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Research Paper

Northern Bobwhite habitat selection during the nonbreeding season in a riparian corridor in Colorado

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ABSTRACT. Northern Bobwhites (*Colinus virginianus*) are a popular game species but also considered a species of conservation concern due to range-wide population declines. Colorado lies at the far northwest corner of the bobwhite range, where individuals generally face more extreme winter conditions than areas further south and east, where most bobwhite research has taken place. These edge-of-range climatic extremes may lead to differences in the utility and selection of various vegetation types and structures than those reported in studies from other regions in the bobwhite range. We used radio-marked bobwhites to assess habitat selection and movements during two nonbreeding seasons in a riparian corridor in northeastern Colorado. Bobwhites selected for greater visual obstruction (β_{vis} = 0.026, SE = 0.005, $P < 0.001$), percent litter cover (β_{litter} = 0.017, SE = 0.006, $P = 0.004$), and percent bare ground (β_{bare} = 0.013, SE = 0.007, $P = 0.045$). Mean daily movement distance was 247.3 m (SE = 10.4), and mean nonbreeding home range size was 50.3 ha (SE = 4.8). Surprisingly, we did not find selection for woody vegetation, which is commonly reported in other studies. Otherwise, our results were consistent with research from other regions, and confirm the importance of maintaining areas with high visual obstruction interspersed with bare patches.

Sélection de l'habitat en dehors de la saison de reproduction chez le Colin de Virginie, dans un corridor riverain au Colorado

RÉSUMÉ. Le Colin de Virginie (*Colinus virginianus*) est un oiseau gibier populaire, mais il est également considéré comme une espèce dont la conservation est préoccupante en raison de la diminution des populations dans l'ensemble de son aire de répartition. Le Colorado se trouve à l'extrême nord-ouest de l'aire de ce colin, et les individus qui s'y trouvent sont généralement confrontés à des conditions hivernales plus extrêmes que dans les régions situées plus au sud et à l'est, où la plupart des recherches sur l'espèce ont eu lieu. Ces extrêmes climatiques en bordure de l'aire de répartition du Colin de Virginie peuvent être responsables de différences dans l'utilité et la sélection de divers types de végétation et de structures par rapport à ce qui a été rapporté dans les études réalisées dans d'autres régions de l'aire. Nous avons suivi des colins au moyen de radios pour évaluer la sélection de l'habitat et les déplacements pendant deux saisons hors reproduction dans un corridor riverain dans le nord-est du Colorado. Les Colins de Virginie ont choisi une plus grande obstruction visuelle (β_{vis} = 0,026, erreur-type = 0,005, P < 0,001), et un certain pourcentage de litière (β_{litter} = 0,017, erreur-type = 0,006, P = 0,004) et de sol nu (β_{bare} = 0,013, erreur-type = 0,007, P = 0,045). La distance moyenne de déplacement quotidien était de 247,3 m (erreur-type = 10,4) et la taille moyenne du domaine vital hors reproduction était de 50,3 ha (erreur-type = 4,8). Étonnamment, nous n'avons pas constaté que le colin avait une préférence pour la végétation ligneuse, préférence qui est souvent rapportée dans d'autres études. Pour le reste, nos résultats sont cohérents avec ceux de recherches menées dans d'autres régions et confirment l'importance de maintenir des zones comportant une obstruction visuelle élevée juxtaposées à des zones dénudées.

Key Words: *Colinus virginianus; habitat selection; nonbreeding; Northern Bobwhite; quail*

INTRODUCTION

Animal space use affects individuals' demographic outcomes, and population-level distribution and abundance. An individual's local environment can influence its ability to survive and reproduce, and these processes can scale up to affect population-level dynamics (Morales et al. 2010, Matthiopoulos et al. 2015). Conspecifics may experience different environmental characteristics throughout their range and thus face different challenges to survive and reproduce. Therefore, variation in space-use behavior exists within species depending on individuals' local environment (Holt 2003, Shirk et al. 2014, Wan et al. 2017), and habitat management strategies should be based on local information and not generalized from other locations in the species' range (Doherty et al. 2016).

