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Density and Herd Composition of White-tailed Deer Populations on Fire Island National Seashore

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Executive Summary

In an effort to better understand the resource and to comply with National Park Service management policies, a two year study was conducted for the purpose of developing a white-tailed deer (*Odocoileus virginianus*) population monitoring protocol on select units of Fire Island National Seashore. A ground-based method employing distance sampling was tested as an alternative to aerial surveys, particularly for the more developed areas of Fire Island. The emphasis of this study was on developing a protocol that was efficient, inexpensive and easy to implement. The four units of Fire Island National Seashore selected for study were the Kismet-Lonelyville (K-L) area, Fire Island Pines (FIP: including Cherry Grove), the Fire Island Wilderness Area (FWA), and the William Floyd Estate (WFE). Distance sampling is relatively easy to conduct and the theory allows for the fact that some deer will not be detected, thus alleviating the need to correct for unseen animals. From a sample of perpendicular distances from the objects of interest (in this case, groups of deer) to a line transect, a mathematical function is generated which describes how detection of objects changes with increasing distance from the transect. The area around the transect from which objects are counted can be derived from this function. Density is computed as the number of deer encountered divided by the effective area sampled. A variety of sampling plans was implemented depending upon the relative access to deer. A random sampling plan that used boardwalk segments for sampling units was adopted in the K-L and FIP study areas. Bicycles were used for transportation in these areas. At WFE, road segments were randomly selected and surveys were conducted from a motorized vehicle. A systematic sampling plan was employed in the FWA and all detections of deer were made on foot. A total of 59 surveys was conducted over a 21 month period from July, 1995 to March, 1997 in the K-L study area. In addition, 5 surveys were conducted in FIP, 8 in FWA and 6 in WFE at various times over the course of study. Average density was 79 deer km^{-2} in K-L, 83 deer km^{-2} in FIP, 16 deer km^{-2} in FWA and 26 deer km^{-2} in WFE. Herd composition data, collected in tandem with distance sampling, indicated that neonatal fawns comprised about 10% of the summer populations of K-L and FIP despite several years of active fertility control. Sex ratio among yearling and adult animals in order of increasing females was K-L: 2♀:1♂; FIP: 3♀:1♂; and WFE: 4♀:1♂. In addition, a trend analysis indicated an increase of 14 deer over the 21 month monitoring period in the K-L study area, though the uncertainty in that conclusion is high relative to larger potential increases and longer monitoring periods. For example, increases of ≥61 deer over a 36 month period can be detected by monitoring on a quarterly basis. Smaller increases can be detected depending on the frequency of monitoring and the degree to which a false claim can be tolerated. From a biological perspective, the method appears to be providing an accurate picture of deer abundance on the various units of Fire Island based on prior notions of population abundance, accounts from knowledgeable staff and residents, or expectations deduced from local habitat conditions. At the recommended minimum standard for statistical precision, the method will demonstrate sufficient power to detect modest (i.e., 10% annually) increases in deer populations with minimal effort. Implications of findings for a full implementation of the protocol, including a discussion on setting alternative statistical tolerances are discussed.

Density and herd composition of white-tailed deer populations of Fire Island National Seashore.

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Introduction

Fire Island National Seashore (FIIS) initiated public meetings in November, 1995 to discuss the issues surrounding perceived problems of overabundant white-tailed deer (*Odocoileus virginianus*) on several units of FIIS. These public meetings, in accordance with federal guidelines, were held in order to openly discuss potential environmental impacts of deer on the park's natural and cultural resources and to explore alternatives for future management.

Because the National Park Service (NPS) policies stipulate that management actions be based upon scientifically credible data (USDI 1988), the NPS funded a two year study to explore alternatives for assessing the number of deer on a given unit to within acceptable statistical limits. In addition, through the course of compliance to federal regulations, should the preferred alternative require that deer numbers be manipulated to acceptable levels, monitoring necessarily would be required to determine the composition (i.e., number of females, males, and fawns) of the herd under study.

Necessary features of a good population monitoring program include ease of implementation, intuitive and comprehensible results, low cost, and defendable statistical properties. Here we report on the use of distance sampling (Buckland et al. 1993) methods for estimating deer population density. The objectives of this study were to:

1. Develop a monitoring protocol for characterizing deer population density and herd composition on units of FIIS.
2. Evaluate the method based on biological, statistical and logistical milestones.
3. Demonstrate the utility of the data in a management application.

Study Area Descriptions

General

Fire Island is a barrier island located along the southern coast of Long Island, New York (40 41' N, 73 00' W). It is approximately 51 km long and averages about 0.5 km in width. The island is bordered by the inlets of Fire Island to the west and Moriches to the east, and is separated from Long Island by Great South and Moriches Bays (Fig. 1). The physiognomy of Fire Island is typical of Atlantic barrier islands, which grade from a primary dune along the ocean to salt marsh along the bay. The development of vegetation is affected by wind, salt spray, erosion and other environmental factors (Art 1976). Dominant vegetation common to Fire Island includes pitch pine (*Pinus rigida*), beach grass (*Ammophilia breviligulata*), wax myrtle (*Myrica cerifera)*, bayberry (*M. pensylvanica*), shadbush (*Amelanchier canadensis*), and common greenbrier (*Smilax rotundifolia*). This particular composition of vegetation is typical of Fire Island except within the various communities where residents have planted non-indigenous vegetation.

Fire Island West

Located throughout the western half of Fire Island are 17 towns and villages. Access to these communities is provided by boat or by vehicle via the Robert Moses Causeway. The Burma Road, a vestige of abandoned development plans, bisects the island along its entire length and represents the focus of restricted vehicular traffic within the towns and villages of Fire Island. However, the Burma Road is largely impassable along sections between adjacent communities. A network of boardwalks is common within most Fire Island communities and serves as the primary thoroughfare for predominantly pedestrian and bicycle traffic (Fig. 2). The villages from the western edge of Kismet to the western edge of Lonelyville (K-L) are included in the primary study area. In addition, the villages of Fire Island Pines and Cherry Grove (collectively: FIP) are included secondarily in Fire Island West. Casual reports suggest that deer numbers throughout the western half of Fire Island began to increase during the early to mid-1980's.

Fire Island East

The Fire Island Wilderness Area (FWA) is the primary land unit of interest in this part of Fire Island. It extends from the Smith Point County Park on the east, to the NPS's Watch Hill development on the west. A parcel (7 ha) of non-federally owned land, Bellport Beach, lies roughly in the middle of the FWA, and is a lightly visited and seasonal recreational site. The FWA is a federally designated wilderness area and represents about 11 km of pristine barrier island shoreline. Access to the FWA is highly restricted, and every attempt is made to minimize human disturbance. The FWA is characterized by a very well developed primary dune system; some dunes are as high as 12 m. In some areas, there is a fairly distinct secondary dune system as well. The vegetation structure of the FWA includes shrub thickets, pine savannahs, patches of maritime forest, and expanses of tidal marshland.

A density estimate of 25 deer km^{-2}, derived from a small sample of radio-collared deer, was reported for the FWA by O'Connell and Sayre (1989). Bi-annual aerial surveys have consistently provided counts between 70-100 deer for the area over a 10 yr period between 1984-94 (Underwood 1991), despite the landfall of hurricane Gloria in 1985 and the harvest of 45 deer through an experimental hunt in the autumn and winter of 1988-89.

William Floyd Estate

The William Floyd Estate (WFE), a unit of FIIS, is located on the southern shore of Long Island, approximately 97 km east of New York City. With respect to Fire Island, WFE is directly opposite the Smith Point County Park across Narrow Bay. It encompasses approximately 220 ha, which include 163 ha of woodland, 41 ha of salt marsh, and 16 ha of maintained fields. Common plant species include oaks (*Quercus* spp.), hickories (*Carya* spp.), pitch pine, and common greenbrier. The property is managed to preserve the historical ambiance of an eighteenth century farm estate. Many of the cultivated fields are maintained through periodic mowing. A loop road and several spur roads provide restricted vehicular access to WFE. According to reports from NPS staff, deer were rare on WFE until about 1980 when their numbers began to steadily increase. While there are no formal estimates of density, NPS staff consistently report seeing dozens of deer during routine spotlight counts (R. Stavdal, pers. comm.).

Methods

Population Density Estimation - Distance sampling methods (Buckland et al. 1993) were used to estimate density for FIIS. Distance sampling is not new to the field of wildlife biology and management (Burnham et al. 1980). However, only recently has a rigorous theoretical basis been formulated and tested for estimating the abundance of wildlife populations. Numerous applications of distance sampling (formerly line transect sampling) appear in the published literature, but a notable paper which pertains to large, herbivorous mammals is Gogan et al. (1986).

Conceptually, the method is straightforward. From a sample of perpendicular distances from the objects of interest to a line transect, a mathematical function is generated which describes how detection of objects changes with increasing distance from the transect. From this function, the area around the transect from which objects are counted can be computed. Density is computed as the number of deer encountered divided by the effective area sampled. Distance sampling theory allows for the fact that some deer within the study area, except those directly on the survey route or transect, will not be detected thus alleviating the need to correct for missed animals. A series of robust estimators have been formulated to efficiently calculate animal density from a modest sample of perpendicular distances.

The formula for density is:

$$\hat{D} = \frac{n * \hat{f}(0) * \bar{s}}{2L} \quad where$$

$\hat{D}$ = *density* $\qquad$ n = *number of deer groups*

$\bar{s}$ = *mean group size* $\qquad$ L = *length of transect*

$\hat{f}(0) = \frac{1}{a}$ *and* , $\qquad$ $a = \int_0^w g(x)d(x)$

$g(x)$ = *detection function* $\qquad$ w = *maximum distance* (x)

The first component in the formula above is the encounter rate (i.e., n), or the number of deer groups encountered during a given survey. In general, the encounter rate contributes most to the overall variation in estimated density. The second component is the mean group size (i.e., $\bar{s}$), or the average number of deer in each group encountered. Finally, the third component is the probability of detection, defined by the integral of the function *g(x)* in the equation above. All components are measured directly from observations of deer along sampled transects.

There are two properties of distance data that are fundamental for reliable density estimation. The first is that enough objects be observed to adequately describe the probability of detection as a function of perpendicular distance from the transect. In general, the more objects observed, the smoother the representation of the detection function. Second, transect length must be sufficient to achieve a desired level of precision, which equates to reliability of the estimate. We used the software program DISTANCE vers. 2.0 (Laake et al. 1993) to assist us in developing statistical guidelines for sampling the various units of FIIS and to analyze data once collected.

In Fire Island West (i.e., K-L and FIP), we sampled directly from the boardwalks and used bicycles for transportation. The name and length of each boardwalk was stored in a database from which samples were drawn randomly and without replacement for a given survey. The total number of boardwalks selected was based upon a minimum length of transect required to achieve a desired level of precision (Appendix I). Using the same sample selection criteria, surveys were replicated on 2-4 consecutive days depending on the number of groups sampled. Therefore, a given boardwalk segment could have been sampled on consecutive days though never twice on the same day.

In Fire Island East, sampling was conducted systematically starting from a random starting point located near the Watch Hill station. Sampling progressed in an easterly direction parallel to the Burma Road until the entire length of the FWA was covered (i.e., to Smith Point). An all terrain vehicle (ATV) was used to transport the observer to and from transect starting

positions along the beach; all detections of deer were made on foot. While traversing the primary transect, occasional North-South transects were established by compass bearing from bay to ocean. Due to dense vegetation in some areas, North-South transects were sampled only where visibility permitted at least a minimal chance of detecting deer.

For the WFE, the entire road network was measured for length and individual road segments were stored in a computer database. Like Fire Island East, a given survey route was comprised of randomly selected road segments meeting a minimum length criterion. The WFE was the only FIIS unit where we stratified our sampling into two distinct cover-types due to an expectation of greatly differing detection probabilities. Cover types were Woodland, where a relatively dense understory vegetation was expected to diminish detection probabilities, and Fields, where a high probability of long-range detections was anticipated. According to established routine, surveys were conducted at approximately biweekly intervals from a motorized vehicle by NPS staff.

We used a nearest neighbor criterion (LaGory 1986) and behavioral cues to aid us in identifying a deer group. Upon detecting a deer group (≥1 deer), the perpendicular distance from the observer was recorded using a handheld laser-rangefinder (Yardage Pro™ 400, Bushnell Corp.) or a handheld prismatic rangefinder (Ranging™ Optimeter Models 60 and 120). In situations where the perpendicular distance could not be measured directly, a radial distance and angle were recorded using a pocket transit and the perpendicular distance was computed later in DISTANCE. Binoculars and a high-intensity light (WFE only) were utilized when needed. Distances measured in the K-L study area from July, 1995 to April, 1996 were measured using the prismatic rangefinders, while all subsequent distances were measured using the laser-rangefinder. For a given area and time period, multiple surveys were either treated as replicate counts, or pooled into a single count, and a density estimate and associated 90%, log-based confidence intervals were computed (Buckland et al. 1993).

