Monitoring Southern Flying Squirrel Populations with Nest Boxes[1]

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ABSTRACT. **Evaluating the practicality, economic, and sampling efficiency of potential monitoring programs is a first step in validation. Thus, we established a system of nest boxes in southeast Ohio to evaluate the feasibility of using a system of nest boxes to monitor changes in southern flying squirrel (*Glaucomys volans*) populations. We recorded the time of box placement until first usage and types of use by flying squirrels as an indicator of presence as well as nest box occupancy trends on a month-to-month basis to assess usage patterns and productivity. Using monitoring results from 4 years, we evaluated alternative survey sampling techniques for occupancy and determined sample sizes necessary to estimate occupancy within specified relative bounds. We also studied the cost of establishing a nest box system and monitoring nest box use. At low nest box occupancy (9.4%), sample size necessary to monitor trend would be extreme (431 boxes for 30% relative bound), but sample size is not restrictive when occupancy rates exceed 17% (211 boxes to achieve 20% relative bound). Monitoring combined spring and summer litter sizes in November or December as a measure of recruitment would require a smaller effort to achieve a tighter relative bound (10%). Assumptions relating these demographic parameters to habitat change or disturbance still must be tested before the systematic placement of nest boxes can be considered the optimum approach to monitor southern flying squirrel response as measured by changes in population density or recruitment.**

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INTRODUCTION

Monitoring distribution and abundance over time provides the empirical data needed to detect population change. The monitoring process should provide the primary feedback loop into basic ecological models used to determine the cause of population change (Verner 1986). The immediate need is to provide sufficient information to assure current management practices are not threatening long-term viability of local populations. Despite the importance of monitoring population changes in responses to habitat, adequate techniques have not been developed for many secretive species.

Southern flying squirrels inhabit a variety of forest types throughout their distribution (Dolan and Carter 1977). Habitat requirements include forest structure allowing gliding travel (Bendel and Gates 1987), snags or other natural cavities for nesting (Muul 1974; Gilmore and Gates 1985; Taulman 1998), and hard mast as primary foods (Muul 1968; Harlow and Doyle 1990). Southern flying squirrels are secondary cavity nesters and will use nest boxes at varying rates of occupancy throughout the year (Sonenshine and others 1973; Caster and others 1994; Taulman 1998). However, there are no published records for southern flying squirrel use of nest cavities (or nest boxes), population densities, or distribution in Ohio, aside from Hotem's (1972) study that was limited to a 2 month period (February-March) in 1972.

During the past few decades, the public has continuously criticized clear-cutting. In response, forest managers have often chosen to implement selective cuts. Gray squirrels *(Sciurus carolinensis)* and fox squirrels *(S. niger)* appear to initially respond favorably to selection cuts in Illinois (Nixon and others 1980). However, single-tree selection cuts can reduce cavity abundances in mixed deciduous forest (Pattanavibool and Edge 1996). Southern flying squirrels respond to single-tree selection as well as clear-cutting (Taulman 1997, 1998) in southern pine stands by avoiding stands <40 years old. The extent of changes in distribution and abundance of southern flying squirrels has not been documented in Ohio's hardwood forests undergoing similar harvest strategies or disturbances.

As part of a long-term study of population dynamics, we are assessing whether the response (abundance and productivity) of southern flying squirrel populations to forest change (due to timber harvest, succession, and others) can be detected by yearly monitoring of nest boxes. In this paper, we examined the cost of establishing and monitoring a nest box monitoring system, pattern of initial use and occupancy of nest boxes by squirrels, and the efficiency of different sampling designs in detecting changes in productivity and occupancy of squirrels nesting in boxes. We compared 2 sampling schemes (systematic and cluster) with and without stratification for monitoring occupancy and determined sample size necessary to achieve an acceptable bound on estimation of occupancy and productivity.

The relationships among rates of occupancy and productivity of southern flying squirrels in nest boxes and abundance and productivity in the target population (geographically defined groups of squirrels that one is interested in monitoring) are unknown. "Because it is less expensive to evaluate the economic and sampling efficiency of a method than to *validate* the technique" (Hayward and others 1992:778), we examined the feasibility of our monitoring method first. If our approach proved

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to be economically and statistically inefficient, there would be no justification for conducting the more expensive and time consuming validation study.

METHODS AND STUDY AREA

Study Area

We hung nest boxes at 5 locations in southeast Ohio (Table 1). The area is part of the unglaciated eastern Allegheny Plateau. All sites lie within the mixed mesophytic forest association (Braun 1961). Three monitoring sites were located in Athens County, 1 in Perry County, and 1 in Meigs County. The topography of the 5 sites is characteristic of the rolling hill country of southeast Ohio. The 5 sites were considered separate strata for statistical analysis and named Hocking Woods Conference Center (HWCC), Woods Property (WOOD), Householder's Property (HOUS), Soren Erikkson Ecosystem Forest (SEEF), and Camp Rotan (CAMP).

The climate of this region is mesothermal with relatively moderate temperatures (Gordon 1969). Mean maximum temperatures range from 31° C in the summer to -2° C in the winter (Goddard 1979). The average frost-free period is 170 days and the annual snowfall is light (50-100 cm).

