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Optimal Sampling for Radiotelemetry Studies of Spotted Owl Habitat and Home Range

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Abstract

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Radiotelemetry studies of spotted owl (*Strix occidentalis*) ranges and habitat-use must be designed efficiently to estimate parameters needed for a sample of individuals sufficient to describe the population. Independent data are required by analytical methods and provide the greatest return of information per effort. We examined time series of relocations and the size, shape, and composition of ranges of nine adult spotted owls in the Oregon Coast Range. Based on two methods of analysis, independent relocations were separated by 3 days in the breeding season and 2-5 days outside the breeding season. We can increase our opportunities to follow more owls by attempting to relocate individuals no more often than every other night and by rotating 2 and 3 nights per week for individuals. Under this schedule, we could obtain 130 relocations per owl annually, 115 of which would be independent. These data will be adequate, in terms of sample size and independence, to estimate home range size and habitat use by spotted owls in the Oregon Coast Range.

Keywords: Spotted owl, *Strix occidentalis*, home range, habitat use, radiotelemetry, sampling, experimental design, Oregon Coast Range.

Summary

Radiotelemetry is the only feasible method for determining spotted owl ranges and habitat use. Although there is no guidance in the literature on what constitutes an adequate sample of telemetric relocations for an individual owl, it is apparent that data used for estimating home range sizes and habitat selection must be independent, unbiased, and sufficient in number. And a sufficient number of owls must be studied to describe the population.

We examined time series of relocations and the size, shape, and composition of ranges of nine adult spotted owls in the Oregon Coast Range. We approached the question of independence of relocations in two ways. Our statistical approach tested relocations for serial correlation. Our biological approach examined movement patterns of the owls relative to the average size of patches in their ranges. Statistically independent relocations were separated by 3 days in the breeding season and 5 days outside the breeding season; biological independence occurred after 3 and 2 days, respectively. The disparity of the two results is due to the large size of non-breeding season ranges compared with the small size of patches within those ranges. Because we seek guidance for sampling plans and do not wish to under-sample, we use the estimates of times to independence provided by the biological approach.

We can increase our opportunities for following more owls by attempting to relocate individuals no more often than every other night and by rotating 2 and 3 nights a week for individuals. Under this schedule, we could obtain 130 relocations per owl annually, 115 of which could be independent. These data will be adequate, in terms of sample size and independence, for estimating home range size and habitat use by spotted owls in the Oregon Coast Range.

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Introduction

Spotted owls (*Strix occidentalis*) use large areas of old-growth forest (Forsman and Meslow 1985). Management for spotted owls has required withholding valuable timber from harvest; thus, controversy over how much old growth the owl needs is substantial (Marcot and Holthausen 1987). Amounts used (and needed) are likely to vary with geographic area, vegetation zone, and prey base. Studies of home range size and habitat use can help tailor management to specific local conditions (Carey 1981, 1984, 1985).

Radiotelemetry is the only feasible way to determine spotted owl ranges and habitat use (Forsman 1983). Because the radio signals are continuously available, most users have collected locations at a high sampling frequency. Statistical analysis of such data poses special problems because of the lack of independence of the successive observations (Dunn and Gipson 1977). Any legitimate analysis must account for the time series nature of high frequency sampling data (Dunn and Brisbin 1985). Independent observations can be obtained through subsampling autocorrelated data sets or through experimental design (Samuel and Garton 1985, 1987; Samuel and others 1985; Schoener 1981; Swihart and Slade 1985a, 1985b, 1986; Van Winkle 1975). Efficiency dictates use of experimental design to achieve independence, especially when redundancy has an opportunity cost; for example, when collecting redundant data on one owl precludes sampling additional owls. Generally, studies of animal range and habitat use are concerned with estimating parameters of the animal population, not just of one or two individuals. Therefore, the problem of opportunity costs is real, and the solution is optimization. It is important to ensure that a sample of radio locations is adequate for estimating the parameters of interest for individuals (for example, home range size and habitat use) while maximizing the number of individuals studied to obtain the best description of the population within the constraints of the resources available for the study.

There is no guidance in the literature on what constitutes an adequate sample of independent telemetric locations for a spotted owl. Both Forsman and others (1984) and Allen and others (1987) showed that sampling throughout the year was necessary for describing an owl's home range as defined by Burt (1943): the area normally used by an animal in its daily activities of foraging, mating, and caring for young. Ranges for spotted owls increased markedly in the fall. Bekoff and Mech (1984) reviewed the literature: 35-175 locations (40-50 independent locations) were needed to describe carnivore ranges; 18-25 or more were needed to measure the ranges of small mammals and reptiles. Based on the literature review, computer simulations, and analysis of the stability of home range estimates, they concluded that 100 to 200 locations should be gathered. They discussed the need for addressing independence but made no suggestions on methods. It is not evident that their simulations and recommendations are pertinent to a wide-ranging, patch-selecting, sit-and-wait, avian predator.

White and Garrott (1986) used Monte Carlo simulations to study the application of radiotelemetry to studies of habitat selection. They showed that the power of chi-square tests for habitat selection (Neu and others 1974) was decreased by increasing habitat complexity, decreasing precision of triangulation bearings, and decreasing sampling effort. Observations used for evaluating selection must be independent and unbiased (Aldredge and Ratti 1986, Byers and others 1984, Johnson 1980, Neu and others 1974).

