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Analysis of Night-Spotlighting Counts for White-tailed Deer

Indiana Dunes National Lakeshore, 1991-2006

Natural Resource Technical Report NPS/GLKN/NRTR—2011/424

ON THE COVER
White-tailed deer by Greg Thompson, U.S. Fish and Wildlife Service.

Analysis of Night-Spotlighting Counts for White-tailed Deer

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Abstract

We analyzed 13 years of night-spotlighting surveys for white-tailed deer (*Odocoileus virginianus*) conducted on the Indiana Dunes National Lakeshore (INDU). An approximately 30 km survey route was established in 1991 and was traversed for five nights in mid-February. Surveys were conducted in 1991, and then from 1995-2006. Data from 1992-93 could not be used. No survey was conducted in 1994. Perpendicular distances from the transect line of all detected deer were either estimated or measured using a hand-held laser-rangefinder. Deer density was calculated using the distance sampling methodology, which combines three independent variance components: detection probability, encounter rate, and cluster size. Because road segments often divided two different Deer Management Units (DMUs), we adapted density formulations to accommodate one- and two-sided transects (i.e., road segments). Deer density was estimated for 10 DMUs across INDU. The highest deer density (>77 deer/km^2) was recorded in the Beverly Shores DMU during 2000. In 2006, deer densities across INDU ranged from about 19 deer/km^2 to just under 58 deer/km^2. An analysis of effective strip half-widths (ESWs) showed that nearly two-thirds of all deer go undetected during surveys, and the probability of detection varies substantially among DMUs and sometimes from one side of the road segment to the other. Estimating perpendicular distance works fine in DMUs with ESWs ≤50m, but where long-range detections are possible, distances are invariably underestimated and sometimes substantially. Improved definition of what constitutes a deer cluster seems to have resulted in lower variation in that component. Precision around estimated density is variable, owing mostly to low effort (roadway driven) in some DMUs. More survey replication or additional road segments are required to increase precision. Specific recommendations for improving the deer population monitoring protocol are discussed.

Acknowledgments

We would like to thank the Natural Resources Management staff of Indiana Dunes National Lakeshore for giving us the opportunity to assist in their deer monitoring program. We are especially grateful to Sarah Nystrom, who assisted with data auditing and analysis. Thanks to Dr. Erik Beever, Quantitative Ecologist, National Park Service Inventory and Monitoring Program, Great Lakes Network, for facilitating the agreement and this analysis and also for his helpful comments. As always, any omissions or mistakes are ours exclusively.

Introduction

Concern over burgeoning deer populations has spread widely due to direct and indirect linkages to human health and safety (Conover et al. 1995). For example, it is common knowledge that deer change the composition and structure of forest communities (Cote et al. 2004), play an important role in the transmission of Lyme disease (Jones et al. 1998), cause thousands of automobile collisions (Romin and Bissonette 1996), and eat millions of dollars of cultivated vegetation and agricultural crops annually (Curtis and Richmond 1994). Counts of deer (in all their manifestations) along a pre-defined route have long been used successfully to monitor deer population abundance (Progulske and Duerre 1964; Sage et al. 1983), and many National Parks and other natural areas are engaged in some type of deer population monitoring. Night-spotlighting along a designated survey route is the most commonly used method we have encountered for a couple of reasons. First, it is simple. Utilizing a high intensity spotlight (>100,000 c.p.), observers count deer at night by capitalizing on the species' crepuscular nature and highly reflective eyes. Thus relatively high encounter rates and high probabilities of detection are nearly guaranteed. Second, the method is relatively inexpensive. One or two people can conduct a count from a motorized vehicle at minimal cost. Spotlighting deer at night is not without its problems, however (McCullough 1982). Primary among them is that detection is assumed to be perfect within the illumination range of the light. Under typical conditions, rarely is this assumption met (Begier 1996). Further, it has long been recognized that conducting counts of wildlife from roads can lead to biased estimates of abundance. While probability of detection can be addressed by adopting methods such as distance sampling, biased counts are more difficult (if not impossible) to remedy.

In applications with large (>100 km^2) spatial extent, the variation in encounter rate due to specific factors that affect detection of deer is homogenized. At smaller spatial extents, however, factors affecting the detection process become more important to an accurate assessment of abundance. The widespread adoption of distance sampling has emerged due to an explicit acknowledgment of the role that detectability plays in good population abundance surveys. The goal of this project was to construct an unambiguous time series of deer population abundance by Deer Management Unit (DMU). Our specific objectives were to:

1) Analyze 13 years of night-spotlighting counts of deer for density estimation;
2) Determine the impact of estimated vs. measured perpendicular distances on ESW;
3) Explore the effects of a new cluster size determination criterion on variation in density estimates;
4) Model temporal encounter rate (i.e., *n/L*) variation by DMU and develop specific recommendations for a full implementation of the distance sampling method for INDU.

Study Area

The Indiana Dunes National Lakeshore (INDU) occupies more than 5600 ha along the southern shore of Lake Michigan (Figure 1). The park was established by Congress and included in the National Park System in 1966 to preserve, maintain, and restore the integrity and character of the natural resources and processes; to protect cultural resource values at the lakeshore; and to provide educational, inspirational, and recreational opportunities compatible with preserving natural and cultural resource values. INDU contains exceptional biological diversity and outstanding floral richness, resulting from the combination of complex geological processes and the convergence of several major North American life zones. Its uniqueness as a natural area was recognized by pioneers of the nascent study of ecology, and its importance in an increasingly urbanized setting was punctuated by a special issue of the Natural Areas Journal (Vol. 19, No. 2) published in 1999. Recreational use of INDU is high, and its proximity to residential, commercial, and industrial areas increases the likelihood of natural resource conflicts. The variety of land cover-types, along a gradient of urban to agricultural, provides excellent habitat for white-tailed deer.

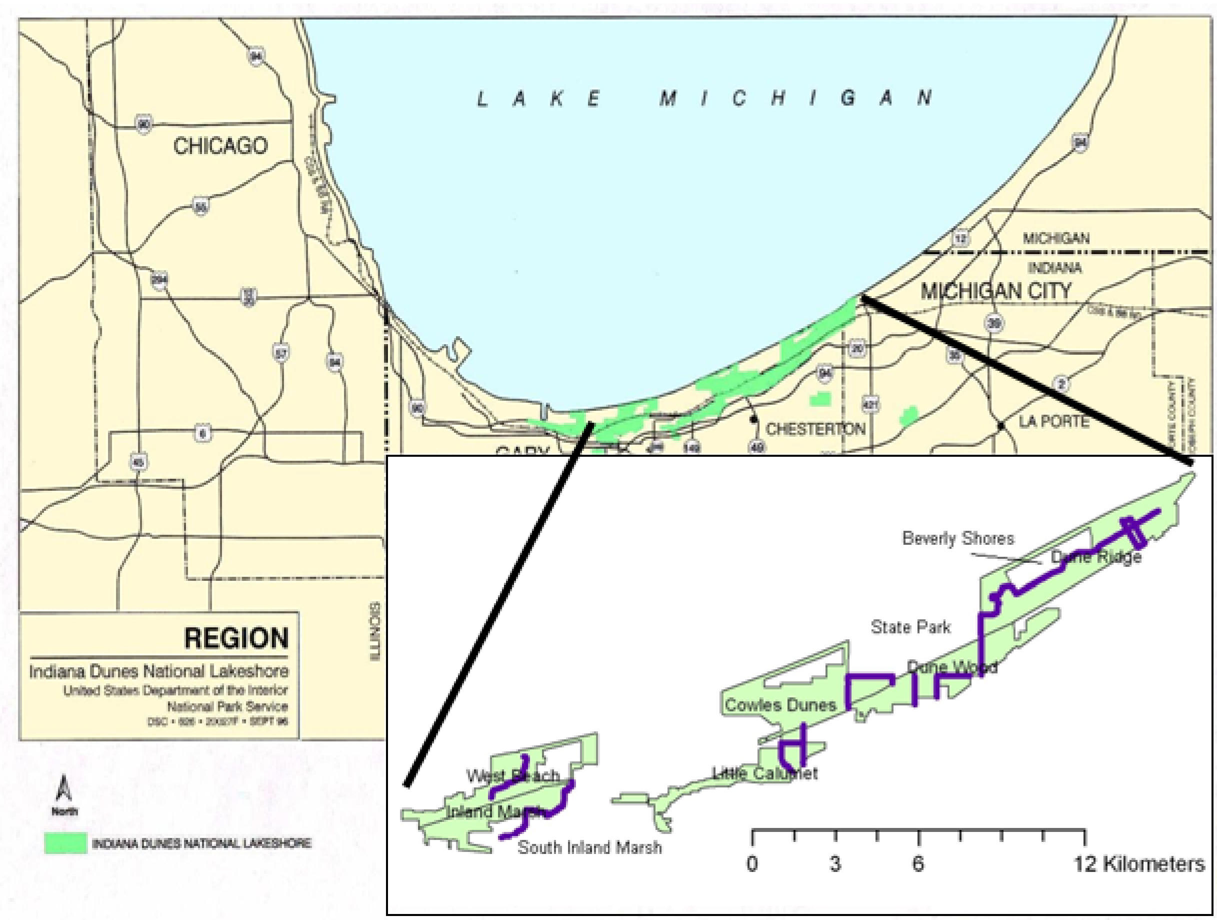

Figure 1. Map of Indiana Dunes National Lakeshore (INDU) along the southern basin of Lake Michigan. The main night-spotlighting route is shown as a bold line in the inset figure.

Surveys of white-tailed deer abundance were initiated at INDU in 1991. A route along nearly 30 km of roadway was established throughout the National Lakeshore, and with few exceptions has been utilized ever since. Counts of deer along this route, made on five successive occasions during the month of February in each year, constituted a survey. The route includes many land cover-types ranging from agricultural to lightly developed, municipal jurisdictions, private and public lands, forested and open environments. In addition, very often the route bisects public and private lands such that one side of the road is National Lakeshore while the other is in different ownership. For that reason primarily, estimates of deer abundance are desired for each jurisdiction, effectively creating one-sided transects. Although the distance sampling theory permits the analysis of one-sided transects (Buckland et al. 2001, Section 7.9.3), very little guidance for application is currently available (but see Underwood et al. 2003). The primary concerns with one-sided transects are that the animal's position relative to the transect line is determined reliably and that movement prior to detection is relatively minor (Buckland et al. 2001). For roadside surveys of deer, reliable placement relative to the center of the road is generally not an issue in our experience, and movement prior to detection can be diagnosed and remediated *ex post facto*.

Methods

Background

Distance sampling is not new to the field of wildlife biology and management (Burnham et al. 1980). However, only recently has a rigorous theoretical basis been formulated and tested for estimating the abundance of wildlife populations (Buckland et al. 1993). Conceptually, the method is straightforward. From a sample of perpendicular distances between the objects of interest and a line transect, a mathematical function is generated which describes how detection of objects changes with increasing distance from the transect centerline. From this function, the effective area around the transect from which objects are counted can be computed. Density is computed as the number of objects encountered divided by the effective area sampled. Distance sampling theory allows for the fact that some objects, except those on the transect centerline, will not be detected. It is, at first, a counterintuitive notion that an accurate estimate of density can be computed when approximately one-third to one-half of the objects go undetected. These concepts are depicted graphically in Figure 2.

Panel A shows the idealized situation where detection declines smoothly as a function of perpendicular distance from the transect. In panel B, the area under the curve represents the proportion of objects detected while the area above the curve represents its complement. The vertical line extending to the X-axis at the inflection of this curve indicates the *effective strip half-width* **(**ESW), or that distance where the proportion of objects missed closer to the transect is equal to the proportion detected at greater distances. Note that objects detected further than the ESW inform us about objects missed closer than the ESW. A series of robust estimators have been formulated to calculate animal density efficiently from a modest sample of perpendicular distances. The formula for density ($\hat{D}$) is (Buckland et al. 2001, Section 3.6.1):

$$\hat{D} = \frac{n * \hat{f}(0) * \bar{s}}{2L}$$ Equation 1.

The first component in the formula above is *n*, the number of objects encountered. Because deer are moderately social animals, the group (hereafter, cluster) is typically considered the object of interest because the detection probability for the second and remaining individuals in the cluster is not the same as for the first individual detected. When *L*, the line length, is included, the quantity *n/L* is the encounter rate. In general, encounter rate contributes most to the overall variation in estimated density. The second component is the mean cluster size (i.e., $\bar{s}$), or the average number of deer in each cluster encountered. Cluster size variation often contributes up to about 25% of the total variance in deer density. Finally, the third component is the probability density (g(x)) evaluated at perpendicular distance of zero. In Equation 1, it is shown as $\hat{f}(0)$; its inverse is ESW. Detection probability contributes least to overall density variation in deer surveys in our experience; it is the only variance component that can be effectively improved through analysis. All components are measured directly from observations of deer sampled along line transects.