Herd Composition— Individuals within each deer group were classified according to sex (i.e., male, female, or unknown) and age at the time of sampling (i.e., fawns: <1 year old, yearlings: ≥1 year and <2 years old, adults: ≥2 years old, or unknown). Other than from the presence of conspicuous antlers, sex and age were determined from physical and morphological criteria developed from thousands of observations of deer. The analysis of herd composition was restricted to the months between July and December in each year due to the increased difficulty of distinguishing sex and age during all other months. Because FWA was sampled in April, no herd composition estimates were computed; however, we felt comfortable with presenting estimates for FIP which was sampled in January. Herd composition was summarized as the proportion of males, females, and fawns in the total sample, and converted to males and fawns per 100 yearling and adult females. Only observations where all group members were classified according to sex and age were used in this analysis. Standard errors for the proportions were calculated using a binomial approximation and using a method which treats the group as the sampling unit (Bowden et al. 1984).

Statistical Analysis— Statistical treatment of the transect data was relegated primarily to the K-L study area because of the extended monitoring period. Time plots of the encounter rate, mean group size and the one-half effective strip width (ESW), derived from DISTANCE, were made to examine trends and potential associations among the various components. In addition, crude (i.e., derived directly from the raw data) estimates of the encounter rate and group size were computed and plotted according to transect segment and month to examine spatial variation across the K-L study area from June, 1996 to February, 1997.

Encounter rate and group size were first summarized by computing the number of groups and group size for each transect segment and survey. Then, totals were summarized over transect segment and month (i.e., a transect segment might have been sampled more than once during the same month). Finally, summary statistics were computed for encounter rate and group size over each of the 5 localities (see Fig. 2) and by year and month.

In other words, if more than one transect segment was sampled in a given locality and month, these segments were used to calculate the minimum, maximum and mean for encounter rate and group size. To explore the statistical precision of density estimates, 90% confidence interval coverage, expressed as a percentage of the mean density, was plotted against the coefficient of variation (CV) reported from DISTANCE.

To demonstrate an important application to management, we used standard regression analysis to determine if a trend in mean density was evident over time in the K-L study area. Mean monthly density estimates were regressed on time. An estimated slope (i.e, β_1) significantly greater than zero is indicative of an increase in deer numbers in the study area. The distribution of the estimated regression slope was explored using the data as the sampling universe and standard resampling methods (Simon 1993).

A statistical analysis of power was also conducted by simulating survey data. This was accomplished by drawing a monthly density estimate from a normal distribution with the mean equal to the observed 19-month average density. An error was added by drawing from the distribution of observed monthly standard deviations ($n = 19$) as if they were also normally distributed. Slopes corresponding to simulated increases of 5, 24, and 48% in the total deer population on the study area over a 36 month period were substituted into the equation for a linear increase. A 36-month time series was generated simply by multiplying the slope by the time index (i.e., time index 0 = July) and adding the overall mean density and error to that quantity.

The effects of different durations between monitoring events on power were explored using a factorial-like approach. Type I errors (α-levels) selected were 0.01, 0.05, 0.10, 0.20 and 1.0, and time between monitoring events included every 1, 2, 3, 6, and 12 months over a 36 month period. Therefore, the number of simulated data points included in regressions were 36, 18, 12, 6 and 3, respectively. Each rate of increase was used to create 1000 time series from which a regression was computed and power was determined for each α-level and monitoring

interval. Following the convention suggested by Forney et al. (1991), we define statistical power as 1-(β+γ). In addition, we have also adopted a minimum standard for power of 80% (Peterman and Bradford 1987).

Results

Fire Island West: K-L

Based upon preliminary sampling, we concluded that a transect length of at least 6 km would be necessary to achieve a minimum working precision (i.e., CV = 50%; Appendix I), and that surveys should be conducted in the hours immediately after sunrise. Surveys conducted in the hours prior to sunset were frequently interrupted by activities of community residents; we noted a strong negative correlation between the number of people we encountered and the number of deer counted. We later adjusted the total transect length upward to 9 km (47% of the total length available) based upon refinement of estimates of the deer encounter rate to achieve greater precision (i.e., CV ≈ 20%).

A total of 59 surveys was conducted over a 21 month period (two months were not sampled) from July, 1995 to March, 1997. Average total duration of surveys conducted with a single observer was 87.4 minutes (range: 35-132). For surveys conducted with two observers, average total duration was 69.5 (range: 45-110) minutes.

Deer density on the study area was highly variable and showed few seasonal trends other than noticeable declines in November, 1995 and August 1996. The average density over the 21 month period was 79 deer km^{-2} (SD = 19 deer km^{-2}). The lowest density was 35 deer km^{-2} sampled in November of 1995; the highest estimated density was 103 deer km^{-2} sampled in February of 1997 (Fig. 3).

The composition of the deer herd occupying the K-L study area did not change appreciably over the duration of the study (Fig. 4). Yearling and adult females (i.e., does) comprised the largest fraction of the total population in each year (≈50%). Although yearling and adult females exhibited greater proportional representation in 1996 than in 1995, the difference is no greater, on average, that the error associated with monthly estimates (Tables 1 and 2). Yearling and adult males comprised about 40% of the total population in each year. The proportion of males was relatively consistent from month-to-month in 1995, whereas the proportion decreased from a high of about 60% in July to about 30% by September of 1996. Neonatal fawns (i.e., ≤2 weeks) were observed by July of each year, their proportion increasing through August. In each year, there was a sharp and significant increase in the proportion of neonatal fawns observed in September surveys (Tables 1 and 2; Fig. 4).

In general, the encounter rate exhibited peaks in the spring (i.e., April-June) and in the late autumn-early winter (i.e., December-February; Fig. 5). The trend in mean group size was inversely related to encounter rate for all months except November (Fig. 5). The correlation between encounter rate and group size was strong (r = -0.66) and highly significant (p = 0.004), excluding November's data. While most prevalent in 1995, there was in each year a sharp and

noticeable decline in the frequency of groups encountered with membership >3 deer between the months of October and December (Figs. 6 and 7). The largest groups were encountered from July-September.

Spatial variation in encounter rate and group size was evident across the K-L study area (Figs. 8 and 9). Overall, the Navy Bay area exhibited the highest encounter rates and group sizes, particularly during the mid-summer to early-winter months (i.e., August-December). The encounter rate for Kismet was noticeably higher from October through December, 1996, than in other months.

The average ESW for the K-L study area was about 22 m (Fig. 10). Estimated ESW decreased slightly over the first year of the study, converged toward the overall mean, and fluctuated without trend for the remainder of the study. Precision around estimated deer density is positively related to the sum contribution of all variance components (Fig. 11). Coverage of 90% confidence intervals is good and exhibits high precision when the CV of the estimated density is ≤20%.

The regression of estimated deer density on time (excluding November, 1995 and August, 1996) for the K-L study area attained a significance level of $p = 0.15$. The fit of a straight line was poor ($r^2 = 13\%$) with moderate residual error (SD = 7.2 deer km^{-2}). The estimated slope parameter was positive ($\beta_1 = 0.414$) suggesting an increase in the deer population on the study area from 79 deer km^{-2} to 88 deer km^{-2}, an increase of about 9 deer km^{-2} over the 21 month period. One-thousand bootstrapped regressions computed by re-sampling the raw data indicated that the probability of obtaining a slope estimate of 0 is less than 1 in 10 (i.e., $p = 0.08$).

The data simulation demonstrated low power for detecting a 5% increase (i.e., 6 deer) in the deer population, and high power for detecting a 24% increase (i.e., 30 deer) in the deer population over a 36 month period depending on the interval between monitoring events and α-error rate. For instance, the regression model demonstrated moderate power for detecting a 24% increase in the deer population at $\alpha = 0.2$ for surveys conducted every other month (Fig. 12). However at $\alpha = 1$, γ-errors inflate rapidly depending upon the rate of change and monitoring interval. The magnitude of γ-errors declined dramatically with larger trends or higher frequency of monitoring.

Fire Island West: FIP

Five surveys were conducted from 21-30 January, 1997, covering an average 7,960 m of boardwalk per survey (including Cherry Grove). Average deer density for FIP during January was 82.7 deer km^{-2} (Table 3), identical to the deer density sampled for K-L during the same month and year. Encounter rate accounted for 60% of the variance in density. Detection and group size variation accounted for the remaining 25% and 15%, respectively. The estimated ESW derived from pooled survey data was 16.2 m. Similar to K-L, this herd was comprised of 60% yearling and adult females, 25% yearling and adult males, and 15% postnatal (i.e., >2 weeks and <1 year old) fawns (Table 4).

Fire Island East: FWA

Eight surveys were conducted on five occasions from 21-26 April, 1997. A total of 22 transects from ocean to bay was traversed, along with the principal east-west transect, covering 59.8 km. Estimated density was 15.5 deer km^{-2} (Table 3). Seventy-six percent of the variation in deer density was attributable to encounter rate. Detection and group size variation accounted for the remaining 7% and 17%, respectively. The estimated ESW derived from pooled data was 55.6 m. No herd composition estimates are available for this unit.

William Floyd Estate

A total of 6 surveys was conducted between 24 August and 8 November, 1996, covering an average 7,213 m of roadway per survey. The data from September surveys only were pooled (i.e., not treated as replicate surveys) to produce an average density of 26 deer km^{-2} (Table 3). Ranked contributions to the variation in density were: encounter rate (65%), group size (34%) and detection (1%). The ESW pooled over the two strata was 74 m; however, deer were detected in the woodlands at much closer distances and detections in fields were often at much greater distances. The deer herd of WFE was comprised of 47% yearling and adult females, 21% yearling and adult males, and 32% postnatal fawns (Table 4). Similar to the K-L study area, there was a noticeable decline in the frequency of deer groups with >3 members during the months of October and November (Fig. 13).

Discussion

Estimating population abundance, by any means, is probably the most demanding of tasks for wildlife biologists (Caughley 1977). The preparation and expense necessary to produce an estimate of abundance is often so great that justifying even a minimal attempt is difficult. Yet, the knowledge of the size and composition of a population is prerequisite to managing effectively, especially where program goals are stated explicitly in numbers of animals (Caughley and Sinclair 1994). Unfortunately, a method that works in one area may not in another due to a host of logistical and biological constraints. Thus, it is essential that new methods be developed or old ones be improved.

Of concern to the manager is whether the abundance of a particular species can be assessed reliably and inexpensively. As with most statistical endeavors, greater reliability often comes at disproportionally greater expense (Green 1979). This is a certain realization for estimating the abundance of a population of large mammals like white-tailed deer. It is therefore paramount that the method employed be carefully selected to match both objective and budget. More often than not, compromises must be made to satisfy both criteria.

Because method is inextricably linked to objective, the process of evaluating a monitoring protocol or program has little meaning outside the context within which it was developed. Thus, caution should be exercised in judging the suitability of our approach to another area or question. That said, our evaluation is tripartite. First, it is important to establish that the method is measuring what it is intended to measure. While no method is bias free, all that is required for

this purpose is that changes in true population abundance are likewise reflected in the data collected. Because we have no other method to validate density estimates presented in this report, we rely on consistency of data interpretations with respect to well-documented aspects of deer biology, particularly those that change seasonally. This reflects a *biological* evaluation of the method. Second, elements of reliability are important and should be an integral part of any population assessment. Here we focus on the sensitivity of the method to changes in population abundance. This represents a *statistical* evaluation. Finally, due to the number of variables that impinge upon the actual conduct of data collection, a crucial *logistical* evaluation is very important in order to accurately predict the costs of implementing the monitoring program. Finally, we conclude with a list of recommendations regarding a full implementation of the method on units of FIIS.

Biological Evaluation

Estimates of mean deer density sampled from units of FIIS seem reasonable based on prior notions of population abundance, accounts from knowledgeable staff and residents, or expectations deduced from local habitat conditions. When prorated over total area, the number of deer estimated for the K-L study area is in agreement with numbers estimated by the Immunocontraception Research Team based on a more intensive exposure to the deer in this area (J. Kirkpatrick, pers. comm.). A count of 74 deer derived from a low-altitude aerial survey conducted in the FWA during December, 1996, falls within the confidence interval of the prorated density we computed (Table 3). While we have no corroborating evidence at the WFE, staff there have indicated that the density derived from distance sampling is at least reasonable (R. Stavdal, pers. comm.).

Consistent co-variation in group size and encounter rate (Fig. 5) suggests an intuitive interpretation about the dispersion of deer, but a counterintuitive interpretation about actual population abundance. When encounter rate is high, deer tend to be more uniformly dispersed in the environment, giving the impression of high abundance. Conversely, when deer are aggregated into larger groups, they are encountered less frequently thus giving the impression of lower abundance. In fact, abundance is unchanged in either situation; only the dispersion changes.

The exception to that general interpretation is when both encounter rate and group size are low. We witnessed this on several occasions in the K-L study area, primarily during the month of November, which at this latitude represents the breeding period for deer (Jackson and Hesselton 1973). During the breeding season, social affiliations are highly disrupted by the actions of both sexes, though males tend to be far more disruptive than females (Hirth 1977). Our data consistently showed a breakdown of groups during November (Figs. 6 and 7). In addition, daily movements of deer increase substantially (Kammermeyer and Marchinton 1977, Tierson et al. 1985), which could exaggerate the dispersion of deer, driving the encounter rate and estimated density downward.

