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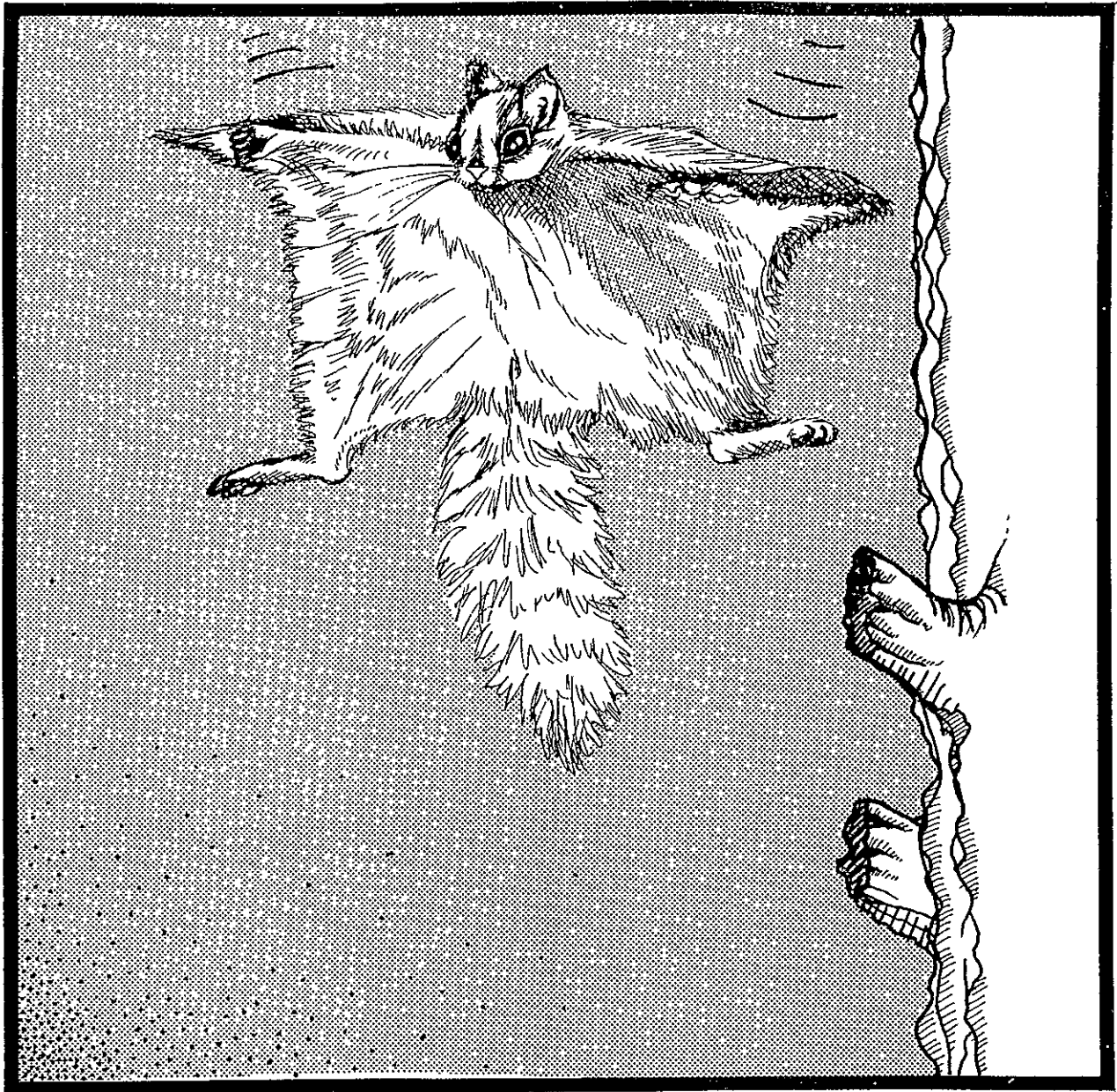
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Methods for Measuring Populations of Arboreal Rodents

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Wildlife Habitat Relationships: Sampling Procedures for Pacific Northwest Vertebrates

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Methods for Measuring Populations of Arboreal Rodents

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Preface

Concern about the value of old-growth Douglas-fir forests to wildlife in the Pacific Northwest began escalating in the late 1970s. The available information on wildlife habitat relationships suggested that as many as 75 species including amphibians, birds, and mammals, could be dependent on old-growth forests. The USDA Forest Service chartered the Old-Growth Forest Wildlife Habitat Program to investigate the role old growth plays in maintaining viable populations of wildlife. It was apparent that broad surveys of vertebrate communities would be necessary to determine which species truly were closely associated with old-growth forests. Insufficient guidance on techniques, procedures, and sample sizes was available in the existing literature. We assembled a team of researchers from universities and Federal agencies to conduct pilot studies to develop sampling protocols and to test the basic experimental design for contrasting the wildlife values of young, mature, and old-growth forests. The sampling protocols resulting from the pilot studies were implemented in 1984-86 across broad areas of the Cascade Range in southwestern Washington and Oregon, the Oregon Coast Ranges, and the Klamath Mountains of southwestern Oregon and northern California. Naturally, improvements were made to the protocols as time passed. A tremendous amount of experience in sampling was gained.

Our goal in this series is to compile the extensive experiences of our collaborators into a collection of methodology papers providing biologists with pilot study-type information for planning research or monitoring populations. The series will include papers on sampling bats, aquatic amphibians, terrestrial amphibians, forest-floor mammals, small forest birds and arboreal rodents, as well as papers on using telemetry for spotted owls studies and a guide to bird calls.

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Abstract

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Three arboreal rodents are sensitive indicators of forest ecosystem function in the Pacific Northwest. The northern flying squirrel (*Glaucomys sabrinus*) is mycophagous, cavity-nesting, and a major prey of the spotted owl (*Strix occidentalis*). The red tree vole (*Phenacomys longicaudus*) is restricted to trees and may prove sensitive to forest fragmentation. The Douglas' squirrel (*Tamiasciurus douglasii*) responds sharply to fluctuations in conifer seed abundance. Live-trapping and mark and recapture methods can be used to estimate densities of northern flying squirrels and some other rodents in contiguous areas of homogeneous vegetation (stands). We recommend 10- by 10-meter grids with 40-meter spacing and two traps per station—one in a tree and one on the ground. Trapping should be done in spring or fall. Techniques are lacking for red tree voles; searching felled trees for nests holds promise. Direct observation can be used to obtain indexes of abundance for Douglas' squirrels.

Keywords: Northern flying squirrel, red tree vole, Douglas' squirrel, bushy-tailed woodrat, dusky footed woodrat, live-trapping, small mammals, density estimation, Oregon, Washington.

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Introduction

Arboreal rodents in the mesic Pacific Northwest Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), mixed conifer, and mixed evergreen forests include the northern flying squirrel (*Glaucomys sabrinus*), the Douglas' squirrel (*Tamiasciurus douglasii*), and the red tree vole (*Phenacomys longicaudus*). The flying squirrel occurs in forested regions over most of northern North America (Wells-Gosling and Heaney 1984), but the Douglas' squirrel is limited to coastal British Columbia, western and central Washington and Oregon, northern California, and the Sierra Nevada (Hall 1981). The red tree vole is even further restricted in its distribution to western Oregon and northwestern California (Hall 1981). All three species are associated with late seral stages of Douglas-fir forest development, although all may be found in young, closed-canopy forests (Carey 1989). Associated with the arboreal rodents are the semiarboreal Townsend's chipmunk (*Tamias townsendii*), bushy-tailed woodrat (*Neotoma cinerea*), and in mixed conifer and mixed evergreen forest types in Oregon and California, the dusky-footed woodrat (*N. fuscipes*).

