32	86.38	0.00	-15162.16	9
Int+ES+DEC+YGF+ManDist+Site	30351.17	95.22	0.00	-15167.58	8
Int+ES+DEC+YGF+WOOD+ManDist	30390.50	134.55	0.00	-15188.25	7
Int+ES+DEC+YGF+ManDist	30404.52	148.58	0.00	-15196.26	6
Int+ESW+DEC+YGF+WOOD+ManDist+Site	30418.78	162.84	0.00	-15200.39	9
Int+ESW+DEC+YGF+WOOD+ManDist	30437.45	181.51	0.00	-15211.73	7
Int+ESW+DEC+YGF+ManDist+Site	30462.24	206.30	0.00	-15223.12	8
Int+ESW+DEC+YGF+ManDist	30480.00	224.06	0.00	-15234.00	6
Int+ES+ESW+DEC+WOOD+ManDist+Site	30481.16	225.21	0.00	-15231.58	9
Int+ES+ESW+DEC+ManDist+Site	30498.12	242.17	0.00	-15241.06	8
Int+ES+ESW+YGF+WOOD+ManDist+Site	30506.30	250.36	0.00	-15244.15	9
Int+ES+DEC+ManDist+Site	30518.49	262.55	0.00	-15252.25	7
Int+ES+ESW+YGF+WOOD+ManDist	30563.23	307.29	0.00	-15274.61	7
Int+ES+ESW+DEC+WOOD+ManDist	30569.39	313.44	0.00	-15277.69	7
ES+ESW+DEC+YGF+WOOD+ManDist+Site	30576.62	320.68	0.00	-15279.31	9

Table D.1. Continued.

Model	AIC	ΔAIC	AICwt	log(L)	df
ES+ESW+DEC+YGF+ManDist+Site	30578.04	322.09	0.00	-15281.02	8
Int+ES+ESW+DEC+ManDist	30602.99	347.05	0.00	-15295.49	6
Int+DEC+Site	30609.55	353.61	0.00	-15299.77	5
Int+ES+ESW+YGF+ManDist+Site	30621.92	365.97	0.00	-15302.96	8
Int+DEC	30659.14	403.20	0.00	-15326.57	3
Int+ES+ESW+YGF+ManDist	30661.98	406.04	0.00	-15324.99	6
ES+ESW+DEC+YGF+ManDist	30701.00	445.06	0.00	-15344.50	6
ES+ESW+DEC+YGF+WOOD+ManDist	30702.70	446.75	0.00	-15344.35	7
DEC+ManDist+Site	30811.83	555.89	0.00	-15400.92	5
DEC+YGF+Site	30960.42	704.48	0.00	-15475.21	5
DEC+ManDist	30966.92	710.97	0.00	-15480.46	3
DEC+YGF	31035.81	779.87	0.00	-15514.91	3
DEC+WOOD+Site	31046.10	790.15	0.00	-15518.05	5
ES+DEC+Site	31062.64	806.69	0.00	-15526.32	5
DEC+Site	31072.19	816.24	0.00	-15532.09	4
ESW+DEC+Site	31072.52	816.58	0.00	-15531.26	5
DEC+WOOD	31193.91	937.96	0.00	-15593.95	3
ESW+DEC	31212.24	956.29	0.00	-15603.12	3
DEC	31218.17	962.22	0.00	-15607.08	2
ES+DEC	31218.23	962.29	0.00	-15606.11	3
Int+ES+YGF+ManDist+Site	31231.20	975.25	0.00	-15608.60	7
Int+ES+ESW+ManDist+Site	31273.99	1018.05	0.00	-15630.00	7
Int+ES+WOOD+ManDist+Site	31686.80	1430.86	0.00	-15836.40	7
Int+ES+Site	31806.52	1550.58	0.00	-15898.26	5
Int+ES	31857.57	1601.63	0.00	-15925.79	3
ES+ManDist+Site	32235.50	1979.56	0.00	-16112.75	5

Table D.1. Continued.

Model	AIC	ΔAIC	AICwt	log(L)	df
ES+ESW+Site	32396.33	2140.39	0.00	-16193.16	5
ES+ManDist	32403.31	2147.36	0.00	-16198.65	3
ES+YGF+Site	32468.28	2212.33	0.00	-16229.14	5
Int+YGF+Site	32475.25	2219.31	0.00	-16232.62	5
ES+YGF	32551.97	2296.03	0.00	-16272.98	3
Int+ManDist+Site	32556.39	2300.45	0.00	-16273.19	5
Int+ManDist	32559.90	2303.95	0.00	-16276.95	3
Int+YGF	32565.80	2309.86	0.00	-16279.90	3
ES+ESW	32594.69	2338.75	0.00	-16294.34	3
YGF+ManDist+Site	32629.82	2373.87	0.00	-16309.91	5
YGF+ManDist	32630.45	2374.51	0.00	-16312.22	3
Int+ESW+Site	32649.03	2393.09	0.00	-16319.52	5
Int+ESW	32679.81	2423.86	0.00	-16336.90	3
ESW+ManDist+Site	32734.17	2478.23	0.00	-16362.08	5
ESW+ManDist	32735.68	2479.74	0.00	-16364.84	3
Int+WOOD+Site	32798.41	2542.47	0.00	-16394.21	5
Int+Site	32799.23	2543.29	0.00	-16395.61	4
Int	32830.54	2574.60	0.00	-16413.27	2
Int+WOOD	32830.91	2574.97	0.00	-16412.46	3
ES+WOOD+Site	32932.68	2676.74	0.00	-16461.34	5
ManDist+Site	32944.34	2688.40	0.00	-16468.17	4
WOOD+ManDist+Site	32944.71	2688.77	0.00	-16467.35	5
ManDist	32945.60	2689.66	0.00	-16470.80	2
WOOD+ManDist	32946.10	2690.16	0.00	-16470.05	3
ES+Site	33033.16	2777.22	0.00	-16512.58	4

Table D.1. Continued.

Model	AIC	ΔAIC	AICwt	log(L)	df
ES+WOOD	33120.49	2864.55	0.00	-16557.25	3
ES	33199.27	2943.32	0.00	-16597.63	2
ESW+YGF+Site	33320.76	3064.82	0.00	-16655.38	5
ESW+YGF	33344.48	3088.54	0.00	-16669.24	3
YGF+WOOD+Site	33656.29	3400.35	0.00	-16823.15	5
YGF+WOOD	33670.03	3414.09	0.00	-16832.01	3
YGF+Site	33684.04	3428.09	0.00	-16838.02	4
YGF	33699.04	3443.09	0.00	-16847.52	2
ESW+WOOD	33749.09	3493.15	0.00	-16871.55	3
ESW+WOOD+Site	33752.21	3496.26	0.00	-16871.10	5
ESW	33774.60	3518.66	0.00	-16885.30	2
ESW+Site	33777.34	3521.39	0.00	-16884.67	4
WOOD	34055.05	3799.11	0.00	-17025.53	2
WOOD+Site	34059.03	3803.09	0.00	-17025.52	4
Null	34073.84	3817.90	0.00	-17035.92	1

* ES = early successional, ESW = early successional woody, DEC = deciduous forest, YGF = young forest, WOOD = woodland, Int = interspersion index, ManDist = distance (m) to nearest linear manmade structure, and Site = study site.

Table D.2. Means and standard errors for measured macro-scale characteristics of bobwhite used and available locations on Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, from 2021 to 2023.

		Breeding season				***Non-breeding season***			
Covariate	**Site**	**Location**		**Random**		**Location**		**Random**	
		$\bar{x}$	**σ**	$\bar{x}$	**σ**	$\bar{x}$	**σ**	$\bar{x}$	**σ**
ES	WR	36.16	0.824	23.96	0.378	29.12	1.191	24.77	0.777
	BF	68.25	0.509	48.86	0.323	62.24	1.239	48.64	0.675
	KB	31.16	0.712	19.53	0.287	18.87	1.706	13.97	0.488
	Pooled	49.07	0.435	33.79	0.208	40.24	0.934	31.68	0.423
ESW	WR	20.72	0.827	6.59	0.212	28.78	1.963	6.92	0.432
	BF	14.78	0.428	9.10	0.173	16.41	0.955	10.33	0.392
	KB	11.99	0.448	12.60	0.228	23.04	1.384	10.44	0.427
	Pooled	15.18	0.307	9.68	0.119	21.49	0.780	9.57	0.244
DEC	WR	12.23	0.592	38.92	0.469	9.26	1.200	37.60	0.946
	BF	1.56	0.135	27.51	0.340	4.63	0.675	26.37	0.709
	KB	18.66	0.616	45.17	0.403	14.99	1.138	49.22	0.829
	Pooled	9.49	0.265	35.79	0.232	9.12	0.565	36.50	0.482
CON	WR	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
	BF	0.04	0.016	0.59	0.053	0.00	0.000	0.00	0.000
	KB	0.34	0.077	1.79	0.090	0.00	0.000	1.06	0.134
	Pooled	0.13	0.026	0.85	0.038	0.00	0.000	0.35	0.044
FP	WR	2.01	0.215	1.16	0.084	0.97	0.182	0.73	0.151
	BF	2.38	0.124	0.94	0.036	1.43	0.181	0.86	0.072
	KB	0.94	0.115	0.67	0.047	0.00	0.000	0.01	0.003
	Pooled	1.83	0.083	0.90	0.029	0.85	0.091	0.55	0.048
SAV	WR	1.64	0.215	1.84	0.084	0.00	0.000	2.14	0.281
	BF	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
	KB	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
	Pooled	0.36	0.063	0.41	0.029	0.00	0.000	0.50	0.067
YGF	WR	6.53	0.436	5.23	0.201	13.44	1.486	5.48	0.424
	BF	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
	KB	15.32	0.680	3.58	0.145	24.28	1.596	4.61	0.341
	Pooled	6.43	0.256	2.32	0.066	11.12	0.687	2.80	0.152

Table. D.2. Continued.