Breeding behavior would not account for the low density estimate for August, 1996, however. Because we have no other verification of abundance for the K-L study area, we cannot rule out the possibility that sampling error is responsible for the very low abundances measured in November, 1995 and August, 1996. It is possible, that the transect segments we sampled in each of those months were located in areas where deer were not. Because our sampling intensity in the K-L study area was relatively high (i.e., about half of the available segments were sampled on any given occasion), attributing a substantial reduction in deer density (i.e., ≈50%) to chance alone seems unlikely, albeit possible.

This suggestion is further supported by the fact that we were able to discern changes in spatial dispersion of deer groups by locality (Figs. 8 and 9). For example, Navy Bay consistently exhibited higher deer encounter rates and group sizes than other locales in the K-L study area. This area represents the isthmus between the much larger western portion of the study area and the smaller eastern portion of study area, and probably concentrates deer moving parallel to the primary dune. In addition, the Navy Bay area is relatively undeveloped and represents one of the largest tracts of continuous vegetation cover in the study area. Moreover, an established and frequently utilized deer bait station is located at the municipal waste transfer station, a prominent feature of the Navy Bay area. The bait station was established under the auspices of the immunocontraception research in an effort to expedite treatment of deer by concentrating them at a central location.

Composition of the various deer herds revealed a significant increase in fawns observed during September surveys in both years on the K-L study area. While these could be fawns that were born earlier in the summer, we have anecdotal observations indicating a birth-pulse during the last two weeks in August and the first two weeks in September. We saw a number of very small (<5 kg) fawns during the late summer which still had prominent scabs on the umbilicus. These scabs ordinarily slough off within a couple of weeks of birth (Haugen and Speake 1958). Backdating an average 202-day gestation for white-tailed deer (Jackson and Hesselton 1973) identifies an active period of breeding, for those females producing fawns, between the end of January and the middle of February. Causes for this phenomenon remain speculative, but probably relate to either logistical or biological aspects of the immunocontraception research project presently in its fifth year in the K-L study area.

Although the percent composition of fawns in the FIP deer herd is nearly identical to the K-L study area, we have no substantive evidence of a late birth-pulse there because we did not sample over time. Disparity in the sex ratio among yearling and adult deer was similar for the Fire Island West study areas (K-L: 2♀:1♂; FIP: 3♀:1♂), and substantially and significantly different for WFE (4♀:1♂). However, WFE is on the mainland where more dispersal opportunities exist for young males, and where the illegal harvest of male deer is probably greater.

In summary, our experience with this method in a variety of settings has been favorable with respect to what it can tell us about individual deer herds. We are encouraged by the fact that we can obtain fairly high resolution herd composition estimates in tandem with the distance sampling. The complementarity of encounter rate and group size dynamics in the K-L study area provides an internal check that the method is sensitive enough to pick up changes in dispersion as well as abundance. This is reassuring when only a single survey (i.e., 1-4 samples) can be conducted.

Statistical Evaluation

We take a pragmatic view of statistics in the present context. Does the method provide a realistic measure of population abundance and composition? While we cannot be absolutely certain, we have presented arguments supporting the method's value (see previous section). With the means available, can we collect enough data to demonstrate real differences when we need to know them? That is, if it takes 10 years to demonstrate a 25% annual increase in deer numbers, then the method is not likely to be very useful to management (i.e., a 25% annual increase over 10 years at a starting population of 100 deer would equal 931 deer, a change of nearly an order of magnitude). The differences we seek are those that impinge on our ability to manage.

At the survey level, we suggest that a precision of CV = 20% be set as the minimum standard. At this level, 90% confidence interval coverage is at or below 50% of the mean density estimate (Fig. 11). Keep in mind that at the sampling intensity we adopted, this level of precision was attained about half of the time. Either increased sampling intensity (i.e., more boardwalk sampled) or increased replication (i.e., number of survey days) or both may be necessary to consistently meet the minimum standard. By comparison to published studies of large mammal survey methods, the proposed minimum standard is reasonable and defensible (Eberhardt 1978).

Although the ordinary regression suggested a modest increase in deer numbers on the K-L study area, we are not entirely satisfied with this conclusion due to difficulties in model selection and the fact that regression through the mean abundance estimates ignores within-month variation. Identifying the correct biological model from an array of competing models remains as a particularly vexing and unresolved *statistical* problem (Burnham and Anderson 1992) with which biologists must contend. We opted to employ an un-weighted regression of abundance on time, in spite of the fact that each survey had a known error associated with it. A fully weighted regression produced an impossibly high slope (2.3 deer km^{-2} per month) due to an overly influential observation early in the time series (November, 1995). Correcting the influence of that data point produced a model with very low residual error, which we also believe is not a realistic expectation of the method. In addition, another overly influential observation (August, 1996) was identified.

The final un-weighted model, with the offending months excluded, was justified on the basis that the error around each point estimates a common variance of deer density in the K-L study area. Most of the point estimates exhibited variances of similar magnitude, and we have no

a priori information to suggest that something other than a common variance should be expected. In addition, only two months out of the 21 month survey period produced density estimates lower than 70 deer km^{-2}. Thus a model with intercept = 79 deer km^{-2}, slope = 0.414 deer km^{-2} and residual error = 7.2 deer km^{-2} is more realistic based upon our experience in the area, but still lacks error associated with monthly density estimates.

The addition of within-month count variation substantially reduced the power to detect a trend equal to the observed regression slope (i.e., about 14 deer). We concede that a modest increase in deer numbers in the K-L study area is equivocal at this time. The analysis suggests that 36 months of monitoring would be required to detect a trend of this magnitude. In addition, we would be wrong in claiming such an increase about 2 times in 10. Nevertheless, we believe that with the addition of approximately 30 fawns born into this population over the last two years, such an increase is at least possible. Without knowledge of potentially offsetting losses to this herd, a more critical evaluation of population trend cannot be made at this time.

We based the power analysis upon a 36 month monitoring period, which includes 3 birth pulses. In any given year, the number of fawns born into the K-L study area will be small (i.e, 10-20). With increasing efficacy of fertility control, and nominal attrition in both fawns and adults, the realized increase would certainly be lower. The probability of detecting a small increase between 2 counts separated by 12 months would be very low based on our analysis. The addition of 2 more birth pulses increases the sensitivity of trend detection, while still minimizing the accrual of additional animals. For example, assuming an initial density of 79 deer km^{-2}, a 24% total increase (or 8% per year) in deer density represents an addition of only 30 deer at the end of 36 months of monitoring. However, the desired level of sensitivity to change is one of a number of factors that should be considered before management begins (Gasaway et al. 1986).

Under the premise (i.e., null hypothesis) of no increase in deer numbers, a manager is faced with three areas of statistical uncertainty, which can be defined in terms of probability of committing the following errors, all of which should be chosen beforehand:

α- the acceptable probability of concluding that an increase had occurred when, in fact, it had not (i.e., Type I error).

β- the acceptable probability of concluding that no change in numbers larger than a consequential one had occurred when, in fact, it had (i.e., Type II error).

γ- the acceptable probability of detecting a consequential change in numbers but in the opposite direction than predicted (i.e., Type III error; Carmer 1976).

Statistical power is commonly defined as the probability of rejecting the null hypothesis (e.g., in our example, the premise of no increase in deer population size) when it is false, which numerically is $1 - \beta$ (Rotenberry and Wiens 1985, Gerrodette 1987, Taylor and Gerrodette 1993, Thomas and Krebs *in press*). However, β-levels are affected by both α-levels and γ-errors. In

trend analysis in particular, γ represents the probability of rejecting the null hypothesis of no trend in deer numbers in favor of a trend in the wrong direction (Forney et al. 1991). By defining power in terms of both β and γ, the analysis includes only the probability of detecting the correct alternate hypothesis.

Ideally, the consequential change in deer density and tolerable levels of α, β, and γ should be determined based upon the costs of committing the various errors with respect to the anticipated change (Toft and Shea 1983). For example, the conventional α-level of 0.05 may be sufficient to guard against making a false claim of increasing deer abundance. However, in the context of population control, that level of certainty is required only when the cost of control is high relative to the cost incurred to the resource if no control action is undertaken and an increase did occur. This tradeoff is illustrated in Figure 14, where the relationships and probabilities are drawn to closely match the present context.

We suggest that in deer population control programs, there is far greater risk to the biotic resources of parks in committing a Type II error than a Type I error. Due to current technological constraints, fertility control measures that use the PZP vaccine must be implemented annually (Kirkpatrick et al. 1996). Therefore, costs are being incurred regardless of whether or not the population increases or declines. So from a program standpoint, if money will be spent anyway, it might be prudent to guard against potentially deleterious resource consequences of not detecting a real population increase (i.e., the Type II error).

Minimizing the probability of committing a Type II error can be accomplished statistically in a couple of ways. First, a one-tailed statistical test, which focuses on a trend in one direction or the other, could be adopted to increase the power of the monitoring program (Gasaway et al. 1986). Second, because we define power as a function of both β and γ, raising the α-level to 1 produces the same result by focusing on the sign of the slope parameter in the regression equation. At $\alpha = 1$ though, γ-errors and power are both maximized (Fig. 14). However, γ-errors can be diminished by either increasing the frequency of monitoring or by permitting a larger change to occur. For example, an 61-deer increase in population size over a 36 month period can be detected with quarterly monitoring while maintaining high power, conservative α-levels and minimal γ-errors (Fig. 12).

Logistical Evaluation

Most of the real work in adopting a monitoring protocol involves addressing problems that invariably arise in field implementation (Buckland et al. 1993). Appendix I outlines the process we used to fine tune the statistical properties of the data. But other, perhaps more consequential details of the method we review here before a full implementation is undertaken.

Initially, we adopted a rule of thumb (Burnham et al. 1980) which required 60 or more detections of deer groups before ending a given survey. We did not stipulate the number of days over which that number of detections could be accumulated. For instance, if 60 could be attained in a single day (although highly unlikely given our sampling intensity), the survey technically

could be terminated. However, we found that in practice, it is better to split the sampling effort across ≥3 days than to achieve ≥60 detections in a single survey. For a variety of reasons, it is safer to have more than a single day's worth of data to deal with the idiosyncrasies encountered during actual surveys. The flexibility afforded by program DISTANCE is only a good as the flexibility embodied in the data set.

Randomization of boardwalks seems to be performing adequately in terms of distributing our sampling effort across the K-L study area. We highly encourage the adoption of random sampling anywhere this method is employed. However, there will be a number of settings where random sampling cannot be performed. For example, random sampling in the FWA would have been prohibitively difficult due to the lack of access. We therefore selected a random starting point, and then systematically sampled the area. Because our inferences were restricted to the FWA, systematic sampling represented a valid alternative sampling method. In some cases, precision can often be improved using systematic, rather than random sampling methods (Caughley and Sinclair 1994).

During the first year of data collection we used the prismatic rangefinders exclusively. We switched to laser-rangefinders after the first year of data collection. The experience factor in using the prismatic rangefinders is evident in Figure 10, as there was a noticeable and steady decline in the estimated ESW over time. However, once the transition to laser technology was made, estimated ESW fluctuated (i.e., sampling variation) but no longer exhibited a time trend. We fully support and encourage the use of laser-rangefinders in distance sampling.

Estimates of deer herd composition are problematic between the months of January and March due to the difficulty in distinguishing males from females (after antler casting) and fawns from yearlings. Unless those participating in the survey are experienced at classifying deer, we highly recommend that all herd composition estimates be confined to the months of July-November.

We ultimately separated deer at bait sites into their constituent groups, which is tedious and often subjective. However, it is very important that an attempt at separation be made, otherwise density estimates can be severely biased upward. Additionally, double counting could be a problem depending upon the area sampled. In general, long-range detections should be recorded such that when the area is sampled at close-range, the probability of counting the same deer twice is minimized.

For training purposes, several months of distance sampling experience are required for high technical proficiency. The essential process of analyzing data with program DISTANCE can be taught in about an hour's time. A user can become reasonably comfortable with DISTANCE, and produce robust density estimates after 3 or 4 surveys. However, a full familiarity with the various models for estimating density, with the nuances of dealing with quirky distance data, and with all the features available to the analyst, will require a much more substantial investment in time.

Acknowledgments

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Tables

Table 1. White-tailed deer herd composition as a fraction of the yearling and adult female segment (♀♀), Kismet-Lonelyville, July-December, 1995, Fire Island National Seashore, New York.

Month	n[1]	Segment (x)	x/(x+♀♀)	SE[2]	SE[3]	x:100♀♀
JUL	85	Males	0.40	0.05	0.04	65.96
		Fawns	0.05	0.02	0.02	5.32
AUG	84	Males	0.44	0.05	0.04	77.08
		Fawns	0.03	0.02	0.02	3.13
SEP	53	Males	0.35	0.06	0.04	54.55
		Fawns	0.15	0.03	0.04	18.18
OCT	57	Males	0.32	0.06	0.04	46.81
		Fawns	0.12	0.03	0.03	13.83
NOV	46	Males	0.34	0.07	0.06	52.27
		Fawns	0.15	0.06	0.05	18.18
DEC	50	Males	0.45	0.08	0.05	82.61
		Fawns	0.15	0.06	0.05	17.39

[1]Number of deer groups.

[2]Standard error computed using the deer group as the sample unit (after Bowden et al. 1984).

[3]Binomial approximation to standard error.

Table 2. White-tailed deer herd composition, as a fraction of the yearling and adult female segment (♀♀), Kismet-Lonelyville, July-December, 1996, Fire Island National Seashore, New York.