Several references should be reviewed before a study of arboreal rodents is begun. Green (1979) provides advice on how to design studies and develop a sampling plan. Hurlbert (1984) discusses the dangers and consequences of a common faulty design—pseudoreplication. Hayne (1976) provides a critique of small mammal studies and makes recommendations on how to design such studies. White and others (1982) discuss in detail the design, conduct, analysis, and interpretation of capture-recapture studies. Otis and others (1978) and White and others (1978, 1982) describe program CAPTURE (which can be used on mainframe computers or microcomputers). Formulation of specific objectives is imperative for proper design and efficient study. We will not address experimental design or sampling plans in this paper but will address methods for estimating relative abundances, population sizes, and densities. We focus on the most appropriate population unit ecologically—the local population found in a contiguous area of homogeneous vegetation.

When we began research on wildlife communities in the Pacific Northwest Douglas-fir forests, guidance on sampling techniques was inadequate. Since then, we have gained considerable experience in studying arboreal rodent communities. We conducted 63 large-scale (>1,000 trap-nights) trapping efforts in 18 stands in southwestern Oregon and smaller scale efforts at 27 additional sites. We expanded our studies to the Olympic Peninsula where we conducted 23 large-scale efforts in 14 stands. Through a cooperative research agreement with Oregon State University we conducted an additional 16 large-scale efforts on 8 sites in the Oregon Cascade Range. In our own efforts, we have caught 2,721 northern flying squirrels, 6,252 Townsend's chipmunks, 220 Douglas' squirrels, 406 bushy-tailed woodrats, and 148 dusky-footed woodrats. We counted more than 1,200 Douglas' squirrels in 47 stands (31 sampled in two years). And we collected 14 red tree voles and 177 tree vole nests (or nest fragments).

Our goal in this report is to provide advice on methodology and the kinds of data the methodology will produce. Many wildlife sampling techniques incorporate both art and science, but we have tried to be as precise as possible and to provide a rationale for our recommendations—some rationale is intuitive, some statistical. First, we provide information on the biology of the arboreal rodents and their potential usefulness as ecological indicators. Next we discuss the arboreal rodent as a target for measurement; specifically, how easily they can be studied. Finally we discuss live-trapping, direct observation, and counting nests and middens as ways to estimate arboreal rodent abundance.

Arboreal Rodents as Ecological Indicators

Wildlife populations are measured for many reasons. Sometimes a species is of particular interest per se, a common situation in research. Threatened species and game species are often of particular interest to managers. In wildlife management and research, species are often chosen for monitoring because they are thought to be representative of a larger class of vertebrates, sensitive to land management activities, and reasonably amenable to study (they can be observed or captured in numbers sufficient for detecting differences among treatments or over time). Species differ markedly in representativeness, sensitivity, and ease of study. We studied arboreal rodents because they are important prey for the spotted owl (*Strix occidentalis*).

The Northern Flying Squirrel

The northern flying squirrel is threatened in the Eastern United States, but we know of no special status accorded this species in the Pacific Northwest. It is of special interest in the Pacific Northwest, though, because it is the most important prey of the spotted owl in the Douglas-fir forests of Oregon and Washington (Forsman and others 1984).

The flying squirrel seems sensitive to timber harvests, and our preliminary data from the Oregon Coast Ranges indicate that the squirrel may not do well in second-growth forests. The reason could be lack of den sites, because we have, in the short-term, used nest boxes to attract squirrels to young stands. Principal limiting factor for the flying squirrel likely is the availability of cavities and nest sites. Flying squirrels use old woodpecker (Picidae) cavities and natural cavities for nests; healthy woodpecker populations may be required for dense flying squirrel populations.

Preliminary results of the old-growth program community studies suggest that cavity users as a group find old growth the optimal environment (Carey 1989). One of the major differences between intensively managed stands and natural stands of the same age or tree-size class is fewer standing dead trees in the managed stands. Large (>50 centimeters in diameter at breast height [d.b.h.]) standing dead trees are essential for both cavity-using birds and cavity-using mammals; both groups prefer even larger snags (>100 centimeters d.b.h) (Carey and others, in press). Flying squirrels are strict mycophagists in the Pacific Northwest; they feed principally on hypogeous fungi (Maser and others 1985, 1986; McIntire and Carey 1989). Many of these fungi are ectomycorrhizal, as they form a symbiotic relation with living trees. Other hypogeous fungi are often associated with large, decaying fallen trees; a

danger in second-growth forests is that forest management may substantially reduce the abundance of well-decayed fallen trees (Maser and Trappe 1984). Other small mammals rely heavily on fungi, too (Maser and others 1978a, 1978b). Thus the abundance of northern flying squirrels will reflect the impacts of forest management on the dead tree component of the forest ecosystem and also will reflect the impact of management on cavity-using wildlife and mycophagous wildlife.

The Douglas' Squirrel

The Douglas' squirrel is closely tied to abundance of conifer seed. Inter-year variation in seed production may be the single most limiting factor for Douglas' squirrels (Smith 1970, 1981). Seed production in Douglas-fir increases with size and age of tree. Position in the canopy and degree of insolation of the crown are also important (Eis and others 1965; Garman 1951, 1955). It may be that the old, dominant trees and diverse genetic stock contained in naturally regenerated late seral forests provide a more reliable minimum seed crop for Douglas' squirrels than can be provided by even-aged, genetically uniform, second-growth stands; synchrony in cone crop failures is common in young forests, even among stands on markedly different sites (Eis and others 1965). Crossbills (*Loxia* spp.), pine siskins (*Carduelis pinus*), red-breasted nuthatches (*Sitta canadensis*), and Townsend's chipmunks also depend on conifer seed production (Smith and Balda 1979). Indeed, it has been suggested that some of the seed-eating birds may be confined to old growth in winters of wide-spread poor cone crops (Manuwal and Huff 1987).

Although the Douglas' squirrel and northern flying squirrel use the same kinds of nest sites, no one has suggested that nest sites are limiting to Douglas' squirrels; indeed Smith (1968) felt the opposite and reports that Douglas' squirrels use a larger variety of nest sites than do flying squirrels.

The Red Tree Vole

The red tree vole lives (nests, feeds, breeds, sleeps) in trees. It is a small animal and may not be well suited either physically or psychologically to moving long distances over land (Benson and Borell 1931, Howell 1926, Taylor 1915). Inability to cross nonforested areas may be the most limiting factor for colonization of second-growth forest by these voles (but their ecology is not well described). The red tree vole may be highly sensitive to forest management at the level of the landscape; in other words, the pattern of cutting, rate of cutting, and the rotation age will determine if the red tree vole persists in future forests. This vole seems closely associated with old growth (Carey 1989; Corn and Bury 1986; Meiselman and Doyle, in press).

Arboreal Rodents and Spotted Owls

The spotted owl is one of the driving forces in the management of public forests, especially mature and old-growth forests, in the Pacific Northwest (Gutiérrez and Carey 1985, Marcot and Holthausen 1987). The northern flying squirrel, the red tree vole, the bushy-tailed woodrat, and the dusky-footed woodrat are the main prey of the spotted owl (Forsman and others 1984), and their patterns of abundance may account for the requirement of owls for large areas of old growth (Carey 1985, Carey and others 1990). Densities of flying squirrels, red tree voles, and woodrats could be

the best measures of spotted owl habitat other than the behavior of the owls themselves. Flying squirrels are most important to spotted owls in the Douglas-fir and western hemlock forest of Washington. The bushy-tailed woodrat and red tree vole join the flying squirrel as important prey in the Douglas-fir forests of western Oregon. All four species (flying squirrel, red tree vole, bushy-tailed woodrat, and dusky-footed woodrat) are present and eaten by owls in the mixed conifer and mixed evergreen forests of southwestern Oregon and northern California (Forsman and others 1984).

