



Vicksburg National Military Park White-Tailed Deer Survey



White-tailed deer (*Odocoileus virginianus*) in Vicksburg National Military Park.

NPS

Vicksburg National Military Park white-tailed deer survey

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Abstract

White-tailed deer (WTD) can exert substantial impacts on the ecosystems in the Southeastern United States, particularly by overabundant WTD populations that are sheltered from recreational hunting pressure such as those in the National Parks. Information on WTD abundance and density is indispensable for science-based WTD population management. WTD populations in Vicksburg National Military Park (VICK) have not been surveyed since 2010. Management of WTD populations has been challenged by the lack of reliable, cost-effective methods, such as a deer visual count-density calibration coefficient, for estimating WTD density within the park. This study aimed to develop a cost-effective visual count-density conversion method using WTD counts from spotlight surveys and density estimates from fecal-DNA spatially explicit capture-recapture (SECR) models.

We conducted seven, six, and five spotlight surveys of WTD in January, March, and May, 2023, respectively. Average visual counts of WTD were 96.0 (standard deviation [SD] = 23.98), 86.47 (SD = 14.22), and 84.0 (SD = 13.02) in January, March, and May, respectively. Direct visual deer counts were greater than those of the 2009 VICK WTD spotlight surveys by 40%–220%. Average WTD relative abundances were 8.5 (SD = 4.94), 7.9 (SD = 4.58), and 7.6 (SD = 4.8) deer per mile in January, March, and May, respectively. Average WTD density estimated by distance sampling models was 0.65 deer per ha. The VICK WTD densities did not differ among the three months in our distance sampling model.

We used eight microsatellite markers to genotype WTD fecal samples within VICK. Fecal DNA spatially explicit capture-recapture models estimated 778 WTD within VICK. The WTD densities were positively related to the proportions of forests and open fields (grass and crop) in VICK. White-tailed deer appeared to be overabundant within VICK, causing concerns relative to WTD-human conflicts and exacerbating the risk of wildlife disease transmission such as Chronic Wasting Disease.

We proposed a cost-effective monitoring method for estimating WTD densities with visual counts based on significant inverse relationships between WTD densities estimated by fecal-DNA SECR models and visual counts from spotlight surveys. Our proposed method will allow park staff to convert WTD visual counts from spotlight surveys to WTD densities until substantial changes in VICK's vegetation and (or) habitat management occur. The timely, cost-effective monitoring of WTD populations can help park staff better manage natural resources within VICK, including the mitigation of the damages caused by overabundant WTD to natural resources.

Acknowledgments

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Introduction

The White-tailed Deer (*Odocoileus virginianus*; hereafter WTD) is a keystone species in the eastern deciduous forest (McShea and Rappole 1992; Waller and Alverson 1997). White-tailed deer have flexible habitat requirements and can thrive within a wide range of habitat types (Strickland 2005). White-tailed deer use upland and bottomland hardwood forests throughout the year feeding on hard mast during the fall and winter and seeking cool thermal cover in the summer. White-tailed deer are considered concentrate-selectors, a ruminant feeding strategy where deer seek particular plants, and only the most nutritious parts of selected plants (Dykes et al. 2020). As such, deer use herbaceous and shrub plant communities year-round, which supply large quantities of forage during the growing season (Strickland 2005; Henderson et al. 2020). The density of WTD in the Vicksburg National Military Park (hereafter, VICK) varies seasonally, increasing from spring to summer, peaking in winter, and declining from winter to spring (Kissell and Bomar 2009). White-tailed deer use VICK as refuge to escape from the hunting pressure outside the park, contributing to the peak density in winter. It is reasonable to predict that the spatial distributions and densities of WTD are positively related to proportions of forests and open lands within VICK. Low recreational hunting pressure and high food availability may result in overabundant WTD populations in VICK, which can cause WTD-human conflicts in the urban area of Vicksburg, MS. Information on WTD population density and spatial distribution within VICK is critically important for managing WTD populations for the sustainability of VICK natural resources, including wildlife, and mitigation of WTD-human conflicts including deer overabundance and the potential spread of wildlife diseases (Demarais et al. 2012). However, WTD populations have not been surveyed in VICK since the 2010s (Kissell and Bomar 2009). There is a need to estimate WTD population density and size to provide sound science for VICK WTD population management.

The overall objectives of our project are to determine deer abundance and distribution within VICK, conduct analyses useful for guiding resource management, and disseminate results to park resource staff:

1. Determine and document presence/absence, abundance, and distribution of white-tailed deer
2. Estimate relative abundance (pellet collection and/or eDNA)
3. Estimate population size
4. Develop a calibration coefficient from pellet and visual surveys as a foundation for continued population monitoring
5. Share results with park resource staff and the larger community via a report

Methods

Study site

Vicksburg National Military Park is located in Vicksburg, Warren County, MS, in the United States (US; 32°20'23"N, -90°51'3" W). The climate is subtropical with mean annual temperatures ranging from 12° C to 25.2° C and annual total precipitation from 73.33 cm to 210.49 cm. The VICK vegetation is primarily comprised of mesic upland deciduous (or hardwood) forests and grasslands. VICK is situated on erodible loess bluff lands with high relief terrain in the East Gulf Coastal Plain. VICK is adjacent to the Yazoo River. These adjacent lands are at the southern edge of the Mississippi Alluvial Valley (i.e., the Mississippi Delta), which is subject to periodic flooding, particularly during winter.

We conducted WTD surveys using three different methods during this study. We counted deer along the paved roads to estimate deer relative abundance (deer count per mile) within VICK using spotlight survey methods. We developed a calibration coefficient with a linear regression of deer density on deer count per mile for park staff to estimate deer densities within the VICK using visual deer counts in the future. We also estimated deer densities using spatially explicit capture-recapture (SECR) models with deer spatial capture and recaptures being estimated based on the multilocus genotypes of deer fecal DNA samples within VICK. The SECR model can predict the spatial distribution of WTD densities within the VICK using landcover variables as predictors, facilitating the development of the calibration coefficient. Due to a high relief terrain of VICK, we changed our WTD fecal sample collection methods from the originally planned equal-distance systematic cluster design to the transect design to collect deer fecal samples along the paved roads and inside the forests. The transect method also provides deer fecal samples in parallel to spotlight survey routes, which facilitates the establishment of correlation between deer count per mile and deer density. Additionally, we collected distance sampling data in three survey nights in January, March, and May 2023 for the comparisons of WTD densities between this study and Kissell and Bomar (2009), which also estimated WTD densities within the VICK using distance sampling models in 2009.

Spotlight surveys

We divided VICK into four sections—South, Middle 1, Middle 2, and North for comparison with Kissell and Bomar (2009), which covered the entirety of VICK. We preselected a fixed survey transect along the tour road for each of the four sections (Figure 1; South 2.4 miles, Middle 1 2.5 miles, Middle 2 4 miles, and North 2.7 miles). These transects were selected to aid the limited VICK staff in their continuing efforts of WTD populations and WTD management efforts subsequent to this study. We repeated 5–7 spotlight surveys on each preselected survey transects in January, March, and May 2023 to quantify variability in deer counts. Due to the rough terrain of VICK, we were not able to randomly place spotlight survey transects within VICK.

