A NON-LINEAR SPOTLIGHT LINE TRANSECT METHOD FOR ESTIMATING WHITE-TAILED DEER POPULATION DENSITIES

THESIS

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Brian L. Pierce

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Special thanks to my wife, Barbara, who supports my every endeavor and with whom I share the joy of learning.

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by

BRIAN L. PIERCE, B. S.
Southwest Texas State Universtiy
May 2000

SUPERVISING PROFESSOR: JOHN T. BACCUS

Abstract: Accurate estimates of population density are a prerequisite for managing exploited white-tailed deer (Odocoileus virginianus) populations. Many state agencies rely upon density estimates obtained from spotlight strip transect surveys to regulate annual harvest. Yet, density estimates from the standard spotlight strip transect method are known to be inaccurate in areas of dense vegetation, and alternatives such as the Hahn method, mark-recapture, or aerial strip transects are cost prohibitive for state wide surveys. The line transect method is an alternative which has been criticized for inaccuracy of distance estimates and the additional time required to collect perpendicular distance data. Results from a two year study of white-tailed deer in central Texas are presented to demonstrate the utility of a new spotlight line transect sampling method. The method generates accurate perpendicular distance data from non-linear transects using inexpensive GPS, GIS, and laser range finding equipment. The new spotlight line transect method is relatively fast (0.15 ± 0.05 hours/km SD), spatially accurate to within limits of the equipment used (15.2 ± 13.9 m SD), consistently obtains larger sample sizes per transect (> 50%), and returns more information per sighting (count, composition, and spatial location) than traditional spotlight strip transect sampling method. Results indicate the new spotlight line transect method is less biased than the traditional spotlight strip transect method, more efficient in terms of cost per unit effort (hours/km), and yields spatial data (deer locations) applicable for monitoring habitat use without identification of individuals (Design 1, Thomas and Taylor 1990).

CHAPTER 1

INTRODUCTION

White-tailed deer (Odocoileus virginianus) management is essentially the balance between maintenance of habitat and control of population density. This is especially true in areas where natural predators have been removed from the environment or where elevated deer densities could adversely impact other sympatric species. In these instances wildlife managers must continually monitor population density in order to properly maintain each species within the biological carrying capacity of the environment. Accurate methods for estimating population density are therefore the cornerstone of any management effort (Leopold 1933). In addition, they are the essential first step if we wish to understand which demographic parameters are most influential in regulating a particular population: natality, mortality, immigration, or emigration. Due to the inherent cost of estimating population density on any large scale, the sampling methodology used must be both accurate and efficient in terms of cost per unit effort. The spotlight strip transect sampling method (Progulske and Duerre 1964, Harwell et al. 1979, and Mitchell 1986) has been used extensively for monitoring white-tailed deer populations throughout the United States. Unfortunately, the strip transect method is burdened with unattainable statistical assumptions, the most limiting of which are the requirements for a complete census within the sampled area and an accurate estimate of sample area size (Davis 1942, Kelker 1943, Kelker 1945, Cronemiller and Fisher 1946, Taylor 1947, Hahn 1949, Hayne 1949, Robinette et al. 1954, Robinette 1956, White 1966, Robinette et al. 1974, Evans 1975, Whipple et al. 1994). These limitations produce severe bias in habitats with dense, obstructive vegetation (forest) and/or when the target species is not randomly distributed (Progulske and Duerre 1964, Evans 1975, Harwell et al. 1979, McCullough 1982, Mitchell 1986, Burnham et al. 1985, Routledge 1982, Cooke 1993). Line transect sampling is an alternative method that is widely used in avian research (Bibby et al. 1993), but seldom is applied for managing ungulate populations. Line transect sampling is more robust to variations in target distribution, does not require a complete census within the sample area, and integrates the factors which effect detectability (visibility) into the estimate of population density (Kelker 1945, Eberhardt 1968, Gates et al. 1968, Gates 1969, Burnham et al. 1979, Burnham et al. 1980, Burnham and Anderson 1984, Burnham et al. 1985, Johnson and Routledge 1985, Routledge and Fyfe 1992a, Routledge and Fyfe 1992b, and Buckland et al. 1993). While there has been continual refinement of line transect sampling theory over the last 20 years, there have been no attempts to develop new methods for collecting line transect data in the field (Buckland et al. 1993). Clearly there is a lack of standard methodology for quickly obtaining accurate data, and there is currently no pragmatic method for obtaining perpendicular distance data from non-linear transects. This void must be addressed if line transect sampling theory is to receive wider usage by wildlife researchers, and particularly if the method is to be adopted for use in spotlight and/or aerial sampling scenarios.

The importance of white-tailed deer management and the need for accurate methodology are of particular concern to the U. S. Army at the Camp Bullis training site in central Texas, where three factors interact to elevate management concerns beyond those normally found throughout the state: 1) the obligation to maintain the indigenous habitat in order to properly train U. S. Armed Forces personnel in the successful military tactics inherent to this and similar environments throughout the world, 2) the need to maintain the training area within a high security fence, thereby producing a geographically closed white-tailed deer population, and 3) occurrence of the federally endangered Black-capped Vireo on the installation, an understory species which often selects known deer forage for nesting sites and could therefore be adversely effected by elevated deer densities. To further complicate matters, the Edwards Plateau Ecological Region of Texas represents the worst possible combination of conditions for obtaining accurate estimates of population size and/or density using the spotlight strip transect sampling method. Visibility is low due to dense vegetation and deer sightings typically occur in clumps distributed across large areas (negative binomial distribution). Based upon conclusions in the previously cited literature (Kelker 1945, Cronemiller and Fisher

1946, Hahn 1949, Robinette et al. 1954, Progulske and Duerre 1964, Robinette et al. 1974, Evans 1975, Harwell et al. 1979, McCullough 1982, Routledge 1982, Burnham et al. 1985, Cooke 1993, Whipple et al. 1994), population estimates obtained from spotlight strip transect surveys are predicted to be positively biased in this region. Positive bias would create elevated estimates of carrying capacity, elevated harvest recommendations, and elevated estimates of recruitment. This, in turn, would result in inability to meet harvest quotas on a sustained basis, inability to predict population trends in response to environmental changes or land use manipulations, and large declines in estimated population size following the application of seemingly moderate harvest quotas (harvest quotas below the estimated rate of recruitment). The problems predicted to occur under these circumstances have been documented on Camp Bullis and in other areas of North America for both mule deer and white-tailed deer (Freeman 1976, Halladay 1976, MacGregor 1976, Connolly 1981, Cooke 1985, Cooke 1993, Bruns 1993, Sawyer 1995).

Federal biologists and hunters on Camp Bullis have reported conflicting evidence concerning the apparent versus estimated white-tailed deer population size, as well as the inability of hunters to achieve harvest quotas in areas with an estimated high deer density (Sawyer 1995, Pierce and Baccus 1999). Yearly reports based on analysis of spotlight strip transect data continually failed to predict future population size, forcing installation biologists to rely upon relative data trends for predicting future population size and harvest quotas. The problem reached a critical juncture in 1987 when analysis of the annual survey data indicated an apparent overabundance of deer and the potential for a large winter die off (Bruns 1987). For three consecutive years installation biologists recommended moderate harvests quotas (25-36%) to counter the potential problem. While less than half of the harvest quota was reached each year (12-15%), the white-tailed deer population declined rapidly to record low levels in 1990. With no logical explanation for this outcome, these events created an atmosphere of conflict between hunters, biologists, and the military command. While the solution to every management problem is not simply a matter of alternative sampling methodology, a review of the problems on Camp Bullis, and within the cited literature, would seem to indicate that there have been many instances where strip transect sampling assumptions could not be met and yet economical alternatives were not available.

The objectives of this study were to determine if new methods and technology could be applied to existing line transect theory to meet requirements for white-tailed deer management in a cost efficient manner. Specifically, could new spotlight line transect sampling methodology be developed which would provide a more accurate estimate of population size while obtaining herd composition and spatial location data for the surveyed species? We demonstrate the utility of a new spotlight line transect sampling method which is relatively fast (0.15 ± 0.05 hours/km SD), spatially accurate to within limits of the ranging device and global positioning system (GPS) used (15.2 ± 13.9 m SD), consistently obtains larger sample sizes per transect (> 50%), and returns more information per sighting (count, composition, and spatial location) than traditional spotlight strip transect sampling methodology. These results indicate the new spotlight line transect method is less biased than traditional spotlight strip transect sampling, more efficient in terms of cost per unit effort (hours/deer), and yields spatial data (deer locations) applicable for monitoring habitat use without identification of individuals (Design 1, Thomas and Taylor 1990). Finally, different combinations of equipment can be used to meet the sampling demands of both ground and aerial surveys.

CHAPTER 2

STUDY AREA

Camp Bullis is a military installation located immediately north of San Antonio, Texas (Figure 1). The installation covers 11,823 ha (27,880 ac), and the area is characterized as an ecotone of the Edwards Plateau, Blackland Prairies and South Texas Plains Ecological Regions of Texas (Gould 1969). The topography is rugged and hilly with elevations ranging from 300 to 450 m (1,000 to 1,500 ft) above mean sea level. The mean annual temperature is 20° C (68° F) with monthly averages ranging from 11° C (52° F) in January to 28° C (84° F) in July. The average date of the last spring freeze is March 16th, and the average date of the first autumn freeze is November 16th. Rainfall varies from 66 cm to 76 cm (26 in - 30 in) per year with more years below average rainfall than above. There are two distinct growing seasons, April through June and September through October, corresponding to periods with the highest average monthly rainfall (Taylor et al. 1966). Several small intermittent streams (Cibolo, Salado, Lewis Valley, and Leon creeks) bisect the area with drainage toward the southeast. Limestone is the dominant parent material from which most local soils are derived, and three major formations underlie the study area: the Buda, Glen Rose, and Edwards Limestone formations. The central portion of the installation, approximately 8,044 ha (19,877 ac) or 71.3%, is classified as rolling Adobe Hills range site and is covered with shallow Tarrant-Brackett association soils. This central area is surrounded by the drainage basins of Cibolo Creek on the northern boundary, Lewis Valley Creek in the south central portion of the base, and Salado Creek along the western and southern boundaries. These drainage basins cover approximately 3,238 ha (8,001 ac) or 28.7% of the installation and are covered with Crawford and Bexar soils, older alluvium deposits of the Krum complex, Trinity-Frio soils, Lewisville silty clay, and Patrick soils in the floodplains.

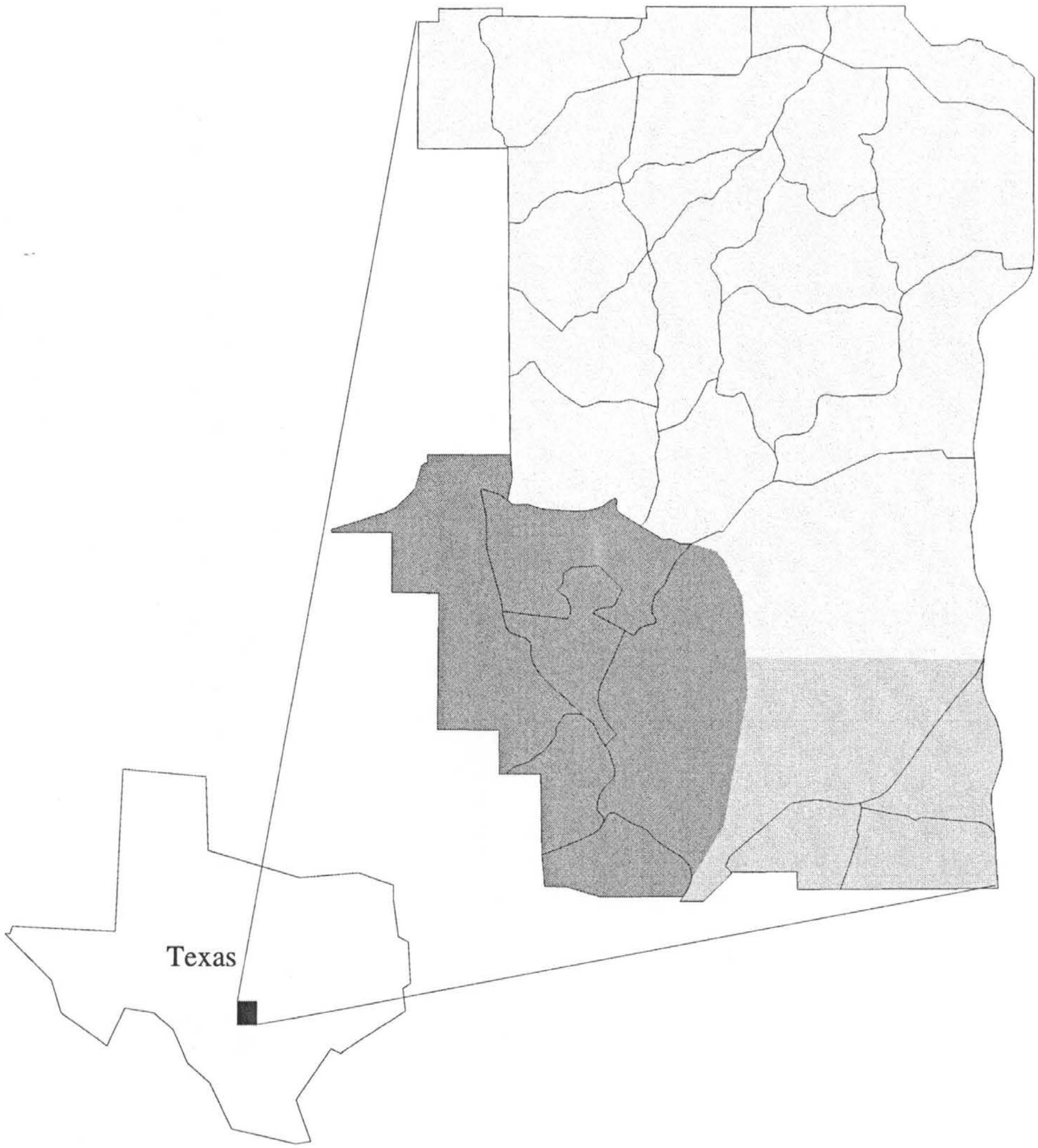

Figure 1. Location of Camp Bullis study area in central Texas.

Vegetational communities associated with the Buda Limestone formation and the Quaternary deposits of intermittent stream beds of the Edwards Plateau Region were studied by Van Auken et al. (1979). Dominant species on the Buda formation were Ashe juniper (Juniperus ashei), plateau live oak (Quercus viginiana), and Texas persimmon (Diospyros texana). Dominant species on Quaternary deposits were Ashe juniper, cedar elm (Ulmus crassifolia), sycamore (Platanus occidentalis), and Texas persimmon. The vegetational communities associated with the Edwards and Glen Rose Limestone formations were studied by Van Auken et al. (1980). Twenty-four woody species were identified, but no statistical differences in plant composition between the two geological formations were detected in the analysis. The dominant species on these two limestone formations were Ashe juniper, plateau live oak, and Texas persimmon. While no direct comparisons between the Buda Limestone and the Edwards Limestone or Glen Rose Limestone formations have been published, the cited results illustrate that plant communities which exist on soils derived from these limestone formations are similar in composition. The scrub evergreen forest and the upland deciduous forest of the Edwards Plateau were studied by Van Auken et al. (1981). Scrub evergreen forest communities typically occupy hilltops and the south to southwest aspects of hill slopes. Upland deciduous forest typically occupy bands on the north to northeastern aspect of hill slopes. Twenty-three woody species were encountered in these two communities. Eleven species (48%) were found exclusively in the deciduous forest, four species (17%) occurred exclusively in the evergreen forest, and eight species (35%) were common to both areas. Dominant species in the deciduous forest were Spanish oak (Quercus texana), Lacey oak (Quercus glaucoides), Ashe juniper and Texas persimmon. Dominant species in the evergreen forest were Ashe juniper, Texas persimmon, and plateau live oak.

Historically, the Edwards Plateau appears to have been a stable grassland or savannah community dominated by tall-grass species and fire tolerant woody species (Smeins et al. 1997). The climax condition of this region likely was maintained by the dynamic interaction of climatic factors, fire, vegetation, and herbivores (Fonteyn et al. 1988; Van Auken 1993). Much of this area was settled by Europeans in the early 1800s, who brought Old World farming and ranching practices with them to the region. Domestic livestock and fire suppression altered the vegetative community by changing the duration and intensity of grazing and resulted in a shift of vegetative dominance away from tall-grass species and toward short grasses or woody species. The unique balance of the ecosystem, once altered, progressively favored the establishment of invasive woody species (Van Auken 1993). Historic clearing of Ashe juniper, military maneuvers, infrastructure development, erosion, overgrazing, gravel mining, and damming of streambeds to control flood waters have altered the native ecosystem. Various stages of secondary succession are evident throughout the installation with Ashe juniper monocultures of varying age and size occurring frequently. However, some small but relatively diverse plant communities do occur on the installation, most of which are intermixed with the disturbed areas (Johnson et al. 1996). Active range management has slowed some of the damage, but brush control efforts have failed to maintain cleared areas in a brush (Ashe juniper) free state. The resulting landscape is a mosaic of live oak savannahs, dense Ashe juniper dominated woodlands, and diverse semi-riparian drainages.

CHAPTER 3

MATERIALS

Materials and equipment used for this study were obtained from the following venders: spotlights (ShowMe Series 08) from Able2 Products Co., laser range finder (Yardage Pro 400) from Bushnell, compasses (Silva Ranger) from Silva, binoculars from Nikon, Swavorski, Cabela's, Pentax, Tasco, Swift, and Leica, spotting scopes from Swift, global positioning system (Garmin 12XL) from Garmin, differential beacon receiver (GBR21) from Garmin, GPS communication software (GPSy) from GPSy.com, H-band DGPS antenna from NavTech, raster GIS (MF Works; available for Windows and Macintosh computers) from Thinkspace, vector GIS (MapGrafix) from ComGrafix, digital orthophotos (DOQ's) from the Texas Orthoimagery Project, digital maps (digital raster graphics [DRG's] and digital line graphs [DLG's]) from USGS, soil maps (SSURGO) from the Natural Resources Conservation Service, DISTANCE line transect analysis software from Colorado State University, USA, TRANSAN line transect analysis software from Simon Fraser University, Canada, word processing and spreadsheet software (ClarisWorks) from Claris, database software (FileMaker Pro) from Claris, statistical software (Statview) from SAS, and a personal computer (Power Macintosh G3) from Apple Computer. The compass rosette (used to collect bearing data) and the vehicle spotting/telemetry platform were designed in house on a Power Macintosh G3 using drafting software (Generic CAD) from AutoCAD. Both devices were fabricated in house using standard tools, lumber and hardware products. The compass rosette was 45 cm (18 in) in diameter, and marked in both compass and polar bearings. The rosette and pointer were mounted to the spotting platform in the bed of a pickup, and aligned with the longitudinal axis of the vehicle. The spotting platform provided a seat height of 1.4 m (55 in) above ground level, and an average viewing height of 2.1 m (84 in) at eye level.