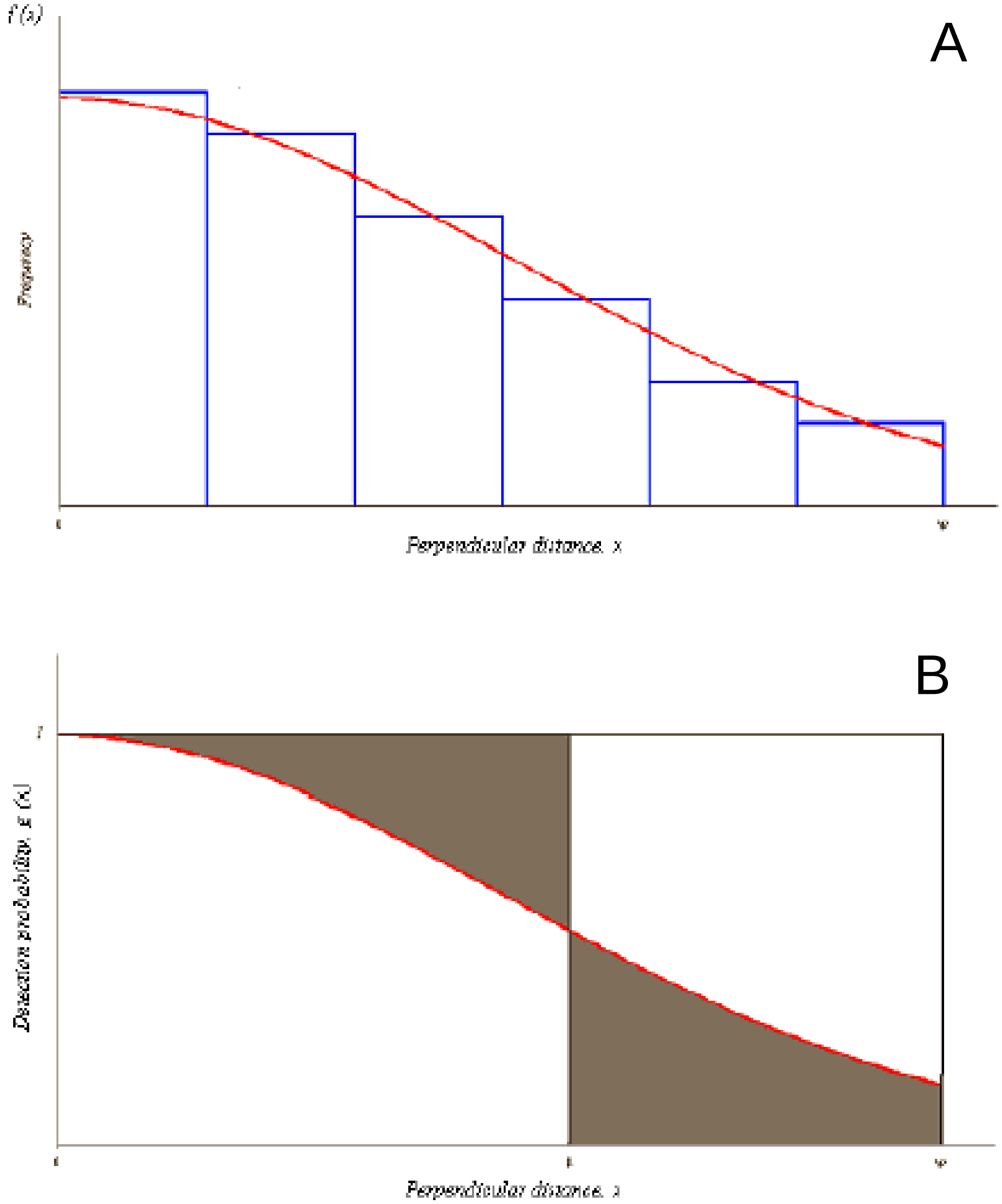

Figure 2. Hypothetical frequency distribution (A) of perpendicular distances, and modeled detection function (B). Quadrants of the same color surrounding the inflection point of the red line show equal proportions.

Several properties of distance data are crucial for reliable density estimation. First, enough objects need to be observed to describe adequately the probability of detection as a function of perpendicular distance from the transect. In general, the more objects observed, the smoother the representation of the detection function. Second, transect length must be sufficient to achieve a desired level of precision. To ensure unbiased counts, samplers (road segments in this case) must be laid out at random relative to animal population distribution.

Data Quality and Consistency

To complete all objectives successfully, we implemented a five-step process to ensure data quality and consistency prior to statistical analyses. Using meta-data accompanying the raw database, we audited 13 years of data (1991, 1995-2006) to resolve several issues related to units of measure and specific non-conforming observations. Second, we made adjustments to road segment lengths as necessary when the route was modified to accommodate construction and other activities. Third, we annexed the database with zero counts for dates when no deer were observed, yet effort was expended, to account properly for variation in encounter rates. Fourth, we coded new variables into the dataset to distinguish estimated distances from those measured with a hand-held laser-rangefinder, to identify one- and two-sided transects (i.e., road segments) within each DMU, and to demarcate years when a new cluster size criterion was implemented. Finally, we purposefully excluded the 1992 and 1993 surveys because the data structure for those years departed greatly from the protocol established in 1991. In addition, maps of surveys for those two years were unavailable to confirm the exact route. No survey was conducted in 1994.

Density Estimation

Estimating density ($\hat{D}$) for each DMU required that one-sided and two-sided road segments (i.e., transects) be analyzed separately, then combined into one composite density estimate for each year. Equation 1 obviously applies to two-sided transects as the area calculation (i.e., denominator 2*L*) explicitly includes both sides. For one-sided transects, the formula is:

$$\hat{D} = \frac{n * \hat{f}(0) * \bar{s}}{L} \qquad \text{Equation 2.}$$

Because the software does not permit mixing of one- and two-sided transects, density must be computed from each type of transect in a spreadsheet (Appendix A). Similarly, the variance must also be composited from the coefficients of variation of each modeled component. The computation for three variance components, where *cv* stands for coefficient of variation of the estimator, is as follows (Buckland et al. 2001, Section 4.8.1):

$$\widehat{\text{var}}(\hat{D}) = \hat{D}^2 \bullet \{[cv(n)]^2 + [cv\{\hat{f}(0)\}]^2 + [cv(\bar{s})]^2\} \qquad \text{Equation 3.}$$

Finally, 95% log-based confidence intervals were constructed around each density estimate as outlined in Section 3.6.1 of Buckland et al. (2001). In this case, we used Satterthwaite’s method of approximating degrees of freedom of the t-distribution. This formulation is more complicated but coverage is more realistic than the standard normal distribution. For three variance components, the Satterthwaite formula for degrees of freedom (*df*) is (Buckland et al. 2001, Section 4.8.1):

$$df = \frac{[cv(\hat{D})]^4}{[cv(n)]^4/(k-1) + [cv\{\hat{f}(0)\}]^4/(n-p) + [cv(\bar{s})]^4/(n-1)}, \qquad \text{Equation 4.}$$

where n = the number of detections, k = the number of samples, and p = the number of parameters used in the estimation of $\hat{f}(0)$. Finally, for DMUs with both one-sided and two-sided transects, densities were estimated separately, then averaged by weighting each estimate by its respective total length of transect according to the approach outlined in Section 3.7.1 in Buckland et al. (2001). Log-based confidence intervals for the overall DMU density estimate were constructed similarly except that we used the Satterthwaite approximation for a sum in computing the degrees of freedom (Buckland et al. 2001, Section 3.7.1). In the frequent case where a road segment density was zero, the weighted mean was computed as usual, but the associated components for variance and degrees of freedom were dropped from the formula.

Modeling Detection Functions

Obviously, an important process in the distance sampling protocol is the estimation of the probability of detection and associated ESW, which requires modeling of the perpendicular distances measured to the objects of interest — clusters of deer in this case. The model is a mathematical function, or Key Function, with desirable properties that make it ideally suited for distance data (Burnham et al. 1980; Buckland et al. 2001; Figure 3). While detection functions are assumed to be monotonic (or nearly so), they can exhibit bumps and humps corresponding to differences in terrain and other factors in the environment that affect the probability of detection. These variations can be accommodated in the modeling process by the addition of Series Expansions, which are a series of cosines or polynomials that are fit to the data. The equation for most detection functions modeled without covariates looks like (Buckland et al. 2001, Section 2.4):

$$\tilde{f} = key(x)[1 + series(x)], \qquad \text{Equation 5.}$$

where $f(x) = \tilde{f}$ rescaled so that it integrates to a value of one, and x is the perpendicular distance. Modeling of detection functions is most easily accomplished using what is now the standard software package for such tasks, PROGRAM DISTANCE (Thomas et al. 2005). The software facilitates multi-model inference using Akaike’s Information Criterion (AIC; Burnham and Anderson 2002) and the processing of myriad command lines and selections through its graphical user-interface. In all cases, we invoked the software to compare the Uniform, Half-Normal, and Hazard Rate Key Functions paired with either simple cosine or polynomial Series Expansions. Interventions during the modeling process were kept to a minimum. Most often, we set the number of intervals and/or the maximum distance interval. Least often, we made minor adjustments to interval cut-points and adjustment terms.

Detection Probability, Encounter Rate, and Cluster Size

We chose to model deer cluster detection probability on both one-sided and two-sided transects using only data collected since 1999 because distances from that year onward were measured using a hand-held laser-rangefinder. The implicit assumption is that detection probability, and hence, the ESW, have not changed appreciably along road segments of each DMU over time.

Key Function	*Series Expansion*
Uniform, $1/w$	Cosine, $\sum_{j=1}^{m} a_j \cos(j\pi x/w)$
Uniform, $1/w$	Simple Polynomial, $\sum_{j=1}^{m} a_j (x/w)^{2j}$
Half Normal, $\exp(-x^2/2\sigma^2)$	Cosine, $\sum_{j=2}^{m} a_j \cos(j\pi x/w)$
Half Normal, $\exp(-x^2/2\sigma^2)$	Hermite Polynomial, $\sum_{j=2}^{m} a_j H_{2j}(x/\sigma)$
Hazard-rate, $1-\exp(-(x/\sigma)^{-b})$	Cosine, $\sum_{j=2}^{m} a_j \cos(j\pi x/w)$
Hazard-rate, $1-\exp(-(x/\sigma)^{-b})$	Simple Polynomial, $\sum_{j=2}^{m} a_j (x/w)^{2j}$

Figure 3. Key functions and series expansions for modeling probability of detection from a set of perpendicular distances.

We estimated encounter rate (i.e., *n/L*) and cluster size (i.e., $\bar{s}$), along with their variances, using the Conventional Distance Sampling (CDS) analysis engine in PROGAM DISTANCE (Version 5.0 Beta 5, Thomas et al. 2005).

For Objective 2, we assessed the effect of measuring distances with a hand-held laser-rangefinder on estimates of ESW for each DMU by modeling the effect as a binary, factor covariate in the Multiple Covariates Distance Sampling (MCDS) engine. Only the Half-Normal and Hazard Rate Key Functions with simple cosines or polynomial series expansions were evaluated. Our primary concern was the detection of any serious bias introduced into the ESW by estimating distances.

To understand the impact of adopting a different cluster size definition in 2002 (and beyond), we computed summary statistics for cluster size by DMU and year. We used the standard deviation (SD) of cluster size in each DMU by year as the focus of our analysis. Because there is often a functional dependence of the variance (i.e., SD^2) on the mean in ecological data (Taylor 1961; Ballantyne and Kerkhoff 2007), cluster size variation might be expected to change independently of the new criterion as mean cluster size increases or decreases with population abundance.

To confirm and remove the functional dependence of the variance on the mean, we regressed the SD of each year's cluster size by DMU on the corresponding mean cluster size. We then subjected the residuals to a two-way analysis of variance with DMU nested within year, and a binary variable indicating years when the new criterion was in effect, as sources of variation. A clue to an effect of the new cluster size criterion would be a consistent pattern in the residual cluster size before and after the implementation year. Generally, greater definition tends to reduce variation and we hypothesized such an effect for INDU.

We modeled the temporal dispersion in encounter rate (i.e., *n/L*) for both one-sided and two-sided road segments within each DMU to provide some parsimony for making future survey recommendations. Deer clusters are most often encountered in the habitats that are either highly suitable or exhibit the highest detection probabilities; many road segments often have zero encounters. Even in high-density herds, encounters with deer along roadsides from night-to-night are highly variable, no doubt a reflection of true dispersion and considerable sampling variation. Buckland et al. (1993) maintain that dispersion is quite stable and can be modeled, thereby reducing the number of parameters needing estimation in temporally repeated surveys on the same area. For each DMU and road segment, the $V = 5$ counts were used to estimate the variance in the number of deer clusters encountered during a survey using the following formula (Buckland et al. 1993, Section 6.3.2):

$$\hat{\text{var}}(n_v) = L_v \frac{\sum_{i=1}^{k_v} l_{vi}\left[\frac{n_{vi}}{l_{vi}} - \frac{n_v}{L_v}\right]^2}{k_v - 1}, \qquad \text{Equation 6.}$$

where $L_v = \sum l_{vi}$, and $\hat{b}_v = \frac{\hat{\text{var}}(n_v)}{n_v}$.

An overall estimate of the dispersion parameter, $\hat{b}$, for each DMU can be made by computing a grand mean of $\hat{b}_v$ weighted by n_v. This was accomplished in an analysis of variance with the effects of road segment nested within DMU, weighted by n_v. All statistical analyses were performed using SAS version 9.1 (SAS Institute, Cary, NC).

We estimated dispersion parameters (i.e., $\hat{b}$) for DMUs to explore the impacts of variable precision around estimated density on: 1) line length requirements, 2) confidence limits, and 3) minimum detectable effect sizes. We conducted simple z-tests for differences in dispersion between pairs of DMUs. Line length requirements for each DMU were computed using estimated dispersion parameters ($\hat{b}$), encounter rates (*n/L*), and a desired coefficient of variation (*cv*) and equation 7.1 on page 242 of Buckland et al. (2001). Transect line length requirements for each DMU were compared to the current allocation of effort to detail where improvements in survey design could be made. We also created a spreadsheet to permit the exploration of the choice of precision *(cv)* and Type I error rate (α) on the detection of meaningful differences in deer density between DMUs. For non-significant ($p > 0.05$) differences in deer density, the minimum detectable effect size (i.e., D_1/D_2) was arbitrarily set to 5x.

