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RESEARCH ARTICLE

Returning neighbors: eastern wild turkey (*Meleagris gallopavo silvestris*) occupancy in an urban landscape

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Abstract

Once extirpated from most of its range because of overharvest and habitat loss in the early 1900s, the eastern wild turkey (*Meleagris gallopavo silvestris*) has been recolonizing landscapes in the eastern United States following restoration and reintroduction efforts. Wild turkey populations have rebounded in the last 50 years, and the wild turkey is now seen as one of the most successful conservation efforts in the United States. More recently, wild turkeys have begun to expand into cities across the United States. While this can be seen as a successful return of a once-extirpated species, it has also given rise to human–wildlife conflict in highly populated areas. Given the ecological differences between urban and rural ecosystems, it is important for conservation and management efforts to understand how wild turkeys use urban landscapes. We used cameras deployed at 75 long-term study sites across the Washington, D.C. region to assess occupancy and habitat use of urban wild turkeys at multiple scales. We found that wild turkey occupancy was positively correlated with the distance to roadways and the proportion of natural vegetation cover within 1 km, whereas occupancy was negatively correlated with the distance to the nearest water source and mean canopy height within 4 km. Our findings add to the understanding of how wild turkeys are returning and using novel urban ecosystems and can inform future management needs, contribute to conservation initiatives, and help reduce negative human–wildlife interactions.

KEYWORDS

rewilding, urban ecology, urban greenspace, urban wildlife, wildlife conflict

Most of Earth's human population lives in cities, and the United Nations predicts that 7 billion people will inhabit cities by 2050 (United Nations 2018). While urbanization has contributed to biodiversity loss worldwide, many urban areas harbor species of conservation concern or provide habitat for species range expansions (Luna et al. 2018, Hansen et al. 2020). For example, milkweed (*Asclepias* spp.) grows in many greenspaces in Chicago, Illinois, USA, providing rich habitat for migratory monarch butterflies (*Danaus plexippus*; Johnston et al. 2019); in New York City, New York, USA, peregrine falcons (*Falco peregrinus*) take advantage of buildings and urban parks (Luniak 2004). Thus, understanding native species' capacity to persist in urban ecosystems is crucial for conservation and management initiatives (McCance et al. 2017).

Eastern wild turkey (*Meleagris gallopavo silvestris*; hereafter wild turkey) is a widespread Galliformes species native to eastern and central North America (Kark et al. 2007). Wild turkeys were once extirpated from much of their historic range during the early 20th century due to overharvest and habitat destruction (Kennamer 1992, Cardoza 1993). After successful reintroduction efforts and subsequent population rebounds, the wild turkey ranks among the great conservation success stories in the United States (Cardoza 1993, Ogden 2015). However, within the last decade, research from hunter harvest data has documented substantial declines in wild turkey populations, and a lack of occurrence and abundance data from state managers has made this decline difficult to track (Chamberlain et al. 2022). Despite recent declines, growing populations of wild turkeys have been documented throughout major cities of the eastern and midwestern United States (Readel 2024). This increase in urban wild turkey populations has led to human–wildlife conflicts, such as property damage, traffic hazards, and aggressive behavior including several highly publicized accounts in local and national media outlets (e.g., Groepper et al. 2013, Miller 2018, de Freytas-Tamura 2020). However, wild turkeys play important ecological roles as dispersers of seeds, controllers of pest insect populations (Wood et al. 2018), and economically important game species (Otieno and Frenette 2017, Chapagain et al. 2020). Given documented declines in wild turkey populations in rural systems and increased presence in urban systems, it is important to understand how wild turkeys are using the urban landscape to better inform management and conservation of this species.

Despite increases in use of urban areas, the natural history of wild turkeys is nearly entirely informed by studies in rural landscapes (Tinsley 2014). Wild turkeys are considered a habitat generalist because of the wide variety of plants and insects in their diet and the plasticity of wild turkey behavior to adapt to changing landscapes (Vander Haegen et al. 1989, Badyaev 1995). Research on resource selection in rural areas has emphasized the value of open areas for foraging, loafing, and socializing during the day (Holbrook et al. 1987, Thogmartin 1999) and forested areas with mature trees for roosting at night (Kilpatrick et al. 1988, Cardoza 1993). Edge habitats also provide low-lying vegetation to hide nesting sites from predators and allow easy access to food resources for hens and poults (Porter 1978, Thogmartin 1999). Further, research has suggested that proximity of roost sites to water is important (Chamberlain et al. 2000), as wild turkeys seek water during winter months because of the low moisture content in food resources (Wheeler 1948, Kilpatrick et al. 1988) and because proximity to water regulates ambient temperatures (Adey et al. 2023). Yet even for species that are considered generalists, many studies have shown that habitat use, breeding, and behaviors of animals in urban ecosystems can be profoundly different compared to more natural ecosystems (Mennechez and Clergeua 2006, Delaney et al. 2010, Gallo et al. 2022).