Month	n[1]	Segment (x)	x/(x+♀♀)	SE[2]	SE[3]	x:100♀♀
JUL	72	Males	0.41	0.05	0.04	69.32
		Fawns	0.01	0.01	0.01	1.14
AUG	21	Males	0.34	0.07	0.04	51.35
		Fawns	0.07	0.03	0.03	8.11
SEP	115	Males	0.34	0.05	0.03	52.46
		Fawns	0.13	0.02	0.03	15.57
OCT	56	Males	0.33	0.06	0.05	48.15
		Fawns	0.10	0.04	0.04	11.11
NOV	75	Males	0.22	0.05	0.04	28.74
		Fawns	0.11	0.03	0.03	12.64
DEC	70	Males	0.31	0.06	0.04	45.78
		Fawns	0.11	0.04	0.03	12.05

[1]Number of deer groups.

[2]Standard error computed using the deer group as the sample unit (after Bowden et al. 1984).

[3]Binomial approximation to standard error.

Table 3. White-tailed deer density estimates for three units of Fire Island National Seashore, New York.

Unit	Month	Year	Density (No. km^{-2})	CV[1] (%)	df[2]	ESW[3] (m)	90% Confidence Limits[4]	
							Lower	Upper
WFE[5]	SEP	'96	26.0	19.8	3	74.0	16.4	41.1
FIP	JAN	'97	82.7	29.2	9	16.2	48.9	139.7
FWA	APR	'97	15.5	21.6	8	55.6	10.4	23.1

[1]Coeffecient of variation around estimated density.

[2]Satterthwaite degrees of freedom (see Buckland et al. 1993; pg. 120).

[3]One-half effective strip width.

[4]Log-based confidence intervals (Buckland et al. 1993; pg. 120).

[5]Only data for the month of September was used to estimate density.

Table 4. White-tailed deer herd composition, as a fraction of the yearling and adult female segment (♀♀), on other units of Fire Island National Seashore, New York. William Floyd Estate (WFE) was sampled from August-November, 1996. Fire Island Pines (FIP) was sampled during January, 1997.

Location	n[1]	Segment (x)	x/(x+♀♀)	SE[2]	SE[3]	x:100♀♀
WFE	119	Males	0.21	0.04	0.03	26.72
		Fawns	0.32	0.03	0.04	46.55
FIP	93	Males	0.25	0.05	0.05	33.33
		Fawns	0.15	0.04	0.04	18.18

[1]Number of deer groups.

[2]Standard error computed using the deer group as the sample unit (after Bowden et al. 1984).

[3]Binomial approximation to standard error.

Figures

Figure 1. Location of Fire Island National Seashore including the Kismet-Lonelyville (K-L), Fire Island Pines (FIP), Fire Island Wilderness Area (FWA) and the William Floyd Estate (WFE) study areas.

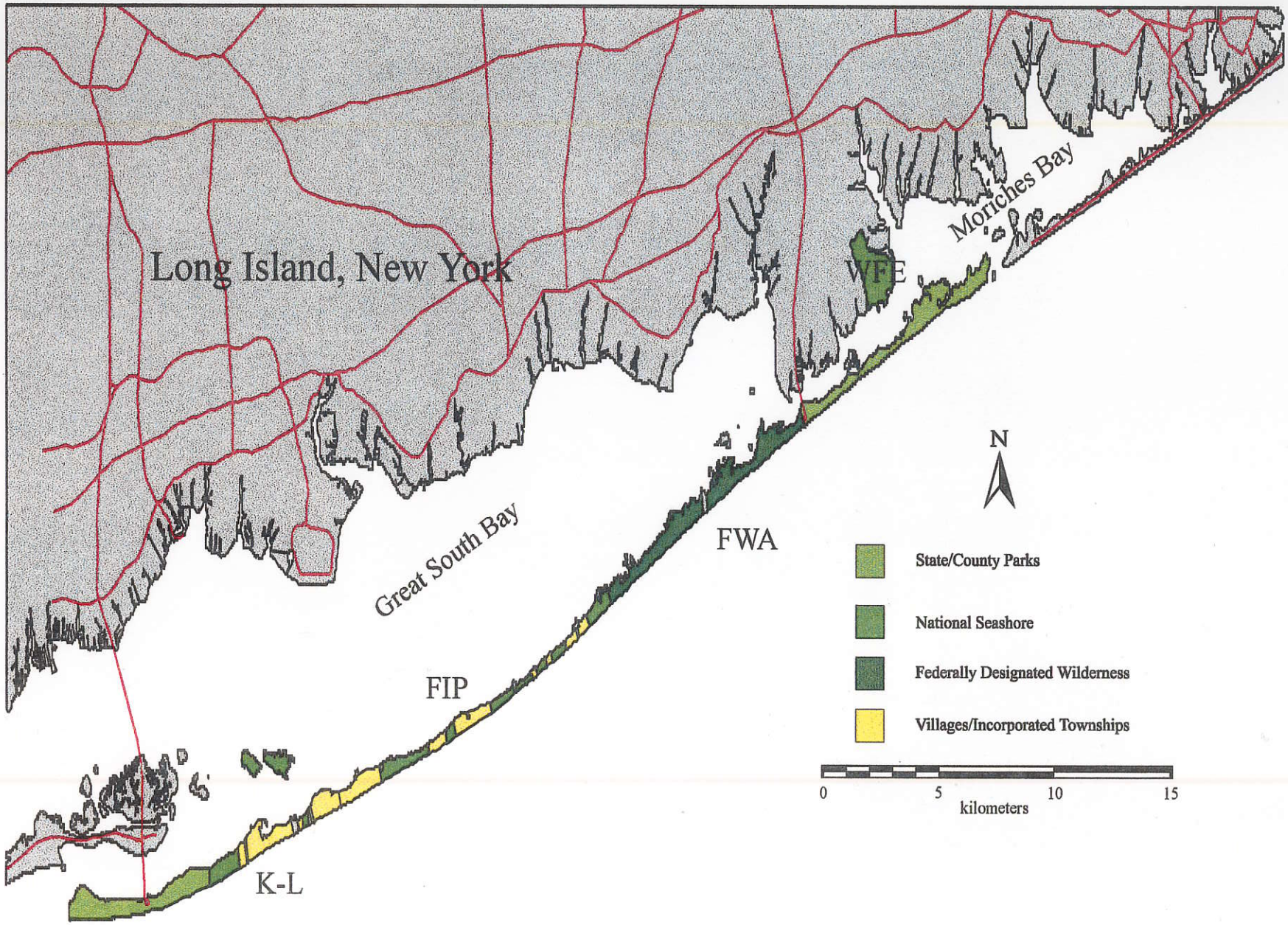

Long Island, New York
Great South Bay
Moriches Bay
WFE
FWA
FIP
K-L
N
State/County Parks
National Seashore
Federally Designated Wilderness
Villages/Incorporated Townships
0
5
10
15
kilometers

Figure 2. Kismet-Lonelyville (K-L) study area and associated localities, Fire Island National Seashore, New York. The area of K-L is approximately 1.6 km^2.

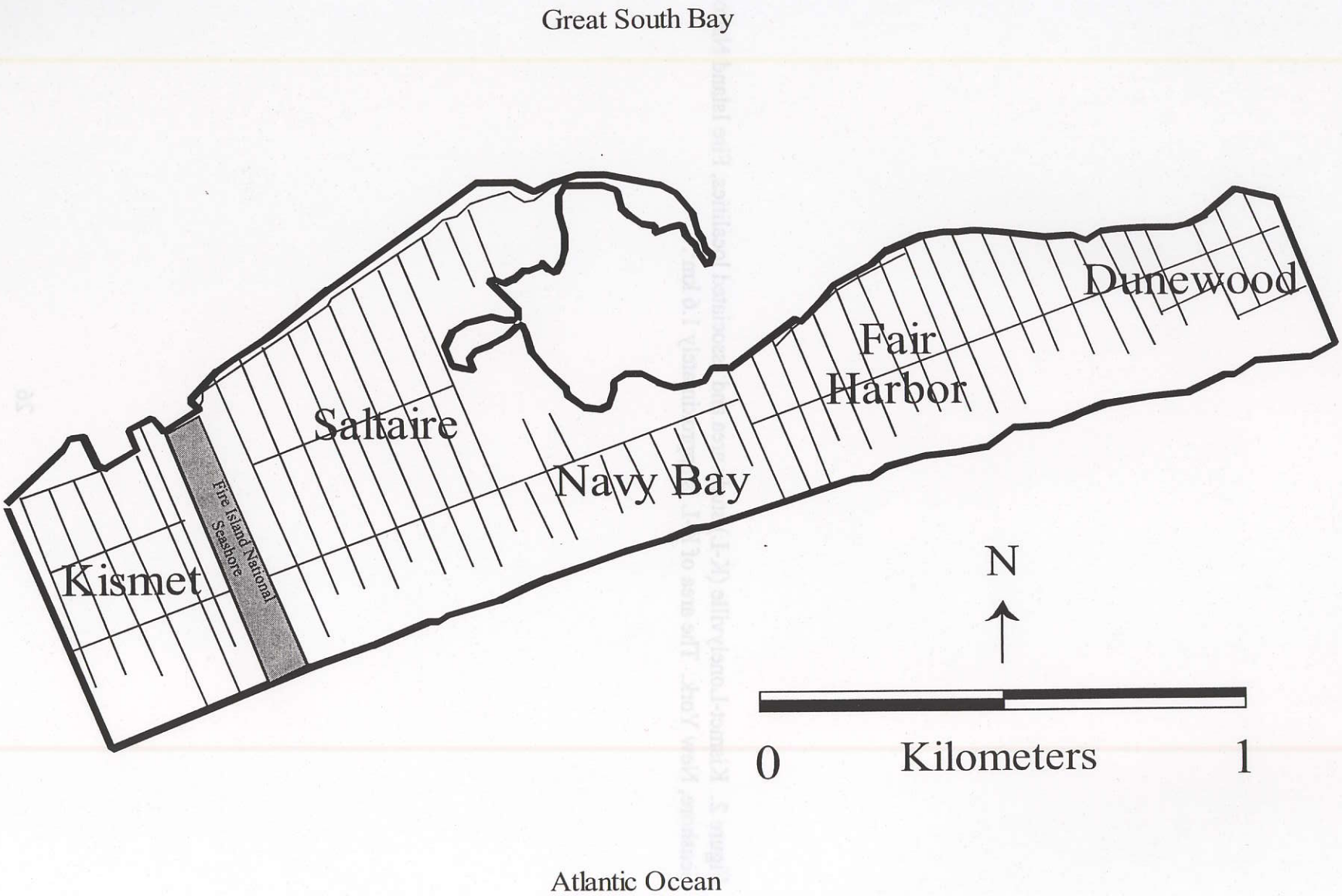

Great South Bay
Dunewood
Fair
Harbor
Saltaire
Navy Bay
Fire Island National
Seashore
Kismet
N
0
Kilometers
1
Atlantic Ocean

Figure 3. Deer density (No. km^{-2}) and 90% confidence limits estimated for the K-L study area, July 1995 - March, 1997, Fire Island National Seashore, New York.

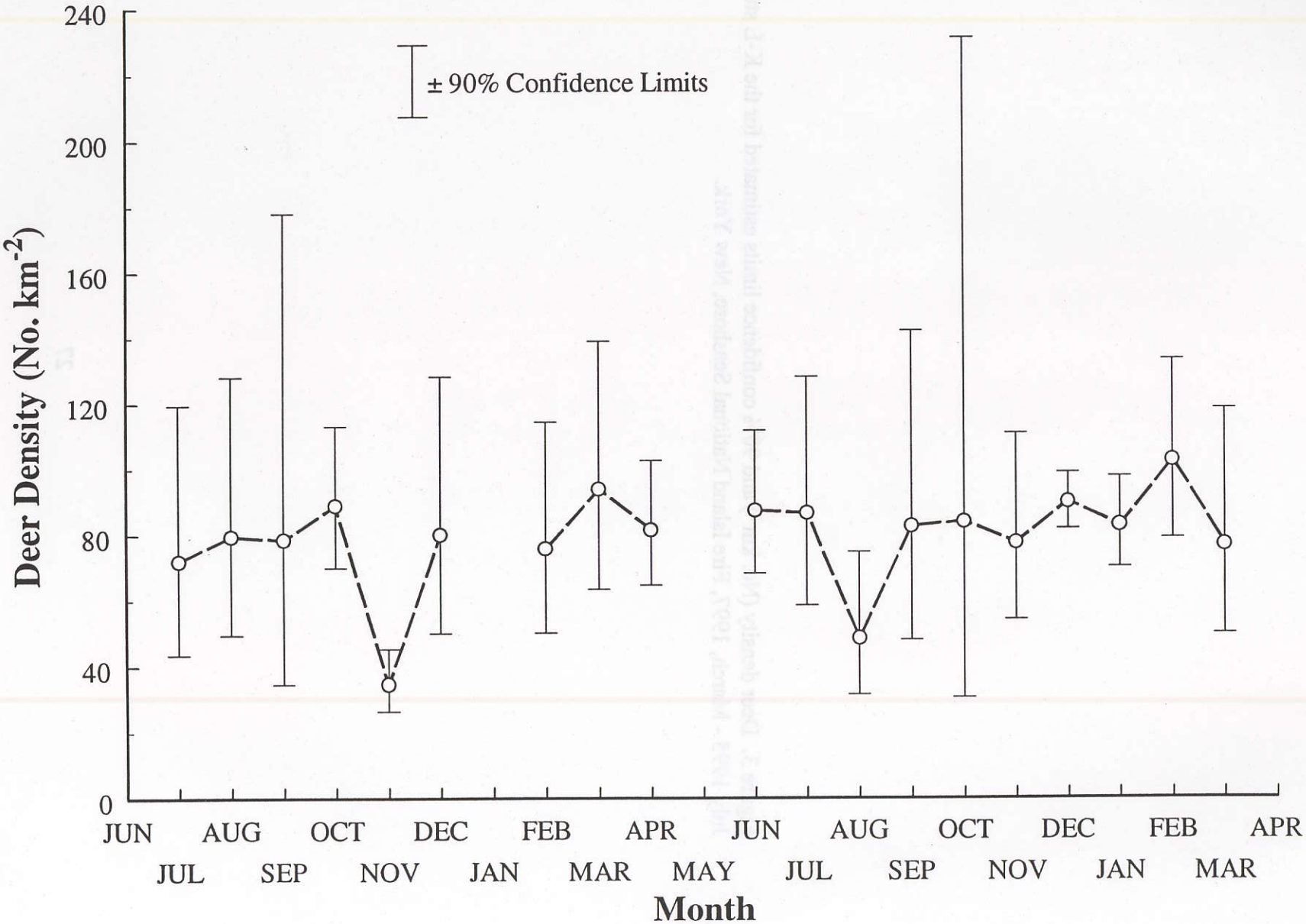

± 90% Confidence Limits
Deer Density (No. km-2)
240
200
160
120
80
40
0
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
Month