Covariate	Site	Breeding season				Non-breeding season			
		Location		Random		Location		Random	
		$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
WOOD	WR	5.94	0.396	5.42	0.163	9.46	1.198	5.56	0.342
	BF	5.09	0.240	6.11	0.141	9.53	0.840	5.87	0.290
	KB	7.94	0.358	3.90	0.132	8.95	0.806	4.53	0.295
	Pooled	6.21	0.183	5.24	0.085	9.32	0.532	5.36	0.179
PAS	WR	0.00	0.316	0.00	0.143	0.00	0.000	0.00	0.000
	BF	0.27	0.065	1.59	0.086	0.05	0.027	1.99	0.204
	KB	4.00	0.000	4.13	0.000	0.74	0.199	3.86	0.282
	Pooled	1.42	0.109	2.06	0.061	0.26	0.067	2.13	0.129
PIN	WR	2.96	0.195	1.50	0.064	1.41	0.278	1.39	0.120
	BF	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
	KB	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
	Pooled	0.66	0.046	0.33	0.015	0.33	0.067	0.33	0.029
ROW	WR	2.19	0.321	8.87	0.293	0.31	0.125	9.07	0.608
	BF	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
	KB	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000
	Pooled	0.49	0.072	1.96	0.068	0.07	0.029	2.13	0.149
OTH	WR	9.57	0.201	6.41	0.090	7.25	0.441	6.33	0.171
	BF	7.67	0.165	5.89	0.082	5.71	0.246	5.94	0.171
	KB	9.78	0.333	9.40	0.177	9.12	0.732	12.22	0.399
	Pooled	8.78	0.140	7.15	0.072	7.19	0.285	8.09	0.160
Int	WR	3.40	0.032	2.81	0.016	3.01	0.073	2.81	0.032
	BF	2.97	0.017	2.48	0.009	2.85	0.037	2.47	0.019
	KB	3.53	0.029	2.76	0.013	3.69	0.058	2.85	0.028
	Pooled	3.25	0.015	2.64	0.007	3.16	0.032	2.67	0.015
ManDist	WR	38.43	1.834	88.35	1.285	46.18	2.82	88.51	2.609
	BF	6.06	0.293	41.13	0.603	12.37	1.069	40.54	1.256
	KB	41.11	1.246	101.09	1.269	68.87	3.385	111.52	2.689
	Pooled	24.64	0.626	71.12	0.592	38.84	1.519	75.06	1.261

Table. D.2. Continued.

Covariate	Site	Breeding season				Non-breeding season			
		Location		Random		Location		Random	
		$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
MArea	WR	6.23	0.127	6.25	0.063	7.78	0.262	6.25	0.121
	BF	4.57	0.068	5.46	0.042	5.14	0.153	5.46	0.090
	KB	6.2	0.120	6.58	0.072	4.54	0.138	6.12	0.161
	Pooled	5.40	0.057	5.94	0.032	5.56	0.107	5.84	0.067
UnitDist	WR	22.22	0.645	24.86	0.340	34.47	1.879	24.69	0.670
	BF	21.90	0.338	25.76	0.245	25.15	0.748	25.27	0.520
	KB	23.24	0.425	32.61	0.409	25.83	0.736	29.24	0.809
	Pooled	22.34	0.256	27.49	0.214	27.60	0.610	26.19	0.372

* ES = early successional (%), ESW = early successional woody (%), DEC = deciduous forest (%), CON = coniferous forest (%), SAV = savanna (%), YGF = young forest (%), WOOD = woodland (%), PAS = pasture/hayfield (%), PIN = open pine row (%), ROW = row crop (%), OTH = other (%), Int = interspersion index, ManDist = distance (m) to nearest linear manmade structure, MSize = size of management unit (ha), and UnitDist = distance (m) to edge of management unit.

Table D.3. Multivariate model ranking based on AIC scores for discrete choice analysis of management resource selection during the breeding season across Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2022–2023.

Model	AIC	ΔAIC	AICwt	log(*L*)	df
MSize+MSize^2+UnitDist+UnitDist^2+OneBurn+HerbSS+Disk+Site	19953.73	0.00	0.68	-9966.86	10
MSize+MSize^2+UnitDist+UnitDist^2+OneBurn+HerbSS+Site	19955.25	1.52	0.32	-9968.62	9
MSize+MSize^2+UnitDist+UnitDist^2+OneBurn+Disk+Site	19977.55	23.82	0.00	-9979.77	9
MSize+MSize^2+UnitDist+UnitDist^2+OneBurn+Site	19981.54	27.81	0.00	-9982.77	8
MSize+MSize^2+UnitDist+UnitDist^2+OneBurn+HerbBC+Site	19983.51	29.79	0.00	-9982.75	9
MSize+MSize^2+UnitDist+UnitDist^2+HerbSS+Site	20000.12	46.40	0.00	-9992.06	8
MSize+MSize^2+UnitDist+UnitDist^2+Disk+Site	20006.07	52.34	0.00	-9995.03	8
MSize+MSize^2+UnitDist+UnitDist^2+TwoBurn+Site	20018.48	64.75	0.00	-10001.24	8
MSize+MSize^2+UnitDist+UnitDist^2+Site	20027.60	73.87	0.00	-10006.80	7
MSize+MSize^2+UnitDist+UnitDist^2+HerbBC+Site	20027.94	74.21	0.00	-10005.97	8
MSize+MSize^2+UnitDist+UnitDist^2+ThreeBurn+Site	20028.54	74.82	0.00	-10006.27	8
MSize+MSize^2+UnitDist+Site	20067.92	114.19	0.00	-10027.96	6
MSize+MSize^2+OneBurn+Site	20089.82	136.09	0.00	-10038.91	6
MSize+MSize^2+HerbSS+Site	20105.26	151.53	0.00	-10046.63	6
MSize+MSize^2+Disk+Site	20108.92	155.19	0.00	-10048.46	6
MSize+MSize^2+TwoBurn+Site	20127.32	173.59	0.00	-10057.66	6
MSize+MSize^2+HerbBC+Site	20132.99	179.26	0.00	-10060.49	6
MSize+MSize^2+Site	20133.07	179.35	0.00	-10061.54	5
MSize+MSize^2+ThreeBurn+Site	20134.66	180.93	0.00	-10061.33	6
MSize+Site	20158.91	205.19	0.00	-10075.46	4
MSize+MSize^2	20176.57	222.84	0.00	-10085.28	3
MSize	20205.75	252.02	0.00	-10100.87	2
UnitDist+UnitDist^2+Site	21648.39	1694.67	0.00	-10819.20	5
UnitDist+UnitDist^2	21654.85	1701.12	0.00	-10824.42	3
UnitDist+Site	21736.28	1782.55	0.00	-10864.14	4
UnitDist	21744.10	1790.38	0.00	-10870.05	2

Table D.3. Continued.

Model	**AIC**	**ΔAIC**	**AICwt**	**log(*L*)**	**df**
OneBurn+Site	21889.62	1935.89	0.00	-10940.81	4
OneBurn	21890.15	1936.43	0.00	-10943.08	2
HerbSS+Site	21903.96	1950.23	0.00	-10947.98	4
HerbSS	21905.69	1951.96	0.00	-10950.85	2
Disk+Site	21913.67	1959.94	0.00	-10952.83	4
Disk	21915.37	1961.64	0.00	-10955.68	2
TwoBurn+Site	21937.01	1983.28	0.00	-10964.50	4
TwoBurn	21939.52	1985.79	0.00	-10967.76	2
HerbBC+Site	21943.22	1989.49	0.00	-10967.61	4
HerbBC	21944.84	1991.11	0.00	-10970.42	2
Null	21945.71	1991.99	0.00	-10971.86	1
ThreeBurn+Site	21947.04	1993.31	0.00	-10969.52	4
ThreeBurn	21947.62	1993.89	0.00	-10971.81	2

* MSize = management unit size (ha), $MSize^2$ = management unit size quadratically, UnitDist = distance (m) to management unit edge, $UnitDist^2$ = distance (m) to management unit edge quadratically, OneBurn = location falls in burn 0-11 months, TwoBurn = location falls in burn 12-23 months, ThreeBurn = location falls in burn 24+ months, Disk = location falls in disked area, HerbBC = location falls in broadcast herbicide application, and HerbSS = location falls in spot-sprayed herbicide application.

Table D.4. Model ranking based on AIC scores for discrete choice analysis of macro-scale resource selection during the non-breeding season across Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2021–2023. Includes both univariate and multivariate models.

Model	AIC	ΔAIC	AICwt	log(L)	df
Int+ES+ESW+YGF+WOOD+Site	6748.91	0.00	0.49	-3366.44	8
Int+ES+ESW+DEC+YGF+WOOD+Site	6750.35	1.45	0.24	-3366.17	9
Int+ES+ESW+DEC+YGF+WOOD+ManDist+Site	6751.28	2.38	0.15	-3365.63	10
Int+ES+ESW+YGF+WOOD	6752.57	3.67	0.08	-3370.28	6
Int+ES+ESW+DEC+YGF+WOOD	6754.03	5.12	0.04	-3370.01	7
Int+ES+ESW+DEC+YGF+WOOD+ManDist	6755.65	6.75	0.02	-3369.82	8
DEC+YGF+Site	7064.00	315.10	0.00	-3527.00	5
DEC+YGF	7071.22	322.31	0.00	-3532.61	3
ESW+DEC+Site	7105.13	356.22	0.00	-3547.56	5
ESW+DEC	7136.41	387.50	0.00	-3565.20	3
Int+DEC+Site	7145.59	396.68	0.00	-3567.79	5
ES+DEC+Site	7153.96	405.05	0.00	-3571.97	5
Int+DEC	7168.02	419.12	0.00	-3581.01	3
DEC+WOOD+Site	7168.23	419.33	0.00	-3579.11	5
ES+DEC	7169.31	420.40	0.00	-3581.65	3
DEC+ManDist+Site	7171.48	422.57	0.00	-3580.74	5
DEC+Site	7172.68	423.78	0.00	-3582.34	4
DEC+WOOD	7211.54	462.63	0.00	-3602.77	3
DEC+ManDist	7215.19	466.28	0.00	-3604.59	3
DEC	7217.07	468.17	0.00	-3606.54	2
ESW+YGF+Site	7339.37	590.46	0.00	-3664.68	5
ESW+YGF	7358.96	610.06	0.00	-3676.48	3
ES+ESW+Site	7477.15	728.24	0.00	-3733.57	5
ES+ESW	7508.76	759.86	0.00	-3751.38	3
Int+YGF+Site	7516.14	767.23	0.00	-3753.06	5
Int+ESW+Site	7527.81	778.91	0.00	-3758.90	5

Table D.4. Continued.

