2003

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Sargeant, Glen A.; Johnson, Douglas H.; and Berg, William E., "Sampling Designs for Carnivore Scent-Station Surveys" (2003). *USGS Northern Prairie Wildlife Research Center*. 231.
http://digitalcommons.unl.edu/usgsnpwrc/231

SAMPLING DESIGNS FOR CARNIVORE SCENT-STATION SURVEYS

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Abstract: Scent stations usually are deployed in clusters to expedite data collection and increase the number of stations that can be operated for a given cost. Presumed benefits of cluster sampling may not be realized, however, unless cluster sizes are chosen with respect to sampling variation within and among clusters. To encourage and facilitate the use of efficient designs and reporting standards, we used data collected in Minnesota, USA, during 1986–1991 to (1) compare the performance of survey designs with various numbers of stations/cluster; (2) estimate relations between required sample sizes and visitation rates, changes in visitation rates, and error rates; and (3) compare 2 measures of carnivore response: proportions of scent stations (station index) and proportions of clusters (line index) visited by red foxes (*Vulpes vulpes*) and striped skunks (*Mephitis mephitis*). Despite broad ecological differences between the species, results were similar for foxes and skunks. Foxes visited 2–21% of stations and 15–84% of lines. Skunks visited 1–16% of stations and 3–54% of lines. Station and line indices were closely related ($r^2 > 0.86$) and were similarly sensitive indicators of change in visitation rates. Low visitation rates greatly limited the potential usefulness of scent-station surveys because required minimum sample sizes increased exponentially as visitation rates decreased. For visitation rates below 5–10%, required minimum sample sizes were very large and difficult to anticipate. Relative to single-stage sampling, cluster sampling with 10 stations/cluster inflated sample variances, hence sample sizes required to achieve a fixed level of precision, by a factor of 1.6–2.2. Cluster sampling is advantageous only when cost savings permit increases in sample sizes that outweigh concomitant increases in sampling variability. Costs and sampling variation both should be considered when choosing survey designs, and designs should be evaluated and refined as data accumulate.

JOURNAL OF WILDLIFE MANAGEMENT 67(2):289–298

Key words: carnivores, Minnesota, population index, sampling variation, scent station, statistical power, survey design.

Most carnivore species are secretive and occur at relatively low densities. Reliable estimates of abundance are therefore difficult and expensive to obtain. Carnivore biologists thus rely heavily on indices of relative abundance, especially indices based on detection rates. Scent-station visitation rates have a long history of use (Cook 1949, Wood 1959, Johnson and Pelton 1981) and currently are among the most popular such indices (e.g., Travaini et al. 1996, Zielinski and Stauffer 1996, Woelfl and Woelfl 1997, Warrick and Harris 2001).

A scent station consists of a lure and a tracking medium, usually soft earth or sand (Linhart and Knowlton 1975) or a track plate (Zielinski and Stauffer 1996). Stations are established and checked after a predetermined period of operation. Tracks at stations permit the identification of species, but not individuals; hence, observers record only whether each station has or has not been visited by each species of interest. Relations between visitation rates (proportions of stations visited) and abundance generally are unknown, but visitation rates are presumed to increase monotonically with abundance.

Scent stations usually are arrayed systematically in lines to reduce travel time and expedite data collection (e.g., Conner et al. 1983, Nottingham et al. 1989, Travaini et al. 1996, Warrick and Harris 2001). This arrangement is a type of cluster sampling, which is presumed to be beneficial because it increases the number of stations that can be operated for a given cost. However, stations within lines generally produce spatially dependent data (Sargeant et al. 1998). Although spatial dependencies can arise from a variety of phenomena (e.g., unwary individuals that visit >1 station; spatial variation in carnivore densities), the net result is the same: outcomes tend to be similar for stations placed close to one another. Because closely spaced stations produce data that are partially redundant, cluster sampling reduces the precision of estimated visitation rates.

Cluster sampling introduces other complications that belie the intuitive appeal and apparent simplicity of visitation rates as indices of abundance. Because many carnivore species occur at low density and individual home ranges are often large, the number of individuals in contact with a cluster of stations is likely to be small, and individuals are likely to visit multiple stations. For this

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reason, Zielinski and Stauffer (1996) questioned the existence of a relation between visitation rates and abundance. Sargeant et al. (1998) believed that clusters with numerous visits had undue influence on visitation rates, given the small number of individuals likely in contact with each cluster. Zielinski and Stauffer (1996) and Sargeant et al. (1998) both suggested reporting the proportion of clusters, rather than the proportion of stations, visited by carnivores.

Despite implications for the validity, precision, and cost of scent-station surveys, numbers of stations/cluster, total sample sizes, and methods for reporting carnivore responses often are chosen without regard to principles of sample survey design. Designs have ranged from single-stage sampling (i.e., simple random, haphazard, or systematic sampling [Diefenbach et al. 1994, Smith et al. 1994]) to cluster sampling with ≥50 stations/cluster (Linhart and Knowlton 1975, Morrison et al. 1981, Linscombe et al. 1983). Numbers of stations/survey have varied by an order of magnitude, from ≤21 (Smith et al. 1994) to 790 (Sargeant et al. 1998). And, although proportions of clusters visited by carnivores have convenient statistical properties, neither Zielinski and Stauffer (1996) nor Sargeant et al. (1998) investigated other postulated benefits of reporting visitation rates for clusters rather than stations.

