MONITORING BOREAL OWL POPULATIONS WITH NEST BOXES: SAMPLE SIZE AND COST

GREGORY D. HAYWARD,[1] Department of Fish and Wildlife Resources, University of Idaho, Moscow, ID 83843
R. KIRK STEINHORST, Department of Mathematics and Statistics, University of Idaho, Moscow, ID 83843
PATRICIA H. HAYWARD,[1] Department of Fish and Wildlife Resources, University of Idaho, Moscow, ID 83843

Abstract: Evaluating the economic and sampling efficiency of potential monitoring programs is a first step in validation. Thus, we established a system of nest boxes in the Payette National Forest to evaluate the feasibility of using a system of nest boxes to monitor response of boreal owl (*Aegolius funereus*) populations to habitat change. We recorded nest site occupancy and productivity as measures of foraging habitat trend. Using monitoring results from 3 years, we evaluated alternative survey sampling techniques for occupancy and determined sample sizes necessary to estimate occupancy and clutch size within specified relative bounds. We also examined the cost of establishing a nest box system and monitoring nest box use. At extremely low nest box occupancy (1%), sample sizes necessary to monitor trend would be extreme (1,909 boxes for 50% relative bound), but sample size is not restrictive when occupancy rates exceed 7% (330 boxes to achieve a 40% relative bound). Monitoring clutch size as a measure of productivity would require a smaller effort to achieve tighter relative bounds. Assumptions relating demographic parameters to habitat change still must be tested before nest boxes can be considered the optimum tool to monitor boreal owl response to habitat change.

J. WILDL. MANAGE. 56(4):777–785

Demographic monitoring provides the empirical data to detect population change, and the monitoring process should provide the primary feedback loop into the basic ecological models used to determine the cause of population change (Verner 1986). Despite the important role that monitoring plays in evaluating changes in habitat, adequate techniques have not been developed for many secretive species that exist at low densities.

The boreal owl inhabits high elevation forests in the Rocky Mountains and is considered sensitive to forest removal (Hayward 1989). Playback surveys have been used extensively to determine the geographic distribution of boreal owls (Palmer and Ryder 1984, Hayward et al. 1987) and have been promoted as a promising monitoring technique for other owls (Johnson et al. 1981, Marion et al. 1981, Smith et al. 1987, Forsman 1983). Playback surveys cannot be considered the best technique to assess trends in boreal owl populations because many factors influence the calling rate of boreal owls, and the relative importance of these factors is not understood. The probability of an individual responding to playback depends on the time of night, current weather conditions, past weather conditions (which influence snowpack, plant phenology, and small mammal availability), the individual owl's physiological condition, degree of competition with other male owls for nest sites, and whether the owl has attracted a mate. Lundberg (1978) suggested that the number of boreal owls singing may be inversely related to breeding success. He found that "territorial and breeding pairs were more silent than non-territorial individuals" and concluded that "censuses made as roadside stops give unacceptable results for population studies of both the Ural owl [(*Strix uralensis*)] and the Tengmalm's [*boreal*] owl" (Lundberg 1978:171).

As part of a long-term investigation of boreal owl population dynamics, we are assessing whether the response (abundance and productivity) of boreal owl populations to forest change can be detected through yearly monitoring of nest boxes. Herein, we examine the cost of establishing a nest box monitoring system and the efficiency of different sampling designs in detecting changes in productivity and occupancy of owls nesting in boxes. We compared 2 sampling schemes (systematic and cluster) with and without stratification for monitoring occupancy, determined sample size necessary to achieve an acceptable bound on estimation of occupancy and productivity, determined the cost of establishing an owl monitoring system using nest boxes, and determined the cost of monitoring nest boxes and the logistical constraints associated with obtaining an adequate sample.

[1] Present address: U.S. Forest Service Research Lab, 222 N. 22nd, Laramie, WY 82070.

The relationships among rates of occupancy and productivity of boreal owls in nest boxes and abundance and productivity in the target population (geographically defined group of owls 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, we decided to examine the feasibility of our method first. If the method proved not to be economically and statistically efficient, there would be no need to conduct the more expensive and time consuming validation study.

We thank T. Heekin, D. D. Musil, and F. Gordon for help with fieldwork and logistical support. E. D. Forsman, B. Kelly, W. C. McComb, G. J. Niemi, and B. R. Noon reviewed the manuscript and provided constructive criticism. E. O. Garton helped conceptualize the monitoring scheme. This is contribution No. 637 of the Idaho Forest, Wildlife, and Range Experiment Station, and was funded in part by the Northwest Pine Association, Payette National Forest, Idaho Panhandle National Forest, a McIntire-Stennis grant, Idaho Department of Fish and Game, U.S. Forest Service Intermountain Forest and Range Experiment Station, Max McGraw Wildlife Foundation, and the North American Bluebird Society.