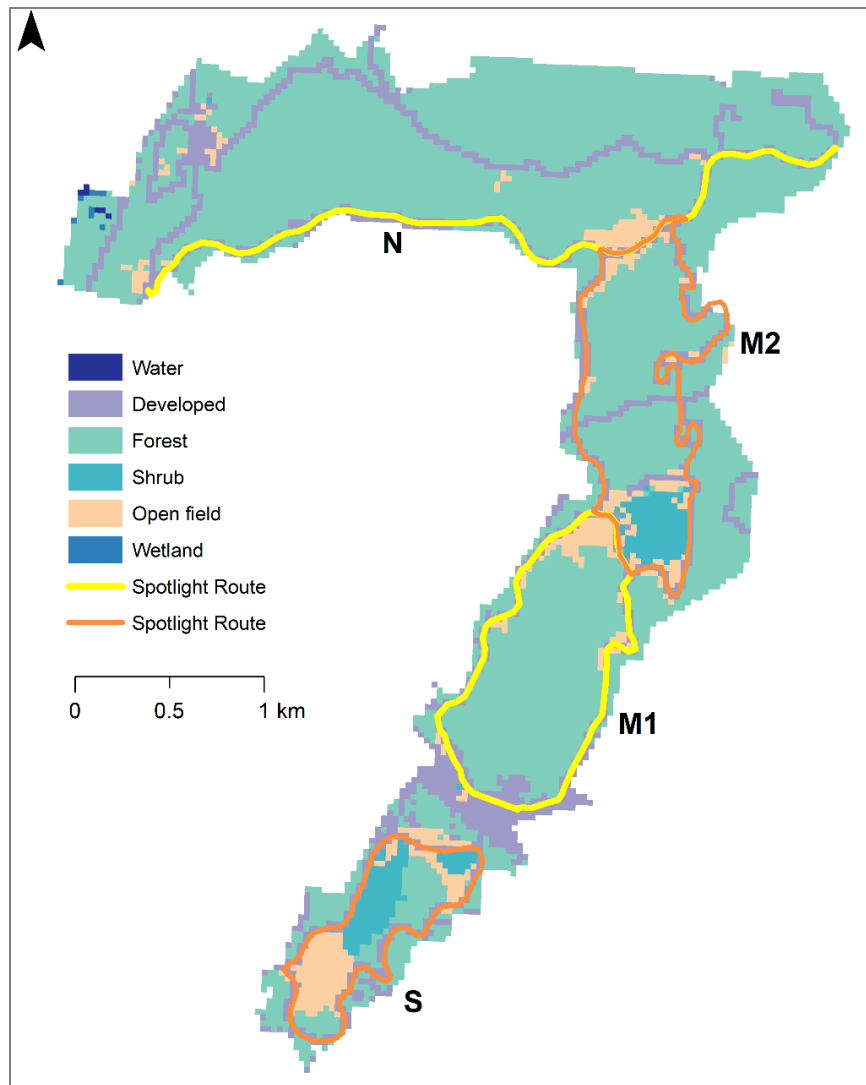


Figure 1. Map of spotlight survey transects in the four sections of Vicksburg National Military Park, Vicksburg, Mississippi. Letters N and S stand for the North and South sections, respectively. Symbols M1 and M2 denote the Middle 1 and Middle 2 sections.

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We conducted spotlight surveys to visually count individual deer along paved tour roads within VICK. Spotlight surveys were conducted at night, starting 30–60 min after sunset and ending when all preselected transects were completed during a survey night. A survey team consisted of a minimum of three personnel: one driver and two observers. Observers stood in the bed of a pickup truck moving at a speed of 5–7 miles per hour (MPH). Each observer detected and counted deer on either the left or right side of roads with a hand-held Maximum Million III spotlight (Brinkmann Corporation, Dallas, TX). We recorded the geographic coordinates (longitude and latitude) of observers with a Garmin Etrex10 hand-held GPS unit (Garmin Ltd., Olathe, KS), distance (meters) between the observer and detected deer with a laser rangefinder (Buckmasters model 1500, Wilsonville, OR), bearing (degree) from the observer to the deer with a Suunto KB-20/360/R look-

through compass (model #: SS020419000, Suunto, Vantaa, Finland), and the time (hour and minute) and date of each detection or count. During the spotlight surveys, we drove counterclockwise consistently along the M1, M2, and S survey loops and westward on the N transect from the same starting points.

Each observer was randomly rotated among the four sections during each survey night to avoid potential observer-related bias. We also randomly rotated the first survey transect and the order of survey transects among 5–7 survey nights each month to avoid potential bias resulting from spatial deer daily activity patterns and transect survey orders.

Measurement of visibility (maximum detection distance) of spotlight surveys

We measured the visibility of spotlight survey transects in the same week of spotlight surveys in January, March, and May. Visibility was estimated at every 1/10th mile along the same survey transects by the same observers in the daytime. Two observers stood in the bed of a pickup truck moving 5–7 MPH. Observers estimated the maximum visible distance (m) perpendicular left and right side of survey transects at each stop using a laser rangefinder. Left-side surveyed interior of the park, while right-side surveyed towards the boundary of the park as we drove counterclockwise through the park in general. Observers also were rotated among the four sections.

Preparation of landcover variables

To inform spotlight surveys, we obtained the National Land Cover Database (NLCD) 2021 from Multi-Resolution Land Characteristics (MRLC) Consortium (<https://www.mrlc.gov/data>). The NLCD 2021 has a spatial resolution of 30 × 30 m² per grid cell (Wickham et al. 2021). We reclassified: 1) the original four developed classes and barren lands (NLCD classes 21, 22, 23, 24, and 31) as developed area (hereafter, developed); 2) deciduous forest, evergreen forest, and mixed forest (NLCD class 41–43) as forest; and 3) grass and cultivated crops (NLCD classes 71, 72, and 82) into open field (Homer et al. 2015). We only used the three reclassified landcover types in our subsequent analysis of the spatial distributions of WTD densities. We generated the raster layers for the proportions of developed, forest, and open field, respectively. All raster layers and associated vector data were projected to the NAD83 / Conus Albers (EPSG: 5070) using R packages *terra* (Hijmans et al. 2024) and *sf* (Pebesma 2018).

Habitat models have good predictive performance for the habitat suitability of birds and mammals with input landscape variables which are derived or “filtered” with a home-range-size circular buffer (Graf et al. 2005, Wang et al. 2019). The size of the circular buffer used in deriving landscape raster layers is equivalent to average daily WTD home range size of about 150 acres (about 60 ha). The proportions of 30 × 30 m² grid cells were derived using all grid cells within a 150-acre circular buffer around the focal grid cell. Forest edge density is the total forest edge length divided by the maximum potential edge length of 150-acre circular buffers that are centered at the focal grid cell (Hirzel et al. 2002). We used the program Biomapper module CircAn to generate the aforementioned raster layers of the landcover proportions and forest edge density (Hirzel et al. 2002).

Deer fecal sample collection

We preselected 11, 1–2 mile routes for WTD fecal sample collection: two routes in each of the North, Middle 1, Middle 2, and South sections, parallel to WTD spotlight survey transects, and one route along the Al Scheller Trail (colloquially called the Boy Scout Trail) in each of the North, Middle 1, and Middle 2 sections for collecting fecal samples in the roadbed off tour roads and along the trails (Figure 2). A team of two observers walked each route to search for WTD fecal pellet piles in the grass and forest stands at the vicinity of each sampling route. When searching for fecal samples, we followed WTD tracks or trails until we found fecal piles without a restricted walking distance. We considered pellets scattered within 20 cm (about 8 inches) as a fecal sample from the same deer. We assessed the quality of fecal pellets based on the freshness and appearance of pellets. We collected wet, shiny intact pellets with a sheen (mucus coating layer), and discarded dry, hard, eroded or cracked pellets. We collected 10 pellets from each pile and stored the pellets of each detected pile in a 50-mL plastic centrifuge tube with a screw-on cap. We marked each tube with sample ID, longitude and latitude, route ID, sampler initials, and date with a fine-end Sharpie marker. We also recorded the route ID, sample ID, quality, geographic coordinates (longitude and latitude), sampler names, and date of all detected fecal samples on the data sheet

To avoid cross-contamination, we wore a new pair of fresh powder-free nitrile examination gloves for collecting each fecal pile.

Fecal samples were stored in a refrigerator within two hours and were transported to Starkville, MS, where they were stored in a –20°C freezer at Mississippi State University within three days after collection.