Results

Of the 10 DMUs analyzed, six included one-sided transects, one included one- and two-sided transects, and three included only two-sided transects (Appendix A). For example, the Dune Ridge DMU contained 12.3 km of road segments, 36% of which included one-sided transects. Compositing transects generally increased precision in estimated density, depending upon the total length of transect in the DMU. In the Dune Ridge DMU, for example, the average CV across years decreased by 81% through the compositing process; all other DMUs experienced less dramatic increases in precision, however. Trends in deer density varied substantially by DMU and over time (Figure 4). The Beverly Shores DMU exhibited the largest range in estimated point densities (approximately 19 – 77 deer/km^2). The best precision was achieved in the Dune Ridge DMU and the worst was in the DMUs bordering Indiana Dunes State Park.

Estimated ESWs ranged from just under 50 m to over 300 m (Figure 5). Fifty meters was a common ESW throughout most of the forested areas of the study site. Effective strip half-widths were generally similar on DMU boundary road segments with a few exceptions. West Derby Avenue which divides the Beverly Shores and Dune Ridge DMUs, Stage Coach Road which separates the Inland Marsh from South Inland Marsh DMUs, and South State Park Road which divides the Cowles Dune and State Park Cowles Dune DMUs are segments that exhibited differences in ESW from one side of the road to the other. On average, nearly two-thirds of all deer escaped detection (Figure 5). The lowest estimated probability of detection was approximately 20%, while the highest was 60%. The most striking difference in ESW and probability of detection across the road segment was exhibited on Stage Coach Road, which is bounded on one side by forested dunes and on the other by a large, flat agricultural field (Figure 6).

For most of the DMUs we analyzed, there was little effect of estimated distances on the computation of ESW (Figure 7). For those DMUs where long-range detections predominated (e.g., South Inland Marsh), however, there was a strong tendency to underestimate the actual distance to deer clusters, sometimes by 50% or more (Figure 8).

There was a strong ($r^2 = 0.7$) and significant ($p < 0.0001$, df = 107) relationship between cluster size variation (i.e., SD) and mean cluster size (Figure 9). While there was a tendency for the magnitude of residual cluster size to decrease after implementation of the new cluster size criterion in several DMUs (Figure 10), only the South Inland Marsh DMU was suggestive ($p = 0.13$).

Estimates of dispersion across the five nights of surveys were remarkably consistent and precise for the predominantly forested DMUs (Figure 11). The Dune Ridge, Inland Marsh, South Inland Marsh, and West Beach DMUs all yielded parameter estimates of >1.0, indicating a moderate to high degree of over-dispersion. At least six additional nights of surveys are needed to achieve a CV of 30% around estimated DMU deer densities (excluding the State Park Cowles Dune and West Beach DMUs; Table 1). A CV of 0.3 yields lower and upper confidence limits that are 32% and 46% of the mean density at $\alpha = 0.05$ (Table 2). In addition to surveying more nights, higher precision can also be attained by using a more liberal Type I error rate (e.g., $\alpha = 0.10$).

High precision (i.e., CV = 10%) allows a distinction between deer densities differing by as little as 1.5x up to 27 deer/km^2 (= 70 deer/mi^2; Figure 12). As precision is eroded, however, minimum detectable effect size increases, and the upper limit of detectable deer density decreases.

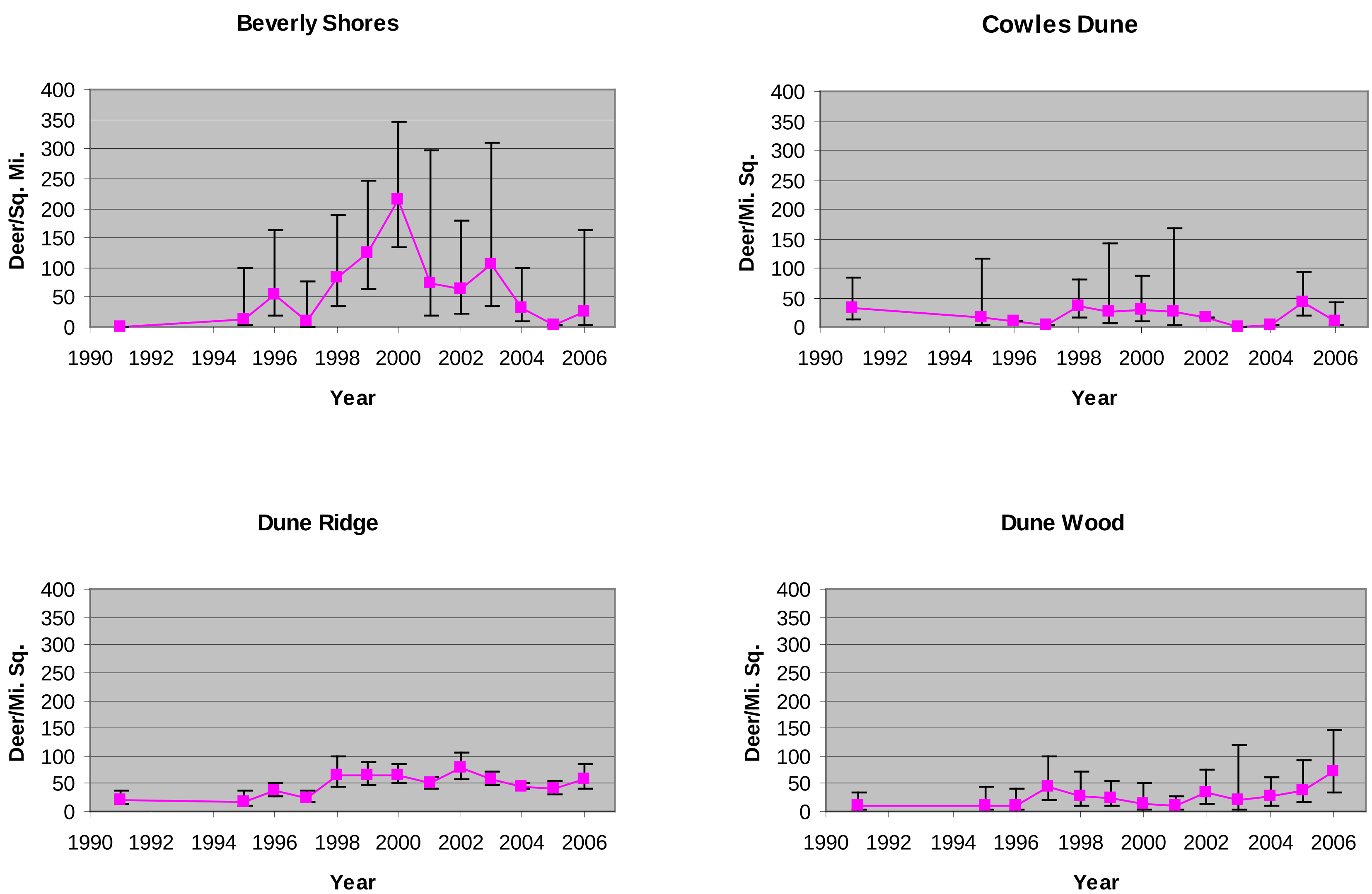

Figure 4. White-tailed deer density (No./mi^2) estimated from a sample of perpendicular distances along roadways of ten Deer Management Units (DMUs) at Indiana Dunes National Lakeshore, 1991, 1995-2006.

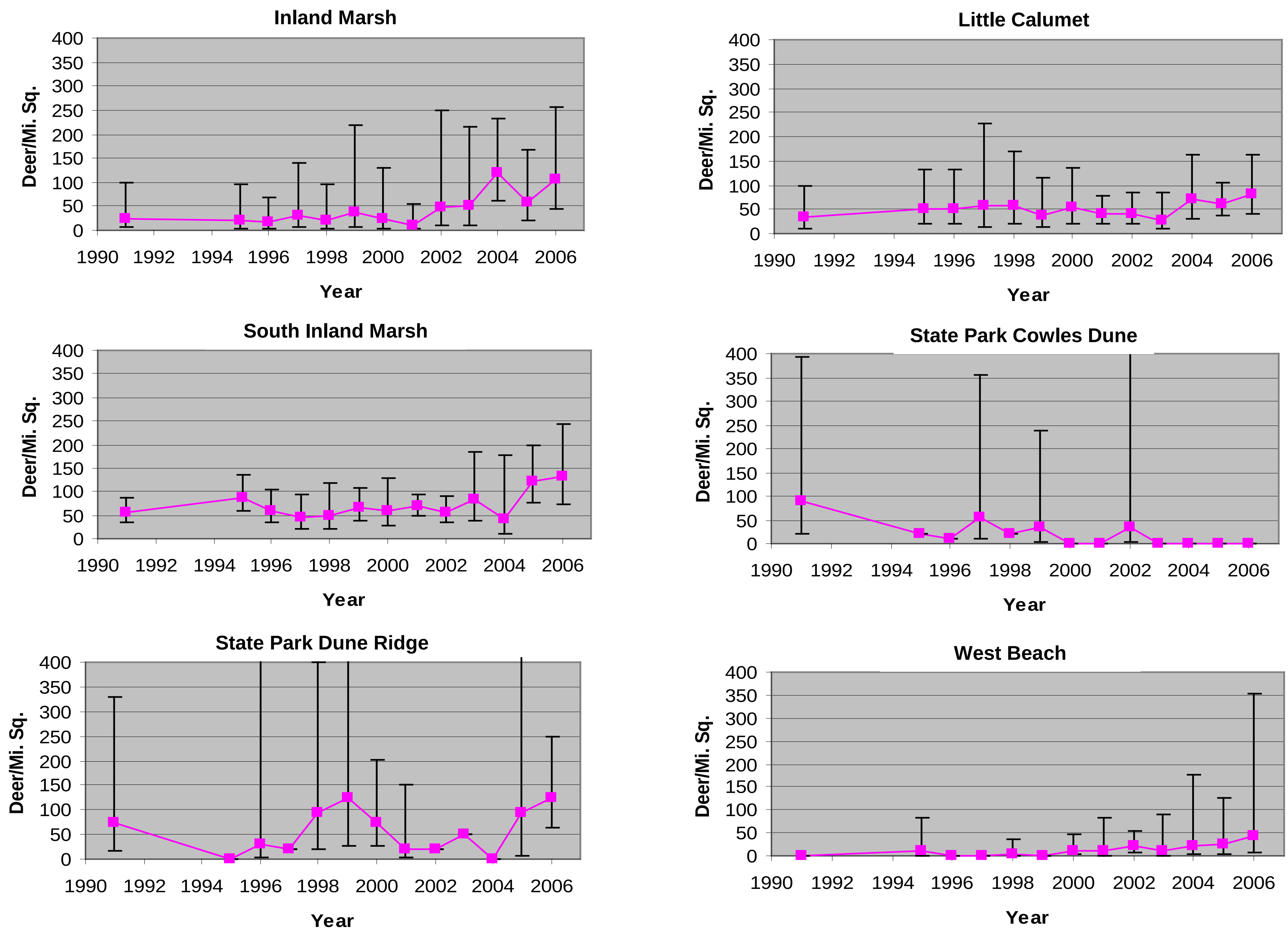

Figure 4. White-tailed deer density (No./mi^2) estimated from a sample of perpendicular distances along roadways of ten Deer Management Units (DMUs) at Indiana Dunes National Lakeshore, 1991, 1995-2006 (continued).

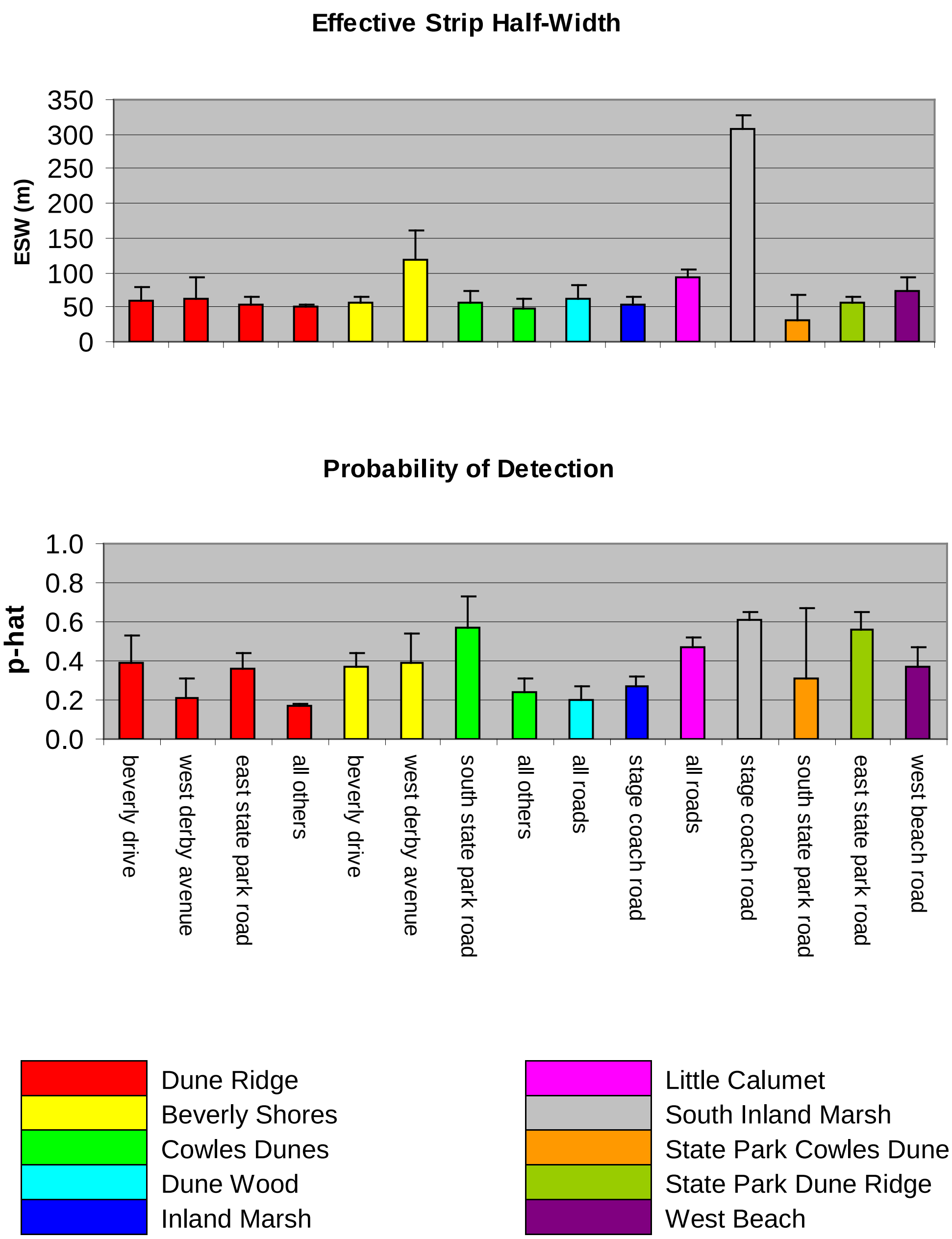

Figure 5. Estimated effective strip half-widths (ESWs) and probabilities of detection for ten Deer Management Units (DMUs) at Indiana Dunes National Lakeshore. Only data collected using a hand-held laser-rangefinder were used to compute ESWs. Each bar represents an individual road segment, while the bar color corresponds to a DMU.

