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Original Article

Road Bias for Deer Density Estimates at 2 National Parks in Maryland

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ABSTRACT Estimating the population density of deer is an essential task for public agencies that plan a herd reduction. Distance sampling has been increasingly utilized to estimate population density, and is used by the National Park Service to estimate white-tailed deer (*Odocoileus virginianus*) densities throughout the eastern United States. Many of these surveys are conducted along public roads due to limited resources and accessibility, which may violate a critical assumption of distance sampling and potentially introduce sampling bias. We used infrared cameras to confirm deer activity with respect to survey roads at 2 national parks in Maryland, USA (Catoctin National Park and Antietam National Historic Battlefield), during 2005 and 2006 and compared results with the predicted distributions. The number of deer observed during road surveys declined with distance intervals at Catoctin, but there was a similar amount of deer activity at each distance interval. At Antietam, survey observations maintained a constant level of activity beyond 200 m from the survey route, while deer activity was inconsistent between distance intervals. The mean number of deer photographs/day/sample point did vary significantly across distance intervals from the survey route at Antietam, but not at Catoctin. In Antietam, the uneven distribution of agricultural fields and public roads were significant predictors of deer activity detected during the camera surveys. At Catoctin, the fit of the detection function was improved by expanding the first distance interval. Although density estimation using DISTANCE can account for most sources of error introduced by use of public roads, our data indicate bias is likely to occur in landscapes with high road densities and long sight distances.

KEY WORDS density estimator, distance sampling, Maryland, *Odocoileus virginianus*, road survey, suburban deer, white-tailed deer.

Managing public lands within suburban or exurban settings in many regions of North America usually means developing population control measures in response to high densities of white-tailed deer (*Odocoileus virginianus*), and the resultant decline in biological diversity (Peck and Stahl 1997, Côté et al. 2004), alteration of forest succession (Frost et al. 1997, Healy 1997), and high level of human–deer conflicts (Stewart et al. 2007, McShea et al. 2008). Management is often reactive on public lands, with control measures triggered when deer densities, or the indirect damage metrics, exceed a predetermined level (Minnis and Peyton 1995, Swihart and DeNicola 1997). The control measures usually cease when deer densities are lowered below the threshold, or the damage metrics show sufficient decline. This management protocol relies on effective measures of deer densities, without the benefit of harvest data afforded managers of annually hunted populations.

Although most population estimates of wildlife are based on harvest data or mark–recapture principles (White et al. 1982, Pollock et al. 1990, Roseberry and Woolf 1991, 1998), population estimates can be obtained for animals where individuals are neither captured nor individually identified (Buckland et al. 2001, Thomas et al. 2010). Distance sampling is a robust method for estimating animal populations when the animals are visible but not readily captured or identifiable as individuals, and allows managers to confidently estimate deer densities as long as sampling assumptions are met. The key feature of distance sampling is that fewer animals are detected at greater distances from the survey line, creating an observation strip of variable width depending on vegetation density and survey mode (Thomas et al. 2010). The software program DISTANCE estimates the detection function for animals with respect to distances from the survey route, which can be used with the number of animals detected and transect length to estimate density within an effective strip width based on the empirical data (Buckland et al. 2001, Thomas et al. 2010).

Distance sampling has become increasingly popular in recent years to collect density information on multiple

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species of wildlife (Koenen et al. 2002, Ruette et al. 2003, Stapp and Guttilla 2006, Marques et al. 2007). Because distance sampling does not require detection of all individuals along a survey route, it is often an effective density estimator for large, forest-dwelling species that are not consistently observable, such as white-tailed deer. Thus, the technique has become increasingly popular with governmental agencies, such as the National Park Service (NPS), whose management plans often require the estimation of white-tailed deer. The National Capital Region of the NPS (NCR) uses distance sampling at 11 parks within its jurisdiction (Bates 2007). The Great Smoky Mountains National Park and Fire Island National Seashore also use distance sampling to estimate deer density (Naugle et al. 2002). Distance sampling is commonly used in the United Kingdom to estimate unhunted populations of different deer species (Gill and Morgan 2010). The NCR sampling protocols combine distance sampling with spotlighting in order to alleviate some of the problems usually associated with strip-transect surveys, including underestimating populations and changes in detectability due to environmental factors (Focardi et al. 2001).