The locations represented a variety of age classes, species, and forest structures. HWCC is predominately medium to well-stocked, sawtimber-sized (>28 cm dbh) oak (*Quercus* sp.) and hickory (*Carya* sp.) with approximately 20% of the area consisting of well-stocked, pole (>10 cm and ≤28 cm dbh) and sawtimber-sized maple (*Acer* sp.). WOOD has two distinct woodlots: one section consisted of poorly stocked, pole-sized oak and hickory with a significant understory of briars (*Smilax* sp.), the second section consisted of mostly well-stocked, sawtimber-sized beech (*Fagus grandifolia*) and maple (*Acer* sp.) with 10% oaks and hickory scattered throughout. HOUS is a mix of well-stocked, sawtimber-sized beech, oak, maple, and hickory. SEEF is a medium-stocked stand of predominately red (*Q. rubra*) and white oak (*Q. alba*) with a moderately stocked understory of raspberry (*Rubus* sp.) and sawbrier (*S. rotundifolia*). CAMP is a well-stocked, sawtimber sized stand of beech, maple, hickory, and oak.

Nest Box Placement, Design, and Monitoring

We hung 109 boxes on the study sites between May 1995 and September 1996 (Table 1). We spaced nest boxes at 50-70 m intervals and where possible, we hung boxes in a non-linear pattern so the boxes formed a grid-like pattern rather than a single string of boxes along one corridor. Approximately 80% of the boxes were grouped at a site in 2 × 3, 3 × 3, or 5 × 5 grid-like patterns.

Each box was hung on a pole- or sawtimber-sized tree ≥100 m from the nearest road. We used a ladder to position boxes 3.0-5.0 m high. All entrance holes were oriented to provide for east, southeast, or south exposure. Inside box dimensions were: bottom 13.8 × 13.8 cm, height 42 cm, and entrance hole 3.1 cm (Fig. 1). The entrance hole was positioned on the side as close to the tree trunk as possible near the top of the box. Our box design was patterned after Sonenshine and others (1973) with the exception of the access to the interior of the box. A wooden front door with a wire-mesh screen behind it enabled easy inspection and removal of squirrels once the entrance hole was plugged (Fig. 1). We constructed nest boxes from 3.0-cm pine and fir. Constructing 109 boxes required 266 m of 3.0 × 20-cm (1.0 × 8.0 in.) lumber, 34 m of 14 cm wide × 0.6 cm (1/4 in.), 218 zinc-plated hinges, and 109 eyelets (for securing the front door).

We monitored boxes within 4-6 weeks of placement, checked them once monthly for 12 consecutive months, every other month for the second year, and in July and December thereafter. Boxes were checked during the last 10 days of the month; the minimum time between checks was 24 days during the month-to-month monitoring phase. To determine nest box use, each box was

TABLE 1

Descriptions of southern flying squirrel nest box monitoring sites in southeast Ohio, 1995-1998.

Site	Abbreviation	County	Location	Area (ha) sampled	No. of boxes	Date hung
Hocking Woods Conference Center	HWCC	Athens	39°26.30N, 82°15.30W	15.0	10 15	15 May 95 12 Aug 95
Wood's Property	WOOD	Meigs	39°11.37N 82°05.06W	14.8	10 14	16 Aug 95 16 Oct 95
Householder's Property	HOUS	Perry	39°39.43N 82°17.30W	6.2	10	18 Aug 95
Soren Erikkson Ecosystem Forest	SEEF	Athens	39°26.00N 82°15.30W	15.0	25	19 Dec 95
Camp Rotan	CAMP	Athens	37°17.30N 82°05.30W	15.0	25	4 Sep 96