Northern Bobwhites (*Colinus virginianus*; hereafter, bobwhites) are distributed throughout the eastern and central United States of America and Mexico. Bobwhites are a popular game species but are also considered a species of conservation concern due to range-wide population declines (Brennan and Kuvlesky 2005, Sauer et al. 2017). Therefore, many habitat management actions are focused on improving bobwhite habitat to, presumably, increase abundance. Bobwhites require a diversity of vegetation types to accommodate their needs. Woody understory cover (protection), bare ground (movement and feeding), forbs (food production), and ground litter and grasses (nesting) are all important for different activities (Roseberry 1964, Snyder 1978, Taylor et al. 1999*a*). Due to variability in environmental conditions within bobwhites' large distribution, habitat

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preferences may vary geographically. For habitat management to be successful, it must focus on habitat attributes that are preferred by bobwhites in that area.

Northeast Colorado serves as an interesting location to study bobwhite habitat selection and movements because it lies at the northwest corner of the bobwhite distribution. Bobwhites in this area experience less rain, more snow, and colder temperatures than other areas further south and east in the bobwhite range. Bobwhite winter survival in Colorado is sensitive to cold and snowy conditions (Wolske et al. 2023). Therefore, vegetation that provides protection from these conditions is likely to be more important for bobwhites in Colorado compared with areas with milder winter conditions. Woody cover can be important for protection from snow (Roseberry 1964) and predators (Perkins et al. 2014). At a regional scale, woody vegetation limits bobwhite distributions in the shortgrass prairie ecosystem in northeastern Colorado because bobwhites are generally found only in river bottom riparian areas where woody vegetation exists (Snyder 1978). However, within these riparian areas, it is less clear how bobwhites select habitat and what management actions could be used to improve habitat quality.

Although some recent research has examined bobwhite habitat selection during the breeding season in Colorado (Behney 2021), little is known about nonbreeding season habitat selection in the northwest part of the bobwhite range. In other areas, woody cover was reported to be selected by bobwhites during winter (Janke and Gates 2013, Cohen et al. 2020), and nearby woody cover was positively associated with daily survival (Janke et al. 2015). Given the low winter survival observed at this study area (Wolske et al. 2023), winter survival could certainly be limiting population growth and contribute to population declines, as suggested by Folk et al. (2007). Understanding habitat preferences during winter would be valuable if managers could create additional preferred habitat, which may reduce mortality from extreme winter weather events.

The scale at which habitat management needs to occur to be effective is likely tied to movement characteristics of the target species (Allen and Singh 2016). Knowledge of bobwhite movements and home ranges can help guide where to conduct habitat management and how to balance fewer large treatments vs. more smaller treatments (Niebuhr et al. 2015) in the face of time and financial limitations of managers. Bobwhites are non-migratory and can have home ranges and movements small enough to be contained on parcels managed by a single entity, making targeted habitat management possible. Bobwhite movement characteristics have been reported for northeastern Colorado during the breeding season (Behney 2023), however, little information exists on winter movement patterns for bobwhites in the northwestern portion of their range.

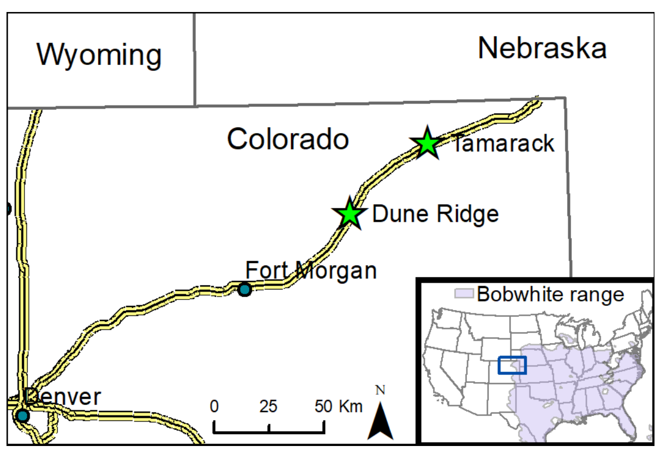
Our research goals were to assess winter habitat selection and movements of bobwhites to better understand their full annual cycle of space use in the northwestern portion of the bobwhite range. Our specific objectives were to (1) determine what specific vegetation features bobwhites selected and (2) estimate daily movement distance and home range size during the nonbreeding season. This research can help to guide habitat management activities for bobwhites in a part of their range where little prior research has been done. Given the low winter survival documented at these study sites (Wolske et al. 2023) and the more extreme winter conditions found in this part of their range, we predicted that protective cover (dense, woody vegetation) would be regularly selected.