Distance sampling has 3 key assumptions: 1) animals are detected at their initial location; 2) animals directly on the survey line are always detected; 3) distances and angles are measured accurately (Buckland et al. 2001:30–34, Thomas et al. 2010). National Park Service protocols account for these assumptions by stipulating that observers be monitored by the driver or data recorder to ensure animals are detected at their initial location and that exact measurements to initial locations are taken every time.

An additional assumption of distance sampling is more problematic. The survey line should traverse a population that is randomly dispersed with respect to the line and some, but not all, of the population can be detected from the survey line (Buckland et al. 2001, Thomas et al. 2010). However, for some park-specific protocols within the eastern United States, park roads and trails are used as the survey route due to practical limits on time and staffing (Underwood et al. 1998, Bates 2004). In municipal parks, or within exurban or suburban communities, the relatively small parcel size and the difficulty in accessing private land, often causes surveys to include public roads. If roads are used for the survey route and these roads either follow habitat features (i.e., streams or ridges) or dictate the distribution of features that also structure the deer population (i.e., agricultural fields or fences), then a critical experimental design assumption is violated, and the potential for bias is introduced to the estimate.

It is difficult to test the assumption of random deer distribution relative to the survey route. One possible means is to use infrared-triggered cameras to measure the distribution of deer activity during the same period that road-based surveys are being conducted. Density estimates based on infrared-triggered cameras have been compared to road surveys for marked populations of white-tailed deer in the Florida Keys (FL, USA; Roberts et al. 2006). They found road survey estimates to be comparable to, but lower than, estimates based on mark–recapture with infrared-triggered cameras. They did not examine the distribution of deer relative to their survey routes using the camera units.

A second source of bias can be activity on the road itself causing animals to move away from the survey route. This second type of road bias can be compensated for using the DISTANCE software through either deleting observations within a set distance of the road or by expanding the first distance interval to encompass the region where shifts may occur. Ward et al. (2004) compared both methods when examining road bias during roe deer (*Capreolus capreolus*) surveys in Great Britain.

We used established deer survey routes in 2 national parks within Maryland, USA to test an underlying assumption of the distance sampling protocol. Both parks use distance sampling protocols adapted specifically for the NCR of the NPS (Bates 2004) from standard guidelines (Underwood et al. 1998, Buckland et al. 2001). Our objectives were to compare the distribution of deer relative to roads used as survey routes, with the null hypothesis that deer activity cannot be predicted based on distance from the survey route. These 2 parks were chosen because of distinct habitat differences between the 2 parks, and the annual deer density estimates for both parks included large confidence intervals.

STUDY AREA

Our study was conducted at 2 national parks: Catoctin National Park (henceforth, Catoctin; Thurmont, MD; 24.2 km^2; 39°38′N, 77°26′W) and Antietam National Battlefield (henceforth, Antietam; Sharpsburg, MD; 13.5 km^2; 39°28′N, 77°44′W). Although both parks are located in exurban communities of Maryland, Catoctin is primarily a forested park (>95% forest), which manages its forest for ecosystem properties, while Antietam is primarily an agricultural park (19% forest), which maintains a historical appearance consistent with its landscape in 1862. Antietam agricultural fields are corn, hay, or fallow, and are bordered by small woods or hedgerows of early successional trees such as cherry (*Prunus* sp.) and black locust (*Robinia pseudoacacia*). Catoctin has mature deciduous forests comprised primarily of oak (*Quercus* sp.) and hickory (*Carya* sp.) species, with a generally open understory due to heavy browsing by deer. Understory shrubs such as mountain laurel (*Kalmia latifolia*) or spicebush (*Lindera benzoin*) do occur in patches throughout the forest. Deer densities were estimated for each park during the autumn of 2005 and 2006 based on distance sampling protocols, which included use of the park roads for all, or a portion of, the survey routes (Underwood et al. 2003, Bates 2004).