CHAPTER 4

METHODS

Transect Placement and Characterization

The spotlight strip transect method (Progulske and Duerre 1964, Harwell et al. 1979, and Mitchell 1986) historically has been used to estimate herd composition and population density on Camp Bullis (Bruns 1993, Williams 1993). Historical spotlight strip transect locations (four transects: NW, SW, NE, and SE) were evaluated for sources of error such as the potential for double counts on transect lines and lack of stratification within the study area. New transect lines were plotted, as needed, to better represent the entire area, remove sample bias, and to improve accessibility during periods of military training (Figure 2). Historic and new transect line positions were recorded with a real-time, differentially corrected global positioning system (DGPS) every 161 m (0.1 mi). All locational data for this project were georeferenced to the Universal Transverse Mercator (UTM) coordinate system, the horizontal North American Datum of 1983 (NAD-83), and the World Geodetic System of 1984 (WGS-84) reference ellipsoid, in order to correspond with the real-time DGPS corrections broadcast by the U. S. Coast Guard (RTCM Type 9-3 correction messages). Strip transect average visibility (1/2 strip width) was determined by perpendicular distance measurement (tape measure or laser range finder) to the first point of visual obstruction at each UTM location. Vegetation, hills and ravines which could obscure counts were considered visual obstructions. UTM points from each transect were downloaded to a geographic information system (GIS) and interpolated to provide a map of each transect route. Visibility (sample area) for each transect was calculated as twice the length multiplied by the average visibility ($2lv$). Historic estimates of transect visibility were compared to the sample areas obtained by perpendicular distance measurement during this study using a one sample t-test. Sample areas from the new transect lines were compared to aerial visibility estimates made

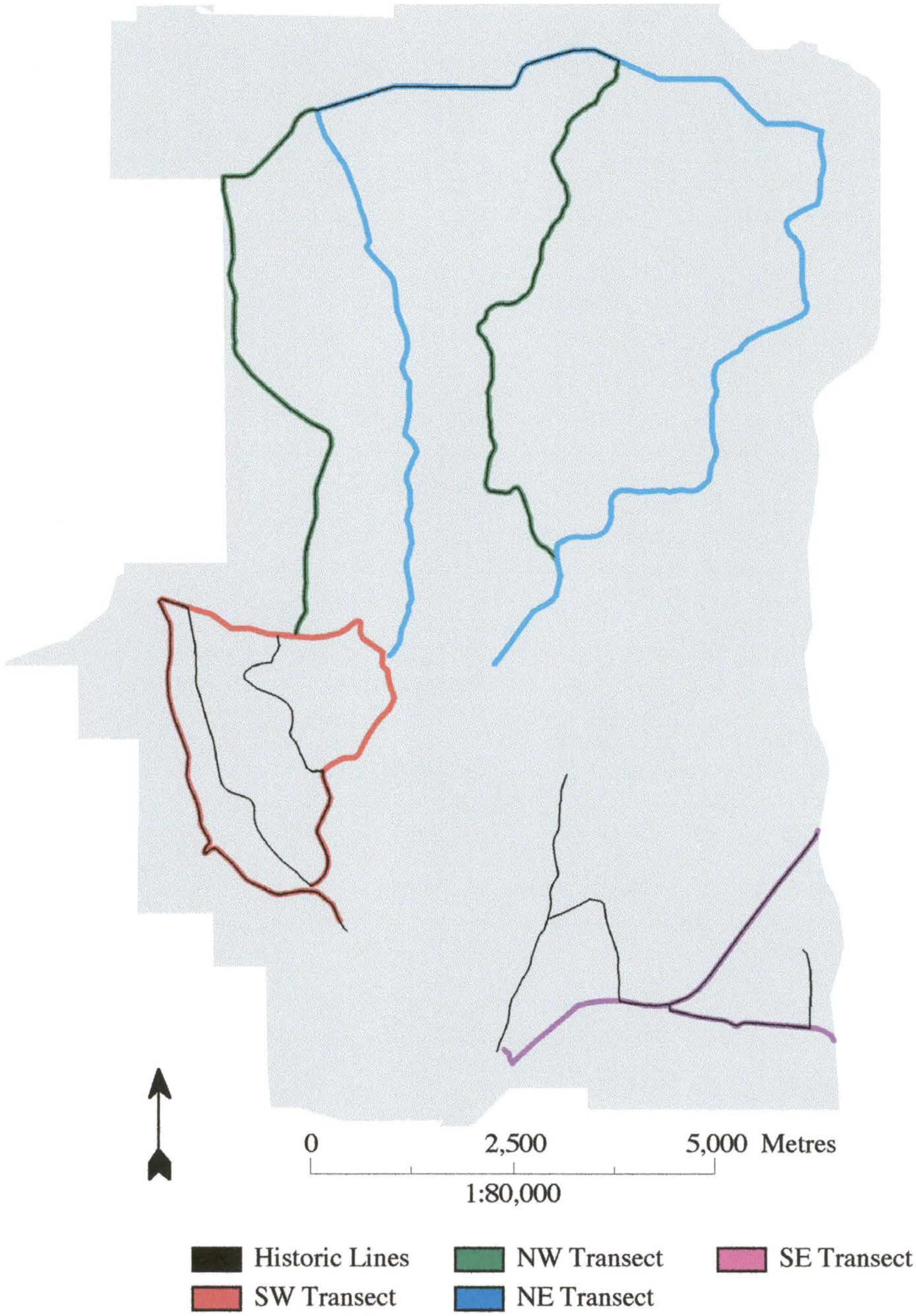

Figure 2. Location of the historic and current spotlight transects on Camp Bullis.

during a 1998 helicopter count using linear regression to assess transect representation of the study area. Individual measurements of perpendicular visibility collected for each spotlight transect were plotted as line graphs and histograms for future reference (Appendices 1-4). These data serve as a unique measure of sample area visual obstruction factors for each transect and can be used to determine changes in visibility over time when compared with future surveys.

Spotlight Strip and Line Transect Data Collection

The new method used to collect these data is a modification of the standard spotlight strip transect (Progulske and Duerre 1964, Harwell et al. 1979, Mitchell 1986) and line transect sampling techniques (Burnham and Anderson 1984, Burnham et al. 1985, Johnson and Routledge 1985, Routledge and Fyfe 1992a, Routledge and Fyfe 1992b, and Buckland et al. 1993), which allows for the calculation of perpendicular distances (from the target to the transect) from non-linear transects. The new method obtained not only the count of animals sighted during each transect, but also the observer location (UTM point), range (distance to target in meters), and bearing (polar bearing) to each animal or group of animals sighted along the transect line (Figure 3). As such, the data collected with the new method could be used to estimate density and population size using both strip transect and line transect density calculation techniques. This permitted a direct comparison between the two methods using the same data sets (1997-1998).

Surveys were conducted during autumn (October-November) 1997 and summer (July-August) 1998. These data were used to compare the suggested survey period (summer) with the historical survey period (autumn), and to compare population estimates generated by line and strip transect techniques. While most state and federal agencies conduct white-tailed deer surveys during autumn to maximize counts when foliar densities are low (McCullough 1982), Camp Bullis surveys were conducted during the summer to obtain density and herd composition estimates when sexual differences in habitat utilization are at a minimum (Downing et al. 1977, McCullough 1982, Beier and McCullough 1990, and McCullough et al. 1994). Each survey was initiated within 30 minutes of official sundown when white-tailed deer activities are at their diel maximum (Downing et al. 1977, McCullough 1982, Beier and McCullough 1990, and McCullough

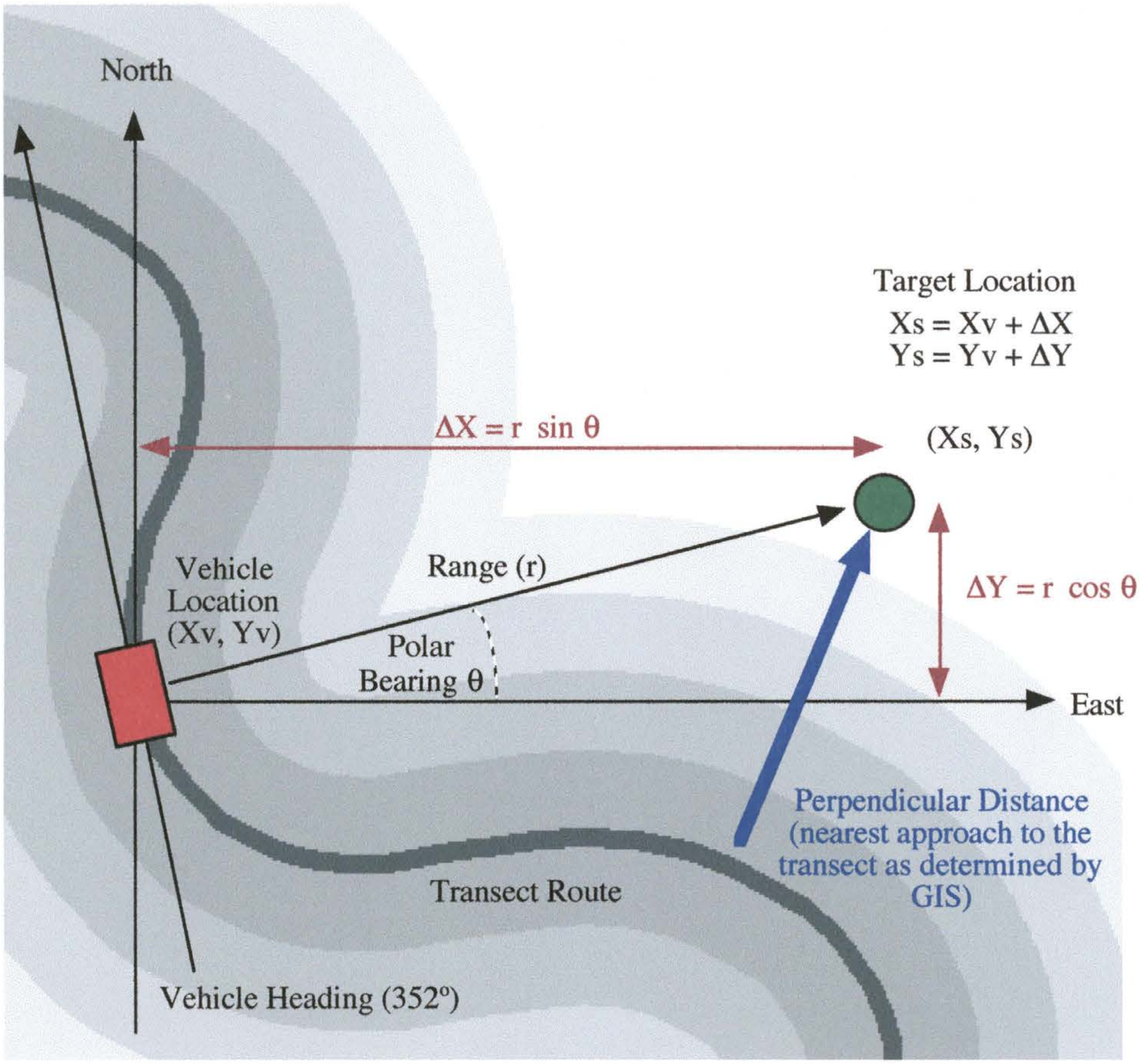

Figure 3. Data and calculations for determining perpendicular distance to a sighting. Target location (Xs,Ys) is calculated from range, bearing, and the point of observation (Xv, Yv) in a Cartesian Plane.

et al. 1994). The four spotlight transect lines were sampled on five non-consecutive nights for a total of 20 transect surveys per season. Only one transect was sampled each night in order to maximize the number of sightings per transect during the diel activity peak. Survey crews usually consisted of a driver, a recorder, and two spotters. Spotters located animals, counted, and identified the composition of animals for the recorder. The recorder collected UTM locations for the vehicle (observer), laser distance measurements to each target (range), polar bearings to each target, and tallied the count data. A minimum crew of three individuals (one driver/recorder and two spotters) was used on several occasions, with one spotter collecting distances and bearings in addition to the normal spotting duties.

Data collected for each transect consisted of the time and climatic conditions at the start and end of the transect, the time of each sighting, the UTM location of the vehicle at the time of each sighting, the number of animals in each group, the distance and bearing to the center of each group or individual, and the composition of any group in which all animals could be identified. Groups were defined as any localized gathering of deer which moved as a unit, whether feeding or fleeing. If the composition of all animals in a group could not be positively identified, each animal in the group was recorded as "unknown." Vehicle speed during each survey was approximately 15 kph with frequent stops to obtain UTM points, range, and bearing measurements. Efforts were focused upon obtaining complete counts within each sample area, rather than maintaining a constant speed. The data obtained from each transect, along with the visibility data (sample area size) collected prior to the counts, were used to estimate density for each management unit using both strip transect (Progulske and Duerre 1964, Caughley 1977, Cochran 1977, Harwell et al. 1979, Mitchell 1986, Caughley and Sinclair 1994, Lancia et al. 1994 and Krebs 1998) and line transect sampling theory (Burnham et al. 1980, Burnham and Anderson 1984, Burnham et al. 1985, Johnson and Routledge 1985, Routledge and Fyfe 1992a, Routledge and Fyfe 1992b, Buckland et al. 1993).

Helicopter Strip Transect Data Collection

A helicopter strip survey was conducted in February 1998. The aerial transect was flown in mid-afternoon to accommodate helicopter scheduling and installation aerial access, and therefore was not scheduled for optimal counting parameters. Ten transects of unequal length crossed the installation in a north-south pattern, avoiding active training and restricted areas as designated by Camp Bullis Operations (Figure 4). The aerial transect covered 77.4 km at an average height of 10-20 m above ground or canopy level and an average ground speed of 35 kph. The survey crew consisted of a pilot and two spotters, one of which also acted as the data recorder. Spotters estimated visibility, located animals, counted, and identified the composition of animals for the recorder. Average visibility (1/2 strip width) was defined as the maximum lateral distance within which a deer could be spotted with relative (subjective) certainty. The recorder collected UTM points, tallied the count, composition, and visibility data. The data collected for each transect consisted of the time and climatic conditions at the start and end of the transect, lateral visibility at each turning point, the time of each sighting, the UTM location of the aircraft for each sighting, the number of animals in each group, and the composition of any group in which all animals could be identified. Data collected during the aerial survey did not contain distance or bearing measurements, and therefore were analyzed using only the strip transect density estimation technique (Progulske and Duerre 1964, Caughley 1977, Cochran 1977, Harwell et al. 1979, Mitchell 1986, Caughley and Sinclair 1994, Lancia et al. 1994 and Krebs 1998). The analysis was an unstratified, unequal area sampling design for 10 transects out of a possible 50 for the study area. Because the aerial survey did not follow roadways or natural boundaries, average visibility estimates (1/2 strip width) obtained from the aerial survey were thought to be more representative of natural habitat and therefore the study area as a whole. As such, aerial and ground transect visibilities (sample areas) were compared using linear regression to determine if the ground transects adequately represented habitat conditions on the study area.

Calculation of Strip Transect Population Estimates

The strip transect sampling method must meet four assumptions to make valid inference of population density from a set of counts: (1) no targets can go undetected within the sample area [detection $g(x) = 1$ for all distances $0 \leq x \leq w$; where w is the estimated 1/2 strip width], (2) sample area size must be accurately estimated, (3) all

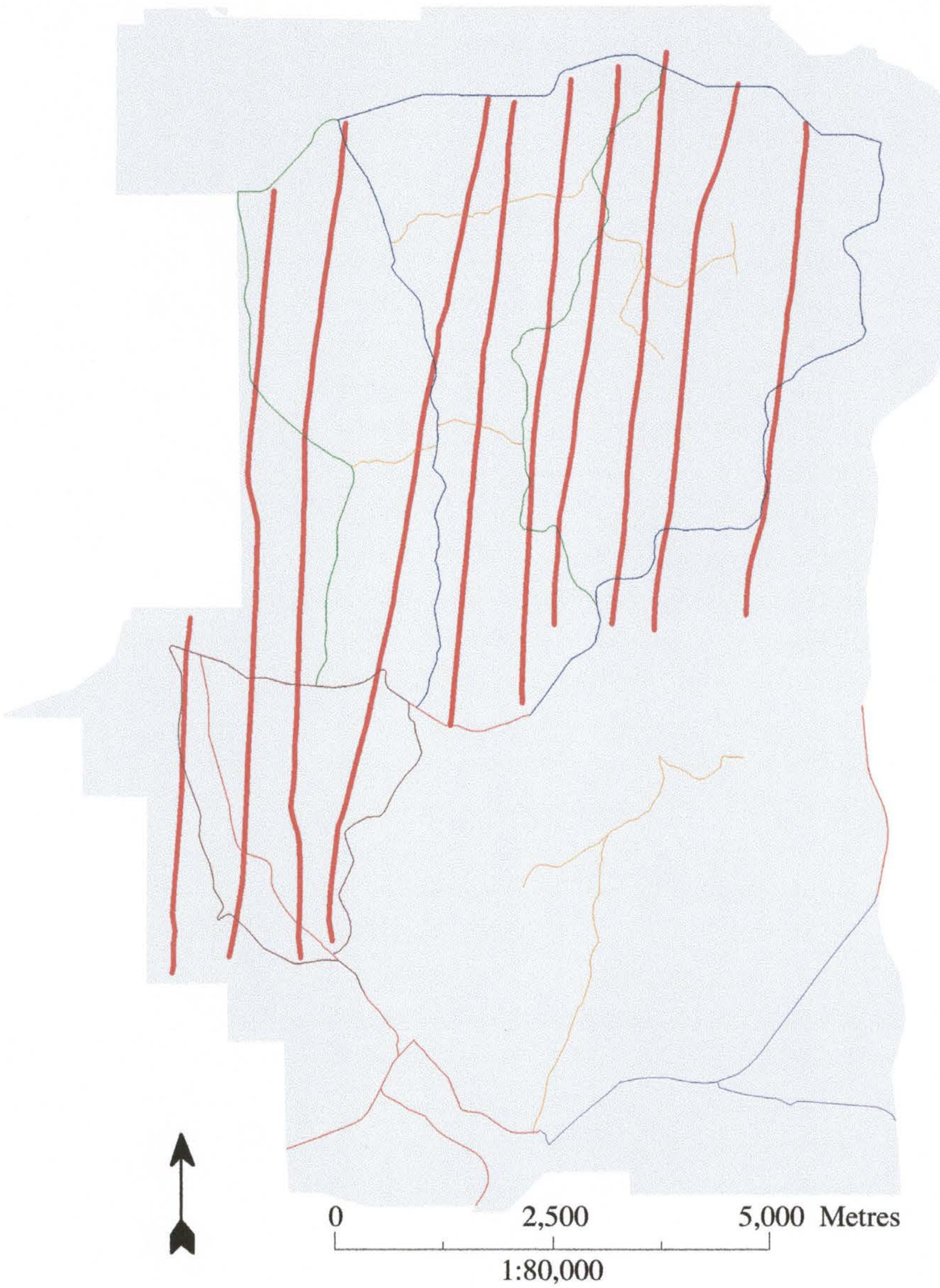

Figure 4. 1998 Camp Bullis helicopter survey route. Helicopter transect area is indicated in red.

observations must be independent, and (4) the sample must be representative of the area as a whole. For the ground transects, the same data sets were used to calculate both the line and strip transect density estimates. Because strip transect estimates require a fixed estimate of sample area size, average visibility (1/2 strip width) was determined for each spotlight strip transect prior to conducting the surveys (Progulske and Duerre 1964, Harwell et al. 1979, Mitchell 1986). Sample area size was calculated for each transect as twice the length of the transect multiplied by the average visibility (1/2 strip width). Spotlight strip transect population estimates were generated for using both stratified equal area and unstratified equal area sample designs. For the unstratified design, a single count from all four transects served as one sample, for a total of five samples per season. For the stratified sample design, population estimates were generated for each management unit using five equal area samples and the results combined to generate the final population estimate (Caughley and Sinclair 1994, Krebs 1998). Density was estimated as the number of individual animals per unit area surveyed using finite sampling theory:

$$\hat{D} = \left(\frac{n}{2l\hat{v}\beta} \right)$$

where $\hat{D}$ is the estimated density, *n* is the number of individuals counted in the sample, *l* is the length of the transect, $\hat{v}$ is the 1/2 strip width or average visibility, and β is the probability of detection (Caughley 1977, Cochran 1977, Caughley and Sinclair 1994, Lancia et al. 1994, Krebs 1998). Because strip transect surveys are designed to be complete counts of a limited sample area, β is assumed to be equal to 1. If the size of each management unit is known, multiplication of the density variables by the management unit area (*A*) generates an estimate of the population size ($\hat{N}$) for each unit as follows:

$$\hat{N} = \left(\frac{n}{2l\hat{v}\beta} \right) A$$

and therefore

$$\hat{N} = \hat{D}A$$

The variance of totals, coefficient of variation, and the 95% confidence limits then were generated using calculations for an equal area sample design (Krebs 1998). Spotlight strip transect and spotlight line transect results were plotted for comparison. A regression of strip transect versus line transect population estimate results was used to produce a correction factor for converting historic spotlight strip transect estimates into an equivalent line transect estimate. In addition, a population reconstruction was generated from annual harvest data to test for sample bias within each set of estimates (historic and converted). Historic spotlight strip transect population estimates and converted strip transect (line equivalent) population estimates then were compared to the population reconstructions using Wilcoxon's signed rank test (Zar 1996).

Calculation of Line Transect Population Estimates

Each data set used to calculate the strip transect density estimate also contained the ancillary distance and bearing data necessary to derive the line transect density estimate. Sightings were discarded if a distance or bearing could not be determined. The spotlight line transect sampling technique requires four assumptions to make valid inference of population density from a set of distance data (Burnham and Anderson 1984): (1) objects located directly on the transect line are detected with certainty [detection at distance zero $g(0) = 1$; some objects away from the line may go undetected], (2) perpendicular distances are accurately measured, (3) objects do not move in response to the observer prior to detection, and (4) detections are independent. The UTM location of the vehicle, the range, and the polar bearing to a sighting constitute the polar coordinates of that sighting in a Cartesian or X, Y plane. The Universal Transverse Mercator (UTM) coordinate system is a Cartesian plane designed to map geographic areas and is ideally suited for this use. In this non-linear line transect sampling method, animal UTM coordinates (sighting locations) were calculated from the polar coordinates as follows:

$$\Delta Y = r\cos\theta$$

and

$$\Delta X = r\sin\theta$$

where ΔY is the displacement in meters from the vehicle UTM position along the Y axis, ΔX is the displacement in meters from the vehicle UTM position along the X axis, r is the range from the vehicle to the sighted animal in meters, and θ is the polar bearing in degrees from the vehicle to the sighted animal relative to true north (Figure 3). The displacement values (meters) were added to the UTM position for the vehicle to produce the estimated UTM position for each sighting as follows:

$$Xs = Xv + \Delta X$$

and

$$Ys = Yv + \Delta Y$$

where Xv, Yv is the vehicle UTM position and Xs, Ys is the estimated sighting UTM position. Using these equations, the UTM positions for each sighting were calculated and formatted in a spreadsheet. The positions then were exported as X, Y, Z point coordinates in an ASCII text file format. The "X" and "Y" values represent the sighting UTM coordinates in meters. The "Z" values were a unique integer code (serial number) used to differentiate between points (sighting locations, vehicle locations, and transect lines) in the resulting ASCII files and raster GIS maps.

The UTM points collected while obtaining perpendicular visibility measurements for each transect were imported into the raster GIS as a set of X, Y, Z coordinates in ASCII text format. The USGS DRG for Camp Bullis then was covered with points from each transect using the COVER operation in the GIS. This operation created an overlay of UTM points for each transect on top of the USGS DRG map of the study area. The UTM points indicated the location of each transect line on the study area, and were interpolated to generate a "route map" for each transect.