Urban areas are characterized by high rates of fragmentation, landscape heterogeneity, and disturbance (Angel et al. 2012). Habitat patches are divided by roads, urban development, and natural features at a higher intensity than rural environments, creating a more diverse mosaic of land cover types. Additionally, urban areas are also created and dominated by people and thus have greater human activity throughout the landscape at all times of the day (Santini et al. 2019). Therefore, our current understanding of wild turkey habitat use may not generalize to wild turkey populations living in urban environments (Rodewald et al. 2011, Santini et al. 2019), and crucial knowledge gaps about wild turkey habitat use remain.

To address the lack of information on wild turkeys in urban settings, we examined wild turkey occupancy in the metropolitan region of Washington, D.C., USA. Our objective was to identify urban landscape features correlated to wild turkey distribution across the region. We used trail cameras to collect data on wild turkey presence and an autologistic occupancy model with a Bayesian variable selection approach to identify important landscape characteristics that correlate with wild turkey presence. Based on land cover factors previously noted as important to wild turkey life history in rural areas (Table 1), we predicted that wild turkey occupancy would be positively correlated with habitat heterogeneity, tree canopy height, natural vegetation cover, and distance away from roads and trails (Table 1). We also predicted that wild turkey occupancy would be negatively correlated with human population density, elevation, terrain ruggedness, and distance from nearest streams, wetland, or open water source (Table 1).

STUDY AREA

Our study was conducted within the Washington, D.C. metropolitan area (38.9072° N, 77.0369° W), which includes Washington D.C., Prince George's and Montgomery Counties, Maryland, and the City of Alexandria, Arlington County, and Fairfax County, Virginia (Figure 1). Washington, D.C. is the sixth-largest metropolitan area within the United States but maintains the highest proportion of parkland of any major city in the United States at 21.9% of total land cover (Cohen et al. 2017). Our study area sits on the ancestral homeland of the Nacochtank (also called Anacostan) and Piscataway people (Tayac 2009). The climate is considered humid subtropical, experiencing all 4 seasons, and averaging 112 cm of precipitation annually (National Oceanic and Atmospheric Administration 2022). The Washington D.C. region contains a geological fall line, separating the city and surrounding lands into 2 distinct ecoregions, the Appalachian Piedmont region to the west and the Mid-Atlantic coastal plain to the east (Ossi et al. 2015). The dominant vegetation communities are deciduous forest to the west (Piedmont) and softwood and hardwood forest to the east (coastal plains). Dominant tree species are oaks (*Quercus* spp.), tulip poplars (*Liriodendron tulipifera*), maples (*Acer* spp.), and American beech (*Fagus grandifolia*; Ossi et al. 2015).

METHODS

Data collection

We overlaid an initial spatial grid of points on our study area, with each point 2 km apart. To identify sampling sites, we randomly chose 75 points from the initial grid and identified the nearest greenspace to each selected point as a sampling location (Figure 1). We conducted site selection using the sf (Pebesma 2018) and raster (Hijmans 2015) packages in R version 3.6.1 (R Core Team 2022). Greenspace types included public parks ($n = 69$), golf courses ($n = 3$), and cemeteries ($n = 3$). All public parks within our study area were used daily by people, and many included or were adjacent to playgrounds, parking lots, biking trails, public restrooms, and athletic recreation areas. Within each selected greenspace, we established sampling sites at a location that maximized detection probability of wildlife species (e.g., game trails).

TABLE 1 Descriptive information and accompanying predictions about each predictor variable used to estimate occupancy of wild turkey in the Washington, D.C. metropolitan region.