STUDY AREA

Our study was conducted from September to March 2019–2021 on Tamarack State Wildlife Area (SWA) and Dune Ridge SWA in Logan County, Colorado (Fig. 1). Tamarack SWA comprises 4,533 ha along a 30-km stretch of the South Platte River whereas Dune Ridge SWA is a 151-ha, 2-km stretch of the South Platte River. Both wildlife areas consist of riparian forests near the river and upland rangeland/meadows further away from the river. The riparian forest averages 0.7 km wide and consists primarily of plains cottonwood (*Populus deltoides*), with an understory of western snowberry (*Symphoricarpos occidentalis*) and sandbar willow (*Salix exigua*). Based on vegetation samples taken during our study, the primary grasses and forbs that intermix with the understory include prairie cordgrass (*Spartina pectinate*), western wheatgrass (*Pascopyrum smithii*), reed canary grass (*Phalaris arundinacea*), smooth brome (*Bromus inermis*), switchgrass (*Panicum virgatum*), cheatgrass (*Bromus tectorum*), common ragweed (*Ambrosia artemisiifolia*), poison hemlock (*Conium maculatum*), and thistle (*Cirsium* spp.). On Tamarack SWA, a large portion of the area to the south of the river bottom is native sand sagebrush (*Artemisia filifolia*) rangeland. Bobwhites use the edge in the sand sagebrush, but rarely travel beyond ca. 0.5 km from the river bottom (J. Wolske, unpublished data).

Mean elevation of Tamarack SWA and Dune Ridge SWA is, respectively, 1,133 m and 1,211 m. Based on a 100-yr climate summary for the area (https://wrcc.dri.edu/cgi-bin/cliMAIN.pl?co7513), mean monthly precipitation during October–March was 1.50 cm, and mean snowfall was 10.29 cm. The historic (1908–2006) mean maximum and minimum winter temperatures were 9.9°C and -7.0°C, respectively (https://wrcc.dri.edu/cgi-bin/cliMAIN.pl?co7513).

Fig. 1. Location of study areas (green stars) in Colorado, USA within the distribution of Northern Bobwhites (purple shading). The Northern Bobwhite distribution is from eBird (Fink et al. 2023).



METHODS

Capture, marking, and monitoring

We trapped bobwhites with baited walk-in traps (Stoddard 1931, Smith et al. 1981, Behney et al. 2020) from 6 September until 17 October 2019 at 288 trap locations, and 1 September to 23 October 2020 at 493 trap locations on Tamarack SWA and Dune Ridge SWA. We distributed traps throughout each property in an attempt to capture bobwhites in as many coveys as possible. We moved traps as areas became saturated with radio-marked bobwhites or if no bobwhites were being caught. In addition to walk-in traps, we used targeted night-lighting during the second season. We tracked previously radio-marked birds at night to locate coveys and used spotlights and a hoop net to capture untagged birds. After cessation of trapping, we removed leftover bait and excluded from analysis any location data collected within 1 wk of the end of trapping to reduce any effect of bait on bobwhite movements.

Bobwhites were fitted with ≤6.5 g necklace-style VHF radio transmitters equipped with an 8-h mortality sensor (American Wildlife Enterprises, Monticello, Florida, USA), which have been used frequently for bobwhites (Burger et al. 1995, DeMaso et al. 1997, Taylor et al. 1999*a*). We did not deploy transmitters on bobwhites weighing less than 130 g to keep the transmitter mass less than 5% of the bird's body mass. Terhune et al. (2007) concluded that 6 g necklace-style transmitters affixed on bobwhites weighing ≥132 g had no effect on survival. We captured 25 birds the first season (2019) and three the second season (2020) that were deemed lighter than the allowable mass to be fitted with transmitters. We fit all captured bobwhites with a numbered aluminum leg band, weighed them, and determined sex and age class. After processing, birds were released at the site of capture. We attempted to locate radio-marked bobwhites four to five times per week using a homing technique where we circled the bobwhite at 15–30 m to estimate a location without flushing it (White and Garrott 1990). Once per month, we intentionally flushed each bird to get an exact location from which to sample vegetation and microclimate. We estimated the position of each bird prior to flushing and did not sample vegetation or microclimate at sites where birds moved from their original position before taking flight. Circling the radio-marked bobwhite at relatively close distances allowed us to estimate bird locations very precisely and ensured that vegetation samples actually represented used locations.