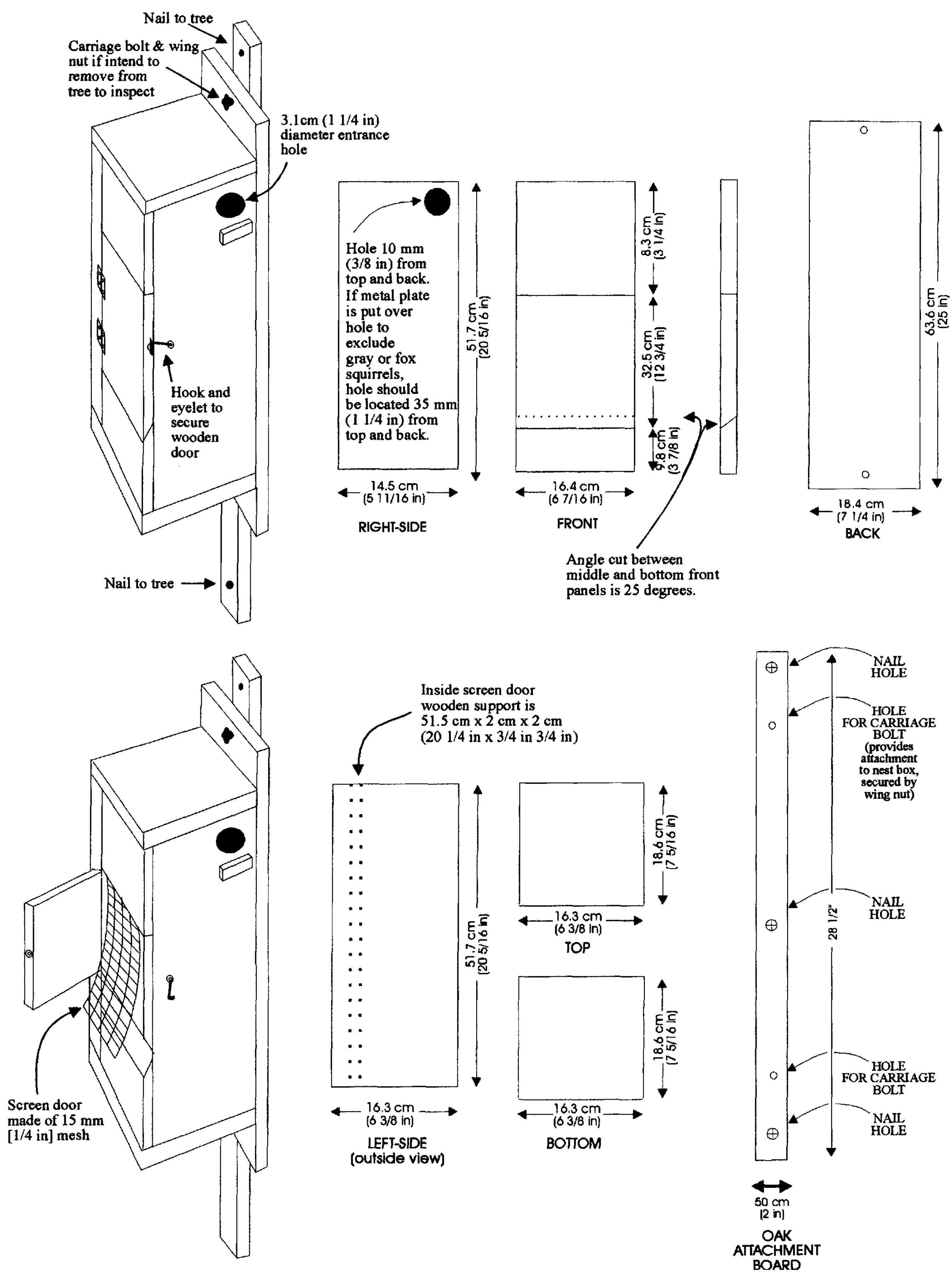

FIGURE 1. Nest box design used to monitor southern flying squirrel populations. Note position of entrance hole and arrangement of doors (wood and wire mesh) which permit inspection and removal of flying squirrels.

inspected and the contents recorded after the entrance hole was plugged. In addition to occupancy, use by southern flying squirrels was evident by feces, shell fragments (particularly the unique elliptical gnawing on hickory shells), and nesting material (Wells-Gosling 1985). Use by other vertebrates and invertebrates was also noted.

An occupied box was removed from the tree and squirrels were processed on the ground. All southern flying squirrels captured in the boxes were weighed, sex noted, and ear tagged (if >8 wk old) and the box was recorded as occupied. Squirrels ≤75 g were recorded as juveniles for November/December checks unless scrotal testes or a perforated vagina were observed for males or females, respectively. Males with scrotal testes were considered reproductively active; females with perforated vaginas and/or evidence of nursing were considered sexually mature (Wells-Gosling 1985; Taulman and others 1998). Young <8 wk old were returned to the nest box; all others were released on the ground.

Sampling Schemes and Sample Size

Presence/Absence—The initial monitoring phase whereby boxes were checked monthly was designed to establish if a characteristic pattern of southern flying squirrel use and occupancy was evident among strata. The intent was to determine if monthly monitoring could be eliminated, in favor of annual checks, without significant loss of information. The time, in months, to first use of a box within a strata was used to estimate the time it takes to detect the presence or absence of squirrels locally.

Population Abundance—Hayward and others (1992) developed a monitoring system for owls based on occupancy of nest boxes. We followed the concepts and statistical approach they adopted. Details regarding the statistical analysis are provided by Mendenhall and others (1971:140-60) as well as Hayward and others (1992:779-80). A summary of key terms and relationships are provided below.

Percent occupancy of nest boxes was used as an index to trend in population abundance. In this scenario, a nest box was defined as the sampling unit. The sampling frame can be defined in several ways. For each frame, we consider installing boxes at points throughout the forest. One can consider locating these points completely at random, with unequal probabilities of occupancy due to some boxes being placed in marginal habitat, systematically within suitable habitat, or in clusters. Systematic random sampling and single stage cluster sampling are the most feasible or logistical sampling designs, according to Mendenhall and other (1971); we evaluated these 2 designs with and without stratification. "The choice between systematic and cluster sampling depends on the pattern of nest box use. Cluster sampling is preferred over simple random sampling when the between-cluster variance is small. Systematic random sampling is equivalent to simple random sampling when the phenomena studied (in this case, box occupancy) is random relative to the systematic placement of samples" (Hayward and others 1992:779).

The sample size (n) required to achieve a desired level of precision for estimating an index to trend in population abundance depends on the variability of nest box occupancy; it is represented by the desired bound on the relative error, P. The sample size required for systematic random sampling is given by

$$n = \frac{N\sigma^2}{(N-1)(P\pi)^2/4 + \sigma^2} \sim \frac{4\sigma^2}{(P\pi)^2}$$

where,

N	=	population size
σ^2	=	variance among sampling units in the population
π	=	true proportion of occupied nests
P	=	is the bound on the relative error that can be achieved with 95% confidence

Therefore, because we are dealing with presence-absence data, $\sigma^2 = \pi(1 - \pi)$. For single stage cluster sampling, the sample size required is given by $n_c m$ where m is the number of boxes in a cluster and

$$n_c = \frac{N\sigma^2_c}{(N-1)(P\pi m)^2/4 + \sigma^2} \sim \frac{4\sigma^2}{(P\pi m)^2}$$

where,

σ^2_c	=	variance among clusters

Assuming box use is independent over years (see Discussion), the data was pooled for the 4 years of the study to estimate the variance, σ^2, among sampling units. To estimate σ^2_c, we formed sequences of clusters by grouping boxes in close proximity to each other (relative to other boxes at a site) (Fig. 2) in sequences m; σ^2_c, is estimated as

$$s^2_c = \Sigma(T_i - \bar{T})^2/(k-1)$$

(Mendenhall and others 1971:137), where the summation is over clusters and

T_i	=	total number of occupied boxes in a cluster
$\bar{T}$	=	the average of T_i over clusters
k	=	is the number of clusters of given size derived over group-segment years