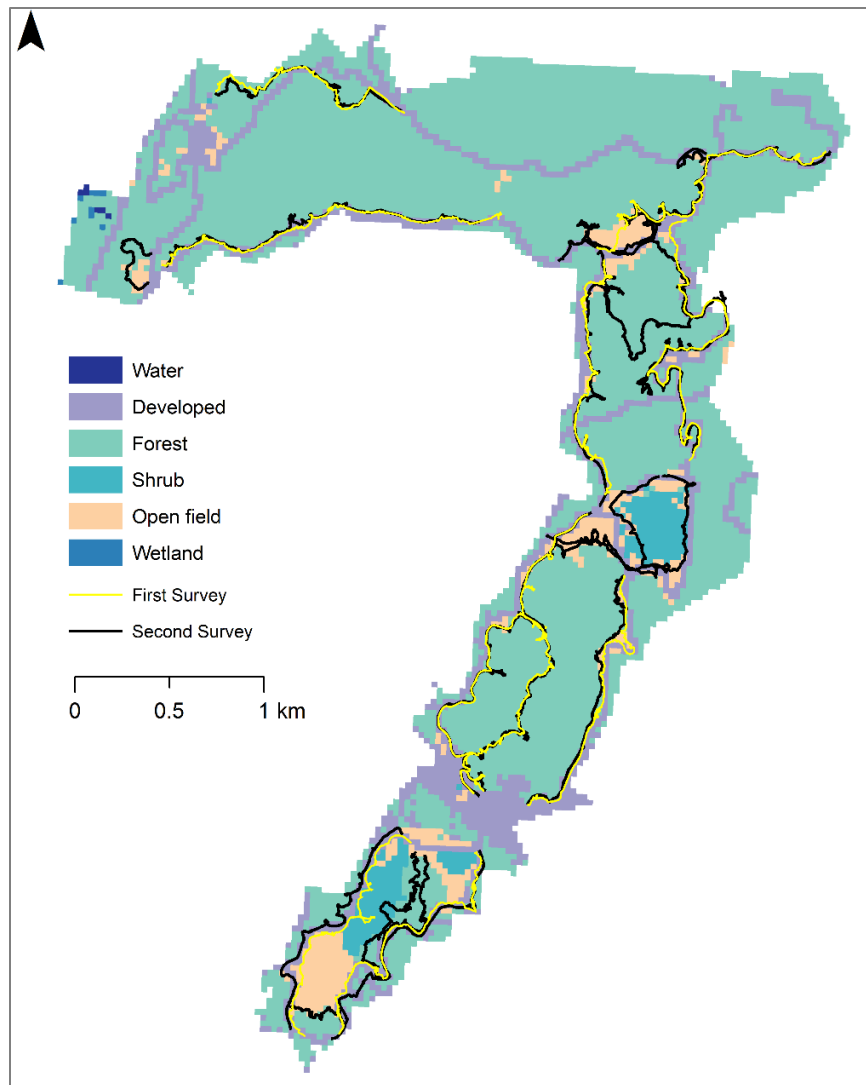


Figure 2. Map of ten routes for white-tailed deer fecal sample collections in the four sections of Vicksburg National Military Park, Vicksburg, Mississippi. Black and yellow lines are the routes that were repeated twice from January 10–19, 2023. The same routes were also searched twice in March and May 2023.
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Microsatellite analysis of eDNA for genotyping WTD fecal samples and individual assignments

DNA extraction

DNA extraction and PCR were carried out in Shan's Lab at Mississippi State University. We extracted DNA from the epithelial cells of six pellets from each sample using QIAamp Fast DNA Stool Mini Kit (Qiagen, Valencia, CA). DNA extraction followed the manufacture's protocol and was checked for the quantity and quality of DNA with a Nanodrop instrument and the visual examination of the PCR agarose gel electrophoresis of WTD microsatellite markers. Extracted DNA was stored in a -20°C freezer for the subsequent PCR runs of microsatellite markers.

WTD Genotyping and microsatellite analysis

We amplified 11 microsatellite markers—BM4107, RT5, SBTD04-A565, BL25, CERVID1-A550, INRA011, BL42-A565, BM848, SBTD06, BM6506, and BM6438—from WTD fecal eDNA to genotype individual deer (Bishop et al. 1994; Goode et al. 2014; Miller et al. 2019b). We amplified the 11 microsatellite markers using the standard PCR protocol in the standard cycling and buffer conditions (Bishop et al. 1994; Goode et al. 2014; Miller et al. 2019b). The genotype sequencing analysis of the 11 microsatellite markers was conducted using the ABI Genetical Analyzer 3730 (Applied Biosystems, Grand Island, NY, USA) with an internal size standard (LIZ-500, Applied Biosystems) in the Center for Quantitative Life Sciences at Oregon State University (Corvallis, OR). We used the program GeneMarker version 2.6.7 (Softgenetics Inc., State College, PA) to score the allele sizes of each microsatellite locus to determine the genotype of each fecal sample. We replicated PCR amplification for each fecal DNA sample and ran additional PCRs on the DNA samples which had inconsistent results in the first two PCRs following Maudet et al. (2004).

Unique multi-locus genotype identifications and white-tailed deer individual assignments of deer fecal samples

We used the R package *ALLELEMATCH* to identify the unique multi-locus genotypes (i.e., genotyped individual deer) among the WTD fecal samples with the data of the allele sizes of the selected microsatellite markers or loci (Galpern et al. 2012). We calculated the probability of identity (PID) and the probability of identity for siblings (PIDSIB) with *ALLELEMATCH*. If PID is $< 10^{-7}$ and PIDSIB is $< 10^{-3}$, we concluded the individual assignment of WTD fecal samples was reliable with negligible error (Kalinowski et al. 2006). We also used the R package *poppr* to determine the minimum number of microsatellite loci that was sufficient to identify the unique multi-locus genotypes of the WTD fecal samples (Kamvar et al. 2015). We used the program GENLAEX added on Microsoft® Excel to calculate the number of unique alleles, the number of effective alleles, observed heterozygosity, expected heterozygosity, and Shannon's index of allelic diversity by microsatellite locus (Peakall and Smouse 2006).

Statistical analysis

Exploratory analysis and summary statistics of spotlight survey

Given the approximately same sampling effort (i.e., the total distance of deer spotlight transects) of each section within VICK between daily spotlight surveys and between months, we tallied the total number of detected deer (deer count) per spotlight survey by section. We calculated the average and standard deviation (SD) of daily deer counts by section and for the entire VICK for each survey month. We calculated the mean and SD of deer count per mile (DCPM) and naïve density (ND), respectively, for each survey section and the entire VICK by month with spotlight transects as sampling units.

We used deer count per mile as a relative abundance index for each survey section (N, S, M1, and M2) and the entire extent of VICK. Deer count per mile was calculated as the total number of deer detected on both sides of a transect divided by the actual total length of the transect recorded during each survey:

$$DCPM = \frac{C}{D},$$

where $DCPM$ is deer count per mile; C total deer count; and D the total length of transect.

We used average spotlight detection width of both sides of the transect (i.e., the sum of the left- and right-side maximum detection distances) as the detection width of spotlight surveyed areas. We then calculated a naïve deer density using the following equation:

$$ND = \frac{C}{D \times W},$$

where ND is naïve density; C is total deer count; D is the total length (m) of transect; and W is detection width (m). We converted density unit to deer per hectare (ha).

Distance sampling models

We used the geographic coordinates of observers, distance between observers and detected deer, and bearing from observer to deer to determine the geographic coordinates of detected deer:

$$X_d = X_o + \cos(B)D$$

$$Y_d = Y_o + \sin(B)D$$

where X_d and Y_d are the geographic coordinates (easting and northing) of deer, X_o and Y_o are the geographic coordinates of observers; B is bearing from observers to deer; and D is distance between observers and deer. We transformed the WGS84 longitude and latitude to the easting and northing of the NAD 83/ Conus Albers Projection to determine the geographic coordinates of deer and distance (m) between observers and deer using R package *sf*. We then calculated the perpendicular distance (m) from deer to spotlight transects using the shapefiles of transects and the geographic coordinates of deer using R package *sf*.

We estimated deer densities using the distance sampling model, which is a probabilistic model for estimating wildlife densities with the probability of detecting animals being a function of perpendicular distances from detected animals to survey transects (Buckland et al. 2001). We estimated WTD density (deer per ha) with all distance data pooled over the four sections to increase our sample size. We built six models with six different combinations of two different key functions and series adjustments to represent the probability of deer detection as a function of distance (Buckland et al. 2001). The six distance sampling models were:

1. half-normal function only (HN model)
2. half-normal + cosine series adjustment (HN+COS model)
3. half normal + Hermite polynomial adjustment (HN+Hermite model)
4. hazard rate function only (HR model)
5. hazard rate + cosine adjustment (HR+COS model)

6. hazard rate + Hermite polynomial adjustment (HR+Hermite model).

We fitted the six models to WTD perpendicular distance data using maximum likelihood methods implemented in the R package *Distance* (Miller et al. 2019a). We conducted the model selection among the six candidate models using Akaike information Criterion (AIC).

Spatially explicit capture-recapture models for estimating white-tailed deer densities and spatial distributions using fecal DNA sampling

Spatially explicit capture-recapture models estimate the density of animal populations using data on the spatial captures and recaptures of tagged individuals (Efford 2004; Efford et al. 2009). The SECR model assumes that the centers of home ranges or animal activities follow a spatial Poisson point process (Royle et al. 2013). The probability of animal detection peaks at the center of activities but declines with increasing the distance from animal capture locations to the center of activities, following a half-normal function, exponential decay function, or hazard rate function (Efford et al. 2009; Royle et al. 2013). The density (i.e., the number of animals per unit area) of animals is represented by the Poisson parameter—intensity rate of the Poisson point process.

Our preselected routes for fecal sample collection covered all the sections of VICK (Figure 2). The geographic coordinates of the fecal samples of the same individual WTDs were used as spatial captures and recaptures to estimate the unknown parameters of SECR models. We searched WTD fecal samples in both sides of each route without a restricted walking distance to follow WTD trails and tracks. The locations of WTD fecal samples were widely spread in the sample areas instead of being distributed on the preselected routes. Thus, we used the SECR models of the polygon detector within the R package *secr* to estimate WTD population size and the spatial distribution of WTD densities within the boundary of VICK (Efford 2022). In our preliminary analysis of spotlight surveys and distance sampling, relative abundance by spotlight surveys and population density by distance sampling did not differ between January, March, and May 2023. The SECR polygon detector used data on the geographic coordinates of all spatial capture and recapture locations of WTD in January and March to estimate WTD densities (Efford et al. 2009; Royle et al. 2013).