Vegetation and microclimate sampling

Within a week of each flush, we sampled vegetation at the center of the covey's location as well as at four random points in the same general habitat type within 200 m of the used location (i.e., within the distance bobwhites typically move in a day; Taylor et al. 1999*a*, *b*) to represent available habitat. We generated random points in ArcMap 10.7 (ESRI, Redlands, California, USA) within a 200-m buffer of the bird location and excluded habitat types that were different from the bird location (e.g., crop fields, road right of ways). We did not impose any minimum separation distance requirements among the four random points within the 200-m buffer. At each used and random point, we visually estimated percent coverage of bare ground, litter, and each vegetation species within a 1-m² sampling frame. We considered litter to be dead vegetation on the soil surface. In cases where species could not be determined, plants were identified to the lowest classification possible. We combined species into a grass, forb, or woody vegetation category for analysis. Where snow was present, we treated it as its own cover type and measured the depth. We also measured the height of the tallest vegetation in the frame. To estimate vegetation density (visual obstruction), we noted the lowest 5-cm mark visible on a 2.5-cm diameter pole, read from 4 m in four directions, 90° apart, from 1 m above the ground (Robel et al. 1970). We used a handheld Kestrel weather meter at each sample point to measure temperature and wind speed at ground level.

Statistical analysis

Habitat selection

We assessed habitat selection as a function of wind speed, temperature, snow depth, percent cover of seven classes (snow, bare ground, litter, woody debris, grasses, forbs, and live woody cover), vegetation height and density (visual obstruction), and plant species richness at each sample site (Table 1). We fit logistic regression generalized linear mixed models (glmm) using glmmTMB package (Brooks et al. 2017) in R (R Core Team 2022) for our selection analysis to assess differences in site characteristics of used and random points. Random points representing available habitat were associated with a bird's location, so we included a variable that grouped the associated bird and four random locations together as a random intercept in all models nested within covey number. We also included a covey identifier number as a random intercept in all models to account for repeated sampling of coveys. We tested for collinearity of continuous variables using Pearson's correlation coefficients with a limit of $|r| < 0.7$ (Dormann et al. 2013). If variables were correlated, we picked the most biologically relevant variable for inclusion in modeling. We used backward stepwise model selection to remove unimportant variables by taking our global model and removing the single variable with the highest associated P value. We stopped when all variables in the reduced model had $P < 0.15$ (Bursac et al. 2008).

Table 1. Means of variables at used and random sites for Northern Bobwhites during the nonbreeding season in northeastern Colorado, USA, 1 October 2019 – 31 March 2020 and 1 October 2020 – 31 March 2021. Four random sites were sampled within 200 m (bobwhite daily movement distance from literature) of each used site.

Vegetation and weather variables	Mean at used sites (SD)	Mean at random sites (SD)
Wind speed at ground (km/h)	2.21 (2.28)	2.69 (2.60)
Temperature (°C)	9.99 (7.12)	10.10 (7.55)
Snow depth (cm)	0.25 (1.15)	0.30 (1.27)
Bare ground cover (%)	11.25 (18.33)	11.67 (19.68)
Litter cover (%)	42.27 (20.78)	37.20 (21.45)
Wood debris cover (%)	1.07 (3.57)	1.39 (7.05)
Grass cover (%)	16.92 (23.73)	22.05 (23.45)
Forb cover (%)	14.67 (14.66)	15.00 (15.28)
Woody cover (%)	11.24 (12.26)	8.74 (12.43)
Tallest plant height (cm)	137.37 (72.59)	112.44 (68.80)
Visual obstruction (%)	38.17 (24.19)	26.95 (19.93)
Species richness (n)	3.62 (1.65)	3.64 (1.66)

Movements

To estimate the distance moved between daily locations, we calculated the distance between locations 1 d apart and present the mean based on an intercept-only linear mixed effects model that included individual bird as a random effect to account for multiple observations from each bobwhite. Locations > 1 d apart were excluded from the daily movement distance analysis. To estimate nonbreeding home range and core area size, we used 95% and 50% kernel density estimators, respectively. We fit utilization distributions using least squares cross validation to estimate the smoothing parameter (Seaman et al. 1999) in the adehabitatHR package (Calenge 2006) in R (R Core Team 2022). We excluded any bobwhite from analysis that had < 30 locations to ensure kernel home range size estimates were accurate (Seaman et al. 1999).