Model	AIC	ΔAIC	AICwt	log(L)	df
Int+ESW	7529.99	781.08	0.00	-3761.99	3
ESW+ManDist	7545.18	796.27	0.00	-3769.59	3
ESW+ManDist+Site	7548.06	799.16	0.00	-3769.03	5
Int+YGF	7552.48	803.57	0.00	-3773.24	3
ES+YGF	7554.29	805.38	0.00	-3774.14	3
ES+YGF+Site	7556.61	807.70	0.00	-3773.30	5
YGF+ManDist+Site	7563.38	814.47	0.00	-3776.69	5
YGF+ManDist	7569.99	821.08	0.00	-3781.99	3
ESW+WOOD	7579.86	830.96	0.00	-3786.93	3
ESW+WOOD+Site	7583.82	834.91	0.00	-3786.91	5
YGF+WOOD+Site	7607.63	858.72	0.00	-3798.81	5
YGF+WOOD	7619.11	870.20	0.00	-3806.55	3
ESW	7659.54	910.63	0.00	-3827.77	2
ESW+Site	7663.33	914.43	0.00	-3827.66	4
YGF+Site	7679.90	931.00	0.00	-3835.95	4
Int+ES	7688.64	939.74	0.00	-3841.32	3
Int+ES+Site	7690.90	942.00	0.00	-3840.45	5
YGF	7692.66	943.76	0.00	-3844.33	2
Int+WOOD+Site	7714.38	965.47	0.00	-3852.18	5
Int+WOOD	7715.14	966.24	0.00	-3854.57	3
Int+ManDist	7725.35	976.45	0.00	-3859.68	3
Int+ManDist+Site	7727.21	978.31	0.00	-3858.60	5
WOOD+ManDist	7745.08	996.18	0.00	-3869.54	3
WOOD+ManDist+Site	7747.81	998.90	0.00	-3868.90	5
Int+Site	7748.83	999.92	0.00	-3870.41	4
ES+ManDist+Site	7749.76	1000.86	0.00	-3869.88	5
Int	7751.36	1002.46	0.00	-3873.68	2
ES+WOOD+Site	7760.32	1011.42	0.00	-3875.16	5

Table D.4. Continued.

Model	AIC	ΔAIC	AICwt	log(L)	df
ES+ManDist	7761.15	1012.24	0.00	-3877.57	3
ES+WOOD	7783.37	1034.46	0.00	-3888.68	3
ManDist	7789.91	1041.00	0.00	-3892.95	2
ManDist+Site	7792.88	1043.98	0.00	-3892.44	4
ES+Site	7851.84	1102.94	0.00	-3921.92	4
ES	7865.69	1116.79	0.00	-3930.85	2
WOOD	7869.96	1121.06	0.00	-3932.98	2
WOOD+Site	7873.88	1124.97	0.00	-3932.94	4
Null	7930.10	1181.19	0.00	-3964.05	1

* ES = early successional, ESW = early successional woody, DEC = deciduous forest, YGF = young forest, WOOD = woodland, Int = interspersion index, ManDist = distance (m) to nearest linear manmade structure, and Site = study site.

Table D.5. Multivariate model ranking based on AIC scores for discrete choice analysis of management resource selection during the non-breeding season across Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2022–2023.

Model	AIC	ΔAIC	AICwt	log(L)	df
MSize+MSize^2+UnitDist+OneBurn+HerbSS+Site	4804.69	0.00	0.72	-2394.33	8
MSize+MSize^2+UnitDist+UnitDist^2+OneBurn+HerbSS+Site	4806.65	1.96	0.27	-2394.31	9
MSize+MSize^2+OneBurn+HerbSS+Site	4812.88	8.19	0.01	-2399.43	7
MSize+MSize^2+OneBurn+Disk+HerbSS+Site	4814.88	10.20	0.00	-2399.43	8
MSize+MSize^2+OneBurn+Site	4828.38	23.70	0.00	-2408.18	6
MSize+MSize^2+OneBurn+HerbBC+Site	4830.09	25.40	0.00	-2408.03	7
MSize+MSize^2+OneBurn+Disk+Site	4830.39	25.70	0.00	-2408.18	7
MSize+MSize^2+OneBurn+Disk+HerbBC+Site	4832.10	27.41	0.00	-2408.03	8
MSize+MSize^2+UnitDist+ThreeBurn+HerbSS+Site	4871.21	66.52	0.00	-2427.59	8
MSize+MSize^2+UnitDist+UnitDist^2+ThreeBurn+HerbSS+Site	4873.17	68.48	0.00	-2427.56	9
MSize+MSize^2+UnitDist+TwoBurn+HerbSS+Site	4883.05	78.37	0.00	-2433.51	8
MSize+MSize^2+UnitDist+UnitDist^2+TwoBurn+HerbSS+Site	4885.03	80.34	0.00	-2433.49	9
MSize+MSize^2+UnitDist+Site	4894.53	89.85	0.00	-2441.26	6
MSize+MSize^2+HerbSS+Site	4894.82	90.14	0.00	-2441.40	6
MSize+MSize^2+UnitDist+UnitDist^2+Site	4896.49	91.81	0.00	-2441.23	7
MSize+MSize^2+ThreeBurn+Site	4896.90	92.21	0.00	-2442.44	6
MSize+MSize^2+Disk+Site	4907.22	102.54	0.00	-2447.60	6
MSize+MSize^2+Site	4907.86	103.18	0.00	-2448.93	5
MSize+MSize^2+HerbBC+Site	4909.03	104.34	0.00	-2448.50	6
MSize+Site	4909.76	105.07	0.00	-2450.87	4
MSize+MSize^2+TwoBurn+Site	4909.84	105.15	0.00	-2448.91	6
MSize	4949.69	145.00	0.00	-2472.84	2
MSize+MSize^2	4949.85	145.16	0.00	-2471.92	3
OneBurn+Site	5157.68	352.99	0.00	-2574.84	4
UnitDist+UnitDist^2+Site	5262.69	458.00	0.00	-2626.34	5
HerbSS+Site	5270.72	466.03	0.00	-2631.36	4
UnitDist+UnitDist^2	5272.64	467.96	0.00	-2633.32	3

Table D.5. Continued.

Model	AIC	ΔAIC	AICwt	log(*L*)	df
ThreeBurn+Site	5273.05	468.36	0.00	-2632.52	4
Disk+Site	5277.38	472.69	0.00	-2634.69	4
UnitDist+Site	5278.85	474.16	0.00	-2635.42	4
HerbBC+Site	5280.39	475.70	0.00	-2636.19	4
TwoBurn+Site	5280.60	475.92	0.00	-2636.30	4
ThreeBurn	5284.81	480.12	0.00	-2640.40	2
HerbSS	5285.24	480.55	0.00	-2640.62	2
UnitDist	5289.93	485.24	0.00	-2642.96	2
Disk	5291.00	486.31	0.00	-2643.50	2
Null	5291.62	486.93	0.00	-2644.81	1
HerbBC	5292.88	488.19	0.00	-2644.44	2
TwoBurn	5293.35	488.66	0.00	-2644.67	2

* MSize = management unit size (ha), MSize^2 = management unit size quadratically, UnitDist = distance (m) to management unit edge, UnitDist^2 = distance (m) to management unit edge quadratically, OneBurn = location falls in burn 0-11 months, TwoBurn = location falls in burn 12-23 months, ThreeBurn = location falls in burn 24+ months, Disk = location falls in disked area, HerbBC = location falls in broadcast herbicide application, and HerbSS = location falls in spot-sprayed herbicide application.

Table D.6. Model ranking based on AIC scores for discrete choice analysis of micro-scale resource selection during the breeding season across Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2021–2023. Includes both univariate and multivariate models.

Model	AIC	ΔAIC	AICwt	log(L)	df
WoodDist+WoodDist^2+BasalArea+N2	490.44	0.00	0.08	-241.195	4
WoodDist+WoodDist^2+BasalArea+N3	490.49	0.04	0.08	-241.217	4
WoodDist+WoodDist^2+BasalArea	491.08	0.64	0.06	-242.525	3
WoodDist+WoodDist^2+BasalArea+N2+Man_Dist	491.16	0.72	0.06	-240.540	5
WoodDist+WoodDist^2+BasalArea+N2+SDR	491.23	0.79	0.06	-240.574	5
WoodDist+WoodDist^2+BasalArea+N2+SmallStem	491.55	1.11	0.05	-240.736	5
WoodDist+WoodDist^2+BasalArea+N2+SEM	491.63	1.19	0.05	-240.775	5
WoodDist+WoodDist^2+BasalArea+N2+Ground	491.64	1.19	0.05	-240.777	5
WoodDist+WoodDist^2+BasalArea+N2+CSG	491.84	1.40	0.04	-240.881	5
WoodDist+WoodDist^2+BasalArea+N2+Litter	491.98	1.54	0.04	-240.950	5
WoodDist+WoodDist^2+BasalArea+N2+FRB	492.24	1.79	0.03	-241.077	5
WoodDist+WoodDist^2+BasalArea+N2+MidStem	492.24	1.79	0.03	-241.078	5
WoodDist+WoodDist^2+BasalArea+N2+SHR	492.24	1.80	0.03	-241.081	5
WoodDist+WoodDist^2+BasalArea+N4	492.28	1.83	0.03	-242.112	4
WoodDist+WoodDist^2+BasalArea+N3+SHR	492.28	1.84	0.03	-241.100	5
WoodDist+WoodDist^2+BasalArea+N2+OTH	492.29	1.85	0.03	-241.104	5
WoodDist+WoodDist^2+BasalArea+N1	492.41	1.97	0.03	-242.178	4
WoodDist+WoodDist^2+BasalArea+N2+TRE	492.46	2.02	0.03	-241.189	5
WoodDist+WoodDist^2+BasalArea+N2+BARE	492.47	2.02	0.03	-241.192	5
WoodDist+WoodDist^2+BasalArea+N2+WSG	492.47	2.03	0.03	-241.194	5
WoodDist+WoodDist^2+BasalArea+N3+SHR+SEM	493.53	3.09	0.02	-240.709	6
WoodDist+WoodDist^2+BasalArea+N4+SHR	494.22	3.78	0.01	-242.069	5
WoodDist+WoodDist^2+BasalArea+N1+SHR	494.36	3.91	0.01	-242.138	5
WoodDist+BasalArea+Ground+N3+SEM	495.70	5.26	0.01	-242.809	5
WoodDist+WoodDist^2+BasalArea+N1+N4+ SHR	495.85	5.40	0.01	-241.866	6
WoodDist+BasalArea+N3+SHR+SEM	496.44	6.00	0.00	-243.179	5

Table D.6. Continued.

Model	AIC	ΔAIC	AICwt	log(L)	df
WoodDist+BasalArea+Ground+N4+SEM	496.96	6.51	0.00	-243.437	5
WoodDist+BasalArea+Ground+N3+SHR+SEM	497.64	7.19	0.00	-242.760	6
WoodDist+BasalArea+Ground+SEM+SHR	498.03	7.59	0.00	-243.975	5
WoodDist+BasalArea+N4+SEM+SHR	498.21	7.76	0.00	-244.062	5
BasalArea+SEM+N3	498.27	7.82	0.00	-246.117	3
WoodDist+BasalArea+Ground+N2+SEM+SHR	498.57	8.13	0.00	-243.227	6
WoodDist+BasalArea+Ground+N4+SEM+SHR	498.96	8.51	0.00	-243.421	6
BasalArea+Ground+N3+SEM	499.26	8.81	0.00	-245.601	4
WoodDist+BasalArea+Ground+N2+N4+SEM+SHR	500.16	9.72	0.00	-243.004	7
BasalArea+N3+SEM+SHR	500.28	9.84	0.00	-246.114	4
N3	501.01	10.57	0.00	-249.504	1
BasalArea+Ground+N3+SEM+SHR	501.28	10.84	0.00	-245.601	5
BasalArea	502.98	12.54	0.00	-250.488	1
WoodDist	503.07	12.62	0.00	-250.531	1
N2	503.71	13.27	0.00	-250.855	1
N4	505.36	14.92	0.00	-251.680	1
Ground	505.70	15.25	0.00	-251.845	1
N1	508.57	18.13	0.00	-253.284	1
SEM	508.72	18.28	0.00	-253.360	1
Null	509.58	19.14	0.00	-254.790	0
OTH	510.72	20.28	0.00	-254.357	1
FRB	510.84	20.40	0.00	-254.418	1
TRE	511.03	20.59	0.00	-254.513	1
CSG	511.27	20.82	0.00	-254.631	1
SHR	511.40	20.96	0.00	-254.697	1
Litter	511.45	21.01	0.00	-254.722	1
MidStem	511.49	21.05	0.00	-254.744	1

Table D.6. Continued.