We suspect that sample allocation, sample sizes, and methods of measuring carnivore response remain largely unaddressed because (1) some practitioners do not fully appreciate sample-size requirements or practical implications of differences between survey designs, and (2) most practitioners do not possess the information needed for survey planning until after data have been collected and these issues are moot. To encourage and facilitate efficient survey methodology, we compared sample variances for cluster sampling designs featuring various numbers of stations, determined sample sizes required to reliably rank visitation rates, described relations between proportions of stations and proportions of lines visited by carnivores, and discussed consequences for the continuity of records when sampling practices are altered during the course of data collection.

METHODS

Data Collection

We analyzed data from 28 scent-station surveys conducted in Minnesota during 1986–1991. We selected these surveys from a larger data set described by Sargeant et al. (1998) based on sample size ($n \geq 30$ lines) and recording format (results reported for each station separately). A survey consisted of data collected in 1 biogeographic section during 1 year. Biogeographic sections were 10 mutually exclusive zones of relatively homogeneous topography and vegetation that collectively encompassed the state of Minnesota. These zones are described in Sargeant et al. (1998).

Methods of data collection were patterned after Linhart and Knowlton (1975), as modified by Roughton and Sweeny (1982), and were representative of many scent-station surveys. Each scent station consisted of a 0.9-m diameter circle of smoothed earth with a fatty-acid scent tablet placed at the center. We placed stations along unpaved roads in lines of 10, at 480-m intervals. We chose locations of lines (described in Sargeant et al. 1998) to assure a minimum spacing of 5 km between lines. Lines were operated for 1 night each year between late August and mid-October, although not all lines could be operated every year. We recorded presence or absence of tracks for individual carnivore species when stations were checked the day after activation. Hereafter, we use "cluster" as a general term for spatial groupings of stations and reserve "line" for the spatial arrangement represented in our data. We refer to the proportion of stations visited as the visitation rate and to indicators of visits as either the station index (sample visitation rate) or line index (sample proportion of lines with ≥1 visit).

We chose red foxes and striped skunks for our analysis because these species occurred throughout the study area, regularly visited scent stations, and displayed substantial spatial and temporal variation in visitation rates. Moreover, foxes and skunks represent physical and behavioral extremes on the continuum of species surveyed with scent stations.

Estimates of Sampling Variation

We assessed consequences of cluster sampling by estimating variance inflation factors (τ ; Cox and Snell 1989), which describe multiplicative increases in sampling variation that result from cluster sampling. Variance inflation factors were particularly useful for this purpose because they are also interpretable as ratios of sample sizes required to estimate visitation rates with equal precision.

To estimate variance inflation factors, we let x_{ijk} denote the outcome for station k in line j during survey i ($k \in 1{:}K, j \in 1{:}J, i \in 1{:}I$). The number of visits to line *j* during survey *i* was thus a random variable, $x_{ij.}$, with variance conditional on K [$\hat{\mathrm{var}}(x_{ij.} \mid K)$]. We let p_i denote the station visitation rate, estimated by $\hat{p}_i = \frac{1}{JK} \sum_j x_{ij.}$. We then computed a sample variance inflation factor for each survey and line size, $\hat{\tau}_{Ki} = \hat{\mathrm{var}}(x_{ij.} \mid K) \,/\, K\hat{p}_i(1 - \hat{p}_i)$. When estimating factors for lines with $K < 10$ stations, we randomly selected a series of K consecutive stations from the 10 stations in each line. Plotting initial estimates revealed a tendency for $\hat{\tau}_{Ki}$ to increase linearly with $\hat{p}$ and suggested a modification of our estimator. We used linear regression through the origin to estimate sample variances as a function of p (i.e., $\hat{\mathrm{var}}(x_{ij.} \mid K) = \hat{\beta}_K p + \varepsilon_i$); smoothed regression coefficients with a second-order polynomial (i.e., $\hat{\beta}_K = \alpha_1 K + \alpha_2 K^2 + \delta_K$; $\tilde{\beta}_K = \hat{\alpha}_1 K + \hat{\alpha}_2 K^2$); and used smoothed regression coefficients to construct an estimator of variance inflation factors that was a function of p and conditional on K (i.e., $\hat{\tau}_K(p) = p\tilde{\beta}_K / Kp\,(1 - p)$). We estimated standard errors of coefficients ($\tilde{\beta}_K$) from 1,000 bootstrap replicates (Efron and Tibshirani 1993), with lines as sampling units. We used S-Plus software (Mathsoft 1999) for data analysis.

Sample Size Computation

Relations between abundance and visitation rates are nonlinear, are likely to be affected by other factors (Sumner and Hill 1980, Griffith et al. 1981, Morrison et al. 1981, Sargeant et al. 1998), and are seldom estimated. Changes in visitation rates are therefore of uncertain value for inferring the magnitude of changes in abundance. We thus treated scent-station indices as ordinal indicators (i.e., useful for ranking) and estimated numbers of stations required to indicate, with specified error rates, reductions in visitation rates.