Variable	Unit	Data source	Description	Predictions
Natural vegetation cover	Proportion	Chesapeake Bay Conservancy 1-m land use/land cover data	Raster cells categorized as forest, natural succession, tree canopy other, wetlands tidal non-forested, wetlands riverine non-forested, and wetlands terrene non-forested	Turkeys are known to use heavily forested rural systems (Holbrook et al. 1987, Thogmartin 1999); therefore, vegetation cover will be positively correlated with turkey occupancy.
Distance to stream	Meters	ESRI Streams & Rivers	Distance to the nearest stream or river	Riparian areas have been recorded as commonly used by turkeys (Wheeler 1948, Perlichek et al. 2005); therefore, turkey occupancy will be negatively correlated with distance to nearest stream or linear waterway.
Distance to water	Meters	Chesapeake Bay Conservancy 1-m land use/land cover data	Distance to the nearest raster cell categorized as water	Open water has been recorded as commonly used by turkeys (Wheeler 1948, Chamberlain et al 2000, Perlichek et al. 2005, Adey et al. 2023); therefore, turkey occupancy will be negatively correlated with distance to water.
Distance to wetland	Meters		Distance to the nearest raster cell categorized as a wetland	Water and riparian areas have been recorded as commonly used by turkeys (Wheeler 1948, Perlichek et al. 2005); therefore, turkey occupancy will be negatively correlated with distance to nearest wetland.
Distance to road	Meters	Chesapeake Bay Conservancy 1-m land use/land cover data	Distance to nearest raster cell categorized as a roadway	Roads create mortality risk through human access and collisions and traffic noise might hinder a turkey's ability to communicate or locate predators (Thogmartin 1999); therefore, turkey occupancy will be negatively correlated with distance to roadways (Adey et al. 2023, Bakner et al. 2024).
Elevation	Meters	1/3-arc second digital elevation model	Mean landscape elevation within 1, 2, or 4 km of each site	Low elevation floodplains in our study could provide nutrient-rich food resources for turkeys, while also allowing easy access to forest cover required for night roosting (Perlichek et al. 2005, Bakner et al. 2024); thus, turkey occupancy will be negatively correlated with elevation.

TABLE 1 (Continued)

Variable	Unit	Data source	Description	Predictions
Ruggedness	Terrain ruggedness index	1/3-arc second digital elevation model	Mean terrain ruggedness index within 1, 2, or 4 km of each site	Literature indicates that turkeys may be more attracted to vegetation communities and adequate cover than specific landscape ruggedness indices (Pollentier et al. 2021) but roost in areas with more ruggedness (Bakner et al. 2024). We predict a negative relationship between ruggedness and turkey occupancy because we will capture more foraging activity on cameras.
Canopy height	Meters	Global Ecosystem Dynamics Investigation (GEDI) LiDAR	Mean canopy height within 1, 2, or 4 km of each site	Turkeys select the tallest available roost trees (Kilpatrick et al. 1988, Yarrow and Yarrow 1999, Perlicher et al. 2009). Given the lack of mature forest options in our urban study area, turkeys will choose areas with the tallest trees; thus, canopy height will be positively correlated with occupancy.
Human population density	People/km^2	2022 United States Census American Community Survey	Mean human population density within 1, 2, or 4 km of each site	Areas of high human development have been categorized as poor-quality habitat for wild turkeys (Gustafson et al. 1994); therefore, turkey occupancy will be negatively correlated with human population density.
Impervious cover	Proportion	Chesapeake Bay Conservancy 1-m land use/land cover data	Proportion of impervious cover within 1, 2, or 4 km of each site	Areas of high human development have been categorized as poor-quality habitat for wild turkeys (Gustafson et al. 1994); therefore, turkey occupancy will be negatively correlated with the proportion of impervious cover.
Habitat heterogeneity	Unitless	Chesapeake Bay Conservancy 1-m land use/land cover data	Landscape entropy within 1, 2, or 4 km of each site	Turkeys have been known to use mixed open-forested land cover types (Donohoe and McKibben 1970, Wright and Speake 1976, Glennon et al. 1999, Niedzielski and Bowman 2016); thus, turkey occupancy will be positively correlated with landscape entropy.
Distance to trails	Meters	Open Street Map	Distance to nearest feature labeled as a foot or bike path, excluding sidewalks and roadway bike lanes	Areas of high human development have been categorized as poor-quality habitat for wild turkeys (Gustafson et al. 1994); therefore, we predict that turkey occupancy will be positively correlated with distance to trails because of consistent human use.

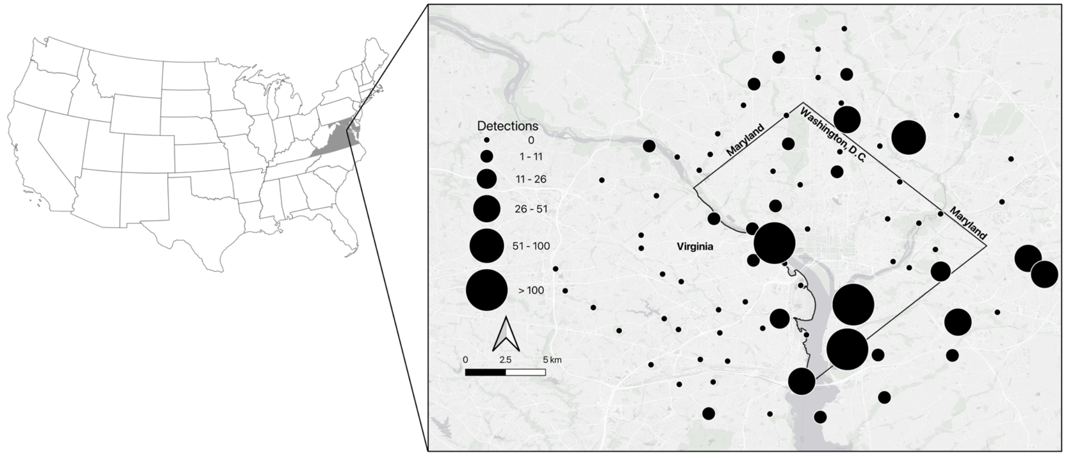

FIGURE 1 Location of the 75 sampling sites used to estimate wild turkey (*Meleagris gallopavo silvestris*) occupancy across the Washington, D.C. metropolitan region, USA (38.9072° N, 77.0369° W). The size of the circles represents the total number of wild turkey detections at each site from July 2020 to November 2023.