METHODS AND STUDY AREA

Study Area

We hung nest boxes in 3 drainages on the McCall and New Meadows districts of the Payette National Forest (PNF) of central Idaho. These included portions of the North Fork Payette River, Secech River, and Goose Creek. These drainages are separated by high, rocky ridges or, in the case of the Secech River and North Fork Payette River, can be distinguished by different vegetation. The 3 drainages were considered separate strata for statistical analysis and named Payette Lake, Burgdorff, and Brundage, respectively.

Topography throughout the study area is mountainous, and elevations range from 1,520 to 2,140 m. Climate in the region has a strong Pacific coastal influence during winter but follows continental patterns in summer (Finklin 1988). Annual precipitation averages >100 cm a year falling largely as snow that accumulates 1.5–2 m. At higher elevations, 50% of the ground is not exposed until after 1 June most years. The landscape is dominated by coniferous forest with a sparse shrub layer but extensive ground layer of low shrubs (*Vaccinium* spp.), grasses, and forbs. The Goose Creek and North Fork Payette River areas are dominated by old spruce-fir (*Picea engelmannii, Abies lasiocarpa*) forests, although lower portions of each support Douglas-fir (*Pseudotsuga menziesii*) habitat types. In contrast, the Secech River drainage (hereafter, Burgdorff area) has extensive lodgepole pine (*Pinus contorta*) forest mixed with stands of spruce-fir.

Nest Box Placement, Design, and Monitoring

We hung 283 boxes on the PNF in July 1987, and an additional 167 boxes were hung by August 1989. We spaced the nest boxes at 0.5-km intervals along primary, secondary, and primitive haul roads. Wherever possible, we hung the boxes along several roads in a network so the boxes formed a grid-like pattern rather than a single string of boxes along 1 corridor. However, in many areas, the existing road network and road management policy led to linear configurations; approximately 30% of the boxes were in a grid-like pattern.

Each box was hung in a tree 10–70 m from the road in a position making the box difficult to see from the road. We climbed live conifers using forester's climbing spurs and hung each box 4.5–9.5 m high after trimming all branches below box height. In all cases, the box faced a small (at least 3 × 3 m) forest opening providing a clear flight path to the box (Hayward 1989).

Box design followed Korpimaki (1985). Inside box dimensions were: bottom 20 × 20 cm, front height 46 cm, back height 51 cm, and cavity diameter 9 cm. We constructed nest boxes from rough-cut, 3-cm pine and fir. Constructing 300 boxes required 382 m of 3- × 20-cm (1- × 8-in.) and 382 m of 3- × 25-cm (1- × 10-in.) lumber. Five cm of wood chips and sawdust were placed in the bottom of each box.

We monitored nest boxes on the PNF for 3 years (1988, 1989, 1990). We checked boxes each spring when snow conditions permitted travel. To determine nest box use, we climbed each tree once each spring during the nesting season using climbing spurs and recorded nest box contents. Adult female owls and owlets in the box were captured, identified, and banded, and the box was recorded as occupied. Presence of a mat of owl feces and prey remains or pellets was considered evidence of a nesting attempt

(Hayward 1989). Owl species was not recorded unless diagnostic feathers were found in the box or the species could be identified by vocalizations heard in the vicinity of the box at night. We removed nest contents other than wood chips and sawdust and repaired damaged boxes.

Sampling Schemes and Sample Size

Population Abundance.—In conceptualizing a monitoring system, we considered percent occupancy of nest boxes as an index to trend in population abundance. A nest box was defined as the sampling unit. The sampling frame can be defined in several ways as outlined in the Discussion. For each frame, we consider installing boxes at points along forest roads. One can consider locating these points completely at random, with unequal probabilities, systematically, or in clusters. Systematic random sampling and single stage cluster sampling are the most feasible sampling designs (Mendenhall et al. 1971) and were evaluated 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. The sample size (n) required, depends on the variability of nest box occupancy and the desired bound on the relative error, P. If π is the true proportion of occupied nests and $\hat{\pi}$ is its estimate, then the relative error is $|\hat{\pi} - \pi|/\pi$. P is the bound on the relative error that can be achieved with 95% confidence. In particular, the sample size required for systematic random sampling is given by