To illustrate our method, let Δp denote the true, but unknown, difference between visitation rates on 2 successive survey occasions. Let $\Delta\hat{p}$ be an estimate of that difference, $\hat{p}_2 - \hat{p}_1$. Given a sufficiently large sample of *J* lines, the distribution of $\Delta\hat{p}$ is approximately normal with mean Δp and variance $\frac{1}{JK}\{[\hat{\tau}_K(p_2)][p_2(1 - p_2)] + [\hat{\tau}_K(p_1)][p_1(1 - p_1)]\}$. The sign of Δp is indicated correctly by negative estimates ($\Delta\hat{p} < 0$) if $\Delta p < 0$ and by positive estimates ($\Delta\hat{p} > 0$) if $\Delta p > 0$; consequently, the expected error rate for indicating reductions in visitation rates is approximately $1 - \Pr(\Delta\hat{p} < 0)$. A continuity correction $\left[1 - \Pr\left(\Delta\hat{p} < \frac{-1}{2JK}\right)\right]$ improves the approximation by adjusting for ties that may occur because numbers of visits are discrete. We estimated required minimum numbers of stations ($n = JK$) by holding K constant and manipulating J until $1 - \Pr\left(\Delta\hat{p} < \frac{-1}{2JK}\right)$ matched specified error rates.

After estimating minima for single-stage sampling ($K = 1$), we used random draws from binomial distributions to determine actual error rates. Specified error rates agreed closely with results, confirming the adequacy of estimates based on normal approximations.

Measures of Carnivore Response

Efforts to validate scent-station surveys have produced equivocal results (Sargeant et al. 1998), and we did not possess data that addressed the issue of index validity. Nevertheless, much can be learned about the potential performance of indices by comparing estimates obtained simultaneously, at the same levels of abundance. We thus compared the station index, the line index, and a third quantity, the conditional station index, which we have not described previously. The conditional station index is the same as the station index, except that lines without visits are not included in the calculations. These quantities are closely related because the station index is the product of the line index and the conditional station index, i.e., *station index = line index × conditional station index.*

We used Pearson correlation coefficients to evaluate associations among station, line, and conditional station indices. We used second-order polynomial regressions through the origin, followed by second-order polynomial smoothing of model coefficients, to estimate relations between station and line indices. We estimated standard errors of smoothed regression coefficients from 1,000 bootstrap replicates (Efron and Tibshirani 1993), with lines as sampling units.

To compare the potential performance of station and line indices, we used methods described in the preceding section (Sample Size Computation) to estimate error rates for specified reductions in visitation rates and corresponding changes in line indices. We used smoothed model coefficients to estimate changes in the line index corresponding to specified changes in the station index.

RESULTS

Estimates of Sampling Variation

Steps in the calculation of variance inflation factors are illustrated in Fig. 1 a–c. Fig. 1a depicts a single bootstrap replicate based on a line size of 5 stations but is typical of relations between sample variances and visitation rates. Fig. 1b also

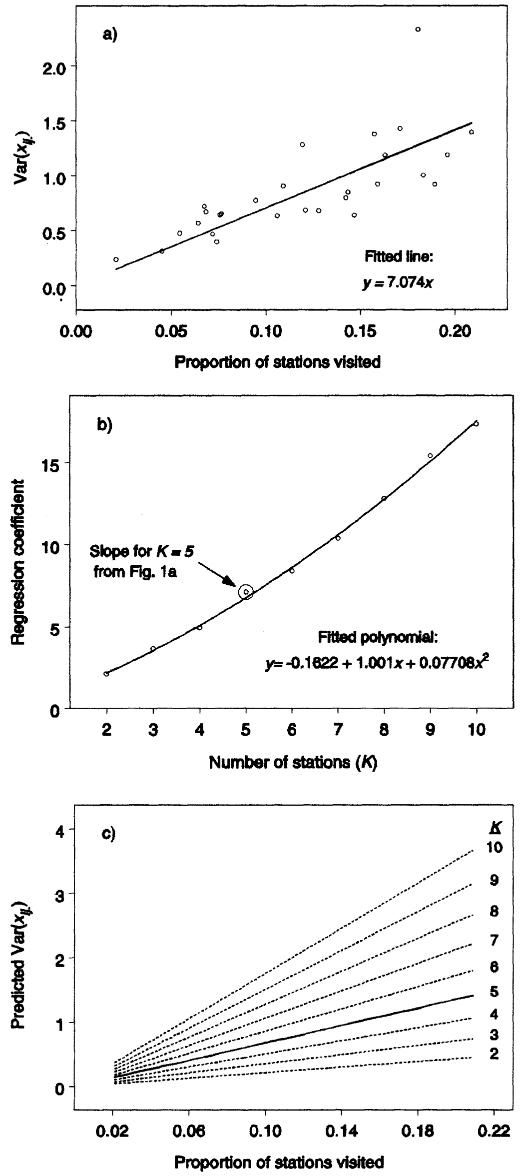

Fig. 1. Estimation of variance inflation factors for scent-station survey designs with $K \in \{2{:}10\}$ stations/line, based on red fox surveys conducted in Minnesota, USA, 1986–1991: (a) bootstrap replicate of regression (for $K = 5$) relating sample variances to visitation rates; (b) bootstrap replicate of polynomial smoothing of regression coefficients; and (c) variances predicted from means of smoothed coefficients.