From July 2020 to November 2023, we deployed one unbaited trail camera at each sampling site for approximately 30–45 days 4 times per year (January, April, July, and October) for a total of 14 primary sampling seasons. Cameras were active an average of 28.7 days per sampling season. We used 3 models of trail camera: Reconyx Hyperfire 2 (Reconyx, Holmen, WI, USA), Bushnell Trophy Cam HD Aggressor, and Bushnell Trophy Cam HD (Bushnell Corporation, Overland Park, KS, USA). We placed cameras on trees approximately 1.5 m from the ground using nylon straps and deployed them at the same location each sampling season. Cameras were set to take 1 image for every motion-activated trigger with a 15-second rest period between triggers. We uploaded images to the Urban Wildlife Information Network online database (Magle et al. 2019) for identification of animals in images to species. Each image was classified by 2 users, and a third independent user validated any discrepancies. For this analysis, we used only wild turkey observations.

Occupancy predictor variables

We predicted that a combination of landscape characteristics within the vicinity of a sampling location would correlate with wild turkey occupancy (Table 1). Only one study exists on the home range size of urban wild turkeys (Tinsley 2014). Therefore, we took a multi-scale approach to calculate landscape characteristics around each sampling site. Based on the home range size of rural wild turkeys in nearby Virginia (Holbrook et al. 1987), we assumed that roughly 50 km^2 would be the largest home range size for urban wild turkeys in the Washington, D.C. area. However, given the nature of disjunct urban patches and the lack of large continuous patches, we predicted that home ranges may be smaller for urban wild turkeys. Therefore, we calculated a 4-km fixed-radius buffer around each sampling site as our largest sampling area and scaled down by 50% to include a 2-km and 1-km fixed-radius buffer around each site. We calculated each landscape characteristic within each of the 3 buffers.

We used the Chesapeake Bay Conservancy Land Cover 1-m resolution raster data (Robinson et al. 2019; Table 1) to calculate the proportion of wild turkey habitat, impervious cover, and habitat heterogeneity within each buffer. To calculate the proportion of wild turkey habitat, we used the sf and terra packages in R and calculated the combined proportion of raster cells classified as a land cover type suitable for turkeys (i.e., forest, natural succession, tree canopy other, wetlands tidal non-forested, wetlands riverine non-forested, and wetlands terrene non-forested). Using these same land cover categories, we calculate a metric of habitat heterogeneity by calculating landscape entropy (Nowosad and Stepinski 2019) using the landscapemetrics (Hesselbarth et al. 2019) package in R. To calculate the proportion of impervious cover, we calculated the combined proportion of raster cells classified as impervious roads, impervious structures, impervious other, and tree canopy over impervious.

We calculated mean elevation and the terrain ruggedness index from 1/3-arc second digital elevation model rasters (United States Geological Service 2016) using the terra package in R, and used the Global Ecosystem Dynamics Investigation (GEDI) LiDAR data set (Potapov et al. 2021) to extract mean canopy height. To calculate human population density, we extracted the total population of 2022 census block groups from the United States Census 2022 5-year American Community Survey (United States Census Bureau 2022) that intersected each buffer using the tidycensus (Walker 2023) package in R. When a census block did not overlap a buffer completely, we used an area-weighted crosswalk approach and divided the population data by the proportion of the respective census block that was within the spatial buffer (Goodchild et al. 1993).

To calculate the distance to the nearest road, open water source, and wetland, we used the Chesapeake Bay Conservancy Land Cover 1-m resolution raster data and calculated the distance from each sampling site to the nearest raster cell categorized as impervious road, water, and wetlands tidal non-forested, wetlands riverine non-forested, or wetlands terrene non-forested, respectively. We calculated the distance to the nearest stream using the ESRI Rivers and Streams data layer (United States Geological Survey 2020) and calculated the nearest distance between each sampling site and a linear waterway. We calculated the distance to the nearest hike and bike trail using the Open Street Map roadway layer (OpenStreetMap contributors 2022). We considered a trail to be any feature in the data layer categorized as a cycleway or footway and did not include bike lanes or sidewalk footpaths. We chose distance to hike and bike trails as an independent variable because, at the time of this study, high-profile human–turkey interactions had taken place on hike and bike trails in our study area.