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

where σ^2 is the variance among sampling units in the population and N denotes the population size (Mendenhall et al. 1971:160). Because we were dealing with presence-absence data, $\sigma^2 = \pi(1 - \pi)$. The sample size required for single stage cluster sampling is given by $n_c m$ where m is the number of boxes in a cluster and

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

where σ^2_c is the variance among clusters (Mendenhall et al. 1971:140). Assuming box use is independent over years (see Discussion), the best estimate of σ^2 and σ^2_c is found by pooling the data from the 3 years of study. σ^2 is estimated by taking the variance over all years and boxes. To estimate σ^2_c, we formed sequences of clusters by mapping box placement along road segments and associating adjacent boxes in sequences of m; σ^2_c is estimated as

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

(Mendenhall et al. 1971:137) where the summation is over clusters, T_i is the total number of occupied boxes in a cluster, $\bar{T}$ is the average of T_i over clusters, and k is the number of clusters of a given size derived over road-segment-years. We consider cluster sizes (m), of 2, 3, 5, and 10. As m increases, the data from some road spurs are omitted because there are not m boxes in a sequence. This occurred frequently for $m = 10$. $P*100$ was set to 20, 30, 40, 50, or 60% of the true occupancy rate. If, for example, $P = 0.5$ and the occupancy rate is 5%, then $100P\pi\% = 2.5\%$. In calculating sample size, the true occupancy rate, π, is estimated by the observed occupancy rate.

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.—In conceptualizing a monitoring system, we used clutch size as a measure of boreal owl productivity. The productivity sample was generated during the occupancy survey. Thus, the sampling frame for productivity was the same as for occupancy, but only occupied boxes produced data. The sample design issue, then, was whether gathering clutch size data from occupied boxes discovered during the occupancy survey led to sufficient sample sizes to adequately characterize clutch size. To be within 100P% of the true clutch size with 95% confidence, one would need a sample size of

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

(Mendenhall et al. 1971:159) where σ^2 is the population variance among clutch sizes and μ

Table 1. Sample size necessary to achieve a given level of precision on estimates of percent occupancy by boreal owls with systematic (1) or cluster sampling (3, 5, 10) of nest boxes on the Payette National Forest, Idaho, 1988–90.[a]

Cluster size	n[b]	Occupancy (%)	Variance[c]	Clusters needed to achieve relative bound of 20%	30%	40%	50%	60%
Boreal owls, Burgdorff strata								
1	357	8.9	0.0818	1,018	453	255	163	113
3	108	9.3	0.2773	359	160	90	57	40
5	57	9.1	0.5025	242	107	60	39	27
10	18	11.1	1.7520	142	63	35	23	16
All owls, all strata								
1	924	6.7	0.0627	1,392	619	348	223	155
3	276	7.0	0.1957	443	197	111	71	49
5	147	6.8	0.3493	302	134	75	48	34
10	45	8.0	1.073	168	74	42	27	19
Boreal owls, all strata								
1	924	4.2	0.0405	2,272	1,010	568	364	252
3	276	4.3	0.1429	840	373	210	134	93
5	147	4.4	0.2674	564	251	141	90	62
10	45	5.6	0.9798	317	141	79	51	35
Boreal owls, Payette Lake strata								
1	165	2.5	0.02380	4,050	1,800	1,012	648	450
3	48	2.1	0.05984	1,532	681	383	245	170
5	30	2.0	0.09310	931	414	233	149	103
10	12	1.7	0.15150	546	242	136	87	61
Boreal owls, Brundage strata								
1	360	0.8	0.0083	11,930	5,304	2,983	1,909	1,326
3	108	0.9	0.0276	3,533	1,057	883	565	393
5	54	1.1	0.0534	1,732	770	433	277	193
10	12	2.5	0.2045	327	146	82	52	36

[a] Table is organized by percent occupancy; number of boxes can be calculated as the product of cluster size and clusters needed to achieve specified relative bound.
[b] Number of clusters of size *m* formed from original data.
[c] Intercluster variance.

is the average clutch size. Pooling clutch size data for all 3 years produced estimates of σ^2 and μ. $P \cdot 100$ was set to 5, 10, 20, or 30%.