We considered cluster sizes (m), of 3, 5, and 7. As m increases, the data from "extra" boxes in the group are omitted because there are not m boxes in a group (Fig. 2). For example, if there were 7 boxes in close proximity to each other (relative to other boxes at the site; hereafter denoted as a "group"), only 2 clusters (boxes 1 - 6) were formed for a cluster size of 3 with 1 box remaining box (that is, the 7th box) for that group excluded from the analysis. $P \times 100$ was set to 20, 30, 40, or 50% of the true occupancy rate. For example, if $P = 0.5$ and the occupancy rate is 5%, then $100P\pi$ % = 2.5%. In determining sample size, the true occupancy rate, π , is estimated by the observed occupancy rate (Mendenhall and others 1971). As noted by Hayward

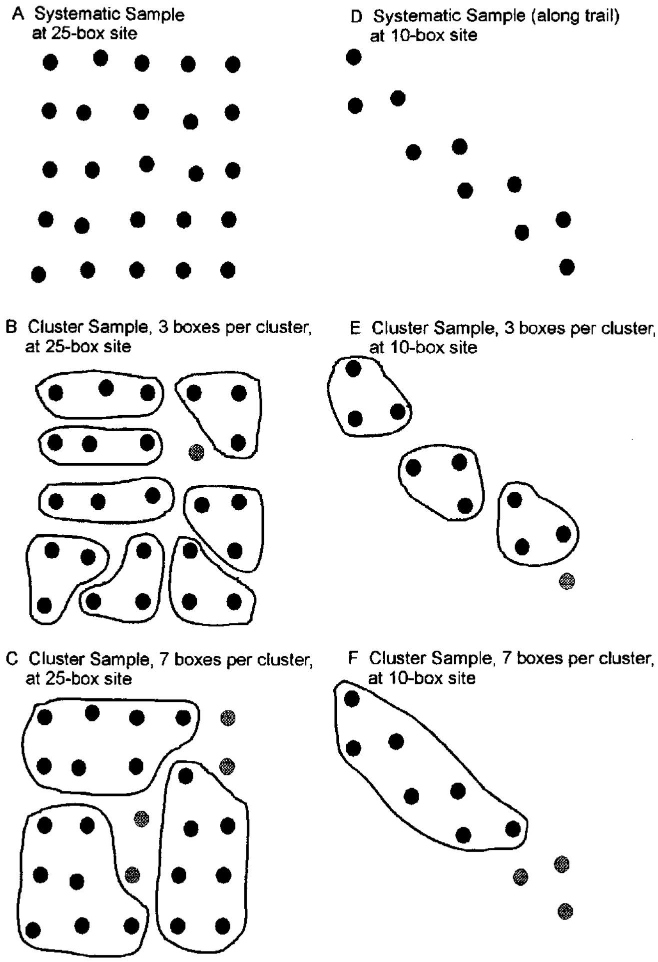

FIGURE 2. Illustrative examples of sampling methods at sites with 25 (A, B, and C) and 10 (D, E, and F) boxes each. For systematic sampling (A and D), all boxes are included in the analysis as each box represents a sampling unit. For cluster sampling (B and E for 3 boxes/cluster; C and F for 7 boxes/cluster), each cluster is a sampling unit; boxes not circled (designated by gray shading) at a site are "dropped" from the analysis because there are not enough remaining boxes to form a cluster of 3 (B and E) or 7 (C and F).

and others (1992:779), "the pattern of occupancy can be clumped, random, or dispersed. In any case, the pattern affects the sample size through the population variance, σ^2 or σ^2_c. Systematic random sampling will be preferred when the occupancies are clumped or random. When the occupancies are dispersed, clusters of a suitable length will have generally the same number of occupied boxes and σ^2_c will be small."

Productivity—We used number of juveniles per box as a measure of southern flying squirrel productivity. This productivity sample was generated during the occupancy surveys conducted in November (1995, 1996) or December (1997, 1998) rather than litter counts from spring and summer surveys due to the lower rate of occupancy during the April-October period; this count also was a closer approximation to annual recruitment than litter counts in late spring or summer. The sampling frame (November-December), therefore, was the same as for occupancy, but only occupied boxes produced data. The issue of sample design, therefore, was whether gathering juvenile count data from occupied boxes discovered during the November-December occupancy surveys led to sufficient sample sizes to adequately characterize litter (spring and summer efforts) sizes. To be within 100*P*% of the true litter size (combining spring and summer efforts) with 95% confidence, one would need a sample size of

$$n = \frac{N\sigma^2}{(N-1)(P\mu)^2/4 + \sigma^2} \sim \frac{4\sigma^2}{(P\mu)^2}$$

(Mendenhall and others 1971:159) where,

σ^2 = population variance among juvenile counts per box
μ = is the average combined (spring and summer) litter size

Pooling combined litter size data for all 4 years produced estimates of σ^2 and μ. P*100 was set to 5, 10, 20, or 30%.