We investigated multicollineary among predictor variables and found combinations with high correlation ($r > 0.7$; Table S1). Therefore, we took a lasso regression approach as described below. We scaled all covariates to have a mean of 0 and a standard deviation of 1.

Statistical analysis

We collapsed wild turkey detections into 6 secondary sampling occasions for each primary sampling season. Each secondary sampling occasion consisted of 7 calendar days. We used the number of days a camera was active at a site during each sampling occasion as a predictor variable for detection probability of wild turkeys.

We fit a single auto-logistic occupancy model (Mackenzie et al. 2002, Royle and Dorazio 2008) using all predictor variables and used Bayesian variable selection to determine the relative importance of each predictor variable on wild turkey occupancy and thus the most parsimonious model (Lykou 2013). We chose not to parametrize a multi-season occupancy model (i.e., with colonization and extinction parameters), as our study was focused on determining the best predictors of occupancy.

Auto-logistic occupancy model

In this model, occupancy (Ψ) takes on a Bernoulli random variable that equals 1 if a wild turkey was present and 0 if it was absent. For i in 1…, I sites and t in 1…, T primary sampling seasons, the probability of occupancy during the first sampling season ($t = 1$) was:

$$\text{logit}(\psi_{1,t=1}) = \beta_0 + \boldsymbol{\beta x}_i$$

$$z_{i,t=1} \sim \text{Bernoulli}(\psi_{i,t=1}),\ t = 1,$$

where β_0 represents the intercept and $\boldsymbol{\beta x}_i$ represents a vector of regression coefficients and their associated covariates. For subsequent sampling seasons (t > 1), we included a temporal auto-logistics parameter (θ_i) to allow for occupancy at site i to be dependent on whether a wild turkey was present the previous year. Thus, for the sampling seasons t = 2…,14, the linear predictor was:

$$\text{logit}(\psi_{1,t=1}) = \beta_0 + \boldsymbol{\beta x}_i + \theta_i \times z_{i,t-1}$$

$$z_{i,t} \sim \text{Bernoulli}(\psi_{i,t}),\ \ t > 1,$$

where θ helps determine if species presence in the previous timestep was associated with species presence in the current time step. We modeled detection probability as a function of the number of days a camera was active in each 7-day secondary sampling session o = 1…,O (*camdays*):

$$\text{logit}(p_{i,o,t}) = \alpha_0 + \alpha_1 \times camdays_{i,o,t},$$

and our data arises as

$$y_{i,o,t} \sim \text{Bernoulli}(z_{i,t} \times p_{i,o,t}).$$

From this model, the average occupancy probability was derived using the following calculation:

$$\overline{\Psi} = \frac{\text{expit}(\beta_0)}{\text{expit}(\beta_0) + (1 - \text{expit}(\beta_0 + \theta))}$$

where expit is the inverse logit function and β_0 is the occupancy intercept. Likewise, site-specific predictions were also derived by including the respective slope terms and covariates into the above equation.

Lasso regression and variable selection

From a Bayesian perspective, lasso can be interpreted as a regression model with Laplace prior distributions for the model coefficients (i.e., Bayesian lasso regression; Tibshirani 1996, Oyeyemi et al. 2015). Following Lykou and Ntzoufras (2013), we specified the priors for each occupancy model coefficient (β) to be a mixture of Laplace (0, λ) and Bernoulli (Ω) distributions. The Laplace distribution shrinks values for variables that have low explanatory value toward 0 based on the tuning (or penalty) parameter λ. By shrinking the coefficients, lasso regression reduces the variance associated with each variable and thus the overall variance of the model, making it less sensitive to small changes in the data and effective at dealing with correlated predictors, as highly correlated predictors can inflate the variance of the model's estimates (Tibshirani 1996, James et al. 2014). Empirically estimating the shrinkage parameter significantly improves the model's effectiveness in mitigating issues of collinearity (Liu 2024). Thus, we allowed for the model to estimate λ, which was given a vague Γ(0.001, 0.001) hyperprior. At each step of the Markov chain Monte Carlo (MCMC) sample, if a given Bernoulli trial for a variable had a value of 1, we sampled from its respective Laplace distribution. If the Bernoulli trial took a value of 0, the parameter was not included in the model at that MCMC step. Thus, the probability that a variable would be included in the model (variable inclusion probability) was the proportion of times a model coefficient's Bernoulli trial resulted in a value of 1 across all MCMC samples. Finally, Ω was given a β(3, 2) hyperprior distribution. All other parameters in the model, β_0, α_0, α_1, and θ, were given vague logit (0, 1) prior distributions.