RESULTS

Evaluation of Sampling Design and Sample Size

Rates of Occupancy.—During the 3 years, boreal owl occupancy averaged 4.2% (3.1, 3.7, and 5.8% in 1988, 1989, and 1990, respectively). Occupied boxes were not distributed uniformly across the study area. In 1990, occupancy was 5.5, 0.8, and 10.8% in Brundage, Payette Lake, and Burgdorff strata, respectively. Over the 3 years, occupancy averaged 2.4, 0.8, and 9.0% among the 3 strata, respectively. Even within strata, occupied boxes were not randomly distributed. For example, 7 occupied boxes in 1990 were located in a sequence of 15 box sites along 1 road. The pattern of box use among strata provided the opportunity to evaluate required sample size under a range of occupancy rates.

Systematic sampling was the most efficient sampling scheme over a range of occupancy rates (Table 1). At low occupancy, the number of boxes necessary to achieve an estimate within even 40% of the true value, 95% of the time, is impractical. For instance, with 2.5% occupancy, a system of 1,012 boxes is necessary to achieve an estimate with a relative bound of 40%. As occupancy exceeds 6.5%, a sample of 350 boxes can be expected to provide confidence intervals of the same size.

Stratification did not reduce the sample size necessary to estimate occupancy with a given level of precision. Using the 3 strata defined, and systematic sampling within strata, we calculated a minimum sample of 368 boxes necessary to estimate occupancy with 50% precision compared to 363 for a simple systematic design. Despite the relatively large differences in oc-

Table 2. Sample size necessary to achieve a given level of precision on estimates of mean clutch size of boreal owls with systematic sampling, Payette National Forest, Idaho, 1988–90.

Drainage	n	Mean clutch size	Variance	Number of occupied boxes to achieve given relative bound of 5%	10%	20%	30%	40%
Payette Lake	3	3.7	0.333	40	9.9	2.5	1.1	0.6
Burgdorff	26	3.4	1.054	144	36	9.0	4.0	2.2
All	31	3.4	1.103	157	39	9.8	4.4	2.5
Brundage	2	2.0	2.00	800	200	50	22	12

cupancy rate among strata, we did not see the usual benefit of stratification because of the extremely low occupancy rates in the Payette Lake and Brundage strata. Because the sample sizes for the 2 sampling schemes were comparable, stratification was preferable because it permitted comparisons among sample areas.

Productivity.—Over the 3 years, clutch size averaged 3.57 (±0.341, 95% bound) when pooled over strata. Yearly averages for 1988, 1989, and 1990 were 3.67 (±1.434), 3.20 (±0.452), and 3.83 (±0.456), respectively.

Mean clutch size can be estimated with greater precision than percent occupancy given a defined number of nest boxes (Table 2). If occupancy rate equals 4%, clutch size can be estimated within 20% of the true value with a sample of 250 nest boxes (0.04 × 250 = 10 occupied boxes), or within 40% of the true value with 62 nest boxes (2–3 occupied).

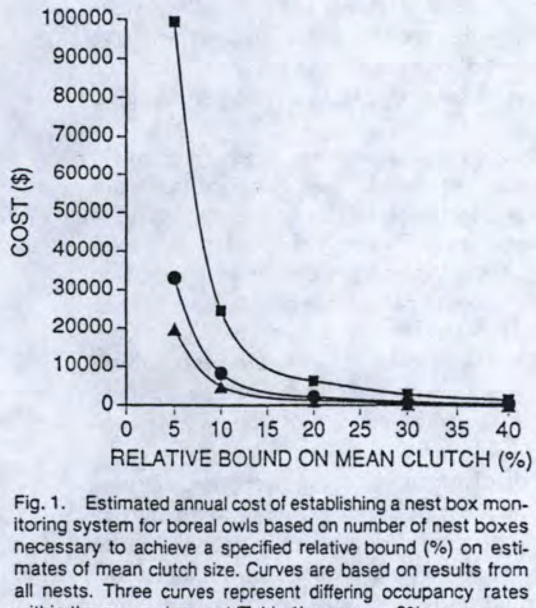

Fig. 1. Estimated annual cost of establishing a nest box monitoring system for boreal owls based on number of nest boxes necessary to achieve a specified relative bound (%) on estimates of mean clutch size. Curves are based on results from all nests. Three curves represent differing occupancy rates within the range observed (Table 1); square = 2% occupancy, circle = 6% occupancy, triangle = 10% occupancy.

Cost of Nest Box System

Establishing the Nest Box Sample.—We estimated it cost $12.67/box to establish the nest box survey system on the PNF. We also have hung 300 boxes on the Idaho Panhandle National Forest (IPH). Establishing this nest box system cost $17.84/box. These estimates assume labor ($10.05/hr crew leader, $6.00/hr crew), material, and transportation costs ($0.15/km) in 1990. We spent 72 person-hours building 300 boreal owl nest boxes. Supplies to build 300 boxes cost $445. We only included costs related directly to building and hanging the boxes; planning costs were not included.