METHODS

Camera Setup

We recorded deer activity along the established deer survey routes of each park (Fig. 1), sampling Catoctin from September to November in 2005 and 2006, and sampling Antietam during October–December 2005 and September–November 2006. We measured deer activity along half of

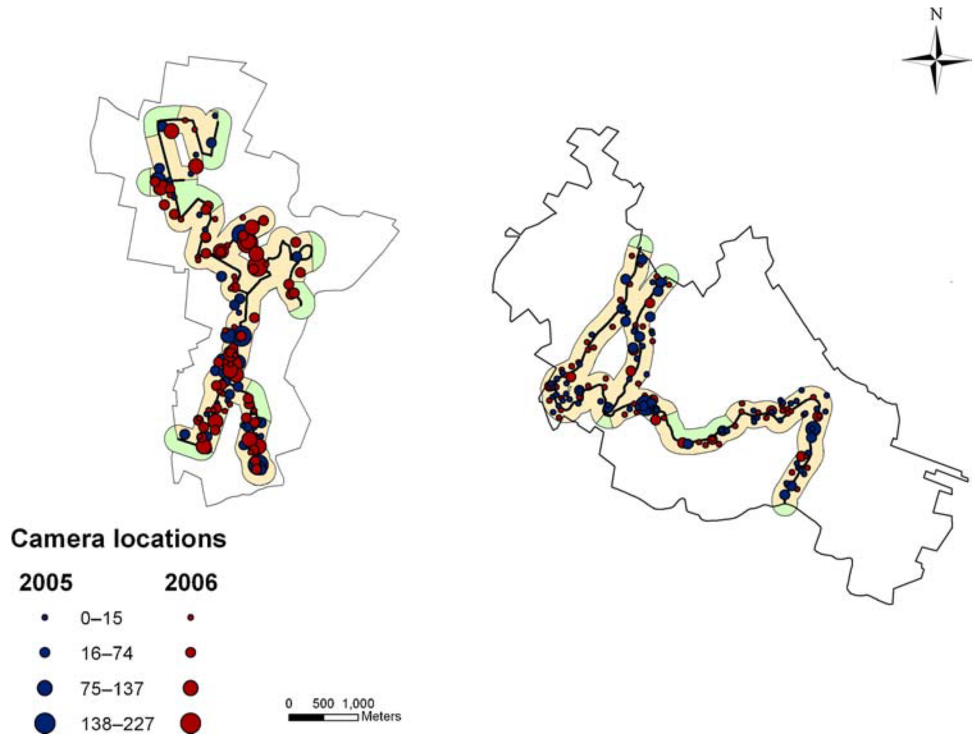

Figure 1. The number and location of deer pictures along each deer survey route at Antietam National Battlefield (left) and Catoctin National Park (right; MD, USA) for autumn of 2005 and 2006. There is a 200-m buffer placed along each route with those portions of the route excluded from census indicated by green shading. The size of the circle indicates the number of deer photographs at that location.

each survey route with 20 digital cameras (Cuddeback™; Non-Typical, Inc., Park Falls, WI) for 20 days before shifting to the other half of the route. The process was repeated to ensure 2 rotations throughout each park, which resulted in ≥80 cameras on each survey route during each year (potentially 1,600 camera-nights for each park/yr).

We divided each survey route into 200-m segments, with cameras distributed at 0–200 m from the survey route in each segment to ensure a relatively even distribution of cameras across the landscape. Sections along each transect that were excluded from the deer survey route due to topography, ownership, or security, were also excluded from sampling for this study (Fig. 1). This process resulted in 99 sample segments at Antietam and 98 at Catoctin. We used a random number generator in Microsoft Excel™ to select the segment and distance interval for each survey. Cameras were placed at proximate center of each sample segment, with the exact distance to road edge measured for cameras <50 m from the road and the distance estimated (with Global Positioning System) for cameras >50 m from the road. Cameras were secured to trees or nearby posts, and oriented parallel to the road to capture only deer active within the distance interval. All cameras were set to a 1-min delay (e.g., minimum time between subsequent pictures). The sites were unbaited to ensure deer movements were random relative to the camera position. Segments never contained more than one camera within 25 m of each other during a survey period and a segment's previous sampling history did not affect its status for the subsequent sampling. At the completion of each rotation, cameras were collected, pictures were downloaded and batteries replaced before being moved to a new location.

Analysis of Photographs

We did not count the number of deer within a photograph or differentiate between deer in sequential pictures. We considered all photographs to be representative of deer activity, and not the number of deer occupying an area. Some camera units did not operate for the entire survey period due to battery failure. If a camera unit failed before 15 days we disregarded the data; if the camera failed 15–19 days into operation we used the last recorded picture as the last day of operation. We report the data as mean number of photographs/camera/day to reflect this uneven sampling process.

