Demonstration of Line Transect Methodologies to Estimate Urban Gray Squirrel Density

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ABSTRACT / Because studies estimating density of gray squirrels (*Sciurus carolinensis*) have been labor intensive and costly, I demonstrate the use of line transect surveys to estimate gray squirrel density and determine the costs of conducting surveys to achieve precise estimates. Density estimates are based on four transects that were surveyed five times from 30 June to 9 July 1994. Using the program DISTANCE, I estimated there were 4.7 (95% CI = 1.86–11.92) gray squirrels/ha on the Clemson University campus. Eleven additional surveys would have decreased the percent coefficient of variation from 30% to 20% and would have cost approximately $114. Estimating urban gray squirrel density using line transect surveys is cost effective and can provide unbiased estimates of density, provided that none of the assumptions of distance sampling theory are violated.

Line transect sampling to estimate the abundance of organisms has been used for nearly 50 years (Hayne 1949) and culminated with comprehensive publications of distance sampling (Burnham and others 1980, Buckland and others 1993) using state-of-the-art software (TRANSECT: Laake and others 1979; DISTANCE: Laake and others 1993). Many studies have used distance sampling to estimate the abundance of biological populations (e.g., see Buckland and others 1993). However, I could find no studies that compared line transect sampling between urban and nonurban populations of the same species.

Gray squirrels (*Sciurus carolinensis*) are used as a habitat indicator species by forest managers (Healy and Welsh 1992). Natural resource managers may, therefore, estimate gray squirrel population density to evaluate the effects of anthropogenic activity (e.g., habitat management). Nonetheless, methods to estimate gray squirrel density can be labor intensive and costly (Barkalow and others 1970, Nixon and others 1975, Bouffard and Hein 1978, Healy and Welsh 1992).

Urban gray squirrels may cause significant damage to trees and ornamental vegetation (Manski and others 1981, Hadidian and others 1983), may gnaw telephone cables (Flyger 1970, Flyger and Gates 1983), and cause frequent electrical power outages (Hamilton and others 1989). Gray squirrels may also be reservoirs for disease (Davis and others 1970, Hadidian and others 1983) and may prey on birds (Bailey 1923) or bird eggs (Bailey 1923, Leimgruber and others 1994). Biologists in urban areas have implemented gray squirrel control programs in small localized areas (Manski and others 1981) and, subsequently, have documented their effects on the squirrel population (Hadidian and others 1983).

Gray squirrel populations have been estimated with mark–recapture and various survey methods (Flyger 1959, Barkalow and others 1970, Nixon and others 1975, Bouffard and Hein 1978, Manski and others 1981) and line-transect sampling (Healy and Welsh 1992). Leaf nest counts and activity indices (Pack and others 1971), time area searches (Goodrum 1940, Uhlig 1956, Bouffard and Hein 1978), and the number of harvested squirrels per unit area (Uhlig 1956) have been used as indices to relative abundance. Indices may lack basic factors (e.g., they may have no measures of precision) required for drawing inferences about population parameters and are useful only when they have been calibrated with the parameters of interest (White and others 1982, Eberhardt and Simmons 1987, Rexstad 1994). Research and management studies may require different degrees of precision of population estimates (White and others 1982). Biologists may, therefore, evaluate cost as it relates to the precision of estimates in deciding whether to estimate density or use an index to population abundance (Healy and Welsh 1992). However, relative abundance indices may not reflect density estimates (Roughton and Sweeny 1982, Burnham and others 1981), may lack statistical power to detect differences between years (Diefenbach and others 1994), and may be ineffectual for detecting changes in population abundance (Rexstad 1994). Conse-

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quently, indices may not be appropriate for monitoring changes in gray squirrel populations.

Healy and Welsh (1992) used line transects for estimating gray squirrel density in an large oak forest, but their study required a minimum of 94 transect-km to estimate density because few squirrels were observed during each survey. Gray squirrel density in urban areas may be higher (Flyger 1959, Manski and others 1981, Hadidian and others 1983) than in nonurban areas (Healy and Welsh 1992). However, it is unknown if distance sampling would be a cost effective and precise technique for estimating gray squirrel density in localized urban areas.

The program DISTANCE (Laake and others 1993) was developed to use distance sampling to estimate the density of populations using primarily line or point transect methodologies (Buckland and others 1993). DISTANCE (Laake and others 1993) is a flexible program that evolved from the program TRANSECT (Laake and others 1979) but supports a wider choice of estimation models, calculates density of clustered populations, and provides better model selection capabilities (Buckland and others 1993).