Figure 4. Monthly composition (% of total population; Y+A = yearling and adult) of the K-L deer herd, 1995-96, Fire Island National Seashore, New York.

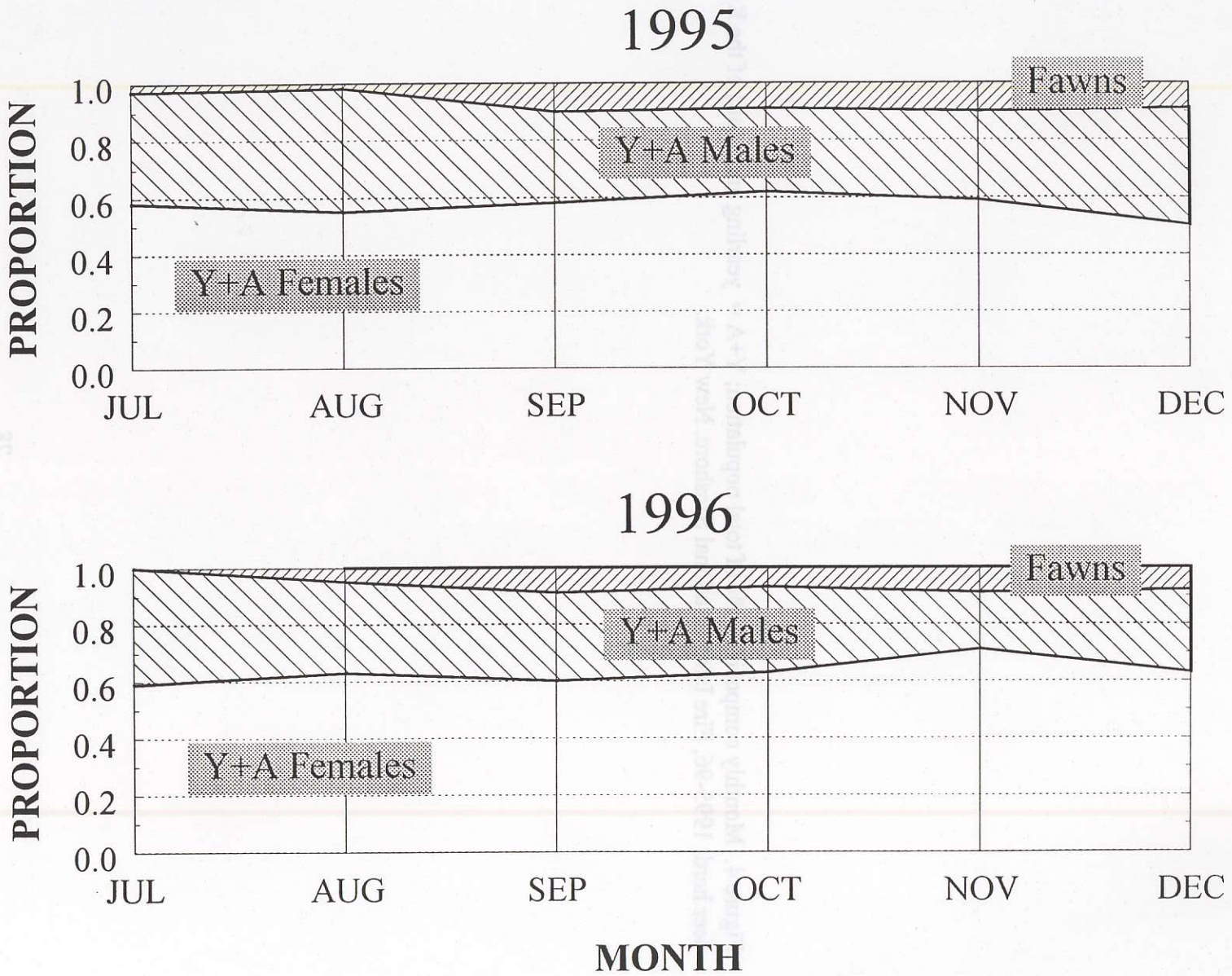

1995
Fawns
Y+A Males
Y+A Females
PROPORTION
1.0
0.8
0.6
0.4
0.2
0.0
JUL
AUG
SEP
OCT
NOV
DEC
1996
Fawns
Y+A Males
Y+A Females
PROPORTION
1.0
0.8
0.6
0.4
0.2
0.0
JUL
AUG
SEP
OCT
NOV
DEC
MONTH

Figure 5. Monthly encounter rates and group sizes (±1 SE) computed using program DISTANCE for the K-L study area, Fire Island National Seashore, New York.

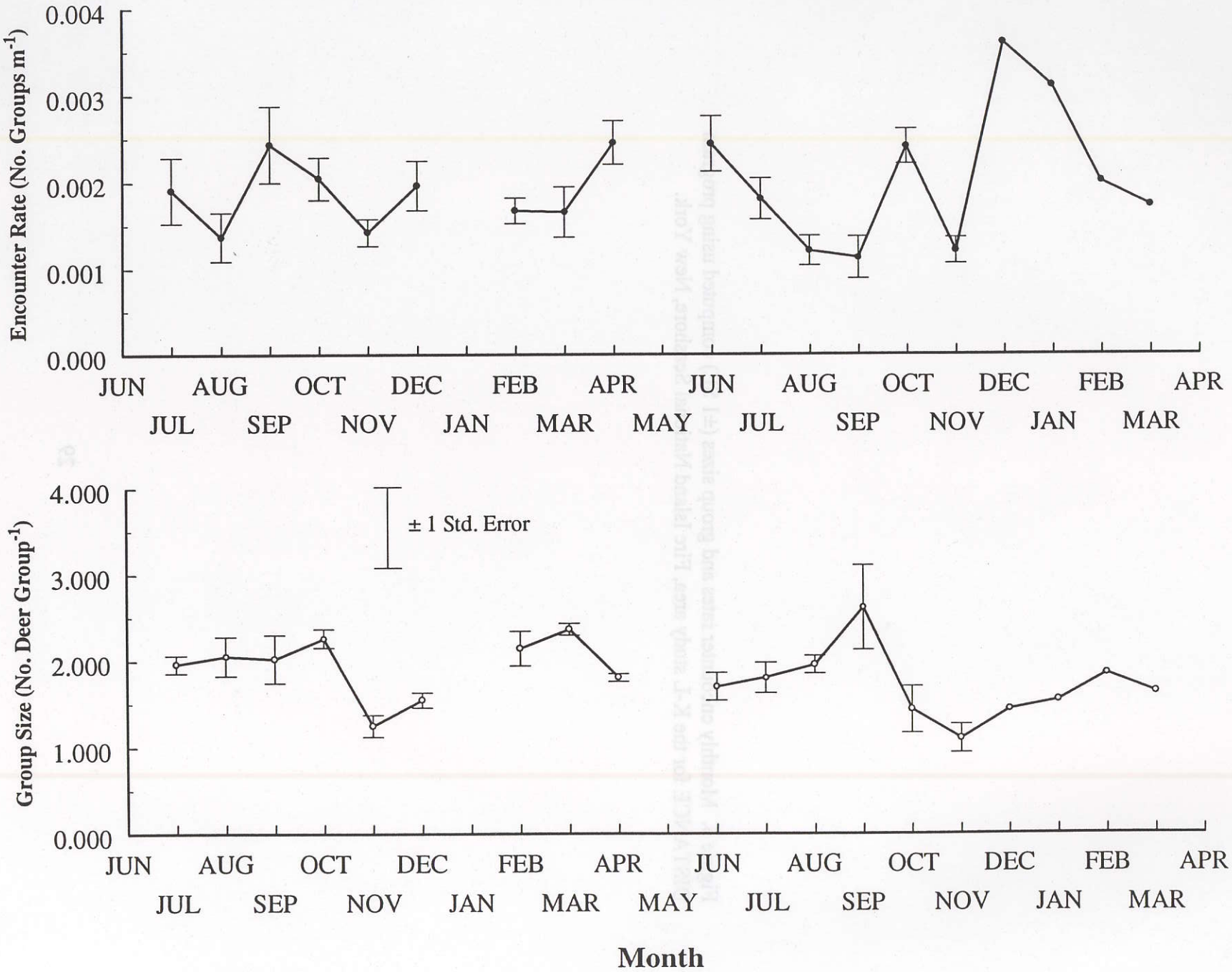

Encounter Rate (No. Groups m-1)
0.004
0.003
0.002
0.001
0.000
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
Group Size (No. Deer Group-1)
4.000
3.000
2.000
1.000
0.000
± 1 Std. Error
Month

Figure 6. Frequency of deer group sizes by month encountered on the K-L study area during 1995, Fire Island National Seashore, New York.

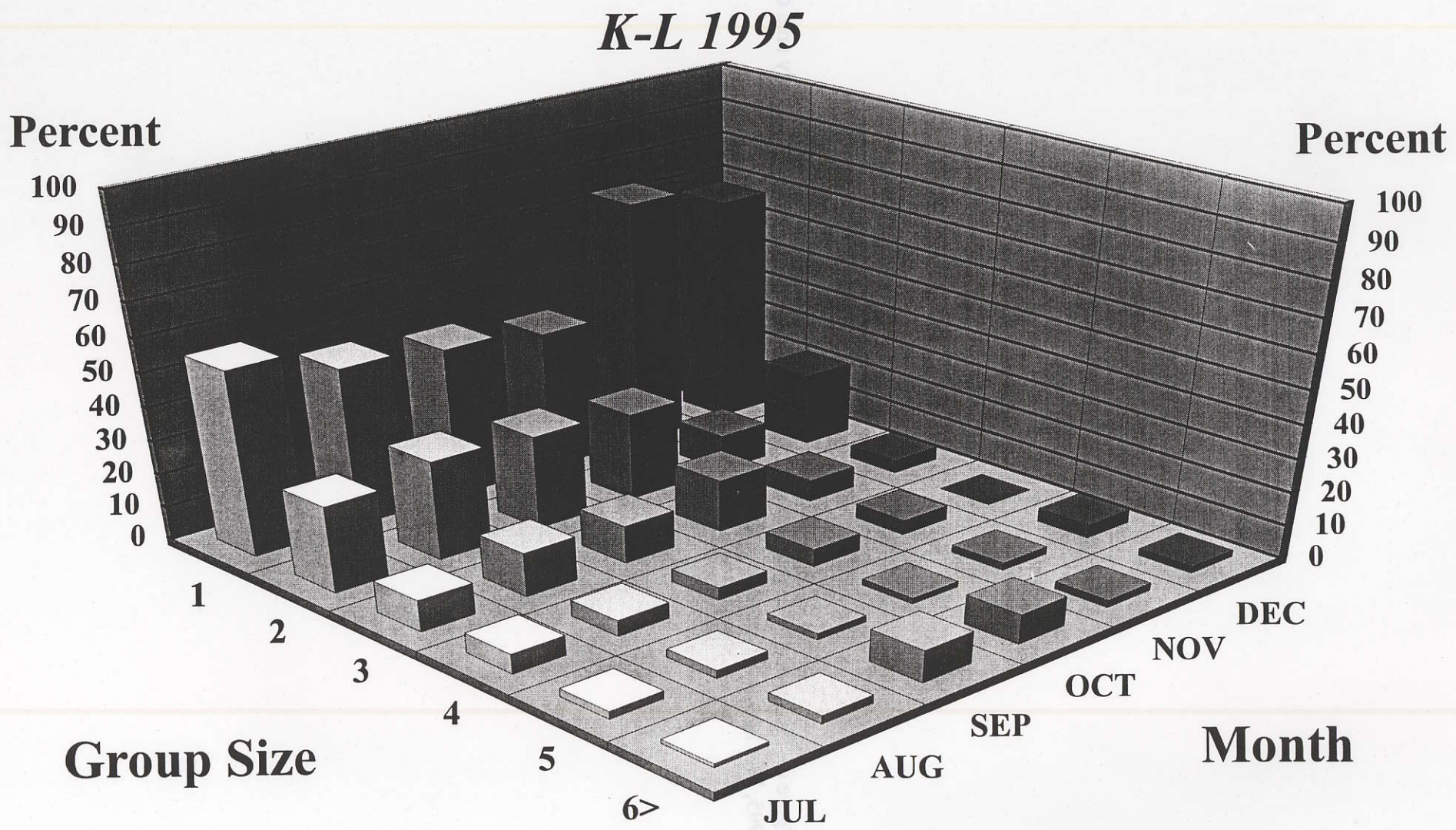

K-L 1995
Percent
100
90
80
70
60
50
40
30
20
10
0
Percent
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6>
Group Size
JUL
AUG
SEP
OCT
NOV
DEC
Month

Figure 7. Frequency of deer group sizes by month encountered on the K-L study area during 1996, Fire Island National Seashore, New York.