In 1986, we began a study of the relation between the spotted owl and its primary prey, the northern flying squirrel (*Glaucomys sabrinus*). As part of that study, we conducted a pilot study of the behavior of the spotted owl as it relates to sampling designs for radiotelemetry and the characteristics of owl ranges as they relate to studies of foraging site selection by the spotted owl. The objective of this paper is to report the results of the pilot study.

Methods

Study Areas

Four areas spanning the range of environmental conditions in the southern Coast Range were chosen for study: (1) Cherry Creek Research Natural Area is on the wet, west slope of the Coast Range; (2) Peterson Point-Lookout Mountain, near the South Fork Smith River northwest of Drain, Oregon, is an area with a mixture of naturally regenerated mature and old-growth forests, as well as managed forest; (3) the Miner Creek area is representative of the east slope of the Coast Range and is generally composed of a mixture of old-growth and managed forest; (4) the Riverview area is at the juncture of the east slope of the Coast Range and the Interior Valley Margin Province—an area composed of old-growth, managed forest, a large riparian area, oak woodlands, and grasslands (including hayfields and pastures).

Telemetry

Both members of five pairs of owls were captured and fitted with radio transmitters following Forsman's (1983) method. Because owls usually forage at night and roost during the day (Forsman and others 1984), we attempted to obtain at least one accurate location before midnight, one after midnight, and one the next day. Initially we located the owls throughout the night at 1/2- to 1-hour intervals. After it became apparent (late September) that the owls were not moving much during the night, we attempted to locate at least two to four owls per night and to get just one accurate triangulation for each owl.

To maximize accuracy of the triangulations, we used a set of principles:

1. Stay above the owl; avoid being below the owl.
2. Work close (within 0.5-1.0 km) to the owl.
3. Take successive bearings quickly.
4. Ensure line-of-sight reception of radio signals.
5. Strive to separate bearings by at least 10 degrees and up to 45-135 degrees.

Often we could not adhere to all five principles. We followed the principles roughly in the order they are listed but always tried to optimize within the specific context (topography and access) of each owl.

Each bearing taken was subjectively evaluated for signal strength and quality; any bearing with an "untrustworthy" signal was ignored. Bearings were taken until three or four "good" bearings were obtained; then the bearings were plotted on aerial photographs. The resulting polygon was evaluated subjectively and by size class.

Daytime triangulations were followed by a walk into the forest to locate the owl visually to assess the accuracy of day locations and to identify areas in which radio signals were misleading. Because owls often roosted in the same area they were located in during the night and because our daytime triangulation procedures were identical to our night procedures, we could often assess the accuracy of night fixes too.

All triangulations with polygons of less than 8 ha were used in initial calculations of home range. We used the minimum convex polygon (MCP) method (Hayne 1949) and the program MCPAAL (Conservation and Research Center, National Zoological Park, Front Royal, Virginia). The MCP method does not require independence among observations but can produce misleading results if sampling was poorly distributed over time. Only one location per night (with a triangulation polygon of less than 2 ha) was used in the analysis of foraging-site selection.

In any set of home range data, there are outlying points that reflect occasional forays outside the normal range of the animal; although these are not within the home range, they may be important in the animal's spatial and social orientation, may reflect natural tendencies for exploration, or may be preparation for invasion of depopulated areas or extension of the species' range (Stickel 1954). In keeping with Burt's (1943) definition and subsequent practice (Anderson 1982, Bekoff and Mech 1984, Burt 1943, Dice and Clark 1953, Don 1983, Ford and Krumme 1979, Harvey and Barbour 1965, Koepl and Hoffmann 1985, Koepl and others 1985, MacDonald and others 1980, Odum and Kuenzler 1955, Stickel 1954), we removed the 5 percent of locations most distant from the arithmetic center of the data from each of two by-season subsets of the data and repeated the analyses.

Determining Independence

The data in our study were relocations of individual birds arrayed in time series. Successive data points in series are independent when their locations in Cartesian (two-dimensional) space are not influenced by the locations of previous points. We used two approaches to analyze independence. Our statistical approach used tests for serial correlation or autocorrelation and followed Swihart and Slade (1985b). Our biological approach incorporated what we know about foraging behavior of owls and the actual arrangement of patches in the landscape. We confined our analyses to the nine owls that were tracked for 6 months or more.

Statistical approach—The Durbin-Watson statistic is a popular method used to test for serial correlation in regression analysis (Chatterjee and Price 1977, p. 125-128). It tests the null hypothesis that the residuals (u) do not constitute a first-order autoregressive series (p = coefficient of autoregression) in a data set ordered by time (t),

$$u_t = \rho u_{t-1} + e_t, \quad |\rho| < 1,$$

where e is random error. The Durbin-Watson statistic is a special case of von Neumann's ratio, $V = d^2/s^2$ (see Swihart and Slade 1985b), which is the ratio of the variance (s^2),

$$s^2 = \frac{1}{n} \sum_{i=2}^n (x_i - \bar{x})^2,$$

and the mean squared difference between successive observations (d^2),

$$(d^2) = \frac{1}{n-1} \sum_{i=2}^n (x_i - x_{i-1})^2,$$

in which x is the value of each observation, n is the number of observations in the series, and i denotes the order of observation. Von Neumann (1941) showed that observed values of V significantly greater than 2 indicated that observations were not positively serially correlated.