Deer Density Survey

In the autumn of 2005 and 2006, Catoctin and Antietam NPS staff conducted a roadside survey of deer over 2–5 consecutive days using a standard protocol for NCR (Bates 2004). They would slowly (8 km/hr) drive a predetermined route, starting at 2 hr after dusk, and complete the route each survey night. The survey truck would contain a driver, data recorder, and 2 observers. The observers would be seated on a raised platform in the bed of a standard pickup truck and use 3-million-candlepower spotlights to observe deer on either side of the vehicle. Sections of the route were excluded to avoid spotlighting within residential houses or across heavily trafficked roads (see Fig. 1). Upon sighting a group of deer the observers would record the sighting distance (m) and angle, as well as the number of deer in the group. The sighting distance and angle are used to calculate the perpendicular distance from the animal to the transect route. Distance was estimated using laser range-finders and angles estimated with handheld compasses. This protocol is presently used for 11 parks within NCR, and generally results in detection rates of >50%. We used the number of deer groups observed in each distance interval for each year of the study to compare to the number of deer photographs/camera-day.

Data Analysis

We derived distance from the camera location to the survey route and distance to any road from Geographic Information System layers provided by each park using ArcMap 9.2 (ESRI 2007). We used the effective strip width calculated post hoc from the deer surveys to place a buffer on the survey route and estimate the park area covered by the survey effort. We estimated distance to nearest forest in Antietam using the same layers, with only forest patches >0.5 ha or patches with linear widths >30 m included in the analysis. The entire survey route within Catoctin was forested. For Antietam, we classified all survey points as forest, agricultural fields, or fallow fields. Using ArcMap, we estimated forest cover by digitizing the boundaries of all forest stands >20 m wide from a 2001 IKONOS (Satellite Imaging Corporation, Burghausen, Germany) image for Catoctin and a 2004 IKONOS image for Antietam provided by the NCR. To compare the camera survey with the deer census data, we assigned groups of sighted deer to the same segment and distance intervals along the survey routes and entered all observations into a spatial database maintained in ArcMap. We subdivided the camera locations into 7 distance intervals: 0–20 m, 21–40 m, 41–60 m, 61–80 m, 81–100 m, 101–140, and >140 m. All metric measures (e.g., distance to any road, distance to survey route, distance to forest, and mean no. of photographs/day/camera) were examined for normality and log transformed, if needed, to fit assumptions of parametric tests. We used a nonparametric test, Kruskal–Wallis 1-way analysis of variance (ANOVA), to compare the number of deer groups seen for each distance interval during the spotlight surveys, due to the nonnormal distribution of observations. We used generalized linear models (PROC GENMOD; SAS Institute 2011) and ANOVA to compare deer activity with distance to survey route and other relevant variables. For evaluating the relative importance of multivariate models, we used an information-theoretic approach to rank the models based on Akaike's information criterion corrected for small sample sizes (AIC_c; Burnham and Anderson 2002). We considered models with a ΔAIC_c <2 of the top model to be equivalent to the top model. To examine for spatial autocorrelation, we divided the distribution of the number of photographs/day/camera into quartiles and compared the mean distance between the locations of the cameras taking the photographs within both the lowest and highest quartiles to the mean distance for an equal number of randomly selected survey points using a paired t-test, and repeated the process 5 times. Differences or relationships were considered significant if P was ≤ 0.05.

RESULTS

Deer Density Survey

During our roadside surveys we observed sufficient groups of deer in both 2005 (86 and 243 groups for Catoctin and Antietam, respectively) and 2006 (111 and 235 groups for Catoctin and Antietam, respectively) to estimate densities using DISTANCE. Deer density estimates at each park were consistent for 2005 and 2006, with approximately 30 deer/km^2 at Catoctin and 42 deer/km^2 at Antietam (Table 1). DISTANCE estimated the effective strip width of the survey as approximately 56 m at Catoctin and 119 m at Antietam (Table 1). When this effective strip width is combined with the distribution of the survey routes (Fig. 1), we estimate 6% of Catoctin and 21% of Antietam were covered in the surveys.