Live-Trapping Flying Squirrels

Trapping with live traps is the most effective way to count northern flying squirrels, Townsend's chipmunks, and woodrats. Flying squirrels are not easy to trap, but we have developed a reasonably reliable technique. In closed canopy forests in the Oregon Coast Ranges, capture rates in spring and fall ranged from 0.50 squirrels per 100 trap-nights in poor habitat to 25.50 squirrels in the best habitat; the mode was 2.5 squirrels per 100 trap-nights. On the Olympic Peninsula, where densities are low, captures rates were 0.1-1.2 flying squirrels per 100 trap nights. Chipmunk captures in the Coast Ranges were 0.50-17.50 per 100 trap-nights with a mode of 6.5 per 100 trap-nights. There were also few chipmunks on the Olympic Peninsula; captures were 0-5.3 per 100 trap-nights. Modal values for the Coast Ranges were based on 63 samples from trapping grids. Values for the Olympics were preliminary and are based on 10 grids. We caught fewer woodrats than sciurids, and our effort was spread over several habitats and seasons, so means and modes are not appropriate. Captures were 0-5 per 100 trap-nights for bushy-tailed woodrats and 0-8 per 100 trap-nights for dusky-footed woodrats (on 89 trapping grids and transects). Captures of Douglas' squirrels were few, even in stands where many Douglas' squirrels were observed. The Douglas' squirrels that were trapped seemed stressed. We do not recommend live-trapping of Douglas' squirrels. We could not catch red tree voles in either wire mesh or aluminum box live-traps.¹ Specifics of the technique follow; we recommend they be followed precisely—minor departures can significantly affect trapping success.

The Trap

Use single-door, collapsible, galvanized wire (16 gauge) fabric box traps with a mesh 1.3 by 2.5 centimeters (fig. 1). Larger meshes (for example 2.5 by 2.5 centimeters) allow some squirrels (and chipmunks) to escape or to get their heads caught in the wire mesh. The trap dimensions should be 41 by 13 by 13 centimeters and should provide enough space for a nest box behind the treadle. Provide nest boxes with bedding (nonabsorbent polyethylene batting).

Nest boxes can have five sides and can be constructed of plywood, or nest cups can be fashioned from 1.9-liter waxed paper milk cartons (two cups from each carton). Enclose the rear three-quarters of the traps with plastic litter bags, 3.8-liter waxed paper milk cartons, or other water-repellent, windproof material. Nest boxes and covers are necessary to minimize stress, hypothermia, and predation on trapped animals.

¹ Gillesberg, Anne-Marie; Carey, Andrew B. Abundance of nests of *Phenacomys Longicaudus* in Oregon. Manuscript in review.

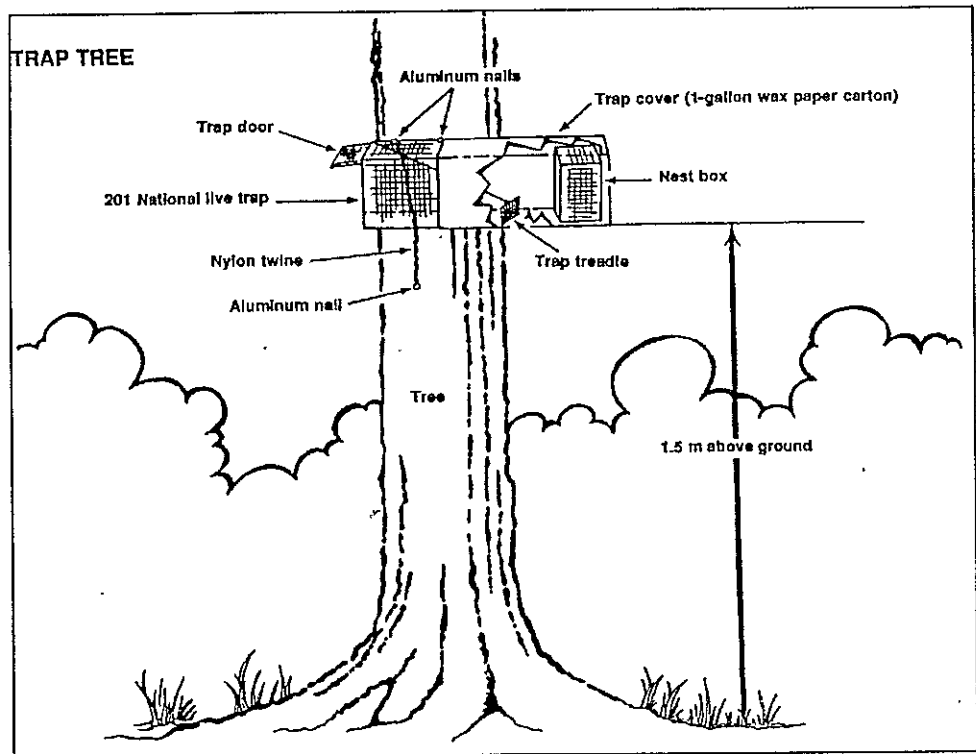


Figure 1—A live-trap in a tree.

Bait

Use a variety of grains mixed with molasses and peanut butter as bait (see appendix). The bait should be sticky enough to stay in a clump; squirrels often kick loose grain out of the trap.

The purpose of the bait is not only to help attract squirrels to the trap but also to provide a source of easily digestible food to aid in combatting hypothermia. Hypothermia is a serious threat to trapped animals throughout the year in the damp Douglas-fir forests of the Pacific Northwest. Mortality in traps can range from 0 to 39 percent of the flying squirrels, with an average of 9.3 percent in fall and 5.2 percent in spring in the Coast Ranges. Mortality rates for the chipmunk were 0-32 percent with an average of 7.9 percent in both fall and spring. Flying squirrels had mortality rates of 10 percent or more in 25 percent of our samples, and chipmunks had the same mortality rate in 40 percent of the samples. Mortalities were due primarily to hypothermia and predation. We felt the chances of an individual dying from hypothermia increased with repeated captures, low ambient temperatures, and heavy rain. The greatest single cause of high mortality seemed to be predation by spotted skunks (*Spilogale putoris*) and weasels (*Mustela* spp.), but it was not possible to judge which animals had been scavenged after dying from hypothermia or stress and which had been preyed on. We have had few problems with woodrats dying in traps.

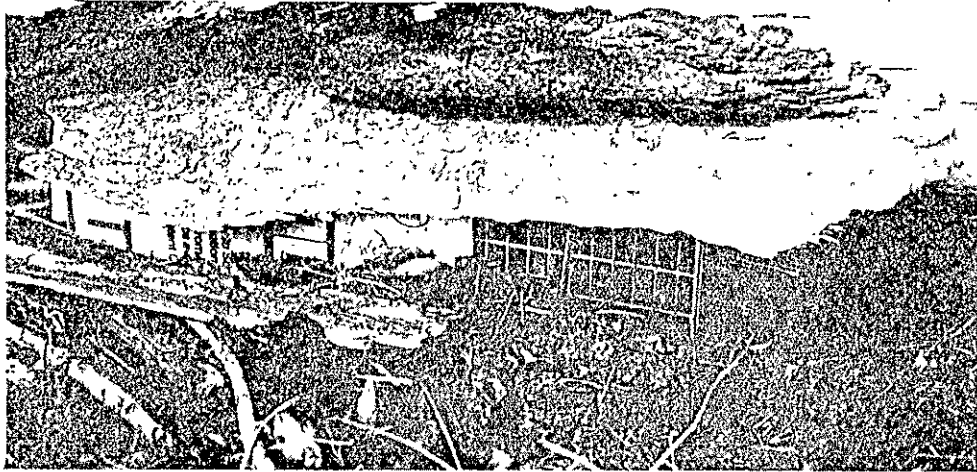


Figure 2—A live-trap on the ground.