RESULTS

We had 159 capture events using walk-in traps, during which we caught 123 unique bobwhites (some individuals were captured multiple times) during 2019 (the first capture season), and had 48 capture events with 43 individuals in 2020 (the second capture season). Ten additional individuals were captured via night-lighting in the second season. We radio tagged 98 individuals (43 females and 55 males) and 49 individuals (20 females and 29 males) in the first and second seasons, respectively. Radio-marked birds were a part of 40 different coveys across both years. We included 110 total vegetation and microclimate surveys in our analysis.

Habitat selection

Snow depth and percent snow cover were correlated, so we only included snow depth in analyses due to its perceived biological importance. Snow can hinder the ability to forage and thermoregulate, and snow depth is a direct measurement of the amount of snow bobwhites must get through to forage, whereas shallow snow can produce percent cover values similar to another site with much greater depths.

Our final habitat selection model (all $P < 0.15$) included visual obstruction, percent bare ground, and percent litter cover. The coefficients for relative probability of selection were positive for each variable in the model (Fig. 2; $\beta_{vis} = 0.026$, 95% CI = 0.016 - 0.036, $P < 0.001$; $\beta_{bare} = 0.013$, 95% CI = 0.0003 - 0.026, $P = 0.045$; $\beta_{litter} = 0.017$, 95% CI = 0.006 - 0.029, $P = 0.004$). On average, within each group of used and associated available locations, used locations had 11.2 % (SD = 22.6) more visual obstruction, 0.4 % (SD = 21.4) more bare ground, and 5.1 % (SD = 18.5) more litter, respectively, than associated random available locations.

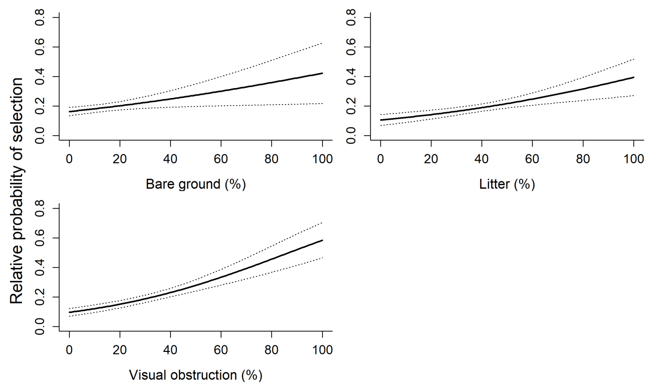
Movements

For the daily movement analysis, we include 3,100 locations from 146 bobwhites. Mean daily movement distance was 247.3 m (SE = 10.4). In the home range analysis, we included 55 bobwhites for which we had ≥30 locations. Mean nonbreeding home range size was 50.3 ha (SE = 4.8) and core area size was 8.1 ha (SE = 0.9).

DISCUSSION

Our results show that bobwhites selected for several vegetation characteristics disproportionately to their availability in northeastern Colorado. Our models predicted selection for sites with more visual obstruction, percent litter cover, and percent bare ground cover, suggesting that bobwhites selected for areas with taller, denser vegetation when looking into a patch from the side, but with areas clear of vegetation (bare ground and litter) when looking straight down into a patch. We did not find evidence that other vegetation or weather variables were being selected or avoided by bobwhites in our sample.

Fig. 2. Predicted relative probability of selection of sites for Northern Bobwhite during the nonbreeding season as a function of percent bare ground, litter, and visual obstruction of sites in northeastern Colorado, USA, 1 October 2019 – 31 March 2020 and 1 October 2020 – 31 March 2021. Visual obstruction was estimated from a Robel pole. Dotted lines represent 85% confidence intervals. Predicted values were calculated while holding other variables constant at their mean.