Model	AIC	ΔAIC	AICwt	log(L)	df
SmallStem	511.53	21.08	0.00	-254.761	1
SDR	511.55	21.10	0.00	-254.770	1
WSG	511.58	21.14	0.00	-254.789	1

* WoodDist = distance (m) to nearest woody cover, BasalArea = basal area, Litter = litter depth (cm), Ground = ground sighting distance (m), N1 = visual obstruction from 0.00–0.25 m, N2 = visual obstruction from 0.26–0.50 m, N3 = visual obstruction from 0.51–1.00 m, N4 = visual obstruction from 1.01–2.00 m, FRB = forb, WSG = warm season grass, CSG = cool season grass, SDR = sedge/rush, SEM = semi-woody, SHR = shrub, TRE = tree, BAR = bare ground, OTH = coarse woody debris or leaf litter, HER = herbaceous, WOO = shrub and tree species, SmallStem = midstory stems between 0.0–5.08 cm diameter, and MidStem = midstory stems between 0.509–11.43 cm diameter.

Table D.7. Means and standard errors for measured micro-scale characteristics of bobwhite used and available locations during the breeding and non-breeding season on Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, from 2021 to 2023.

		Breeding				**Non-breeding**			
Covariate	**Site**	**Location**		**Random**		**Location**		**Random**	
		$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
WoodDist	WR	21.77	2.482	27.49	2.116	13.76	1.645	20.40	1.916
	BF	31.91	3.164	35.65	3.200	25.10	3.507	27.06	2.864
	KB	7.77	0.822	12.14	1.184	6.61	1.115	10.07	1.348
	Pooled	20.87	1.499	26.30	1.456	15.54	1.477	19.39	1.314
BasalArea	WR	3.08	0.550	6.46	0.725	2.37	0.481	5.13	0.659
	BF	0.57	0.170	4.25	0.680	1.46	0.532	3.96	0.690
	KB	1.22	0.295	1.27	0.271	3.38	0.629	5.36	0.627
	Pooled	7.78	1.102	4.59	0.411	2.36	0.318	4.80	0.382
Ground	WR	1.19	0.058	1.45	0.077	--	--	--	--
	BF	1.01	0.044	1.22	0.062	--	--	--	--
	KB	0.93	0.062	1.08	0.058	--	--	--	--
	Pooled	1.06	0.030	1.29	0.043	--	--	--	--
Litter	WR	2.73	0.283	3.26	0.271	--	--	--	--
	BF	2.80	0.228	2.30	0.177	--	--	--	--
	KB	2.05	0.165	1.90	0.158	--	--	--	--
	Pooled	2.56	0.143	2.64	0.142	--	--	--	--
Height	WR	--	--	--	--	9.86	1.012	10.45	1.040
	BF	--	--	--	--	18.55	1.229	11.51	0.973
	KB	--	--	--	--	6.56	0.561	7.90	0.877
	Pooled	--	--	--	--	11.89	0.667	10.00	0.565
N1	WR	0.92	0.014	0.89	0.015	0.69	0.033	0.64	0.030
	BF	0.94	0.017	0.90	0.016	0.73	0.025	0.60	0.025
	KB	0.94	0.016	0.90	0.021	0.65	0.030	0.53	0.026
	Pooled	0.93	0.009	0.90	0.010	0.69	0.017	0.59	0.016
N2	WR	0.87	0.019	0.82	0.018	0.65	0.032	0.57	0.028
	BF	0.88	0.020	0.82	0.021	0.60	0.026	0.49	0.024
	KB	0.91	0.018	0.85	0.024	0.61	0.029	0.47	0.024
	Pooled	0.88	0.011	0.83	0.012	0.62	0.017	0.51	0.015
N3	WR	0.77	0.022	0.68	0.021	0.51	0.024	0.44	0.014
	BF	0.68	0.026	0.63	0.025	0.44	0.017	0.39	0.016
	KB	0.77	0.024	0.69	0.027	0.45	0.024	0.38	0.016
	Pooled	0.75	0.014	0.67	0.014	0.47	0.015	0.40	0.012
N4	WR	0.59	0.025	0.52	0.021	0.37	0.029	0.30	0.023
	BF	0.42	0.024	0.42	0.022	0.33	0.021	0.31	0.020
	KB	0.56	0.025	0.48	0.027	0.36	0.027	0.32	0.019
	Pooled	0.53	0.015	0.48	0.014	0.35	0.013	0.31	0.009
SmallStem	WR	23.44	3.549	20.48	4.461	43.08	11.996	21.83	2.575
	BF	9.58	2.065	11.16	2.736	8.28	2.137	10.34	2.035
	KB	24.51	2.736	22.60	2.823	43.82	5.168	34.38	3.833
	Pooled	19.52	1.800	18.10	2.295	31.10	4.579	21.89	1.747

Table D.7. Continued.

Covariate	Site	Breeding				Non-breeding			
		Location		Random		Location		Random	
		$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
MidStem	WR	0.86	0.334	0.78	0.143	1.18	0.681	0.92	0.196
	BF	0.16	0.070	0.66	0.243	0.07	0.046	0.30	0.101
	KB	0.61	0.144	0.86	0.301	1.03	0.223	1.52	0.301
	Pooled	0.57	0.146	0.76	0.122	0.74	0.245	0.90	0.125

* WoodDist = distance (m) to nearest woody cover, BasalArea = basal area (m^2/ha), Litter = litter depth (cm), Ground = ground sighting distance (m), Height = average vegetation height (cm), N1 = visual obstruction from 0.00–0.25 m, N2 = visual obstruction from 0.26–0.50 m, N3 = visual obstruction from 0.51–1.00 m, N4 = visual obstruction from 1.01–2.00 m, FRB = forb, WSG = warm season grass, CSG = cool season grass, SDR = sedge/rush, SEM = semi-woody, SHR = shrub, TRE = tree, BAR = bare ground, OTH = coarse woody debris or leaf litter, HER = herbaceous, WOO = shrub and tree species, SmallStem = midstory stems between 0.00–5.08 cm diameter, and MidStem = midstory stems between 0.509–11.43 cm diameter.

Table D.8. Model ranking based on AIC scores for discrete choice analysis of micro-scale resource selection during the non-breeding season across Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2021–2023. Includes both univariate and multivariate models.

Model	**AIC**	**ΔAIC**	**AICwt**	**log(L)**	**df**
WoodDist+Height+HRB+N2+SmallStem	276.26	0.00	0.17	-133.06	5
WoodDist+WoodDist^2+Height+HRB+N2+SmallStem	277.04	0.79	0.11	-132.42	6
WoodDist+BasalArea+Height+HRB+N2+SmallStem	278.22	1.96	0.06	-133.01	6
WoodDist+Height+HRB+N2+N4+SmallStem	278.30	2.05	0.06	-133.06	6
WoodDist+WoodDist^2+Height+Height^2+HRB+N2+SmallStem+SmallStem^2	278.37	2.12	0.06	-132.06	7
WoodDist+WoodDist^2+Height+Height^2+HRB+N2+SmallStem	278.37	2.12	0.06	-132.06	7
WoodDist+WoodDist^2+Height+HRB+N2+SmallStem+SmallStem^2	278.83	2.58	0.05	-132.29	7
WoodDist+BasalArea+HRB+N2+SmallStem	278.99	2.73	0.04	-134.43	5
WoodDist+BasalArea+Height+SEM+N2+SmallStem	279.38	3.13	0.04	-133.60	6
WoodDist+BasalArea+Height+WOO+N2+SmallStem	279.51	3.25	0.03	-133.66	6
WoodDist+Height+Height^2+HRB+N2+SmallStem+SmallStem^2	279.74	3.49	0.03	-132.74	7
WoodDist+WoodDist^2+Height+Height^2+HRB+N2+SmallStem+SmallStem^2	280.24	3.99	0.02	-131.96	8
WoodDist+BasalArea+Height+HRB+SEM+N2+SmallStem	280.26	4.01	0.02	-133.00	7
WoodDist+BasalArea+Height+HRB+WOO+N2+SmallStem	280.28	4.03	0.02	-133.01	7
WoodDist+Height+HRB+SEM+WOO+N2+SmallStem	280.34	4.09	0.02	-133.04	7
WoodDist+Height+HRB+N2+SmallStem+Site	280.37	4.12	0.02	-133.06	7
WoodDist+Height+HRB+N2	280.50	4.24	0.02	-136.20	4
WoodDist+BasalArea+HRB+N2+N4+SmallStem	281.01	4.75	0.02	-134.41	6
BasalArea+Height+HRB+N2+SmallStem	281.09	4.84	0.01	-135.48	5
WoodDist+BasalArea+Height+SEM+N2+N4+SmallStem	281.42	5.17	0.01	-133.58	7
WoodDist+BasalArea+Height+SEM+WOO+N2+SmallStem	281.45	5.19	0.01	-133.60	7
WoodDist+BasalArea+Height+WOO+N2+N4+SmallStem	281.55	5.29	0.01	-133.65	7
WoodDist+Height+HRB+N2+N4	282.33	6.07	0.01	-136.10	5
WoodDist+BasalArea+Height+HRB+SEM+WOO+N2+SmallStem	282.33	6.08	0.01	-133.00	8
WoodDist+BasalArea+Height+HRB+SEM+N2+N4+SmallStem	282.33	6.08	0.01	-133.00	8
WoodDist+BasalArea+Height+HRB+WOO+N2+N4+SmallStem	282.35	6.10	0.01	-133.01	8

Table D.8. Continued.