Schoener (1981) developed a bivariate extension of von Neumann's ratio to test for autocorrelation in time series of animal locations in Cartesian space. This statistic, Schoener's ratio (t^2/r^2), is the ratio of the mean squared distance between successive observations,

$$t^2 = \frac{1}{(n-1)} \sum_{i=1}^{n-1} (x_{i+1} - x_i)^2 + \frac{1}{(n-1)} \sum_{i=1}^{n-1} (y_{i+1} - y_i)^2,$$

and the mean squared distance from the "center of activity" ($\bar{x}, \bar{y}$),

$$r^2 = \frac{1}{(n-1)} \sum_{i=1}^{n-1} (x_i - \bar{x})^2 + \frac{1}{(n-1)} \sum_{i=1}^{n-1} (y_i - \bar{y})^2,$$

in which x and y are Cartesian coordinates, n is the number of observations, and i denotes the order of the series of observations.

Although Schoener's ratio is conceptually similar to von Neumann's V , its true expected value and statistical distribution have not been mathematically proved. Swihart and Slade (1985b) examined the statistical distribution of Schoener's ratio using simulation techniques with data from bivariate normal and uniform distributions. They also randomly sampled with replacement from an unusual distribution (a series of locations of a cotton rat) to generate critical values for that distribution. Their results supported the notion that data are independent for $t^2/r^2 \geq 2$ and suggested that the underlying distributions of x and y have little effect on the distribution of t^2/r^2 .

We used the tables of critical values presented by Swihart and Slade (1985b) to test the null hypothesis that observations separated by a particular time interval are independent or overdispersed (that is, $t^2/r^2 \geq 2$, $p = 0.05$, one-tailed). We also used $p = 0.25$ (as suggested by Swihart and Slade 1986) because the ultimate aim of the test is to select interval classes in which the null hypothesis is accepted and moderate values of p reduce the chance of type II errors (the probability of falsely accepting the null hypothesis).

We selected all possible pairs of locations from the series of observations for each owl that were separated by specified time intervals (at 6-h increments for intervals ≤ 24 h and 24-h increments for intervals > 24 h, out to intervals of 2 weeks). Subsets with ≥ 4 pairs of locations were then tested for serial correlation. We tested each time series for each individual in its entirety, then as breeding season (Feb.-Aug., combining 1986 and 1987 locations) and nonbreeding season (Sept.-Jan.) subsets. We repeated the analysis after removing the outermost 5 percent of the locations. We

generalized the analyses of the individual owls within interval classes by noting whether or not locations of the majority, or a significant portion, of the individuals in each class were independent (essentially similar to comparing the median and quartile values of t^2/r^2 within each interval class to 2).

Biological approach—During the day, owls spend most of their time roosting in trees; owls leave their day roost to begin foraging soon after sunset and cease foraging shortly before sunrise. Owls watch and listen for their prey and may spend up to several hours on the same perch. When a large prey (such as a flying squirrel) is caught, owls consume part of the prey, cache the rest, and roost in the vicinity until the entire prey is consumed. Thus, owls appear to decide where to forage each evening but may forage in only one patch in a night; they will switch patches in a night, however (Forsman and others 1984). Forsman and others (1984) report that owls move at the rate of 247-323 m/h during the night. But most of this movement is at dusk and just before dawn, although during the breeding season, the male often returns to the nest site between foraging bouts within a night (Forsman,¹ personal communication). Thus, in each 24-h period, owls appear to engage in two distinct primary activities (nocturnal foraging and diurnal roosting) and to make two distinct decisions (where to forage and where to roost). The decision on where to forage could easily depend on the success of the previous night's efforts and the time of the year. Owls with young are more pressed to be successful in foraging than are owls without young and may have to quickly abandon patches with low-to-moderate availability of prey.

To determine if the owls in our samples were making more than one choice in a night (a choice being which patch to forage in) and to determine if roosting locations were in the same stands as the foraging locations (closely dependent) or in distant stands (independent), we used the average patch width as calculated from transects. We compared this average with the average distances moved over various time intervals. We used a one-tailed t-test ($p = 0.05$) of the hypothesis that the average distance between locations within a time-interval class is not greater than the average patch width. We used the same time intervals and seasonal breakdown we used for the tests of statistical independence.

Home Range Composition

We used aerial photos, U.S. Department of the Interior, Bureau of Land Management inventories, and field reconnaissance to characterize each owl's range. Patch (stand) boundaries were traced onto Mylar overlays and digitized. We identified nine patch types: clearcut, sapling, pole, young, mature, mixed-age, and old-growth stands; hardwood-riparian zones; and nonforested areas. Acreages in each patch type were summed for each owl's home range and for each pair's combined home range. We determined average patch size in two ways. Using the nest area of each owl as a center of activity, we chose a transect that spanned the greatest length of the minimum convex polygon. A second transect was located at right angles to the initial

¹ Forsman, Eric D. 1988. Forestry Sciences Laboratory, 3625 93rd Avenue, S.W., Olympia, Washington 98502.

transect, through the nest grove, and extending to the polygon boundaries. The transects were drawn to scale on 1:12,000 aerial photographs. We counted changes in patch type along each transect. And we used the changes in patch type per kilometer as an index to average patch size. In addition, we placed each stand into one of the following size classes (in hectares): 0-10, 11-20, 21-40, 41-60, 61-80, 81-100, and 100+.