Table 1. Variance inflation factors ($\hat{\tau}_K(p) = p\tilde{\beta}_K / Kp(1 - p)$) for cluster sampling designs with $K = 2{:}10$ scent stations/line and minimum, median, and maximum visitation rates observed in Minnesota, USA, 1986–1991.

	Red fox			Striped skunk		
	Min	Med	Max	Min	Med	Max
K	(0.02)	(0.12)	(0.21)	(0.01)	(0.07)	(0.12)
2	1.10	1.22	1.36	0.97	1.03	1.09
3	1.20	1.34	1.49	1.13	1.20	1.27
4	1.29	1.44	1.61	1.23	1.31	1.38
5	1.38	1.54	1.71	1.31	1.40	1.47
6	1.47	1.63	1.82	1.38	1.47	1.55
7	1.55	1.72	1.92	1.44	1.54	1.62
8	1.63	1.81	2.02	1.50	1.60	1.69
9	1.71	1.90	2.12	1.56	1.66	1.76
10	1.79	1.99	2.22	1.62	1.72	1.82

depicts a single bootstrap replicate and shows the effect of polynomial smoothing, which improved estimates by exploiting the relation among coefficients for different line sizes. Fig. 1c shows sample variances predicted from line sizes, visitation rates, and bootstrap means of smoothed regression coefficients. We used predicted sample variances to estimate variance inflation factors for minimum, median, and maximum visitation rates (Table 1). Smoothed regression coefficients ($\tilde{\beta}_K$), which can be used to compute variance inflation factors for other visitation rates, appear in Table 2; however, caution always should be exercised when extending predictions beyond the range of existing data.

Cluster sampling had somewhat less effect on sample size requirements for striped skunks than for red foxes. However, cluster sampling required substantially larger sample sizes for both species than single-stage sampling, especially at high visitation rates. The cluster sampling design used in Minnesota required approximately twice as many stations as would have been required to obtain an equally precise estimate via single-stage sampling.

Table 2. Smoothed regression coefficients (with standard errors) used to estimate ratios of sample sizes, assess minimum sample size requirements, and compare measures of carnivore response for scent-station surveys in Minnesota, USA, 1986–1991.

	Red fox		Striped skunk	
K	$\tilde{\beta}_K$	SE	$\tilde{\beta}_K$	SE
2	2.15	0.15	1.91	0.11
3	3.53	0.16	3.34	0.12
4	5.07	0.27	4.87	0.22
5	6.77	0.40	6.49	0.32
6	8.62	0.53	8.20	0.40
7	10.62	0.68	10.01	0.47
8	12.78	0.84	11.91	0.54
9	15.09	1.03	13.90	0.62
10	17.55	1.25	15.99	0.71