Model	AIC	ΔAIC	AICwt	log(L)	df
WoodDist+Height+HRB+SEM+WOO+N2+N4+SmallStem	282.41	6.15	0.01	-133.04	8
WoodDist+BasalArea+HRB+SEM+WOO+N2+SmallStem	282.90	6.64	0.01	-134.32	7
BasalArea+Height+HRB+N2+N4+SmallStem	283.12	6.86	0.01	-135.46	6
WoodDist+BasalArea+Height+SEM+WOO+N2+N4+SmallStem	283.49	7.24	0.00	-133.58	8
WoodDist+BasalArea+Height+HRB+SEM+WOO+N2+N4+SmallStem	284.41	8.16	0.00	-133.00	9
WoodDist+BasalArea+HRB+SEM+WOO+N2+N4+SmallStem	284.93	8.68	0.00	-134.30	8
N2	287.25	10.99	0.00	-142.62	1
WoodDist+BasalArea+Height+HRB+SEM+WOO+N1+SmallStem	288.44	12.19	0.00	-136.06	8
WoodDist+BasalArea+Height+HRB+SEM+WOO+N3+SmallStem	288.99	12.73	0.00	-136.33	8
WoodDist+BasalArea+Height+HRB+SEM+WOO+N1+N4+SmallStem	289.99	13.73	0.00	-135.79	9
WoodDist+BasalArea+Height+HRB+SEM+WOO+N4+SmallStem	291.12	14.86	0.00	-137.40	8
N1	295.63	19.38	0.00	-146.81	1
Height	297.37	21.12	0.00	-147.68	1
N3	297.91	21.66	0.00	-147.95	1
WoodDist	301.73	25.47	0.00	-149.86	1
SmallStem	302.10	25.85	0.00	-150.05	1
N4	304.93	28.68	0.00	-151.46	1
BasalArea	307.71	31.45	0.00	-152.85	1
Null	307.76	31.50	0.00	-153.88	0
SEM	308.77	32.52	0.00	-153.38	1
HRB	309.16	32.90	0.00	-153.57	1
WOO	309.46	33.21	0.00	-153.73	1
BAR	311.88	35.63	0.00	-154.94	1
MidStem	312.17	35.92	0.00	-155.08	1
OTH	312.53	36.27	0.00	-155.26	1

* WoodDist = distance (m) to nearest woody cover, BasalArea = basal area, Height = average vegetation height (cm), N1 = visual obstruction from 0.00–0.25 m, N2 = visual obstruction from 0.26–0.50 m, N3 = visual obstruction from 0.51–1.00 m, N4 = visual obstruction from 1.01–2.00 m, SEM = semi-woody, BAR = bare ground, OTH = coarse woody debris or leaf litter, HER =

herbaceous, WOO = shrub and tree species, SmallStem = midstory stems between 0.0–5.08 cm diameter, and MidStem = midstory stems between 0.509–11.43 cm diameter.

Table D.9. Groundcover composition means and standard errors for bobwhite used and available locations during the breeding and non-breeding season for Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, from 2021 to 2023.

Type	**Pooled**				**Wolf River**				**Bridgestone Firestone**				**Kyker Bottoms**			
	Location		Random		Location		Random		Location		Random		Location		Random	
	x̄	σ	x̄	σ	x̄	σ	x̄	σ	x̄	σ	x̄	σ	x̄	σ	x̄	σ
Breeding season																
FRB	0.74	0.013	0.70	0.014	0.73	0.023	0.68	0.025	0.80	0.019	0.73	0.023	0.67	0.023	0.68	0.024
WSG	0.28	0.014	0.28	0.013	0.35	0.023	0.35	0.019	0.25	0.023	0.28	0.023	0.19	0.019	0.16	0.018
CSG	0.18	0.012	0.19	0.011	0.15	0.015	0.13	0.014	0.29	0.025	0.31	0.023	0.11	0.017	0.14	0.018
SDR	0.12	0.009	0.11	0.008	0.09	0.012	0.11	0.011	0.09	0.013	0.07	0.010	0.19	0.022	0.17	0.021
SEM	0.43	0.014	0.39	0.013	0.34	0.020	0.37	0.019	0.38	0.022	0.34	0.021	0.60	0.022	0.51	0.024
SHR	0.05	0.005	0.06	0.005	0.03	0.006	0.02	0.004	0.05	0.009	0.09	0.012	0.08	0.010	0.08	0.012
TRE	0.10	0.008	0.12	0.008	0.10	0.010	0.10	0.009	0.05	0.008	0.11	0.015	0.17	0.019	0.16	0.019
BAR	0.01	0.002	0.01	0.001	0.00	0.001	0.00	0.002	0.00	0.003	0.01	0.003	0.01	0.005	0.01	0.003
OTH	0.02	0.003	0.04	0.005	0.03	0.006	0.05	0.009	0.01	0.006	0.03	0.007	0.02	0.005	0.02	0.007
Non-breeding season																
HER	0.59	0.018	0.56	0.017	0.55	0.033	0.54	0.032	0.53	0.028	0.52	0.029	0.70	0.028	0.63	0.028
SEM	0.21	0.013	0.18	0.011	0.18	0.026	0.18	0.020	0.22	0.017	0.17	0.017	0.22	0.023	0.19	0.020
WOO	0.09	0.009	0.10	0.008	0.14	0.019	0.12	0.015	0.07	0.012	0.11	0.015	0.06	0.014	0.09	0.013
BAR	0.26	0.045	0.31	0.038	0.22	0.075	0.21	0.070	.033	0.074	0.41	0.060	0.23	0.085	0.32	0.067
OTH	0.07	0.012	0.13	0.015	0.12	0.028	0.16	0.027	0.06	0.019	0.11	0.022	0.03	0.010	0.10	0.026

* FRB = forb, WSG = warm season grass, CSG = cool season grass, SDR = sedge/rush, SEM = semi-woody, SHR = shrub, TRE = tree, BAR = bare ground, OTH = coarse woody debris or leaf litter, HER = herbaceous, WOO = shrub and tree species.

Table D.10. Model ranking based on AICc scores for known-fate survival analysis of biological characteristics across Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2021–2023.

Model	**AICc**	**ΔAIC**	**AICwt**	**Deviance**	**df**
Site+Season	1054.991	0.000	0.373	585.927	4
Site*Season	1055.091	0.099	0.355	582.015	6
Year	1058.460	3.468	0.066	585.384	6
Site*Season*Year	1058.467	3.476	0.066	563.257	17
Site*Year	1058.467	3.476	0.066	563.257	17
Site+Year	1059.452	4.461	0.040	582.362	8
Null	1062.622	7.630	0.008	599.566	1
Site	1062.715	7.724	0.008	595.655	3
Age	1063.788	8.796	0.005	598.731	2
Site+Age	1064.002	9.010	0.004	594.937	4
BC	1064.426	9.435	0.003	1060.423	2
Weight	1064.581	9.589	0.003	1060.578	2
Sex	1065.930	10.938	0.002	598.869	3
Site+Sex	1065.949	10.957	0.002	594.879	5

* Site = focal area, Age = age of individual bird (juvenile or adult), Sex = sex of bird (male or female), Weight = mass of bird (g), BC = body condition of bird, Season = breeding or non breeding season, and Year = annual calendar year.

Table D.11. Model ranking based on AICc scores for known-fate survival analysis of macro characteristics on Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2021–2023.

Model	AICc	∆AIC	AICwt	Deviance	df
--- *Breeding season* ---					
YGF+DEC	727.45	0.000	0.148	721.443	3
YGF	728.01	0.561	0.112	724.009	2
YGF+ES	728.05	0.600	0.110	722.043	3
YGF+DEC+WOOD	729.15	1.695	0.063	721.131	4
YGF+Site	729.24	1.782	0.061	721.218	4
YGF+ES+ESW	729.40	1.947	0.056	721.383	4
YGF+DEC+ESW	729.41	1.956	0.056	721.392	4
YGF+WOOD	729.52	2.062	0.053	723.505	3
YGF+ESW	729.90	2.447	0.043	723.890	3
YGF+DEC+Site	729.92	2.467	0.043	719.895	5
YGF+ES+WOOD	730.06	2.607	0.040	722.043	4
ES	730.52	3.065	0.032	726.514	2
Site	730.91	3.454	0.026	204.543	3
YGF+ESW+WOOD	731.44	3.986	0.020	723.422	4
Null	731.59	4.138	0.019	209.235	1
DEC	731.88	4.430	0.016	727.878	2
ES+Site	731.91	4.454	0.016	723.890	4
DEC+Site	732.52	5.068	0.012	724.504	4
YGF+DEC+ESW+WOOD+Int	732.64	5.183	0.011	720.599	6
ESW+Site	732.74	5.287	0.011	724.723	4
WOOD+Site	732.77	5.312	0.010	724.748	4
Int	732.85	5.394	0.010	728.842	2
Int+Site	732.87	5.411	0.010	724.847	4
YGF+ES+ESW+WOOD+Int	733.08	5.624	0.009	721.041	6
WOOD	733.36	5.906	0.008	729.354	2
ESW	733.58	6.129	0.007	729.577	2
--- *Non-breeding season* ---					
DEC	344.83	0.000	0.078	340.820	2
Null	344.86	0.029	0.077	123.872	1
Site	345.49	0.663	0.056	120.494	3
DEC+Site	345.61	0.779	0.053	337.583	4
ESW+Site	345.86	1.036	0.047	337.840	4
DEC+ESW+Site	346.18	1.354	0.040	336.146	5
YGF	346.22	1.389	0.039	342.209	2
DEC+ES	346.57	1.739	0.033	340.552	3

Table D.11. Continued.

Model	AICc	ΔAIC	AICwt	Deviance	df
DEC+YGF	346.61	1.782	0.032	340.595	3
ES	346.73	1.898	0.030	342.718	2
DEC+WOOD	346.74	1.918	0.030	340.731	3
DEC+ESW	346.79	1.967	0.029	340.780	3
ESW	346.85	2.019	0.028	342.839	2
WOOD	346.86	2.032	0.028	342.852	2
YGF+Site	346.96	2.133	0.027	338.936	4
Year	347.04	2.209	0.026	122.041	3
DEC+ES+Site	347.07	2.247	0.025	337.039	5
DEC+YGF+Site	347.32	2.490	0.022	337.282	5
DEC+WOOD+Site	347.43	2.600	0.021	337.392	5
WOOD+Site	347.45	2.624	0.021	339.427	4
ES+Site	347.50	2.670	0.021	339.473	4
DEC+YGF+ES	347.70	2.878	0.019	339.681	4
DEC+YGF+ESW+Site	347.78	2.954	0.018	335.733	6
DEC+ESW+WOOD+Site	348.07	3.243	0.015	336.022	6
DEC+YGF+ES+Site	348.19	3.359	0.015	336.138	6
DEC+ES+ESW+Site	348.19	3.367	0.015	336.145	6
DEC+ES+WOOD	348.46	3.630	0.013	340.434	4
DEC+YGF+WOOD	348.47	3.646	0.013	340.450	4
DEC+YGF+ESW	348.50	3.677	0.012	340.480	4
DEC+ES+ESW	348.56	3.729	0.012	340.533	4
DEC+ES+WOOD+Site	348.69	3.861	0.011	336.640	6
DEC+ESW+WOOD	348.73	3.899	0.011	340.703	4
DEC+YGF+WOOD+Site	349.04	4.209	0.010	336.987	6
DEC+YGF+ES+ESW+WOOD+Site	351.16	6.338	0.003	335.081	8
YGF+DEC+ES+ESW+WOOD	351.16	6.338	0.003	339.116	6

* ES = home range in early successional (%), ESW = home range in early successional woody (%), DEC = home range in deciduous forest (%), YGF = home range in young forest (%), WOOD = home range in woodland (%), and Site = focal area.