We used maximum likelihood methods to estimate the known parameters of SECR models. We used Akaike information criteria corrected for small sample sizes (AICc) to select the best SECR detection function among hazard rate (HHR), hazard half-normal (HHN), and hazard exponential (HEX) functions with a full sub-model of density, which included all four landcover variables. The selected best detection function was used to select the best approximating density submodel. We developed 16 SECR models including all possible combinations of the four landcover variables. We then used AICc to select the best SECR model. We used the best SECR model with the selected landscape covariates as predictors to generate a raster map of the spatial distribution of WTD densities and estimated WTD population size within VICK.

Results

White-tailed deer spotlight surveys and fecal sample collections

We conducted seven, six, and five spotlight surveys on each preselected transect in January, March, and May 2023, respectively (Table 1). We collected distance sampling data from three spotlight surveys in January and March and two spotlight surveys in May for estimation of WTD densities. During each trip, we measured the visibility of each of the four spotlight transects once. A single distance sampling survey was aborted before completion due to severe weather conditions in May 2023.

Table 1. Dates, the number of spotlight surveys, and the number of fecal samples of white-tailed deer in Vicksburg National Military Park in January, March, and May 2023.

Trips	Dates	The number of transects	The number of surveys per transect	The number of fecal samples
Trip 1	5–10 January	4	7	309
Trip 2	10–19 March	4	6	198
Trip 3	10–19 May	4	5	39

We walked each of the ten fecal sampling routes twice for fecal sample collection during each survey month. Thus, our sampling efforts of fecal sample collections were similar in terms of the total miles walked among the three months. However, the number of fecal samples detected declined substantially over the three months primarily because of the greening and growth of grasses, herbaceous plants, and shrub plants in springtime (Table 1).

Results of deer spotlight surveys

Total deer counts by section and within VICK

Average total deer count within VICK ranged from 84 to 96 (Tables 2–3). Average total deer counts exhibited a decreasing spatial gradient from south to north within VICK (Table 2), suggesting that more WTD were visible or detectable in the southern than in the northern part of VICK. On average we detected more WTD during our spotlight surveys in January, March, and May than Kissell and Bomar (2009) did in each corresponding survey month (Table 3). Average relative abundance indices (DCPM) also exhibited a decreasing spatial trend from south to north within VICK (Tables 4–6, Figure 3).

Table 2. Average total counts and standard deviations (in parentheses) of white-tailed deer in the four sections of Vicksburg National Military Park in January, March, and May 2023. Symbol VICK denotes entire park. The four sections were displayed in Figure 1.

Month	North section	Middle 1 section	Middle 2 section	South section	VICK
January	13.83 (11.53)	22.33 (8.78)	29.83 (15.21)	30.00 (12.93)	96.00 (23.98)
March	11.33 (4.63)	27.67 (11.83)	17.00 (4.24)	27.67 (6.38)	86.67 (14.22)
May	13.80 (3.27)	7.80 (5.07)	30.00 (10.86)	32.40 (7.83)	84.00 (13.02)

Table 3. Comparisons of monthly average total counts of white-tailed deer in Vicksburg National Military Park between Kissell and Bomar (2009) and this study. Kissell and Bomar (2009) conducted spotlight surveys in December 2008, March 2009, and May 2009, respectively.

Year	December or January	March	May
2008–2009	30	60	43
2023	96	84	84

Table 4. The average, standard deviation (in parentheses), range, and coefficient of variation of deer count per mile (DCPM) and naïve density (deer per hectare) of white-tailed deer in Vicksburg National Military Park in January 2023. CV denotes coefficient of variation. VICK stands for entire park. The four sections were displayed in Figure 1.

Section	DCPM	Range of DCPM	CV of DCPM	Naïve density	Range of naïve density	CV of naïve density
North	5.24 (4.38)	0.00–10.77	0.84	0.43 (0.36)	0.00–0.87	0.84
Middle 1	8.45 (3.56)	4.44–14.00	0.42	0.47 (0.17)	0.25–0.77	0.42
Middle 2	7.59 (3.94)	2.50–13.33	0.52	0.28 (0.15)	0.09–0.49	0.52
South	12.74 (5.45)	3.91–18.75	0.43	0.38 (0.16)	0.12–0.55	0.43
VICK	8.50 (4.94)	0.00–18.75	0.58	0.39 (0.23)	0.00–0.87	0.58

Table 5. The average, standard deviation (in parentheses), range, and coefficient of variation of deer count per mile (DCPM) and naïve density (deer per hectare) of white-tailed deer in Vicksburg National Military Park in March 2023. CV denotes coefficient of variation. VICK stands for entire park. The four sections were displayed in Figure 1.

Section	DCPM	Range of DCPM	CV of DCPM	Naïve density	Range of naïve density	CV of naïve density
North	4.36 (1.78)	1.54–6.15	0.41	0.55 (0.22)	0.19–0.77	0.41
Middle 1	10.92 (4.80)	5.19–17.60	0.44	0.67 (0.30)	0.32–1.09	0.44
Middle 2	4.36 (1.09)	2.82–5.60	0.25	0.24 (0.06)	0.16–0.32	0.25
South	11.98 (2.88)	6.67–15.22	0.24	0.59 (0.14)	0.33–0.75	0.24
VICK	7.90 (4.58)	1.54–17.60	0.58	0.51 (0.25)	0.16–1.09	0.49

Table 6. The average, standard deviation (in parentheses), range, and coefficient of variation of deer count per mile (DCPM) and naïve density (deer per hectare) of white-tailed deer in Vicksburg National Military Park in May 2023. CV denotes coefficient of variation. VICK stands for entire park. The four sections were displayed in Figure 1.

Section	DCPM	Range of DCPM	CV of DCPM	Naïve density	Range of naïve density	CV of naïve density
North	5.31 (1.26)	3.46–6.92	0.24	0.59 (0.14)	0.39–0.77	0.24
Middle 1	3.10 (2.05)	1.11–6.00	0.66	0.26 (0.30)	0.09–0.50	0.66
Middle 2	7.73 (2.77)	4.10–10.51	0.34	0.51 (0.18)	0.27–0.69	0.36
South	14.09 (3.40)	11.74–20.00	0.24	0.78 (0.19)	0.65–1.11	0.24
VICK	7.56 (4.80)	1.11–20.00	0.64	0.54(0.25)	0.09–1.11	0.46

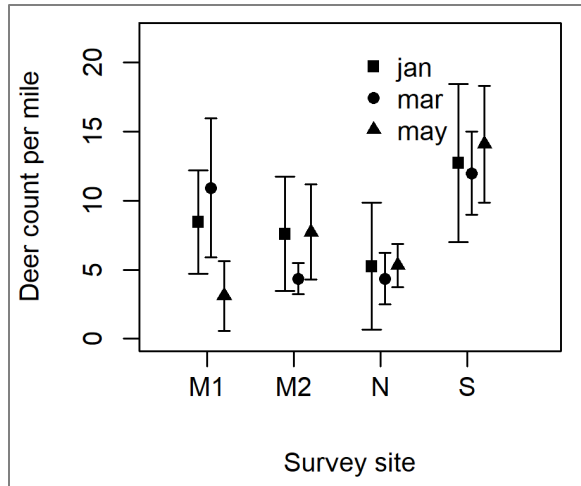


Figure 3. Error plot of the mean and 95% confidence interval [CI] of deer count per mile (DCPM) derived from spotlight surveys in the North, Middle 1, Middle 2, and South sections of Vicksburg National Military Park, Vicksburg, Mississippi in January, March, and May 2023. Vertical lines are 95% CIs. Symbol jan, mar, and may stand for January, March, and May, respectively. Symbols and letters M1, M2, N, and S denote sections Middle 1, Middle 2, North, and South, respectively.

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Comparisons of deer count per mile (DCPM) within VICK between January, March, and May

We compared average DCPMs within VICK among January, March, and May with spotlight transects as sampling units. We included month and transect ID as random effects to account for repeated measures within a month using R package glmmTMB (Brooks et al. 2017). Neither March nor May mean DCPM significantly differed from the January mean DCPM (March: $P = 0.56$; May: $P = 0.39$; Figure 4). Our comparisons suggest the average WTD relative abundance was not significantly different among the three months.