Sighting and vehicle UTM point files (XYZ ASCII text files) were imported into the GIS to create the "vehicle and sighting map." The "route map" was covered with the "vehicle and sighting map" using the COVER operation and visually inspected for locational errors. Any vehicle points that occurred off the transect route were the result of DGPS error during data collection. This occurred due to either transmission or reception failure in the DGPS signal, and could be readily identified by errant vehicle UTM locations (vehicle locations that plotted off the known transect route). Because errors of this type were extremely rare, any errant points located by this practice were identified and discarded from the file.

Point files containing only sighting UTM locations were imported into the GIS to create a "sighting map." The "route map" for each transect was converted to a series of parallel lines out to a distance of 600 m on either side of the transect using the SPREAD operation in the GIS. This operation is analogous to building a border or buffer around the transect made up of consecutive polygons 1 m in width. This result was saved as the "raw distance map."

The "raw distance map" was combined with the "sighting map" using a COMBINE operation in the GIS to determine the perpendicular distance from the transect line to each sighting location. The COMBINE operation generates a unique cell value for each combination of input values from the operand map layers (Z values in each map file). Therefore, each sighting point in the "sighting map" is appended or concatenated with a distance interval value from the "raw distance map." As such, each sighting and its associated distance value were reported in the resulting "distance map" legend. This legend was saved as an ASCII text file. The "distance map" legend (ASCII text file) then was imported into a spreadsheet, sorted by perpendicular distance, and plotted as a histogram for inspection (Figures 5 and 6). This procedure served to illustrate the general shape of the distance data, and can be used to detect heaping or other defects if they exist within the data. Heaping is particularly common and occurs when observers arbitrarily round distances (to the nearest 5 or 10 m interval) or sighting angles (0, 15, 30, and 45 degrees are common) during data collection (Buckland et al. 1993). Plots were created using different frequency class intervals to determine a parsimonious grouping interval for the line transect (distance) data. This smoothed the data set and was used during the analysis to evaluate the fit of the selected model (probability density function)

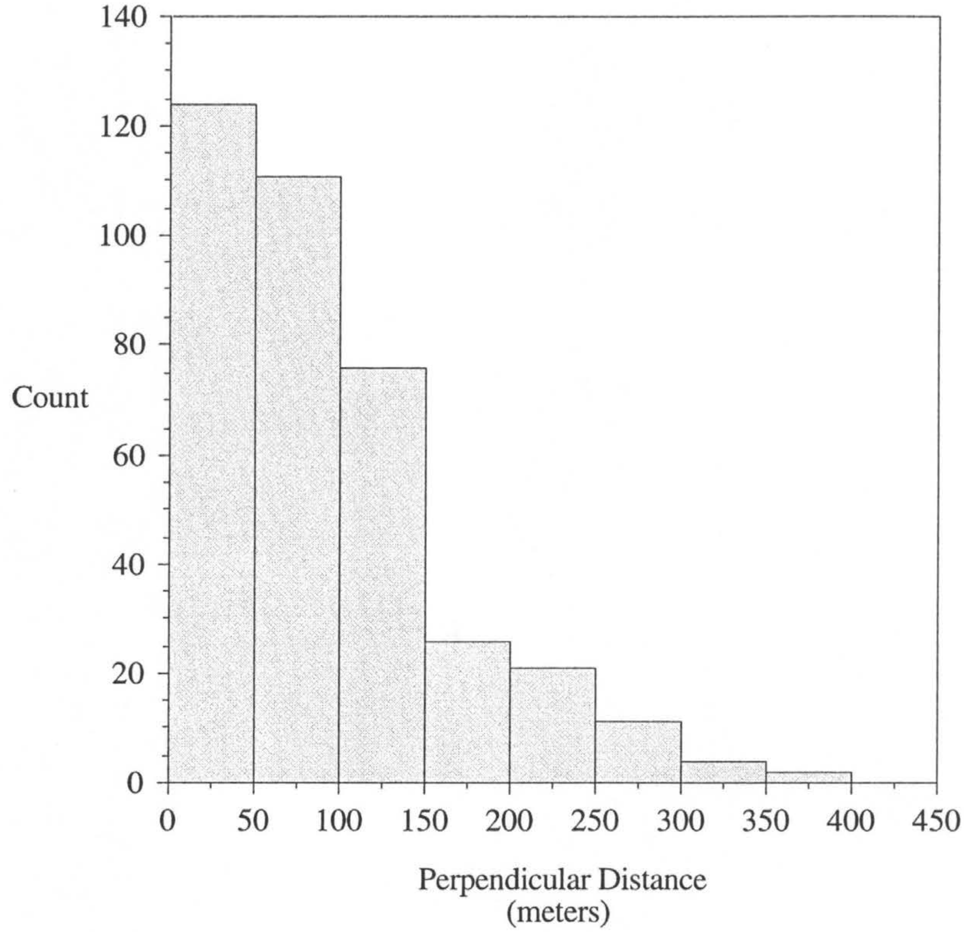

Figure 5. Histogram of perpendicular distances for all sighting locations (375) obtained during the 1997 Camp Bullis spotlight line transect surveys.The detection function shoulder occurs at approximately 50 m.

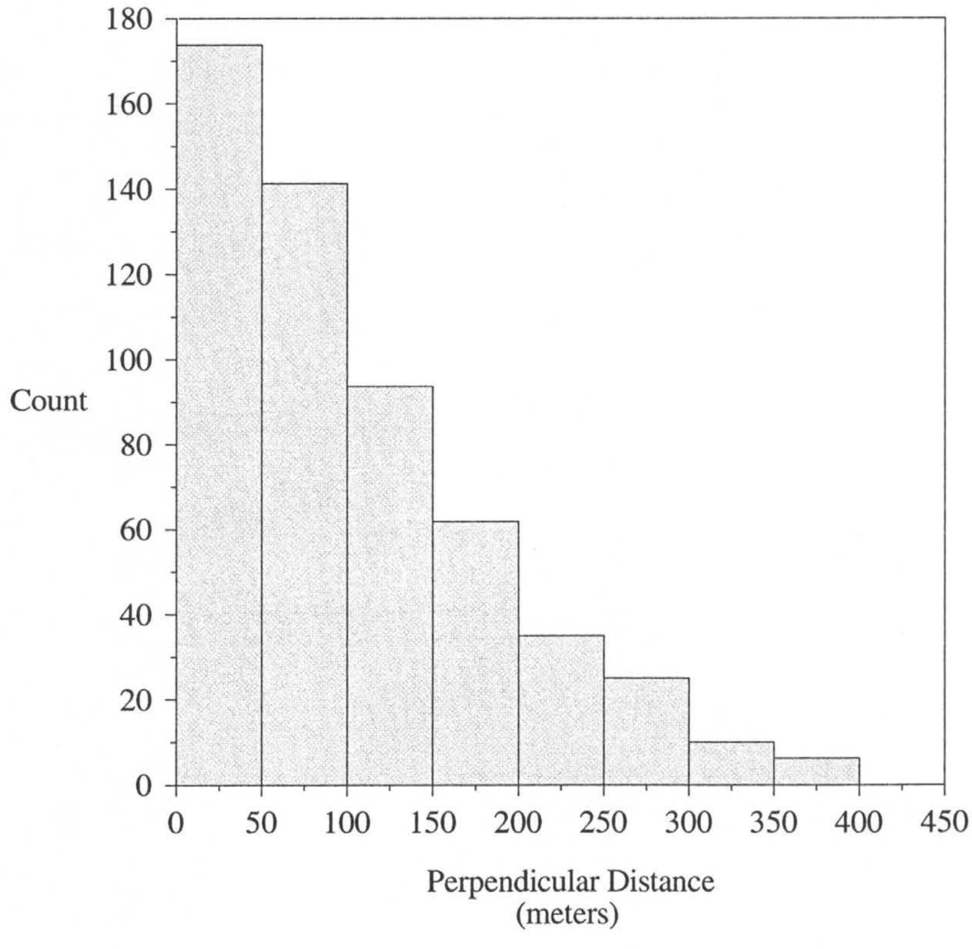

Figure 6. Histogram of perpendicular distances for all sighting locations (548) obtained during the 1998 Camp Bullis spotlight line transect surveys. The detection function shoulder occurs at approximately 50 m.

to the data using a Chi-squared goodness of fit (GOF) test (Buckland et al. 1993, Laake et al. 1996). A 50 m grouping interval was determined to be appropriate, as it adequately smoothed each histogram while maintaining the distinctive shape of the raw data.

The perpendicular distance data then were formatted for analysis in the DISTANCE and TRANSAN software packages. Both software packages allow for either direct keyboard input or batch processing of the information necessary for density estimation: number of transects in each stratum, transect length, number of sightings, the perpendicular distance of each sighting, and the number of animals in each group. Each package produces an estimate of density and the corresponding 95% confidence limits by modeling the probability of detection as a function of perpendicular distance from the transect line (Johnson and Routledge 1985, Routledge and Fyfe 1992a, Routledge and Fyfe 1992b, and Buckland et al. 1993).

In DISTANCE, each data set was stratified by management unit, truncated to 350 m, and analyzed as clusters (groups) using the exact perpendicular distances. Models were generated using each combination of key function and series expansion terms, up to a maximum of three terms. Goodness of fit testing for each candidate model was performed using Chi-squared analysis with seven, 50 m grouping intervals. Group size and encounter rates were analyzed within strata, while the probability density function was evaluated across strata (Buckland et al. 1993). Model selection was made based upon Akaike's Information Criterion or AIC (Akaike 1973), model shape (no spikes at $x = 0$), and goodness of fit test results.

In TRANSAN the density estimate for each data set was generated using the default parameters. As such, each data set was analyzed without stratification, without truncation, using 10 frequency class (grouping) intervals. Because TRANSAN produces only an estimate of cluster density and the corresponding 95% confidence intervals for cluster density, estimated group size obtained from the DISTANCE size bias analysis was used to calculate the final population estimates (multiplication by the DISTANCE group size). The 95% confidence limits for population size generated in this fashion did not contain the additional variation for the number of individuals within clusters, and therefore underestimates the true 95% confidence limits.

Specific directions for data analysis are provided with each software package

(Fyfe and Routledge 1992, Laake et al. 1996), and general recommendations for the modeling process can be found within the cited literature. A copy of the analysis parameters used with each program is provided in Appendices 5-8. Population estimate results from the spotlight strip transect and spotlight line transect analysis were plotted for comparison. A regression of strip transect versus line transect population estimate results was used to produce a correction factor for converting historic spotlight strip transect estimates into an equivalent line transect estimate. In addition, a population reconstruction was generated from annual harvest data to test for sample bias within each set of estimates (historic and converted). Historic spotlight strip transect population estimates and converted strip transect (line equivalent) population estimates were compared to the population reconstructions using Wilcoxon's signed rank test (Zar 1996).

Generation of a Conversion Factor For Historic Surveys

A conversion factor was obtained by non-linear regression of strip transect versus line transect population estimates obtained during concurrent sampling in 1997-1998. The same data sets were used to calculate both the strip and line transect estimates, thereby providing a direct comparison between methods. The conversion factor was applied to historic strip transect population estimates to generate an equivalent (in relative magnitude) line transect population estimate. This assumed the variables (detectability variables) which created the difference between the two methods were relatively constant and could therefore be applied to historic data. While this assumption may be arguably viewed as weak or unattainable, the conversion factor generated under this assumption provided a means to test for gross bias in the historic strip transect population estimates. As such, reconstructed populations were generated for both the historic strip estimates and the converted historic strip estimates using annual harvest data. Reconstructed populations were created using a population estimate for the initial date (1987), followed by consecutive addition of annual fawn production estimates and subtraction of annual harvest values over time (1988-1993). Fawn production was estimated using lactation rates of harvested does > 2 year of age (Harmel and Litton 1981, Ramos 1988). Reconstructed population trends were compared with the parent population estimate using Wilcoxon's paired sample test (Zar 1996).

Evaluation of Survey Period

Review of the historic survey data indicated that survey dates for the annual population estimate varied among years. Counts of deer from each transect were available from 1993-1998, and were evaluated to determine the affects of sampling period on counts. Spotlight transect counts were transformed (square root plus 5) to obtain normality and homoscedasticity (Zar 1996). Historic counts from 1993-1998 were analyzed by ANCOVA to determine the affect of sampling date on counts from each transect (Zar 1996). Spotlight transect counts collected in summer and autumn of 1997 were analyzed by 2-factor ANOVA to determine the affect of sampling period (summer versus autumn) on counts from each transect when population size was assumed to be constant (Zar 1996).

Strip and Line Transect Survey Efficiency

Strip transect and line transect population estimates obtained during the 1997-1998 study period were plotted as cumulative frequency graphs to determine effects of 1/2 strip width (average visibility used to determine sample area size) and cutpoint (perpendicular detection/truncation distance for inclusion of counts in the estimate of population size) on estimate bias and survey efficiency. Line transect survey data from 1997-1998 was compared with historic strip transect survey data collected during 1990-1993 to determine the relative survey efficiency between methods. In each case, the data selected to represent the method was collected by the same survey crew, over the same spotlight lines, using a standardized procedure. These data were normalized to alleviate the effects of differences in animal density during the survey periods. Efficiency data were compared using a Mann-Whitney test (Zar 1996). The effects of transect length and number of deer counted on survey duration for each method was compared using Partial Correlation Analysis (Zar 1996). Fisher's r to z Test was used to determine significance for each variable (Zar 1996).

Spotlight Survey of Simulated Deer

Surveys of simulated deer were conducted to compare spotlight strip and line transect population estimates using an artificial population of known size and distribution

(Whipple et al. 1994). The parameters used for the simulation represented the minimum recommended number of replications, and the minimum recommended number of sightings per transect, for density estimation by line transect theory (Routledge and Fyfe. 1992a, Buckland et al. 1993). The simulation was conducted along the SW transect survey route (Figure 2) to provide comparable habitat conditions. Simulated deer were constructed using 66 cm x 40 cm cardboard targets with reflective tape for "eyes." A spreadsheet was used to distribute 62 simulated deer randomly along the 11.9 km transect, out to a maximum of 240 m in perpendicular distance (1/2 strip width). The number of simulated deer positioned at each location (1-4) was randomly determined. Wooden survey stakes were driven securely into the ground and simulated deer were stapled at a height of approximately 100 cm. All simulated deer were positioned to face the transect. Once the 62 simulated deer were distributed, 39 simulated deer (62.9%) in 16 groups were actually visible from the spotlight route. The remaining 23 simulated deer (37.1%) were completely hidden by either vegetation or terrain features. Target condition and visibility were verified prior to conducting each survey. Four spotlight surveys were conducted using different survey crews with no prior spotlight line transect survey experience. The methodology used for the simulated surveys was identical to that used for the actual white-tailed deer surveys on Camp Bullis. Sighting location estimates obtained from the spotlight line transect method were compared to UTM positions collected independently by Camp Bullis personnel after the surveys were completed. Positional error (in the X and Y planes) and total displacement was calculated for each sighting and used to assess the accuracy of the location estimates obtained using the new spotlight line transect method. A cumulative frequency graph was generated for comparison of the line transect and strip transect estimation results.

Estimation of Habitat Use

Sighting locations collected for white-tailed deer during the 1997-1998 surveys were used to analyze habitat selection within the study area without identification of individual animals (Johnson 1980, Thomas and Taylor 1990, Knick and Dyer 1997). Because sighting location data were not corrected for differences in geographic detectability (visibility), diel period, or season, the map of predicted habitat use is more properly defined as a map of predicted sighting locations for white-tailed deer on Camp Bullis during the survey period. Regardless, if all sightings are considered to have occurred within an animals home range, the data represent the general selection of habitat variables for home range, within the study area, during the survey period and therefore are comparable in utility to telemetry data (Knick and Dyer 1997). Ordinal categories for six macro habitat variables and one nominal habitat variable were developed for the study area: aspect, slope, elevation, canopy density, proportion, distance to water, and soil type. GIS maps for aspect, slope, and elevation were derived from a USGS 1:24,000 scale digital elevation model (DEM) for the study area (Berry 1993). Proportion is a comparative index to interspersion and juxtaposition that can be measured in a GIS environment (Berry 1993). To create the proportion map, canopy coverage at 1 m resolution was obtained by density slicing (Jensen 1996) six latitudinal sections of color infrared, digital orthophoto quads (CIR DOQs) which covered the study area. Latitudinal sectioning was required to offset the skewed spectral resolution inherent to the CIR orthophotographs used to create the DOQs. After density slicing each section to isolate foliar canopy, the images were reassembled to produce a thematic map of canopy coverage. Maps of proportion and canopy density then were derived in the GIS using the map of canopy coverage for the study area (Berry 1993). The distance to water map was created by combining digitized points for natural water sources and UTM positions for man-made water sources on Camp Bullis. The soil map was derived from the 1995 U.S. Department of Agriculture, Natural Resources Conservation Service, 1:24,000 scale Soil Survey Geographic (SSURGO) data base for Bexar County, Texas. The SSURGO vector map was imported into a vector GIS (MapGraphix), and polygon points for each soil type were exported as an X, Y, Z ASCII text file. The polygon point files then were imported into the raster GIS and interpolated to create the map of soil types for the study area.

The map for each habitat variable was combined with the "sighting maps" for the 1997-1998 surveys using the COMBINE operation in the raster GIS. The intersection of habitat variables and sighting locations were contained in the resulting map legends. GIS results were exported to a spreadsheet as ASCII text files for analysis of habitat use versus availability (Neu et al. 1974, McClean et al. 1998). The magnitude and sign of the difference between use and availability for each habitat variable was used to create a

Boolean map (Berry 1993) of predicted habitat use on Camp Bullis during the survey period.

CHAPTER 5

RESULTS

Evaluation of Transects

It was speculated that inaccurate visibility (sample size) estimates were partially responsible for the bias in historic population estimates. Different survey crews estimated the visible area for each original transect from 1993-1996. We measured visibility on each original transect in 1997, and a one sample t-test was used to compare the accuracy of estimates among these survey crews. The measured visible area for each transect was used as the hypothesized mean in each case (Table 1). No statistical difference between the measured and estimated visible areas (sample size) was detected for any transect [P ($t_{0.05(2),3}$) > 0.05] among these survey crews.

Inspection of the historic spotlight transects (Figure 2) revealed a potential for double counts on two transects (old NW and old SW), while limited access to training areas prevented effective use of a third transect (old SE). The old NW transect line historically overlapped the NE transect line. Thus, a section of the old NW transect was eliminated, leaving the remainder of the original transect line. The new NW transect line now exists in two sections. The NE transect was not altered. The old SW transect doubled back upon itself around the Salado Creek flood containment basin, an area of high deer density and high visibility, creating the potential for double counts of individuals or groups. The eastern 1/3 of the old SW transect traversed an area that now has limited access due to military training, and did not adequately represent the poorer habitat areas located within the Glen Rose Archery Management Unit. The new SW transect was routed to improve access, remove the potential for double counts, and to provide a more representative sample for the management unit. The new SW transect now circumnavigates the management unit using approximately 1/2 of the original transect and places the entire transect upon non four wheel drive (4WD) roadways. The western and southeastern ends of the old SE transect were located within military

Table 1. One sample t-test results comparing measured versus estimated visibilities (sample area) for the Camp Bullis 1993-1997 spotlight surveys. The 1997 measured visible areas were used as the hypothesized mean for each transect.

Statistic	Old SW	Old SE	Old NW	NE
Hypothesized Mean (ha)	175	97	204	149
Estimated Mean (ha)	159.2	98.6	200.4	158.9
Degrees of Freedom	3	3	3	3
t-value	-1.5	0.4	-0.2	1.4
P-value	0.222	0.686	0.823	0.261
95% Lower CI	126.4	86.9	153.9	135.8
95% Upper CI	191.9	110.4	246.9	182

training areas that contained roads only passable by 4WD vehicles. These sections of the old SE transect were eliminated. The new SE transect was routed to better roadways with improved access. In each case the new transect lines were positioned to cover the same general habitat on major roads, with non-overlapping sample areas, and with fewer access restrictions. The new transect lines were plotted, measured, and the routes were logged by DGPS for future use.

The new SW, NW, and SE transects contained slightly less visible area than the historic transects, but maintained similar habitat coverage (Figure 7). The new SE transect differed appreciably in sample area from the original transect, while the new NE, NW, and SW transect lines each contained similar sample areas when compared to the original transects. Visibility measurements and histograms for each transect were plotted to produce a record of visibility during the study period (Appendices 1-4). The visibility graphs for each transect are analogous to a "fingerprint" and can be compared with future visibility measurements to determine the location and amount of any change in visible area along a transect.

An ANOVA, with a linear regression through the origin and 95% confidence intervals for the visibility mean, was used to compare transect visibility (sample size) versus route length for each new spotlight transect and the helicopter transect under the null hypothesis of no linear relationship between length of transect and visibility (Figure 8). The null hypothesis was rejected [$P(F_{0.05(1),1,4} \geq 141.231) = 0.0003$] and the coefficient of determination for the regression indicated that 97.2% of the variability in visible area (sample area) could be explained by transect length. The NE transect showed the greatest deviation from the regression line, due to dense vegetation which lowered visibility along the transect. Average visibility for the NE transect was still within the 95% confidence intervals for the regression mean. The helicopter survey route crossed the entire study area and was not dependent on roadways. It was therefore more representative of the study area as a whole, and as such was the appropriate standard of comparison for all spotlight transects used on Camp Bullis. The ANOVA and regression results indicated the new transect lines were similar in visibility per unit length, and therefore comparable in habitat representation to the 77.4 km helicopter survey conducted in 1998.