Table D.12. Means ($\bar{x}$) and standard errors (SE) for measured survival covariate characteristics of bobwhite locations during the breeding season on Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, from 2021 to 2023. Includes groups of covariates including macro, micro, and management characteristics.

Covariate	**WR**		**BF**		**KB**		**Pooled**		**Group**
	$\bar{x}$	**SE**	$\bar{x}$	**SE**	$\bar{x}$	**SE**	$\bar{x}$	**SE**	
Man	32.93	1.592	29.54	1.472	27.72	1.260	29.99	0.865	Micro
WoodDist	20.33	1.468	33.02	1.861	7.92	268	22.35	1.125	Micro
BasalArea	12.49	0.759	3.66	0.613	3.82	0.663	6.23	0.465	Micro
Ground	1.17	0.027	0.99	0.039	0.98	0.025	1.04	0.020	Micro
Litter	2.85	0.196	2.57	0.134	2.11	0.114	2.52	0.090	Micro
FRB	0.892	0.009	77.42	1.317	67.81	1.707	73.31	0.798	Micro
WSG	1.208	0.012	23.52	1.612	19.31	1.176	25.88	0.925	Micro
CSG	0.785	0.008	28.57	1.252	12.33	1.456	20.18	0.834	Micro
SDR	0.988	0.010	9.18	0.843	20.46	2.036	12.59	0.777	Micro
SEM	1.185	0.012	36.47	1.316	59.96	1.510	42.37	1.043	Micro
SHR	0.323	0.003	4.77	0.487	7.12	0.808	4.79	0.328	Micro
TRE	0.539	0.005	4.95	0.499	16.27	1.318	9.44	0.529	Micro
BARE	0.038	0.000	0.87	0.401	1.27	0.178	0.79	0.172	Micro
OTH	0.193	0.002	1.29	0.471	1.14	0.220	1.61	0.214	Micro
N1	0.637	0.006	88.27	1.381	83.24	1.916	88.02	0.812	Micro
N2	0.900	0.009	82.62	1.375	80.86	1.974	83.61	0.835	Micro
N3	1.163	0.012	61.16	1.632	69.32	2.183	68.29	1.056	Micro
N4	1.573	0.016	38.21	1.384	50.60	1.835	48.10	1.081	Micro
SmallStem	412.99	23.06	186.97	17.902	429.93	28.979	319.68	14.878	Micro
MidStem	14.86	2.78	3.28	0.950	11.75	23.589	8.99	1.089	Micro
MArea	6.27	0.227	4.46	0.249	6.20	0.343	5.56	0.162	Mang
UnitDist	24.80	0.692	23.23	0.699	25.42	0.630	24.36	0.404	Mang
OneBurn	22.69	2.178	23.36	1.696	20.44	2.339	22.52	1.168	Mang
TwoBurn	16.97	1.716	18.42	1.825	9.74	1.160	16.10	1.025	Mang
ThreeBurn	22.69	2.051	13.20	2.043	4.19	0.900	14.56	1.212	Mang
HerbBC	2.54	0.358	3.58	0.635	0.00	0.000	2.48	0.305	Mang
HerbSS	5.75	0.958	39.33	3.786	6.11	1.826	20.96	1.973	Mang
Disk	1.55	0.365	11.42	1.151	0.00	0.000	161.74	0.598	Mang

***** WoodDist = distance (m) to nearest woody cover, Basal = basal area (m^2/ha), Ground = average sight tube measurement (m), Litter = average litter depth (cm), N1 = visual obstruction from 0.00–0.25 m (%), N2 = visual obstruction from 0.26–0.50 m (%), N3 = visual obstruction from 0.51–1.00 m (%), N4 = visual obstruction from 1.01–2.00 m (%), FRB = forb coverage (%), WSG = warm-season grass coverage (%), CSG = cool-season grass coverage (%), SEM = semi-woody coverage (%), SHR = shrub coverage (%), TRE = tree coverage (%), BAR = bare ground coverage (%), OTR = coarse woody debris or leaf litter coverage (%), SmallStem = midstory stems between 0.0–5.08 cm diameter (stems/ha), MidStem = midstory stems between 5.09–11.43 cm diameter (stems/ha), MSize = average management unit size (ha), UnitDist =

average distance (m) to management unit edge, OneBurn = home range located in burn 0-11 months (%), TwoBurn = home range located in burn 12-23 months (%), ThreeBurn = home range located in burn 24+ months (%), Disk = home range located in disked area (%), HerbBC = home range located in broadcast herbicide application (%), and HerbSS = home range located in spot-sprayed herbicide application (%).

Table D.13. Model ranking based on AICc scores for known-fate survival analysis of micro characteristics on Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2021–2023.

Model	**AICc**	**ΔAIC**	**AICwt**	**Deviance**	**df**
---------- *Breeding season* ----------					
SmallStem+SmallStem^2+MidStem+MidStem^2+FRB	709.65	0.000	0.158	697.615	6
SmallStem+SmallStem^2+MidStem+MidStem^2	709.77	0.119	0.149	699.744	5
SEM+MidStem+MidStem^2	709.80	0.149	0.147	707.800	1
Ground+MidStem+MidStem^2	709.97	0.317	0.135	707.967	1
YGF+MidStem+MidStem^2	712.95	3.302	0.030	704.937	4
ES+MidStem+MidStem^2	713.16	3.503	0.027	705.137	4
ES+MidStem+MidStem^2+FRB	714.07	4.422	0.017	704.047	5
YGF+MidStem+MidStem^2+FRB	714.08	4.431	0.017	704.056	5
SR+MidStem+MidStem^2+FRB	714.16	4.504	0.017	704.130	5
MidStem+MidStem^2	714.20	4.552	0.016	708.193	3
WOOD+MidStem+MidStem^2+FRB	714.23	4.579	0.016	706.213	4
OTR+MidStem+MidStem^2	714.41	4.758	0.015	706.393	4
FRB+MidStem+MidStem^2	714.93	5.274	0.011	706.908	4
SR+MidStem+MidStem^2	714.97	5.314	0.011	706.948	4
DEC+MidStem+MidStem^2	715.13	5.476	0.010	707.110	4
N3+MidStem+MidStem^2	715.34	5.692	0.009	707.326	4
WoodDist+MidStem+MidStem^2+FRB	715.48	5.827	0.009	705.452	5
MidStem+MidStem^2+Site	715.50	5.851	0.008	705.477	5
WoodDist+MidStem+MidStem^2	715.55	5.902	0.008	707.537	4
WOOD+MidStem+MidStem^2	715.56	5.905	0.008	707.539	4
SHR+MidStem+MidStem^2	715.68	6.024	0.008	707.658	4
Ground+Ground^2+MidStem+MidStem^2	715.72	6.063	0.008	705.688	5
OTR+MidStem+MidStem^2+FRB	715.75	6.100	0.007	705.725	5
DEC+MidStem+MidStem^2+FRB	715.76	6.107	0.007	705.733	5
SmallStem+MidStem+MidStem^2	715.76	6.107	0.007	707.742	4
N3+MidStem+MidStem^2+FRB	715.80	6.148	0.007	705.773	5
WSG+MidStem+MidStem^2	715.81	6.162	0.007	707.796	4
CSG+MidStem+MidStem^2	715.85	6.198	0.007	707.832	4
Basal+MidStem+MidStem^2	715.89	6.236	0.007	707.870	4
SHR+MidStem+MidStem^2+FRB	715.89	6.239	0.007	705.864	5
SmallStem+MidStem+MidStem^2+FRB	715.90	6.243	0.007	705.868	5
BARE+MidStem+MidStem^2	715.90	6.247	0.007	707.882	4
N4+MidStem+MidStem^2	715.98	6.327	0.007	707.961	4
N2+MidStem+MidStem^2	716.17	6.522	0.006	708.157	4
TRE+MidStem+MidStem^2	716.18	6.528	0.006	708.162	4

Table D.13. Continued.

Model	AICc	ΔAIC	AICwt	Deviance	df
ESW+MidStem+MidStem^2	716.21	6.555	0.006	708.189	4
N1+MidStem+MidStem^2	716.21	6.558	0.006	708.192	4
SEM+MidStem+MidStem^2+FRB	716.39	6.733	0.005	706.359	5
N4+MidStem+MidStem^2+FRB	716.49	6.836	0.005	706.462	5
TRE+MidStem+MidStem^2+FRB	716.55	6.896	0.005	706.522	5
Ground+MidStem+MidStem^2+FRB	716.73	7.075	0.005	706.700	5
WSG+MidStem+MidStem^2+FRB	716.74	7.091	0.005	706.716	5
BARE+MidStem+MidStem^2+FRB	716.83	7.179	0.004	706.804	5
Basal+MidStem+MidStem^2+FRB	716.85	7.198	0.004	706.824	5
N2+MidStem+MidStem^2+FRB	716.89	7.239	0.004	706.865	5
ESW+MidStem+MidStem^2+FRB	716.92	7.266	0.004	706.891	5
N1+MidStem+MidStem^2+FRB	716.94	7.283	0.004	706.908	5
WoodDist+WoodDist^2+MidStem+MidStem^2+FRB	717.16	7.510	0.004	705.125	6
Ground+Ground^2+MidStem+MidStem^2+FRB	717.19	7.537	0.004	705.151	6
SmallStem+SmallStem^2	717.31	7.663	0.003	711.304	3
WoodDist+WoodDist^2+MidStem+MidStem^2	717.49	7.841	0.003	707.466	5
SmallStem+SmallStem^2+Site	720.53	10.881	0.001	710.506	5
YGF+DEC	727.45	17.802	0.000	721.443	3
Ground+Ground^2	728.41	18.759	0.000	722.400	3
Ground+Ground^2+Site	728.72	19.068	0.000	718.693	5
Site	730.91	21.256	0.000	204.543	3
Null	731.59	21.939	0.000	209.235	1
N3	731.67	22.022	0.000	727.668	2
CSG+Site	731.88	22.233	0.000	723.867	4
WSG+Site	731.94	22.284	0.000	723.919	4
N3+Site	732.00	22.349	0.000	723.983	4
FRB+Site	732.09	22.433	0.000	724.068	4
MidStem+Site	732.10	22.449	0.000	724.084	4
N4	732.10	22.452	0.000	728.099	2
OTR+Site	732.10	22.452	0.000	724.087	4
WoodDist	732.18	22.527	0.000	728.174	2
BARE+Site	732.29	22.636	0.000	724.271	4
SR	732.49	22.838	0.000	728.485	2
N4+Site	732.55	22.899	0.000	724.533	4
SmallStem	732.56	22.911	0.000	728.558	2
OTR	732.70	23.052	0.000	728.699	2
SR+Site	732.72	23.063	0.000	724.697	4
SEM+Site	732.72	23.069	0.000	724.704	4

Table D.13. Continued.