Distance sampling, using line transect methods for estimating gray squirrel density, has not been demonstrated in small urban areas. Therefore, I used gray squirrels to demonstrate the general application of line transect sampling and to illustrate that survey effort and cost of conducting surveys can vary within species.

Materials and Methods

This study was conducted on the Clemson University campus (565 ha) located in northwestern South Carolina. The campus is characterized by gently rolling hills to flat open areas and is dominated by mature mast-producing trees such as pecan (*Carya pecan*) and oak (*Quercus* spp.) with an understory of mixed ornamental shrubs, flowers, and grass. Line-of-sight visibility exceeds 60 m in any direction.

Transect starting points were systematically centered in the westernmost point of four forested areas randomly selected from six areas that were able to contain ≥140 m of transect. Transect bearings were randomly selected from within constrained regions to avoid buildings, roads, and paralleling sidewalks; however, the spatial distribution and age of trees in the constrained regions was similar to trees near buildings, roads, and sidewalks. An all-terrain measuring instrument (Chainman Industries, White Rock, British Columbia, Canada) was used to lay out four transects totaling 1 km, and a steel tape (Spencer Products Co. Seattle, Washington) to measure 20-m intervals on the transects. Intervals were marked by pushing a flagged 16-penny nail into the ground and painting the vegetation around each flag with florescent orange paint (Krylon, Sherwin-Williams Co., Solon, Ohio), making the point visible from approximately 25 m. Nonintrusive marking was chosen because these areas were mowed approximately every week. Transect flags remained visible for approximately one month and painted vegetation for approximately two weeks. Each of the four transects was surveyed five times from 30 June to 9 July 1994. One survey began shortly after sunrise (06:23 h), whereas four surveys began mid-morning ($\bar{x}$ = 08:45 h, range = 07:47–09:42 h). All transects were walked at approximately 1 km/hr (100 m/6 min) (Healy and Welsh 1992). Aggregations of squirrels, or clusters, were defined as squirrels ≤2 m from each other. I scanned overhead, in front of, and to the sides of the transect for squirrels as I walked. Squirrels were acclimated to people; most animals were approached within ≤5 m before they moved. I used landmarks (e.g., grass clumps, sticks, and trees) to visually mark a squirrel's position(s) or the center of clusters of squirrels, walked directly to the location, marked the site with a piece of flagging, and then measured the perpendicular distance back to the transect. When squirrels were observed in trees, I visually estimated the location on the ground directly beneath the animal, and then measured the perpendicular distance back to the transect. Returning to the transect and searching for additional squirrels did not continue until all measurements were taken, but occasionally more than two squirrels' locations were marked and measured if they were observed from the transect and were ≤10 m apart. No surveys were conducted when wind was >10 km/hr and/or there was precipitation. Only one squirrel was heard vocalizing during surveys, and it was not used in the analysis because it could not be located in the overstory.

I used five general models of the detection function (i.e., uniform/cosine, uniform/polynomial, half-normal/hermite, hazard rate/polynomial, and hazard rate/hermite and adjustment functions) (Buckland and others 1993) to examine all possible combinations (select = all) of models and select the best-fitting model using Akaike's information criteria (AIC) (Buckland and others 1993, Laake and others 1993). All models are presented for comparison with the uniform estimator. The uniform estimator has been recommended as an omnibus model (Buckland and others 1993) because it is both model and pooling robust (Burnham and others 1980). A robust model was required because the data were pooled across days and transects and because too few squirrels were observed on each transect to estimate transect densities individually.

Table 1. Estimates of gray squirrel density from 5 line transects on Clemson University campus using 5 general models in program DISTANCE[a]

Estimator	Estimate	PCV[b]	95% CI	AIC[c]
Half-normal/hermite	4.65	30.27	2.04–10.58	394.19
Hazard/polynomial	5.11	33.65	2.20–11.86	395.93
Hazard/hermite	5.11	33.65	2.20–11.86	395.93
Uniform/cosine	4.70	29.87	1.86–11.92	394.01
Uniform/polynomial	4.63	30.58	2.02–10.61	396.14

[a]Buckland and others 1993, Laake and others 1993.

[b]Percent coefficient of variation.

[c]Aikaike's information criteria (Buckland and others 1993).