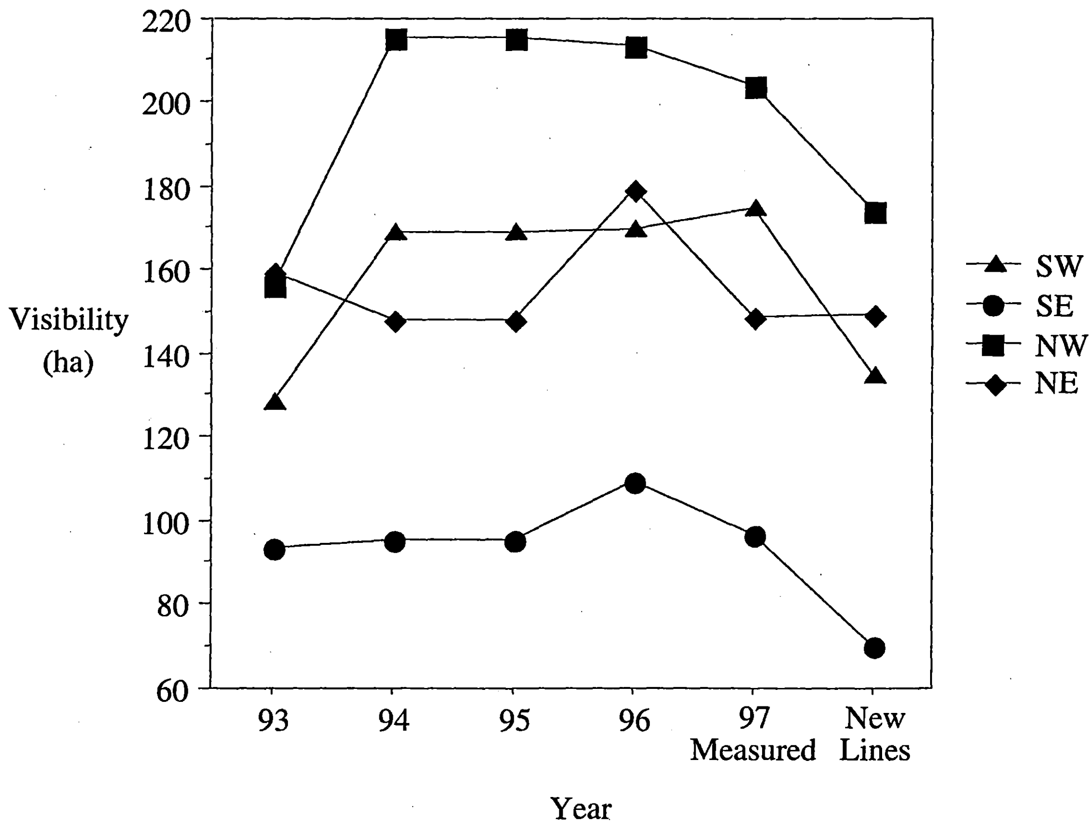

Figure 7. Graph of estimated and measured visibilities (sample area) for the historical spotlight transects on Camp Bullis (1993-1997). New transect lines were plotted for the study, and results are shown for comparison with the historical transects.

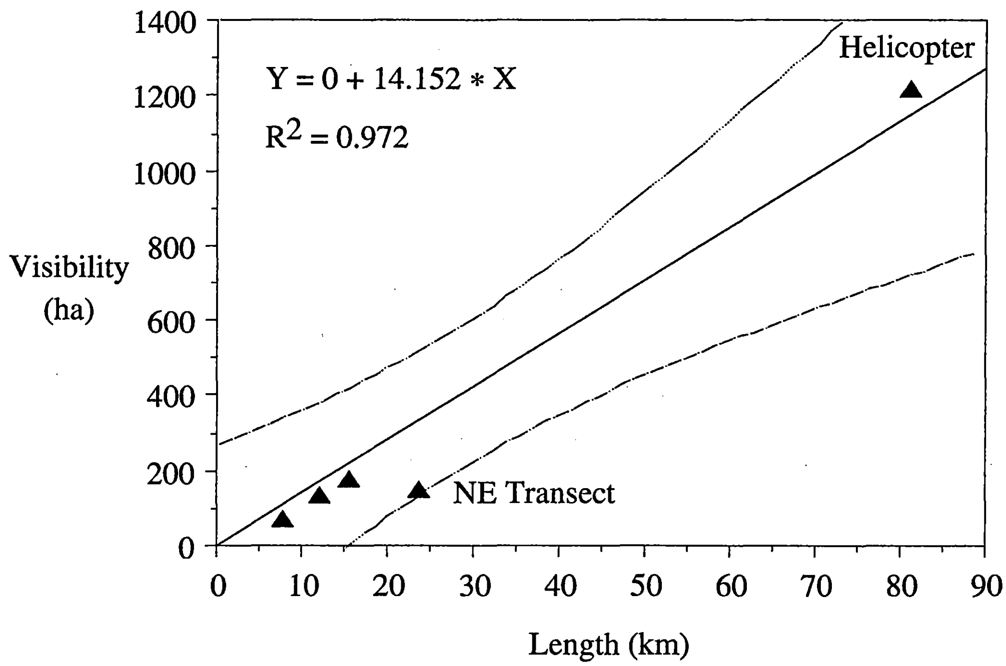

Figure 8. Comparison of visibilities between the 1997-1998 spotlight transects and the 1998 helicopter transects on Camp Bullis. The plot shows a linear regression with 95% confidence intervals for the visibility (ha) mean.

Comparison of Deer Survey Population Estimates

Population estimates for the 1997-1998 white-tailed deer surveys were calculated using strip transect and line transect estimation techniques. The four spotlight transects totaled 58.2 km in length with an average perpendicular visibility of 45 m. A total of 684 deer in 375 sightings were counted in the 1997 autumn survey with an average range and an average perpendicular distance of 130 m and 93 m, respectively. The majority of the sightings, 235 (62.7%) or 400 deer, were located within 100 m of the transect at an average range of 88 m and average perpendicular distance of 50 m. A total of 1176 deer in 548 sightings were counted in the 1998 summer survey with an average range and average perpendicular distance of 145 m and 105 m, respectively. The majority of the sightings, 315 (57.5%) or 577 deer, were located within 100 m of the transect at an average range of 91 m and an average perpendicular distance of 48 m. The 1998 helicopter consisted of ten transects which totaled 77.4 km in length with an average visibility (1/2 strip width) of 75 m. A total of 47 deer in 29 sightings were counted on the combined transects, which covered 1161.1 hectares.

Although the same data sets were used to obtain the spotlight strip and line transect estimates, large differences were apparent (Tables 2 and 3). In the ground surveys, average perpendicular distance (Figure 3) was greater than the average visibility (1/2 strip width) each year. This indicated that deer sightings were not uniformly distributed within the sample areas. The strip transect population estimates were 3 to 4 times higher than the associated line transect estimates. The aerial transect estimate was approximately 3 times lower than the line transect estimates, and a full order of magnitude lower than the associated strip transect estimates. Clearly one or more of the estimates were biased, and the possible sources for this bias are limited. Because sample area size was fixed in the strip transect population estimates, negative bias could only occur due to overestimation of sample area size and/or overestimation of β (probability of detection). Positive bias could only occur due to underestimation of sample area size and/or underestimation of β. Error in either variable would effect the population calculations proportionally.

Comparisons between the 1993-1998 survey crews indicated no significant differences in estimation of average visibility and therefore sample area (Table 1). As

Table 2. Population estimates from the 1997 Camp Bullis white-tailed deer surveys. Line transect estimators are annotated by software and model type. The coefficient of variation (%CV) and degrees of freedom (df) were not reported by TRANSAN. An asterisk (*) identifies data stratified by management unit prior to analysis.

Type	Cut Point	Count	Estimate	%CV	df	95% LCL	95% UCL
Strip Transect*	None	684	2793	17.22	14	2323	3264
Strip Transect	None	684	2922	20.50	4	2243	3602
DISTANCE, HN*	350	677	930	13.13	32	713	1214
DISTANCE, Haz*	350	677	880	12.34	26	683	1133
DISTANCE, HN	350	677	855	20.68	26	561	1303
DISTANCE, Haz	350	677	826	20.22	23	546	1250
TRANSAN	None	684	830	na	na	625	1204

Table 3. Population estimates from the 1998 Camp Bullis white-tailed deer surveys. Line transect estimators are annotated by software and model type. The coefficient of variation (%CV) and degrees of freedom (df) were not reported by TRANSAN. An asterisk (*) identifies data stratified by management unit prior to analysis.

Type	Cut Point	Count	Estimate	%CV	df	95% LCL	95% UCL
Strip Transect*	None	684	4820	19.35	14	4165	5476
Strip Transect	None	684	5024	11.77	4	4349	5700
DISTANCE, HN*	350	1158	1295	6.90	41	1127	1489
DISTANCE, Haz*	350	1158	1287	8.55	92	1086	1525
DISTANCE, HN	350	1158	1241	17.99	22	857	1798
DISTANCE, Haz	350	1158	1236	18.69	25	844	1810
TRANSAN	None	1176	1221	na	na	928	1692
Helicopter	75	47	457	7.93	9	321	593

such, all survey crews were accurately estimating what they believed to be the total sample or visible area. When counts were made, it was assumed that any animal seen from the transect must be within the visible area. As such, all detected animals were included in the count. Because the new method allowed for the collection of accurate perpendicular distance measurements to each sighting, both data sets could be analyzed as a continuous function of population estimate versus perpendicular distance to each sighting (Figures 9 and 10). Plot data were generated using the strip transect technique where sample area size (based upon average visibility) was held constant for calculating the population estimate, and the search area was a growing strip centered on the transect line. As the search area was incrementally increased in width from zero to 600 m, animals were added into the population estimate as they were encountered by the growing search polygon. With the sample area held constant, population estimates reached a functional limit as the search area grew in perpendicular distance. It was evident from this analysis that the population estimate was a function of strip width or detection area. The bias in the strip transect estimates relative to the line transect estimates occurred because the estimated sample area was smaller than the area over which the animals were detected. Unfortunately, many investigators have claimed that the bias inherent to the spotlight strip transect population estimates are irrelevant when results are used as a relative index (Caughley 1977, Lancia et al. 1994). Examination of a combined plot of the 1997 and 1998 results (Figure 11) indicated that the relative difference between each data set increased with increasing perpendicular distance. As such, if the data were used as a relative index, the difference in estimates between years would not equal the change in population size for all distances along the X axis. The only point along the X axis where the change in actual population size equaled the relative difference between indices occurred at the point of average visibility. Again, this analysis would not be possible without the additional perpendicular distance data collected using the spotlight line transect method.

This problem of incongruence between sample area and count area developed because visibility measurements were taken systematically along the transect route, including the closed habitat areas where deer sightings were infrequent. This decreased the estimate of average visibility, and therefore sample area size, relative to the area over

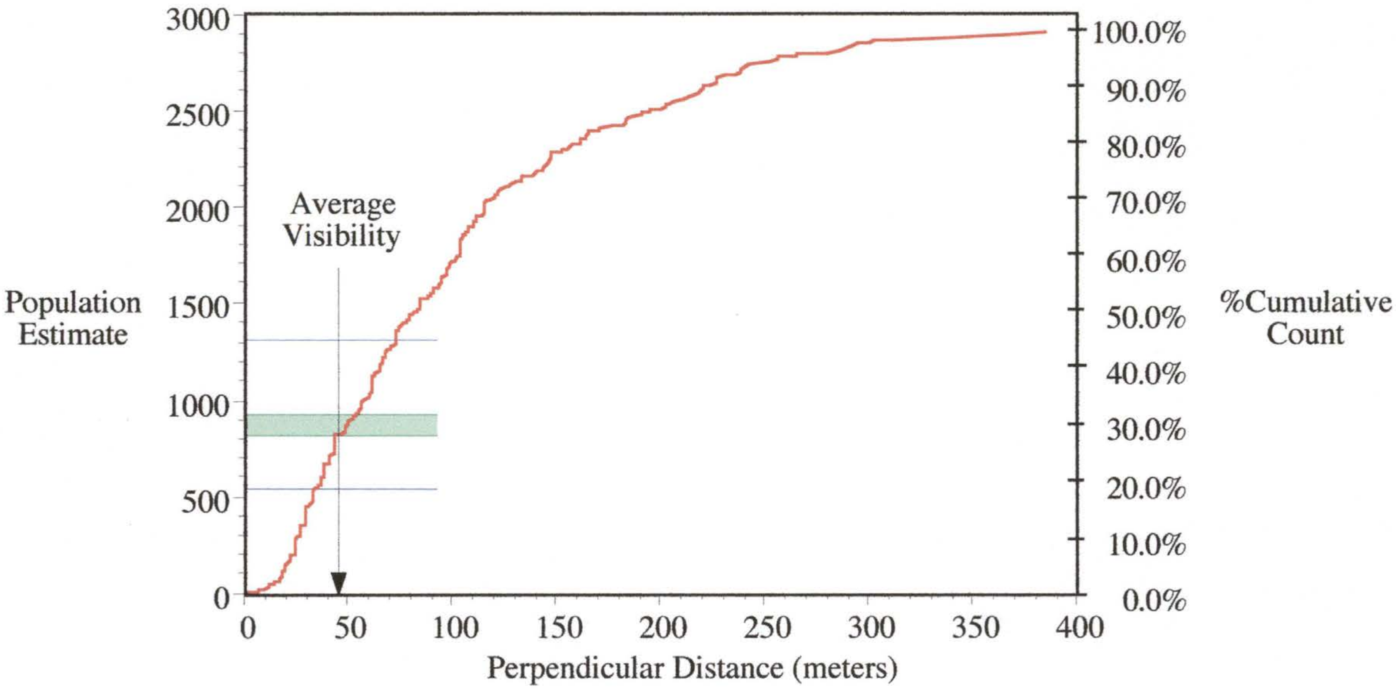

Figure 9. Cumulative frequency graph of the 1997 white-tailed deer surveys. The data are plotted as a continuous function of population estimate versus perpendicular distance to each sighting. The sample area size is held constant, and was determined by the average perpendicular visibility (45 m) for all spotlight lines (58.2 km) on Camp Bullis. Blue lines indicate the 95% confidence limits for all line transect estimates. The green bar indicates the range for all line transect estimates.

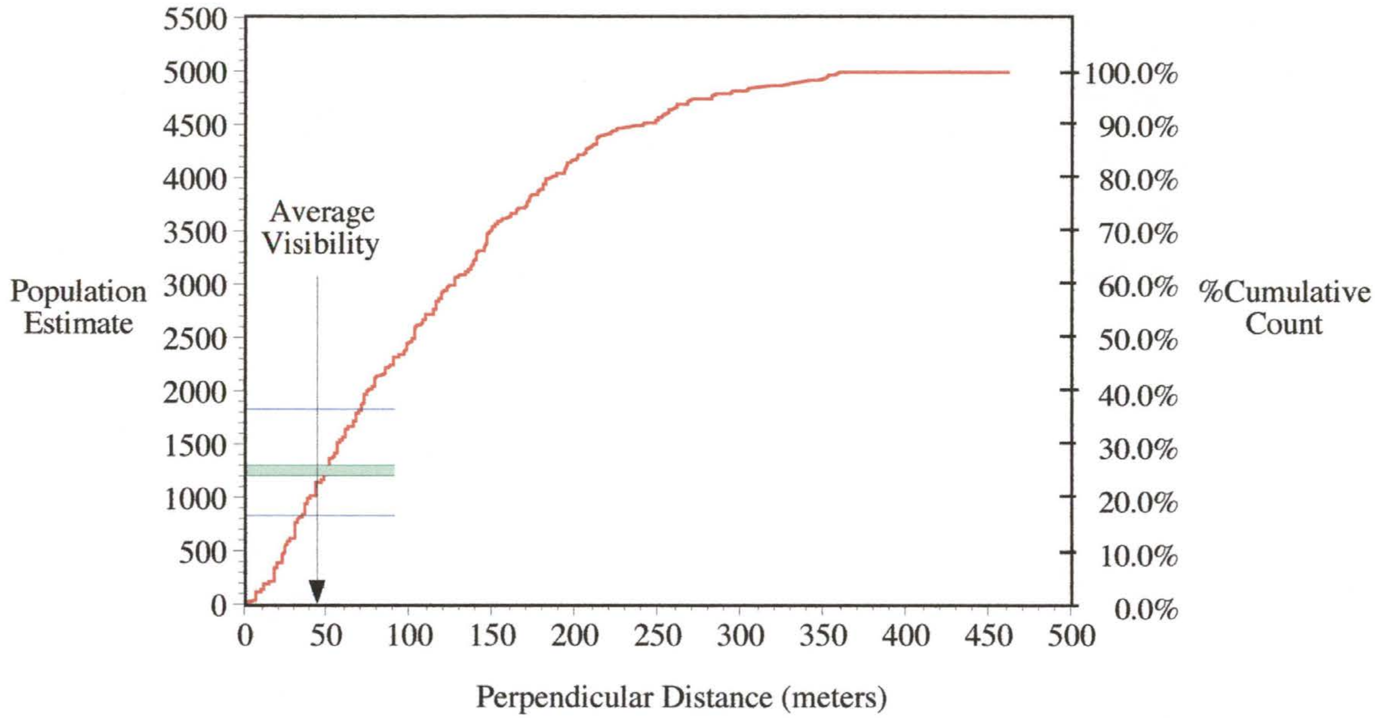

Figure 10. Cumulative frequency graph of the 1998 white-tailed deer surveys. The data are plotted as a continuous function of population estimate versus perpendicular distance to each sighting. The sample area size is held constant, and was determined by the average perpendicular visibility (45 m) for all spotlight lines (58.2 km) on Camp Bullis. Blue lines indicate the 95% confidence limits for all line transect estimates. The green bar indicates the range for all line transect estimates.

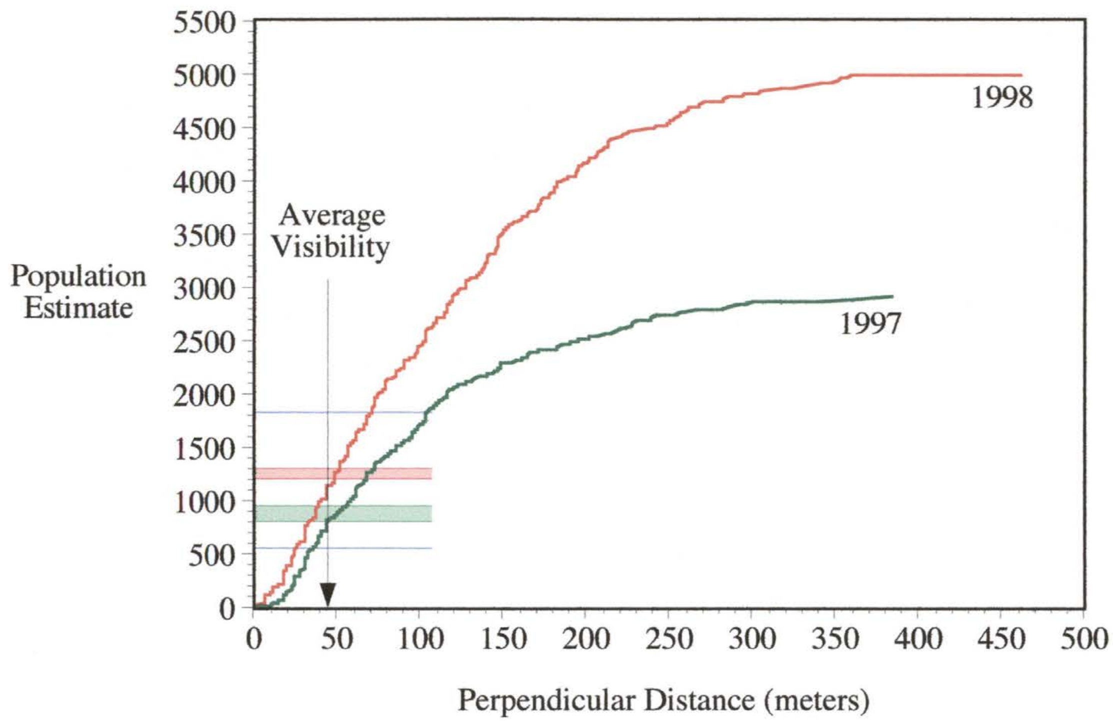

Figure 11. Cumulative frequency plot of the 1997 (green) and 1998 (red) white-tailed deer surveys. The data are plotted as a continuous function of population estimate versus perpendicular distance to each sighting. The sample area size is held constant, and was determined by the average perpendicular visibility (45 m) for all spotlight lines (58.2 km) on Camp Bullis. Blue lines indicate the 95% confidence limits for all line transect estimates. The green and red bars indicate the range for the line transect estimates within each year.

which the majority of animals actually were counted. As such, the sample area size used to calculate population estimates was negatively biased. Unfortunately, estimating visible area by any other means would likely be subjective, and therefore, variable between surveyors. An alternative would be to stratify each transect by sighting frequency and perpendicular visibility, but the additional effort required to generate weighted correction factors would be inefficient and prohibitive. Another possible solution would be to truncate the distance over which animals are counted by the inclusion of a "cutpoint" (a distance beyond which no animals are included in the count). The problem then becomes one of objectively determining the appropriate cutpoint distance for each survey. Review of the analysis for 1997 and 1998 data indicated that the population estimates converged at the point where cutpoint distance was equal to the average visibility or 1/2 strip width (Figures 9, 10, and 11). This suggest that cutpoint distances greater than the 1/2 strip width would result in positive bias, while cutpoint distances less than the 1/2 strip width would result in negative bias. So, while cutpoints of 250 m often are recommended based upon effective illumination by spotlights (Harwell and Gore 1981, Mitchell 1986), the analysis indicated that any cutpoint (perpendicular distance) used to truncate animal detections must be equal to the 1/2 strip width used to calculate the sample area. Any incongruence between sample area and count area would result in bias. Thus, when sample area was allowed to vary with strip width, population estimates decreased as strip width increased beyond the point of average visibility (Figure 12), but the curves were approximately parallel between years. In each case, the population estimate changed at a functional rate defined by the probability of detection (β) and the increase in count per unit area. As such, the estimates of population size reached a maximum at the point of average visibility, and decreased for all distances appreciably greater than or less than the average visibility. This type of plot can not be generated without the additional perpendicular distance data collected using the spotlight line transect method.