At Catoctin, the distribution of deer observed during the spotlight surveys does decline with increasing distance from the survey route, but the decline is not significant (Kruskal–Wallis 1-way ANOVA, $K = 12.05$, $P = 0.061$, df $= 6$) due to the large number of deer groups observed in the 21–40-m distance interval and not the 0–20-m distance interval. At Antietam there was no obvious pattern to the distribution of observed groups (Kruskal–Wallis 1-way ANOVA, $K = 7.12$, $P = 0.31$, df $= 6$; Fig. 2).

Camera-Trapping Data

At Antietam camera-traps recorded 6,171 pictures of white-tailed deer at 156 sample points, while at Catoctin they recorded 1,703 pictures from 157 sample points (Table 1). The distribution of deer photographs across the survey routes appeared to show spatial clumping of high- and low-density areas (Fig. 1). However, when we compared cameras that were placed in the same location, but during different 20-day rotations, there was no significant correlation between the numbers of photographs for these repeat samples ($n = 29$, Pearson's $r = 0.09$, $P > 0.1$).

Table 1. Camera-trapping and deer survey results for Catoctin National Park and Antietam National Battlefield, Maryland, USA in 2005 and 2006.

		Camera survey					Deer density estimate		
Park	Yr	Survey points	Camera-trap nights	Photographs	Mean photographs/ survey point	Route length (km)	Effective strip width (m)	Deer density (km^2)	CL
Antietam	2005	66	1,280	2,084	33	12.1	118.1	42.5	33.0–54.8
	2006	90	1,860	4,087	44	12.1	119.9	42.8	26.9–68.1
Catoctin	2005	79	1,540	659	9	14.6	56.3	28.4	23.7–33.9
	2006	78	1,580	1,044	13	14.6	58.0	34.9	30.1–40.4

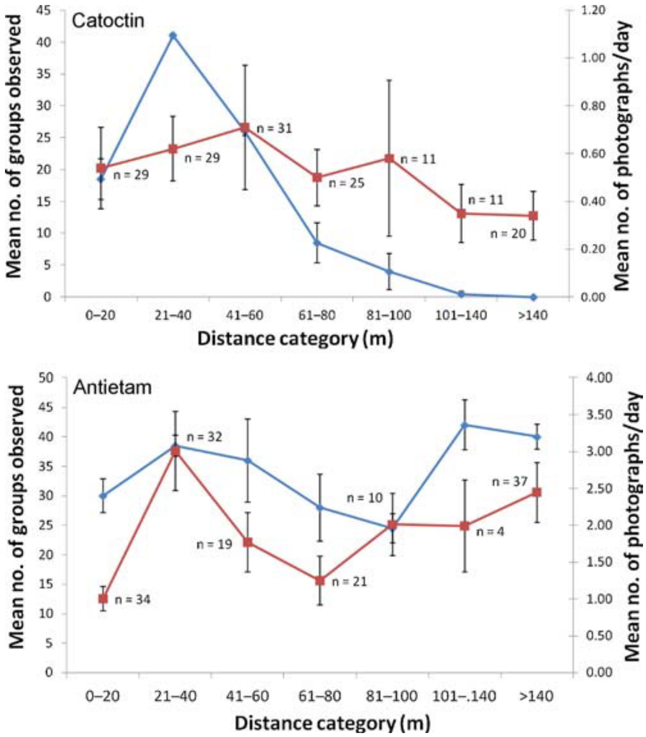

Figure 2. Mean number of deer groups (±SE) seen during deer surveys (blue line) and mean number detected with infrared cameras (±SE) in each distance interval (red line) during 2005 and 2006 at Catoctin National Park and Antietam National Battlefield, Maryland, USA.

Distribution of Deer Relative to the Survey Route

There was no significant linear relationship between the number of photographs/camera-day at each sample point and the distance from the sample point to the survey route at either Catoctin ($F_{1,154} = 1.80$, $r^2 = 0.11$, $P = 0.183$) or Antietam ($F_{1,155} = 3.75$, $r^2 = 0.15$, $P = 0.055$). To duplicate the process used by DISTANCE, where observations are placed into distance categories, we compared the mean photographs/camera-day for sample points grouped into 7 distance categories (Fig. 2). At Antietam, there was a significant difference between the distance categories (ANOVA; $F_{6,150} = 3.28$, $P = 0.005$), with fewer deer photographs/day/sample point at 0–20 m when compared to 21–40 m (pair-wise comparison of means with Bonferroni adjustment). At Catoctin, there was no significant difference in deer activity between the distance categories (ANOVA; $F_{6,149} = 0.47$, $P = 0.83$).