Observing Occupancy and Productivity.—Checking the system of 300 nest boxes on each forest required an average of 220 person-hours and involved vehicle travel between 1,440 and 1,680 km/year (900–1,050 miles). Monitoring and repairing the boxes involved few other direct expenses aside from the cost of hand tools to repair boxes and tree climbing equipment. Cost of monitoring naturally increases as level of precision desired increases (Fig. 1).

DISCUSSION

We suggest that the cost of establishing a nest box system with an adequate sample to detect changes in owl productivity, and in some cases occupancy, will not be prohibitive. A systematic random design was most efficient over a range of occupancy rates because the dispersion of owls was not uniform. By geographically stratifying the study area, separate estimates of occupancy and clutch size could be calculated with little reduction in sampling efficiency. On the Payette National Forest, a monitoring scheme employing 350 nest boxes would permit estimation of occupancy within 40% of the true value with 95% confidence. Tracking clutch size would require only 245 boxes to obtain estimates within 20% of the true value with 95% confidence (assuming 6% occupancy). Cost will depend on the precision necessary to meet defined objectives (Fig. 1).

Although we suggest 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 paramount when considering the efficacy of using nest boxes: (1) logistical constraints of establishing a large enough sample of nest boxes in drainages of interest and accessing those boxes at the appropriate time of year to monitor occupancy and clutch size, and (2) underlying assumptions must be identified so that monitoring results may be evaluated properly.

Logistical Problems

We identified several logistical problems that must be overcome when designing a nest box monitoring scheme for a particular landscape. Each of the problems relates to factors which limited our access to the target population of nesting boreal owls during the incubation stage of the nesting cycle.

The existing road network constrained sampling boreal owls in the target population. Roads tended to access landscapes that were presently fragmented, providing little access to unfragmented forest. Road closures that used permanent barriers further limited access. These conditions limited the population of boreal owls sampled. Even after the nest box system was established, road conditions limited access to boxes during monitoring. Road closures and deterioration of road conditions increased the effort needed to monitor nest boxes.

To monitor box use and clutch size, fieldwork must coincide with the incubation and nestling period of the owl nesting cycle. This period coincided with spring thaw. Early in the field season, snow drifts and saturated roadbeds prevented access to boxes except along major haul roads which were paved and plowed. Each year some boxes were not checked until after some owlets had fledged, which reduced the potential sample for evaluating clutch size. Snowdrifts will always limit monitoring of boreal owl nests because of the timing of boreal owl nesting.

To monitor owl productivity, field crews must climb all trees with occupied nest boxes. Tree climbing presents a safety hazard and only properly trained personnel should be employed. Furthermore, after being climbed for 3 years using climbing spurs, over 5% of the trees on the PNF exhibited reduced vigor and some died. Dead trees present an additional safety problem, and it may not be reasonable to check some boxes after 5 years. Climbing trees with tree ladders would reduce damage to trees but increase the time needed to monitor nest boxes.

To limit damage to trees and to facilitate rapid monitoring, we are developing an optic device to check boxes (Hayward and Deal 1993). Monitoring also may be more feasible if combined with other field activities. For example, saw-whet owls (*Aegolius acadicus*), and northern flying squirrels (*Glaucomys sabrinus*) which also use the nest boxes could be investigated concurrently.

Assumptions

We envision nest boxes as a management tool to assess the demographic response (abundance and productivity) of boreal owl populations to forest change. Changes in forest structure will influence nesting and/or foraging habitat (Hayward 1989) that may be reflected in different demographic variables measured at nest sites. Changes in nesting habitat will influence the number of nesting pairs if nesting habitat is limiting; whereas changes in foraging habitat will influence productivity of breeding pairs as well as the number of pairs that attempt to breed. Because past investigations suggest that boreal owls in the Northern Rockies are frequently limited by food availability (Korpimaki 1987, Lofgren et al. 1986, Hayward 1989) and therefore potentially limited by foraging habitat, we have concentrated our efforts on a monitoring scheme that should be sensitive to changes in foraging habitat.