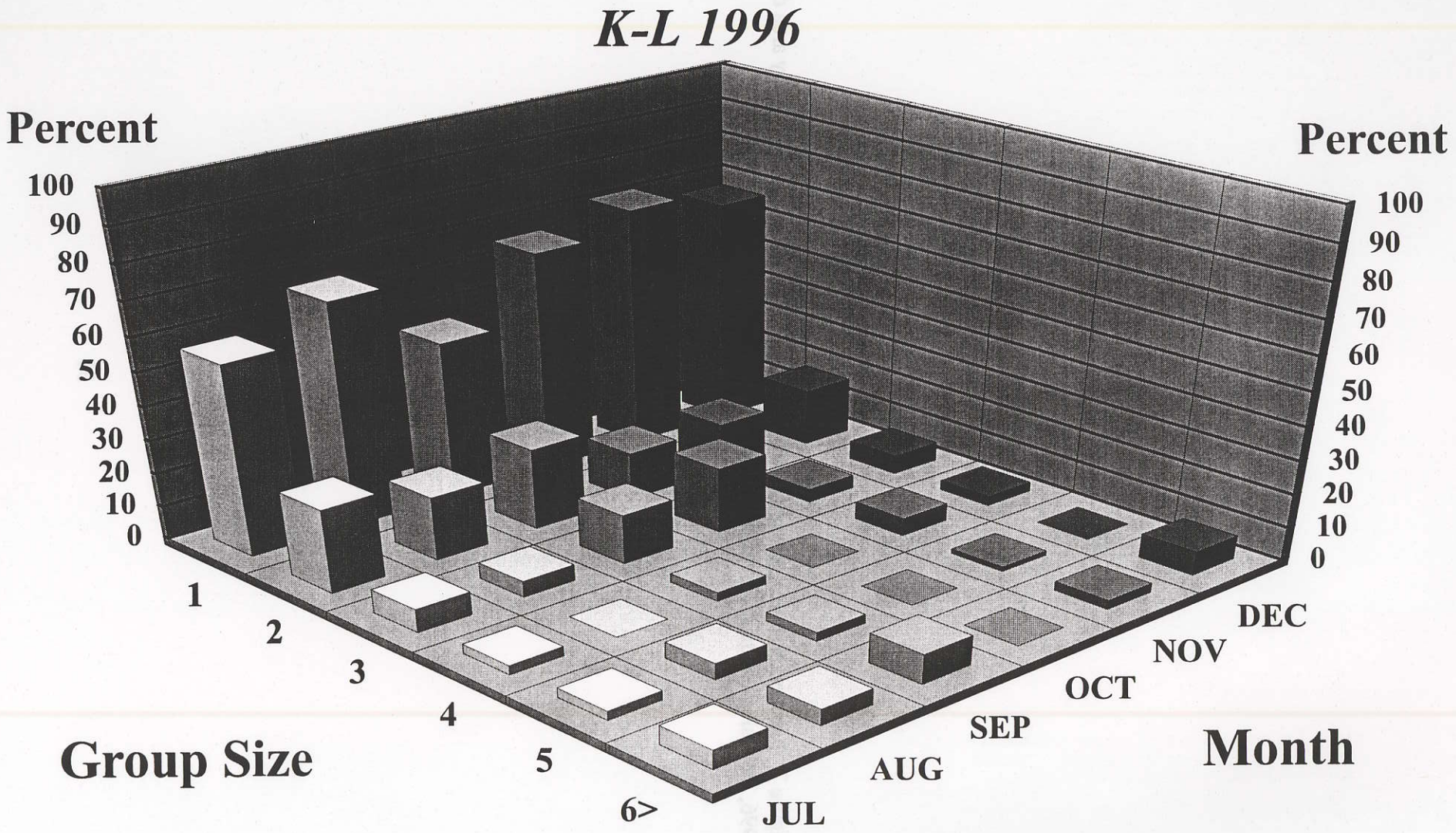

K-L 1996
Percent
100
90
80
70
60
50
40
30
20
10
0
Percent
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6>
Group Size
JUL
AUG
SEP
OCT
NOV
DEC
Month

Figure 8. Spatial and temporal variation in crude encounter rates from June, 1996 to February, 1997 in the K-L study area, Fire Island National Seashore, New York.

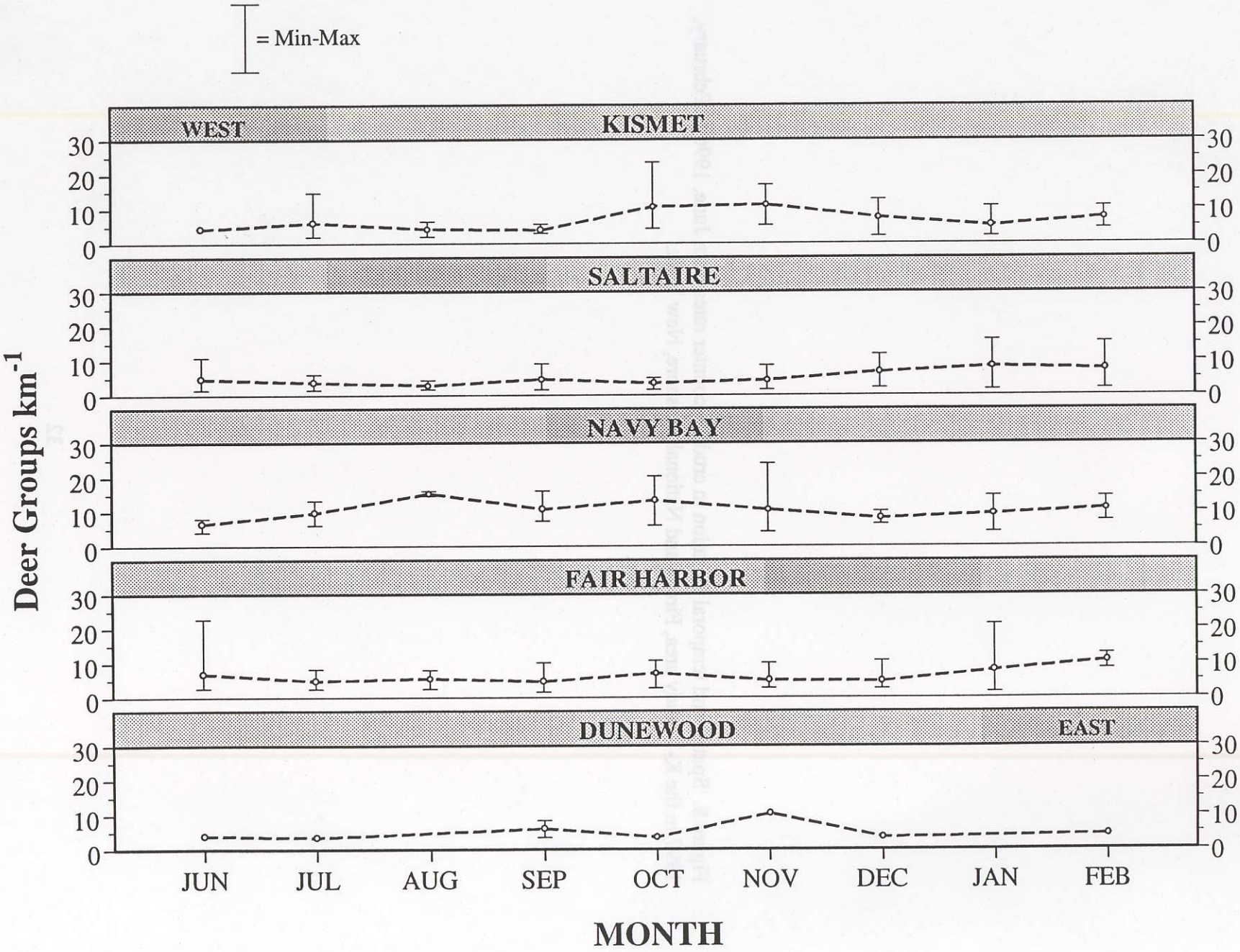

= Min-Max
WEST
KISMET
SALTAIRE
NAVY BAY
FAIR HARBOR
DUNEWOOD
EAST
Deer Groups km-1
0
10
20
30
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MONTH

Figure 9. Spatial and temporal variation in deer group size from June, 1996 to February, 1997 in the K-L study area, Fire Island National Seashore, New York.

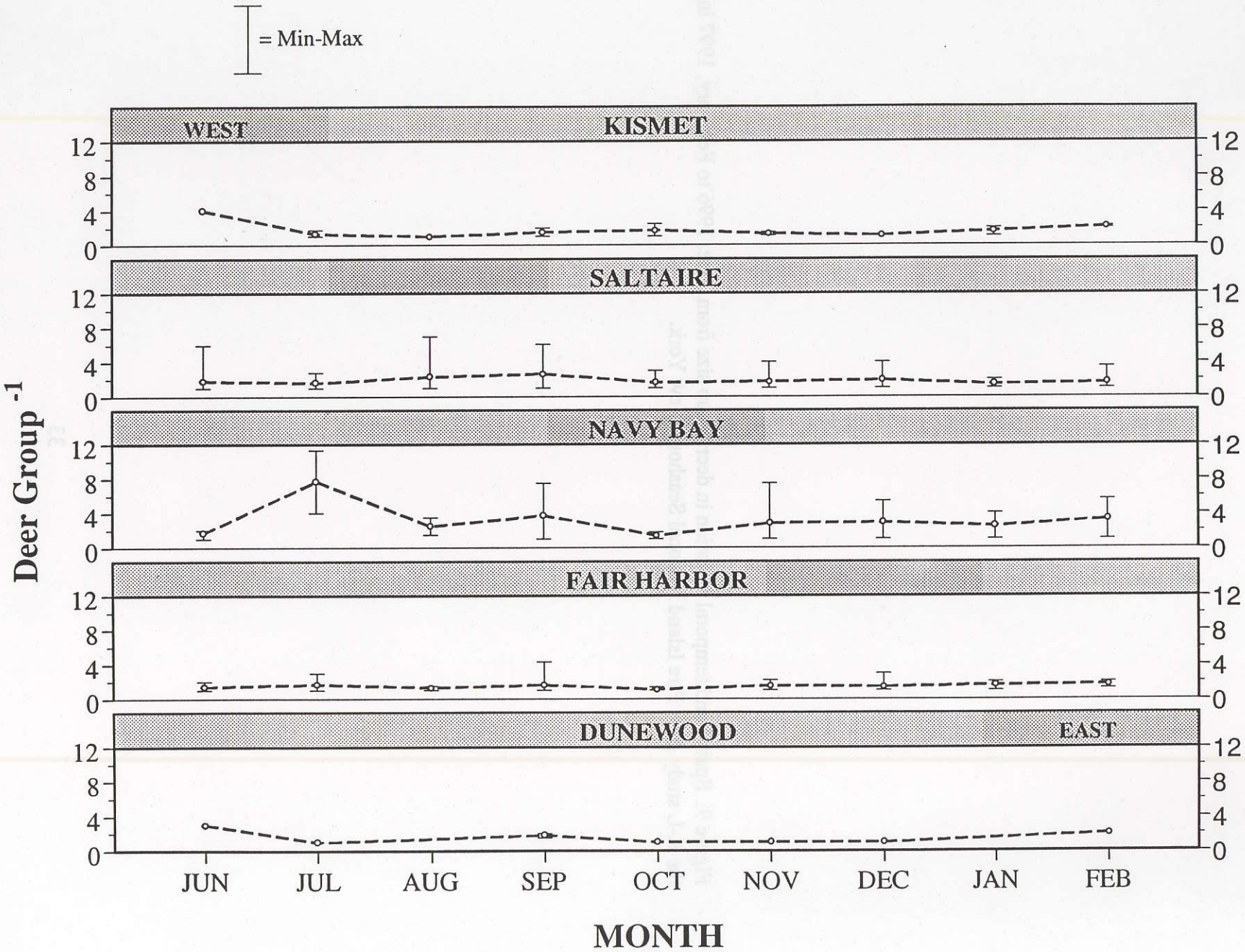

= Min-Max
WEST
KISMET
SALTAIRE
NAVY BAY
FAIR HARBOR
DUNEWOOD
EAST
Deer Group -1
0
4
8
12
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MONTH

Figure 10. Estimates of the one-half effective strip width and associated 90% confidence limits for the K-L study area from July, 1995 to March, 1997, Fire Island National Seashore, New York.