General Factors Determining Deer Activity

For Antietam, the highest ranked models (ΔAIC_c <2 of the top model) identified habitat and shortest distance to a road as important determinants of deer activity, while the covariates of year, distance to woods, and distance to the survey route were less frequent among these models (Table 2). When we examined habitat at Antietam, active agricultural fields had significantly more deer activity than fallow fields (ANOVA; $F_{2,154} = 5.21$, $P = 0.006$). For Catoctin, where all points were within forest habitat and no roads were closer to the camera location than the survey route, only year and survey route were present in the top-ranked models (Table 3).

Road Bias

Distance to the closest paved road, but not distance to the survey route, was a significant factor in determining deer activity along the survey route at Antietam. Excluding all observations within 50 m of a road (whether survey route or peripheral road) reduced the sample size from 156 to 72 and 2 of the 3 top equivalent models predicting deer activity (e.g., photographs/camera-day) still contained the road covariate (Table 4).

For Catoctin, only the survey route had the potential to create a road bias, and there was no variation in habitat along the survey route. There are 2 options within DISTANCE to compensate for road bias related to the survey route itself, either deletion of observations closest to the road, referred to as left truncation, or expansion of the first distance interval to include deer that may have shifted away from the road. When we compared the density estimates and relative fit of the detection function within DISTANCE using both methods, we found expansion of the first distance interval to produce an estimate with a lower coefficient of variation and

Table 2. The importance of covariates for determining mean number of photographs/camera-day at 156 sample points in Antietam, Maryland, USA during autumn 2005 and 2006. We conducted a generalized linear model for all combinations of variables, including interaction terms, and ranked models according to Akaike's information criterion (AIC) values. We list the top 10 models and considered models with ΔAIC_c <2 of the top model to be equivalent (indicated with dashed line).

Model	K	AIC_c	ΔAIC_c	w_i
Habitat Road[a] Woods[b] Yr Month	14	504.17	0	0.219
Habitat Road Month	11	504.3	0.11	0.207
Habitat Road Survey[c] Yr Month	14	504.9	0.78	0.148
Habitat Road Woods Month	12	505.7	1.55	0.100
Habitat Road Woods Survey Yr Month	15	506.3	2.12	0.076
Habitat Survey Road Month	12	506.5	2.31	0.069
Habitat Survey Road Woods Month	13	507.8	3.60	0.036
Habitat Road Yr	9	509.5	5.34	0.015
Habitat Road	7	510.3	6.11	0.010
Habitat Road Woods Yr	10	510.3	6.15	0.010

[a] Distance from camera to closest road.
[b] Distance from camera to closest woods.
[c] Distance from camera to survey route.

Table 3. Model covariates for top-ranked generalized linear models predicting deer activity (photographs/camera-day) at 157 locations along the survey route in Catoctin National Park, Maryland, USA in autumn of 2005 and 2006. All models with ΔAIC_c <2 (Akaike's information criterion) of the top model are considered equivalent and indicated with dashed line.

Model	K	AIC_c	ΔAIC_c	w_i
Yr	4	517.82	0	0.377
Road[a] Yr	5	518.61	0.79	0.254
Null	2	520.51	2.69	0.098
Yr Month	8	520.63	2.81	0.093
Road	3	521.06	3.24	0.075
Road Yr Month	9	521.48	3.66	0.061
Month	6	523.35	5.53	0.024
Road Month	7	523.95	6.13	0.018

[a] Distance from survey road to camera location.

a lower AIC value than truncation of observation within the first 30 m (Table 5).

DISCUSSION

Within distance sampling protocols, there is the underlying assumption that a lower percentage of the deer will be detected at greater distances from the survey route (i.e., that the detection function decreases with increasing distance from the survey route; Buckland et al. 2001, Thomas et al. 2010). Our comparisons between deer detections during a road-based survey and deer activity via camera-trapping supports this assumption for a forested park (Catoctin), but does not support this assumption for a park within an agricultural setting (Antietam). The problem appears to be due to the lack of decline in the detection function within the open farmland and a bias due to both the survey route and nearby public roads.