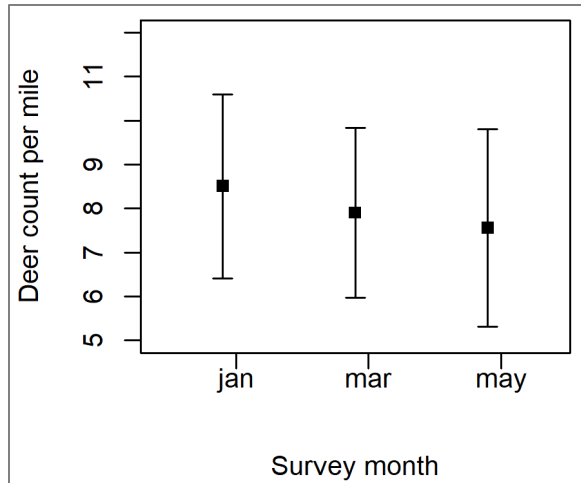


Figure 4. Error plots (a) of the means and 95% confidence intervals [CI] of deer count per mile (DCPM) derived from spotlight surveys in Vicksburg National Military Park, Vicksburg, Mississippi in January, March, and May 2023. Vertical lines are 95% CIs. Symbols jan, mar, and may stand for January, March, and May, respectively. Average DCPMs did not differ among January, March, and May as demonstrated by the overlapping 95% CIs among the three months.

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Survey work followed current traffic flow at VICK which was roughly counterclockwise through the park, with the exception of transect roads that bridged the eastern and western perimeter roads. In general left-side observer surveyed interior of the park, while right-side observer surveyed towards the boundary of the park. The left-side visibility decreased from the south to north sections, whereas the right-side visibility was similar among the four sections (Figure 5). Therefore, the total visibility (i.e., the sum of left- and right-side visibility) decreased from south to north. The similar spatial trends of WTD relative abundance and transect visibility probably resulted in a less obvious spatial gradient of naïve densities than those of relative abundance indices (DCPM) (Tables 4–6). The difference in the spatial gradients between WTD relative abundance and naïve density suggests that estimation of WTD densities with detection distances being accounted for is critically important for estimation of WTD densities.

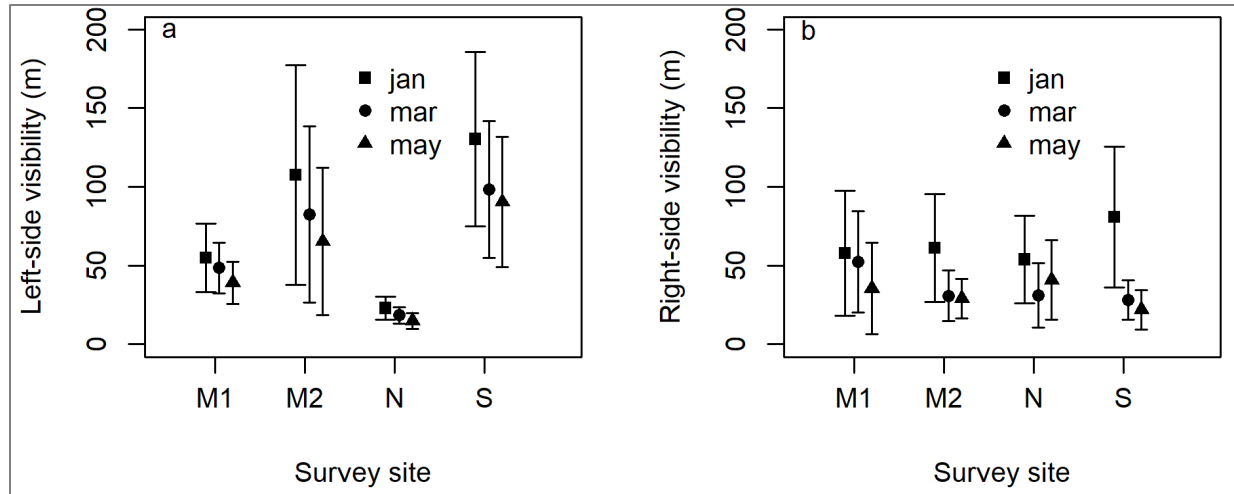


Figure 5. Error plots of the mean and 95% confidence interval [CI] of spotlight survey visibility on the left (a) and right (b) side of transects in Vicksburg National Military Park, Vicksburg, Mississippi in January, March, and May 2023. Vertical lines are 95% CIs. Symbol jan, mar, and may stand for January, March, and May, respectively. In general, left-side surveyed interior of the park, while right-side surveyed towards the boundary of the park as we drove counterclockwise along the M1, M2, and S transect loops and westward along the transect N.

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Except for transect visibility in the South section in March and May, the 95% confidence intervals (CIs) of the left and right side visibility overlapped, suggesting comparable visibility between the two sides of transects (Figure 5). Estimated distances perpendicular to the left- and right-sides of transects pooled over the distance sampling over the three months were not significantly different ($t = 1.16$, $df = 222$, $P = 0.25$, Figure 6). The comparable perpendicular distances between the two sides of transects met the assumption of equal left- and right-side detection distances for distance sampling models.

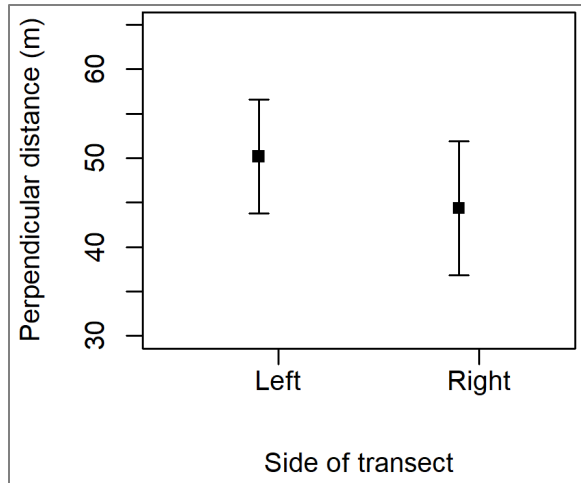


Figure 6. Error bar plots (mean and 95% confidence interval [CI]) of estimated distances perpendicular to the left and right of transects from distance sampling in Vicksburg National Military Park, Vicksburg, Mississippi pooled over January, March, and May 2023. Vertical lines are 95% CIs. In general, left-side surveyed interior of the park, while right-side surveyed towards the boundary of the park as we drove counterclockwise along the M1, M2, and S transect loops and westward along the transect N.

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Results of distance sampling models

We fit six distance sampling models to the distance data pooled over all distance sampling surveys to increase our sample size. Our results of WTD relative abundance (DCPM) and naïve density (ND) suggest that WTD abundance did not differ significantly among January, March, and May, justifying the distance data pooling. Additionally, in a preliminary analysis of distance sampling models, inclusion of month as a categorical predictor of deer densities did not improve the AIC value of the model. The 95% CI of the coefficient for March was -0.08 – 0.88 and that for May was -0.56 – 0.38 , both including 0.0 and suggesting insignificance at the $\alpha = 0.05$. Therefore, we combined all distance sampling data of January, March, and May to fit distance sampling models.

Both models of hazard rate function only and hazard rate function plus Hermite polynomial adjustment had the lowest AIC value (Table 7). We selected the hazard rate function only model because it has the simpler model structure between the two models. The coefficients of variation (CV) of WTD density estimates from distance models were < 0.2 , much less than those of WTD naïve estimates (Tables 4–7). Nevertheless, 95% CI's of WTD naïve densities and distance model estimates overlapped except for the naïve density of Middle 2 section in March, which was below the 95% CI of distance sampling model estimate (Figure 7). Therefore, distance model estimates of WTD densities tended to be higher than average WTD naïve densities. The estimate of WTD population size within VICK was 545 deer (95% CI: 442–648).

Table 7. Selection of distance sampling models for estimating the WTD density in Vicksburg Military National Park, Mississippi in January, March, and May 2023. Initial AIC denotes Akaike Information Criterion. CV stands for coefficient of variation of the density estimate of distance sampling models. Symbol $\hat{D}$ stands for WTD density estimate (deer per hectare).

Model	AIC	$\hat{D}$ (deer/ha)	CV
Half-normal only	2297.25	0.57	0.16
Half-normal + COS adjustment	2287.83	0.71	0.17
Half-normal + Hermite polynomial	2297.25	0.57	0.16
Hazard rate only ^A	2287.17	0.65	0.18
Hazard rate + COS adjustment	2288.90	0.66	0.18
Hazard rate + Hermite polynomial	2287.17	0.65	0.18

^A The selected model.