RESULTS

Patterns of Discovery and Use of Nest Boxes

One or more boxes at each site were used by southern flying squirrels within 10 months of placement (Fig. 3). Signs of use were observed within 1-2 months at HWCC, WOOD, SEEF, and CAMP. In contrast, no signs of use were observed at HOUS for the first 10 months. Eventually, all boxes at all sites showed signs of use; the time from placement-to-use averaged 11 months (range 6-19).

Monthly occupancy rates and densities fluctuated considerably (Fig. 3). The highest rate of occupancy noted was 60% (HOUS, Sep 1996); the highest density was 10 squirrels/ha (HOUS, Nov 1996) (Fig. 3, Table 2). Not all boxes were used for resting and/or nesting, however multiple occupancy (>1 squirrel/box) was typical for occupied boxes (84%, n = 264), particularly from October through February. Peak occupancy rates (72%, n = 18) and densities (77%, n = 18) were usually in November or December (Fig. 3).

Dramatic year-to-year fluctuations were noted at all sites (Fig. 3). Densities encountered during winter (November or December) box inspections at HWCC were 4.2 squirrels/ha in 1995, 0.7 in 1996, 2.2 in 1997, and 1.5 in 1998. For WOOD, the density of squirrels peaked in 1996 and 1998 at 4.0 and 3.9 squirrels/ha, respectively, with lows of 0.0 in 1995 and 1997. The pattern for SEEF densities were similar to those observed for WOOD from 1996-1998 with peaks in 1996 (7.2) and 1998 (4.8) and a low of 0.0 1997. HOUS densities were 0.0 in 1995, 10.0 in 1996, 5.0 in 1997, and 0.0 in 1998. CAMP densities went from a high of 4.8 in 1996 to 0.6 in 1997 before rebounding slightly to 1.9 in 1998. Cursory observations of hard mast production indicated peak flying squirrel densities coincided with abundant acorn or hickory nut production and vice versa. For example, 10-15% of the boxes not used for daytime retreats were filled with 40-50 cm of recently (2-3 months) cut nut shells (usually hickory) during peak densities and peak years of nut production. During years of low squirrel densities at a particular site, the total absence of freshly cut nut shells in boxes was obvious.

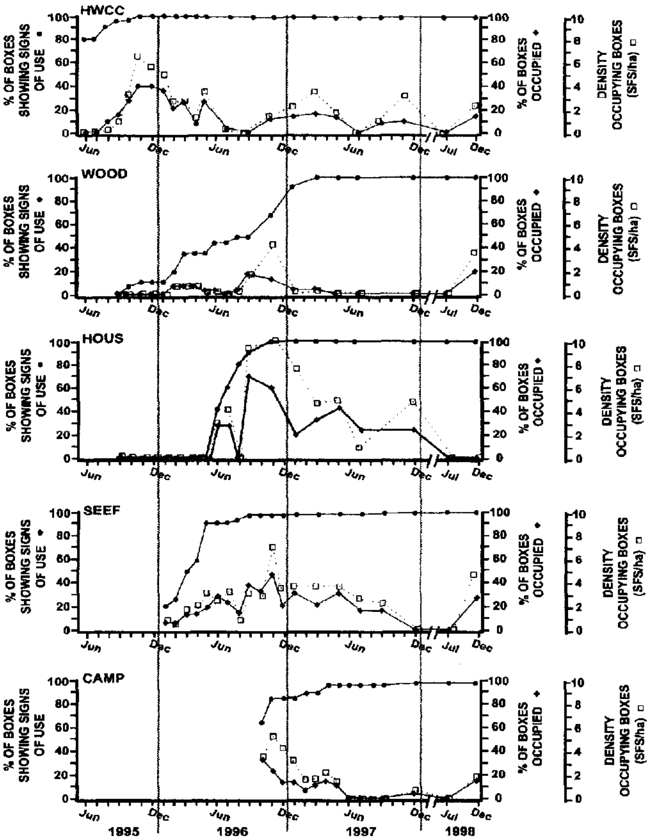

FIGURE 3. The number of nest boxes showing signs of southern flying squirrel use, the number of boxes occupied by flying squirrels use, and densities (squirrels per hectare) of flying squirrels at five study sites in southeast Ohio, 1995-1998. HWCC = Hocking Woods Conference Center, WOOD = Wood's Property, HOUS = Householder's Property, SEEF = Soren Erikkson Ecosystem Forest, and CAMP = Camp Rotan. Circles = % of boxes showing signs of use, diamonds = % of boxes occupied per monthly check, and unfilled squares = density of squirrels per hectare.

Evaluation of Sampling Design and Sample Size

Rates of Occupancy—During the 4 years, southern flying squirrel occupancy during November-December averaged 17.4% (16.9, 27.5, 6.4, and 18.3% in 1995, 1996, 1997, and 1998, respectively). Occupied boxes were not distributed uniformly across the study area. In 1996, occupancy was 60.0 (HOUS), 44.0 (SEEF), 24.0 (CAMP), 16.6 (WOOD), and 12.0% (HWCC). In 1997, occupancy was 20.0 (HOUS), 16.0 (HWCC), 4.0 (CAMP), 0.0 (WOOD), and 0.0 (SEEF). Over the study period (4 years for HWCC, HOUS, and WOOD; 3 years for SEEF and CAMP), occupancy averaged 21.0, 20.0, 9.4, 24.0, and 14.6% among the 5 strata, respectively (Table 2). Even within strata, occupied boxes were not randomly distributed. For example, 6 occupied boxes in 1996 were located in a sequence of 10 boxes at HOUS (the highest rate of occupancy observed for a stratum) but in 1998 none of those 10 were occupied. The pattern of box use among strata provided the opportunity to evaluate required sample size over a range of occupancy rates.