The Bayesian variable selection procedure combined with the Laplace priors helps to identify the most important predictors, even in the presence of multicollinearity, as the lasso tends to favor one variable over its correlated counterparts (Liu 2024). We assessed the relative importance of each variable by 1) inspecting the variable inclusion probability of each variable (Oyeyemi et al. 2015) and 2) only considering variables in a final model that had a median coefficient value greater or less than 0.0001 (Oyeyemi et al. 2015). We then fit a reduced autologistic occupancy model using only our final predictor variables. The reduced model followed the same lasso formulation described above, minus the Bernoulli variable selection procedure. We considered model parameters to be significant if the 95% credible intervals in our final model did not overlap 0.

Model fitting and estimation

We fitted our model using an MCMC algorithm in JAGS (Plummer 2003) with the package runjags in R (Denwood 2016). We ran 4 parallel chains from randomized starting values. The first 25,000 iterations of each chain were discarded as burn-in. Each chain then ran for 140,000 iterations with a thinning rate of 4. Thus, we retained 35,000 samples from each chain for a total of 140,000 samples. We evaluated model convergence by checking that the Gelman-Rubin statistic for each parameter was <1.1 (Gelman and Rubin 1992) and by visual inspection of all trace plots for proper mixing.

RESULTS

From July 2020 to November 2023, wild turkeys (including adults and poults) were detected 2,656 times at 32 of 75 sampling sites (Figure 1). Of the 32 sites where wild turkeys were detected, 29 sites were public parks, 2 were cemeteries, and 1 site was a privately owned golf course. Wild turkeys were detected, on average, 22.9 days per season, and detected the most days in spring ($\bar{x}$ = 29.7), followed by fall ($\bar{x}$ = 23.0), winter ($\bar{x}$ = 21.7), and summer ($\bar{x}$ = 18.8). Our final model estimated a 0.07 (95% CI = 0.04–0.10) average probability of wild turkey occupancy across our study area.

After fitting all predictor variables in a single model and using a lasso regression form of Bayesian variable selection, we considered distance to nearest road, mean canopy height within 4 km of a camera site, distance to nearest water source, proportion of natural vegetation cover within 1 km of a camera site, distance to nearest hike and bike trail, proportion of impervious cover within 1 km, 2 km, and 4 km of a camera site, distance to nearest stream, and mean ruggedness within 2 km of a site to be informative given that each had a median posterior value not centered on 0 (Table 2). We retained these variables in our reduced autologistic occupancy model. The variables included in our final model all had a variable inclusion probability of >0.69 (Table 3). From our final reduced model (Table 2), we found that distance to nearest road (β = 0.26, 95% CI = 0.03–0.50), mean canopy height within 4 km of a camera site (β = −0.54, 95% CI = −1.01–−0.08), distance to nearest water source (β = −0.43, 95% CI = −0.82–−0.03), and proportion of natural vegetation cover within 1 km of a site (β = 0.40, 95% CI = 0.02–0.78) had credible intervals that did not overlap 0 (Figure 2).

Our model results indicate that as the distance to the nearest roadway increased by 1 standard deviation (67 m), wild turkeys were 30% more likely to occupy a site (odds ratio [OR] = 1.30). They were 49% more likely (OR = 1.49) to occupy a site as the proportion of natural vegetation cover within 1 km increased by 1 standard deviation (0.13; Figure 2). Conversely, we found that wild turkeys were 42% (OR = 0.58) and 35% (OR = 0.65) less likely to occupy a site as mean canopy height within 4 km increased by 1 standard deviation (2.96 m) or as distance to the nearest water source increased by 1 standard deviation (498 m), respectively (Figure 2).

DISCUSSION

To our knowledge this is one of the first studies to assess habitat use and occupancy of wild turkey in a major city (Tinsley 2014). We estimated wild turkey occupancy across the Washington, D.C. region and found that the probability of wild turkey presence was correlated with sites that had more natural vegetation cover, were farther from roadways, and closer to open water sources. Generally, these results were consistent with past research in more

TABLE 2 Mean model coefficients and 95% credible intervals of the posterior distribution for each predictor variable used in a final reduced autologistic occupancy model to predict wild turkey occupancy in the Washington, D.C. region from July 2020 to November 2023.

Parameter	Median	95% Credible Intervals	
		Lower	Upper
Intercept	−2.96	−3.33	−2.60
Distance to nearest road	0.26	0.03	0.50
Mean canopy height in 4-km buffer	−0.54	−1.01	−0.08
Distance to nearest water source	−0.43	−0.82	−0.03
Proportion of natural vegetation cover in 1-km buffer	0.40	0.02	0.78
Distance to nearest hike and bike trail (log)	0.25	−0.03	0.54
Proportion of impervious cover in 1-km buffer	0.49	−0.06	1.17
Proportion of impervious cover in 2-km buffer	−0.37	−1.05	0.14
Proportion of impervious cover in 4-km buffer	−0.09	−0.52	0.29
Distance to nearest stream	0.14	−0.06	0.37
Mean ruggedness in 2-km buffer	0.22	−0.18	0.72
Mean ruggedness in 4-km buffer	−0.10	−0.66	0.36
Theta (autologistic term)	2.15	1.48	2.78

rural areas. However, given that cities are expanding rapidly, our findings provide valuable insight into how wild turkeys are using urban areas.