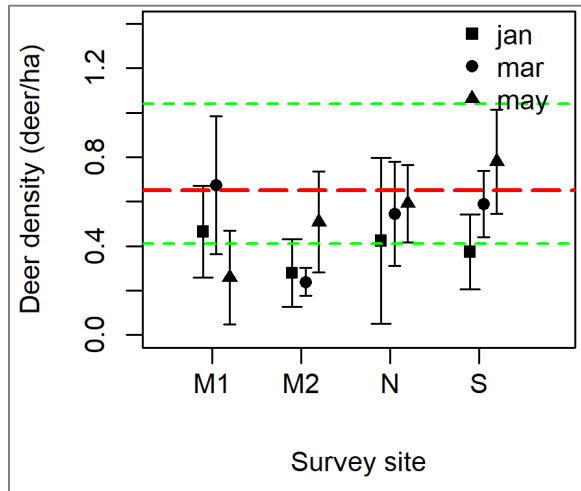


Figure 7. Error plot of the mean and 95% confidence interval [CI] of the naïve densities of white-tailed deer in Vicksburg National Military Park, Vicksburg, Mississippi in January, March, and May 2023. Red dashed line is the mean density of deer estimated by distance sampling models and two green dashed lines delimit the 95% CI of the distance sampling density estimate. Vertical lines are 95% CIs. Symbol jan, mar, and may stand for January, March, and May, respectively.

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Microsatellite genotyping and individual assignments of white-tailed deer

We extracted DNA from 546 WTD fecal samples. Ninety-eight fecal samples (18%), including all 39 fecal samples of May, did not render high-quality DNA for the PCR runs. Therefore, overall success rate of fecal DNA genotyping is 81%. PCR failed to amplify three microsatellite markers—RT5, SBTD04-A565, and BL42-A565—in most of 448 fecal samples.

We used the eight remaining microsatellite markers from the original eleven for the genotyping of WTD fecal samples.

Individual assignment analysis using the R package ALLEMATCH identified 408 unique genotypes, with each unique genotype corresponding to a unique individual deer.

The genotype accumulation curve indicated that three of the eight microsatellite markers were adequate to identify about 400 deer with a low uncertainty (Figure 8). Furthermore, ≥ 4 microsatellite markers can identify 408 unique genotypes, that is, 408 unique individual deer with a high certainty (Figure 8). We used all eight microsatellite markers listed in Table 8 to genotype the 448 fecal samples. The PID was $1.46 \times 10^{-11} \approx 0$. The PIDSIB was 0.0003. Therefore, the genotyping and individual assignment had negligible error. The number of alleles per locus ranged from 11 to 25 among the eight markers (Table 8). Observed heterozygosity ranged from 0.40 to 0.9, indicating medium to high diversity (Table 8).

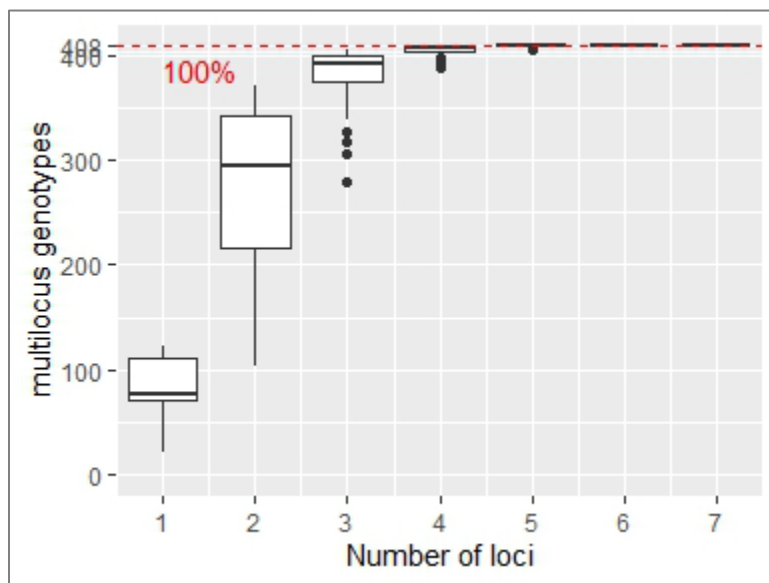


Figure 8. Genotype accumulation curve of eight microsatellite markers—BM4107, BL25, CERVID1-A550, INRA011, BM848, SBTD06, BM6506, and BM6438. The x-axis is the number of microsatellite loci randomly sampled without replacement. The y-axis is the number of unique multi-locus genotypes (MLG) that were assigned by the number of microsatellite loci. The red dashed line represents the total number of unique genotypes. The box plot illustrates the uncertainty of individual assignment. The horizontal black line inside the box indicates the average number of unique genotypes identified by the number of microsatellite markers. Inter-quantile distance (height of box) measures the variability (or uncertainty) of genotype assignments.

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Table 8. Summaries of allelic polymorphism and heterozygosity of eight microsatellite markers of white-tailed deer in Vicksburg National Military Park, Vicksburg, Mississippi from January to March 2023. Letter N stands for sample size. Letter I denotes Shannon's diversity index. Symbol Na is the number of alleles, Ne the number of effective alleles, Ho observed heterozygosity, and He expected heterozygosity.

Locus name	N	Na	Ne	I	Ho	He
BL25	400	15	4.55	1.94	0.71	0.78
CERVID1-A550	403	25	9.70	2.55	0.88	0.90
INRA011	400	11	1.77	0.93	0.40	0.44
BM4107	389	21	11.40	2.68	0.62	0.91
RT5	408	19	7.80	2.30	0.90	0.87
SBTD06	391	11	3.74	1.51	0.85	0.73
BM6506	407	23	9.01	2.56	0.77	0.89
BM6438	369	19	7.20	2.36	0.82	0.86

With the microsatellite tagging technique and the geographic coordinates of each fecal sample, we found that 31 genetically tagged deer were spatially captured and recaptured a total of 71 times within VICK. The spatial captures and recaptures of 408 deer were used in the SECR analysis for the estimate of WTD population size and WTD spatial distribution within VICK.

Spatially explicit capture-recapture models for estimation of spring WTD population size and spatial distribution based on fecal DNA

We included forest edge, proportion of developed, proportion of forest, and proportion of open land in the full sub-model of deer density (Figure 9). We did not detect any collinearity among the four covariates with the variation inflation factor ($VIF < 10$) being 4.73, 1.41, 4.35, and 1.11 for developed proportion, forest edge density, forest proportion, and open field proportion, respectively. The landcover variables were also used for prediction of the spatial distribution of WTD density within VICK to generate a raster image of WTD densities.