Systematic sampling was the most efficient sampling scheme over the observed range of occupancy rates (Table 2) because fewer boxes would be required to achieve desired levels of precision compared to stratified random sampling. At low occupancy (<10%), the number of boxes necessary to achieve an estimate within even 30% of the true value, 95% of the time, is impractical. For instance, with a 9.4% occupancy as observed in the WOOD stratum, a system of 431 boxes is necessary to achieve an estimate with a relative bound of 30%. As occupancy exceeds 14% as in the CAMP stratum, a sample of 264 boxes can be expected to provide confidence intervals of the same size.

Stratified sampling did not reduce the sample size necessary to estimate occupancy with a given level of precision. Using the 5 strata defined and systematic sampling within strata, we calculated a minimum sample of 84 boxes (17.3% occupancy rate) necessary to estimate occupancy with 50% precision compared to 75 boxes for a simple systematic design (17.4% occupancy rate) (Table 2). Despite the relatively large differences in occupancy rates among strata, we did not see the usual benefit of stratification because of the lower occupancy rates in the WOOD and CAMP strata. Because sample sizes for the 2 sampling schemes were comparable, stratification was preferable because it permitted comparisons among the 5 strata sampled.

Productivity—Over the 4 years, juvenile counts averaged 2.08 squirrels/occupied box (± 0.404, 95% bound) for November-December counts when pooled over strata. Yearly averages for 1995, 1996, 1997, and 1998 were 2.29 (± 0.936), 1.92 (± 0.349), 0.0, and 2.14 (± 1.116), respectively.

Mean juvenile counts can be estimated with greater precision than percent occupancy given a defined number of nest boxes (Table 3). If occupancy rate equals 7%, juvenile counts can be estimated within 20% of the true value with a sample of 343 nest boxes (0.07 × 343 = 26 occupied boxes), or within 40% of the true value with 86 nest boxes (6-7 occupied).

Cost of Nest Box System

Establishing the Nest Box Sample—It cost approximately $16.21/box to establish the nest box survey system in southeast Ohio. These estimates assume labor ($12.50/hr for 2-person crew), material ($10.25/box), and transportation cost ($0.19/km) in 1996. Approximately 82 person-hours were needed to build 109 flying squirrel boxes. Supplies to build 109 boxes cost $1150. Only costs related directly to building and hanging the boxes were included; planning and maintenance costs were not included.

Observing Occupancy and Productivity—Based on box inspections in either November or December, checking the system of 109 boxes throughout the study area required an average of 80 person-hours and involved vehicle travel of 320 km/year. Monitoring and repairing the boxes (including entrance hole enlarged by gray and fox squirrels) involved approximately $200/year (excluding the cost of hand tools to repair boxes and a ladder for inspection). The cost of monitoring boxes increased as the percent occupancy decreased and/or the desired level of precision increased (Fig. 4).

TABLE 2

Sample size necessary to achieve a given level of precision on estimates of percent occupancy by southern flying squirrel with systematic (1) or cluster sampling (3, 5, 7) of nest boxes in southeast Ohio, 1995-98.[a]

Cluster Size	n[b]	Occupancy (%)	Variance[c]	Clusters needed to achieve relative bound of 20%	30%	40%	50%	60%
Camp Rotan								
1	75	14.6	0.1289	597	264	149	95	66
3	24	13.8	0.4275	248	112	63	40	28
5	15	20.0	0.5429	55	25	14	9	7
7	9	15.9	1.1112	90	40	23	15	10
Hocking Woods Conference Center								
1	100	21.0	0.1676	381	169	95	61	42
3	32	22.0	0.5444	125	56	32	20	14
5	20	22.0	0.7258	60	27	15	10	7
7	12	19.0	0.7879	45	20	12	8	5
Householder's Property								
1	40	20.0	0.1641	410	182	102	66	46
3	12	29.1	0.7431	98	44	25	16	11
5	8	20.0	2.2857	229	102	58	37	26
7	3	28.6	1.8889	48	21	12	8	6
Soren Erickkson Ecosystem Forest								
1	75	24.0	0.1849	322	143	80	51	38
3	24	22.2	0.4928	112	50	28	18	13
5	15	22.7	0.6381	50	23	13	8	6
7	9	22.2	2.5278	105	47	27	17	12
Wood's Property								
1	96	9.4	0.0859	973	431	244	155	108
3	32	10.0	0.0287	232	104	58	38	26
5	16	10.0	0.4000	160	72	40	26	18
7	12	11.9	0.6970	101	45	26	17	12
All sites combined								
1	386	17.4	0.1438	473	211	118	75	53
3	124	17.3	0.4632	172	77	43	28	20
5	74	18.9	1.0343	116	52	29	19	13
7	45	17.4	1.4060	95	43	24	16	11

[a]Number of boxes can be calculated as the product of cluster size and clusters need to achieve specified relative bound.

[b]Number of clusters of size m formed from original data.

[c]Intercluster variance.

DISCUSSION

We propose that the cost of establishing a nest box system with an adequate sample to detect changes in southern flying squirrel productivity, and in most cases occupancy, would not be prohibitive. Since dispersion of squirrels was not uniform, a systematic random design was most efficient over a range of occupancy rates. Geographically stratifying the study area results in little reduction of sampling efficiency to estimate occupancy and litter size for winter populations. For the area sampled, a monitoring system using 211 boxes would permit estimation of occupancy within 30% of the true value with 95% confidence. Tracking productivity would require only 142 boxes to obtain estimates within 20% of the true value with 95% confidence assuming 17% occupancy. Cost for such a system would be less than $5000 (Fig. 4).