Nest Occupancy.—In our proposed monitoring scheme, trends in nest box occupancy are used as an index to trends in breeding population abundance. To apply this system in a habitat monitoring framework, we must assume that the trend in occupancy rate of nest boxes reflects the trend in the breeding segment of the target population and that this trend reflects habitat conditions. Therefore, we must assume that field methods accurately measure occupancy, occupancy of a nest box does not influence the probability of other boxes being occupied, status of a box in 1 year does not influence occupancy in subsequent years, degradation of owl habitat will be reflected in a reduction in nest box use, and the population sampled by a nest box system is representative of the target population. Below we address each of these assumptions.

If nest boxes are checked before owls begin nesting, estimates of occupancy will be negatively biased. To reduce this problem we began checking boxes each spring in late May; in our previous studies of radio-marked owls, 15 nests were occupied prior to 20 May (Hayward 1989). Based on old nest remains located in 300 nest boxes checked during 1988–90, we failed to record 2 of 64 occupied boxes during the year of use because the boxes were checked prior to initiation of the nest. Therefore, our estimates of occupancy were slightly biased. To further reduce this problem, boxes could be checked twice each spring although this would increase the cost of monitoring. Alternatively, a larger field crew could check the boxes more rapidly but begin in early June when all owls will have begun nesting.

During 1988–90 we found owls nesting in neighboring nest boxes on 1 occasion and frequently found owls using boxes 1 km apart suggesting that boxes neighboring occupied boxes can be considered available for nesting. Boreal owls do not defend a large nesting territory and nests within 100 m of another are reported in Europe (Mikkola 1983:258).

Although Sonerud (1985) suggested that owls avoid nesting in a cavity used the previous year, we found nest boxes on the PNF that were used 2 years in succession. We agree that the probability of box use is reduced the year following occupancy if boxes are not cleaned. If boxes are cleaned and provisioned with new bedding, we believe that the probability of use the following year approaches that of unused boxes.

The link between habitat degradation and a decline in nest box use is critical for use of nest boxes to monitor response to habitat change. It is obvious that the hypothesized relationship will *not* hold for some forms of habitat degradation. If available natural cavities decline, nest box use will likely increasing providing an erroneous indication of improving habitat quality. Additional information on trends in snag abundance will be necessary to detect this problem. On the other hand, the relationship between nest occupancy and prey availability has been shown in a variety of geographic settings (Lofgren et al. 1986, Korpimaki 1988, Hayward 1989). In each study, the number of owl nests declined in years of reduced prey abundance (indexed using yearly small mammal trapping). This suggests that patterns of nest box occupancy will be related to trends in foraging habitat or prey populations. The validity of occupancy as an index to foraging habitat should be evaluated experimentally.

Researchers must consider meeting the assumption that the population sampled in a nest box system is representative of the target population. The target population must be identified, the most efficient survey sampling technique should be determined, and the sample size necessary to recognize population changes at the desired level of precision should be determined. The sampling frame encompassed by a road-based nest box system must be considered.

The sampling frame for a nest box monitoring program may be structured in several configurations depending on the likelihood of meeting assumptions. We illustrate a range of choices by discussing 3 sample frames. First, a very restricted sampling frame may be considered (FRAME 1): Boreal owl nest sites (0.5-km road segments) along forest roadways in 3 sampled drainages on the PNF. This sampling frame assumes the sample population encompasses only nest sites along roadways. Each 0.5-km road segment is considered an independent site at which 1 boreal owl pair could nest in a box. Population estimates are limited to road-side nest sites if we assume roadways influence nest site quality. Our sample may be a census of nesting sites, but it is a biased sample because owls that nest on sampled sites but do not use boxes will not be detected.

If we assume that nest selection by boreal owls is not influenced by roads but that topographic position is important in nest site selection, then FRAME 2 could be considered: nest sites at topographic positions traversed by roads in 3 drainages on the PNF. Because boxes are along roads, the sample is constrained to those topographic positions traversed, and the analysis must consider the proportion of roads in each topographic type. The sample does not approach a census, and this would be reflected in variance estimates. If we assume that because boreal owls use home ranges exceeding 1,200 ha (Hayward 1989) and generally remain in a drainage, then each owl has access to nest boxes regardless of topographic position. So, FRAME 3 might be: Nest sites for boreal owls that may nest in boxes within sampled drainages on the PNF. Our analysis of sample size used FRAME 3 and therefore assumed inferences could be made to all owls in sampled drainages. If FRAME 1 or 2 were used, a finite correction factor would be used to estimate variance, and variance estimates would be reduced substantially. Sample sizes necessary for a given level of precision may be reduced as much as 50% under these sample frames but the population sampled may be irrelevant for management.