Trap Placement

Place two traps within 5 meters of each sampling point. Place one trap on the ground, on or near a fallen tree or at the base of a standing tree (fig. 2). Ensure that the trap is firmly placed (it should not wobble or move with slight hand pressure). Cover the trap with rocks, moss, or woody debris to increase rigidity and to further insulate the trap. Adjust the trigger-to-treadle mechanism to ensure the trap will spring with a slight pressure. Prevent treadle "creep"; release of the door should be crisp. Set the trap treadle at an angle of 10-20 degrees from the bottom of the trap. Make sure the door will shut completely and lock in place. Most collapsible wire traps have sturdily constructed but malleable side braces that can be adjusted to make the trap rigid and the entrance square; a square entrance is necessary for proper door operation. Place a handful (1 tablespoon) of bait in front of the trap and a handful in the back of the trap. Hang the second trap 1.5 meters high in a tree within 5 meters of the sampling point. Choose the largest tree available. It is easier to correctly mount a trap on a large tree than on a small tree. Two aluminum nails 5 centimeters apart (horizontally) will hold the front of the trap flush with the tree. Hang the trap on the nails. Tie a string to one of the nails, pull the string across the outside of the trap, and tie it to a third nail about 0.5 meter below the center of the trap. The trap should be horizontal or on a slight incline with the front down to keep rain from flowing into the back of the trap. The edge of the entrance should be flush (or nearly so) with the tree, but there should be enough space to insert the cloth funnel of a handling cone between the trap and the tree (fig. 3). The side of the trap with the trigger mechanism should be away from the tree for easy adjustment and manipulation. The trap should be immobile. As with the trap on the ground, place moss or woody debris on top of the trap and ensure proper operation. Place a handful of bait in the rear of the trap.

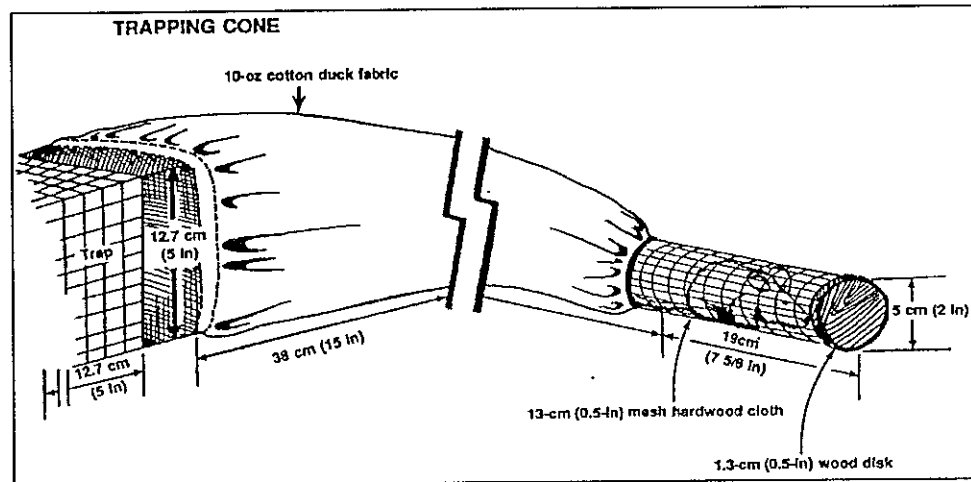


Figure 3—A cone for removing an animal from a trap.

We believe these instructions will help increase trapping success, but we have not tested these procedures against alternative procedures (no moss or debris on traps, and other variations). Large-scale trapping is labor intensive, and standardizing the trapping technique is important to reduce the variability in captures due to differences among trappers. If many trappers are used, they should be systematically rotated among trap sites, especially if some are less experienced than others. Inexperienced trappers can learn by observing the results obtained by experienced trappers, and experienced trappers can observe and critique the techniques of the inexperienced trappers. And variability due to differences among trappers would be equally distributed over the sites studied.

We believe the two placements (ground and tree) are necessary for studying northern flying squirrels. Squirrels change their preference for tree traps versus ground traps with site, season, stand type, or a combination of factors; we do not know why. Squirrels in one old-growth stand showed a 7-to-1 preference for ground traps; in another old-growth stand they preferred tree traps 3 to 1 over ground traps. Tree traps generally were more effective in old growth and in the fall, and ground traps were more effective in young stands and in the spring (table 1). Squirrels showed no overall preference for traps in trees versus traps on the ground in old-growth (57.3 ± 3.9 , SE, percent of captures), mature (56.0 ± 4.3 percent), or young stands (44.8 ± 4.4 percent). The percentage of flying squirrels caught in the traps in fall (68.2 ± 3.8 percent) was greater than in spring (45.9 ± 2.5). The sum of the two effects (age and season) was that 74-75 percent of the flying squirrels caught in mature and old-growth stands in fall were caught in tree traps, but only 39 percent of the flying squirrels caught in spring in young stands were caught in tree traps (table 1). Townsend's chipmunk showed a 2-to-1 preference for ground traps, the dusky-footed woodrat showed a 7-to-1 preference for ground traps, and the bushy-tailed woodrat showed a 3-to-1 preference for ground traps. These differences were statistically significant ($P < 0.01$), but we caution the reader that there were confounding factors not accounted for: stand type, season, year, and repeated measures on the same stands, in different seasons and years.

Table 1—Percentage of northern flying squirrels captured in traps in trees versus traps on the ground in fall and spring in young, mature, and old-growth stands, Oregon Coast Ranges, 1986-88

Season	Captures in tree traps by stand type		
	Young	Mature	Old growth
	----- Percent -----		
Fall	58 ± 8	75 ± 4	74 ± 4
Spring	39 ± 4	51 ± 3	49 ± 1

We think that the trap preferences of flying squirrels have to do with the way squirrels move through the differently structured stands—moving along the ground in young stands and from tree to tree in old stands. This hypothesis also explains the relation between tracks left on smoked track plates and the actual numbers of individual northern flying squirrels using the stand. Track plates overestimated abundance in young stands and underestimated abundance in old growth (Carey and Witt, in press). There are other explanations for the differential use of traps on the ground versus in the trees; for example, food (hypogeous fungi) could be less abundant but evenly distributed in young stands but clumped in abundance (perhaps with the distribution of clumps changing seasonally) in old growth. The former condition would call for a foraging strategy of systematic ground searches over the stand; the latter for concentrated foraging in small areas, with tree-to-tree flights across a stand to the foraging areas.

In stands with many Townsend's chipmunks, two traps are necessary just to keep the diurnal chipmunks from occupying both traps at particular stations, thereby precluding capture of the nocturnal flying squirrel at those stations. Exclusion of nocturnal flying squirrels from traps by diurnal chipmunks would lead to biased estimates. We often caught more chipmunks than flying squirrels even with a surplus of traps.