Data were entered as ungrouped and truncated at ≥43 m. I tested for cluster size bias by regressing the natural logarithm of size of the ith cluster [$\log_e(s_i)$] against the detection probability of the ith cluster at distance x [$g(x_i)$] (Laake and others 1993). The strength of this relationship aids in selecting the estimate of cluster size [i.e., the average cluster size $\bar{s}$ or size-biased estimate of the expected cluster size $E(s)$] that is used in calculating density. Density is calculated by multiplying the estimate of the density of clusters $\hat{D}_s$ by the selected cluster size [i.e., $\hat{D} = \hat{D}_s * E(s)$]. I compared the average cluster size and the size-biased estimate of expected cluster size density estimates, using the best fitting model, to examine the precision between the different estimates. An estimate of transect length L, required to achieve a percent coefficient of variation (PCV) of 20% and 10%, was calculated for clustered populations using the equation (Buckland and others 1993, p. 306)

$$L = \frac{L_0\,[b + (\widehat{sd}\,(s)/\bar{s})^2]}{n_0 \cdot cv_t^2}$$

to estimate the cost and sampling effort of increasing precision in future surveys. From this study, L_0 is line length (5), b is an unknown parameter that is estimated as the product of the sample size times the coefficient of variation of the density estimate squared {e.g., $b = n_1[cv(D)]^2 = 9.9$}, $\widehat{sd}(s)$ is the standard deviation (0.54) of the mean cluster size $\bar{s}$ (1.2), n_0 is the number of animals or clusters observed (110) during a pilot study, and cv_t is the coefficient of variation required (0.20).

Results

There was a weak relationship between the $\log_e(s_i)$ and $g(x_i)$ ($r = -0.14$, 106 df, $P = 0.071$), so the expected cluster size was used to calculate density. The uniform estimator with a cosine adjustment was selected as the best fitting model to these data (Table 1).

Table 2. Estimates of gray squirrel density/ha in urban and nonurban areas

Density estimate (SE[a])	Area	State	Source
0.16[b] (0.06)	nonurban	MA	Healy and Welsh (1992)
0.78[c] (0.10)	nonurban	WV	Uhlig (1957)
1.27 (0.24)	nonurban	NC	Barkalow and others (1970)
1.36[c] (0.22)	nonurban	WV	Uhlig (1957)
1.84[c] (0.47)	nonurban	WV	Uhlig (1957)
1.85[c] (0.26)	nonurban	WV	Uhlig (1957)
1.90 (0.24)	nonurban	OH	Nixon and others (1975)
2.92 (0.48)	urban	MD	Flyger (1959)
3.83 (0.50)	nonurban	PA	Bouffard and Hein (1978)
4.7 (1.41[d])	urban	SC	This study
51.5 (—)	urban	DC	Manski and others (1981)
32.15 (1.81)	urban	DC	Hadidian and others (1983)

[a]Calculated from multiple estimates across months or years.

[b]Calculated using a pooled Fourier series estimate (Burnham and others 1981) from multiple years.

[c]One of four areas studied.

[d]Calculated from five surveys on four line transects.

The estimated density of gray squirrels, using the size-biased cluster size, at Clemson was 4.7 (SE = 1.41, 95% CI = 1.86–11.92, PCV = 29.9), whereas the average cluster size density estimate was 4.98 (SE = 1.5, 95% CI = 1.96–12.69, PCV = 30.0) gray squirrels/ha. The uniform/cosine model fit these data well ($\chi^2 = 1.20$, 5 df, $P = 0.945$) and was selected over other adjustments to the estimator (likelihood ratio test: $\chi^2 = 24.16$, 1 df, $P < 0.001$). Cluster size of 110 groups averaged 1.2 (range = 1–4, SE = 0.05) squirrels, whereas the expected cluster size estimate was 1.14 (SE = 0.03). I observed 73% (96 of 132) of gray squirrels on the ground, at an average distance of 16.16 (SE = 1.2) m by walking 5 km of transects. An average of 22 (range = 3–52) squirrels were observed per kilometer of transect surveyed. Three squirrels were observed during the survey shortly after sunrise, whereas 129 squirrels were observed during mid-morning surveys. I estimated that 11.48 and 45.92 km of transect would have decreased PCV to 20% and 10%, respectively.