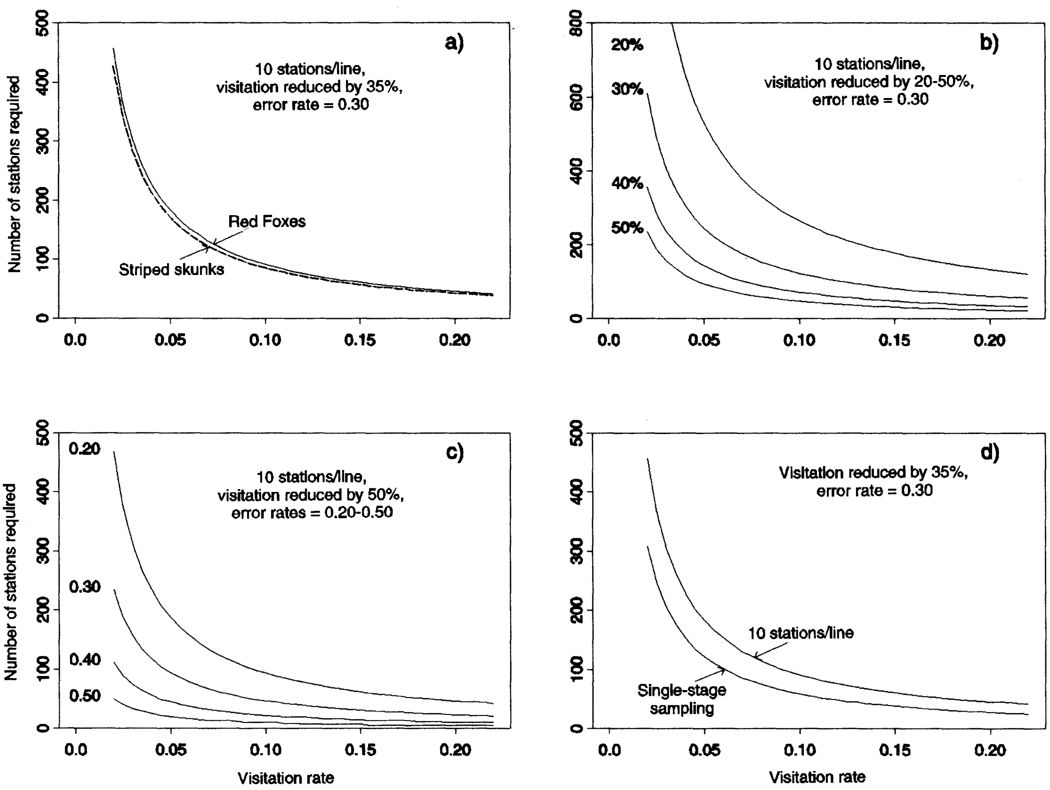

Fig. 2. Minimum required sample sizes for determining the direction of change in visitation rates. Plots illustrate (a) differences between species; (b) consequences of varying the effect (a reduction in visitation rates) to be detected; (c) implications of desired error rates; and (d) the influence of cluster size.

Sample Sizes

Selected results are shown in Fig. 2 to illustrate the nature of relations between visitation rates, effects (reductions in visitation rates), error rates, line sizes, and required sample sizes. Required sample sizes were greater for red foxes than for striped skunks, but differences between the species were minimal (Fig. 2a). Required sample sizes were more strongly affected by visitation rates than by any other factor and increased exponentially as visitation rates decreased. Below critical values determined by effects (Fig. 2b) and error rates (Fig. 2c), slight changes in visitation rates had dramatic effects on required minimum sample sizes. Low visitation rates sharply limited the potential usefulness of scent-station surveys because required minimum sample sizes were very large and difficult to anticipate. Once visitation rates reached about 10%, however, the influence of visitation rates declined markedly. Cluster sampling inflated required sample sizes but did not change the nature of relations between visitation rates, effects, and error rates (Fig. 2d).

Measures of Carnivore Response

For the 28 surveys included in our analysis, station visitation rates ranged from 0.02 to 0.21 for red foxes (median = 0.12) and from 0.01 to 0.12 (median = 0.07) for striped skunks. The proportion of lines with ≥1 visit ranged from 0.15 to 0.84 (median = 0.55) for red foxes and from 0.03 to 0.54 (median = 0.44) for striped skunks. Line indices and station indices were closely related ($r^2 > 0.86$ for both species; Table 3; Fig. 3). In contrast, the conditional station index explained only 62% (red foxes) and 38% (striped skunks) of variation in the station index and was weakly related (red foxes $r^2 = 0.28$; striped skunks $r^2 = 0.13$) to the line index.

For large sample sizes and large effects, and for visitation rates near the median, error rates for detecting changes in visitation rates were similar for line and station indices (Fig. 4a). At high visitation rates, station indices gained an increasing

Table 3. Smoothed polynomial regression coefficients ($\tilde{\gamma}_1 p + \tilde{\gamma}_2 p^2$) used to predict proportions of scent-station lines with ≥1 visit (l) from visitation rates for individual stations (p). Based on data collected in Minnesota, USA, 1986–1991. Standard errors (SE) estimated from 1,000 bootstrap replicates with lines as sampling units.

	Red foxes				Striped skunks			
K	$\tilde{\gamma}_1$	SE	$\tilde{\gamma}_2$	SE	$\tilde{\gamma}_1$	SE	$\tilde{\gamma}_2$	SE
2	2.01	0.13	−2.06	0.83	1.93	0.13	−0.42	1.42
3	2.73	0.09	−3.44	0.62	2.96	0.09	−5.02	0.97
4	3.40	0.11	−4.80	0.77	3.92	0.11	−9.43	1.15
5	4.03	0.13	−6.15	0.92	4.82	0.13	−13.67	1.38
6	4.60	0.14	−7.48	0.94	5.66	0.14	−17.73	1.44
7	5.12	0.13	−8.80	0.87	6.43	0.13	−21.61	1.41
8	5.59	0.13	−10.11	0.87	7.14	0.15	−25.31	1.56
9	6.00	0.18	−11.41	1.21	7.79	0.21	−28.84	2.21
10	6.37	0.29	−12.69	1.92	8.38	0.32	−32.19	3.41

advantage as effects declined (Fig. 4a) because line indices increased at a progressively decreasing rate relative to station indices. At low visitation rates, station indices gained an increasing advantage as sample sizes decreased (Fig. 4b) because the number of possible outcomes is less for line indices than for station indices. Ties thus increased disproportionately for line indices, increasing error rates.

DISCUSSION

Survey Design

Although many sampling designs have been described, we are aware of only 1 published analysis of sample allocation for scent-station surveys. Roughton and Sweeny (1982) compared designs with 10–50 stations/line, operated for periods of 1–4 days. Results favored lines with 10 stations operated for a single day and led to the widespread use of that design. As our results help show, however, such findings are special cases of a more general phenomenon. Because stations within clusters are unlikely to be independent sampling units (Roughton and Sweeny 1982, Diefenbach et al. 1994, Sargeant et al. 1998), the sampling strategy that allocates the fewest stations to each line and operates each line for the fewest nights will always produce the most precise estimate for a given number of station-nights.