Despite offering that an adequate sample may be obtained to estimate occupancy and productivity with a sufficient degree of precision, we have not validated the technique for monitoring population change. Two concerns beyond feasibility are critical when considering the efficacy of using nest boxes: 1) logistical constraints of establishing a large enough sample of boxes in woodlots of interest and 2) underlying assumptions must be identified so that monitoring results may be evaluated properly. However, we believe the pattern of usage on a month-to-month basis clearly identifies the

TABLE 3

Sample size necessary to achieve a given level of precision on estimates of mean combined litter sizes of southern flying squirrels with systematic sampling, southeast Ohio, 1995–98.

Site	*n*	Mean litter size[a]	Variance	Number of occupied boxes to achieve relative bound of 5%	10%	20%	30%	40%
Camp Rotan	1	1.00	—	—	—	—	—	—
Hocking Woods Conference Center	7	2.20	1.24	413	105	26	12	7
Householder's Property	2	2.00	0.00	—	—	—	—	—
Soren Erikkson Ecosystem Forest	10	2.10	0.99	360	90	23	10	6
Wood's Property	6	1.83	1.77	846	212	53	24	13
All sites	26	2.08	1.03	370	96	24	11	6

[a]Litter size represents juveniles (spring and summer litters) surviving to November or December.

months of November and December are the best to encounter squirrels using the boxes (Fig. 3).

Logistical Considerations

We identified several logistical items that must be considered when designing a nest box monitoring scheme for this landscape and climate. These items relate to factors that may result from limiting our access to the target population, particularly during the period when squirrels are most likely to use boxes.

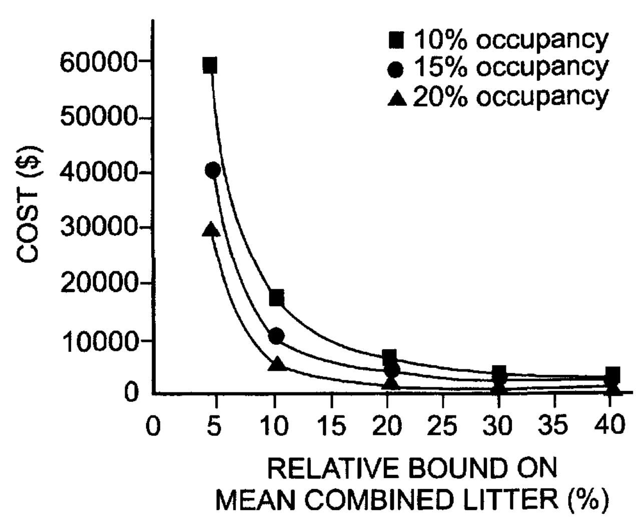

FIGURE 4. Estimated annual cost of establishing a nest box monitoring system using systematic sampling for southern flying squirrels based on number of nest boxes necessary to achieve a specified relative bound (%) on estimates of productivity (that is, number of juveniles surviving until November-December). Curves based on results from all nests. Three curves represent differing occupancy rates within the range observed (Table 2).

Weather conditions during November or December in southeast Ohio rarely result in extended periods of inaccessible roads or trails. Snow depths seldom prevent travel, both to sites (via vehicle) and within a site (on foot). However, freezing rain or daytime snow melt with subsequent overnight freezing makes opening of the doors or removal from the tree for ground inspection impossible, without damaging the boxes, on some days. Since this set of weather conditions is not uncommon in this region, additional staff time and, therefore, cost should be anticipated for mid-winter monitoring.

The life span of boxes being suitable for flying squirrels may not exceed 3-5 years without some maintenance. In addition to weathering, larger gray and fox squirrels significantly altered boxes. Within 2 years of placement at two sites (HWCC and SEEF), we observed more than 50% of the boxes with enlarged entrance holes allowing occupancy by the larger sciurid species. Besides occupying the boxes, both gray and fox squirrels produced late (October and November) litters. The presence of the larger squirrels precluded use as nesting sites for flying squirrels. We repaired some boxes by placing a metal, electrical outlet-type plate with a 40 mm diameter hole over the existing hole (35 mm diameter). This effectively eliminated gray and fox squirrel use while providing access to flying squirrels. We recommend such a plate because they do not significantly increase the cost ($0.50 each in 1996).

All boxes were used as feeding sites (to cut nuts) or daytime retreats and nest sites. Shell fragments accumulate in the boxes, reaching depths of 10-15 cm within 2-3 years in some instances. Likewise, repeated use for nesting results in accumulation of bedding material and feces. In some instances, boxes were abandoned when they become foul (Muul 1968; Madden 1974).

We recommend boxes be cleaned every 2-3 years. This may take place during the regular monitoring for unoccupied boxes. However, occupied boxes or those with evidence of *recent* use as a daytime retreat should not be cleaned until spring; this will increase the cost of maintaining the nest box system.

Assumptions

A nest box system could be used as a management tool to assess the demographic response (abundance and productivity) of southern flying squirrel population to forest change due to natural fluctuations or logging (both clearcut and selective cut harvests). Changes in structure, fragmentation, and mast production influence nesting and foraging habitat (Weigl 1978; Taulman 1997; Taulman and others 1998) for this species in other parts of its distribution. Other tree squirrel species in southeast Ohio respond positively to high hard mast production (>168 kg/hectare) with increased litter sizes, improved survival of summer-born young and increased survival of adults (Nixon and Donohoe 1975). The systematic monitoring scheme described herein might be sensitive to similar changes in foraging habitat.