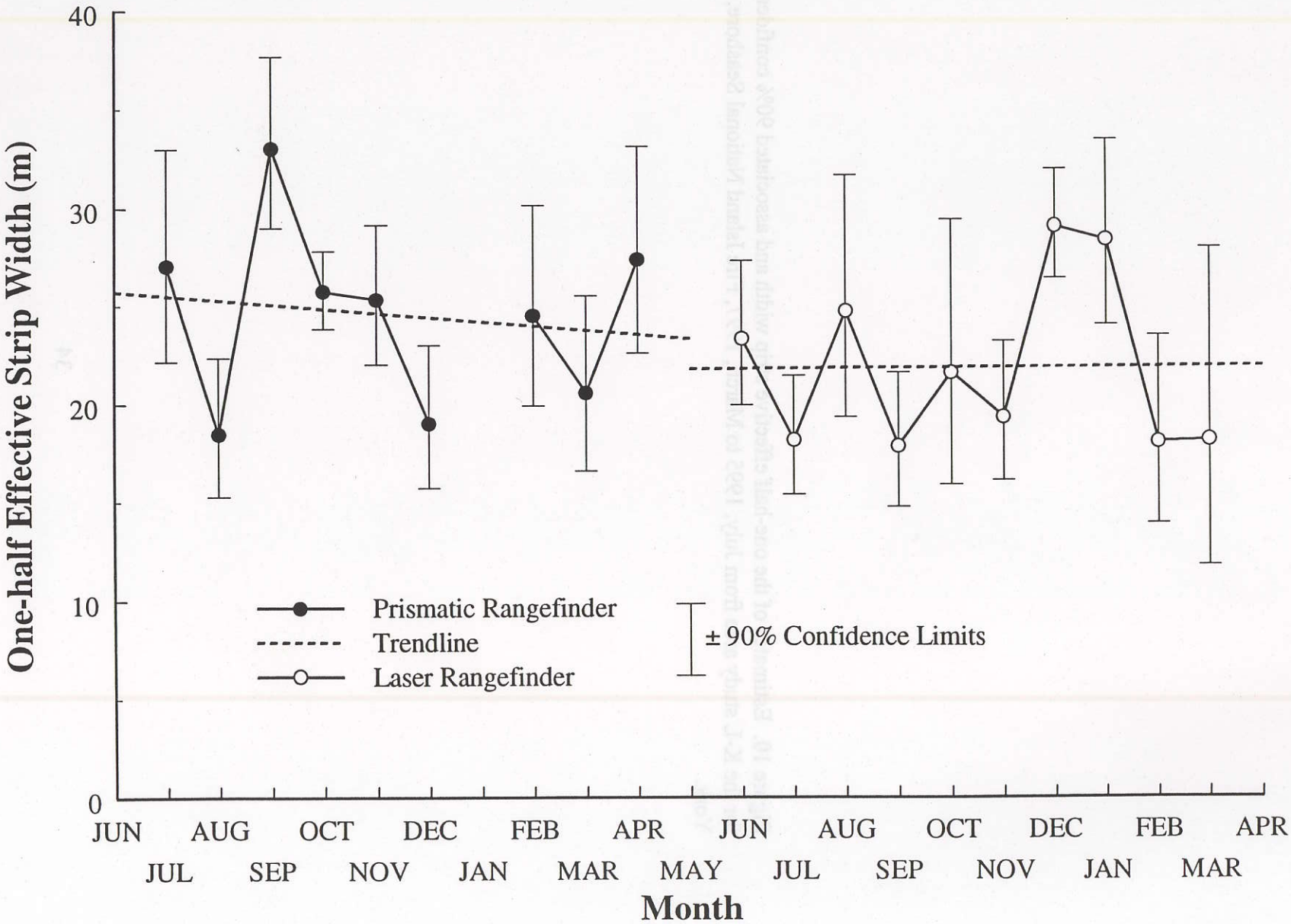

One-half Effective Strip Width (m)
40
30
20
10
0
Prismatic Rangefinder
Trendline
Laser Rangefinder
± 90% Confidence Limits
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
Month

Figure 11. Confidence interval coverage, expressed as a percentage of the mean density, as a function of the combined variation in encounter rate, detection and group size, K-L study area, Fire Island National Seashore, New York. Outliers shown with square markers.

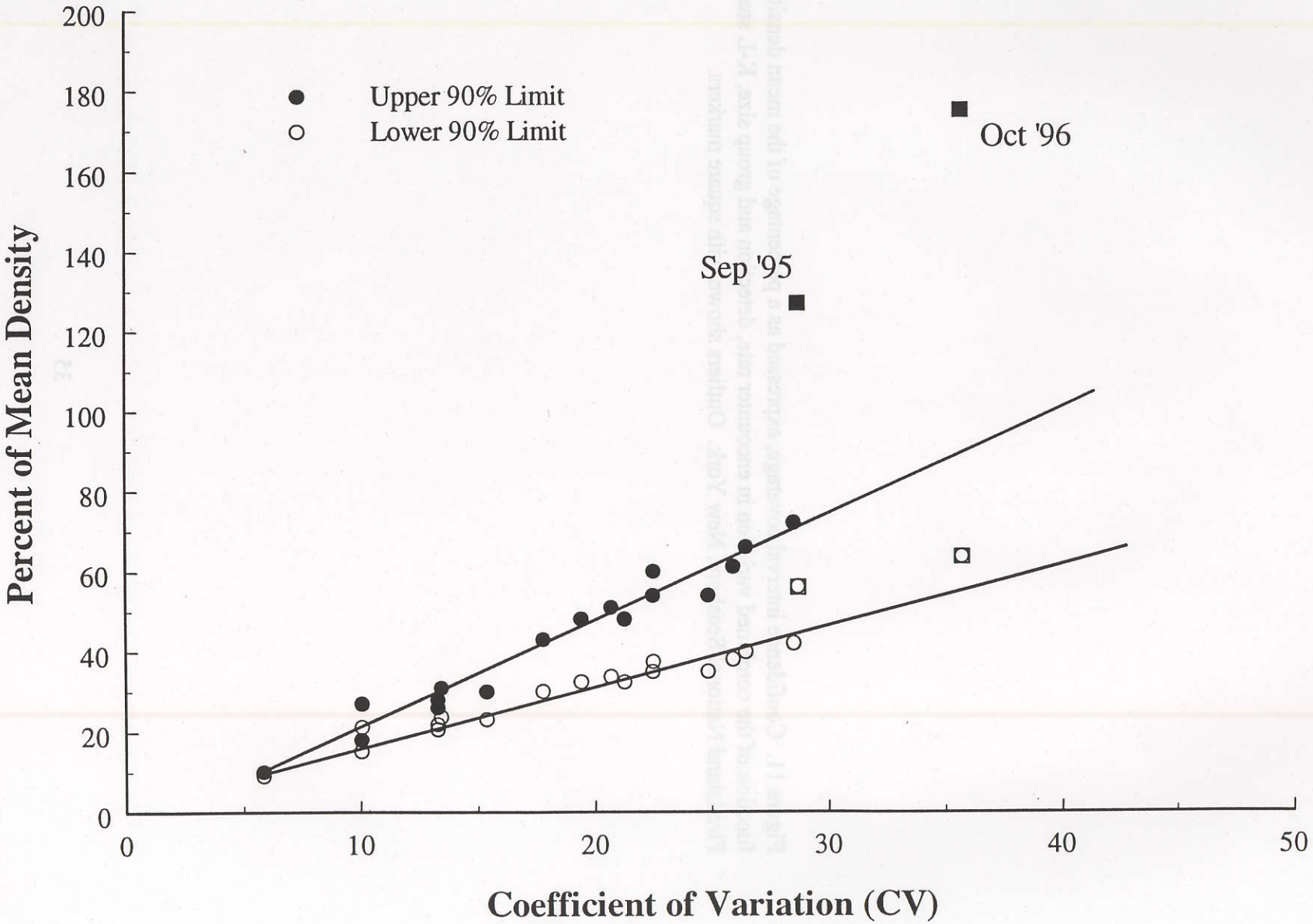

Upper 90% Limit
Lower 90% Limit
Oct '96
Sep '95
Percent of Mean Density
Coefficient of Variation (CV)
0
20
40
60
80
100
120
140
160
180
200
0
10
20
30
40
50

Figure 12. Statistical power (i.e, 1-[β+γ]) of simulated deer monitoring data as a function of the Type I error rate (i.e., α-level). Power and γ-errors are shown for simulated increases of 6, 30 and 61 deer over a 36 month monitoring period.

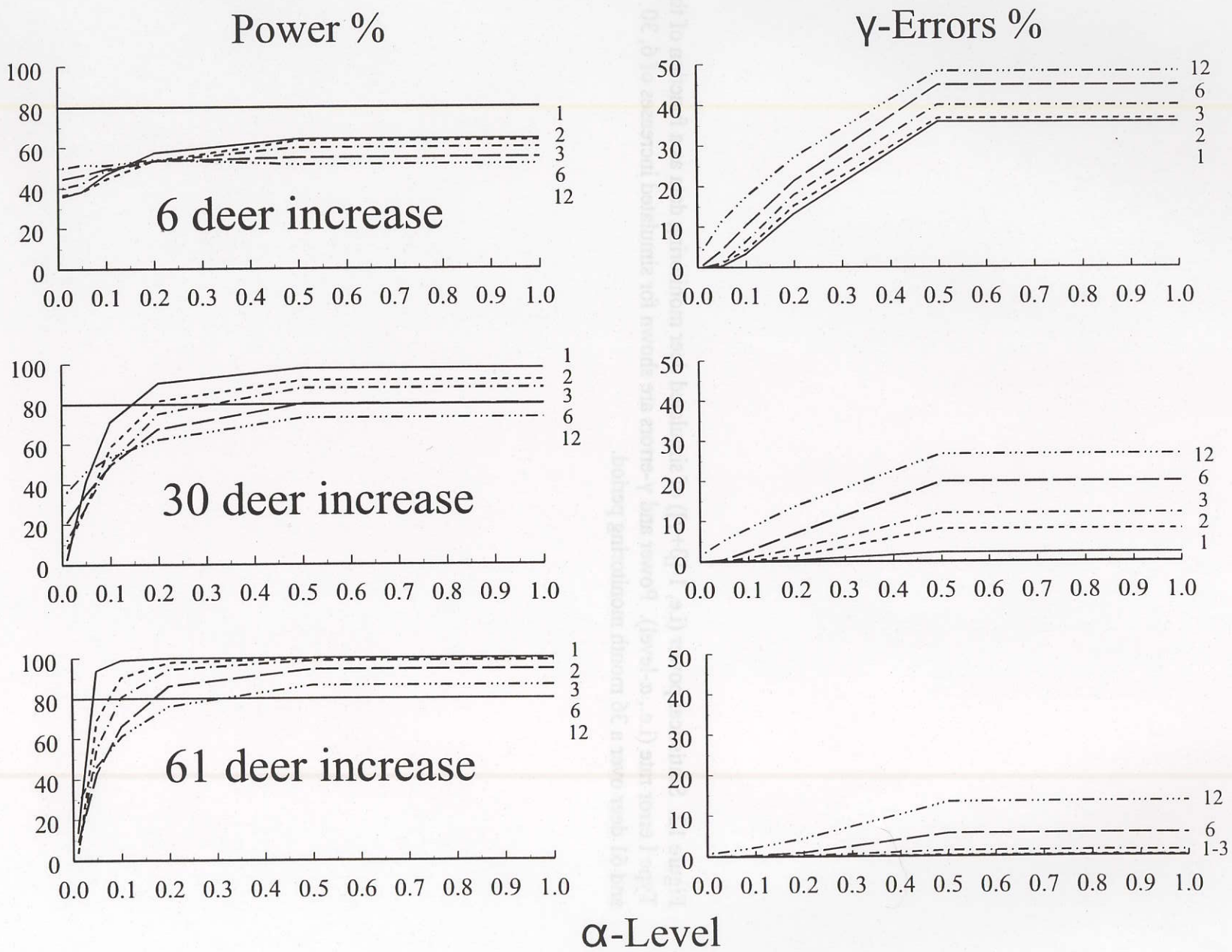

Power %
γ-Errors %
6 deer increase
30 deer increase
61 deer increase
1
2
3
6
12
1-3
α-Level

Figure 13. Frequency of deer group sizes by month encountered on the WFE study area during the autumn of 1996, Fire Island National Seashore, New York.