Figure 6. A stark example of how effective strip half-width (ESW) can vary from one side of the road to the other. Stage Coach Road separates the Inland Marsh and South Inland Marsh Deer Management Units, Indiana Dunes National Lakeshore.

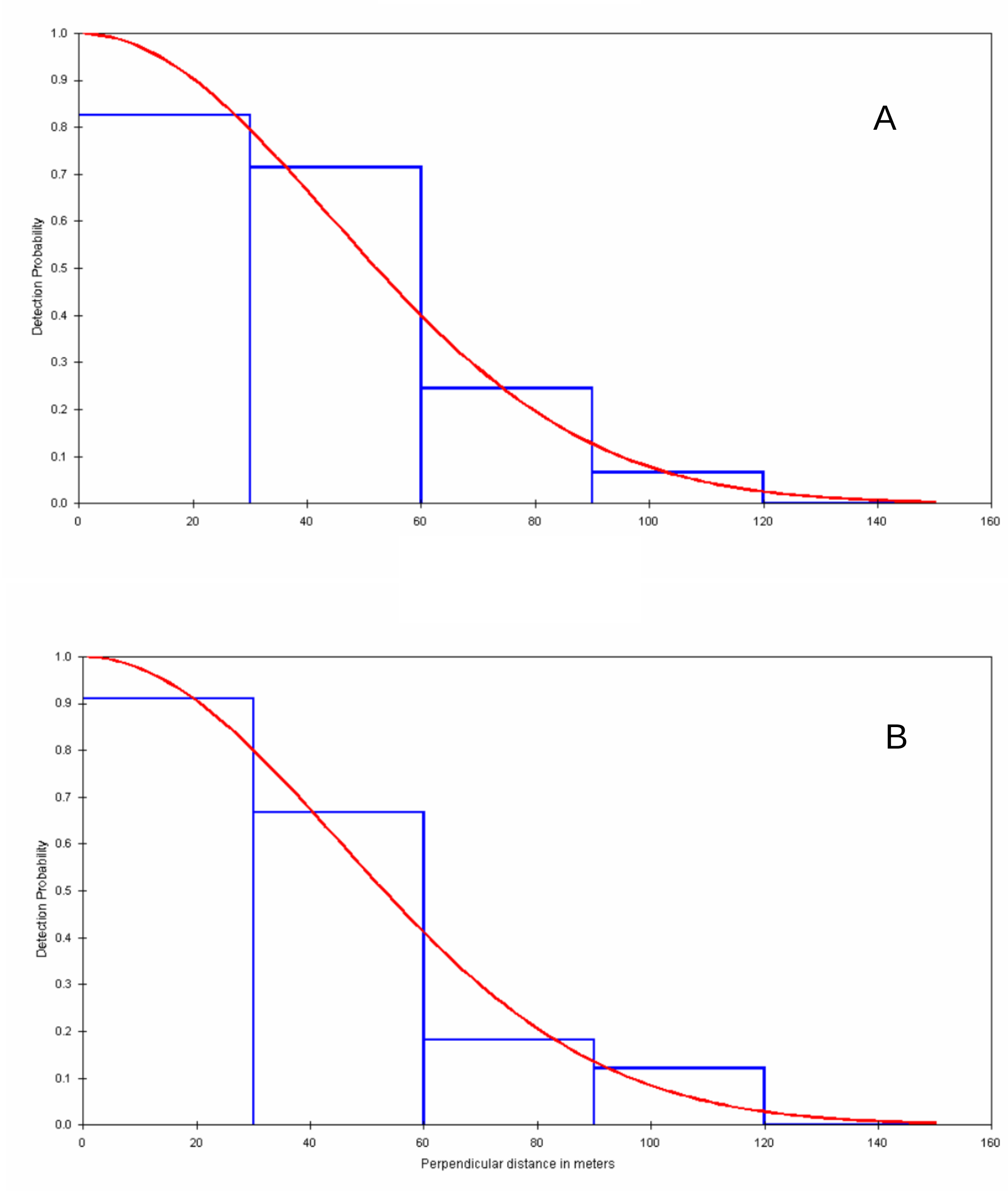

Figure 7. Effect of measured (Panel A) versus estimated (Panel B) perpendicular distances on the effective strip half-width for the Beverly Shores Deer Management Unit, Indiana Dunes National Lakeshore.

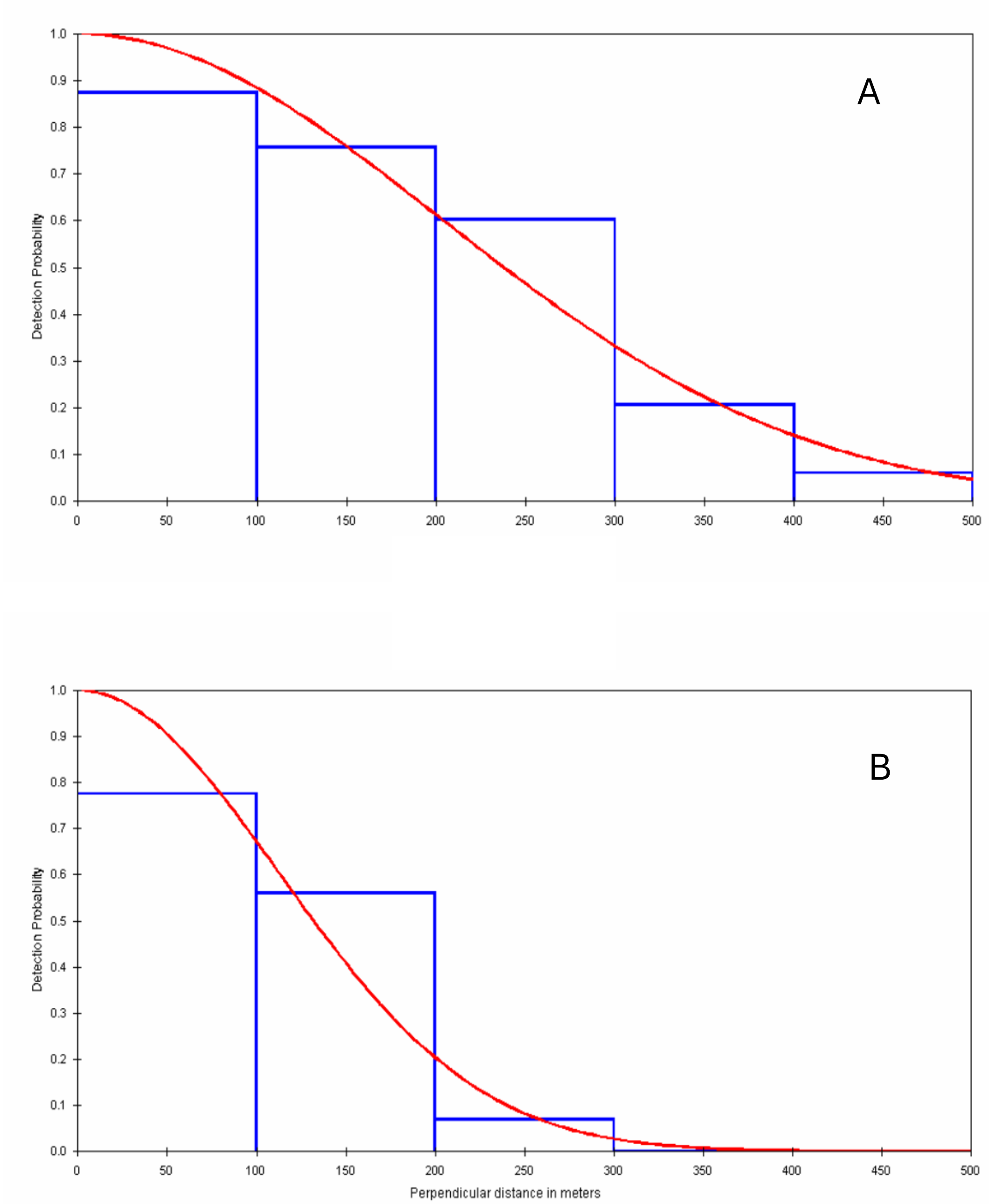

Figure 8. Effect of measured (Panel A) versus estimated (Panel B) perpendicular distances on the effective strip half-width for the South Inland Marsh Deer Management Unit, Indiana Dunes National Lakeshore.

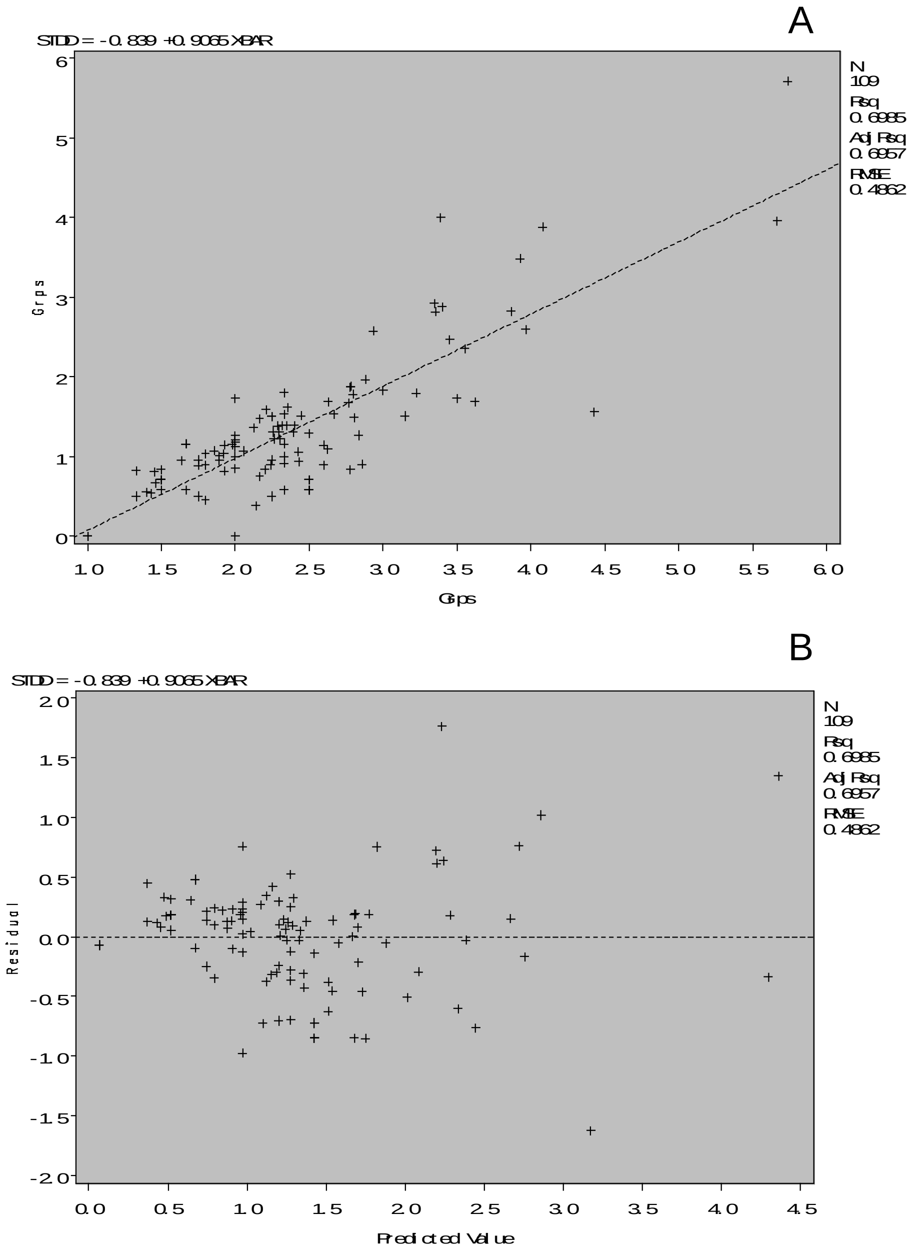

Figure 9. Regression plot of standard deviation (STDD) of cluster size (Grps) on mean cluster size (Panel A), and residual on predicted cluster size (Panel B), for night-spotlighting counts of white-tailed deer at Indiana Dunes National Lakeshore, 1991, 1995-2006.