Model	AICc	ΔAIC	AICwt	Deviance	df
SHR+Site	732.79	23.140	0.000	724.775	4
TRE+Site	732.82	23.170	0.000	724.804	4
N1+Site	732.85	23.200	0.000	724.835	4
SmallStem+Site	732.87	23.215	0.000	724.850	4
Ground+Site	732.87	23.217	0.000	724.851	4
N2+Site	732.88	23.227	0.000	724.861	4
WoodDist+Site	732.90	23.250	0.000	724.884	4
Basal+Site	732.92	23.263	0.000	724.897	4
WSG	733.00	23.348	0.000	728.995	2
TRE	733.16	23.511	0.000	729.158	2
SHR	733.20	23.552	0.000	729.199	2
BARE	733.22	23.565	0.000	729.212	2
SEM	733.22	23.569	0.000	729.216	2
MidStem	733.42	23.766	0.000	729.413	2
Basal	733.52	23.865	0.000	729.512	2
FRB	733.54	23.889	0.000	729.536	2
Ground	733.56	23.903	0.000	729.550	2
N2	733.56	23.906	0.000	729.553	2
N1	733.59	23.941	0.000	729.588	2
CSG	733.59	23.942	0.000	729.589	2
WoodDist+WoodDist^2	734.18	24.529	0.000	728.171	3
WoodDist+WoodDist^2+Site	734.23	24.577	0.000	724.203	5
-- *Non-breeding season* --					
BARE	343.07	0.000	0.051	339.062	2
WDD	343.19	0.117	0.048	339.179	2
MidStem+BARE	343.29	0.223	0.045	337.278	3
BARE+WDD	343.36	0.291	0.044	337.346	3
OTR	343.50	0.434	0.041	339.496	2
Height+Height^2+Site	343.80	0.735	0.035	333.769	5
Basal+BARE	343.93	0.861	0.033	337.916	3
OTR+Site	344.16	1.094	0.029	336.140	4
N4+BARE	344.26	1.189	0.028	338.244	3
N3+BARE	344.47	1.398	0.025	338.453	3
ESW+BARE	344.48	1.413	0.025	338.468	3
HRB	344.56	1.496	0.024	340.557	2
MidStem+MidStem^2+BARE	344.60	1.527	0.024	336.573	4
WoodDist+BARE	344.64	1.575	0.023	338.630	3

Table D.13. Continued.

Model	AICc	ΔAIC	AICwt	Deviance	df
Basal	344.70	1.634	0.022	340.696	2
Height+BARE	344.75	1.678	0.022	338.733	3
HRB+BARE	344.79	1.724	0.021	338.779	3
Null	344.86	1.787	0.021	123.872	1
N2+BARE	344.86	1.795	0.021	338.850	3
Height+Site	344.87	1.799	0.021	336.845	4
N1+BARE	344.91	1.841	0.020	338.895	3
SHR+BARE	344.93	1.858	0.020	338.913	3
SmallStem+BARE	344.95	1.884	0.020	338.939	3
BARE+Site	345.02	1.952	0.019	336.998	4
WOOD+BARE	345.06	1.993	0.019	339.048	3
SEM+BARE	345.07	1.999	0.019	339.054	3
ES+BARE	345.08	2.007	0.019	339.062	3
MidStem	345.30	2.231	0.017	341.293	2
Site	345.49	2.421	0.015	120.494	3
MidStem+Site	345.54	2.471	0.015	337.517	4
Height	345.62	2.553	0.014	341.615	2
Wood+Site	345.66	2.594	0.014	337.640	4
Basal+Site	345.73	2.661	0.013	337.707	4
N1+Site	345.86	2.791	0.013	337.836	4
N1	346.14	3.072	0.011	342.134	2
HRB+Site	346.24	3.171	0.010	338.217	4
N3	346.26	3.190	0.010	342.252	2
WoodDist	346.36	3.291	0.010	342.352	2
N4	346.41	3.342	0.010	342.404	2
SmallStem	346.45	3.385	0.009	342.447	2
N2	346.54	3.469	0.009	342.531	2
N4+Site	346.58	3.508	0.009	338.554	4
N3+Site	346.64	3.572	0.008	338.618	4
WoodDist+WoodDist^2+BARE	346.65	3.583	0.008	338.629	4
WoodDist+Site	346.81	3.740	0.008	338.786	4
SEM	346.85	3.779	0.008	342.841	2
MidStem+MidStem^2+Site	346.92	3.850	0.007	336.884	5
SmallStem+SmallStem^2+BARE	346.95	3.878	0.007	338.924	4
MidStem+MidStem^2	347.01	3.938	0.007	340.993	3
N2+Site	347.03	3.966	0.007	339.012	4
SmallStem+Site	347.45	4.379	0.006	339.425	4

Table D.13. Continued.

Model	AICc	ΔAIC	AICwt	Deviance	df
SEM+Site	347.49	4.423	0.006	339.469	4
SmallStem+SmallStem^2+Site	347.94	4.874	0.004	337.908	5
SmallStem+SmallStem^2	347.99	4.925	0.004	341.980	3
WoodDist+WoodDist^2+Site	348.34	5.266	0.004	338.301	5

***** ES = home range in early successional (%), ESW = home range in early successional woody (%), DEC = home range in deciduous forest (%), YGF = home range in young forest (%), WOOD = home range in woodland (%), WoodDist = distance (m) to nearest woody cover, Basal = basal area (m^2/ha), Litter = average litter depth (cm), Ground = average sight tube measurement (m), Height = average vegetation height (cm), N1 = visual obstruction from 0.00–0.25 m (%), N2 = visual obstruction from 0.26–0.50 m (%), N3 = visual obstruction from 0.51–1.00 m (%), N4 = visual obstruction from 1.01–2.00 m (%), FRB = forb coverage (%), WSG = warm-season grass coverage (%), CSG = cool-season grass coverage (%), HRB = forb and grass coverage (%), SEM = semi-woody coverage (%), SHR = shrub coverage (%), TRE = tree coverage (%), WDD = shrub and tree coverage (%), BAR = bare ground coverage (%), OTR = coarse woody debris or leaf litter coverage (%), SmallStem = midstory stems between 0.00–5.08 cm diameter (stems/ha), and MidStem = midstory stems between 5.09–11.43 cm diameter (stems/ha).

Table D.14. Model ranking based on AIC scores for known-fate survival analysis of management characteristics on Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2022–2023.

Model	AICc	ΔAIC	AICwt	Deviance	df
-- *Breeding season* --					
Disk+MSize+MSize^2	542.56	0.000	0.274	536.547	3
ThreeBurn+MSize+MSize^2+Disk	544.34	1.780	0.113	534.307	5
HerbBC+MSize+MSize^2	544.76	2.197	0.092	536.735	4
MSize+MSize^2	545.01	2.445	0.081	538.993	3
HerbSS+MSize+MSize^2	545.11	2.546	0.077	537.084	4
ThreeBurn+MSize+MSize^2	545.40	2.836	0.066	537.374	4
TwoBurn+MSize+MSize^2+Disk	545.73	3.173	0.056	535.700	5
OneBurn+MSize+MSize^2	546.15	3.591	0.046	538.129	4
HerbSS+MSize+MSize^2+Disk	546.34	3.783	0.041	536.310	5
OneBurn+MSize+MSize^2+Disk	546.44	3.880	0.039	536.407	5
TwoBurn+MSize+MSize^2	546.66	4.104	0.035	538.642	4
HerbSS	548.01	5.453	0.018	544.007	2
Disk	549.19	6.631	0.010	545.186	2
UnitDist+UnitDist^2	549.62	7.058	0.008	543.606	3
UnitDist	550.19	7.633	0.006	546.187	2
MSize	550.66	8.103	0.005	546.657	2
ThreeBurn+Site	550.85	8.290	0.004	542.828	4
HerbSS+Site	551.08	8.516	0.004	543.054	4
HerbBC	551.34	8.779	0.003	547.333	2
Site	551.37	8.810	0.003	152.343	3
UnitDist+Site	551.78	9.220	0.003	543.758	4
HerbBC+Site	551.96	9.400	0.002	543.938	4
Null	552.16	9.597	0.002	157.141	1
Disk+Site	552.26	9.702	0.002	544.241	4
ThreeBurn	552.43	9.866	0.002	548.421	2
MSize+Site	552.73	10.167	0.002	544.705	4
OneBurn+Site	553.38	10.816	0.001	545.354	4
TwoBurn+Site	553.38	10.818	0.001	545.357	4
OneBurn	554.11	11.551	0.001	550.105	2
TwoBurn	554.16	11.598	0.001	550.152	2
-- *Non-breeding season* --					
HerbSS+TwoBurn	286.68	0.000	0.087	280.660	3
UnitDist+TwoBurn+HerbSS	286.69	0.011	0.087	278.660	4
TwoBurn	287.48	0.802	0.059	283.470	2

Table D.14. Continued.