Season of Trapping

We found our highest rates of capture for flying squirrels were in the spring (April-June) and fall (October-November). Summer was a particularly poor time to trap; we had rates as low as one capture per 900 trap-nights; the fall rate for the same stand was one capture per 150 trap-nights. Fall and spring rates generally are two to three times the summer rates. We have not trapped in winter. Success in trapping flying squirrels seemed to be related to rainfall; for example, in one old-growth stand we caught one new individual per 38 trap-nights in early October before the summer drought was broken and one individual per 18 trap-nights in late October after a period of rain. Rain stimulates the fruiting of hypogeous fungi and a concomitant increase in foraging activity by the squirrels.

Trapping Effort

Trapping effort has four independent variables: the number of traps per trap-station, the spacing between trap-stations, the number of trap-stations, and the number of nights the traps are left open. The number of trap-stations, the spacing between stations, and the movements of the species being trapped determines the area being trapped. Traps should be placed in a square or rectangular grid with more than five rows and five columns if capture-recapture or removal methods for estimating population size are being used (White and others 1982).

For indexes of relative abundance, grids or lines may be used; for example, two lines 20 meters apart, each with 25 trap-stations and 20 meters between stations (a total of 50 trap-stations with two traps per station, or 100 traps). We used the index suggested by Nelson and Clark (1973). Effort is the number of traps multiplied by the number of nights the traps are left open; one-half a trap-night is subtracted for each trap sprung (either catching an animal or not catching an animal). Results are reported by species as captures per 100 trap-nights. We caution, however, that captures per trap-night are affected by extraneous variables such as habitat, weather, bait, condition of traps, trapper experience, capture history of the target population, and other influences on the behavior of the target species. These influences can be quite independent of the target population density.

Number of traps per station—We recommend two traps per station because of the range in preference for tree traps versus ground traps and the relatively high capture rates for nontargeted species (for example, the high rate of chipmunk captures when flying squirrels are the target). Other animals routinely caught include the spotted skunk, woodrats, mountain beaver (*Aplodontia rufa*), long-tailed weasel (*Mustela frenata*), and brush rabbit (*Sylvilagus bachmani*). Small mammals (*Peromyscus* spp., *Clethrionomys* spp., *Microtus* spp.), large mammals (*Cervus elaphus*, *Odocoileus hemionus*, *Ursus americanus*), wind, and rain can spring traps. Two traps at a station help ensure that all individuals of the target species have ample opportunity for capture. Lack of interference from nontargeted species is important to obtain sufficient recaptures for density estimates and to study microhabitat preferences. Our mean trap occupancies were 3.5 ± 0.9 percent for flying squirrels, 6.8 ± 0.5 percent for chipmunks, 1.2 ± 1.0 percent for dusky-footed woodrats, 0.8 ± 0.4 for bushy-tailed woodrats, and 0.4 ± 0.1 for Douglas' squirrels. Total trap occupancy averaged about 10 percent, which we feel is optimal for studies of density and habitat use.

Spacing between stations—For the probability of capture to be reasonably high, at least four trap-stations should be present in each squirrel's home range. We used the computer program CAPTURE (Otis and others 1978; White and others 1978, 1982) to calculate the mean maximum distance an animal has moved between capture and subsequent recaptures (MMDM), which can be used as an estimate of home range diameter. Flying squirrel MMDM varied slightly among stand types (57 trapping occasions), with movements in young stands (mean=112 meters) greater than movements in mature (82 meters) and old-growth stands (93 meters) (table 2). For chipmunks, MMDM varied by year and season, with spring movements (116 meters) being greater than fall movements (92 meters); MMDM did vary by age classes. The

Table 2—Mean maximum distances moved (MMDM) between subsequent recaptures for northern flying squirrels and Townsend's chipmunks in spring and fall in young, mature, and old-growth stands, Oregon Coast Ranges, 1986-88

Species and season	Distance moved by stand type					
	Young		Mature		Old growth	
	Mean	SE	Mean	SE	Mean	SE
----- Meters -----						
Flying squirrel:						
Fall	108	13.3	52	7.6	89	8.9
Spring	114	9.1	90	12.7	97	6.3
Mean	112	7.0	82	5.6	93	5.7
Townsend's chipmunk:						
Fall	93	13.8	83	5.4	93	5.0
Spring	119	11.9	110	7.2	118	8.1+

40-meter spacing we used resulted in 5 to 10 trap-stations per home range, on average, depending on age of stand for flying squirrels and year and season for chipmunks. The resulting initial probabilities of capture for flying squirrels averaged 0.51 ± 0.03 ; the mean probability of capture (sometime during a sampling period) was 0.79 ± 0.02 (over 61 trapping occasions). The mean probability of capture for chipmunks was 0.95 ± 0.01 (57 trapping occasions). These are high probabilities of capture, and we recommend a spacing of 40 to 50 meters.

We have less precise information on woodrats. Many of our woodrat captures were on trap lines, and we know that MMDMs calculated from trap lines are unreliable. Bushy-tailed woodrats moved a maximum of 379 meters between subsequent recaptures in grids. This distance is wider than the width of a 10-by-10 grid, which suggests that MMDMs this high would be underestimates. In spring and fall, the average MMDM (for 15 grids) was 85 ± 16 meters; the one summertime MMDM was 164 meters. Dusky-footed woodrats were caught in two grids in the fall; the MMDM was 35 meters (less than the distance between traps), which suggests very small movements.

We used paired trap lines with 20-meter spacing for exploratory studies and for sampling small stands and linear habitats, such as streamside riparian zones. We used 20 meters instead of 40 meters because there is more "edge effect" per trap in paired lines than in grids; that is, traps on the exterior lines of a grid, sample larger areas than interior traps do because they are the first traps encountered by animals adjacent to the grid. Each trap in paired lines is an exterior trap. Because there are only two lines, fewer traps are present in an animal's home range and probability of capture will drop if trap spacing is equal to that in grids. Given that movements range around 80-100 meters, halving the trap spacing maintains the trapping intensity. The

mean maximum distances moved calculated from lines were 31 ± 10 meters for bushy-tailed woodrats and 9 ± 6 meters for dusky-footed woodrats. This reduction in MMDM was expected given that lines sample movements in only one dimension. For bushy-tailed woodrats MMDMs were highest in linear (streamside) habitat (73 meters) and lowest in Douglas-fir stands (19-24 meters). Because we did most of our line-trapping for woodrats in the summer and used only ground traps, we caught no flying squirrels. The movement data suggest that 20-meter spacing would be good for bushy-tailed woodrats and flying squirrels, but that smaller spacing (for example, 15 meters) might increase captures of dusky-footed woodrats.