Historic and Reconstructed Population Estimates

Strip and line transect population estimates obtained for each management unit during the 1997-1998 surveys were compared. Spearman's Rank Correlation indicated that the two estimates were significantly correlated [P ($rs_{0.05(2), 6} \geq 0.943$) = 0.0350]. The

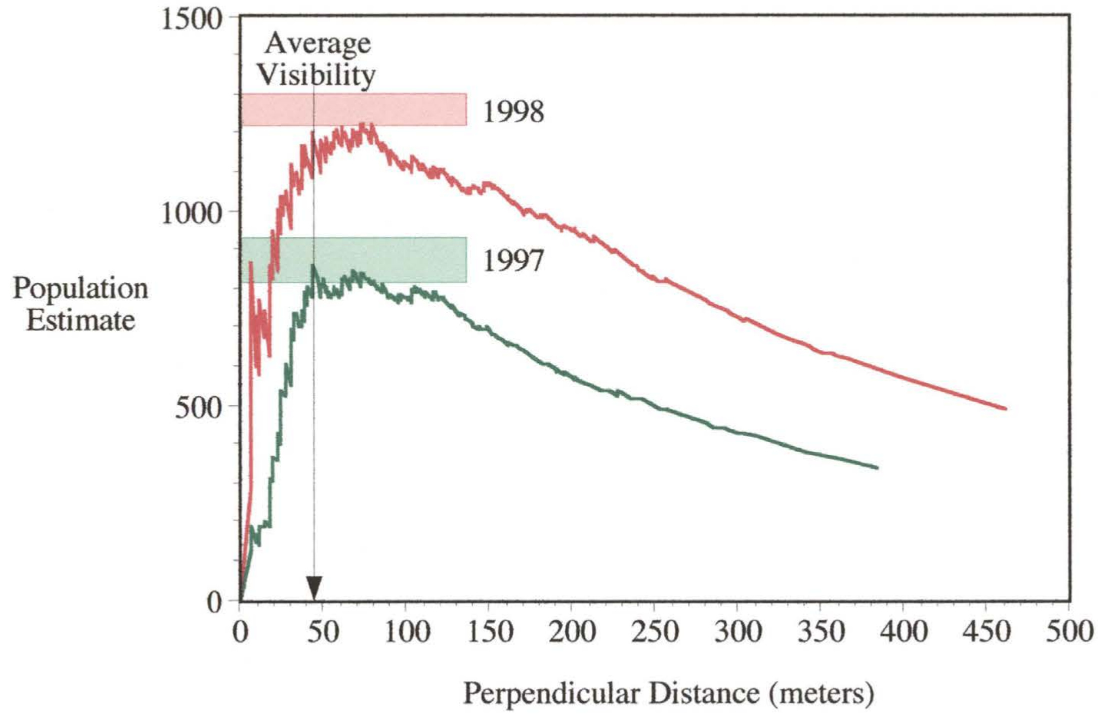

Figure 12. Cumulative frequency plot of the 1997 (green) and 1998 (red) white-tailed deer surveys. The data are plotted as a continuous function of population estimate versus perpendicular distance to each sighting. The sample area size is allowed to vary with perpendicular distance for all spotlight lines (58.2 km) on Camp Bullis. The green and red bars indicate the range for the line transect estimates within each year.

non-linear regression provided an equation for relating the two estimates (Figure 13), which was used to convert historical spotlight strip transect population estimates into a line transect equivalent.

Interviews with hunters and Camp Bullis staff indicated that strip transect survey results predicted the presence of more animals than were actually available for harvest (Pierce and Baccus 1999). Overestimation of the white-tailed deer population was demonstrated by comparison of historic spotlight strip transect estimates and reconstructed populations derived from harvest and survey data (Figure 14). Data from 1987-1998 were selected to span the period containing a large population decline. Results from a Wilcoxon's paired sample test indicated a significant difference between the historic strip transect population estimate and the reconstructed population [P ($T_{0.05(2),12} \leq 0$) = 0.0033]. As such, the strip transect population estimates did not correlate with recruitment and harvest data collected each year. The progressive expansion of the reconstructed population, over the period examined, could only occur if recruitment rates were consistently greater than harvest rates each year. If this were the case, the historic population decline could not have occurred. Hunters, Army personnel, and base staff were interviewed and all agreed that a large die-off of animals could not have gone undetected, due to the intensive training effort on the installation. If we assume the spotlight strip transect data was positively biased, and that the relative bias was constant, then the survey data indicated a population decline of unknown magnitude during the period. The population declined likely occurred as a result of over harvest, due to positive bias in the strip transect population estimates.

Application of the conversion factor to the historic spotlight strip transect estimates yielded a reconstructed population with some of the positive bias removed (Figure 15). The trends for both the converted estimate and the reconstructed population were the same upon visual examination. Results from the Wilcoxon's paired sample test confirmed that the converted estimate was not significantly different from the reconstructed population [P ($T_{0.05(2),12} \leq 23$) = 0.3739]. The converted spotlight strip transect estimates therefore more accurately depict the demographic events which occurred during 1987-1998. When harvest rates were greater than the corrected estimate of recruitment, the population decreased. When harvest levels were reduced below the

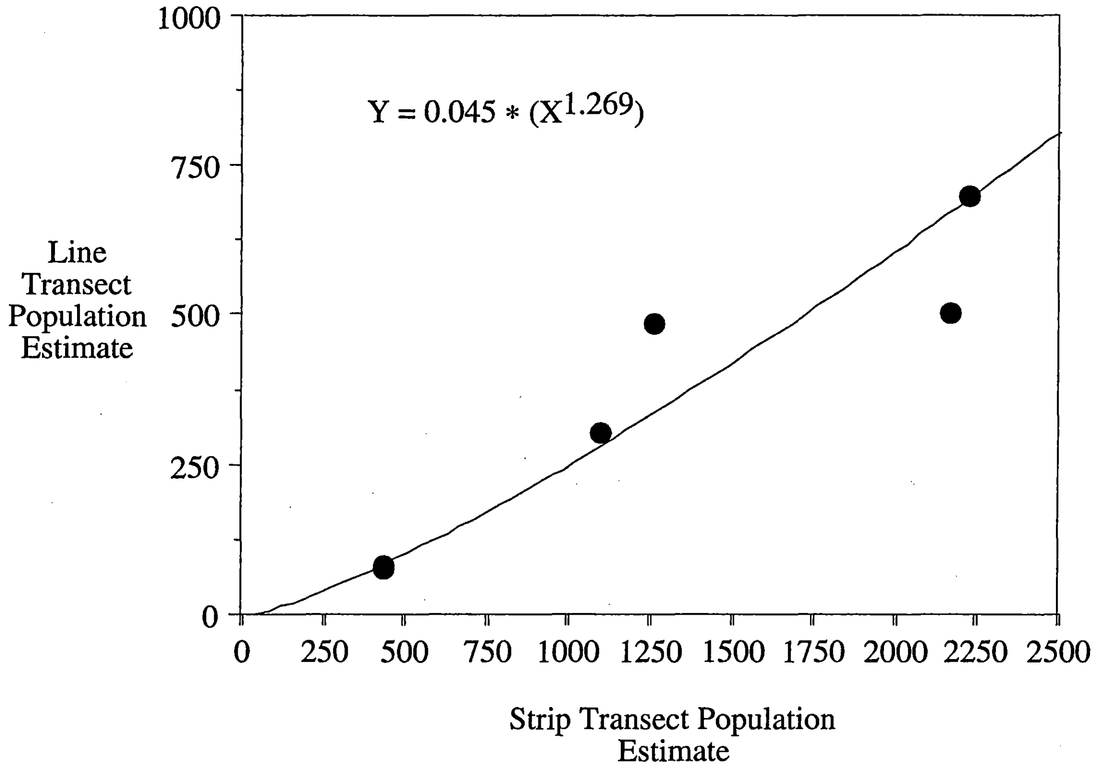

Figure 13. A non-linear regression of spotlight strip transect versus spotlight line transect population estimates for each of three management units surveyed during 1997-1998.

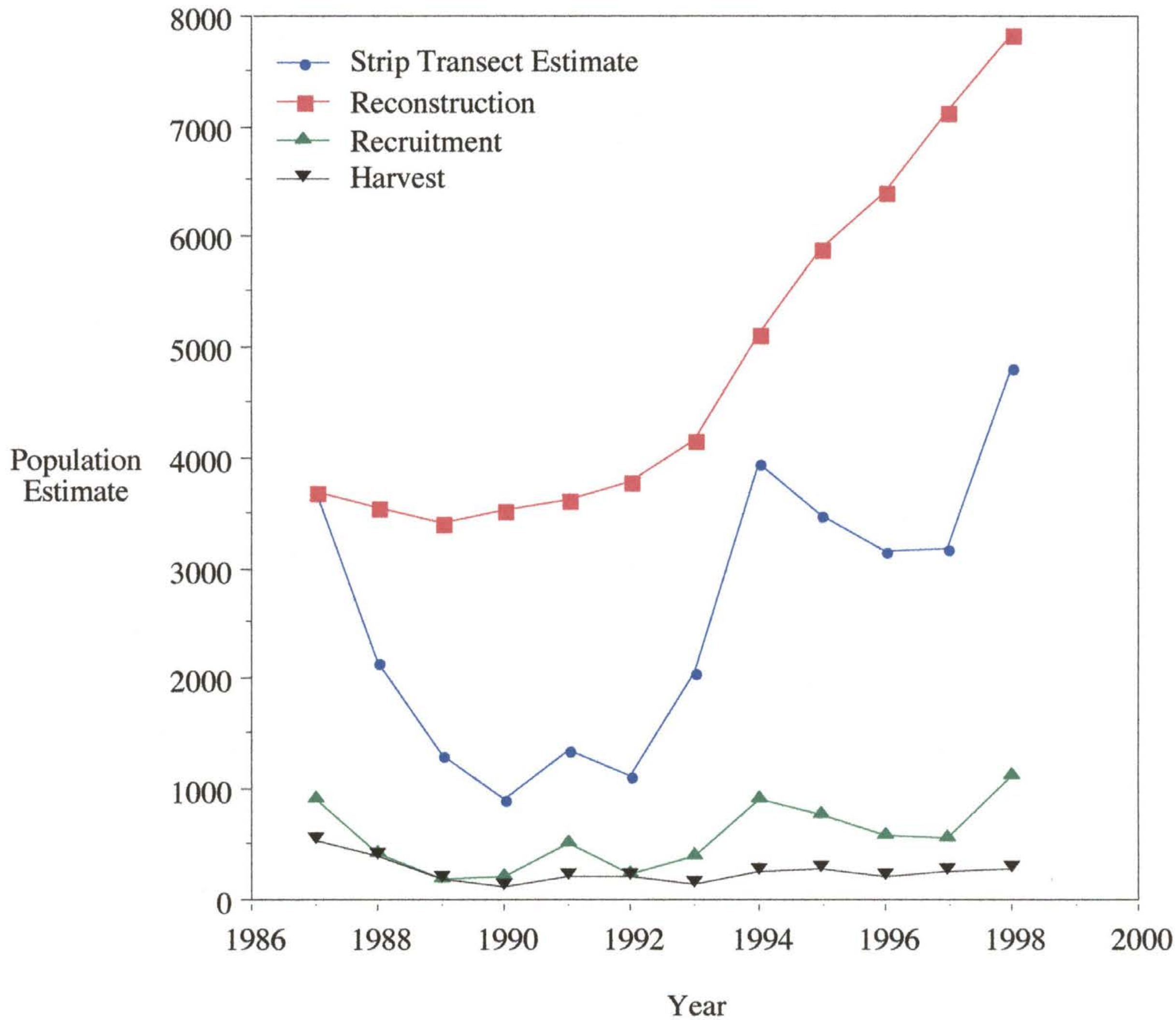

Figure 14. Strip transect population estimates, estimated recruitment (lactation rates for harvested does ≥ 2 yoa), annual harvest values, and the reconstructed population values for the Camp Bullis white-tailed deer herd from 1987-1998.

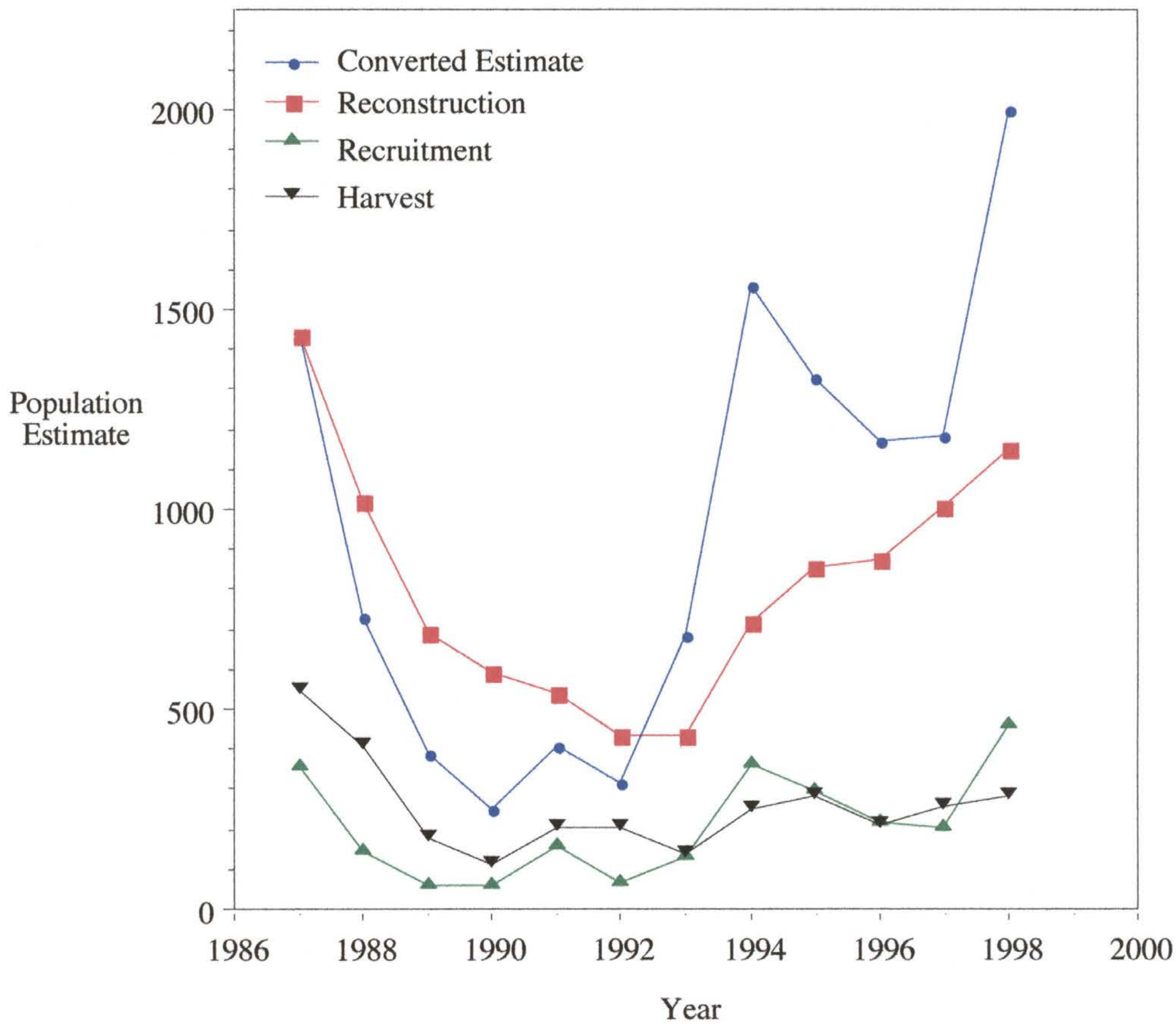

Figure 15. Converted strip transect population estimates, estimated recruitment (lactation rates for harvested does ≥ 2 yoa), annual harvest values, and the reconstructed population for the Camp Bullis white-tailed deer herd from 1987-1998.

corrected estimate of recruitment, the population increased. While the corrected estimates could not account for all factors affecting the historic spotlight strip transect estimates, the corrected estimates did correlate better with the recruitment and harvest data collected during 1987-1998. As such, these comparisons served as additional evidence of bias in the spotlight strip transect method.

Evaluation of Survey Period

Analysis of historic survey data from 1993-1998 revealed that the date of survey significantly affected the magnitude of counts on each spotlight transect (Figure 16). The homogeneity of slopes test result indicated no significant factor-covariate interaction affects [P ($F_{0.05(1), 3, 109} \geq 1.399$) = 0.2469] on the dependent variable (counts). The date-transect interaction variable was therefore removed, and the model recalculated. The results indicated a significant difference for counts between transects [P ($F_{0.05(1), 3, 112} \geq$ 89.588) < 0.0001] and between dates [P ($F_{0.05(1), 1, 112} \geq 6.595$) = 0.0115]. The negative regression coefficient for the model indicated that counts decreased from summer into autumn on Camp Bullis.

Seasonal differences between summer and autumn 1997 spotlight strip transect surveys were analyzed (Figure 17). Because no large change in population size occurred during this period, this analysis served as a controlled comparison of counts between seasons. While test results for a single year have relatively low power, the ANOVA revealed that counts were significantly different between seasons (summer versus autumn) for all transect lines [P ($F_{0.05(1)1, 32} \geq 13.19$) = 0.0010]. Mean counts were higher during the summer survey period for all transects, as indicated in the interaction plot. Counts were significantly different between transect lines [P ($F_{0.05(1)3, 32} \geq 29.94$) < 0.0001], with Scheffe's multiple comparison test confirming significant statistical differences between all but the NE and SE transects. The interaction line plot for the two factors (transect and season) indicated that mean counts were approximately the same for the NE and SE transects during the two survey periods.

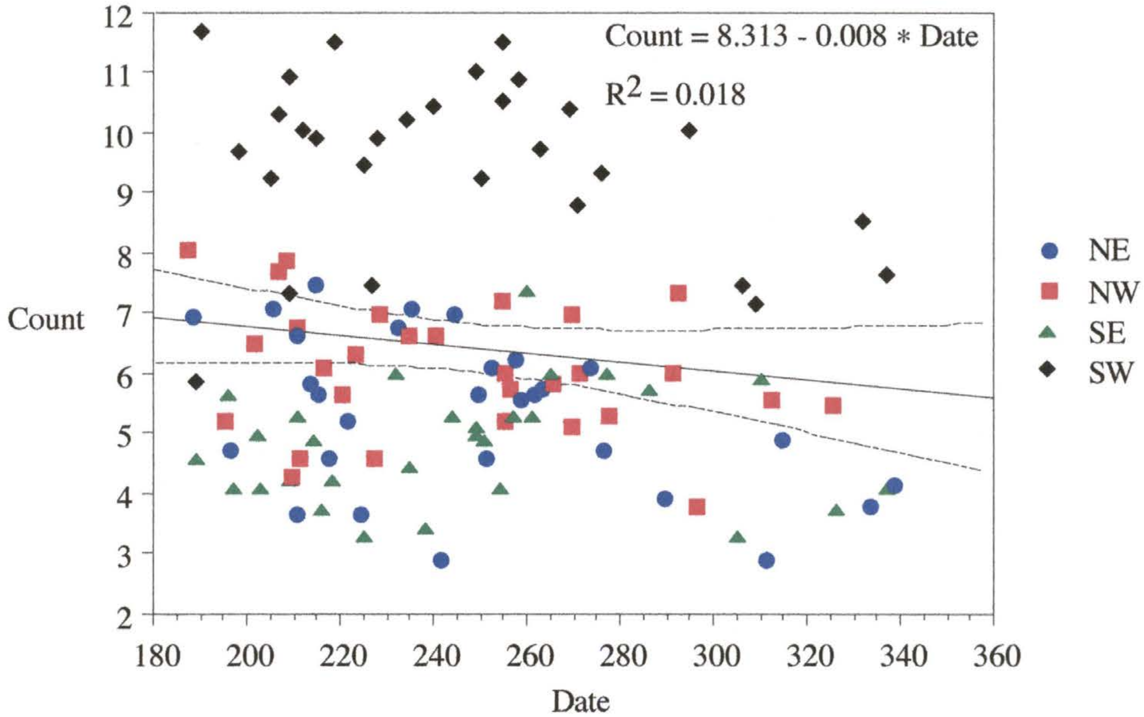

Figure 16. ANCOVA results for counts by date. The graph is a grouped regression of counts versus date with 95% confidence intervals for the mean. All counts were square root + 5 transformed.