Within both parks we observed lower deer activity within 20 m of the survey route; in Catoctin this effect was significant (Fig. 2). There are 2 general sources of road bias for deer surveys; attributes of the road itself and the position of the road within the landscape (Ward et al. 2004). The road itself can either repel animals due to disturbance (i.e., noise, human presence, passing vehicles) or attract animals due to roadside vegetation or use of minerals (i.e., salt). One mechanism within DISTANCE to compensate for this type of bias is through truncation of observations near the road following a post hoc examination of the data. A survey for pampas deer (*Ozotoceros bezoarticus*) in open grasslands of Brazil compared the distribution of deer detected along roads with deer detected on straight transect routes and found the results comparable, but only if the road survey was truncated to exclude sightings within 100 m of the road (Tomás et al. 2001). To compensate for road bias, Ward et al. (2004) compared a left truncated dataset to expanding the size of first distance interval of their survey data for a population of roe deer (*C. capreolus*) observed from roads and trails in the United Kingdom. They found a better fit to the detection function as a result of expanding the first distance interval beyond the trough observed in their close-to-road observations (20 m). Similar to Ward et al. (2004), we do not know the true density of the populations we are estimating but our results agree; that a density estimation with a lower confidence interval and AIC value can be obtained through either method, but preferably through expanding the size of the first distance interval. In our experience, DISTANCE is quite robust to adjustments in the width of distance categories, which produce very small differences (<5 deer/km^2) in density estimates. These results indicate road bias should be considered when planning deer surveys in suburban or exurban areas, but the bias can be adequately addressed within the program software.

With regards to the second source of road bias, roads and trails are rarely distributed randomly with respect to habitat or land use, and animal populations may be dispersed in conjunction with these features (Buckland et al. 2001, Hiby and Krishna 2001). There were noticeable differences in the distribution of roads within the 2 parks. In Catoctin, there is a low density of roads within the park, and the survey route follows the main paved road that traverses the park. Although there was no evidence of deer being unequally distributed relative to the road, the low density of roads and the short effective strip width meant that <6% of the park was surveyed. In Antietam, the survey route is not the only road within the park boundaries, the overall road density is much higher, and the survey route traverses both paved roads and agricultural fields. A higher portion of Antietam was covered in the survey (21%) due to both high road density and large effective strip widths, but our results indicate the distribution of these peripheral roads is influencing the distribution of deer.

Habitat also has a role in the distribution of deer at Antietam, as type of field influenced the number of deer detected at Antietam. Agricultural fields had more activity than fallow fields, apparently due to increased feeding by deer in these recently harvested fields. The detection of more deer within corn fields, as opposed to grass hay or fallow fields, reflects the clumped distribution of deer within the park. The importance of time (both month and yr) and habitat in determining the amount of deer photographed indicates

Table 4. Covariates for top-ranked generalized linear models for deer activity at 72 camera locations placed in 2005 along deer survey route in Antietam National Battlefield Park, Maryland, USA after exclusion of all sample points within 50 m of a road (either survey or peripheral). All models with ΔAIC_c <2 (Akaike's information criterion) of the top model were considered equivalent and indicated with dashed line.

Model	K	AIC_c	ΔAIC_c	w_i
Survey[a] Month	7	238.19	0	0.241
Road[b] Month	7	239.57	1.38	0.121
Habitat Survey Road Woods[c] Yr Month	15	241.17	2.98	0.054
Survey Road Woods Month	9	241.22	3.03	0.053
Survey Road Yr Month	10	241.36	3.17	0.049
Survey	3	241.56	3.37	0.044
Month	6	241.70	3.51	0.042
Survey Road	4	241.81	3.62	0.039
Road	3	242.05	3.86	0.035
Habitat Survey Month	11	242.61	4.42	0.026

[a] Distance from camera location to survey route.
[b] Distance from camera location to nearest road.
[c] Distance from camera location to nearest woods.

Table 5. Three alternative density estimates using DISTANCE 6.0 for a deer survey within Catoctin National Park, Maryland, USA in 2005. There were 86 groups of deer detected during the survey. The second (Left Truncation) and third (Increased First Distance Interval) alternatives were conducted to account for road bias introduced from using park roads as survey routes.