Results

We tracked nine owls for 119-365 days. Five of the nine owls were followed for more than 338 days. We obtained 57-216 nocturnal locations and 28-54 diurnal locations per owl. Thus, we recorded 1349 locations. Locations are displayed by owl and by season in tables 1 and 2.

Table 1—The number of telemetric relocations obtained during the breeding season (February through August) and the effect of deleting redundant observations on sample sizes and home range sizes for 9 adult spotted owls in the Oregon Coast Range, 1986-87

Owl	All observations		Observations ≥ 3 days apart		Change in area
	Area	Number	Area	Number	
	<i>Hectares</i>		<i>Hectares</i>		<i>Percent</i>
Cherry Creek:					
Female	800	84	608	31	-24
Male	498	73	257	18	-48
Lookout Mountain:					
Female	342	45	214	14	-37
Male	664	91	546	47	-18
Miner Creek:					
Female	704	98	568	37	-19
Male	543	75	405	25	-25
Peterson Point:					
Female	703	56	468	18	-33
Male	806	92	610	35	-24
Riverview:					
Male	1544	150	1128	41	-27

Table 2—The number of telemetric relocations obtained outside the breeding season (September through January) and the effect of deleting redundant observations on sample sizes and home range sizes for 9 adult spotted owls in the Oregon Coast Range, 1986-87

Owl	All observations		Observations ≥ 2 days apart			Observations ≥ 5 days apart		
	Area	Number	Area	Number	Change in area	Area	Number	Change in area
	<i>Hectares</i>		<i>Hectares</i>		<i>Percent</i>	<i>Hectares</i>		<i>Percent</i>
<i>Cherry Creek:</i>								
Female	1016	69	815	29	-20	611	18	-40
Male	702	56	487	18	-31	490	15	-30
<i>Lookout Mountain:</i>								
Female	1748	40	1141	16	-35	1114	13	-36
Male	3635	58	2726	27	-22	2701	19	-26
<i>Miner Creek:</i>								
Female	1066	79	701	29	-34	581	20	-45
Male	628	72	481	26	-23	393	18	-37
<i>Peterson Point:</i>								
Female	1108	30	711	11	-36	572	9	-48
Male	1353	49	1189	26	-12	1106	18	-18
<i>Riverview:</i>								
Male	1522	113	1455	30	-8	1154	21	-24

Statistical Independence

Using all data—The number of telemetric relocations obtained for each owl is in table 1 (breeding season) and table 2 (nonbreeding season). All but one set of successive locations separated by 4 days or fewer were serially correlated ($p = 0.05$) (fig. 1). Only sets of locations more than 2 weeks apart were independent for the majority of owls. The large areas used by the owls resulted in a large denominator in Schoener's ratio (the mean squared distance from the center of activity) which, in part, is an artifact of the seasonal range expansion by the owls (fig. 2). The seasonal expansion produces a large range diameter; the large diameter dwarfs the mean squared distance between successive locations, especially in the breeding season when the birds concentrate their activities in a relatively small area.

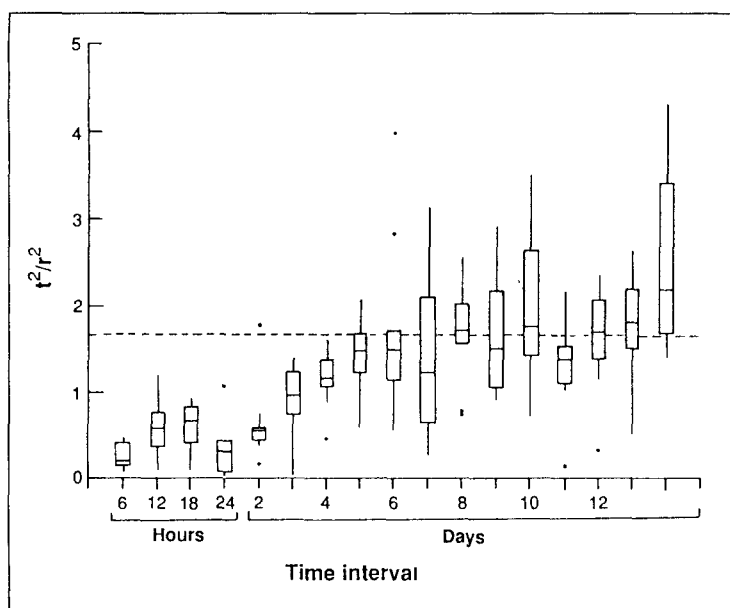


Figure 1—Serial correlation as a function of time between successive observations, using all relocations of nine adult spotted owls in the Oregon Coast Range, 1986-87. The boxes enclose the upper and lower quartiles of the values of Schoener's ratio (t^2/r^2) for each owl with ≥ 4 pairs of observations in each time interval. The whiskers span the range of values of t^2/r^2 that span 1.5 times the inter-quartile range; outlying values are displayed as points. The ratio value for $p = 0.05$ varies around 1.7 (dashed line); exact values vary with the eccentricity of the home range and sample size of relocations.