Quality bobwhite habitat consists of a diversity of vegetation types and structure (Stoddard 1931). Therefore, it is not surprising that we found selection for areas with more visual obstruction, yet also more bare ground and litter. Areas at our study site with high visual obstruction and high levels of bare ground were patchy at local levels, providing preferred vegetation structure. Bobwhites rely on relatively open areas near the ground to facilitate movement and foraging, and thicker overhead cover can provide protection from predators and more favorable thermal conditions (Palmer et al. 2021). Selection of habitat with increased visual obstruction during the nonbreeding season is consistent with previous research (Kopp et al. 1998, Brooke et al. 2015). Visual obstruction can provide protection from predators, snow, and wind (Chamberlain et al. 2002). Selection for bare ground is also commonly reported, providing surfaces for dusting, loafing, and forage (Stoddard 1931, Brown and Samuel 1978, Johnson and Guthery 1988). Kopp et al. (1998) found that there was evidence of selection between 10–60% bare ground at flush points.

Our results show selection for litter cover, which contrasts with research that suggests that litter is less beneficial for bobwhites. Kuvlesky et al. (2002) concluded bobwhites selected for areas with less litter cover during fall and winter, and results from Peters et al. (2015) showed that litter depth decreased survival. Other studies that included litter as a variable found that it was not a predictor of site selection (Brooke et al. 2015, Unger et al. 2015); however, these conflicting results may be due to the type of litter. Peters et al. (2015) contributed that sericea lespedeza (*Lespedeza cuneata*) dominated their study site, as its seeds are virtually indigestible by bobwhites and an accumulation of this litter has been associated with reduced forb establishment and species richness. In addition to agricultural grains, forb seeds are the main food of bobwhites during the nonbreeding season (Brennan et al. 2020), and in Colorado, plants such as ragweed (*Ambrosia* spp.), knotweeds and smartweeds (*Polygonum* spp.), and field pennycress (*Thlaspi arvense*) have been reported to be important food items (Snyder 1978). In habitats such as pine stands, litter can be of complete coverage and composed of almost entirely pine needles, creating habitat of little value to bobwhites (Brennan 1991). In our study, litter mainly consisted of forbs and grasses that provide food, with a mean of 55.8% of coverage at used sites, and, although we did not take litter depth measurements, litter was relatively shallow (approximately ≤1 cm). This leads us to assume that differences in litter composition, cover, and depth can both alter and determine the value of litter to bobwhites. Furthermore, our finding of selection for litter and bare ground is interesting, considering they are different types of ground cover. We interpret this finding to indicate bobwhites were selecting habitat with space between plants, regardless of the specific type of ground cover.

We did not find evidence of selection based on thermal characteristics. Chamberlain et al. (2002) found that bobwhites selected roost sites with more litter cover, litter depth, and visual obstruction and suggested site vegetation structure is related to favorable thermal characteristics. Although we did not investigate nighttime roost sites, we included thermal measures in our sampling design to evaluate this hypothesis. Our microsite weather variables did not vary between used and available sites, but our daytime microsite vegetation structure findings are consistent with those of Chamberlain et al. (2002). Bobwhites may be selecting for sites with denser vegetation and more litter during the daytime for reasons other than weather, or we may not have captured a weather metric that is important to bobwhites in our sampling.

Woody understory cover is well documented as important to bobwhites during the nonbreeding season, providing escape cover from predators, protection from snow and wind, and patches of bare ground (Roseberry 1964, Roseberry and Klimstra 1984, Williams et al. 2000, Janke and Gates 2013, Perkins et al. 2014, Kroeger et al. 2020). Predation by avian and mammalian predators is a primary source of natural mortality for bobwhites (Brennan et al. 2020). The relative contribution of birds vs. mammals to overall mortality is similar but varies considerably among studies (Rectenwald et al. 2021). Bobwhites were regularly documented using woody cover, so we were surprised not to find evidence of selection, as we predicted. This finding is likely a result of the scale at which we measured selection. At a landscape scale, woody vegetation is clearly selected by bobwhites in Colorado. However, within the river bottom riparian area, there may not be enough variation in woody vegetation cover to detect selection, or sufficient cover exists so bobwhites did not need to select it in greater proportion to its availability. Alternatively, the 1-m^2 sampling frame in which we recorded percent cover may be too small to accurately capture the patchy distribution of woody vegetation. In future studies, it would be valuable to estimate the distance to nearest woody cover to further explore the importance of woody cover configuration and distribution within the riparian area. Kassinis and Guthery (1996) found that bobwhites landed in woody cover more than what is randomly available at the end of an escape flight and recommended that escape cover should be <100 m from any given point. Determining if bobwhites behave the same in our region, and if woody cover is adequately distributed, would be valuable to managers, especially given the sensitivity of bobwhite survival to winter weather (Wolske et al. 2023).