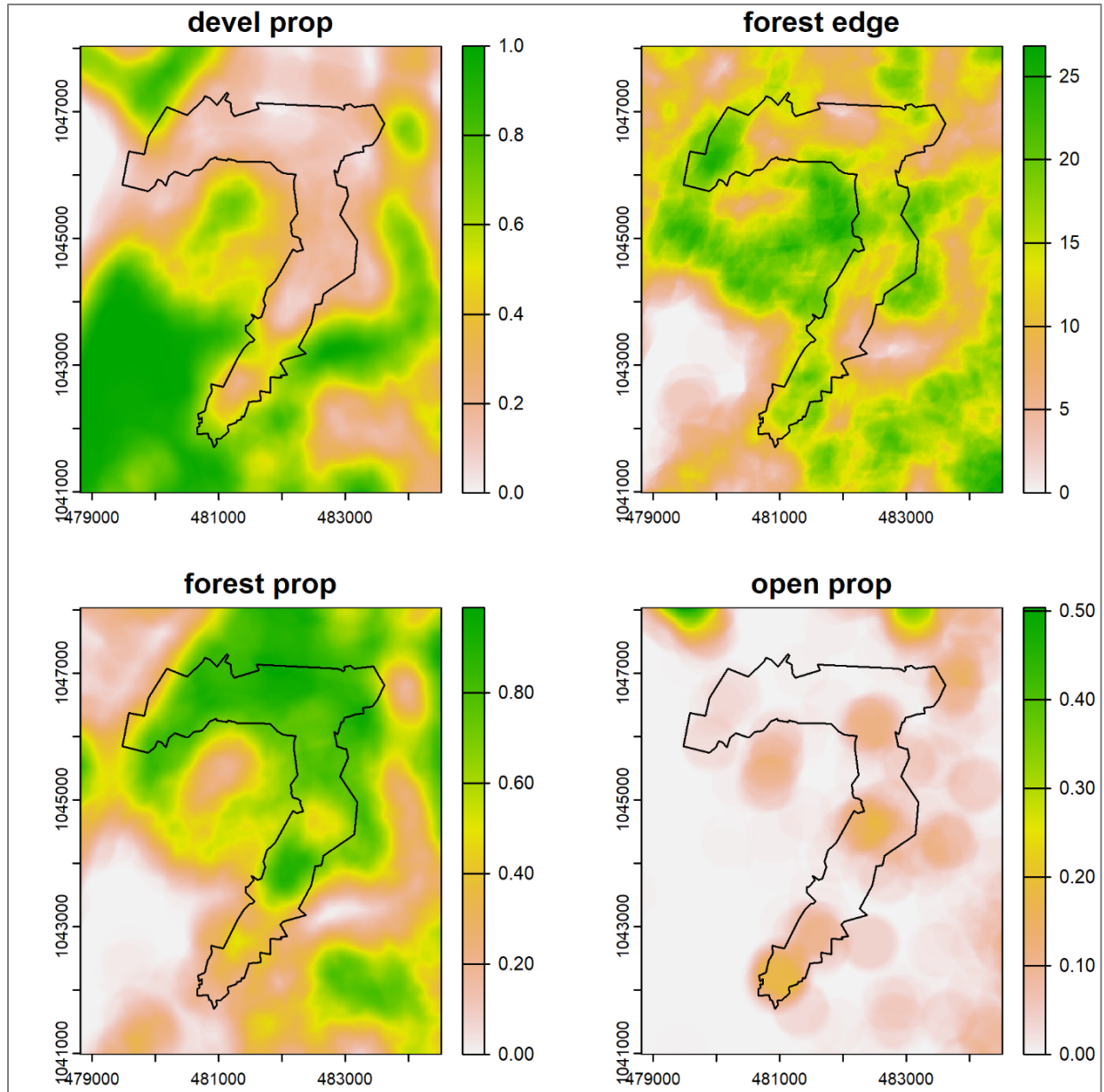


Figure 9. Raster layers of forest edge density and proportions of developed land (devel prop), forests (forest prop), and open field (open prop) for the area of Vicksburg National Military Park. The raster layers were derived from the National Land Cover Database 2023. The x axis is easting and the y axis is northing in the NAD83/Conus Albers projection. The vertical bar of each panel is the color legend of proportion or edge density.

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We used the full density sub-model to determine the best approximating detection function of deer fecal samples among hazard rate function, half-hazard rate function, and exponential function. Hazard rate function was the best detection for our data, having the lowest AICc (Table 9). We used hazard rate function as the detection function of SECR models in the subsequent analysis.

Table 9. Model selection of the best detection function of spatially explicit capture-recapture models for genetically tagged white-tailed deer in Vicksburg National Military Park, Mississippi in 2023.

Model	AICc	Δ AICc	AICc weight
Full density model, hazard rate, $\lambda_0 \sim 1$, $\sigma \sim 1$, $z \sim 1$ ^A	15263.75	0.00	1.0
Full density model, hazard exponential, $\lambda_0 \sim 1$, $\sigma \sim 1$	15323.75	60.00	0.0
Full density model, hazard half-hazard rate, $\lambda_0 \sim 1$, $\sigma \sim 1$	15391.26	127.79	0.0

^A Selected model.

We built 16 SECR models with all possible combinations of four landcover variables for the functions of deer densities (D). We listed the top five SECR models of which the first four models had Akaike weights > 0 in Table 10. In the best model with the lowest AICc value, the coefficient of forest proportion was 3.45 (95% CI: 2.95–3.94), and that of open land proportion was 8.74 (95% CI: 7.52–9.96). Thus, WTD densities increased with increased proportions of both forests and open lands within VICK.

Table 10. Selection of the best spatially explicit capture-recapture (SECR) models for genetically tagged white-tailed deer in Vicksburg National Military Park, Mississippi in 2023. Letter D denotes deer density (number of deer per ha), K the number of unknown parameters, and w Akaike weight. Symbol AICc stands for Akaike information criteria corrected for small sample sizes; Δ AICc for difference in AICc between a model and the best model; devel prop for the proportion of developed area; forest edge for the edge density of forest; forest prop for the proportion of forest; and open prop for the proportion of open field. The SECR models had hazard rate detection functions.

Model	K	AICc	Δ AICc	w
D ~ forest prop + open prop	6	15262.23	0	0.36
D ~ forest edge + forest prop + open prop	7	15262.83	0.59	0.27
D ~ devel prop + forest prop + open prop	7	15263.46	1.22	0.20
D ~ devel prop + forest edge + forest prop + open prop	8	15263.75	1.52	0.17
D ~ devel prop + forest edge + open prop	7	15300.17	37.94	0.0

Although the 2nd–4th models were the competing models with the top model (Table 10), the 95% CIs of forest edge and developed (devel) prop included 0, which would increase uncertainties in the estimation of WTD population sizes and the predictions of WTD spatial densities.

Estimate of white-tailed deer population size and spatial distributions of deer density

We used the best SECR model and the proportions of forests and open lands to generate a raster map of modeled WTD spatial density distributions within VICK (Figure 10). The expected mean population size within VICK was 778.17 deer (95% CI: 577.96–1047.72; CV = 0.15).

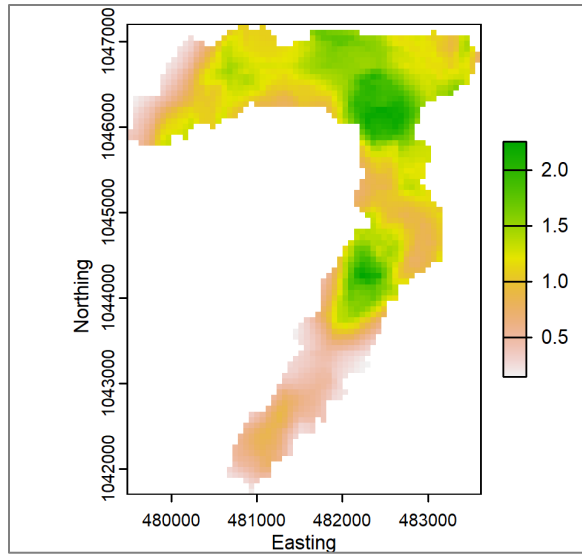


Figure 10. Spatial distributions of white-tailed deer densities (the number deer per ha) in Vicksburg National Military Park, Mississippi from January to March 2023. Deer densities were predicted by spatial capture-recapture models with the proportions of forests and open fields as predictors. The x axis is easting, and the y axis.

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Relationship between spotlight count and density of white-tailed deer based on fecal DNA capture/recapture

We added a 150-m buffer to both sides of transects N (north), M1 E (Middle section 1 east), M1W (west), M2 E (Middle section 2 east), M2 W (west), SE (south section east), and SW (south section west) (Figure 1) to create seven polygons. We calculated mean WTD density by each transect polygon using the R *terra* package function *extract()* and the raster file of WTD densities (Figure 10). We also calculated deer count per mile of the January and March surveys by each transect to standardize the counting efforts, resulting in 14 values (7 for each month, Table 12). Deer density was significantly related to deer count per mile ($P = 0.0001$, $R^2 = 0.7$, Fig. 11). This results in the calibration coefficient which can be used to estimate deer density from spotlight survey results: Deer density (y) = $1.48 - 0.1 \times$ deer count per mile (x). We expanded the distribution of the 14 deer counts per mile values to generate 100 potential WTD count records and predicted the 95% confidence band of the linear regression line (Figure 11). Due to small sample sizes of deer visual count (January: $n = 7$; March: $n = 7$), we were not able to carry out regression by month.

Table 12. Density based on fecal DNA and deer spotlight transect count per mile of white-tailed deer in Vicksburg National Military Park, Mississippi in January and March 2023. Density (deer per ha) was estimated using fecal DNA spatially explicit capture-recapture models. Deer were counted with spotlight surveys at night. Initial DCPM stands for deer count per mile. Symbol Jan for January and Mar for March.

Transect	Month	Density	DCPM
Middle 1 E	Jan	0.996	3.939
Middle 1 E	Mar	0.996	3.742
Middle 1 W	Jan	0.872	3.769
Middle 1 W	Mar	0.872	5.735
Middle 2 E	Jan	1.299	2.165
Middle 2 E	Mar	1.299	3.464
Middle 2 W	Mar	1.357	1.530
Middle 2 W	Jan	1.357	1.530
North	Jan	1.371	2.658
North	Mar	1.371	3.114
South E	Jan	0.547	7.262
South E	Mar	0.547	5.496
South W	Jan	0.603	10.649
South W	Mar	0.603	9.411

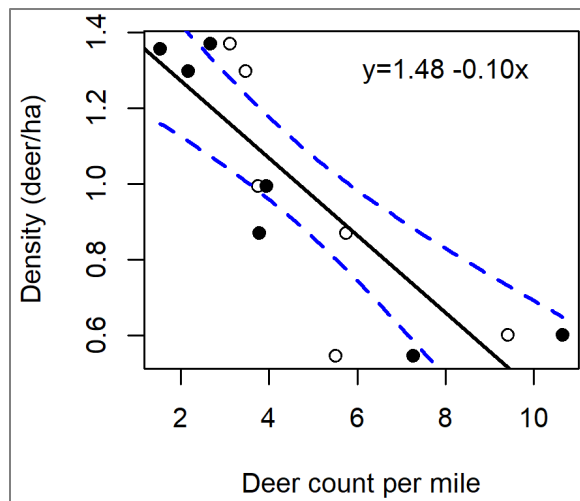


Figure 11. Linear relationship between the visual count per mile and the density (the number of deer per ha) of white-tailed deer in Vicksburg National Military Park, Mississippi, US, in January ($n = 7$) and March ($n = 7$) 2023. The x axis is the deer count along a transect divided by the length of the transect. Black dots represent observations in January and open circles are observations in March. The calibration coefficient equation is deer density (y) = $1.48 - 0.10 \times$ deer count per mile (x).