Number of trap stations—Trapping in grids is used when mark-recapture or removal estimators are used to estimate population size (and density). We have used grids ranging from 15 rows by 15 columns (36 hectares) to 7 by 9 (10 hectares) with 40 meters between traps. The largest grids were too large for many of the stands we wished to sample in the Coast Ranges, where stand size averages 29 hectares (Carey and others, in press). When we found a stand in excess of 36 hectares, we found considerable heterogeneity in the vegetation composition and structure within the stand, even though the stand covered only one major aspect and had been created by a single major regenerative disturbance. We feel that such large areas are not homogenous units to flying squirrels, but rather they are adjacent stands of the same (or similar) ages. We tried establishing large grids, because we thought large grids would produce many captures and provide greater flexibility in analysis and greater precision in our estimates of population sizes than small grids would. However, we gained no flexibility in analysis, and our coefficients of variation were only slightly smaller than when we decreased grid size to 10 by 10; for example, estimates from a 15 by 15 grid had a coefficient of variation of 3 percent; a 10 by 10 on the same area (in a different year) had an estimate with a coefficient of variation of 10 percent. We trapped in three stands where we reduced grid sizes from 12 by 12 to 10 by 10; coefficients of variation changed from 15 percent to 20 percent, 5 percent to 3 percent, and 31 percent to 16 percent, thereby indicating that grid size was not the governing factor for the coefficients of variation. We decided to use 10 by 10 grids for future trapping because they will fit in most (but not all) stands; they required less effort to lay out, fewer traps, and fewer people to check traps than the large grids. We found one experienced trapper could usually check the traps and mark and release the animals caught in a 10 by 10 grid without excessively long days, whereas a 12 by 12 grid usually required two people (a 44-percent increase in area and number of traps), and a 15 by 15 would require four or five people (area and traps were more than doubled). Statistically, grid size should reflect the anticipated number of individuals in the population, number of individuals that are caught, initial probabilities of capture, density of the target population, effective area sampled (often defined as half the MMDM), and the number of times the traps are checked (generally the number of nights the traps are left open). Given our initial probabilities of capture (about 0.50), modal densities of 1.5 flying squirrels per ha, MMDM of 100 meters, and high probabilities of capture within the trap period (0.80), formulas in White and others (1982, p. 167) suggest a grid width of 500 meters (25 hectares), which would be a 10 by 10 grid with 50-meter spacing or a 12 by 12 to 13 by 13 grid with 40-meter spacing. Smaller populations require larger grids and larger populations, smaller grids. The more nights the traps are left open, the smaller the grid has to be (within a limited range, say 4 to 8 nights).

Our recommendation for the number of trap-stations for line-trapping are subjective because we have not line-trapped areas with established population densities. Capture statistics give some guidance. Captures can be as high as one per 18 trap nights (best habitat) and as low as one per 336 trap-nights (poor habitat) during favorable trapping seasons in stands where animals are present. We settled on a standard effort of 300 trap-nights, two lines 20 meters apart with 25 trap-stations per line, traps 20 meters apart (50 stations, 100 traps), and trapping for 3 nights (effort of 300 trap-nights). It is important to standardize because statistics on catch per unit of effort are not directly comparable if the spacing between traps or between lines differ (length of line is probably not as important to standardize). Data from lines can be used as presence-absence data, ranked data, or relative abundances, depending on the results (Carey and others 1981). All such measures, however, are more subject to influences on probabilities of capture than are estimates of population size or density based on mark and recapture methods. It is wise to trap on at least two different occasions when line-trapping, because catchability can vary week to week.

Generally the catch per 100 trap nights is positively correlated with density; for example, captures of flying squirrels had a Pearson correlation of 0.46 ($p=0.00$) and a Spearman rank correlation of 0.63 ($p=0.00$) with density over 62 trapping occasions. Captures of Townsend's chipmunks had a Pearson correlation of 0.71 ($p=0.00$) and a Spearman's rank correlation of 0.69 ($p=0.00$) over 62 trapping occasions. These correlations are based on treating the same data in different ways and probably would be lower if the correlations were based on independent samples. It is apparent that the correlations are not perfect (1.0). Care should be taken to standardize effort; contrast trap areas simultaneously, in pairs, or randomly with respect to time; and sample at least twice (to get an average).

The relation between the number of individuals captured and the population size is clearer than the relation between captures per unit effort and density. The number of individual flying squirrels captured (2 to 58) was highly correlated with population size estimates (2 to 68; $r=0.92$; $p=0$). A simple linear regression of size on individuals was significant ($p=0$) and explained 84 percent of the variation in population size; the slope was 1.1 and the intercept did not differ significantly from zero ($p=0.11$). The regression of chipmunk population size on the number of individual chipmunks caught was also very good ($r=0.99$; $p=0$), with a slope of 1.1 and 99 percent of the variance in population size explained by the number of individuals captured. These regressions span three years, two seasons, and three habitat types. Our results suggest that an index based on the number of individuals captured (per 100 trap-nights or per 100 meters of a standardized trap-line) might be better than an index based on total captures. Again, these results are based on treating the same data differently and probably are better than results from independent samples would be.

Number of trap-nights—The final component of effort is the number of nights that the traps are left open. Three things should be considered in deciding on the number of trap-nights. First, the overall sampling period should be relatively short to meet the assumption of demographic closure required by most analytical techniques; that is, the period should be short enough to avoid changes in the sampled population due to births, deaths, immigration, and emigration. Trapping should be done during a relatively homogeneous period of squirrel behavior; we have already discussed the

influence of season on trapping results. Second, the period should be long enough to result in a reasonable number of captures (greater than 20) and recaptures. Third, sampling periods must be short enough so that individual squirrels are not recaptured more than twice in 3 or 4 days because the stress of capture and recapture can lead to shock, hypothermia, and death. Initially we trapped for 8 consecutive nights. Because of problems with hypothermia and mortality, we now keep trapping periods short—3 or 4 nights (depending on the weather, 3 nights for cold, rainy weather; 4 nights for dry, warm weather). Then we close the traps for 3 nights and open them again for another 3 or 4 nights. Sixty of 63 trapping efforts for flying squirrels met the assumption of closure ($p > 0.05$); three did not meet the assumptions of the test (no behavior or heterogeneity effects) so the null hypothesis of closure could not be rejected (White and others 1982). Twenty-five of 52 trapping efforts for Townsend's chipmunks met the assumption of closure ($p > 0.05$), and 27 violated the assumptions of the test. We conclude that closure is not a problem with either an 8-night trapping period or two 4-night trapping periods separated by 3 nights. We had too few data on woodrats to test for closure.

Summary—For estimating densities of flying squirrels or chipmunks, we recommend trapping in spring or fall, using 10 by 10 to 12 by 12 grids, 40- to 50-meter spacing with two traps (ground and tree) per station, and two 3- or 4-night trapping periods separated by 3 nights. We expect this procedure would work well for woodrats, too, but we have not had sufficient experience sampling woodrat populations to be sure.

For estimates of relative abundance of woodrats, we recommend using two trap-lines 20 meters apart with 25 trap-stations 20 meters apart per line and two traps (on the ground) per station; traps should be left open for 3 or 4 nights. Spring, summer, or fall would be appropriate. Repeat sampling is recommended. Standardization of technique and experimental designs that account for weekly changes in trapability are recommended. We have not demonstrated that measures of relative abundance accurately reflect population size: caution in interpreting results is appropriate.

Hypothermic and Stressed Squirrels

Oral administration of a sugar (or sugar and electrolyte) solution can aid the recovery of squirrels suffering from trap stress (Guthrie and others 1967) and hypothermia. The solution can be carried in small bottles with eye-dropper caps. A few drops into the mouth of a lethargic squirrel (be careful not to drown the squirrel) will often revive the squirrel. Sometimes carrying the squirrel in a shirt pocket, in addition to administering the solution, will be necessary to warm and revive the squirrel. If a squirrel cannot be readily revived to a fully active state in the field, the squirrel should be held overnight. We have observed that releasing a lethargic or obviously weak squirrel will often result in the squirrel's death. An insulated box in a vehicle can be used to keep hot water bottles warm. Hypothermic squirrels can be held in such boxes during transport. We built a "squirrel hospital" for our field laboratory. The hospital consisted of eight small cubicles (just large enough to hold one squirrel, bedding, food, and water) in a plywood box. The box could be placed next to a heater when necessary and provided a secure shelter for recovering squirrels. Squirrels are subject to stress when handled, but this stress can be reduced by using a hardware cloth and cloth cone to remove the squirrels from the traps (see fig. 3). Ear tags can be affixed to animals in the cones. The sex, age class, and reproductive status of the animal also can be determined while the animal is in the cone.

Estimating Densities

Estimating the density of a population requires estimating two parameters: the population size (total number of individuals present) and the area sampled. Capture-recapture methods and removal methods can be used to obtain estimates of the population sizes of small mammals.