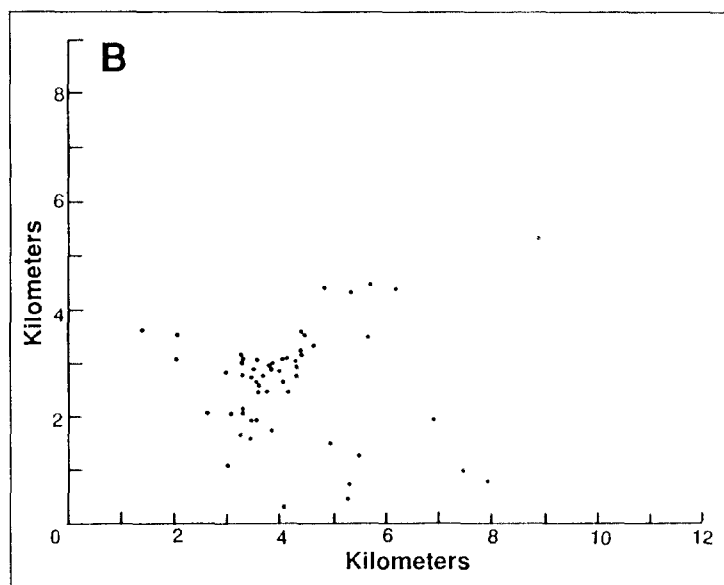
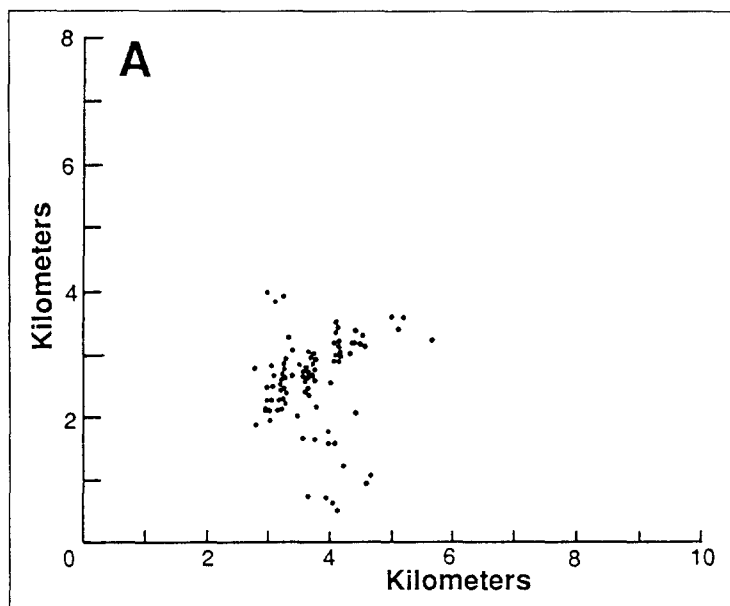


Figure 2—Seasonal locations of an adult male spotted owl in the Oregon Coast Range, 1986-87. **A.** Breeding season locations were from June 15 to August 30 1986, and February 1 to June 14, 1987. **B.** Nonbreeding season locations were from September 1, 1986, to January 31, 1987.

Using all data, but separated by season—Nearly all sets of successive breeding season locations separated by 3 days or fewer were serially correlated (fig. 3). Owl-by-owl tests for independence (critical values ranged around 1.7) revealed that locations separated by 4 days or more were likely to be independent. Sets of successive locations outside the breeding season were serially correlated until a separation of 5 days. Only sets of locations 8 or more days apart were independent for the majority of owls. Again, large range diameters seemed to dwarf the distances between successive locations. The large range diameters were due partly to the outlying observations. Such locations are not necessarily part of the home range and could be the “sallies outside the area” discussed by Burt (1943) and Stickel (1954).

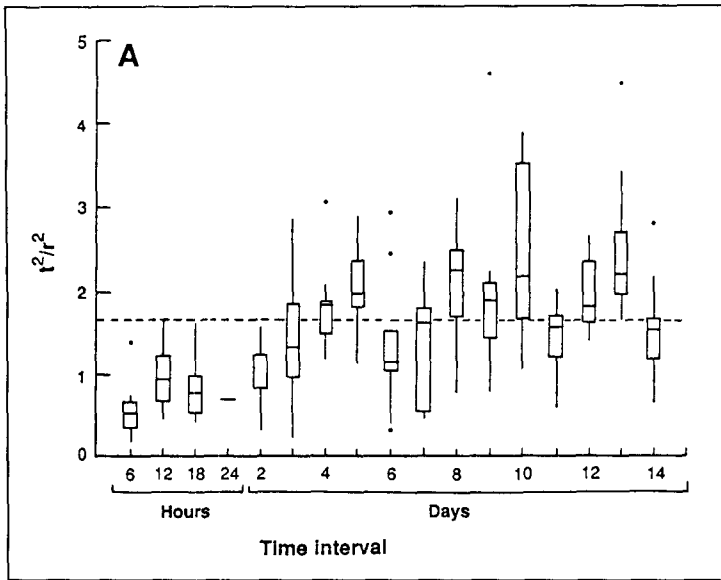
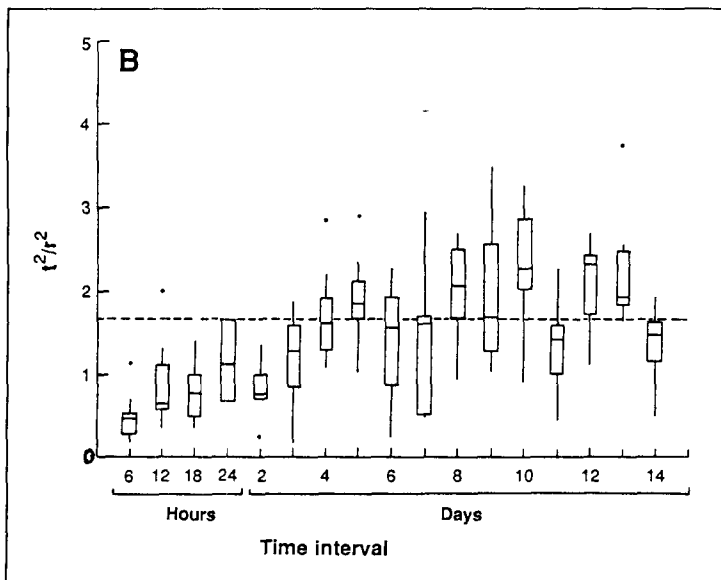