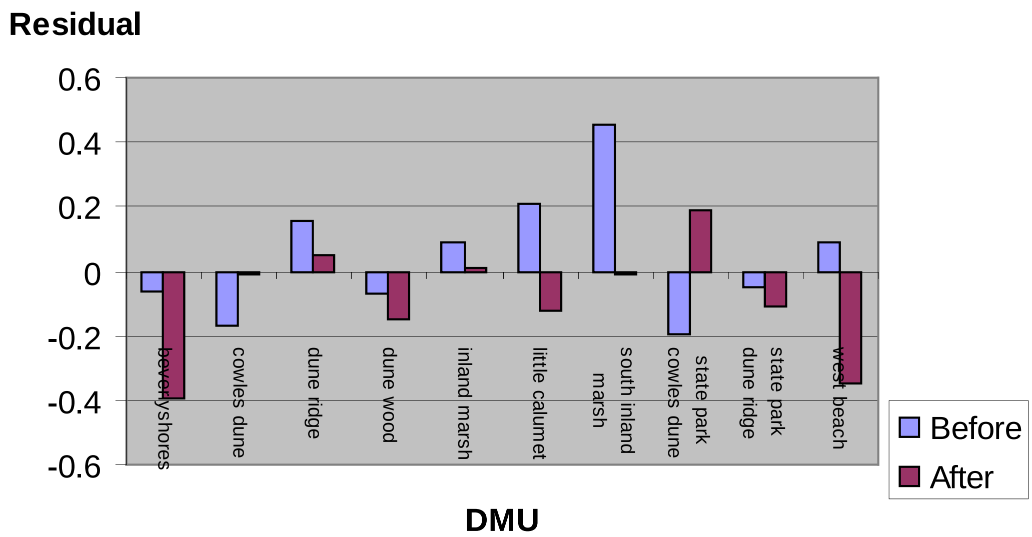

Figure 10. Residual cluster size by Deer Management Unit (DMU) before (1991, 1995-2001) and after (2002-2006) the implementation of a new cluster size criterion, Indiana Dunes National Lakeshore.

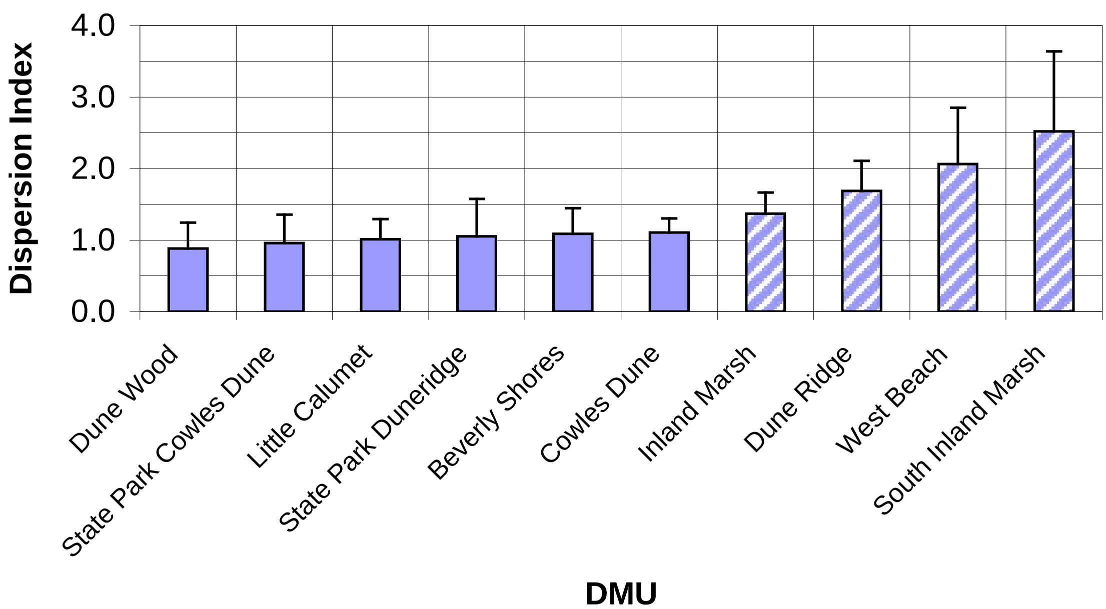

Figure 11. Temporal dispersion parameter estimates (+2SE) computed from five nights in each Deer Management Unit (DMU), Indiana Dunes National Lakeshore, 1991, 1995-2006. Cross-hatched bars indicate temporal dispersion significantly different from unity.

Table 1. Current and required road segment lengths (km) calculated from estimates of encounter rate and dispersion by DMU, Indiana Dunes National Lakeshore, 1999-2006.

DMU	$\hat{b}$ [1]	n/L	Required[2]	Inflation[3]	Current[4]	Difference	Per Survey	Nights[5]
Dune Wood	0.88	0.55	15.7	19.6	22.0	-2.4	4.4	0.0
State Park Cowles Dune	0.96	0.12	85.0	106.3	7.5	98.8	1.5	65.9
Little Calumet	1.01	1.29	8.8	11.0	16.5	-5.5	3.3	0.0
State Park Dune Ridge	1.05	0.65	18.9	23.7	4.5	19.2	0.9	21.3
Beverly Shores	1.09	0.60	21.8	27.3	17.5	9.8	3.5	2.8
Cowles Dune	1.10	0.35	38.8	48.4	14.0	34.4	2.8	12.3
Inland Marsh	1.37	0.40	51.9	64.9	21.0	43.9	4.2	10.4
Dune Ridge	1.69	0.69	45.9	57.3	61.5	-4.2	12.3	0.0
West Beach	2.06	0.29	163.2	204.0	12.0	192.0	2.3	83.5
South Inland Marsh	2.52	2.63	26.8	33.5	21.0	12.5	4.2	3.0

[1] dispersion parameter
[2] required length (km) of road segments to achieve an arbitrary CV = 0.30
[3] a 25% upward adjustment to account for cluster size variation (Buckland et al. 1993)
[4] current allocation of effort (km) in the DMU
[5] additional number of count occasions to accommodate required effort allocation

Table 2. Lower and upper confidence limits expressed as a percentage of estimated deer density for five levels of precision (CV) and two Type I error rates (α).

		CV				
	α	0.1	0.2	0.3	0.4	0.5
Lower CL	0.05	12	23	32	39	46
	0.10	10	20	28	35	41
Upper CL	0.05	14	29	46	64	84
	0.10	12	25	38	53	69

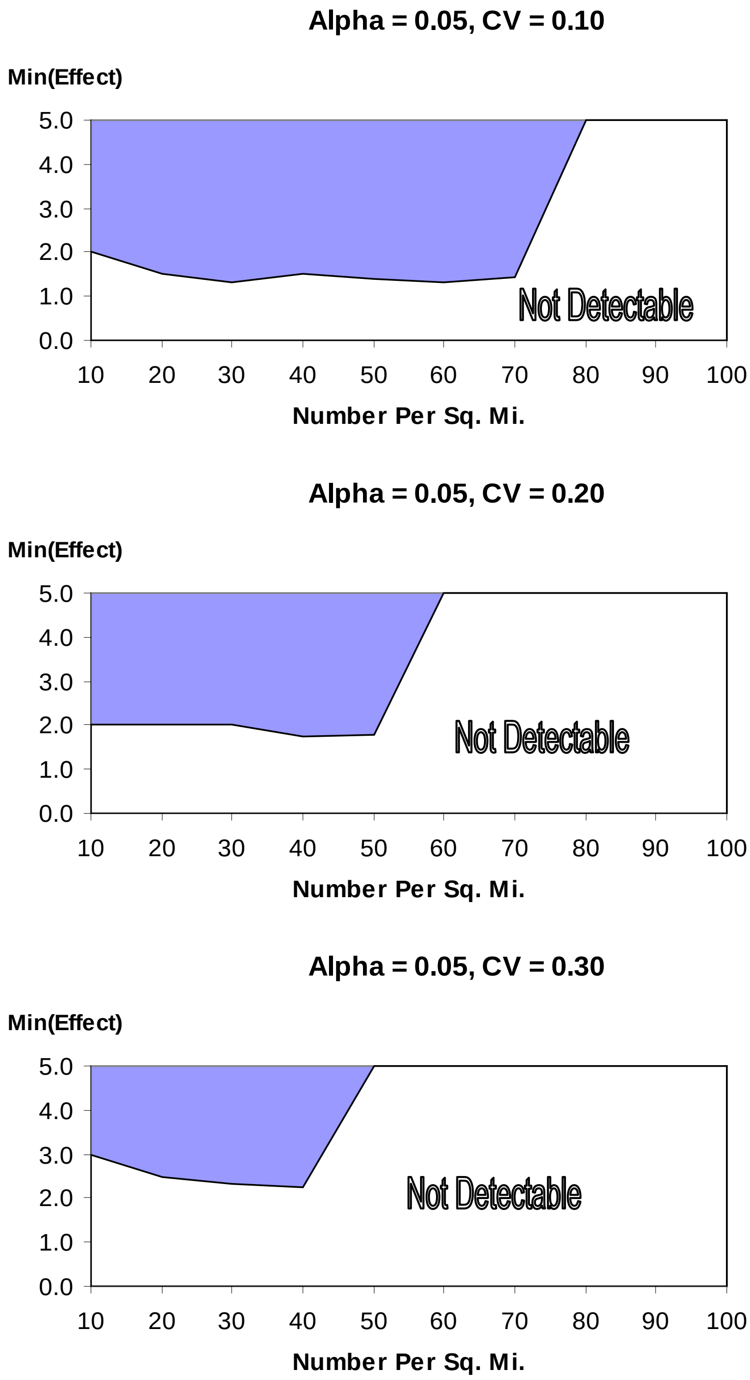

Figure 12. Minimum detectable effect size (shaded area) for a Type I error rate of α = 0.05 and three levels of precision. The effect size is measured as the ratio of D1, the density of deer in area 1, to D2, the density of deer in area 2, expressed as a multiple of D1. Examples are based on night-spotlighting counts of white-tailed deer along roadways in and around Indiana Dunes National Lakeshore, 1991, 1995-2006.

Discussion

The ability to adapt the formulation for density to accommodate one-sided transects is clearly advantageous in places like INDU and other natural areas where stark differences in land use and land cover may occur between jurisdictions and from one side of the road to the other. A major disadvantage is that variance components must be estimated separately and then composited into an overall density, a task greatly facilitated by electronic spreadsheets (Appendix B). We found PROGRAM DISTANCE effective for estimating DMU variance components by taking advantage of the STATS file created at runtime. We pasted results directly into an opened Microsoft Excel spreadsheet. The filtering feature of Microsoft Excel, combined with the STATS file legend, greatly facilitated compilation of the necessary variance components prior to the final estimation of deer density.

By choosing to model detection probabilities from data collected from 1999-2006, we assumed that associated ESWs would not show a great deal of variation from one year to the next. It certainly could be argued that variation in ESW exists within a year due to seasonal changes in vegetation, which may obstruct visibility and conceal deer (Begier 1996). Because deer surveys at INDU were conducted at about the same week every year, we feel fairly comfortable that visibility obstruction due to seasonal vegetation changes was not important. Changes in vegetation through succession that could affect ESW, however, are distinctly possible. The fact that nearly all the ESWs were estimated with high precision (Figure 5) suggests that temporal variation, if present, is not overwhelming. The most important finding was that only 20-60% of deer within the effective area counted were detected, which underscores the danger of comparing raw counts between DMU pairs.

Our analysis revealed a bias in modeled ESW resulting from the ocular estimation of perpendicular distances in areas where long-range detections were common (Figure 8). The tendency is to substantially underestimate distances furthest from the transect. One of us has documented the same bias on another unit of the National Park Service (Underwood 1998). Because estimated and measured distances were not recorded contemporaneously, we could not produce appropriate correction factors for years when distances were not measured. Fortunately, the bias was not evident throughout most DMUs of INDU.

A more serious problem occurred where road segments served as boundaries between two very different land-cover types or physiographic zones. In these cases, recording detections as if both sides of the road were similar would obviously inflate the variance in detection probability, thus reducing the precision around key parameters (i.e., $\hat{f}(0)$, ESW, and $\hat{p}$). This phenomenon occurred on only a couple of road segments (e.g., Figure 6), and was effectively dealt with by the analysis of one-sided transects.

Within the variability of the data, we found no significant implications of the adoption in 2002 of a new cluster size definition criterion. The new criterion came about through consultation with one of us; it uses tripartite criteria, based on published studies of deer behavior, for determining cluster size: behavioral, social, and nearest-neighbor (Underwood et al. 1998). Six of 10 DMUs exhibited reductions in cluster size variation (with the effect of mean cluster size removed) after the implementation year, as we predicted (Figure 10), though none was statistically significant.

Two DMUs (i.e., Beverly Shores and West Beach) exhibited substantial increases in cluster size variation after the implementation year. A more detailed examination of the cluster size dataset, especially with respect to herd composition, might reveal why these DMUs departed from expectation. For example, variance would increase using a new definition that tended to include >1 deer as an identifiable group.