Nest Occupancy—Our proposed monitoring scheme to determine nest box occupancy is used as an index to population abundance and recruitment. For habitat monitoring, we must assume the trend in occupancy rate of nest boxes reflects trends in the breeding segment of the target population and this trend reflects habitat conditions. Therefore, we assume that field methods accurately measure occupancy, occupancy of a nest box does not influence the likelihood of other boxes being occupied, status of a box in one year does not influence occupancy in subsequent years, and degradation of flying squirrel habitat will be reflected in nest box use. We address these assumptions below.

If nest boxes are checked before mid-November or after mid-January, our estimates of occupancy will be negatively biased because use of boxes does not generally peak before November and usage declines after January as observed during this study and in western Maryland (Gilmore and Gates 1985). Southern flying squirrels are communal during the early winter months for energy conservation during cold weather (Muul 1974). Thus, the decline in number of nest boxes used after mid-January cannot be attributed solely to mortality. Mid-January through late February represents the coldest period for our study area. Because natural cavities are better insulated, they provide more stable temperatures regimes for squirrels than nest boxes (McComb and Noble 1981; Gilmore and Gates 1985). Therefore, nest boxes do not always provide the most energetically optimum environment for nesting squirrels during low temperatures.

When each site was initially under a monthly inspection schedule, we observed lactating females with young using nest boxes. On 2 occasions, neighboring boxes <0.75m apart contained females with <8 week old juveniles. During November-December, neighboring boxes were routinely occupied by squirrels. This suggests that boxes next to occupied boxes can also be considered available for nesting at any time of the year. Although nest boxes may be abandoned during warmer months (Madden 1974; Muul 1974; Caster and other 1994) due to flea infestations from middens, winter occupancy of the same boxes year-to-year was common in our study area. The potential for high parasite loads in boxes used for rearing young or communally during winter months, however, is our justification for recommending boxes be cleaned every 2-3 years. Nonetheless, use for one year does not negatively bias use the following year unless larger sciurids enlarge the entrance hole and take up residency in the box.

The relationship between habitat degradation and a decline in nest box use is fundamental to employing a systematic sampling scheme to monitor response to habitat change. There are likely scenarios where this hypothesized relationship will not hold true if the habitat is degraded. We suggest, that if selective harvest significantly reduces the number of suitable natural cavities, increased occupancy of nest boxes will occur. We did not investigate this aspect during our study because no harvest occurred at any of our sites. Although in predominately pine-hardwood forests of Arkansas (compared to strictly hardwoods at our sites), Taulman (1998) and Taulman and others (1998) noted even low-intensity, single-tree selection treatments resulted in southern flying squirrel populations vacating the stands for up to 3 years, even when trees with nest boxes were left. The removal of mature trees almost certainly reduced the quality as well as quantity of foraging and escape cover during that study. Our cursory observations of reduced hard mast production preceding declines in squirrel densities at individual sites in the absence of timber harvest suggest disturbance may not be a prerequisite for significant decline in habitat quality. Therefore, we surmise a change in habitat quality may be detected using a nest box scheme but caution changes in density do not always reflect habitat suitability for a species (Van Horne 1983).

Population Productivity Monitoring—While nest box occupancy is an index to a population parameter, combined litter sizes (that is, number of juveniles) surviving at least to mid-winter is a measure of productivity closely approximating recruitment. We must assume that trends in mean combined litter sizes using nest boxes reflect recruitment of the target population in order to assess squirrel responses to habitat change using this measure. As a measure of recruitment, we must assume that no additional mortality occurs after winter checks are made. We know that assumption cannot be valid as some mortality will occur, but measuring this in November or December is more accurate than estimates generated from summer or fall monitoring. Juveniles are present in the population in summer and fall but, like adults, are not as likely to use nest boxes prior to November.

The positive relationship between abundant food resources and litter or clutch sizes or number of litters per female per breeding season (1 versus 2) has been demonstrated for a variety of species including other sciurids such as gray and fox squirrels (Nixon and

Donohoe 1975) and eastern chipmunks (*Tamias striatus*) (Yahner and Svendsen 1978) in eastern hardwood forests. Obtaining litter counts shortly after partuition would provide a better indication of female reproductive condition relative to *seasonal* (overwinter) habitat conditions than fall juvenile counts. However, the number of individuals about to reach breeding age (that is, recruitment) usually provides a better measure of *annual* habitat quality. This measure combined with occupancy data would provide a better indicator of long-term habitat quality (Van Horne 1983).

CONCLUSIONS

Our evaluation of adequate sample size and cost shows the nest box method can be expensive and time-consuming if occupancy rates are <10% and desired precision of the relative bound is <20%. Yet, precise estimates of occupancy and productivity can be realized when occupancy exceeds 10%. It appears productivity can be estimated more efficiently than occupancy. Considering no additional effort is expended in collecting data on both variables, information on occupancy can be used to support evaluations of habitat trend. Compared to other possible monitoring techniques, such as trapping and telemetry, which typically are more labor-intensive and expensive (particularly telemetry equipment), we conclude monitoring southern flying squirrel populations with nest boxes shows economical and statistical efficiency, and is therefore feasible. Further study is needed to validate the technique over the long-term (>5 years). Researchers must also examine the relationship between trends observed for flying squirrels using boxes and trends experienced by squirrels in the larger target populations before adopting this system.

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