Model	Density estimate (deer/km^2) and CL	CV	Effective strip width (m)	Model AIC[a]
Standard[b]	23.89 (20.0–28.4)	0.089	63.4	539.8
Left truncated[c] (20 m)	33.15 (26.4–41.6)	0.114	41	440.0
Increased first distance interval (40 m)	24.18 (20.9–28.5)	0.078	61.3	159.1

[a] Akaike's information criterion.
[b] Right truncation of detections >80 m; best detection function selected based on AIC. Sample size after right truncation = 84 observations.
[c] Sample size after left truncation = 76 observations.

deer are mobile across the park in response to shifting resources. The detection function within DISTANCE is not heavily influenced by deer being clumped along the survey route; the issue is primarily with a clumped distribution relative to the survey route itself.

In our opinion, the ultimate cause of problems in estimating deer densities at Antietam is the marginal decline in observations with increasing distance from the survey route. These long sighting distances bring peripheral roads into consideration, lead to adoption of the uniform distribution for the detection function, and the lack of a tight fit for the density estimation model. The open habitat and complex road network around Antietam typifies other exurban areas, and the observers' ability to view deer at great distances from the survey route effectively transforms distance sampling into generalized spotlight counts, which have limited value to managers in accurately estimating the abundance of white-tailed deer populations (Anderson 2003, Collier et al. 2007). The observed 95% confidence interval for Antietam was higher than Catoctin, but it compared favorably with surveys conducted in other years, including years when the uniform–cosine model and the half-normal–hermite model were selected (S. Bates, personal communication). Antietam staff have compensated for long sighting distances by adjusting the distance intervals to obtain estimate models that meet program criteria. Compensating for this bias at Antietam may also be accomplished by adjusting the survey route, adjusting the time of the survey to later in the evening when traffic on the peripheral roads is lighter, and/or treating the survey as a strip transect. It may be possible to account for some of this variability within the DISTANCE 6.0 software. Marques et al. (2007) recommend adding environmental covariates to better model the detection function and reduce variance in bird point-counts using distance sampling; this can be done within the multicovariate option in DISTANCE 6.0. However, not all NPS protocols record sighting locations along the transect (Bates 2004), so it is not always possible to incorporate the site-specific covariates needed to account for road bias. A protocol modification at Antietam to include spatial data with each sighting would allow managers to use more of the analytical capacity within DISTANCE to improve the density estimations.

A second consideration for road-based surveys is the proportion of the area covered by the survey routes. National Park Service protocols consider 10% park coverage as adequate for distance sampling surveys of deer (Bates 2004). Whereas, the density of roads and long sighting distances in Antietam allows for a more extensive coverage of the park (approx. 21%), this degree of coverage was not possible using the roads of Catoctin (approx. 6%). As with many parks, the existing roads in Catoctin traverse the high-use areas where deer densities are of the most concern (e.g., campgrounds, visitor center), but extrapolating these densities across the entire park is not advisable. The proportion of area surveyed also has been considered to affect the precision of the density estimates (Cassey and McArdle 1999). However, although Catoctin has the second lowest proportion of land surveyed within NCR parks it also has the highest precision of the 10 parks annually surveyed from 2000 to 2010 (S. Bates, personal communication). The 10% area rule should be tested on a park-by-park basis.

MANAGEMENT IMPLICATIONS

It is possible for managers to obtain unbiased and reliable data using distance sampling from paved roads. Our results at Catoctin indicate that the distribution of observations during the distance survey match the assumptions based on the distribution of deer activity, and the road bias from the survey route can be compensated for within the capacity of the DISTANCE software. However, for this forested park, the short sighting distances and low road coverage make it unwise to extrapolate results much beyond the area covered by the survey. The fragmented landscape, complex road network, and increased sight distances found in Antietam National Battlefield Park may typify bias associated with distance sampling from paved roads in exurban areas that share similar characteristics. In areas with high visibility, such as the agricultural lands of Antietam, or developed areas where deer movement will be influenced by road density, density estimates based on distance sampling from roads and trails may be biased. We consider it prudent to use nonpublic roads and trails when possible, and including spatial data in all survey protocols. The more developed the landscape that encompasses the public land to be surveyed, the more difficulty will be encountered in selecting survey routes that are not biased by adjacent roads.

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