Though our analysis has demonstrated that one- and two-sided transects can be accommodated in deer surveys, the precision attained in most of the DMUs is lackluster (Figure 4). Low precision has implications for management, particularly if adjacent DMUs might be managed to different deer densities. Our analysis shows that at a realized precision of 30% (i.e., CV = 0.3), deer densities would have to differ by at least a factor of 2x to be statistically distinguishable (Figure 12). For example, a DMU with a deer density of 35 deer/km^2 could not be distinguished from one with 19 deer/km^2 at this level of precision. Moreover, in DMUs with 19 deer/km^2 or more, it is unlikely that any statistical distinction is possible given the current level of survey effort. Notice that doubling of precision does not translate to a doubling of effort; a fourfold increase in effort is a more likely expectation.

Overall, precision around estimated density is affected by the temporal dispersion of detections across the five nights of sampling, the encounter rate (i.e., n/L) which is primarily a function of deer activity, and overall length (km) of transect allocated to each DMU. Because dispersion and encounter rate are not within the direct control of the biologist (i.e., at least in the absence of herd reduction), the allocation of effort is the only reasonable way of attaining greater precision. Increased allocation of effort can occur by increasing the number of road segments surveyed in a DMU, or by increasing the number of nights surveyed. The former is more desirable than the latter, though we recognize that it is also the least practicable way. We believe that, in general, precision should be no lower than 30% (i.e., CV = 0.3) to keep confidence limits within 50% of the mean density. Clearly though, the desired level of precision will be dictated by the resolution of management, so we hesitate to make a specific recommendation here.

Alternatively, we believe much greater parsimony, and ultimately precision, can be achieved through careful stratification of the data set. For example, our analysis demonstrated that 50 m is a common ESW throughout much of the survey route. In addition, six of the 10 DMUs exhibit temporal dispersion parameters that are essentially identical. Using methods similar to those we have adopted, a stratified density estimate that incorporates both independently estimated components and shared components could be derived (see Section 3.7.1, Buckland et al. 2001).

Much has been written about the problems with conducting wildlife surveys from roads, most of which we will not repeat here. Wildlife can be either attracted to or repelled from roadsides. With respect to distance sampling, the primary problem with conducting wildlife surveys from roads is that the transect is not selected independently of the animal population distribution (Marques 2007). We are concerned with how the animal population is distributed only as it relates to the allocation of transects. For example, consider a gradient of animal density across a study area. Naively locating transects perpendicular to the gradient would cause a violation of the availability proportional to area (APTA) condition, and seriously bias estimates of animal density or abundance; transects located parallel to the gradient would cause no such bias (Buckland et al. 2001). Rarely do we have such knowledge beforehand with which to design wildlife surveys. Consequently, our only defense against violating the APTA condition is to ensure some degree of randomness in the allocation of transects.

The APTA condition is valid on average over a large number of design realizations, and is more likely to be met from a larger allocation of transects than a smaller allocation, over multiple survey periods rather than just one, etc. Even a completely randomized allocation of transects can lead to severely biased density estimates, depending on the particular placement relative to the distribution of animals in the study area. Conversely, an unbiased survey design could be constructed on average from a single transect over many realizations (e.g., multiple survey periods). The allocation of multiple transects is a hedge against a violation of APTA, thus giving us greater confidence in our single design realization. This is currently an area of intensive investigation, and more work is needed to explore the effects of sampling intensity and seasonal habitat utilization. We intend to pursue these two issues at a later time.

Recommendations

Based on our analyses, we offer several recommendations for improving the deer population monitoring protocol in INDU:

1) *Identify a coefficient of variation (CV) appropriate to the resolution required for management*. This may be accomplished by first choosing an effect size and sensitivity needed to evaluate potential management actions, and then backtracking through Figures 11-12 and Table 1 to arrive at an appropriate CV value. The choice of CV and the Type I error rate will directly affect the level of survey effort. We encourage the use of the attached spreadsheet for this exercise.

2) *Eliminate DMUs or road segments for which an increased allocation of effort is not possible, either through temporal replication or augmented transect length.* We suggest the DMUs adjacent to the State Park might be a place to start. Alternatively, a coordinated survey conducted in the State Park would probably be more useful. The West Beach DMU is problematic due to the lack of access; however, it is an important site to monitor because of an apparent emerging trend in deer density in that location. Temporal replication in this DMU might be beneficial in terms of increasing precision.

3) *Add an additional week of night-spotlighting counts to gain an immediate increase in precision around estimated density.* A re-allocation of Student Conservation Association interns and/or the use of volunteer deer counters may help to accomplish this task.

4) *Conduct a stratified analysis of deer density that incorporates variance components that are estimated independently as well as shared among DMUs.* This will require technical expertise in the theory and formulation of stratified density estimates.

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Appendix A. Component statistics for white-tailed deer surveys by DMU, Indiana Dunes National Lakeshore.

DMU	Segment	Length (km)	f(0)[1]	cv[2]	m[3]	Year	n/L[4]	cv	s-bar[5]	cv	n[6]	k[7]	L[8]
Beverly Shores	**Beverly Drive (1-sided)**	**2.8**	**0.0180**	**0.0823**	**1**	**1991**	**0.2857**	**0.4677**	**1.5000**	**0.1925**	**4**	**5**	**14.0**
Beverly Shores	Beverly Drive (1-sided)	3.2	0.0180	0.0823	1	1995	0.1875	0.6667	1.6667	0.2000	3	5	16.0
Beverly Shores	Beverly Drive (1-sided)	3.2	0.0180	0.0823	1	1996	0.5625	0.3239	2.3333	0.2575	9	5	16.0
Beverly Shores	Beverly Drive (1-sided)	3.2	0.0180	0.0823	1	1997	0.1250	0.6124	2.0000	0.0000	2	5	16.0
Beverly Shores	Beverly Drive (1-sided)	3.2	0.0180	0.0823	1	1998	0.8125	0.2609	2.3077	0.1727	13	5	16.0
Beverly Shores	Beverly Drive (1-sided)	3.2	0.0180	0.0823	1	1999	0.8750	0.2082	3.2143	0.1669	14	5	16.0
Beverly Shores	Beverly Drive (1-sided)	3.2	0.0180	0.0823	1	2000	1.6250	0.0720	2.8846	0.1076	26	5	16.0
Beverly Shores	Beverly Drive (1-sided)	3.2	0.0180	0.0823	1	2001	0.7500	0.4290	2.3333	0.1429	12	5	16.0
Beverly Shores	Beverly Drive (1-sided)	3.2	0.0180	0.0823	1	2002	0.5000	0.3187	2.8750	0.1026	8	5	16.0
Beverly Shores	Beverly Drive (1-sided)	3.2	0.0180	0.0823	1	2003	0.8125	0.4142	2.9231	0.0905	13	5	16.0
Beverly Shores	Beverly Drive (1-sided)	3.2	0.0180	0.0823	1	2004	0.3125	0.3162	2.2000	0.3340	5	5	16.0
Beverly Shores	Beverly Drive (1-sided)	3.2	0.0180	0.0823	1	2005	0.0000	0.0000	2.6000	0.1538	0	5	16.0
Beverly Shores	Beverly Drive (1-sided)	3.2	0.0180	0.0823	1	2006	0.3125	0.5477	2.0000	0.0000	5	5	16.0
Beverly Shores	West Derby Avenue (1-sided)	0.3	0.0084	0.1462	1	1991	0.0000	0.0000	1.0000	0.0000	0	5	1.5
Beverly Shores	West Derby Avenue (1-sided)	0.3	0.0084	0.1462	1	1995	0.0000	0.0000	1.0000	0.0000	0	5	1.5
Beverly Shores	West Derby Avenue (1-sided)	0.3	0.0084	0.1462	1	1996	0.0000	0.0000	1.0000	0.0000	0	5	1.5
Beverly Shores	West Derby Avenue (1-sided)	0.3	0.0084	0.1462	1	1997	0.0000	0.0000	1.0000	0.0000	0	5	1.5
Beverly Shores	West Derby Avenue (1-sided)	0.3	0.0084	0.1462	1	1998	0.6667	1.0000	2.0000	0.0000	1	5	1.5
Beverly Shores	West Derby Avenue (1-sided)	0.3	0.0084	0.1462	1	1999	2.0000	0.6667	1.3333	0.2500	3	5	1.5
Beverly Shores	West Derby Avenue (1-sided)	0.3	0.0084	0.1462	1	2000	3.3333	0.6325	2.4000	0.1667	5	5	1.5
Beverly Shores	West Derby Avenue (1-sided)	0.3	0.0084	0.1462	1	2001	0.0000	0.0000	1.0000	0.0000	0	5	1.5
Beverly Shores	West Derby Avenue (1-sided)	0.3	0.0084	0.1462	1	2002	0.6667	1.0000	2.0000	0.0000	1	5	1.5
Beverly Shores	West Derby Avenue (1-sided)	0.3	0.0084	0.1462	1	2003	2.0000	1.0000	1.3333	0.2500	3	5	1.5
Beverly Shores	West Derby Avenue (1-sided)	0.3	0.0084	0.1462	1	2004	0.6667	1.0000	2.0000	0.0000	1	5	1.5
Beverly Shores	West Derby Avenue (1-sided)	0.3	0.0084	0.1462	1	2005	0.6667	1.0000	2.0000	0.0000	1	5	1.5
Beverly Shores	West Derby Avenue (1-sided)	0.3	0.0084	0.1462	1	2006	0.0000	0.0000	1.0000	0.0000	0	5	1.5
Cowles Dune	**South State Park Road (1-sided)**	**1.5**	**0.0175**	**0.1102**	**1**	**1991**	**0.4000**	**0.4082**	**1.6667**	**0.4000**	**3**	**5**	**7.5**
Cowles Dune	South State Park Road (1-sided)	1.5	0.0175	0.1102	1	1995	0.1333	1.0000	2.0000	0.0000	1	5	7.5
Cowles Dune	South State Park Road (1-sided)	1.5	0.0175	0.1102	1	1996	0.0000	0.0000	1.0000	0.0000	0	5	7.5

Appendix A. Component statistics for white-tailed deer surveys by DMU, Indiana Dunes National Lakeshore (continued).

DMU	Segment	Length (km)	f(0)	cv	m	Year	n/L	cv	s-bar	cv	n	k	L
Cowles Dune	South State Park Road (1-sided)	1.5	0.0175	0.1102	1	1997	0.1333	1.0000	1.0000	0.0000	1	5	7.5
Cowles Dune	South State Park Road (1-sided)	1.5	0.0175	0.1102	1	1998	0.0000	0.0000	1.0000	0.0000	0	5	7.5
Cowles Dune	South State Park Road (1-sided)	1.5	0.0175	0.1102	1	1999	0.5333	0.7289	1.5000	0.1925	4	5	7.5
Cowles Dune	South State Park Road (1-sided)	1.5	0.0175	0.1102	1	2000	0.1333	1.0000	2.0000	0.0000	1	5	7.5
Cowles Dune	South State Park Road (1-sided)	1.5	0.0175	0.1102	1	2001	0.4000	0.6667	2.0000	0.2887	3	5	7.5
Cowles Dune	South State Park Road (1-sided)	1.5	0.0175	0.1102	1	2002	0.1333	1.0000	2.0000	0.0000	1	5	7.5
Cowles Dune	South State Park Road (1-sided)	1.5	0.0175	0.1102	1	2003	0.0000	0.0000	1.0000	0.0000	0	5	7.5
Cowles Dune	South State Park Road (1-sided)	1.5	0.0175	0.1102	1	2004	0.0000	0.0000	1.0000	0.0000	0	5	7.5
Cowles Dune	South State Park Road (1-sided)	1.5	0.0175	0.1102	1	2005	0.2667	0.6124	2.5000	0.2000	2	5	7.5
Cowles Dune	South State Park Road (1-sided)	1.5	0.0175	0.1102	1	2006	0.0000	0.0000	1.0000	0.0000	0	5	7.5
Cowles Dune	All Others (2-sided)	1.3	0.0209	0.1256	2	1991	0.7692	0.4216	1.8000	0.2079	5	5	6.5
Cowles Dune	All Others (2-sided)	1.3	0.0209	0.1256	2	1995	0.4615	1.2517	1.6667	0.2000	3	5	6.5
Cowles Dune	All Others (2-sided)	1.3	0.0209	0.1256	2	1996	0.3077	0.4660	2.5000	0.2000	2	5	6.5
Cowles Dune	All Others (2-sided)	1.3	0.0209	0.1256	2	1997	0.0000	0.0000	1.0000	0.0000	0	5	6.5
Cowles Dune	All Others (2-sided)	1.3	0.0209	0.1256	2	1998	2.0000	0.2710	1.4615	0.1253	13	5	6.5
Cowles Dune	All Others (2-sided)	1.3	0.0209	0.1256	2	1999	0.4615	0.3282	1.3333	0.2500	3	5	6.5
Cowles Dune	All Others (2-sided)	1.3	0.0209	0.1256	2	2000	0.6154	0.4660	2.7500	0.2288	4	5	6.5
Cowles Dune	All Others (2-sided)	1.3	0.0209	0.1256	2	2001	0.1538	1.8708	3.0000	0.0000	1	5	6.5
Cowles Dune	All Others (2-sided)	1.3	0.0209	0.1256	2	2002	0.3077	0.4660	2.5000	0.2000	2	5	6.5
Cowles Dune	All Others (2-sided)	1.3	0.0209	0.1256	2	2003	0.0000	0.0000	1.0000	0.0000	0	5	6.5
Cowles Dune	All Others (2-sided)	1.3	0.0209	0.1256	2	2004	0.3077	0.4660	1.0000	0.0000	2	5	6.5
Cowles Dune	All Others (2-sided)	1.3	0.0209	0.1256	2	2005	1.2308	0.2712	1.6250	0.2308	8	5	6.5
Cowles Dune	All Others (2-sided)	1.3	0.0209	0.1256	2	2006	0.4615	0.3282	1.6667	0.4000	3	5	6.5
Dune Ridge	**Beverly Drive (1-sided)**	**2.8**	**0.0172**	**0.1549**	**2**	**1991**	**0.2857**	**0.4677**	**1.0000**	**0.0000**	**4**	**5**	**14.0**
Dune Ridge	Beverly Drive (1-sided)	3.2	0.0172	0.1549	2	1995	0.2500	0.7289	1.7500	0.2736	4	5	16.0
Dune Ridge	Beverly Drive (1-sided)	3.2	0.0172	0.1549	2	1996	0.1875	0.6667	2.3333	0.2857	3	5	16.0
Dune Ridge	Beverly Drive (1-sided)	3.2	0.0172	0.1549	2	1997	0.1250	1.0000	2.0000	0.5000	2	5	16.0
Dune Ridge	Beverly Drive (1-sided)	3.2	0.0172	0.1549	2	1998	1.0000	0.3878	1.8125	0.1256	16	5	16.0
Dune Ridge	Beverly Drive (1-sided)	3.2	0.0172	0.1549	2	1999	0.5000	0.3187	2.3750	0.1939	8	5	16.0
Dune Ridge	Beverly Drive (1-sided)	3.2	0.0172	0.1549	2	2000	0.4375	0.4845	1.5714	0.1892	7	5	16.0
Dune Ridge	Beverly Drive (1-sided)	3.2	0.0172	0.1549	2	2001	0.4375	0.3642	1.7143	0.2097	7	5	16.0
Dune Ridge	Beverly Drive (1-sided)	3.2	0.0172	0.1549	2	2002	0.1875	0.4082	2.3333	0.3780	3	5	16.0

Appendix A. Component statistics for white-tailed deer surveys by DMU, Indiana Dunes National Lakeshore (continued).