Because single-stage sampling is certain to require fewer stations, cluster sampling is advantageous only when resulting cost savings permit sample sizes to be increased by a factor exceeding the resulting increase in sampling variation. Our methods suggest means for estimating variance inflation factors when sample data are available. If data are not available, variance inflation factors in Table 1 and coefficients in Table 2 may be useful for initial planning. However, survey designs should be evaluated and refined as data accumulate.

Once data have been collected, the continuity of historical records becomes a matter of concern that may discourage adaptive approaches to survey design. Practitioners should thus understand the nature of effects that could result from changes in sample allocation. Changing the number of stations in each line is certain to affect the line index, but correction factors are easy to estimate if station visitation rates are unaffected. For example, lines of 10 stations can be subsampled to estimate the line index, at the same visitation rate, for lines of <10 stations.

Sample allocation will not affect station visitation rates unless 2 conditions are met: (1) initial encounters with stations must influence reactions of individuals during subsequent encounters, and (2) different survey designs must present dif-

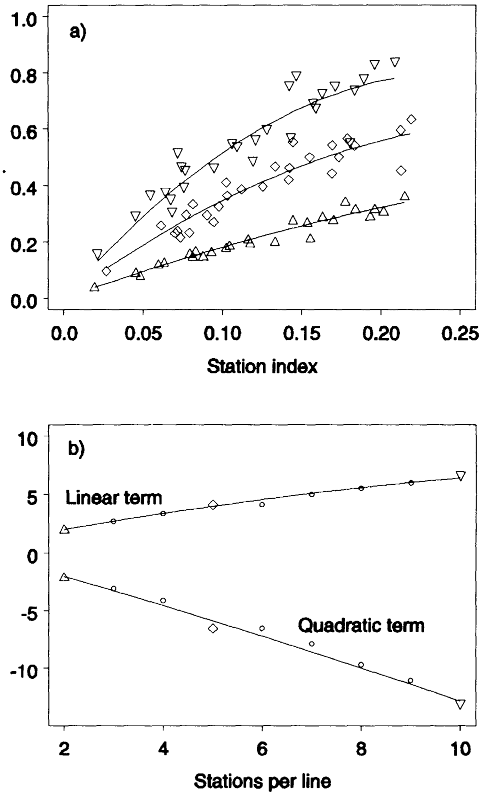

Fig. 3. Examples of (a) regressions relating proportions of scent-station lines with visits to visitation rates for stations and (b) smoothing of regression coefficients. Symbols other than O correspond with line sizes of 2 (△), 5 (◇), and 10 (▽) stations. Based on surveys of red foxes in Minnesota, USA, 1986–1991.

ferent numbers of stations to individuals. A biologically and statistically significant effect seems unlikely, but abrupt changes in visitation rates should be viewed with caution if they correspond with changes in methodology. If bias is a concern, analyzing ratios or differences of successive estimates will help limit impacts to a single year and facilitate comparisons of data collected before and after changes in sample allocation.

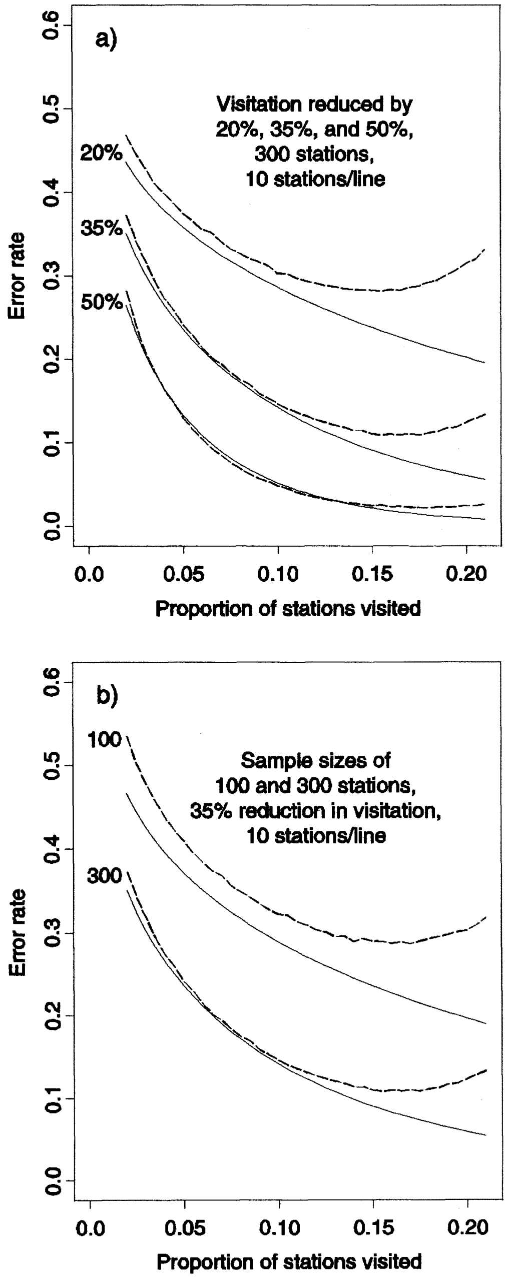

Fig. 4. Error rates of station indices (solid line) and line indices (dashed line) for correctly indicating the sign of reductions in visitation by red foxes. Based on scent-station surveys conducted in Minnesota, USA, 1986–1991.