Dice (1938) suggests adding one-half of the diameter of the species' average home range to the perimeter of the grid to estimate the area sampled.

Estimating the area sampled—Area sampled can be estimated from the MMDM, telemetry data, assessment lines, or nested grids. The practical usefulness of these methods is overrated because of the difficulty in meeting assumptions and obtaining sufficient numbers of captures (White and others 1982). Nested grids in particular require more data than likely will be collected in the field (Wilson and Anderson 1985b). The MMDM method seems to be the method most amenable to practical implementation (Wilson and Anderson 1985a). The MMDM is used to calculate the area being sampled by adding a strip equal to half the mean MMDM to the area of the grid. The mean maximum distance moved is influenced, however, by spacing of the traps and by the inhibition of movement when animals are trapped; it may underestimate area sampled. We have collected a limited amount of telemetry data on flying squirrels. Our estimates of home range size based on telemetry do not differ greatly from home range estimates based on MMDM. Given a nominal area of 14.4 hectares for a 10 by 10 grid, a MMDM of 100 meters suggests the actual area sampled would be 16.8 hectares, 17 percent greater than the nominal area (thus density would be 17 percent lower than the nominal area would indicate).

Estimating population size—Two classes of estimators are used with mark and recapture live-trapping of closed populations: removal estimators and mark-recapture estimators. Removal estimators are based only on initial captures of individuals and are used when trap-associated mortality is 20 percent or more. When trap-associated mortality is 5 to 20 percent, removing the dead animals from the data set and adding them to the population estimate derived from the mark-recapture estimators may be preferable to using a removal estimator (White and others 1982). Simple mark-recapture estimators, such as the Petersen-Lincoln index and Chapman's (1951) modification of the Petersen-Lincoln index, assume that individuals do not differ in their initial probability of capture, the probability of capture does not change after an animal has been caught and released, and the probability of capture does not change with time over the sampling period (Otis and others 1978, Seber 1982, White and others 1982). These assumptions are labeled "heterogeneity" (H), "behavior" (B), and "time" (T), respectively. Violations of these assumptions necessitate the use of more complex, general models to obtain unbiased estimates. The models (M) are labeled after the assumption; for example, when individuals differ in initial probability of capture (heterogeneity), the MH model should be used. When probability varies with time, the MT model should be used, and so on for MB and MBH. Not all models have estimators. Using the more complex models requires a computer program like CAPTURE (Otis and others 1978, White and others 1982), which we used to examine our data for effects due to heterogeneity, time, and behavior (table 3). Chipmunks exhibited more individual heterogeneity and trap response (behavior) than did flying squirrels. Initial probabilities of capture for flying squirrels was 0.51 ± 0.03 ; recapture probability averaged 0.50 ± 0.03 . Chipmunks became "trap-happy": initial probability

Table 3—Percentages of samples showing heterogeneity, behavior, time, or multiple effects as reflected in mark-recapture model selection by CAPTURE for northern flying squirrels and Townsend's chipmunks, southern Oregon Coast Ranges, 1985-88

Model	Flying squirrel (60 trapping periods)	Townsend's chipmunk (61 trapping periods)
----- Percent of samples -----		
None ^a	5	15
No effects (0)	47	8
Heterogeneity (H)	15	26
Behavior (B)	8	28
Time (T)	0	2
BH ^b	8	8
TB	7	5
TH	5	3
TBH	5	5

^a Captures too few or no estimator exists.

^b Model BH is also the general removal model and was selected when trap-associated mortality exceeded 10 percent.

was 0.66 ± 0.03 , recapture was 0.79 ± 0.03 . Our population sizes were small for mark and recapture studies, ranging from 12 to 78 for chipmunks and from 8 to 107 for flying squirrels; only two flying squirrel and three chipmunk populations were larger than 60. When population sizes are small, the model selection procedure may not work well (Menkens and Anderson 1988, White and others 1982). Menkens and Andersen (1988) suggest using Chapman's (1951) method as an alternative to CAPTURE. The Chapman method lumps days into two periods, whereas CAPTURE treats each day as a separate mark-recapture period. Captures of individuals on any given day may be random with small populations; lumping days may reduce what seem to be effects of heterogeneity, time, or behavior. But there are no tests for time and heterogeneity when there are only two trap periods; we therefore estimated populations by using CAPTURE (and supporting documentation) and using Chapman's modification and comparing the two. Estimates of density were highly correlated ($r=0.88$ for chipmunks and 0.86 for flying squirrels) and quite similar: simple linear regressions showed intercepts of zero and slopes of 1.1 for chipmunks and 0.99 for flying squirrels ($t=1.40$, $p=0$). There were three outliers on the regression curve where CAPTURE removal models estimated very high populations compared to the Chapman estimate (and compared to all other estimates). Coefficients of variation of the Chapman estimates had fewer extreme values than those from CAPTURE (fig. 4); the average was 20 ± 315 percent. But Chapman estimates for chipmunks had lower coefficients of variation with fewer extreme values than did the CAPTURE estimates (4 ± 86 percent versus 11 ± 145 percent; fig. 4). About 20 percent of our trapping efforts produced either too few data or data such that CAPTURE would not work well, but for which the Chapman modification seemed to be able to produce a reasonable estimate. Thus the Chapman modification proved to be a useful adjunct to CAPTURE.

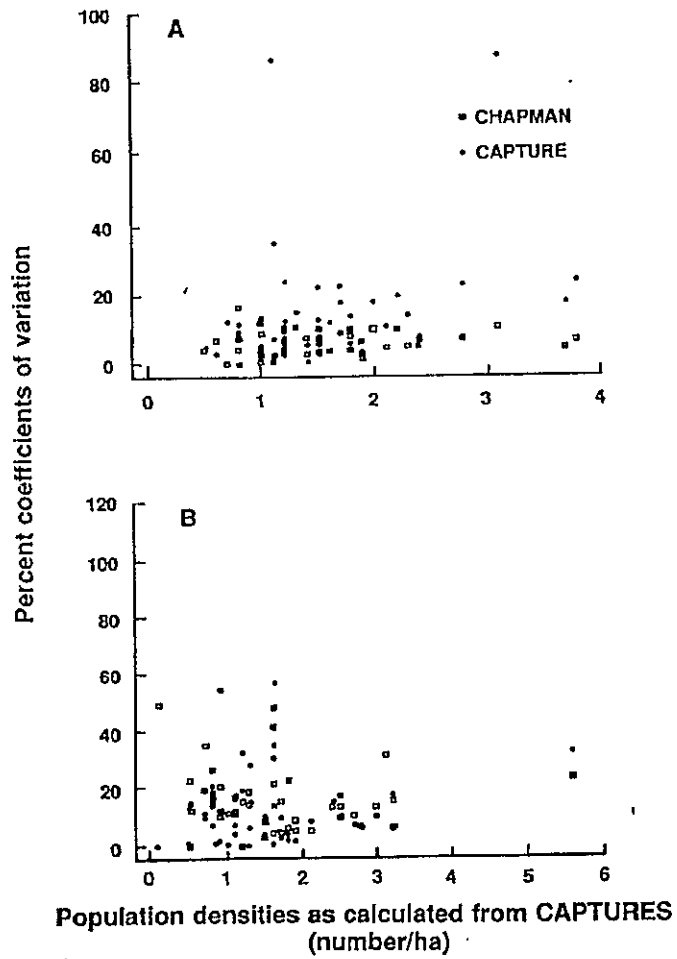


Figure 4—A comparison of coefficients of variation associated with density estimates for Townsend's chipmunks (A) and northern flying squirrels (B) derived from program CAPTURE and from Chapman's (1951) modification of the Petersen-Lincoln index.