Figure 3—Serial correlation as a function of time between successive observations, using breeding season relocations of nine adult spotted owls in the Oregon Coast Range, May to August 30, 1986, and February 1 to June 1987. Beginning and ending dates differed slightly between owls, but all owls were tracked for ≤ 365 days. The boxes enclose the upper and lower quartiles of the values of Schoener's ratio (t^2/r^2) for each owl with ≥ 4 pairs of observations in each time interval. The whiskers span the range of values of t^2/r^2 that span 1.5 times the interquartile range; outlying values are displayed as points. The ratio value for $p = 0.05$ varies around 1.7 (dashed line); exact values vary with the eccentricity of the home range and sample size of relocations. A. All relocations. B. Central 95 percent of relocations.



Using a 5-percent trim, data separated by season—When we repeated the analyses using the central 95 percent of the locations, the breeding season results changed little, suggesting that the owls made few sallies outside their normal range. But outside the breeding season, locations were independent for four of the nine owls after 5 days in contrast to 8 days using all locations, suggesting that owls were making sallies outside their normal range (fig. 4).

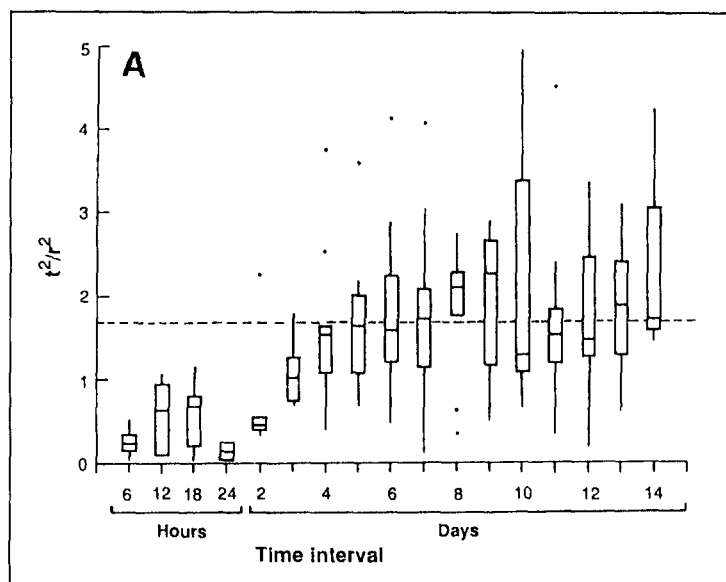
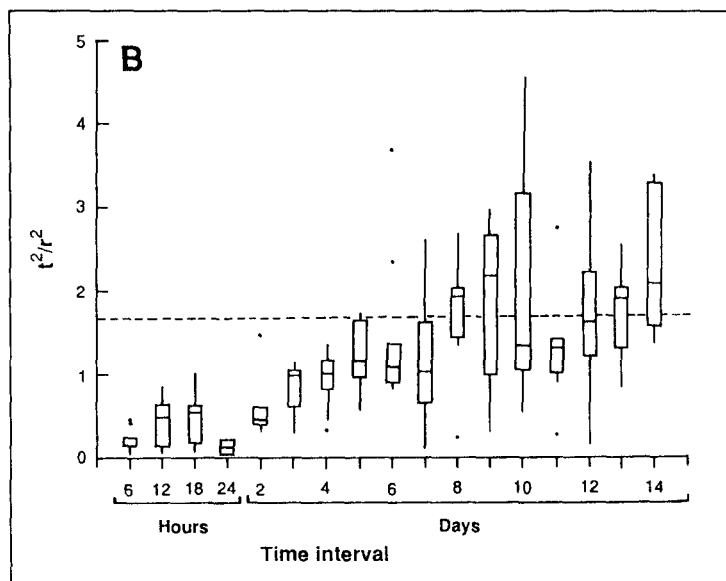


Figure 4—Serial correlation as a function of time between successive observations, using nonbreeding season relocations of 9 adult spotted owls in the Oregon Coast Range, from September 1, 1986, to January 31, 1987. The boxes enclose the upper and lower quartiles of the values of Schoener's ratio (r^2/r^2) for each owl with ≥ 4 pairs of observations in each time interval. The whiskers span the range of values of r^2/r^2 that span 1.5 times the interquartile range, outlying values are displayed as points. Extreme outlying points, with r^2/r^2 of 10 and 13 at 9- and 14-day intervals, are not displayed on either graph. The ratio value for $p = 0.05$ varies around 1.7 (dashed line); exact values vary with the eccentricity of the home range and sample size of relocations. A. All relocations. B. Central 95 percent of relocations.