Sample Sizes

Depicting required sample sizes is awkward because sample-size requirements are influenced by numerous factors. To simplify our presentation, we followed Roughton and Sweeny (1982), Kendall et al. (1992), and Zielinski and Stauffer (1996) by basing sample-size computations on pairwise comparisons of survey occasions. Like our predecessors, however, we realize that analyses often will involve >2 surveys and required sample sizes will decrease as numbers of surveys increase. Our results thus include variance inflation factors that can be used to estimate sample sizes for tests other than pairwise comparisons. S-Plus code that can be used to repeat our analysis for different visitation rates, effects, line sizes, and variance inflation factors is available from the senior author.

Effects of visitation rates on sample size requirements and statistical power are an issue of longstanding interest. According to Roughton and Sweeny (1982), the optimal range of visitation rates for detecting changes is 0.4–0.6. Much effort has been expended to improve the performance of scent-station surveys by increasing visitation rates (Diefenbach et al. 1994). However, Diefenbach et al. (1994) questioned the practical value of increasing visitation rates because sampling variation increases concomitantly. Our results show that visitation rates >0.10 are critical to the potential usefulness of scent-station surveys, but that benefits of further increases are of limited practical significance (Fig. 2).

Implications of Nonrandom Sampling and Spatial Heterogeneity

We used binomial models to represent sample variances for single-stage sampling. Binomial models generally describe numbers of events resulting from independent trials that each have the same probability of success. In reality, stations are likely to be deployed in a haphazard or pseudorandom fashion, and visitation rates are likely to be heterogeneous. Nonrandom sampling can inflate variances substantially if it becomes a source of inconsistent bias. Inconsistent bias is likely if visitation rates display strong spatial patterns and sampling effort is uneven and variable. We minimized bias by (1) partitioning Minnesota into physiographic zones, which eliminated large-scale spatial trends; (2) distributing lines throughout these zones; and (3) establishing lines in the same locations on successive survey occasions. Heterogeneity does not affect sampling variation if bias is consistent and stations are visited independently.

Measures of Carnivore Response

The number of individuals that visit a scent station cannot be determined reliably from tracks. Practitioners respect this limitation by recording only whether stations have or have not been visited. Although determining the number of individual visitors to a cluster is equally problematic, carnivore response traditionally has been measured by the proportion of stations visited, even when individuals are suspected of visiting multiple stations, individuals are likely to vary in detectability, and the number of individuals in contact with each cluster is likely to be small (e.g., Wood 1959, Linhart and Knowlton 1975, Roughton and Sweeny 1982, Travaini et al. 1996).

For members of the genus *Martes*, multiple visits by individuals are likely and provide no information about abundance. Zielinski and Stauffer (1996) thus questioned the relation between visitation rates and abundance. To rectify this perceived problem, Zielinski and Stauffer (1996) reported the proportion of clusters with visits but did not evaluate relations between this index and actual abundance.

We observed close relations between line and station indices, which suggest that both were potentially useful indicators. The question that remains is whether generalizations can safely be drawn from our results, or whether the correspondence between indices might not exist under other circumstances, such as those typical of surveys for *Martes*. During surveys for *Martes*, track plates typically are checked repeatedly during extended sampling periods (Zielinski et al. 1997). Such practices are likely to exacerbate false perceptions of local density that can result from repeated visits by the same individuals. Nevertheless, proportions of clusters with visits are unlikely to be a valid index (i.e., monotonically related to abundance) when visitation rates are not, because the former measure is an important component of variation in the latter.

We previously tried to map visitation rates for Minnesota and found our efforts frustrated by a few lines with numerous visits, which produced misleading impressions of local densities. Sargeant et al. (1998) thus suggested reporting proportions of clusters with visits (i.e., the line index) to dampen the influence of such lines, and speculated that any resulting loss of information would be of limited practical importance. We found that line indices and station indices performed comparably when visitation rates were modest and sample sizes or changes in population were substantial. However, station indices had a meaningful advantage over line indices when visitation rates were high because the line index increases at a progressively slower rate than the station index as visitation rates increase (Fig. 3a). Differences in the performance of station indices and line indices at very low visitation rates and for modest sample sizes were due to large number of ties for the line index, but are of limited practical importance. Neither index reliably indicated the direction of changes in visitation rates under such circumstances.

Our results may seem counterintuitive because reporting the line index is similar to dichotomizing an interval-scaled variable, which generally reduces explained variation (Cohen 1983). However, dichotomization usually results in a loss of information because it amounts to cruder measurement on the same scale. The situation is somewhat different for the line index, which is a component of the station index, not merely a cruder measure. Strong associations between line and station indices suggest that the 2 measures are nearly equivalent, and implicate sampling error as the primary source of variation in the conditional station index.

Interspecific Variation

We restricted our analysis to red foxes and striped skunks because these species readily visited scent stations and exhibited ranges of visitation rates that facilitated our analysis. However, the clustering of visits in a comparatively small proportion of lines is such a general phenomenon for carnivores in Minnesota (Sargeant et al. 1998) that important disparities among survey designs should be expected for most species and locations. Disparities are likely to be greatest for species with the lowest overall visitation rates and the greatest potential to visit many stations in a small proportion of clusters.