Several studies have documented that the areas along roadways provide low vegetation edge habitats that are used by wild turkey for nesting (Lambert 1986) and foraging (Butler et al. 2005). However, in these studies, roadways were gravel roads with low traffic volume (Lambert 1986, Butler et al. 2005, Delahunt 2011). In our study, we found that sites farther from roadways had higher probabilities of urban wild turkey presence (Figure 2). Roadways in our study area were multi-lane highways, primary roads, or secondary paved roads, and several studies have found wild turkeys avoid primary and high traffic roads (Gerrits 2019, Carl et al. 2023). Wild turkeys have keen eyesight and acute hearing (Thogmartin 1999) and may avoid high traffic roads because traffic volume obstructs communication, predator-avoidance signals, and visual cues (Paris and Schneider 2009). Another explanation may be that wild turkeys are selecting habitat patches with fewer roads or trails to stay within a connected movement corridor and avoid fragmented patches. However, we did not have cameras along mowed edges of roads. Therefore, it is possible that we missed observations of wild turkey using areas within the road right-of-way. Whether urban roadways could limit the connectivity of wild turkey populations and reduce movement between urban and rural populations of wild turkey remains an open question. Future research should focus on turkey movement and population genetics to understand how urban and rural turkey populations operate within a metapopulation framework.

Wild turkey occupancy in our study was negatively correlated with distance away from the nearest water source but not with respect to the nearest stream or wetland. Rural wild turkey broods select riparian areas for foraging and loafing because poults need almost constant foraging opportunities to maintain energy for survival (Healy 1985, Chamberlain et al. 2020). Additionally, floodplains provide wild turkey flocks open edge habitats and nutrient-rich soil accumulation, which can lead to high productivity rates of preferred plant species (Chamberlain et al. 2013). However, urban streams and wetlands may not provide the same quality of resources

TABLE 3 Variable inclusion probability and median model coefficient value of the posterior distribution for all predictor variables used in an auto-logistic occupancy model to predict wild turkey occupancy in the Washington, D.C. region from July 2020 to November 2023.

Parameter	Variable inclusion probability	Median coefficient
Distance to nearest road	0.93	0.25
Mean canopy height in 4-km buffer	0.91	−0.43
Distance to nearest water source	0.91	−0.34
Proportion of natural vegetation cover in 1-km buffer	0.89	0.32
Distance to nearest hike and bike trail (log)	0.83	0.19
Proportion of impervious cover in 1-km buffer	0.83	0.25
Proportion of impervious cover in 2-km buffer	0.80	−0.16
Distance to nearest stream	0.75	0.11
Proportion of impervious cover in 4-km buffer	0.72	−0.06
Mean ruggedness in 2-km buffer	0.70	0.03
Mean ruggedness in 4-km buffer	0.69	−0.02
Proportion of natural vegetation cover in 2-km buffer	0.68	0.00
Mean canopy height in 2-km buffer	0.67	0.00
Mean elevation in 1-km buffer	0.67	0.00
Mean elevation in 4-km buffer	0.67	0.00
Human population density in 4-km buffer	0.66	0.00
Mean elevation in 2-km buffer	0.66	0.00
Mean canopy height in 1-km buffer	0.65	0.00
Human population density in 2-km buffer	0.64	0.00
Human population density in 1-km buffer	0.64	0.00
Mean ruggedness in 1-km buffer	0.64	0.00
Proportion of natural vegetation cover in 4-km buffer	0.62	0.00
Distance to nearest wetland	0.62	0.00
Habitat heterogeneity in 4-km buffer	0.61	0.00
Habitat heterogeneity in 2-km buffer	0.61	0.00
Habitat heterogeneity in 1-km buffer	0.60	0.00

owing to surrounding urbanization and associated alteration of stream health and riparian quality (Brown et al. 2009, Kilburg et al. 2015). Future research should focus on wild turkey movement and resource selection to tease out fine-scale habitat requirements regarding the importance of urban wetlands and water sources.