Counting Douglas' Squirrels

Douglas' squirrels can be studied by direct observation because they are diurnal and they rapidly adjust to the presence of an observer. But their marked fluctuations in population size in response to seed abundance make Douglas' squirrels unattractive as indicators of overall forest condition in any one year or as representatives of large groups of species. But for representing those species dependent on Douglas-fir seed, the Douglas' squirrel is a good indicator species for evaluating the effects of forest management. Seed-eating birds are highly mobile and "irruptive" in terms of population size; their population sizes are much harder to measure accurately than are the sizes of the Douglas' squirrel populations (see Verner 1985 for a review of difficulties in measuring bird populations). Densities of Douglas' squirrels can be obtained by using a variation of the territory mapping method used for birds; relative abundance can be obtained with the variable-radius circular plot technique (Carey and Witt, in press; Reynolds and others 1980). Relative abundance could be expressed as numbers per 8-minute count. But it may be hard to relate the numbers per count to actual abundance without a study to calibrate the index to some independent estimate of density.

Because we did not try to estimate densities, we used a different measure of relative abundance. Douglas' squirrels are highly territorial and maintain home ranges about 100 meters in diameter (Smith 1968). We placed 12 counting stations 100 meters apart on a line transect through each of 47 stands. We visited each stand six to eight times and recorded the Douglas' squirrels within 50 meters of each station (trying to avoid counting the same squirrel twice). Then we determined if, across all visits, the station was "occupied" by a Douglas' squirrel. We used the proportion of stations occupied as an index to the abundance of Douglas' squirrels, akin to a measure of habitat saturation (assuming that ranges of Douglas' squirrels stay close to 100 meters in diameter). Relating our index to the range size seemed likely to be more representative of population size than would the mean number counted per 8-minute count. When we tallied our data by hand, it was evident that range sizes were unlikely to be less than 100 meters in diameter (we had few occasions when more than four squirrels would be counted from a station and few occasions when each station had one squirrel or more). Our index values ranged from 0 to 0.92, with a median of 0.42 and quartiles of 0.25 and 0.58, which suggest the index was sensitive to a wide range of squirrel densities. We counted 1,156 squirrels in 2 years of sampling, or an average of 21 squirrels per stand in 1986 and 10 squirrels per stand in 1985. Daily modal counts were 0 to 6. Total counts per stand were 0 to 56.

A potential indirect measure of density of Douglas' squirrels is the density of their middens (large caches of unopened cones). *Tamiasciurus* spp. are noted for their central storage of food and strong defense of the cache. We spent considerable time and effort looking for middens over 3 years. We looked along the transects, around each of our trap stations (in the flying squirrel study), and as we worked in the woods. We found only two middens. We attempted to observe squirrels caching cones; few did. Those that did, scatter-hoarded the cones. It may be that the presence of the seed-eating Townsend's chipmunk in our study areas made central storage of large number of cones infeasible (the abundant chipmunks would raid the cache).

We used smoked aluminum track plates to record tracks of the Douglas' squirrel (Carey and Witt, in press). Track counts gave misleading indexes to the abundance of Douglas' squirrels.

Nests of Red Tree Voles

The red tree vole is highly specialized and has the potential to become threatened because of intensive forest management. It is very hard to study. No one has yet developed a reliable technique for capturing red tree voles other than climbing a nest tree, disturbing the nest, and grabbing the voles as they attempt to flee (Maser and others 1981). Tree voles were caught in pitfalls operated by old-growth program biologists (Carey 1989, Corn and Bury 1986), but there were few voles per unit effort. Meiselman and Doyle (in press) used strip transects to find and determine the use of tree vole nests in California. That has not been the case in Oregon (see footnote 1), where we rarely find nests of the type red tree voles use. Such nests may be used by northern flying squirrels or Douglas' squirrels; and the nests may be quite high in trees, which requires experienced tree climbers to determine occupancy. Nests usually are in the green foliage, often covered with moss or lichen, and sometimes in cavities. Populations of red tree voles are patchily distributed in the forest; no one has provided an explanation for this distribution. Thus one could visit apparently suitable habitat and not find red tree voles. These characteristics make red tree voles challenging subjects for research and poor candidates for monitoring by managers. In California, strip transects for red tree vole nests may prove useful for determining if, or how rapidly, red tree voles colonize second-growth forest. It might be possible, theoretically to use results of nest searches as indexes to population size. Searching felled trees for nests of red tree voles has been successful (see footnote 1). Over half the old-growth trees searched had nests; 117 nests or nest fragments were found in 50 trees. The abundance of nests suggests searches for nests may be used in conjunction with presale timber sampling for defect and commercial thinnings (when special arrangements are made as part of a sale contract). The relation between number of nests and number of red tree voles is unknown, however. And as with any indirect measure of relative abundance, calibration to actual numbers of red tree voles would be necessary to determine the sensitivity of nest counts as an index to abundance.

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Appendix

Equipment and Supplies¹

Pliers
Hammers
Pocket knife
Trap cone
Tweezers (4-inch round tip)
Weighing bag
Body bags and tags (plastic bags and write-in-the-rain labels for specimens)
Bottle with eye dropper (filled with a 5-percent sucrose solution)
300-gram pesola scale (an additional 500-gram or 1000-gram scale may be needed for woodrats)
Backpack (equipped to move traps)
Clipboard
Field notebook
Data sheet
Code sheet
Animal capture list
Pencils
Permanent marking pen
Compass
Vest
Fecal sample vials (10-20, 1-dram size)
Bait
Road and stand maps
Ear tags (model 1005-1 monel ear tag, National Band & Tag Co.)
Ear tag pliers (model 1005-1S ear tag applicator, National Band & Tag Co.)
Nylon twine
Aluminum nails
Flagging
Trap cover cartons (1 gallon, wax paper)
Nest box cartons (1/2 gallon, wax paper)
Bedding (polyester fiber stuffing)

Bait

Bait is a sticky mixture of rolled oats, peanut butter, and molasses. It should be just sticky enough to be pressed into a small ball. The mixture we use is about 12 parts oats, 4 parts peanut butter, and 1 part molasses.

¹ Use of a trade name does not imply endorsement or approval of any product by the USDA Forest Service to the exclusion of others that may be suitable.

Carey, Andrew B.; Biswell, Brian L.; Witt, Joseph W. 1991. Methods for measuring populations of arboreal rodents. Gen. Tech. Rep. PNW-GTR-273. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 24 p.

Three arboreal rodents are sensitive indicators of forest ecosystem function in the Pacific Northwest. The northern flying squirrel (*Glaucomys sabrinus*) is mycophagous, cavity-nesting, and a major prey of the spotted owl (*Strix occidentalis*). The red tree vole (*Phenacomys longicaudus*) is restricted to trees and may prove sensitive to forest fragmentation. The Douglas' squirrel (*Tamiasciurus douglasii*) responds sharply to fluctuations in conifer seed abundance. Live-trapping and mark and recapture methods can be used to estimate densities of northern flying squirrels and some other rodents in contiguous areas of homogeneous vegetation (stands). We recommend 10- by 10-meter grids with 40-meter spacing and two traps per station—one in a tree and one on the ground. Trapping should be done in spring or fall. Techniques are lacking for red tree voles; searching felled trees for nests holds promise. Direct observation can be used to obtain indexes of abundance for Douglas' squirrels.

Keywords: Northern flying squirrel, red tree vole, Douglas' squirrel, bushy-tailed woodrat, ducky footed woodrat, live-trapping, small mammals, density estimation, Oregon, Washington.

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