Minimum time interval to achieve Independence—The level of autocorrelation decreased rapidly with 2-5 days between successive observations (figs. 3 and 4). Thereafter, the values of Schoener's ratio hovered around the asymptotelike value of 2. The ratio value for a level of significance of 0.05 is around 1.7 (exact values vary with eccentricity of the home range and sample size of relocations). Successive locations of one-third or more of the owls are independent after 3 days in the breeding season and after 5 days outside the breeding season. Median ratio values did not differ significantly from 2 for the first time at 4 days separation in the breeding season and at 8 days separation outside the breeding season. Using $p = 0.25$ did not influence these results appreciably.

Biological Independence

The average distance between patches in the home ranges of the nine owls was 0.45 km. The results of the transect analyses were supported by our accounting of patch size classes: 56-63 percent of the owl pairs' ranges were composed of patches of less than 20 ha. Within-night movements (6 h or fewer between successive locations) did not differ significantly ($p = 0.05$) from the average distance between patches, which suggested the scale of movement that was within patch (table 3). Movements between successive night and day locations were larger ($p = 0.05$) than the average distance between patches and indicated that, on the average, an owl foraged in one patch and roosted in another. The average difference between night and day locations was about 1.8 times the average distance between patches, suggesting that the owls frequently roosted in a patch near the foraging patch. Between-night movements did not differ significantly from the average distance between patches, suggesting that between-night movements were also on the scale of within patch. During the breeding season, even movements 2 days apart did not, on the average, differ significantly from the average distance between patches. Movements separated by more than 3 days averaged three times the average distance between patches during the breeding season and four times the average outside the breeding season (table 3).

Table 3—Distances between successive observations of 9 adult spotted owls in the Oregon Coast Range, 1986-87

Time between observations	Year-round	Summer	Winter
<i>Kilometers</i>			
Hours:			
6	0.516	0.525	0.487
12	.817 ^a	.790 ^a	.896 ^b
18	.805 ^a	.764 ^a	.791 ^b
24	.750	.721	.513
Days:			
2	.840 ^a	.747	1.068 ^b
3	1.021 ^a	.867 ^b	1.044 ^a
4	1.242 ^a	1.160 ^a	1.491 ^a
5	1.378 ^a	1.263 ^a	1.593 ^a
6	1.481 ^a	1.047 ^a	1.819 ^a
7	1.359 ^a	.962 ^b	1.524 ^a

See footnotes on next page.

Table 3—Distances between successive observations of 9 adult spotted owls in the Oregon Coast Range, 1986-87 (continued)

Time between observations	Year-round	Summer	Winter
<i>Kilometers</i>			
8	1.457 ^a	1.272 ^a	1.683 ^a
9	1.474 ^a	1.240 ^a	1.906 ^a
10	1.590 ^a	1.347 ^a	1.914 ^a
11	1.265 ^a	1.016 ^a	1.703 ^a
12	1.423 ^a	1.329 ^a	1.726 ^a
13	1.552 ^a	1.379 ^a	1.809 ^a
14	1.781 ^a	1.031 ^a	2.232 ^a

^a Average distances between observations greater than the average stand width, 0.4509 km (1-tailed t-tests, $p < 0.01$).

^b Average distances between observations greater than the average stand width, 0.4509 km (1-tailed t-tests, $p < 0.05$).

Minimum time to Independence—The results of our biological analysis of independence are that owls foraged within a patch (or within two small patches) for 3 consecutive nights during the breeding season and for 2 consecutive nights outside the breeding season. We conclude that selections of foraging and roosting sites within 2-3 nights are not independent. Movements separated by 2 days outside the breeding season and 3 days within the breeding season were two to five times the average distance between patches and can be considered independent.

Home-Range Size and Composition

Individual home ranges averaged about 1600 ha. One-half the patches were of one type, old growth. Each of the five early seral stages of coniferous forest contributed 6-15 percent to the ranges' areas. And mixed-age, hardwood-riparian, and nonforested patches contributed 2-3 percent each. Patch sizes were small compared with range size; one-half to two-thirds the patches were 20 ha or less (5 percent or less of the range). Large patches (greater than 100 ha) composed 9-16 percent of the ranges. Most of the owl locations (84 percent) were in old growth. One location was in a clearcut; none were in nonforested areas. Other types were either avoided or used in proportion to their occurrence; average use for each of these other types was less than 3 percent.

Effect of Data Selection on Sample Size

Selecting independent observations from the seasonal data sets reduced the number of observations by 65 percent during the breeding season (table 1) and 63-73 percent outside the breeding season (table 2). Breeding season ranges based on independent observations were 72 percent of the ranges based on all observations; non-breeding season ranges were 66 percent of the ranges based on all observations even when a 5-day separation (and 73-percent reduction in observations) was used to achieve independence. The small reduction in range sizes (28-34 percent) relative to the large reduction (65-73 percent) in total sample size emphasizes the redundant nature of the total sample. If we had designed our study optimally, we could have collected 71 statistically independent (separated by 3 days) locations per owl during

the breeding season and 31 independent observations (separated by 5 days) per owl outside the breeding season. If we use the biological criterion for independence (separated by 2 days), 76 observations per owl could be obtained outside the breeding season. We could have doubled the size of our independent sample and substantially reduced the chance of underestimating home range sizes. The annual number of independent locations that could be obtained under optimal sampling would be 147, in the middle of the range suggested by Bekoff and Mech (1984).