We suspect different phenomena produced similar results for red foxes and striped skunks. Striped skunks can occur at relatively high densities, are nonterritorial, and can occur in temporary concentrations associated with food resources or den sites (Rosatte 1987; A. B. Sargeant and R. J. Greenwood, Northern Prairie Wildlife Research Center, unpublished data). Conversely, local concentrations of foxes are comparatively unlikely because fox families tend to occupy contiguous, nonoverlapping home ranges that are large relative to typical distances between scent stations (Sargeant 1972). For foxes, clustered visits probably reflect extensive daily movements within large home ranges, combined with individual variation in responses to stations. Because canids are notoriously wary, many encounters with scent stations go undetected (Griffith et al. 1981, Sargeant et al. 2003). However, unwary individuals can easily encounter and visit >1 station.

MANAGEMENT IMPLICATIONS

Efforts to validate scent-station indices of carnivore abundance have produced equivocal results, in part because visitation rates have been estimated with inadequate precision (Sargeant et al. 1998). Estimating visitation rates precisely is thus the common goal of all scent-station surveys, whether the objective is to evaluate scent-station methodology or to monitor carnivore abundance. Considering the widespread use of scent-station surveys and the effect of survey design on the precision of estimated visitation rates, attention to optimal allocation of survey effort is overdue. Regardless of the design chosen, however, our results are a sobering reminder that scent-station surveys are a large-sample proposition. Small-scale surveys cannot possibly provide useful estimates of visitation rates, especially when visitation rates are low, and are not worthwhile. Data we analyzed represent surveys conducted on an appropriate scale.

Roughton and Sweeny (1982) recommended a sampling design based on lines of 10 stations. The design has been widely regarded as good for general use, and most surveys published subsequently have featured cluster sampling with 10 stations/line. Interstation distances, however, are typically 0.3 km (8 of 12 surveys cited) rather than the 0.5 km recommended by Roughton and Sweeny (1982) and used in Minnesota. The degree of spatial dependence among stations increases as interstation distances decrease, hence our results may be optimistic for designs with shorter distances between stations. The effect, however, is likely to be less important than effects of other uncertainties associated with the extension of our results to other species and areas.

Recommendations of Roughton and Sweeny (1982) were motivated largely by logistic considerations specific to coyote (*Canis latrans*) surveys in the western United States. Similar designs may predominate in other settings, although logistic considerations vary, because Roughton and Sweeny (1982) did not address more general principles of sample survey design. Our methods and results illustrate these more general principles and provide a means for developing sampling designs that accommodate site-specific logistic considerations. One simple way to compare sampling designs is to determine achievable sample sizes for various candidate designs, and compare ratios of achievable sample sizes to ratios of variance inflation factors. For example, consider red foxes in Minnesota at median visitation rates (Table 1), and let n_K be the number of stations that can be deployed in lines of K stations. In such case, lines of 10 stations are more efficient than lines of 5 stations only when $\frac{n_{10}}{n_5} > \frac{1.99}{1.54}$. Our estimates of variance inflation factors can serve as a starting point if site- and species-specific estimates are unavailable. However, designs should be evaluated and refined, if necessary, as data accumulate.

In choosing a method for reporting results, investigators should consider mathematical relations among the line index, station index, and conditional station index, and weak relations between the sample conditional line index and the sample line index. The first relation dictates that both measures will be valid if either is valid, but the second casts doubt on the value of information conveyed by the number of visits/line. At moderate visitation rates, investigators can probably use the simpler line index without sacrificing an appreciable amount of information.

Despite limitations, scent-station surveys have a long history of widespread use that is likely to continue because satisfactory alternatives have not been developed: most suffer equally severe limitations or are too costly for routine use. However, our experience suggests that visitation rates often are too low and numbers of stations too small to produce useful insights. Wildlife managers and referees should thus be watchful for null results that are uninformative consequences of low statistical power (Steidl et al. 1997) and should not be reassured by findings of significance based on small sample sizes, which may be a symptom of data dredging (Anderson et al. 2001). Low visitation rates and modest sample sizes should inspire immediate suspicion: small-scale scent-station surveys are not a reliable basis for inference or action, especially when visitation rates are < 0.10.

ACKNOWLEDGMENTS

We thank the Minnesota Department of Natural Resources (MDNR) for the use of survey data. Cooperators in surveys included the MDNR Wildlife Division; MDNR St. Croix State Park; U.S. Fish and Wildlife Service National Wildlife Refuges and Wetland Management Districts; the Cass and Beltrami county land departments; the Fond du Lac, White Earth, and Leech Lake Indian reservations; the 1854 Treaty Authority; the University of Minnesota Itasca Biological Station; and Chippewa and Superior national forests. Early drafts of this manuscript were improved by constructive criticism of W. E. Newton, M. R. Riggs, M. A. Sovada, D. A. Buhl, and M. H. Sherfy. Project funding and logistical support was provided by the Northern Prairie Wildlife Research Center of the Biological Resources Division, U.S. Geological Survey.

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Received 7 March 2002.
Accepted 23 December 2002.
Associate Editor: White, Jr.