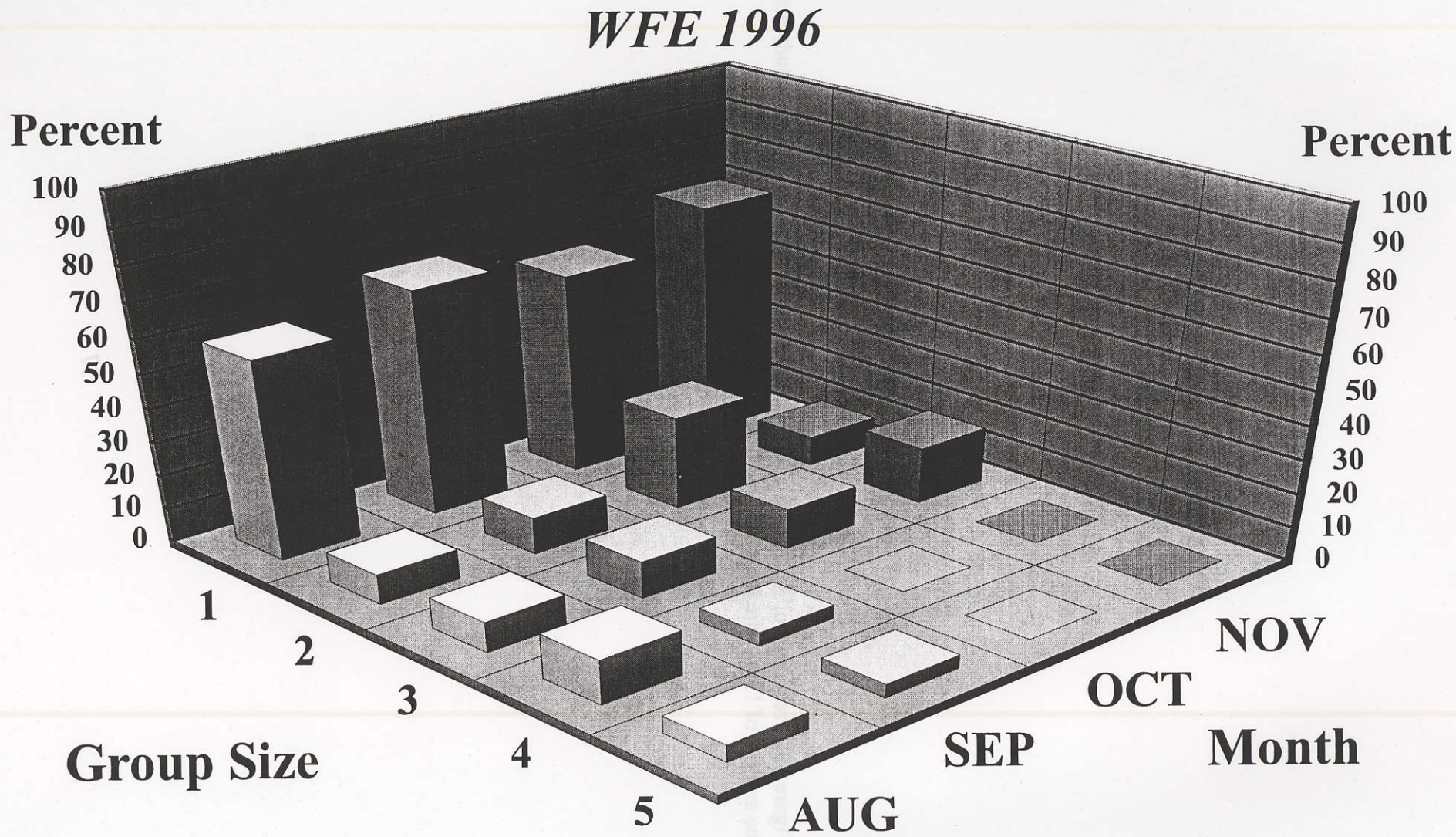
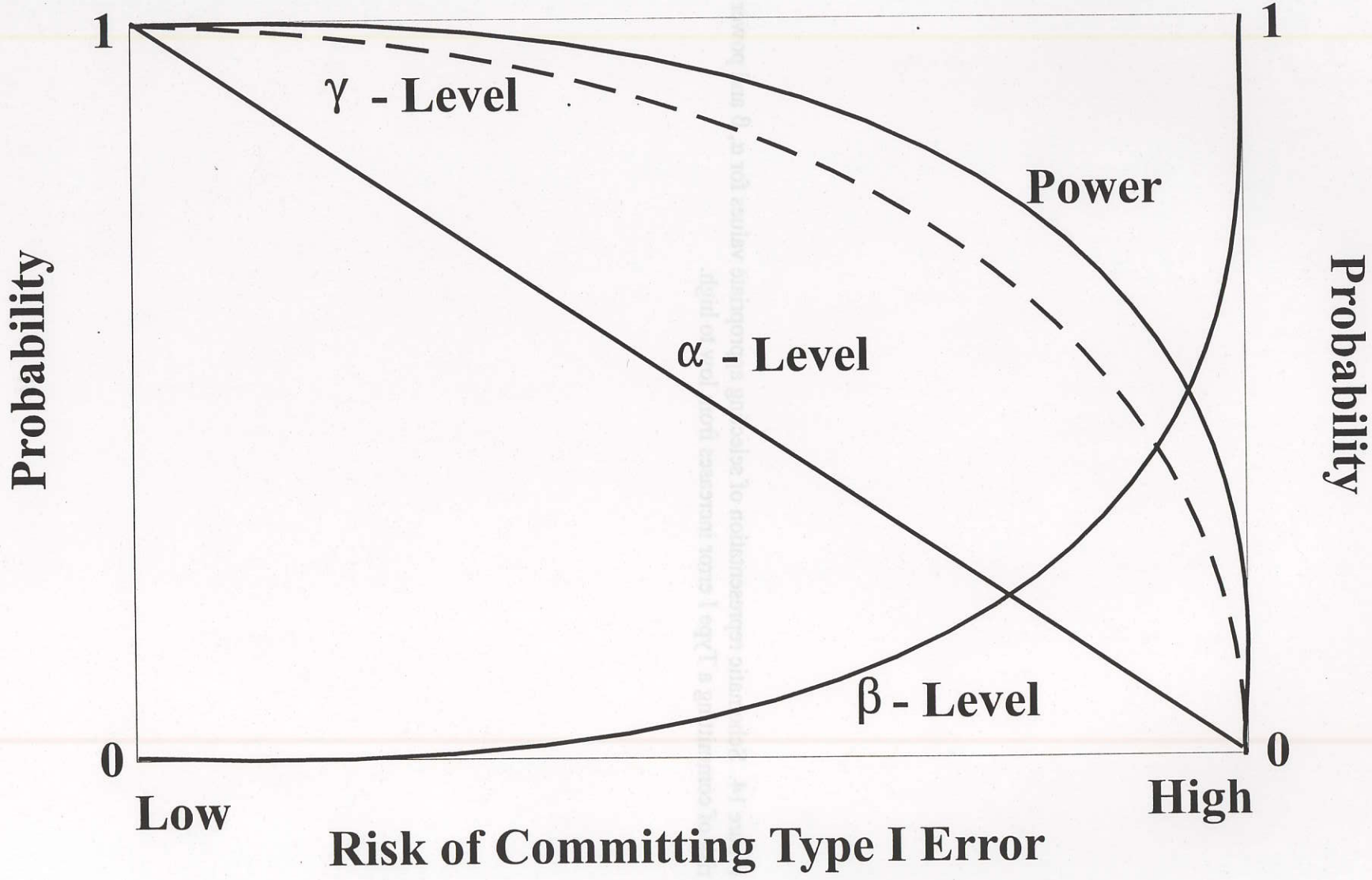

WFE 1996
Percent
100
90
80
70
60
50
40
30
20
10
0
Percent
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
Group Size
AUG
SEP
OCT
NOV
Month

Figure 14. Schematic representation of selecting appropriate values for α, β and power as the risk of committing a Type I error increases from low to high.


1
1
γ - Level
Power
Probability
Probability
α - Level
β - Level
0
0
Low
High
Risk of Committing Type I Error

Appendices

Appendix I. Transect length considerations for distance sampling of deer abundance in Fire Island communities and National Seashore lands.

Computing Transect Length Requirements— Precision determines the degree to which the estimate of density embraces the true, but unknown density of the population. Precision is affected by many factors in any sampling design. However, in distance sampling, several factors dominate. The first is the natural variability in density associated with the particular population, which is usually expressed as the CV: coefficient of variation, or $100*[\sigma/\mu]$. Another factor is encounter rate or the number of objects observed per unit length of transect. Still another factor is the probability of detection, which was described in the previous section. Most factors that contribute to the variation in density cannot, in general, be controlled by the sampler by simply changing the transect or line length. Fortunately, the encounter rate contributes most the overall variation in estimated density and its estimation can be directly controlled by changing overall transect line length. Therefore, by increasing the line length, greater precision around the estimated density can be attained. The length of transect line needed to attain a desired level of precision can be determined by a preliminary sample of data and the following formula:

$L = (b/CV_D^2)*(L_i/n_i)$, where

L = estimated line length required

b = unknown dispersion parameter

L_i/n_i = ratio of line length and objects observed in a preliminary sample.

Because b cannot be estimated without conducting a full survey, an initial guess must be entered into the equation to estimate L. Others have discovered that b often falls into the interval of 2.0 - 4.0 for a variety of populations and study areas. For the purpose of this exercise, a value of 3.0 will be substituted for b in subsequent calculations. From 5 preliminary surveys conducted between the hours of 0500-0700 on consecutive days, an estimated average 34.2 groups of deer were observed over a length of transect of 55,775 feet (17 km). Using a value of 50% for CV_D, and estimates of L and n from the preliminary sample, a transect length of 19,570 feet (6 km) would be required.

Sampling Design— A key design element for improving precision is replication. While it is not absolutely necessary in distance sampling, it is most highly recommended for a very simple reason. Because the sample CV is derived from estimates of population parameters (i.e., mean and standard deviation), it too represents a parameter and is theoretically constant for a given population. However, the standard error (SE) represents the standard deviation of means computed from replicated surveys in this instance, and is not a constant. The SE determines the width of confidence intervals constructed around estimates of density, and can be influenced by

the number of replicate samples taken. So where the natural variation of population density is high, replication represents the only means of attaining precise estimates of density. Replication can be conducted in space (multiple lines sampled on a give occasion), or in time (a single line sampled on multiple occasions); replication in time will be used in this study.

Another important design element is random selection of sampling units (i.e., transects). Because the necessary transect length is about one-half of the total available, random selection of boardwalk segments such that the sum of lengths ≥L is possible. For this purpose, we wrote a computer program to randomly select boardwalk segments from those available for sampling. Each segment, along with its designation, length, and locality was entered into a digital database that is used by the program. For each survey, a new selection of boardwalk segments will be performed. Because they are chosen at random, some boardwalk segments may be sampled more than once on consecutive days, though never twice in one day. Other boardwalk segments may not be sampled at all.

The use of random selection procedures provides good sampling coverage over the entire study area during the time that deer are most active. Time is the most important consideration when choosing the sampling intensity. The encounter rate drops off rapidly as deer begin to seek shelter during the late morning hours. Alternatives for boosting the sampling intensity include adding additional observers during a particular survey, or splitting the survey into morning and evening components.

Analytical Procedures— Program DISTANCE permits the pooling of replicate samples for the determination of the detection function, *g(x)*. Total effort, including number of groups needed to adequately describe the detection function and the number of survey days, can be computed using the preliminary sample data. For example, the predicted number of groups for a line length of 19,570 feet (6 km) is 12 based on the preliminary sample. Therefore, surveys conducted daily for 5 days will provide an estimated 60 detections to be used for estimating *g(x)*.

Appendix II. Field survey protocol for collecting distance data for the purpose of estimating population density and herd composition.

The following represents a retrospective analysis of various glitches and remedies we encountered in implementing a distance sampling-based monitoring program on the various units of Fire Island. While we have attempted to cover as many contingencies as possible, there will invariably be others that arise due to unforseen circumstances.

1. Record all relevant information of the data sheets prior to initiation of a survey including date, start time, and general weather conditions. Record end times when finished and make sure that no data fields have been left blank.

2. Measure sighting distances, angles, and perpendicular distances from the center of the transect. Note that on S-curves, this means moving to the location that is nearest and perpendicular to the group's location.

4. Take duplicate measurements of distances and angles until to ensure a consistent reading. If the perpendicular distance can be measured directly (either using the tape or rangefinder), do so. If this requires changing locations, be mindful of other deer that may be between you and the intended location. Also, in the time it takes to move into position, the deer might have moved; record the distance from the group's original location (estimate if necessary).

4. If group membership is questionable, record distances and angles (if needed) to each deer as if it were alone. Mark these observations uniquely, then discuss and resolve later.

5. Carefully record group size and composition separately. If not all members of a group can be accurately classified according to sex and age, mark composition as unknown, but remember to record group size.

6. Proceed slowly! There is a tendency to traverse transects (especially while on a bicycle) too fast. If conducting the survey from within a vehicle, constrain speeds to no more than 10 mph. Great care must be taken to scan both sides of the transect thoroughly and with equal efficiency.

7. Generally, sampling should be conducted during times of low human activity (unless otherwise instructed, initiate surveys within 20 minutes of official sunrise).

8. Occasional re-calibration of equipment may be necessary to insure accurate data collection. If using the laser-rangefinder, carry a spare 9 volt battery.

As the nations's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people. The department also promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen responsibility of the public lands and promoting citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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