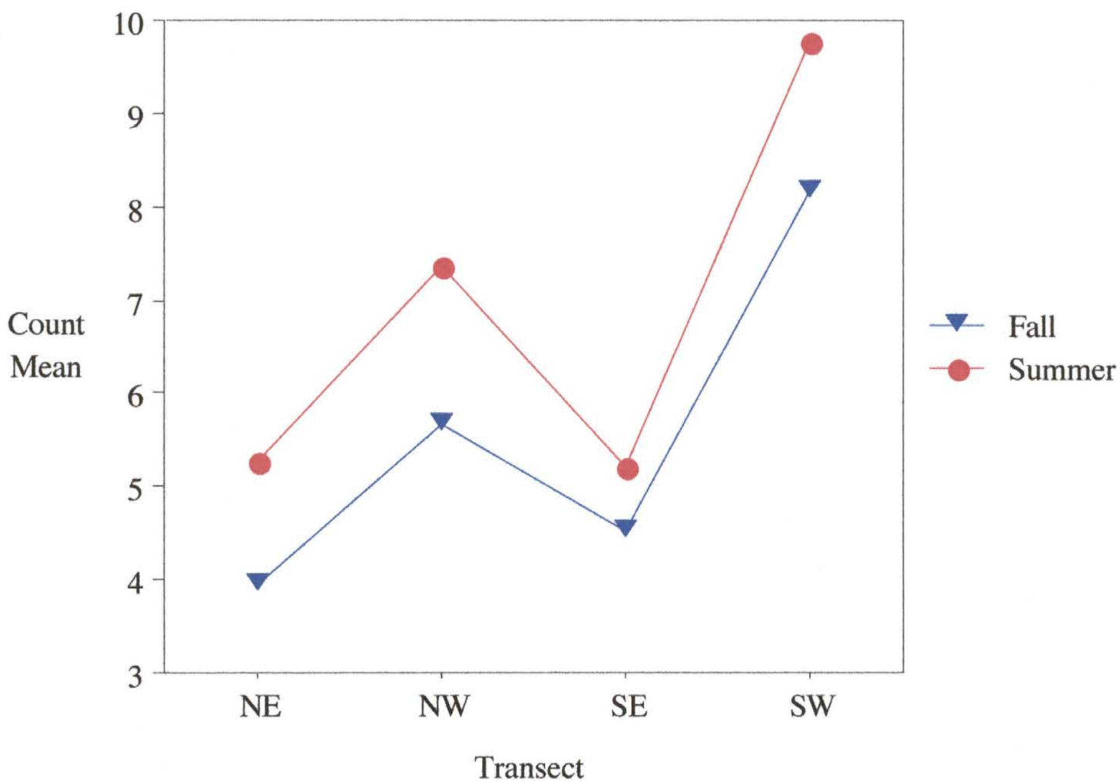

Figure 17. ANOVA for counts between seasons. The plot is an interaction line graph for the 1997 summer and fall spotlight strip transect surveys. All data were square root +5 transformed prior to analysis.

Comparison of Method Efficiency

Cumulative frequency graphs of the 1997-1998 white-tailed deer surveys suggested a correlation between 1/2 strip width and spotlight strip transect bias (Figures 9 and 10). To obtain accurate spotlight strip transect population estimates, the counting area would need to be truncated or reduced to the level of average visibility (1/2 strip width) by use of a cutpoint. In each case, if the cutpoint and average visibility (1/2 strip width) were congruent, large portions of the count data would be discarded. The 1997 spotlight strip transect surveys would discard approximately 65% of observations, while the 1998 surveys would discard approximately 70% of observations. The incorporation of a cutpoint, in order to obtain accurate spotlight strip transect estimates, would require an equivalent increase in transect length to maintain parity of sample size with the new spotlight line transect methodology. In each case, the strip transect effort would have to be more than doubled in order to obtain sample sizes similar to the spotlight line transect method. This would create a proportional increase in the cost per unit effort for the spotlight strip transect method.

Spotlight line transect and strip transect survey efficiency was compared in terms of duration (hrs), time required per unit length (hrs/km), and time required per deer (hrs/deer). For this analysis 56 line transect surveys obtained during 1997-1998 were compared with 27 historic strip transect surveys obtained during 1990-1993 (Table 4). Mann-Whitney test results indicated that transect length, area sampled, and time per deer counted were not significantly different between the two methods. Mean deer density, survey duration, and time per unit length of transect were significantly different between the two methods prior to normalization. When the data were normalized (multiplied by the ratio of densities) to account for the differences in deer density between the two survey periods, the normalized line transect values for survey duration (0.952 hrs) and time per unit length of transect (0.072 hrs/km) were not appreciably different from the strip transect method values for these two metrics. For the spotlight line transect method, duration of each survey was equally influenced by length of transect [$r = 0.572$, $P < 0.0001$] and number of deer counted [$r = 0.516$, $P < 0.0001$]. By contrast, the strip transect survey results indicated that duration of each survey was significantly influenced only by the length of transect [$r = 0.925$, $P < 0.0001$], and not

Table 4. Mann-Whitney test results comparing survey efficiency between the 1990-1993 strip transect (st) and 1997-1998 line transect (lt) white-tailed deer surveys on Camp Bullis. The indicated data (*) were statistically different between survey periods (prior to normalization for differences in density).

Parameter	Mean	Std. Dev.	Std. Error	Count	Coef. Var.
Length (km), lt	14.470	6.014	0.804	56	0.416
Length (km), st	15.950	7.569	1.457	27	0.475
Area (ha), lt	131.002	39.663	5.300	56	0.303
Area (ha), st	146.550	68.776	13.236	27	0.469
Density, lt*	0.362	0.236	0.032	56	0.652
Density, st	0.168	0.133	0.026	27	0.796
Hours, lt *	2.052	0.610	0.081	56	0.297
Hours, st	0.929	0.407	0.078	27	0.439
Hours, lt (Normalized)	0.952	0.283	0.038	56	0.297
hrs/km, lt*	0.154	0.050	0.007	56	0.323
hrs/km, st	0.060	0.012	0.002	27	0.197
hrs/km, lt (Normalized)	0.072	0.023	0.003	56	0.323
hrs/deer, lt	0.063	0.043	0.006	56	0.679
hrs/deer, st	0.059	0.036	0.007	27	0.602
hrs/deer/km, lt	0.005	0.003	0.000	56	0.647
hrs/deer/km, st	0.005	0.005	0.001	27	1.048

significantly influenced by the number of deer counted [r = 0.229, P = 0.2539]. Because line transect metrics were significantly impacted by differences in deer density while strip transect metrics remain mostly unchanged, line transect values should be normalized for density to obtain equitable comparisons with strip transect survey results. The strip transect sampling efficiency would be further reduced if a cutpoint were used to truncate the count at the level of average visibility in order to obtain greater accuracy in the point estimates of population size.

Estimates of Habitat Use

Data collected by the new spotlight line transect method during the two year study were used to assess habitat selection within the study area without identification of individual animals (Design 1, Thomas and Taylor 1990). White-tailed deer sightings indicated a preference by deer for low canopy density, low elevation, distances less than 500 m from water, medium proportion (high interspersion and high juxtaposition), slopes of less than 5°, and Trinity-Frio soil associations (Table 5). Deer avoided areas of high canopy density, moderate to high elevation, low water density, high proportion, moderate or steep slopes, Brackett soil associations, Lewisville silty clay, Tarrant soil associations, and Venus loam soil associations. The Chi-squared analysis (Neu et al. 1974) indicated that all other variables were represented in accordance with their availability (neither selected for or against). The sign and magnitude of the difference between habitat use versus habitat availability was used to generate a predictive model (Boolean model) for sighting locations on Camp Bullis (Figure 18). The map depicts areas of high and low sighting probability, based upon the 1997-1998 sightings. Because the 1997-1998 data sets were used to generate the model (map), the same points could not be used to analyze model accuracy. Future transect results will be needed to determine to relative accuracy and predictive power of the Boolean model.

Comparison of Simulated Deer Survey Results

Surveys of simulated deer were conducted to compare spotlight strip and line transect population estimates (Table 6) using an artificial population of known size and

Table 5. Habitat use for the 1997-1998 white-tailed deer sightings on Camp Bullis. Results were generated using Chi-squared analysis (Neu et al. 1974). Habitat variables are identified where use differed significantly from availability on the study area: greater than (+), less than (-).

Habitat Variables	1997 % Use	1998 % Use	CB % Avail.	1997 Selection	1998 Selection
N, NE, E Aspect	38.0%	33.9%	39.9%		
S, SW, W Aspect	30.7%	35.2%	34.5%		
SE, NW, Flat Aspect	31.3%	31.0%	25.7%		
Low Canopy Density	65.5%	61.4%	25.8%	+	+
Medium Canopy Density	18.2%	21.4%	19.3%		
High Canopy Density	16.3%	17.2%	55.0%	-	-
307.4m - 359.8m Elevation	64.2%	60.1%	29.7%	+	+
359.9m - 385.7m Elevation	10.4%	15.0%	33.8%	-	-
385.8m - 458.5m Elevation	25.4%	24.9%	36.6%	-	-
< 500m Distance to H2O	39.8%	43.2%	25.8%	+	+
501m - 1000m Distance to H2O	29.1%	30.0%	44.5%	-	-
1000m - 1500m Distance to H2O	14.2%	11.9%	23.1%	-	-
Low Proportion	3.2%	4.8%	6.2%	-	
Medium Proportion	71.4%	69.6%	23.8%	+	+
High Proportion	25.4%	25.6%	70.0%	-	-
< 5 degrees Slope	95.2%	93.0%	70.6%	+	+
5 - 10 degrees Slope	4.3%	7.0%	24.5%	-	-
> 10 degrees Slope	0.5%	0.0%	4.8%	-	-
Brackett soils, 12%-15% slopes	11.0%	15.2%	26.5%	-	-
Brackett-Tarrant assoc., hilly	0.0%	0.7%	4.8%	-	-
Crawford clay	0.8%	0.5%	1.1%		
Crawford-Bexar stony soil	10.7%	11.2%	13.7%		
Krum complex	16.0%	20.9%	14.6%		+
Lewisville silty clay, 0%-1% slopes	0.0%	0.0%	0.1%	-	-
Lewisville silty clay, 1%-3% slopes	0.0%	0.4%	0.8%	-	
Patrick soils, 1%-3% slopes	0.3%	0.4%	0.4%		
Tarrant assoc., gently undulating	28.3%	22.5%	21.3%		
Tarrant assoc., hilly	0.0%	0.0%	5.9%	-	-
Tarrant assoc., rolling	0.8%	1.3%	7.3%	-	-
Trinity-Frio soils	32.1%	26.9%	3.3%	+	+

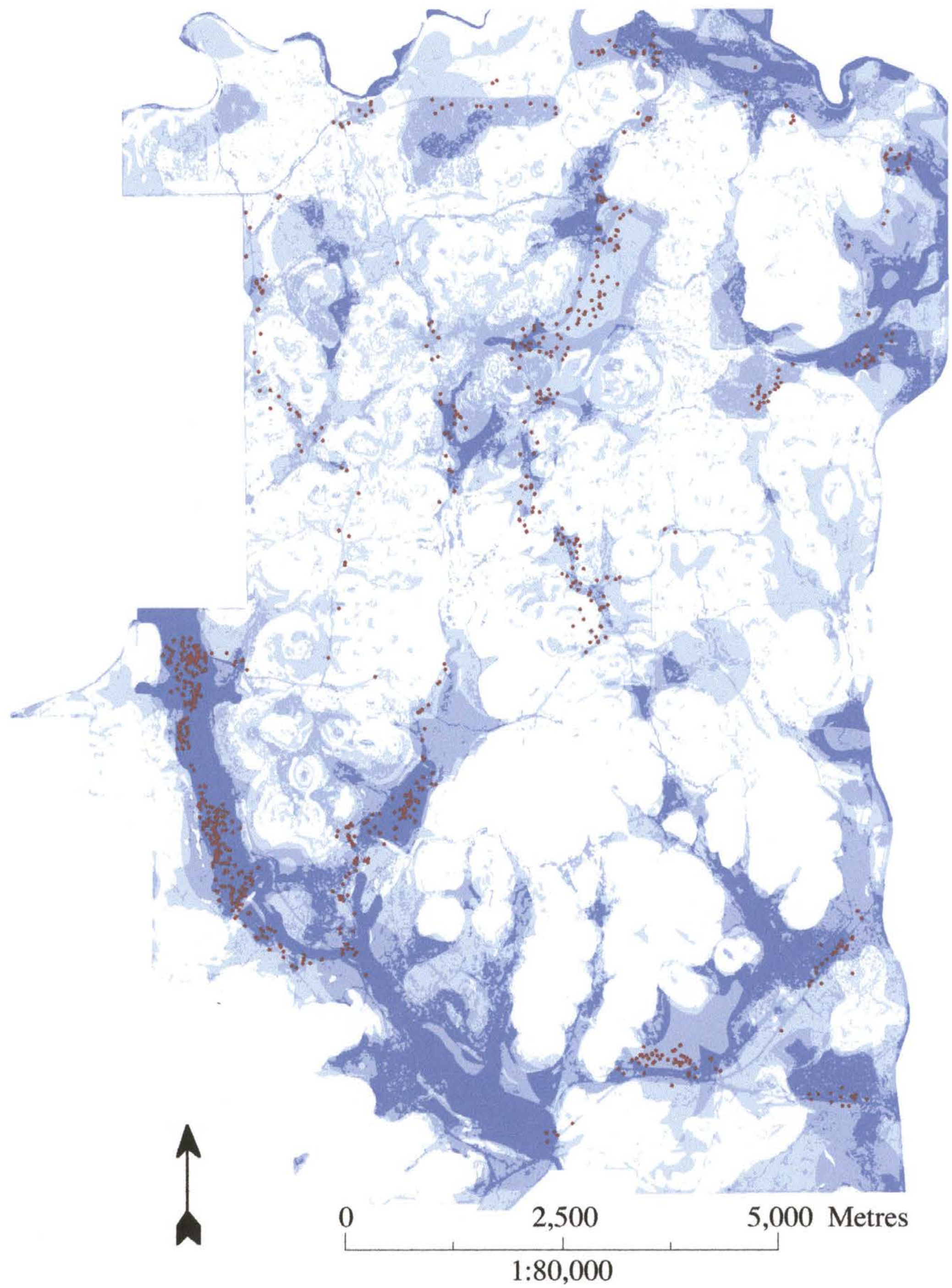

Figure 18. Predicted white-tailed deer habitat use during the 1997-1998 survey period for Camp Bullis. Darker areas represent intersections of preferred habitat variables. Red dots indicate deer sightings.

Table 6. Population estimates for the 1998 simulated deer surveys on Camp Bullis. Line transect estimators are annotated by software and model type. The coefficient of variation (%CV) and degrees of freedom (df) were not reported by TRANSAN.

Type	Cut Point	Count	Estimate	%CV	df	95% LCL	95% UCL
Strip Transect	None	127	133	3.5	3	99	166
DISTANCE, Uniform[a]	None	127	67	12.4	19	52	87
DISTANCE, HN[b]	None	127	70	14.8	32	2	95
DISTANCE, HN[c]	None	127	71	17.8	47	50	101
TRANSAN[d]	None	127	83	na	na	54	129
TRANSAN[e]	None	127	69	na	na	45	103

[a] Uniform model with a 1st order cosine adjustment term.
[b] Half-normal model with no adjustment terms.
[c] Half-normal model with a 4th order polynomial adjustment term.
[d] Using program default parameters.
[e] Perpendicular distances grouped into 5 frequency classes (40 m grouping interval).

distribution (Whipple et al. 1994). The known population was comprised of sixty-two simulated deer distributed along an 11.9 km survey route (SW transect; Figure 2). Average visibility (1/2 strip width) was 57 m, and the known population was contained within an area of 571.2 ha (11.9 km in length and 480 m in width). In four surveys, 126 simulated deer in 53 clusters were sighted by the survey crews. Average range was 66 m and average perpendicular distance was 66 m. The spotlight strip transect population estimate was positively biased, and did not capture the known population size within the 95% confidence intervals. Five line transect population estimates were generated using different analysis parameters within the TRANSAN and DISTANCE software packages. The spotlight line transect population estimates were relatively unbiased, and each model captured the known population size within the 95% confidence intervals (Table 6).

Because simulated deer were not moved between surveys, pseudoreplication of sighting distances occurred during the four surveys. While this might have adversely affected the analysis, results from the simulated survey are similar to those obtained during white-tailed deer surveys (Figure 19). When data were analyzed as a continuous function of population estimate versus perpendicular distance to each sighting, the simulated survey curve was similar to the actual deer survey results in both shape and characteristics. Again, the strip transect population estimate would be accurate if the sightings were truncated to the point of average visibility.

Sighting location estimates generated during the spotlight line transect analysis were compared to differentially corrected UTM positions obtained independently by Camp Bullis personnel (Table 7). Mean positional error was less than 1 m in both the X (Easting) and Y (Northing) planes. Average displacement error for all sightings was 15.2 m ± 13.9 m SD. The results indicated that the new spotlight line transect method was relatively accurate in terms of locational error. Additional equipment (palm computers) can be obtained to link offset laser range finders (distance, bearing, and inclination) with GPS equipment. This would eliminate the compass rosette and the manual method of determining target bearings, and is predicted to yield further increases in the accuracy and precision of the locational estimates.

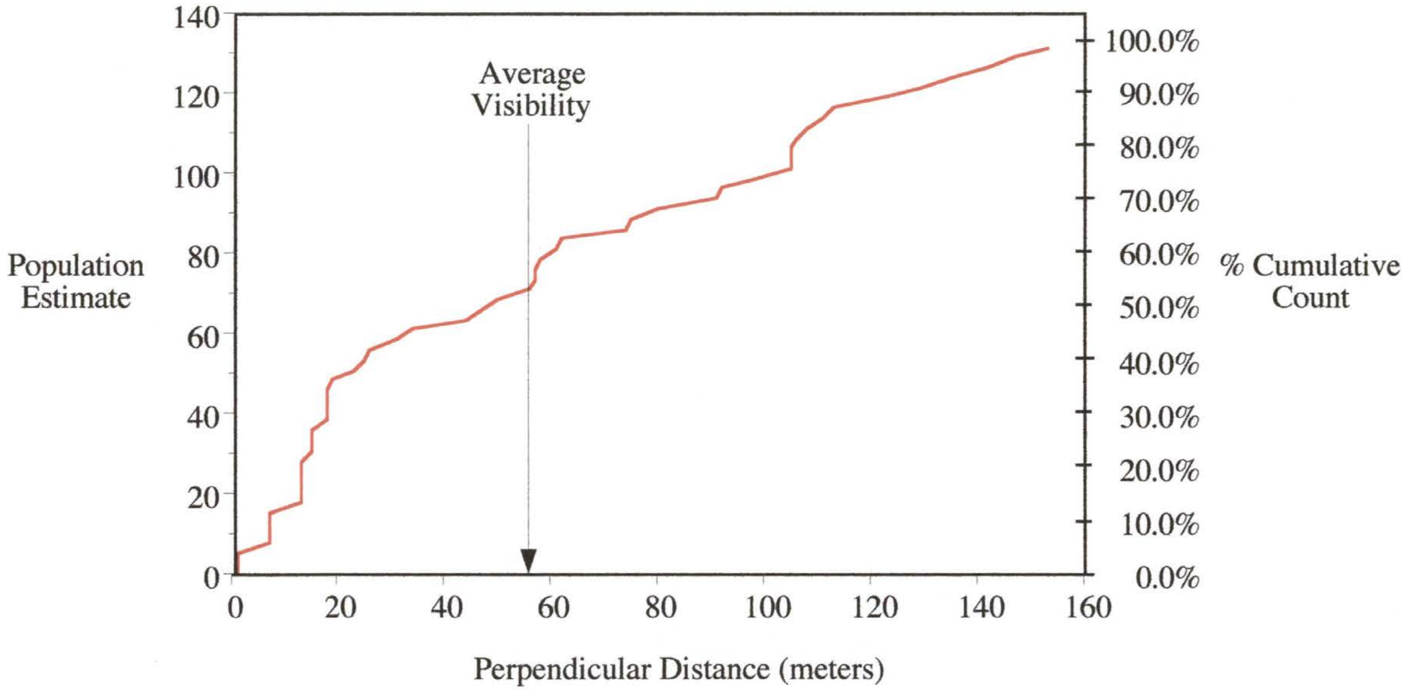

Figure 19. Cumulative frequency plot of the 1998 simulated deer survey. The data are plotted as a continuous function of population estimate versus perpendicular distance to each sighting. The sample area size is held constant, and was determined by the average perpendicular visibility (57 m) on the SW spotlight line (11.9 km).

Table 7. Locational (X and Y) and displacement error results for the 1998 simulated deer surveys on Camp Bullis. Displacement error was calculated as the difference between the estimated and measured UTM locations (n = 126).