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Discussion

The national parks play an important role in the conservation of wildlife and biodiversity of the United States. The diversity of vegetation and landscapes enhance the quality of the parks as wildlife habitats, providing food resources and cover. Furthermore, game wildlife species use the parks as refuge from recreational hunting pressures. On the other hand, high reproductive potential and the sanctuary of the parks may lead to overabundance of large herbivores and result in wildlife-human conflicts (Demarais et al. 2012).

Our study shows that WTD numbers are elevated in VICK relative to areas in the rest of the state. Average white-tailed deer (WTD) visual counts ranged from 84 to 96 in Vicksburg National Military Park (VICK) in 4–5 days of park-wide spotlight surveys during January, March, and May 2023. Average relative abundance of WTD ranged from 7.56 to 8.6 deer per mile in VICK during the same period. Average naïve WTD density was 0.46 deer per ha, equivalent to 119.14 deer per square mile. The VICK deer naïve density is about 3–4 times greater than the highest deer density in the Desoto and Homochitto National Forest among eight National Forests surveyed by spotlight visual counting from 2018–2019 (Jones et al. 2020). Spatially explicit capture-recapture (SECR) models with WTD fecal genotyping data estimated a total of 778 (95% CI: 577–1047) deer within VICK. White-tailed deer densities within VICK were at the high end of WTD density gradient within the state of Mississippi (Jones et al. 2020).

Deer visual counts may not be comparable among studies due to different counting methods and differences in the visibility of transects. We used the similar spotlight survey technique for the WTD visual counting as Jones et al. (2020). The transect visibility of Jones et al. (2020) ranged from 22.25 m to 50.6 m (converted from feet), which is similar to those of this study (Figures 5–6). Therefore, our naïve estimate of WTD density is comparable to those of Jones et al. (2020) across the National Forests within Mississippi and was at least 3 times of those in the National Forests. Kissell and Bomar (2009) conducted three spotlight surveys of WTD in VICK in December 2008 and March–May 2009. The survey routes are identical between Kissell and Bomar (2009) and this study. The average total WTD visual counts were 30, 60, and 43 in December, March, and January, respectively, in 2008 and 2009. The average total visual counts of our study were 96, 84, and 84 deer in January, March, and May 2023, respectively, about 1.3 to 3 times of those in 2008–2009 (Table 3). The density estimates from distance sampling were 0.14 in December 2008, 0.27 in March 2009, and 0.16 in May 2009 with their 95% CIs overlapping, suggesting no significant differences among the three surveys. We tested for differences in WTD densities among January, March, and May in our distance modeling. Survey month was not a significant factor influencing WTD densities in our data. Our estimate of VICK WTD density is 3.4 times the average of the aforementioned three estimates of Kissell and Bomar (2009). Therefore, the WTD population has increased substantially with a finite rate of increase being 2.0–3.0 over the past 15 years comparing the density estimates by the same distance sampling methods between Kissell and Bomar (2009) and this study.

The number of microsatellite markers, the polymorphism of microsatellite markers, the total sample size (i.e., the number of genotyped fecal samples), and the number of spatial recaptures of genetically

tagged individuals influence the precision of SECR density estimates (Maudet et al. 2004; Wehausen et al. 2004; Brommer et al. 2021). Average observed heterozygosity (0.74) over the eight microsatellite markers is similar to that (0.72) of a WTD population in Tennessee, US (Goode et al. 2014) but greater than that of WTD in Finland (Poutanen et al. 2019). Brommer et al. (2021) spatially recaptured 19 WTD two or more times in 2016 and 29 WTD two or more times in 2017. Wang et al. (2024) found that the coefficient variation (CV) of the estimates of giant panda population sizes was < 0.2 with the polygon detector of SECR models using 7–11 microsatellite markers when > 25 pandas were recaptured > 1.5 times within a season in a much larger spatial extent than this study. We spatially captured a total of 408 unique genetically tagged deer, out of which 31 deer were recaptured 2–3 times during our study. Those spatial recaptures provided information for estimating the capture probability of WTD. The CV of our SECR estimate of WTD population size is less than 0.2. Goode et al. (2014) detected 33 unique deer with each being recaptured 3–4 times on average in southern Tennessee. The proportion of WTD spatial recaptures in this study was less than that of Goode et al. (2014) probably because our deer population size was several times greater than that in Tennessee. At very high densities, the chance of encountering the feces of the same individual is low due to the “dilution” effect. Nonetheless, the precision of our estimate of WTD population size is desirable ($CV < 0.2$).

Fecal DNA SECR models can estimate WTD densities in the dense forested areas, where visibility is low for spotlight-based distance sampling. Spotlight surveys along roads may miss detecting WTD inside a forest stand and underestimate WTD densities (Buckland et al. 2023). Average SECR estimate of WTD density evaluated with the averages of forest proportion and open field proportion was 1.07 deer per ha within VICK, which was greater than the average WTD density of distance sampling by 0.4 (by about 64%). Distance sampling with spotlight surveys may underestimate deer population densities in the forest area. We found an inverse relationship between the visual counts per mile (x) and the SECR estimate of WTD densities (y) ($y = 1.48 - 0.1x$; Figure 11). Within VICK, observers may detect more deer in the less forested areas such as in the South section of the park or Middle section 2 (i.e., M2 and S in Figure 1), in which WTD density is less than in the forested areas. Section M2 in which the Illinois Monument is located has a big open grass field. The grass areas can serve as a bedding area and provide food. The higher visibility towards the left side of transects or the interior of VICK led to greater WTD detections and counts (Table 2; Figure 5). Additionally, SECR models including environmental covariates can generate a raster map of the spatial distribution of WTD density within VICK (Figure 10), providing insight for the WTD-habitat relationship and WTD management. For instance, WTD densities are positively related to the proportion of open fields that provide food from broad-leaved plants in the grass areas in the vicinity of the monuments within VICK. Prescribed burning in the large grass areas and grass mowing surrounding the small-sized monuments in the late fall may reduce the availability of food and bedding habitats of WTD and subsequently reduce WTD densities within VICK for a few months until the grass and broad-leaved plants regenerate.

Future Recommendations

White-tailed deer are overabundant in VICK with the density being 2–3 times greater than that of the Homochitto National Forest, about 68 miles south of VICK. The WTD overabundance may cause concerns relative to over-browsing plant communities and causing damage to natural resources and biodiversity within the park. Chronic Wasting Disease (CWD) has been detected in Warren County, MS, where VICK is located (MDWFP 2021). The winter flooding of the Yazoo River drives WTD into VICK from the surrounding areas. Winter flooding, inward deer flux, and WTD overabundance may increase the risks of CWD transmission among WTD inside the park. There is an urgent need to develop a cost-effective, timely monitoring method for estimating WTD densities in different parts of VICK. The inverse relationship between WTD density and visual count can be used to develop a cost effective WTD monitoring method.

We recommend the park staff conduct visual counts of WTD during the leaf-off winter season and use the inverse relationship shown in Figure 11 to convert WTD counts to WTD densities for different sections of the park, such as sections N, S, M1, and M2 (Figure 1). To better use the inverse relationship for the monitoring and count-to-density conversion, we make the following recommendations:

1. Two observers *count* deer on each survey route in the targeted section or area; one observer for the left and the other observer for the right side of the route.
2. The length (L) of survey route in an area should be 2–3 miles. Observers should record the length of routes in miles.
3. Deer counts should be repeated three or more times for a survey route during a week to account for variability in weather conditions.
4. Average ($\bar{C}$) of repeated counts from the same route is used to calculate the WTD density (D) with the following formula which represents the calibration coefficient:

$$D = 1.47 - 0.10 \times (\bar{C}/L)$$

where D is WTD density (the number of deer per ha), L is the length of survey route in miles, and $\bar{C}$ is average WTD count.

This recommended method is based on the selected statistical model fitted to data collected within VICK. methods will be for WTD monitoring in other national parks. Furthermore, WTD populations and their use of VICK are likely to change over time. If WTD population density changes substantially from the current level in the future, our recommended method may generate biased estimates of WTD density. Therefore, white-tailed deer density and its relationship with visual count will need to be updated and revised with new surveys or studies like ours, every five years.

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