Discussion

A density of 4.7 gray squirrels/ha on Clemson University is higher than most reported density estimates from nonurban areas (Table 2). Healy and Welsh (1992) suggested the number of squirrels observed per kilometer of line transect (i.e., the encounter rate) as a relative index of abundance, but Burnham and others

(1981) proved that the number of objects seen during line transect surveys is a poor index of abundance and density. The encounter rate can be used to calculate the sample size required to meet the precision of study objectives (Burnham and others 1980, Buckland and others 1993) and may also be used to compare effort between studies of the same species using line transect surveys.

All assumptions of line transect theory (Burnham and others 1980) are believed to have been met in this study. I believe that all squirrels on the ground and on the canopy line were observed. $\hat{D}$ is an unbiased estimate only if all animals on the transect were seen with probability 1 (Burnham and others 1980) [i.e., $g_{\text{ground}}(0) + g_{\text{canopy}}(0) = 1$]. If this assumption is violated, [i.e., $g_{\text{ground}}(0) + g_{\text{canopy}}(0) < 1$], then the estimate will be biased low (Buckland and others 1993). I was careful to ensure that all animals were seen (Burnham and others 1980, Buckland and others 1993), but could not validate this assumption. In fact, the assumption $g(0) = 1$ may be violated to some extent in most line transect studies (e.g., see Bergstedt and Anderson 1990, Otto and Pollock 1990, Buckland and others 1993). The scope of this study was to determine the amount of effort to estimate a detection function, and hence density, for gray squirrels based on distance sampling, not to validate the assumption of $g(0) = 1$. Healy and Welsh (1992) reported that squirrels in the overstory, cavities, or nests may have been missed and suggested that density estimates for gray squirrels should be considered minimal estimates. Although gray squirrels forage most of the time on the ground (Kenward and Tonkin 1986) and the majority (96 of 132) of squirrel observations in this study were on the ground, future studies may investigate (e.g., using radiotelemetry) if the assumption of $g(0) = 1$ is valid for gray squirrels.

The density estimates from the five general models (Table 1) were similar. However, the uniform/cosine estimator provided the best fit and was the most precise, which agrees with the conclusion that this is an excellent omnibus model (Buckland and others 1993). The size-biased estimate using the expected cluster size 4.7 (95% CI = 1.86–11.92) was similar to the average cluster size density estimate of 4.98 (95% CI = 1.96–12.69). Point and variance estimates using the average cluster size or the size-biased estimate of expected cluster size were similar because the relationship between $\log_e(s_i)$ and $g(x_i)$ was weak (Laake and others 1993), but a weak relationship does not always indicate a lack of size bias (Drummer and McDonald 1987). However, if a strong relationship between cluster size and detection distance exists, techniques for obtaining unbiased estimates using DISTANCE are available (Buckland and others 1993).

Healy and Welsh (1992) reported most squirrels were observed between the first half hour after sunrise and <2 h after sunrise. Bouffard and Hein (1978) reported that time–area counts observed the most squirrels during June between 08:00 and 10:00 h. Manski and others (1981) found gray squirrel activity peaked between 05:00 and 07:00 h. In this study, more squirrels were observed during mid-morning than shortly after sunrise, but this study did not have an adequate sample size to determine the influence of time of day on number of squirrel observations. I recommend a presurvey study to decide the best time for squirrel observations and to estimate the number of transects and survey effort required to obtain precise estimates.

Laying out and marking transects cost approximately \$24.00 (3 h × \$8.00) and each survey cost \$10.40 (1.3 h × \$8.00). Eleven additional surveys would have decreased PCV from 30% to 20% and would have cost approximately \$114. Line transect studies with fewer squirrels observed per unit of transect (e.g., Healy and Welsh 1992) would be more labor-intensive and costly than this study. However, line transects conducted in urban areas, which usually have higher density (Table 2), and therefore more detections/unit of transect, should be less costly than nonurban areas. Healy and Welsh (1992) suggested line-transect surveys that observe <0.5 squirrels/km may be cost prohibitive. I observed an average of 22 squirrels/transect km and expended <3% of the effort of Healy and Welsh (1992). Although there is no minimum size of an area that can be surveyed using line transects, approximately 100 detections are required to generate a reliable estimate (Buckland and others 1993).

Line transect surveys are a cost efficient and easy technique for estimating urban gray squirrel density. Future studies should verify the assumption $g(0) = 1$, to investigate the potential bias of density estimates using line transects. A pilot study should be used to determine transect length for required precision (Burnham and others 1980, Buckland and others 1993); then the associated costs of conducting line transects surveys on an urban squirrel population can be estimated.

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