DMU	Segment	Length (km)	f(0)	cv	m	Year	n/L	cv	s-bar	cv	n	k	L
Dune Ridge	Beverly Drive (1-sided)	3.2	0.0172	0.1549	2	2003	0.1250	0.6124	2.5000	0.2000	2	5	16.0
Dune Ridge	Beverly Drive (1-sided)	3.2	0.0172	0.1549	2	2004	0.0625	1.0000	1.0000	0.0000	1	5	16.0
Dune Ridge	Beverly Drive (1-sided)	3.2	0.0172	0.1549	2	2005	0.2500	1.0000	1.2500	0.2000	4	5	16.0
Dune Ridge	Beverly Drive (1-sided)	3.2	0.0172	0.1549	2	2006	0.1875	0.6667	2.0000	0.2887	3	5	16.0
Dune Ridge	East State Park Road (1-sided)	0.9	0.0187	0.1011	1	1991	0.6667	0.6667	2.0000	0.2887	3	5	4.5
Dune Ridge	East State Park Road (1-sided)	0.9	0.0187	0.1011	1	1995	0.2222	1.0000	2.0000	0.0000	1	5	4.5
Dune Ridge	East State Park Road (1-sided)	0.9	0.0187	0.1011	1	1996	0.0000	0.0000	1.0000	0.0000	0	5	4.5
Dune Ridge	East State Park Road (1-sided)	0.9	0.0187	0.1011	1	1997	0.2222	1.0000	1.0000	0.0000	1	5	4.5
Dune Ridge	East State Park Road (1-sided)	0.9	0.0187	0.1011	1	1998	0.0000	0.0000	1.0000	0.0000	0	5	4.5
Dune Ridge	East State Park Road (1-sided)	0.9	0.0187	0.1011	1	1999	0.2222	1.0000	1.0000	0.0000	1	5	4.5
Dune Ridge	East State Park Road (1-sided)	0.9	0.0187	0.1011	1	2000	1.1111	0.5477	2.0000	0.2236	5	5	4.5
Dune Ridge	East State Park Road (1-sided)	0.9	0.0187	0.1011	1	2001	0.8889	0.2500	1.7500	0.2736	4	5	4.5
Dune Ridge	East State Park Road (1-sided)	0.9	0.0187	0.1011	1	2002	1.7778	0.3750	2.8750	0.1533	8	5	4.5
Dune Ridge	East State Park Road (1-sided)	0.9	0.0187	0.1011	1	2003	0.2222	1.0000	2.0000	0.0000	1	5	4.5
Dune Ridge	East State Park Road (1-sided)	0.9	0.0187	0.1011	1	2004	0.0000	0.0000	1.0000	0.0000	0	5	4.5
Dune Ridge	East State Park Road (1-sided)	0.9	0.0187	0.1011	1	2005	0.4444	0.6124	1.5000	0.3333	2	5	4.5
Dune Ridge	East State Park Road (1-sided)	0.9	0.0187	0.1011	1	2006	1.7778	0.3187	2.3750	0.2096	8	5	4.5
Dune Ridge	West Derby Avenue (1-sided)	0.3	0.0161	0.1904	1	1991	0.6667	1.0000	3.0000	0.0000	1	5	1.5
Dune Ridge	West Derby Avenue (1-sided)	0.3	0.0161	0.1904	1	1995	0.6667	1.0000	1.0000	0.0000	1	5	1.5
Dune Ridge	West Derby Avenue (1-sided)	0.3	0.0161	0.1904	1	1996	0.6667	1.0000	1.0000	0.0000	1	5	1.5
Dune Ridge	West Derby Avenue (1-sided)	0.3	0.0161	0.1904	1	1997	0.0000	0.0000	1.0000	0.0000	0	5	1.5
Dune Ridge	West Derby Avenue (1-sided)	0.3	0.0161	0.1904	1	1998	0.6667	1.0000	1.0000	0.0000	1	5	1.5
Dune Ridge	West Derby Avenue (1-sided)	0.3	0.0161	0.1904	1	1999	2.0000	0.6667	2.6667	0.3307	3	5	1.5
Dune Ridge	West Derby Avenue (1-sided)	0.3	0.0161	0.1904	1	2000	2.0000	0.6667	1.0000	0.0000	3	5	1.5
Dune Ridge	West Derby Avenue (1-sided)	0.3	0.0161	0.1904	1	2001	0.0000	0.0000	1.0000	0.0000	0	5	1.5
Dune Ridge	West Derby Avenue (1-sided)	0.3	0.0161	0.1904	1	2002	0.0000	0.0000	1.0000	0.0000	0	5	1.5
Dune Ridge	West Derby Avenue (1-sided)	0.3	0.0161	0.1904	1	2003	1.3333	0.6124	2.5000	0.2000	2	5	1.5
Dune Ridge	West Derby Avenue (1-sided)	0.3	0.0161	0.1904	1	2004	0.0000	0.0000	1.0000	0.0000	0	5	1.5
Dune Ridge	West Derby Avenue (1-sided)	0.3	0.0161	0.1904	1	2005	0.6667	1.0000	2.0000	0.0000	1	5	1.5
Dune Ridge	West Derby Avenue (1-sided)	0.3	0.0161	0.1904	1	2006	2.0000	1.0000	2.0000	0.2887	3	5	1.5
Dune Ridge	All Others (2-sided)	9.1	0.0196	0.0285	1	1991	0.5055	0.2935	1.3913	0.1173	23	5	45.5

Appendix A. Component statistics for white-tailed deer surveys by DMU, Indiana Dunes National Lakeshore (continued).

DMU	Segment	Length (km)	f(0)	cv	m	Year	n/L	cv	s-bar	cv	n	k	L
Dune Ridge	All Others (2-sided)	7.9	0.0196	0.0285	1	1995	0.3544	0.2947	1.8571	0.1366	14	5	39.5
Dune Ridge	All Others (2-sided)	7.9	0.0196	0.0285	1	1996	0.8608	0.1947	2.2941	0.0930	34	5	39.5
Dune Ridge	All Others (2-sided)	7.9	0.0196	0.0285	1	1997	0.6329	0.2033	1.9600	0.0806	25	5	39.5
Dune Ridge	All Others (2-sided)	7.9	0.0196	0.0285	1	1998	1.0633	0.1854	2.5476	0.0909	42	5	39.5
Dune Ridge	All Others (2-sided)	7.9	0.0196	0.0285	1	1999	1.4430	0.1315	1.9298	0.0787	57	5	39.5
Dune Ridge	All Others (2-sided)	7.9	0.0196	0.0285	1	2000	1.4937	0.1465	1.9661	0.0684	59	5	39.5
Dune Ridge	All Others (2-sided)	7.9	0.0196	0.0285	1	2001	0.9367	0.1701	2.3514	0.1202	37	5	39.5
Dune Ridge	All Others (2-sided)	7.9	0.0196	0.0285	1	2002	1.4430	0.1445	2.3684	0.0566	57	5	39.5
Dune Ridge	All Others (2-sided)	7.9	0.0196	0.0285	1	2003	1.2911	0.2106	2.3922	0.0795	51	5	39.5
Dune Ridge	All Others (2-sided)	7.9	0.0196	0.0285	1	2004	1.4474	0.2088	1.9091	0.0670	55	5	38.0
Dune Ridge	All Others (2-sided)	7.9	0.0196	0.0285	1	2005	1.2152	0.1804	1.6667	0.0863	48	5	39.5
Dune Ridge	All Others (2-sided)	7.9	0.0196	0.0285	1	2006	1.1139	0.2621	1.9091	0.0898	44	5	39.5
Dune Wood	**All Roads (2-sided)**	**4.4**	**0.0163**	**0.1484**	**2**	**1991**	**0.2273**	**0.3721**	**2.2000**	**0.1701**	**5**	**5**	**22.0**
Dune Wood	All Roads (2-sided)	4.4	0.0163	0.1484	2	1995	0.1818	0.4686	2.5000	0.1155	4	5	22.0
Dune Wood	All Roads (2-sided)	4.4	0.0163	0.1484	2	1996	0.2727	0.3839	2.0000	0.2582	6	5	22.0
Dune Wood	All Roads (2-sided)	4.4	0.0163	0.1484	2	1997	0.9545	0.2433	2.2381	0.0867	21	5	22.0
Dune Wood	All Roads (2-sided)	4.4	0.0163	0.1484	2	1998	0.6818	0.2913	2.0000	0.1091	15	5	22.0
Dune Wood	All Roads (2-sided)	4.4	0.0163	0.1484	2	1999	0.5455	0.2549	2.0000	0.1741	12	5	22.0
Dune Wood	All Roads (2-sided)	4.4	0.0163	0.1484	2	2000	0.3182	0.4601	1.8571	0.2176	7	5	22.0
Dune Wood	All Roads (2-sided)	4.4	0.0163	0.1484	2	2001	0.2727	0.3492	1.5000	0.2277	6	5	22.0
Dune Wood	All Roads (2-sided)	4.4	0.0163	0.1484	2	2002	0.5455	0.2607	2.8333	0.1291	12	5	22.0
Dune Wood	All Roads (2-sided)	4.4	0.0163	0.1484	2	2003	0.3182	0.5995	2.8571	0.1190	7	5	22.0
Dune Wood	All Roads (2-sided)	4.4	0.0163	0.1484	2	2004	0.6364	0.2601	1.9286	0.1581	14	5	22.0
Dune Wood	All Roads (2-sided)	4.4	0.0163	0.1484	2	2005	0.9091	0.2693	2.0000	0.1257	20	5	22.0
Dune Wood	All Roads (2-sided)	4.4	0.0163	0.1484	2	2006	1.2273	0.2070	2.7778	0.1294	27	5	22.0
Inland Marsh	**Stage Coach Road (1-sided)**	**4.2**	**0.0184**	**0.0811**	**1**	**1991**	**0.1905**	**0.4677**	**2.5000**	**0.1155**	**4**	**5**	**21.0**
Inland Marsh	Stage Coach Road (1-sided)	4.2	0.0184	0.0811	1	1995	0.1905	0.4677	2.2500	0.3333	4	5	21.0
Inland Marsh	Stage Coach Road (1-sided)	4.2	0.0184	0.0811	1	1996	0.2857	0.4082	1.3333	0.2500	6	5	21.0
Inland Marsh	Stage Coach Road (1-sided)	4.2	0.0184	0.0811	1	1997	0.1905	0.4677	3.5000	0.2474	4	5	21.0

Appendix A. Component statistics for white-tailed deer surveys by DMU, Indiana Dunes National Lakeshore (continued).