Statistic	Perpendicular Distance in meters	Range to Target in meters	ΔX Error in meters	ΔY Error in meters	Displacement Error in meters
Mean	65.9	66.2	-0.7	-0.9	15.2
Maximum	146.0	171.0	37.7	50.0	58.1
Minimum	6.0	6.0	-34.5	-41.0	1.4
Std. Error	51.8	54.6	13.7	15.5	13.9

CHAPTER 6

DISCUSSION

Transect Placement

Spotlight transects must be representative of the habitat found within the management unit or area being sampled. The three new transects eliminated the potential for double counting error, minimized the conflict between military training and survey access, and maintained habitat coverage similar to the historical surveys. In each case the old transect lines were altered as little as possible in order to preserve continuity with the historic spotlight surveys. Two transects were relocated onto better roadways which may have improved data quality by lowering the amount of noise generated during data collection on 4WD trails. In addition, visibility along the new transects correlated well with visibilities obtained from the 81 km helicopter transect survey, indicating that the ground and aerial transects covered habitat of similar shape and composition. Because the aerial transect route did not follow roadways or other boundaries, it was more representative of the study area habitat as a whole and was therefore the appropriate standard for comparison on Camp Bullis.

Visibility Measurements

The comparison of measured versus estimated visible area indicated no significant difference among surveyors on Camp Bullis (Table 1). But comparisons between strip and line transect population estimates (Figures 9-12), and subsequent analyses using reconstructed populations (Figures 14 and 15) would indicate that sample area size was underestimated by all survey crews during the 1993-1998 period. This contrasts with Whipple et al. (1994). They found observers tended to underestimate visibility by an average of 45% in open habitat, while in closed habitat observers overestimated visibility by an average of 26%. They also found no correlation between estimation accuracy and observer experience. As such, strip transect density estimates can change drastically due to small differences in the estimate of sample area, which serves as the denominator in the strip transect density equation. The Camp Bullis survey results demonstrated that the estimated visible area and the area over which deer could be detected differed significantly. The apparent negative bias in sample area estimates, combined with the large area over which deer could be detected by eye shine, provided a source of positive bias in the strip transect method. The new spotlight line transect method does not require an estimate of visible (sample) area to generate a density estimate, as the technique is a boundless count. This eliminated one source of bias from the estimates of population size. But visibility measurements collected during the study were useful, as they provided a means for comparing transects within the study area (Figure 8) and established visibility records for monitoring habitat changes through time (Appendices 1-4).

Transect Avoidance or Flight from the Observer

Unfortunately, no spotlight transect conducted over man-made paths or roadways is truly representative of natural white-tailed deer habitat. Roadways typically parallel topography and other natural habitat gradients, resulting in samples that capture less total variation than often exist within the area being studied. This bias varies with the relative heterogeny of the study area, the extent to which the area immediately adjacent to the roadway deviates from the remainder of the habitat being sampled, and the proportion of altered habitat captured within each sample. As such, roadways are narrow corridors where the frequency of disturbance and the abundance of resources differs from the surrounding area. If the roadway provides resources at a higher density than are generally available in the surrounding environment, the benefits of occupying the space near the road outweigh the risk or cost of disturbance. Yet, if the roadway provides resources at a density equal to or lower than the surrounding environment, then the risk or cost of disturbance near the roadway outweighs the benefit of occupying that space relative to the surrounding area. In this latter circumstance animals would avoid the area near the roadway. The new transects on Camp Bullis were conducted from roadways that receive heavy use by military personnel. In general, roadways on the installation provide no resources that are not also available elsewhere, but do offer frequent traffic disturbance. Historic surveys conducted by installation wildlife biologists have noted the relative infrequency with which deer were detected standing or feeding near roadways. During this two-year study, deer often were detected and recorded while crossing roadways, but these animals did not stop until they were several meters from the road, regardless of the distance from the vehicle. Furthermore, deer seldom fled ahead of the vehicle unless the vehicle left the roadway, again, regardless of distance from the vehicle. Therefore, it was speculated that conditioning to traffic may have resulted in animals avoiding the areas immediately adjacent to the transect lines.

The distance data collected in line transects can not distinguish between animals avoiding the habitat occupied by the transect and animal flight in response to the observer. For analytical purposes, this phenomenon should create negative bias in both the strip transect and line transect population estimates by reducing the number of animals detected in the areas immediately adjacent to the roadway. The solution to such problems are directly addressed during sample collection by either altering transect placement or by making a more stealthy approach to the target. When such alterations are not possible, strip transect surveys have no ancillary data to correct the bias. Line transect methodology collects distance data with the counts, which may be used to alleviate some of the bias by either increasing the size of the perpendicular distance grouping interval or through left truncation of the distance data (Buckland et al. 1993). Larger grouping intervals produce a smaller number of frequency classes, each containing a higher percentage of the total data available. This smoothes the data and permits a better fit of the selected model to the data set, generally with a lower number of adjustment terms. Left truncation can be used to remove portions of the data near the transect line, discarding sightings in those distance intervals which are negatively biased due to flight from the line or habitat avoidance. This technique reduces the total number of sightings used in the analysis and is recommended only in those instances where parsimonious grouping is ineffective.

The Camp Bullis white-tailed deer and the simulated deer survey data were not severely influenced by avoidance of habitat near the line or flight from the observer prior to detection (Figures 5 and 6). Goodness of fit testing for each line transect model was evaluated using 50 m grouping intervals for the Chi-squared analysis. In each case, model fits were obtained for the raw data with a minimum number of low order adjustment terms. The narrow range occupied by line transect population estimate results each year (Figure 11) indicated that neither flight ahead of the observer nor avoidance of habitat near the line biased the results relative to the strip transect estimates. In each case the strip transect population estimates increased with strip width, but reached a functional limit due to the decreasing probability of detection. Because these opposing forces effect the strip transect population estimate simultaneously, the strip transect estimate was negatively biased relative to the line transect estimate (Figure 12) when sample size was allowed to vary with detection distances. While these results were limited by the size and duration of the study, they clearly demonstrated the advantages of the spotlight line transect sampling method and the robust character of line transect data analysis.

Data Collection from Non-Linear Transects

The new spotlight line transect sampling method was designed to address two criticisms of line transect sampling raised in the literature: 1) the additional time required to collect distance and bearing data (Burnham et al. 1985), and 2) the accuracy of the perpendicular distance measurements (Buckland et al. 1993, Whipple et al. 1994, and Pojar et al. 1995). A more important consideration for the Camp Bullis study was devising a method which could be used to investigate the relative bias between strip and line transect population estimates. It is this latter aspect or ancillary benefit of the new method which provides a source for additional research. Caughley (1977) stated that to determine how well a sampling method copes with a real population, we would need know the exact number of animals in the population. And to determine why the sampling method copes well or badly, we would need to determine where each animal was standing at the time of each survey. Our simulated surveys demonstrate that the new method, by utilizing GPS and GIS, delivers the capacity to capture spatial/temporal data from populations of known size and distribution (Tables 6 and 7). It therefore provides a means for the further investigation of sampling designs and analytical techniques used to estimate animal populations.

The new method has raised concerns that the non-linear transects may bias the data in the same fashion as the random movement of surveyed objects (Buckland et al. 1993). This concern is only warranted if the objects being surveyed are moving at greater than 1/3 the velocity of the surveyor (Hiby 1986). It is the movement of surveyed objects, not the observer, which enhances their detection near the transect line. As such, objects moving randomly near the line would have an increased chance of detection relative to objects moving at a greater distance or stationary objects near the line. This movement skews the detection function in favor of moving objects near the line. In contrast, while the observer may move toward or away from observed objects along non-linear transects, this movement would not make objects at any distance interval more conspicuous. Therefore no bias due to data collection from non-linear transects is anticipated if all line transect sampling assumptions can be met during the survey.

Survey Period

Seasonal shifts in the habitat usage of male and female white-tailed deer affect the number and composition of animals observed during spotlight surveys. Recent studies have indicated that sexual differences in white-tailed deer habitat utilization are minimized during the summer period (Downing et al. 1977, McCullough 1982, Beier and McCullough 1990). If composition and count data are to be obtained simultaneously, then surveys should be conducted during the summer. To decrease variability between surveys, spotlight counts must be conducted over short periods of time and within the same time period each year. Analysis of historic survey data (counts and dates) from 1993-1998 by ANCOVA (Figure 16) indicated a significant difference for counts between transects and a decrease in counts from summer into autumn. This analysis combined data across several years without consideration of animal density. While changes in density could have increased the probability of alpha error in the analysis, the significance level selected provided adequate power to support the conclusions. To isolate the problem, the ANOVA data (Figure 17) were collected across a short time duration to alleviate any affects due to changes in animal density between surveys. The ANOVA results also indicated a significant decrease in counts from summer into autumn on Camp Bullis. This is not the currently recognized paradigm, as most spotlight counts in Texas are performed during autumn. Regardless, these results indicated that July-

August may be a more appropriate survey period for white-tailed deer on the Edwards Plateau of Texas.

Bias in Population Estimates

The spotlight strip transect census method is commonly used to estimate population densities in open rangeland and savannah type habitats where visibility is high, but dense vegetation and other factors which limit visibility decrease the accuracy of the method (Progulske and Duerre 1964, Harwell et al. 1979, McCullough 1982, and Mitchell 1986). Most investigations of strip transect sampling and analysis have focused entirely upon the negative bias caused by incomplete counts within the sampled area, but none have offered any practical correction for the strip method when this basic assumption is violated. In fact, Routledge (1982) demonstrated that strip transect sampling can not produce accurate results unless complete or nearly complete counts are obtained with certainty from the sampled area. As such, ancillary data of some type are required to either demonstrate the probability of complete counts or to correct the count for the negative bias. The perpendicular distances associated with count data from transect surveys are ideally suited for both of these purposes, resulting in the development of line transect theory (Burnham and Anderson 1984).

Results from the 1997-1998 Camp Bullis study indicated a substantial amount of positive bias in the spotlight strip transect method and negative bias in the aerial strip transect method, when compared with the spotlight line transect estimates. While incomplete counts may be the overwhelming factor responsible for the negative bias in the aerial survey, it can not explain the positive bias identified in the ground transacts. Caughley (1974) dismissed the causes of positive bias in aerial strip transects, concluding that they were minor factors in properly designed aerial surveys. Pojar et al. (1995) agreed with Caughley (1974) in their study of aerial survey techniques and concluded that quadrat counts produced results comparable to line transect and narrow strip transect surveys, without the inherent subjectivity of distance estimation. Pojar et al. (1995) identified the perpendicular distance to the detection function shoulder as the proper cutpoint width, and speculated that narrower strip widths would produce positive bias while wider strip widths would produce negative bias. It was felt that positive bias would occur due to inclusion of animals outside the 1/2 strip width. While aerial strip transect methodology dictates that 1/2 strip width and cutpoint distance must be congruent, Camp Bullis spotlight transect results indicated that negative bias is the probable result when sample area is allowed to vary with perpendicular distance (Figure 12), regardless of strip width. In contrast to aerial methodology, spotlight strip transects utilize a fixed sample area size derived from systematic perpendicular visibility estimates (measurements). As such, the 1/2 strip width (average visibility) may not be congruent with the area over which animals are counted. It was this incongruence which produced positive bias in the spotlight strip transect method (Figure 11). The Camp Bullis results indicated that the standard spotlight strip transect method would produce positive bias if no cutpoint were used during data collection. If the cutpoint used during the survey was beyond the distance defined by the average visibility (1/2 strip width), the estimate would be positively biased. If the cutpoint used during the survey was below the distance defined by the average visibility, the estimate would be negatively biased. In each case, counts decreased rapidly at all distances beyond the detection function shoulder (Figures 5 and 6), and therefore spotlight strip transect bias was primarily a function of sample area size (average visibility) and target detectability.

Historic and Reconstructed Population Comparisons

The Camp Bullis white-tailed deer population decline of 1987-1992 illustrates how bias in spotlight strip transect populations estimates can adversely effect management of a species (Figure 14). Managers estimated the population size to be 3,702 deer in 1987. They predicted that the population would exceed carrying capacity and result in a significant mortality if the trend continued, particularly if a drought or severe winter occurred. Harvest recommendations were therefore set in an effort to maintain the population in a viable and healthy condition (Bruns 1987). The harvest quota for 1987 was derived using the annual spotlight strip transect survey results. As such, the number of animals to be harvested was based on a biased estimate of population size. The result was a harvest recommendation of 1,343 animals from a population that was believed to contain 3,702 deer (equivalent to a 36.3% harvest). Check station records (Keith 1997) indicate that 549 animals were harvested that year, or 14.8% of the estimated standing population. The post harvest population size should have been 3,153. The 1988 stoplight strip transect surveys estimated the population size to be 2,161 deer. This indicated a population decrease of 1,541 deer (41.6%) from the previous year, and a loss of 992 deer beyond the amount harvested in 1987.

Interviews with personnel that were present on the installation during the period indicated that a die-off or winter loss of 992 animals (amount lost beyond what was harvested) could not have occurred without notice, due to the amount of training activity on the installation. In fact, Camp Bullis experienced a 63% winter loss of the white-tailed deer herd in 1976, and reference to that event was made to support the harvest recommendations issued in 1987 (Bruns 1987). Due to previous experience with winter mortality incidents, and a lack of carcasses to support a winter mortality event (Marburger and Thomas 1965), it is unlikely that a large winter loss of deer occurred on Camp Bullis in 1987. Unfortunately, no other explanation was offered as to the disappearance of the 992 deer.

The 1988 spotlight strip transect results estimated a standing population of 2,161 deer, and a harvest of 550 animals was recommended (25.5% of the standing population). The 1988 check station records indicate that 409 animals were harvested that season (18.9% of the estimated standing population). The post harvest population was predicted to contain 1,752 deer. The autumn 1989 spotlight strip transect surveys indicated a standing population of 1,319 deer, a decrease of 39.0% or 842 deer from the previous year. As such, 433 animals were lost beyond the number harvested during the 1988 hunting season. Again, no explanation was offered to account for the inconsistency.

The 1989 harvest quota was set at 363 deer, or 27.5% of the standing population. Check station records for 1989 indicated a harvest of 180 deer, or 13.6% of the estimated population. Spotlight surveys from 1990 indicated a standing population of 919 deer. This represented a decrease of 30.3% or 400 deer from the previous year (1989).

This pattern of spotlight estimation, quota recommendation, and lower than anticipated harvest levels was repeated until 1998 (Table 8). Examination of the Camp Bullis data (Figure 12) indicated that annual harvest values were consistently below the estimated rate of recruitment from 1987-1998. While this should have resulted in an exponential population increase, as demonstrated by the reconstructed population, the

Table 8. Spotlight strip transect population estimates, estimated recruitment, harvest quotas, and seasonal harvest values for the 1987-1998 Camp Bullis white-tailed deer herd.

Year	Estimate	Recruitment	Quota	Harvest
1987	3702	16%	1343	549
1988	2161	20%	550	409
1989	1319	33%	363	180
1990	919	58%	126	115
1991	1362	38%	266	205
1992	1126	48%	187	202
1993	2054	43%	200	140
1994	3955	39%	562	251
1995	3482	46%	533	282
1996	3154	34%	594	211
1997	2793	38%	584	257
1998	4820	37%	459	284

Camp Bullis population continued to cycle without regard for this discrepancy. The only logical conclusion that can be drawn from this illustration is that the spotlight strip transect population estimates were positively biased, and as such provided little or no predictive power for management use.

By 1998 sufficient data were available from concurrent strip and line transect surveys to generate a conversion factor for the historic spotlight strip transect results (Figure 11). The conversion factor generated an equivalent line transect estimate for each historical strip transect estimate (Figure 13). The data trends for the converted estimate were identical to the historic data trends, but were shifted downward in magnitude. Due to the shift, converted estimates correlated with historic events (Figure 13). For example, the 1987 standing population estimate was adjusted to 1,434 with a harvest of 549 animals or 38.3% of the standing population. The 1988 population estimate was adjusted to 727, or a decline of 49.3% from the previous year. Assuming a wounding loss of 10%, this number was in agreement with the historical data trends. The 1988 harvest was 409 animals or 56.3% of the standing population. The 1989 standing population was adjusted to 390, or a decline of 46.4% from the previous year. Again, assuming wounding loss and recruitment, this number correlated with the available data for the period.

The impact from wounding loss was considered to be proportional to the total harvest, but was a variable that could only be roughly estimated. Hunter surveys and harvest records from Camp Bullis conservatively estimated the wounding loss for rifle hunting at 8% and the wounding loss for archery hunting at >10% (Bruns 1993). In addition, results from the two-year survey indicated that archery hunters on Camp Bullis failed to recover 76% of the animals believed to have been wounded (Bruns 1993). Therefore, the magnitude of wounding loss at Camp Bullis could easily range from 5%-20%. Regardless, conversion of the historic spotlight strip transect population estimates to equivalent line transect estimates produced a more accurate depiction of historic demographic events. Results from the Wilcoxon's paired sample tests support the hypothesis of positive bias in the historic strip transect population estimates. As such, it was concluded that the Camp Bullis white-tailed deer population decline of 1987 -1992 occurred because harvest quotas were derived from positively biased spotlight strip transect estimates.

It should be noted that the biased results obtained in the historical surveys was unavoidable, due to the state of sampling methodology that was available at that time. Reports from 1976-1998 indicated that all surveys on Camp Bullis were completed in a competent manner, and in accordance with the published methods. Records indicated that annual results were transmitted to biologist at the Texas Department of Parks and Wildlife for comment, and responses from department officials verified this viewpoint (Williams 1993, Reagan 1994).

Sampling Efficiency

Wildlife management is increasingly impacted by economic constraints. Any method selected for monitoring a population must therefore be accurate and efficient in terms of cost per unit effort. Total equipment cost for this project were less than $5000, including the computer, GPS equipment, and all software. Because most agencies or contractors already have access to computers, GPS equipment, and GIS software, the new spotlight line transect method can be reproduced with minimal capital expenditures. The data, equipment, and software used to generate these results are compatible with both PC and Macintosh computers. Minimal training of personnel was required for accurate data collection, while moderate training was required for reliable data analysis. As such, capital expenditures for equipment and training should be comparable to strip transect methodology.

Spotlight line transect data collection was demonstrated to be more efficient than the standard strip transect method (Figures 7-10) due to sample size and accuracy constraints. Strip transect estimates require an accurate estimate of visibility and complete counts within the sample area. Narrow 1/2 strip widths, with congruent cutpoints, must be utilized to generate accurate strip transect population estimates. This reduced the number of observations that could be used in the strip transect analysis. The spotlight line transect sampling method is a boundless count, and does not require an estimate of sample area size to derive the population density estimates. As such, there is no need to truncate counts and all observations can be included in the survey, regardless of perpendicular distance. This maximized the number of observations collected for the analysis. The Camp Bullis results indicated that more than 65% of the observations collected during the 1997-1998 surveys would have to be discarded to obtain accurate strip transect population estimates. As such, the number of spotlight strip transects would have to be increased to maintain parity in sample size with the spotlight line transect method. Thus, in terms of sampling efficiency (cost per unit labor), the spotlight line transect method was far more efficient than the spotlight strip transect method.

Comparisons of survey efficiency on Camp Bullis indicated that duration of survey was equivalent for the spotlight strip and line transect methods when deer densities were equal (Table 4). Additional speed enhancements could be realized by application of new technology (GPS units coupled to offset laser range finders) to automate the spotlight line transect data collection process. Mobile survey equipment is now available from several venders which combines laser range finder and GPS abilities. The new equipment determines the range, bearing, and inclination to a target, generates the X, Y, Z coordinates, and stores the information for later use. Data can now be collected in the time it takes to point and activate a laser range finder. This should increase ground sampling efficiency, and make the new method compatible for aerial transect use.

Results from 1997-1998 Camp Bullis study indicated that the new spotlight line transect method was both more accurate (Tables 2, 3 and 6) and more economical (Table 4) than the spotlight strip transect method. The information obtained during this study provided the Camp Bullis staff with a retrospective view of historical problems that resulted from inaccurate estimation of the standing population size. The new method was simple to learn, required a minimal capital investment, provided spatial data applicable for estimating habitat use (Figure 18), and was conducted within the same time constraints as the standard spotlight strip transect method.

CHAPTER 7

CONCLUSIONS

The cumulative evidence indicates that the spotlight strip transect method was severely biased due to limited visibility (overestimation of β) and underestimation of sample area size on Camp Bullis. While some authors have promoted the idea that monitoring an index relative to population size and/or density is appropriate for managing a population, the overharvest which occurred on Camp Bullis in 1987-1993 demonstrates that uncalibrated relative indices are insufficient for determining appropriate harvest levels (Bruns 1993, Bruns 1995). Indeed, the volume of literature devoted to strip transect analysis indicates that multiple entities have struggled unsuccessfully with this same problem for many years. The spotlight line transect methodology developed during this two-year study is robust to changes in animal distribution, requires no additional sampling effort, and yields additional information that is not available from spotlight strip transect surveys. The new spotlight line transect method captures herd composition, group size, spatial location, and the time of sighting for each target counted along the transect. Habitat variables for stratification can be collected simultaneously during the count or generated *post facto* using GIS and/or remote sensing techniques. The new method addresses the criticisms developed in the literature concerning accuracy and efficiency, and provides the spatial/temporal data necessary for further investigation of sampling designs and/or analytical techniques. As such, the paradigm for management of white-tailed deer should be improved through application of the new spotlight line transect method which will alleviate some of the bias caused by failure to meet strip transect sampling assumptions, yield greater accuracy, and provide additional data which can be utilized for species management.