Model	AICc	ΔAIC	AICwt	Deviance	df
UnitDist+UnitDist^2	287.59	0.917	0.055	281.577	3
MSize+TwoBurn+HerbSS	287.70	1.026	0.052	279.675	4
UnitDist	287.87	1.196	0.048	283.864	2
UnitDist+UnitDist^2+TwoBurn+HerbSS	287.96	1.282	0.046	277.918	5
UnitDist+TwoBurn	287.96	1.287	0.046	281.947	3
HerbBC+TwoBurn	288.11	1.431	0.043	282.092	3
Disk+TwoBurn+HerbSS	288.36	1.683	0.038	280.333	4
Null	288.46	1.782	0.036	103.467	1
Disk+TwoBurn	288.67	1.990	0.032	282.651	3
HerbBC+TwoBurn+HerbSS	288.69	2.009	0.032	280.659	4
UnitDist+UnitDist^2+TwoBurn	288.82	2.145	0.030	280.794	4
UnitDist+Site	289.12	2.449	0.026	281.098	4
MSize+TwoBurn	289.29	2.618	0.024	283.278	3
TwoBurn+Site	289.34	2.660	0.023	281.310	4
MSize+MSize^2+TwoBurn+HerbSS	289.35	2.675	0.023	279.311	5
HerbBC	289.63	2.951	0.020	285.619	2
UnitDist+UnitDist^2+Site	289.67	2.997	0.020	279.633	5
OneBurn	289.75	3.075	0.019	285.744	2
HerbSS	289.86	3.182	0.018	285.851	2
MSize	289.92	3.246	0.017	285.915	2
HerbBC+Site	290.20	3.526	0.015	282.175	4
MSize+Site	290.24	3.561	0.015	282.210	4
Disk	290.37	3.695	0.014	286.363	2
ThreeBurn	290.37	3.696	0.014	286.364	2
HerbSS+Site	290.89	4.215	0.011	282.864	4
Disk+Site	290.97	4.295	0.010	282.945	4
OneBurn+Site	291.13	4.451	0.009	283.101	4
ThreeBurn+Site	291.14	4.460	0.009	283.109	4
MSize+MSize^2+TwoBurn	291.25	4.575	0.009	283.224	4
MSize+MSize^2	291.39	4.709	0.008	285.369	3
MSize+MSize^2+Site	292.13	5.452	0.006	282.088	5

* MSize = average management unit size (ha), MSize^2 = management unit size quadratically, UnitDist = average distance (m) to management unit edge, UnitDist^2 = distance (m) to management unit edge quadratically, OneBurn = home range in burn 0-11 months (%), TwoBurn = home range in burn 12-23 months (%), ThreeBurn = home range in burn 24+ months (%), Disk = home range in disked area (%), HerbBC = home range in broadcast herbicide application (%), and HerbSS = home range in spot-sprayed herbicide application (%).

Table D.15. Model ranking based on AIC scores for influence of predator index on survival on Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2022–2023.

Model	AICc	ΔAIC	AICwt	Deviance	df
--- *Breeding season* ---					
Pred	728.91	0.000	0.628	724.901	2
Pred+Site	731.12	2.214	0.208	723.102	4
Null	731.59	2.685	0.164	209.235	1
--- *Non-breeding season* ---					
Pred	184.67	0.000	0.398	180.660	2
Pred+Site	185.10	0.425	0.322	177.059	4
Null	185.37	0.695	0.281	59.587	1

[*] Pred = predator index value.

Table D.16. Means ($\bar{x}$) and standard errors (SE) for measured survival covariates of bobwhite locations during the non-breeding season on Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, from 2021–2023. Includes different groups of covariates including macro, micro, and management characteristics.

Covariate	**WR**		**BF**		**KB**		**Pooled**		**Group**
	$\bar{x}$	**SE**	$\bar{x}$	**SE**	$\bar{x}$	**SE**	$\bar{x}$	**SE**	
WoodDist	11.81	0.717	25.19	1.002	11.46	1.281	18.35	0.737	Micro
Basal	11.14	1.079	6.83	0.680	9.84	0.571	8.74	0.489	Micro
Height	8.72	0.473	19.11	0.356	5.28	0.427	13.13	0.462	Micro
HRB	0.876	0.011	53.22	0.871	66.20	1.346	55.83	0.677	Micro
SEM	0.615	0.009	19.28	0.747	21.94	1.164	20.64	0.480	Micro
WDD	0.639	0.007	9.84	0.709	6.17	0.491	10.04	0.427	Micro
BARE	1.041	0.010	13.26	0.882	17.60	1.803	12.61	0.701	Micro
OTR	1.621	0.016	23.27	1.528	31.17	1.953	26.24	0.987	Micro
N1	2.247	0.022	69.46	1.690	58.30	1.497	65.13	1.137	Micro
N2	2.037	0.022	58.82	1.922	53.17	1.389	57.20	1.139	Micro
N3	1.496	0.016	44.14	1.562	41.57	1.457	42.85	0.918	Micro
N4	0.993	0.010	33.09	1.036	31.73	0.824	31.49	0.608	Micro
SmallStem	42.93	2.819	7.13	0.485	30.00	3.928	22.50	1.628	Micro
MidStem	1.46	0.252	0.05	0.015	0.86	0.154	0.62	0.094	Micro
MSize	7.71	0.353	4.76	0.256	8.63	0.991	6.65	0.311	Mang
UnitDist	32.63	1.277	24.39	0.703	26.64	1.577	27.55	0.679	Mang
OneBurn	14.36	2.342	23.67	1.790	25.02	3.018	21.22	1.320	Mang
TwoBurn	31.66	3.031	15.31	2.538	7.49	1.567	18.46	1.642	Mang
ThreeBurn	0.00	0.000	19.44	2.075	2.41	0.998	10.11	1.158	Mang
HerbSS	9.71	4.729	47.31	0.764	3.23	1.962	26.92	2.634	Mang
HerbBC	1.15	0.945	5.85	1.665	3.57	0.217	3.98	0.596	Mang
Disk	0.28	0.077	11.10	1.235	9.08	2.029	7.49	0.796	Mang

***** WoodDist = distance (m) to nearest woody cover, Basal = basal area (m^2/ha), Height = average vegetation height (cm), N1 = visual obstruction from 0.00–0.25 m (%), N2 = visual obstruction from 0.26–0.50 m (%), N3 = visual obstruction from 0.51–1.00 m (%), N4 = visual obstruction from 1.01–2.00 m (%), HRB = forb and grass coverage (%), SEM = semi-woody coverage (%), WDD = shrub and tree coverage (%), BAR = bare ground coverage (%), OTR = coarse woody debris or leaf litter coverage (%), SmallStem = midstory stems between 0.00–5.08 cm diameter (stems/ha), MidStem = midstory stems between 5.09–11.43 cm diameter (stems/ha), MSize = average management unit size (ha), UnitDist = distance (m) to management unit edge, OneBurn = percentage of home range located in burn 0-11 months (%), TwoBurn = percentage of home range located in burn 12-23 months (%), ThreeBurn = percentage of home range located in burn 24+ months (%), Disk = percentage of home range located in disked area (%), HerbBC = percentage of home range located in broadcast herbicide application (%), and HerbSS = percentage of home range located in spot-sprayed herbicide application (%).

Table D.17. Relationship between supported covariates and analyses (resource selection and survival) during the breeding and non-breeding season on Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, from 2021–2023. Includes different groups of covariates including macro, micro, and management characteristics.

Covariate	**Breeding season**		**Non-breeding season**	
	Selection	**Survival**	**Selection**	**Survival**
--- *Macro-scale* ---				
Early succession	+	NA	+	NA
Early succession woody	+	NA	+	NA
Deciduous forest	-	-	NA	+
Young forest	+	-	+	NA
Woodland	NA	NA	+	NA
Interspersion	+	NA	+	NA
Manmade distance (m)	-	NA	NA	NA
--- *Micro-scale* ---				
Small midstory stems (<5.1 cm dbh)	NA	-	+	NA
Distance to woody cover (m)	-	NA	-	NA
Medium midstory stems (5.1-11.4 cm dbh)	NA	-	NA	NA
Herbaceous (%)	NA	NA	NA	NA
Bare ground (%)	NA	-	NA	NA
Visual obstruction 0.25-0.50 m (%)	+	NA	+	NA
Basal area (stems/ha)	-	NA	NA	NA
--- *Management* ---				
One-burn	+	NA	+	NA
Two-burn	NA	NA	NA	+
Three-burn	NA	NA	NA	NA
Spot-spray herbicide	+	NA	-	+
Disk	+	+	NA	NA
Management unit size (ha)	-	-	NA	NA
Distance to management unit edge	+	NA	+	NA

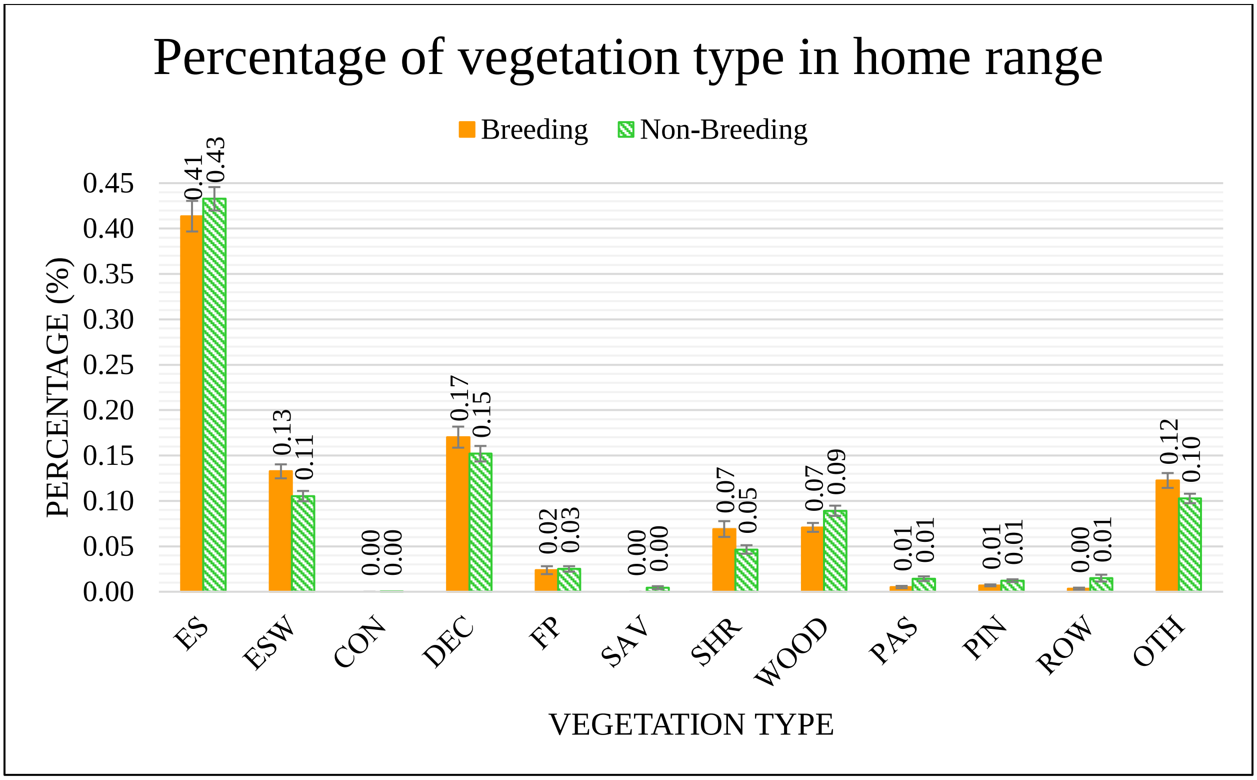

Figure D.1. Average percentage of bobwhite home range (respective to each season) in vegetation types during the breeding and non-breeding season for Wolf River, Bridgestone-Firestone, and Kyker Bottoms quail focal areas, TN, 2021–2023. Includes standard error bars.

VITA

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