DMU	Segment	Length (km)	f(0)	cv	m	Year	n/L	cv	s-bar	cv	n	k	L
Inland Marsh	Stage Coach Road (1-sided)	4.2	0.0184	0.0811	1	1998	0.1905	0.4677	2.2500	0.3333	4	5	21.0
Inland Marsh	Stage Coach Road (1-sided)	4.2	0.0184	0.0811	1	1999	0.2381	0.5477	3.4000	0.3789	5	5	21.0
Inland Marsh	Stage Coach Road (1-sided)	4.2	0.0184	0.0811	1	2000	0.2381	0.5477	2.0000	0.2236	5	5	21.0
Inland Marsh	Stage Coach Road (1-sided)	4.2	0.0184	0.0811	1	2001	0.1429	0.4082	1.6667	0.4000	3	5	21.0
Inland Marsh	Stage Coach Road (1-sided)	4.2	0.0184	0.0811	1	2002	0.4286	0.5386	2.3333	0.1429	9	5	21.0
Inland Marsh	Stage Coach Road (1-sided)	4.2	0.0184	0.0811	1	2003	0.4286	0.4779	2.4444	0.2058	9	5	21.0
Inland Marsh	Stage Coach Road (1-sided)	4.2	0.0184	0.0811	1	2004	1.0952	0.2016	2.3043	0.1106	23	5	21.0
Inland Marsh	Stage Coach Road (1-sided)	4.2	0.0184	0.0811	1	2005	0.6190	0.3353	1.9231	0.1497	13	5	21.0
Inland Marsh	Stage Coach Road (1-sided)	4.2	0.0184	0.0811	1	2006	0.9524	0.2739	2.3500	0.1320	20	5	21.0
Little Calumet	**All Roads (2-sided)**	**3.3**	**0.0107**	**0.0564**	**1**	**1991**	**0.9697**	**0.3448**	**2.4375**	**0.1674**	**16**	**5**	**16.5**
Little Calumet	All Roads (2-sided)	3.3	0.0107	0.0564	1	1995	1.0909	0.2749	3.3889	0.2783	18	5	16.5
Little Calumet	All Roads (2-sided)	3.3	0.0107	0.0564	1	1996	0.8485	0.2809	4.4286	0.0938	14	5	16.5
Little Calumet	All Roads (2-sided)	3.3	0.0107	0.0564	1	1997	0.7273	0.4429	5.6667	0.2018	12	5	16.5
Little Calumet	All Roads (2-sided)	3.3	0.0107	0.0564	1	1998	1.2121	0.3430	3.3500	0.1952	20	5	16.5
Little Calumet	All Roads (2-sided)	3.3	0.0107	0.0564	1	1999	0.9091	0.3594	2.9333	0.2268	15	5	16.5
Little Calumet	All Roads (2-sided)	3.3	0.0107	0.0564	1	2000	1.0909	0.2878	3.5556	0.1563	18	5	16.5
Little Calumet	All Roads (2-sided)	3.3	0.0107	0.0564	1	2001	1.2121	0.2049	2.4000	0.1297	20	5	16.5
Little Calumet	All Roads (2-sided)	3.3	0.0107	0.0564	1	2002	1.2727	0.2307	2.3333	0.0854	21	5	16.5
Little Calumet	All Roads (2-sided)	3.3	0.0107	0.0564	1	2003	0.8485	0.3304	2.4286	0.1032	14	5	16.5
Little Calumet	All Roads (2-sided)	3.3	0.0107	0.0564	1	2004	2.2424	0.2577	2.2973	0.0937	37	5	16.5
Little Calumet	All Roads (2-sided)	3.3	0.0107	0.0564	1	2005	2.1818	0.1537	2.0556	0.0866	36	5	16.5
Little Calumet	All Roads (2-sided)	3.3	0.0107	0.0564	1	2006	2.1212	0.2077	2.8000	0.1074	35	5	16.5
South Inland Marsh	**Stage Coach Road (1-sided)**	**4.2**	**0.0033**	**0.0316**	**2**	**1991**	**1.9048**	**0.1311**	**3.4500**	**0.1132**	**40**	**5**	**21.0**
South Inland Marsh	Stage Coach Road (1-sided)	4.2	0.0033	0.0316	2	1995	2.6667	0.1244	3.9286	0.1185	56	5	21.0
South Inland Marsh	Stage Coach Road (1-sided)	4.2	0.0033	0.0316	2	1996	1.8095	0.1746	3.8684	0.1183	38	5	21.0
South Inland Marsh	Stage Coach Road (1-sided)	4.2	0.0033	0.0316	2	1997	0.9048	0.2105	5.7368	0.2285	19	5	21.0
South Inland Marsh	Stage Coach Road (1-sided)	4.2	0.0033	0.0316	2	1998	1.4286	0.2838	3.9667	0.1193	30	5	21.0
South Inland Marsh	Stage Coach Road (1-sided)	4.2	0.0033	0.0316	2	1999	2.2857	0.1531	3.3542	0.1212	48	5	21.0
South Inland Marsh	Stage Coach Road (1-sided)	4.2	0.0033	0.0316	2	2000	1.7619	0.2325	4.0811	0.1564	37	5	21.0
South Inland Marsh	Stage Coach Road (1-sided)	4.2	0.0033	0.0316	2	2001	2.5238	0.0971	3.2264	0.0764	53	5	21.0
South Inland Marsh	Stage Coach Road (1-sided)	4.2	0.0033	0.0316	2	2002	2.5714	0.1446	2.6296	0.0872	54	5	21.0

Appendix A. Component statistics for white-tailed deer surveys by DMU, Indiana Dunes National Lakeshore (continued).

DMU	Segment	Length (km)	f(0)	cv	m	Year	n/L	cv	s-bar	cv	n	k	L
South Inland Marsh	Stage Coach Road (1-sided)	4.2	0.0033	0.0316	2	2003	3.1905	0.2414	3.1194	0.0589	67	5	21.0
South Inland Marsh	Stage Coach Road (1-sided)	4.2	0.0033	0.0316	2	2004	2.2381	0.4183	2.2553	0.0847	47	5	21.0
South Inland Marsh	Stage Coach Road (1-sided)	4.2	0.0033	0.0316	2	2005	5.2381	0.1445	2.7727	0.0648	110	5	21.0
South Inland Marsh	Stage Coach Road (1-sided)	4.2	0.0033	0.0316	2	2006	5.6667	0.1843	2.7731	0.0555	119	5	21.0
State Park Cowles Dune	**South State Park Road (1-sided)**	**1.5**	**0.0323**	**0.2451**	**1**	**1991**	**0.4000**	**0.4082**	**2.6667**	**0.3307**	**3**	**5**	**7.5**
State Park Cowles Dune	South State Park Road (1-sided)	1.5	0.0323	0.2451	1	1995	0.1333	1.0000	2.0000	0.0000	1	5	7.5
State Park Cowles Dune	South State Park Road (1-sided)	1.5	0.0323	0.2451	1	1996	0.1333	1.0000	1.0000	0.0000	1	5	7.5
State Park Cowles Dune	South State Park Road (1-sided)	1.5	0.0323	0.2451	1	1997	0.2667	0.6124	2.5000	0.2000	2	5	7.5
State Park Cowles Dune	South State Park Road (1-sided)	1.5	0.0323	0.2451	1	1998	0.1333	1.0000	2.0000	0.0000	1	5	7.5
State Park Cowles Dune	South State Park Road (1-sided)	1.5	0.0323	0.2451	1	1999	0.2667	0.6124	1.5000	0.3333	2	5	7.5
State Park Cowles Dune	South State Park Road (1-sided)	1.5	0.0323	0.2451	1	2000	0.0000	0.0000	1.0000	0.0000	0	5	7.5
State Park Cowles Dune	South State Park Road (1-sided)	1.5	0.0323	0.2451	1	2001	0.0000	0.0000	1.0000	0.0000	0	5	7.5
State Park Cowles Dune	South State Park Road (1-sided)	1.5	0.0323	0.2451	1	2002	0.2667	1.0000	1.5000	0.3333	2	5	7.5
State Park Cowles Dune	South State Park Road (1-sided)	1.5	0.0323	0.2451	1	2003	0.0000	0.0000	1.0000	0.0000	0	5	7.5
State Park Cowles Dune	South State Park Road (1-sided)	1.5	0.0323	0.2451	1	2004	0.0000	0.0000	1.0000	0.0000	0	5	7.5
State Park Cowles Dune	South State Park Road (1-sided)	1.5	0.0323	0.2451	1	2005	0.0000	0.0000	1.0000	0.0000	0	5	7.5
State Park Cowles Dune	South State Park Road (1-sided)	1.5	0.0323	0.2451	1	2006	0.0000	0.0000	1.0000	0.0000	0	5	7.5
State Park Dune Ridge	**East State Park Road (1-sided)**	**0.9**	**0.0180**	**0.0774**	**1**	**1991**	**0.8889**	**0.4677**	**1.7500**	**0.2736**	**4**	**5**	**4.5**
State Park Dune Ridge	East State Park Road (1-sided)	0.9	0.0180	0.0774	1	1995	0.0000	0.0000	1.0000	0.0000	0	5	4.5
State Park Dune Ridge	East State Park Road (1-sided)	0.9	0.0180	0.0774	1	1996	0.4444	1.0000	1.5000	0.3333	2	5	4.5
State Park Dune Ridge	East State Park Road (1-sided)	0.9	0.0180	0.0774	1	1997	0.2222	1.0000	2.0000	0.0000	1	5	4.5
State Park Dune Ridge	East State Park Road (1-sided)	0.9	0.0180	0.0774	1	1998	0.8889	0.4677	2.2500	0.1111	4	5	4.5
State Park Dune Ridge	East State Park Road (1-sided)	0.9	0.0180	0.0774	1	1999	0.8889	0.4677	3.0000	0.3043	4	5	4.5
State Park Dune Ridge	East State Park Road (1-sided)	0.9	0.0180	0.0774	1	2000	1.1111	0.3162	1.4000	0.1750	5	5	4.5
State Park Dune Ridge	East State Park Road (1-sided)	0.9	0.0180	0.0774	1	2001	0.4444	0.6124	1.0000	0.0000	2	5	4.5
State Park Dune Ridge	East State Park Road (1-sided)	0.9	0.0180	0.0774	1	2002	0.2222	1.0000	2.0000	0.0000	1	5	4.5
State Park Dune Ridge	East State Park Road (1-sided)	0.9	0.0180	0.0774	1	2003	0.2222	1.0000	5.0000	0.0000	1	5	4.5
State Park Dune Ridge	East State Park Road (1-sided)	0.9	0.0180	0.0774	1	2004	0.0000	0.0000	1.0000	0.0000	0	5	4.5
State Park Dune Ridge	East State Park Road (1-sided)	0.9	0.0180	0.0774	1	2005	1.1111	0.7746	1.8000	0.1111	5	5	4.5

Appendix A. Component statistics for white-tailed deer surveys by DMU, Indiana Dunes National Lakeshore (continued).

DMU	Segment	Length (km)	f(0)	cv	m	Year	n/L	cv	s-bar	cv	n	k	L
State Park Dune Ridge	East State Park Road (1-sided)	0.9	0.0180	0.0774	1	2006	2.0000	0.2079	1.3333	0.1250	9	5	4.5
West Beach	**West Beach (2-sided)**	**2.3**	**0.0137**	**0.1231**	**1**	**1991**	**0.0000**	**0.0000**	**1.0000**	**0.0000**	**0**	**5**	**11.5**
West Beach	West Beach (2-sided)	2.3	0.0137	0.1231	1	1995	0.2609	0.6667	2.0000	0.5000	3	5	11.5
West Beach	West Beach (2-sided)	2.3	0.0137	0.1231	1	1996	0.0000	0.0000	1.0000	0.0000	0	5	11.5
West Beach	West Beach (2-sided)	2.3	0.0137	0.1231	1	1997	0.0870	1.0000	1.0000	0.0000	1	5	11.5
West Beach	West Beach (2-sided)	2.3	0.0137	0.1231	1	1998	0.1739	0.6124	1.5000	0.3333	2	5	11.5
West Beach	West Beach (2-sided)	2.3	0.0137	0.1231	1	1999	0.0000	0.0000	1.0000	0.0000	0	5	11.5
West Beach	West Beach (2-sided)	2.3	0.0137	0.1231	1	2000	0.2609	0.4082	2.6667	0.1250	3	5	11.5
West Beach	West Beach (2-sided)	2.3	0.0137	0.1231	1	2001	0.2609	0.6667	2.3333	0.3780	3	5	11.5
West Beach	West Beach (2-sided)	2.3	0.0137	0.1231	1	2002	0.5217	0.3118	2.1667	0.1418	6	5	11.5
West Beach	West Beach (2-sided)	2.3	0.0137	0.1231	1	2003	0.2609	0.6667	2.6667	0.3307	3	5	11.5
West Beach	West Beach (2-sided)	2.3	0.0137	0.1231	1	2004	0.6087	0.6227	2.1429	0.0667	7	5	11.5
West Beach	West Beach (2-sided)	2.3	0.0137	0.1231	1	2005	0.6087	0.5345	2.2857	0.2282	7	5	11.5
West Beach	West Beach (2-sided)	2.3	0.0137	0.1231	1	2006	0.6957	0.7016	3.6250	0.1643	8	5	11.5

[1] f(0) is probability density of g(x) evaluated at perpendicular distance of zero
[2] cv is coefficient of variation
[3] m is method for determining perpendicular distance
[4] n/L is encounter rate
[5] s-bar is mean cluster size
[6] n is number of deer clusters encountered
[7] k is number of samples
[8] L is transect line length (km)

Appendix B. Excel Spreadsheets and PROGRAM DISTANCE project files for the analysis and interpretation of distance sampling of deer night-spotlighting surveys, Indiana Dunes National Lakeshore.

We include all Distance Project Files and also four Microsoft Excel spreadsheets for compiling and comparing the various statistics used in this analysis. What follows is a brief description of the sheet and its intended purpose. All of the multiple worksheet files have an instructions tab.

datatablesandfigs.xls	A compilation of component statistics, composited density estimates, and tables and figures included in this report.
dispersionstats.xls	Survey statistics having to do with the computation of var(n), effort, summary statistics, and SAS program for computing the dispersion statistic.
disptestlinelengtheffectsize.xls	Includes simple z-tests for differences in dispersion between pairs of DMUs, line length requirements based on desired levels of precision, confidence intervals as a percentage of the mean density, and effect size calculations.
bhatlencrateoncv.xls	Simple plots of the time averaged CV on estimates of dispersion and encounter rate, and actual road segment lengths by DMU.
*.dst	Project files to be used with PROGRAM DISTANCE version 5. Files ending without a number are used for modeling detection functions using the measured perpendicular distances (1999-2006). Files ending with the number 2 correspond to use of the MCDS engine and the testing of estimated vs. measured distances. Files ending with the number 3 were used to estimate encounter rate and cluster size only (includes all usable data).

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