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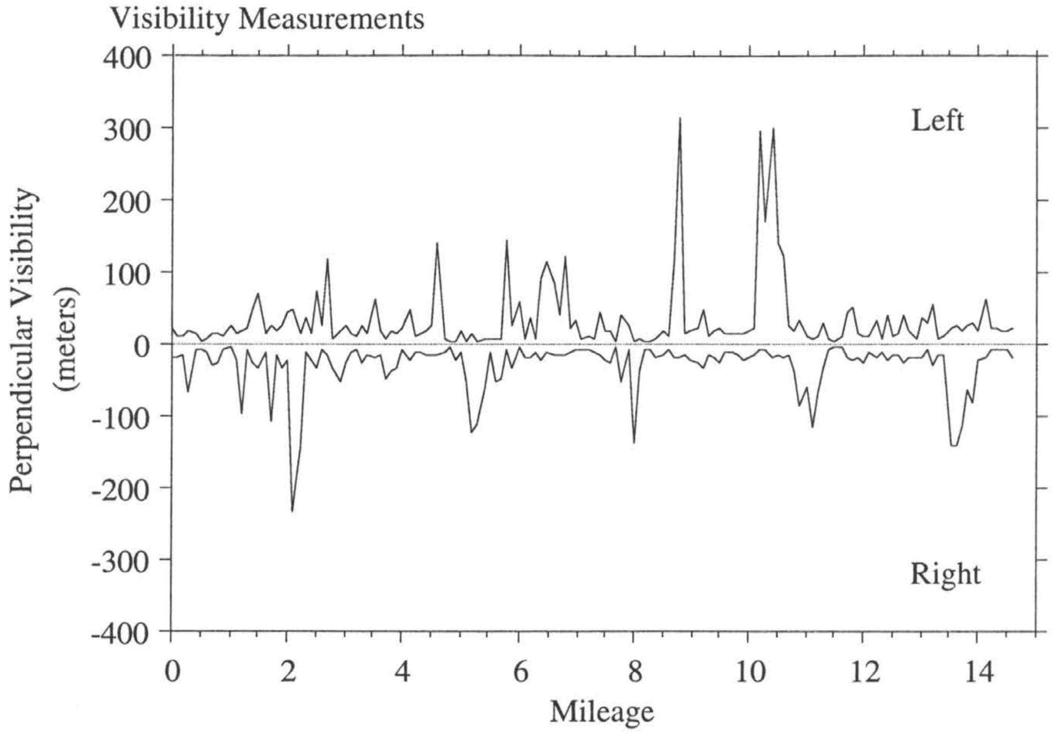
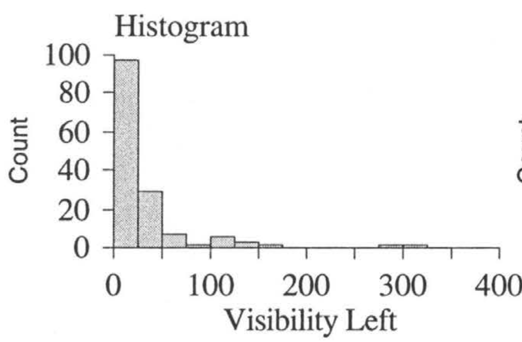
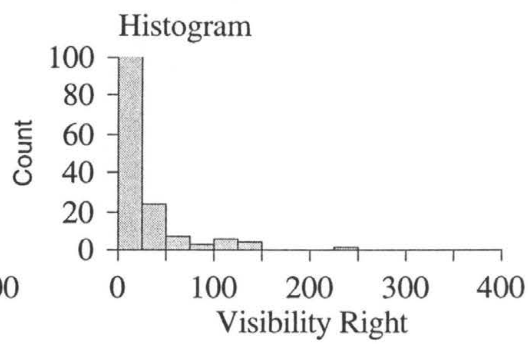
Appendix 1: Northeast Spotlight Line



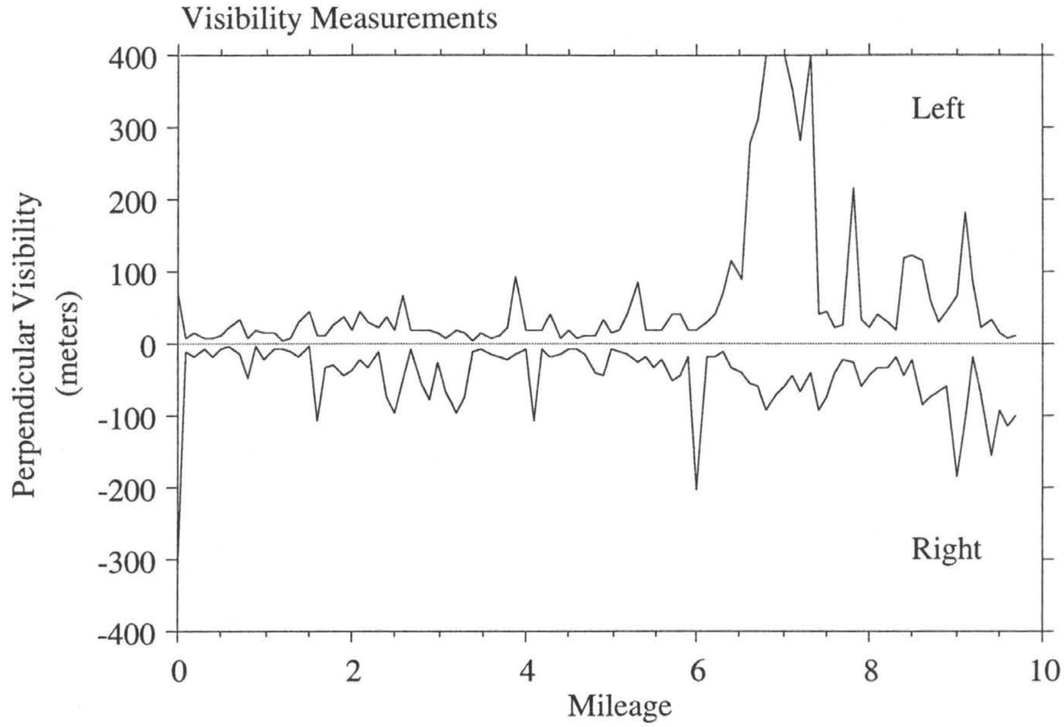


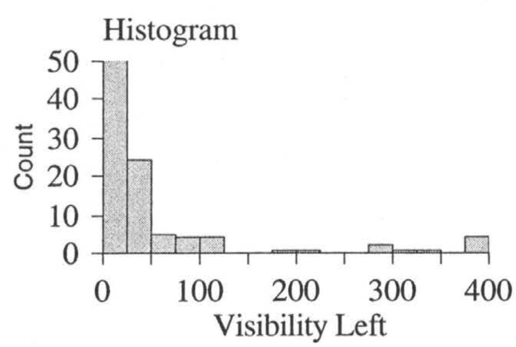


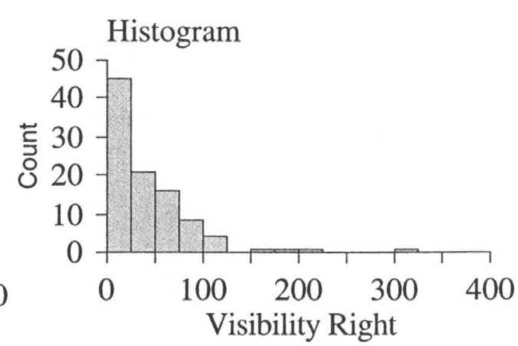
	NE Left
Mean	34.4
Std. Dev.	50.1
Std. Error	4.1
Count	147
Minimum	4.0
Maximum	316.0
Coef. Var.	1.5

	NE Right
Mean	29.1
Std. Dev.	34.6
Std. Error	2.9
Count	147
Minimum	5.0
Maximum	234.0
Coef. Var.	1.2

Appendix 2: Northwest Spotlight Line



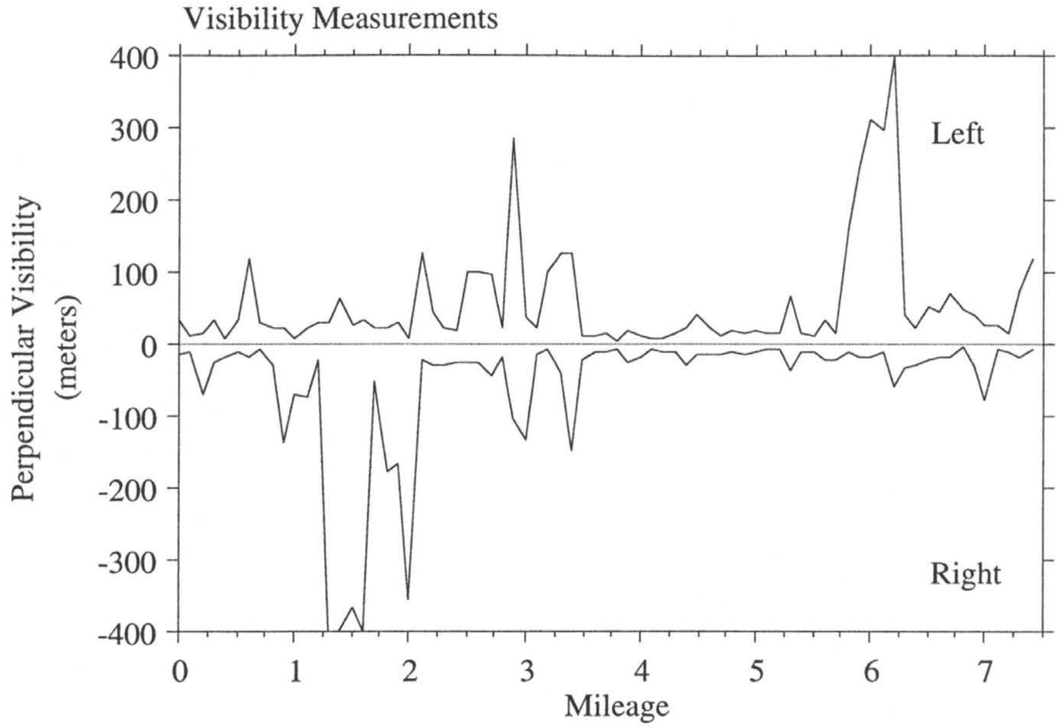


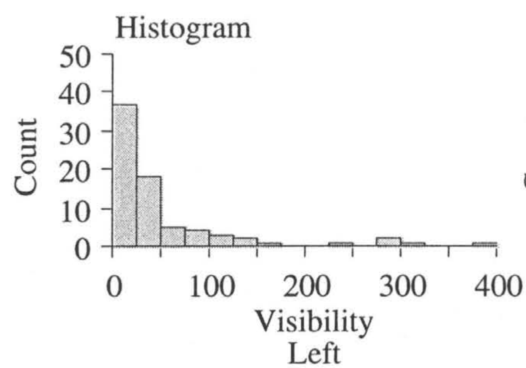


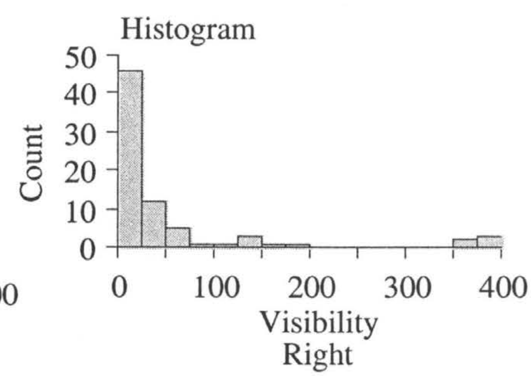
	NW Left
Mean	61.3
Std. Dev.	95.2
Std. Error	9.6
Count	98
Minimum	4.0
Maximum	400.0
Coef. Var.	1.6

	NW Right
Mean	46.5
Std. Dev.	47.3
Std. Error	4.8
Count	98
Minimum	3.0
Maximum	316.0
Coef. Var.	1.0

Appendix 3: Southwest Spotlight Line



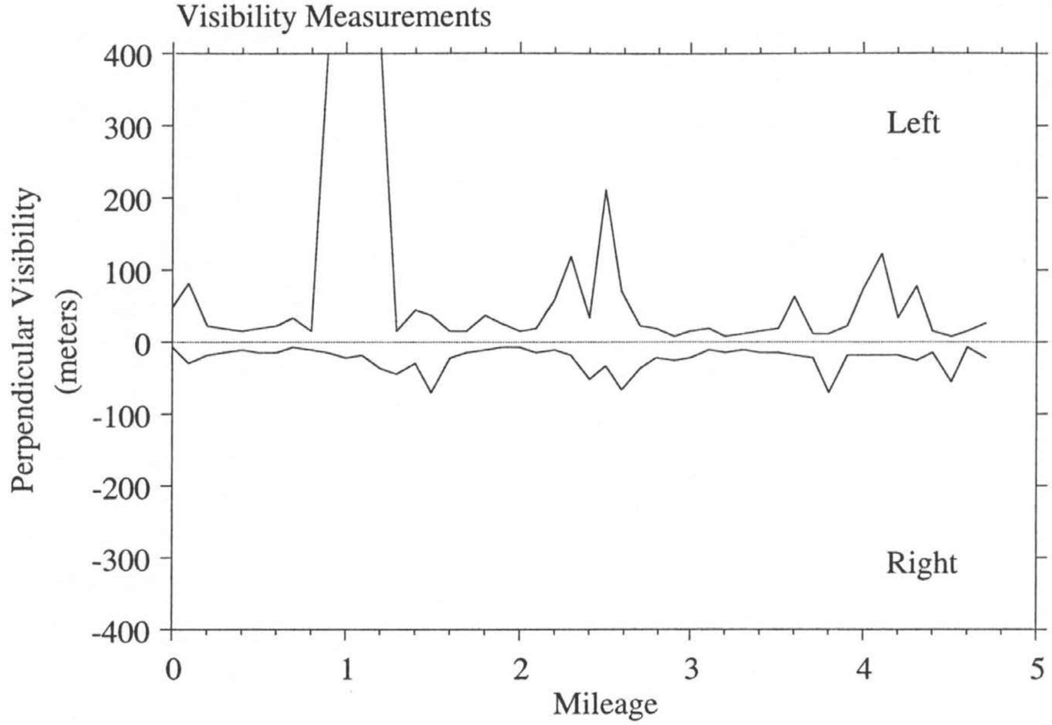


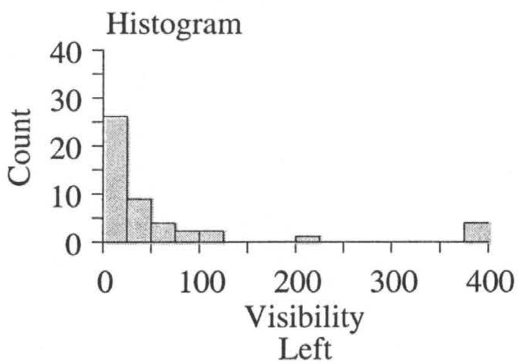


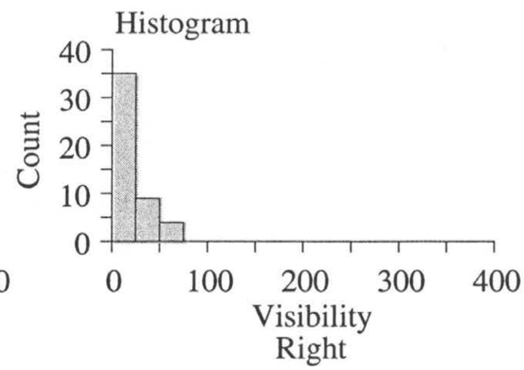
	SW Left
Mean	56.7
Std. Dev.	77.3
Std. Error	8.9
Count	75
Minimum	4.0
Maximum	400.0
Coef. Var.	1.4

	SW Right
Mean	56.7
Std. Dev.	95.9
Std. Error	11.1
Count	75
Minimum	5.0
Maximum	400.0
Coef. Var.	1.7

Appendix 4: Southeast Spotlight Line







	SE Left
Mean	66.9
Std. Dev.	108.0
Std. Error	15.6
Count	48
Minimum	6.0
Maximum	400.0
Coef. Var.	1.6

	SE Right
Mean	23.0
Std. Dev.	16.1
Std. Error	2.3
Count	48
Minimum	6.0
Maximum	71.0
Coef. Var.	.7

Appendix 5. DISTANCE template file for the unstratified 1997 Camp Bullis line transect analysis. The parameters are the same for the unstratified 1998 DISTANCE template file.

```
;Camp Bullis Analysis Template for Whole Area
;Line Transect - Perpendicular Distance, Ungrouped, Clustered
ASSIGN LOG=CB97.LOG/REPLACE;
ASSIGN OUTPUT=CB97.OUT/REPLACE;
ASSIGN RECORD=CB97.REC/REPLACE;
ASSIGN STATS=CB97.STA/REPLACE;
ASSIGN PLOT=CB97.PLO/REPLACE;
Options;
  Title='1997 Camp Bullis Line Transect Analysis by Unit';
  Object=Cluster;
  Maxterms=3;
End;
Data;
  Infile=CB97.dat/echo;
End;

Estimate;
  Distance/width=350;
  GOF/nclass=7;
  Estimator /Key=HNormal /adjust=poly/select=specify/order=4;
  Cluster/Bias=GXLOG/Test/;
  Density by ALL;
  Encounter by ALL;
  Size by ALL;
  Detection All;
End;

Estimate;
  Distance/width=350;
  GOF/nclass=7;
  Estimator /Key=Hazard /adjust=poly/select=specify/order=4;
  Cluster/Bias=GXLOG/Test/;
  Density by ALL;
  Encounter by ALL;
  Size by ALL;
  Detection All;
End;
```

Appendix 6. TRANSAN log file for the 1997 Camp Bullis line transect analysis. An estimated group size of 1.6727 deer/cluster was obtained from DISTANCE. The study area is 11,283 ha in size. This analysis would yield a population estimate of 830.42 (625.45, 1203.65 CL).

```
***************************
* TransAn -- Version 1.03 *
***************************
Data from file: 97.raw
Data Analyzed: 1997 Camp Bullis Sighting Distances

TOTAL TRANSECT LENGTH        = .2910E+06 METERS
TOTAL NUMBER OF OBSERVATIONS =  375

Constraints on the detection function are:

1) NUMBER OF CLASSES = 10
2) INFLECTION PT. is between  70.0 th %tile and 100.0 th %tile.
3) SHOULDER WIDTH = 1 (minimum is 1)
4) MIN. TAIL HEIGHT =   .10 % of shoulder ht.
5) MAXIMUM SIGHTING DIST. = 450.0     METERS

DENSITY ESTIMATE
          = 0.4404E-05 / SQUARE METER
          = 0.0440 / HECTARE
          = 4.4037 / SQUARE KILOMETER

LOWER LIMIT IS  .33140E-05 / SQ. METER
UPPER LIMIT IS  .63776E-05 / SQ. METER

End of TransAn analysis using
 1997 Camp Bullis Sighing Distances
*****************************
```

Appendix 7. TRANSAN log file for the 1998 Camp Bullis line transect analysis. An estimated group size of 1.8200 deer/cluster was obtained from DISTANCE. The study area is 11,283 ha in size. This analysis would yield a population estimate of 1220.81 (927.61, 1692.15 CL).

```
***************************
* TransAn -- Version 1.03 *
***************************
Data from file: 98.raw
Data Analyzed: 1998 Camp Bullis Sighting Distances

TOTAL TRANSECT LENGTH        = .2910E+06 METERS
TOTAL NUMBER OF OBSERVATIONS =  548

Constraints on the detection function are:

1) NUMBER OF CLASSES = 10
2) INFLECTION PT. is between  70.0 th %tile and 100.0 th %tile.
3) SHOULDER WIDTH = 1 (minimum is 1)
4) MIN. TAIL HEIGHT =  .10 % of shoulder ht.
5) MAXIMUM SIGHTING DIST. = 500.0    METERS

DENSITY ESTIMATE
         =  0.5945E-05 / SQUARE METER
         =  0.0595 / HECTARE
         =  5.9450 / SQUARE KILOMETER

LOWER LIMIT IS  .45172E-05 / SQ. METER
UPPER LIMIT IS  .82403E-05 / SQ. METER

End of TransAn analysis using
1998 Camp Bullis Sighting Distances
****************************
```

Appendix 8. DISTANCE template file for the 1997 Camp Bullis line transect analysis. The parameters are the same for the 1998 DISTANCE template file.

```
;Camp Bullis Analysis Template for 3 Management Areas
;Line Transect - Perpendicular Distance, Ungrouped, Clustered
ASSIGN LOG=CB97.LOG/REPLACE;
ASSIGN OUTPUT=CB97.OUT/REPLACE;
ASSIGN RECORD=CB97.REC/REPLACE;
ASSIGN STATS=CB97.STA/REPLACE;
ASSIGN PLOT=CB97.PLO/REPLACE;
Options;
  Title='1997 Camp Bullis Line Transect Analysis by Unit';
  Object=Cluster;
  Maxterms=3;
End;
Data;
  Infile=CB97.dat/echo;
End;

Estimate;
  Distance/width=350;
  GOF/nclass=7;
  Estimator /Key=HNormal /adjust=poly/select=specify/order=4;
  Cluster/Bias=GXLOG/Test/;
  Density by Stratum;
  Encounter by stratum;
  Size by Stratum;
  Detection All;
End;

Estimate;
  Distance/width=350;
  GOF/nclass=7;
  Estimator /Key=Hazard /adjust=poly/select=specify/order=4;
  Cluster/Bias=GXLOG/Test/;
  Density by Stratum;
  Encounter by stratum;
  Size by Stratum;
  Detection All;
End;
```