Finally, we observed a strong positive correlation between the proportion of natural vegetation cover within a 1-km radius and wild turkey occupancy; yet we found a significant negative relationship between occupancy and mean tree height at the 4-km scale. While this might seem conflicting, these findings likely indicate that wild turkeys prefer vegetation cover and less human development in their near vicinity but occupy a mix of open areas and closed forest—and potentially avoid areas of contiguous closed forest—at larger scales as observed by studies in

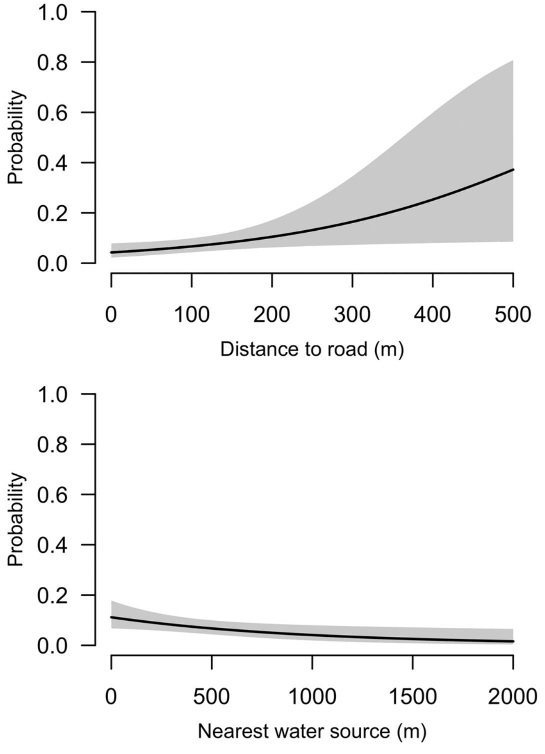

FIGURE 2 Predicted site occupancy as a function of the top predictor variables in an autologistic occupancy model to predict wild turkey occupancy in the Washington, D.C. region from July 2020 to November 2023. Solid line indicates the median posterior values, and the shaded areas represent the 95% credible intervals.

rural or agricultural systems (Porter 1978, Thogmartin 1999, Pollentier et al. 2021). These results highlight the importance of considering scale when assessing habitat use across large landscapes.

Patch size and thus habitat fragmentation could be a major driver of occupancy of wild turkeys (Gustafson et al. 1994, Glennon et al. 1999). However, there is little consensus among urban wildlife ecology studies on how to define or measure the size of an urban patch. For example, one may consider a park boundary the edge of a patch, and measure the patch based on administrative boundaries. However, different wildlife species use differing land use types (e.g., residential yards, utility rights-of-ways, alleys, cemeteries) at varying extents (Markovchick-Nicholls et. al 2008, Gallo et al. 2017, Delaney et al. 2021). Therefore, without fully understanding species-habitat relationships in urban areas, it is hard to delineate a habitat patch. Thus, we chose not to include patch size as a specific variable in our analysis and instead used variables that might relate to fragmentation (i.e., roads, impervious cover, and proportion of natural vegetation cover).

Urban wild turkeys have the potential to contribute to the broader goal of wild turkey conservation. We identified wild turkey-habitat relationships in urban ecosystems. However, a lack of research on urban wild turkey ecology leaves a substantial knowledge gap for the management and conservation of wild turkey populations. A better understanding of urban wild turkey movement, resource selection, demography, and gene flow between urban and rural populations can contribute meaningfully to the management and conservation of wild turkeys. As large charismatic birds, eastern wild turkeys can also serve as a surrogate for understanding how urban wildlife use available habitat, and to what degree urban areas might provide habitats for animals and thus buffer populations declining in more rural landscapes.

MANAGEMENT IMPLICATIONS

Given the generalist nature of wild turkeys, it is likely that they will continue to colonize and persist in urban landscapes. Generally, our observations of the conditions urban wild turkeys occupy were consistent with their more rural counterparts. Yet urban greenspaces are often simultaneously managed for human use and biodiversity conservation. If improving habitat for urban wild turkeys is a goal, our study indicates that restoration and creation of urban greenspaces should 1) focus on restoring and managing habitats farther away from roadways, 2) reduce the creation of roads in larger urban greenspaces, and 3) create patches of vegetation cover even at smaller scales. If mitigating human–wild turkey conflict is a goal, then our model indicates that turkeys are likely to occupy, and thus conflict with people, in naturally vegetated areas near water and mostly away from roads. In 2021, several human–turkey conflicts occurred in urban Washington, D.C. near a hike and bike trail running along the Anacostia River (Hedgpeth 2022). When trails and human access are encouraged in areas that intersect wild turkey habitat (even if wild turkeys have not been detected in the area), signage might be placed to help inform the public about the natural history of turkeys and how to avoid conflict with them. Data-driven information campaigns such as these would increase the likelihood of coexistence between humans and urban wildlife.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ETHICS STATEMENT

This study adhered to relevant regulations and was exempt regarding the ethics of animal welfare protocols.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in Dryad at https://doi.org/10.5061/dryad.x0k6djhxj.

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