Population Productivity Monitoring.—While nest box occupancy is only an index to a population parameter, clutch size is a measure of productivity. To monitor owl response to habitat change using this measure, we must assume that trends in mean clutch size of boreal owls using nest boxes reflect productivity of the target owl population. Therefore, we must assume that no nestling mortality or complete nest loss occurs prior to nest observations and clutch size of owls nesting in boxes reflects clutch sizes in natural nest sites, which is influenced by foraging habitat quality of the target population. Below we address these assumptions.

Snow drifts and poor road conditions will prevent field crews from reaching some nests prior to hatching, and other nests will completely fail prior to observations. The assumption that the number of nestlings matches clutch size will be most closely met if nests located after the youngest nestling is 3 days old are eliminated from the sample for mean clutch size. Nestling mortality often occurs between 3 and 9 days after hatching (G. D. Hayward, pers. observ.). If early nest failure is a function of clutch size, the estimate of mean clutch size may be biased by nests that fail prior to monitoring. This bias will be difficult to eliminate because of the frequent nest-checking that would be necessary to count clutches in all nests that fail early.

The positive relationship between prey availability and clutch size has been demonstrated for a wide variety of raptors (Newton 1979) including boreal owls (Korpimaki 1987, 1988). This relationship can be extended to include foraging habitat (Garton et al. 1989). We believe that long-term trends in clutch size rather than nesting success or number of young fledged should be used to monitor foraging habitat quality because of the relationship between clutch size and female condition upon laying. Clutch size is largely determined by female fat reserves (Hirons 1985, Korpimaki 1987), which are related to both male and female foraging success over a portion of the winter. Female boreal owls occupy year-round home ranges and therefore, clutch size reflects foraging conditions in their home ranges. Nesting success or number of young fledged, on the other hand, responds in part to short-term conditions. Rainy spring weather or nest predation by pine martens (*Martes americana*) could reduce the number of fledglings or boreal owl nesting success.

As in the case of monitoring abundance, the sampling frame for owl productivity should be considered to determine the relationship between the sample population and the target population. Modified sample frames like those outlined for monitoring population abundance could apply to sampling productivity depending on assumptions relating clutch size to distance from roads and topographic position. We considered only a very general frame that assumed owls nesting in boxes along roads were a random sample of owls within each of the 3 drainages of interest.

RESEARCH AND MANAGEMENT IMPLICATIONS

Before nest box systems are adopted to monitor boreal owl populations, researchers must examine the relationship between trends observed for owls nesting in boxes and trends experienced by owls in the larger target population. Our evaluation of adequate sample size and cost demonstrates that the method is intensive and expensive but that precise estimates of occupancy and productivity can be detected when occupancy exceeds 6%. Productivity can be estimated more efficiently than occupancy. No additional effort is involved in collecting data on both variables, and information on occupancy can be used to corroborate conclusions reached concerning habitat trend.

We suggest that changes in owl demography that result from degradation of habitat will be detected only through long-term monitoring. Numbers of nesting boreal owls and clutch size fluctuate widely from year to year because prey populations fluctuate and winter and spring weather conditions vary (Lofgren et al. 1986, Hayward 1989). Based on boreal owl dynamics observed in central Idaho (Hayward 1989), biologists should monitor for ≥5 years before making decisions concerning trend. Statistical techniques designed to remove noise from year-to-year fluctuations will aid in revealing long-term trends. Nonparametric trend analysis such as the seasonal Kendall test (VanBelle and

Hughes 1984, Gilbert 1987) may be modified to examine trends. If hypothesis testing is employed, we suggest 1-tailed tests of the hypothesis that there is not a downward trend to reduce the probability of type II errors. Alternatively, managed and unmanaged sites may be compared by examining the patterns of abundance over a time series using analysis of covariance techniques (Kirk 1982).

Finally, it is important to emphasize that a nest box program that uses the demographic variables we measured will not be suitable for measuring trend in *nesting* habitat because of the problems with shifts to nest boxes as natural cavities become less common. A successful monitoring program will require an integrated approach that tracks habitat features and owl demographics. A program that tracks snag availability and the variables we described above should be tested further as a tool in managing populations of boreal owls.

LITERATURE CITED

FINKLIN, A. I. 1988. Climate of the Frank Church, River of No Return Wilderness, Central Idaho. U.S. For. Serv., Gen. Tech. Rep. INT-240. Ogden, Ut. 221pp.

FORSMAN, E. D. 1983. Methods and materials for locating and studying spotted owls. U.S. For. Serv., Gen. Tech. Rep. PNW-162. Portland, Oreg. 8pp.