Owl ranges contained a maximum of nine types of patches. Average expected values per type would be 16 on an annual basis and about 8 on a seasonal basis. Neu and others (1974) stated that the chi-square goodness-of-fit test could be used when there is at least one expected observation in each category and no more than 20 percent of all categories contain less than five expected observations. These criteria would be met by optimal sampling. Use of the Bonferroni z-test on patches composing as little as 10 percent of the range would require a sample size of 50 independent observations (Neu and others 1974).

Discussion

Determining Time to Independence

We obtained slightly different estimates of the time to independence with the two techniques: 3 days in the breeding season and 5 days outside the breeding season using Schoener's ratio (for at least one-third the owls at $p = 0.05$) and 3 days in the breeding season and 2 days outside the breeding season using the average distance between patches. The discrepancy between the two results is due to three factors that influence the denominator of Schoener's ratio. The seasonal range expansion, the outlying observations, and the disjunct nature of the owls' ranges all contribute to large denominators. We tried to reduce the effect of the first two influences by determining the time to independence by season and by removing the outermost 5 percent of the observations. But we could not quantitatively assess the effect of the patchy nature of the owls' ranges. The patchiness of the ranges was accentuated by the strong selection of one patch type by the owls. At least two patch types were not used at all. We believe it is evident that when patches are small, ranges are large, and a sit-and-wait predator is selective in its use of patches, Schoener's ratio will be characterized by a denominator that is large relative to the numerator and the time to independence will be overestimated. Because we are looking for guidance for sampling plans and we do not wish to undersample, we will use a 3-day separation during the breeding season and 2-3 days outside the breeding season as our estimates of time to independence. These intervals will generate about equal sampling intensities per season (a consideration in examining patch-type selection). If the data still prove to be autocorrelated, we can sample from the data set. Few authors have addressed the problems associated with home range analysis in patchy environments, and there is little guidance in the literature (Anderson 1982, Cockburn 1984, MacDonald and others 1980, Schoener 1981, Spencer and Barrett 1984).

Testing for Patch-Type Selection

Median patch sizes in the owls' ranges were just under 20 ha; patch types were few (7-9); triangulation polygons were less than 4 ha; the owls demonstrated strong selectivity. Seasonal (about 70) and annual (about 140) sample sizes that would be obtained with 2-3 days separation between locations should be adequate for determining the types of patches selected by owls (Alldredge and Ratti 1986, Byers and others 1984, Johnson 1980, Neu and others 1974, White and Garrott 1986).

Implementation

We will be unable to obtain the maximum number of independent samples per season because we collect data during 5-day workweeks. Given the time to independence is 2-3 days (at a minimum), we could collect only one or two observations per week. But 1 or 2 days per week would often lead to observations being separated by as long as 7 days with the nonworking weekend. Trying to maintain two field crews with differently defined workweeks is impractical. What would the effect on independence be if we collected observations every other night during the workweek? This schedule would be equivalent to rotating 2 and 3 nights per week for individual owls. We constructed a calendar to find the answer.

We assumed a worst case (from the standpoint of independence) scenario of owls always remaining in the same patch for 3 consecutive nights during the breeding season. There are only three mutually exclusive schedules (each offset by 1 day) the owls could follow in a 7-day week. We plotted these on a calendar. Then we plotted our sampling occasions. Given every-other-night sampling during a 5-day workweek, we determined that there would be two chances in three opportunities (for the weeks in which three samples were taken) for the midweek observation to be redundant (nonindependent) during the breeding season. There was one chance in three opportunities that the second observation in the week would be redundant when two samples were taken. Observations taken outside the breeding season would be independent.

There are 30 weeks in the breeding season; three observations per week would be taken for 15 of the weeks and two observations per week would be taken for the other 15 weeks. Thus, 75 observations per owl could be taken. We calculated that 60 of these would be independent. There are 22 weeks outside the breeding season; 55 independent observations would be obtained under the sampling scheme, and 115 of 130 observations per owl per year would be independent. Given regularly and randomly occurring exigencies (telemetry illness, vehicle breakdowns, holidays, failure to locate an owl on a given night, bad weather creating impassable roads, and so on), we would not be able to achieve the maximally possible sample size and the chances of redundant observations would be reduced. We conclude that separating observations by 2 days would provide reasonably adequate and independent data for determining home range size and patch-type selection.

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Radiotelemetry studies of spotted owl (*Strix occidentalis*) ranges and habitat-use must be designed efficiently to estimate parameters needed for a sample of individuals sufficient to describe the population. Independent data are required by analytical methods and provide the greatest return of information per effort. We examined time series of relocations and the size, shape, and composition of ranges of nine adult spotted owls in the Oregon Coast Range. Based on two methods of analysis, independent relocations were separated by 3 days in the breeding season and 2-5 days outside the breeding season. We can increase our opportunities to follow more owls by attempting to relocate individuals no more often than every other night and by rotating 2 and 3 nights per week for individuals. Under this schedule, we could obtain 130 relocations per owl annually, 115 of which would be independent. These data will be adequate, in terms of sample size and independence, to estimate home range size and habitat use by spotted owls in the Oregon Coast Range.

Keywords: Spotted owl, *Strix occidentalis*, home range, habitat use, radiotelemetry, sampling, experimental design, Oregon Coast Range.

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