Bobwhite daily movement distance presented in this study (247.3 m) was similar to that presented elsewhere, whereas nonbreeding home range size (50.3 ha) was toward the upper end of estimates presented elsewhere. For comparison, some recently reported nonbreeding home range sizes were 26.1 ha in Ohio (Janke and Gates 2013), 14.8 and 48.7 ha in Texas (Buckley et al. 2015, Miller et al. 2017), and 29.2 ha in New Jersey (Lohr et al. 2011). Mean daily movement distance in New Jersey was 158 m (Lohr et al. 2011) and 512.5 m in Texas for bobwhites equipped with GPS transmitters (Cohen et al. 2020). Larger bobwhite home ranges at the western extent of their range (i.e., Colorado), may be a function of lower primary productivity associated with less precipitation than more easterly areas of the bobwhite range (Harestad and Bunnel 1979). As productivity of the habitat declines, individuals need to cover larger areas to meet their energetic needs (Relyea et al. 2000). Similarly, if snow cover limited access to food, larger home ranges may have been necessary to find sufficient food. Results from nonbreeding season studies further south in the bobwhite range may differ from this study due to differences in snow cover.

In this same system, Behney (2023) reported smaller home ranges (18–29 ha) and shorter daily movement distance (163 m) during the breeding season than what we present here for the nonbreeding season. Differences in home range size may be a result of using different estimators (Nilsen et al. 2008); we used kernel density estimators in this study, whereas Behney (2023) used minimum convex polygons. The difference in daily movement distance and possibly home range size between seasons highlights the need to think about scale when conducting vegetation management targeted at improving breeding vs. nonbreeding season habitat. With bobwhites moving greater distances during the nonbreeding season, management for nonbreeding habitat could occur at larger scales, with treatments potentially farther apart because bobwhite home ranges cover such a large area as opposed to during the breeding season.

Our results can be compared among regions to assess levels of similarity across the bobwhite range, but our results are also useful to inform local management decisions. Recommending specific habitat management practices to increase nonbreeding preferred vegetation characteristics is challenging, given the terrain and climatic differences from other areas where most habitat management for bobwhites has been evaluated. However, our results can be used as a target or evaluation for habitat management actions. Because bobwhites in this study selected areas with greater amounts of visual obstruction, we would caution against any widespread disturbance at a frequency high enough to reduce vegetation density and lead to less visual obstruction. Furthermore, even though we did not observe bobwhites using woody vegetation proportionally greater or less than its availability within the riparian corridor, woody cover is known to provide shelter from extreme winter conditions (Roseberry 1964, Janke and Gates 2013, Janke et al. 2015), which are a primary mortality source for bobwhites in this study area (Wolske et al. 2023). Wolske et al. (2023) demonstrated dramatic patterns of mortality during the harshest cold and snow depth conditions, which may indicate a limit to the amelioration that habitat can provide to weather conditions (Martin and Wiebe 2004).

Finally, our monitored bobwhites generally stayed within the riparian corridor, and we recommend avoiding any actions that would reduce the amount of woody cover. Exotic, cool-season grasses such as cheatgrass and smooth brome were abundant on the study area and can grow in dense monocultures (Booth et al. 2003, Palit and DeKeyser 2022) providing little bare ground or litter between plants. Furthermore, when cheatgrass senesces after the growing season, we observed that it provides little visual obstruction. Reducing or eliminating these invasive grasses through herbicide or other treatments, and replacing with native bunchgrasses and forbs, may help to increase or maintain visual obstruction while also creating more bare ground around the bunches or forbs.

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