GARTON, E. O., P. H. HAYWARD, AND G. D. HAYWARD. 1989. Management of prey habitats and populations. Pages 298–304 *in* Proc. of the western raptor management symp. and workshop. Natl. Wildl. Fed., Washington, D.C.

GILBERT, R. O. 1987. Statistical methods for environmental pollution monitoring. Van Nostrand Reinhold, New York, N.Y. 320pp.

HAYWARD, G. D., P. H. HAYWARD, E. O. GARTON, AND R. ESCANO. 1987. Revised breeding distribution of the boreal owl in the northern Rocky Mountains. Condor 89:431–432.

———, AND J. W. DEAL. 1993. An optic device to inspect nest boxes from the ground. J. Field Ornith. In press.

———. 1989. Habitat use and population biology of boreal owls in the Northern Rocky Mountains, USA. Ph.D. Thesis, Univ. of Idaho, Moscow. 113pp.

HIRONS, G. J. M. 1985. The importance of body reserves for successful reproduction in the tawny owl (*Strix aluco*). J. Zool. Lond. (B) 1:1–20.

JOHNSON, R. R., B. T. BROWN, L. T. HAIGHT, AND J. M. SIMPSON. 1981. Playback recordings as a special avian censusing technique. Pages 68–75 *in* C. J. Ralph and J. M. Scott, eds. Estimating numbers of terrestrial birds. Studies in avian biology No. 6. Cooper Ornithol. Soc.

KIRK, R. E. 1982. Experimental design: procedures for the behavioral sciences. Brooks/Cole Publ., Belmont, Calif. 911 pp.

KORPIMAKI, E. 1985. Clutch size and breeding success in relation to nest-box size in Tengmalm's owl *Aegolius funereus*. Holarctic Ecology 8:175–180.

———. 1987. Clutch size, breeding success and brood size experiments in Tengmalm's owl *Aegolius funereus*: a test of hypothesis. Ornis Scand. 18:277–284.

———. 1988. Effects of territory quality on occupancy, breeding performance and breeding dispersal in Tengmalm's owl. J. Anim. Ecol. 57: 97–108.

LOFGREN, O., B. HORNFELDT, AND B. G. CARLSSON. 1986. Site tenacity and nomadism in Tengmalm's owl (*Aegolius funereus* (L.)) in relation to cyclic food production. Oecologia 69:321–326.

LUNDBERG, A. 1978. Census methods for the Ural owl *Strix uralensis* and the Tengmalm's owl *Aegolius funereus*. Anser, Supplement 3:171–175.

MARION, W. R., T. E. O'MEARA, AND D. S. MAEHR. 1981. Use of playback recordings in sampling elusive or secretive birds. Pages 81–85 *in* C. J. Ralph and J. M. Scott, eds. Estimating numbers of terrestrial birds. Studies in avian biology No. 6. Cooper Ornithol. Soc.

MENDENHALL, W., L. OTT, AND R. L. SCHEAFFER. 1971. Elementary survey sampling. Duxbury Press, Belmont, Calif. 247pp.

MIKKOLA, H. 1983. Owls of Europe. Buteo Books, Vermillion, S.D. 397pp.

NEWTON, I. 1979. Population ecology of raptors. Buteo Books, Vermillion, S.D. 399pp.

PALMER, D. A., AND R. A. RYDER. 1984. The first documented breeding of boreal owl in Colorado. Condor 86:215–217.

SMITH, D. G., A. DEVINE, AND D. WALSH. 1987. Censusing screech owls in southern Connecticut. Pages 255–267 *in* R. W. Nero, R. J. Clark, R. J. Knapton, and R. H. Hamre, eds. Biology and conservation of northern forest owls: symposium proceedings. U.S. For. Serv., Gen. Tech. Rep. RM-142. Fort Collins, Colo.

SONERUD, G. A. 1985. Nest hole shift in Tengmalm's owl *Aegolius funereus* as defense against nest predation involving long-term memory in the predator. J. Anim. Ecol. 54:179–192.

VANBELLE, G., AND J. P. HUGHES. 1984. Nonparametric tests for trend in water quality. Water Resour. Res. 20:127–136.

VERNER, J. 1986. Future trends in management of nongame wildlife: a researcher's viewpoint. Pages 149–171 *in* J. B. Hale, L. B. Best, and R. L. Clawson, eds. Management of nongame wildlife in the midwest: a developing art. Proc. 47th Midwest Fish and Wildl. Conf.

Received 13 June 1991.
Accepted 11 May 1992.
Associate Editor: Mannan.