AN ABSTRACT OF THE THESIS OF

Rebecca L. Thompson for the degree of Master of Science in Wildlife Science presented on September 9, 1996. Title: Home Range and Habitat Use of Western Red-backed Voles in Mature Coniferous Forests in the Oregon Cascades

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William C. McComb

Short rotations associated with forest management practices in the Pacific Northwest may reduce the abundance of habitat features within home ranges of western red-backed voles (*Clethrionomys californicus*). I studied western red-backed voles and attempted to define habitat use to provide data that could be used to guide management of this species. I described home ranges and movements of western red-backed voles in 3 mature Douglas-fir stands in the southern Oregon Cascades. Red-backed voles were radio-collared in August and September 1994 (n = 12), and in July and August 1995 (n = 11). Telemetry locations were recorded hourly during the vole's active periods (dusk to dawn). I used the adaptive kernel method to estimate size of home ranges and core areas. Average sizes of home ranges were 0.13 ha for females (range 0.03 - 0.23 ha) and 0.74 ha for males (range 0.52 - 0.96 ha). Size of core areas averaged 0.02 ha for females (range 0.003 - 0.04 ha) and 0.17 ha for males (range 0.09 - 0.34 ha). Movements between successive telemetry locations averaged 12 m for females (range 5 - 19 m) and 30 m for males (range 24 - 43 m). Females exhibited bimodal patterns of activity, whereas males were active all evening.

Radio-telemetry and pitfall trapping were used to identify habitat used by western red-backed voles. Of the home ranges estimated in 1994, vegetative components and habitat features were measured within vole core areas and compared to measurements taken randomly in the remainder of the home ranges. Associations of vole abundance with coarse woody debris volume and organic soil relationships detected between red-backed vole abundance and volume of coarse woody debris at a stand or trap station level. Home range core areas were characterized by deep organic soil layers and large volumes of decayed logs. Deeper organic soil and greater volume of medium-diameter, decayed logs distinguished core areas from randomly selected areas of the home range. Because of the biases and assumptions associated with trapping data, the telemetry-based habitat associations in my study are stronger that those based on capture data. Nest sites of six adult females were located within or under decaying logs. Nest material consisted of moss, bark pieces, and lichen. Silvicultural prescriptions in coniferous forest stands that provide deep organic layers and high down log volumes should be conducted when managing future populations of western red-backed voles.

HOME RANGE AND HABITAT USE OF WESTERN RED-BACKED VOLES IN MATURE CONIFEROUS FORESTS IN THE OREGON CASCADES

by

Rebecca L. Thompson

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Dean of Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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HOME RANGE AND HABITAT USE OF WESTERN RED-BACKED VOLES IN MATURE CONIFEROUS FORESTS IN THE OREGON CASCADES

CHAPTER 1

INTRODUCTION

Coniferous forests in the Pacific Northwest have changed from predominantly mature and old-growth forests to young, even-aged forests that are managed on short rotations for timber (Harris 1984). Many structural features that develop in naturally regenerating forests over long time periods (broken top trees, snags, and large logs) are less abundant in even-aged forests managed for timber production (Spies and Franklin 1991). Wildlife that require these forest structures may have lower levels of abundance and population recruitment in young, managed stands (Hooven and Black 1976, Maser et al. 1978b, Rosenberg and Anthony 1993). Furthermore, clearcutting has created a fragmented landscape with large amounts of edge but little interior habitat that may reduce the suitability of these areas for some species (Harris 1984; Mills 1993, 1995). Thus forest managers are faced with the challenge of managing forests differently to accommodate these species.

Western red-backed voles (*Clethrionomys californicus*) are endemic to western Oregon and northern California with their distributions restricted to coniferous forests (Ingles 1965, Alexander and Verts 1992). Western red-backed voles make up a large proportion of the small mammal communities in mature (80 - 195 years old) (Spies and Franklin 1991) Douglas-fir forests (Doyle 1987; Corn et al. 1988, 1991; Gomez 1992) and they disperse spores of mycorrhizal fungi (Maser et al. 1978a, Maser et al. 1978b, Hayes et al. 1986, Maser and Maser 1988). Red-backed voles also are prey for northern spotted owls (*Strix occidentalis caurina*) (Forsman 1975, 1980; Thomas 1990), saw-whet owls (*Aegolius acadicus*) (Forsman and Maser 1970), martens (*Martes americana*), ermines (*Mustela erminea*), long-tailed weasels (*Mustela frenata*), and spotted skunks (*Spilogale gracilis*) (Maser et al. 1981).

Studies indicate that red-backed voles are absent or rare in clearcuts (Gashwiler 1970; Hooven and Black 1976; Raphael 1988; Mills 1993, 1995), thus the dispersal of hypogeous fungi, which forms an obligate symbiotic association with some tree species (Maser 1978b), and its availability as a food source for other animals, may be reduced in clearcut stands. Rosenberg et al. (1994) found the abundance of red-backed voles to be lower in managed, young forests (30-60 years old) than in old-growth stands (> 400 years). Raphael (1988), and Gomez (1992) found abundance of red-backed voles to be lower in unmanaged, young stands than in old-growth stands. In contrast, some investigators found no difference in abundance of voles in unmanaged young, mature (80-195 years old) (Spies and Franklin 1991), and old-growth stands (Corn et al. 1988, Aubry et al. 1991, Corn and Bury 1991, Gilbert and Allwine 1991).

Clearcut regeneration is the most widely used silvicultural system by state and private forest land managers, and the impact of even-aged forest management practices on long-term populations of red-backed voles is not known. It is likely that they will become less abundant as the forested landscape continues to change from old-growth and mature forests to managed young forests through intensive timber harvesting activity (Gilbert and Allwine 1991, Rosenberg et al. 1994).

Red-backed vole abundance and habitat associations have received moderate attention over the last decade, but the majority of these studies were conducted using live or death trapping in old-growth forests, naturally regenerated early seral stages, and/or young, managed clearcut stands (Gashwiler 1959, 1970; Hooven and Black 1976; Doyle 1987, 1990; Ruggiero et al. 1991; Mills 1993, 1995; Rosenberg et al. 1994). Only limited information has been collected on home range size of western red-backed voles (Hooven 1971, Tallmon and Mills 1994), and no home range data have been collected in managed second-growth forests. Recent advances in radio-telemetry have enabled radio-tracking studies to be performed on small mammals, and allow for less biased estimation of home range and habitat use patterns. The use of this method to estimate home range and high use areas, and to distinguish habitat selection by red-backed voles provides an opportunity to gain further insight into the habitat associations of this species.

The purpose of this study was to provide information describing summer home range size, temporal use patterns, and high use areas (core areas), and to describe the microhabitat features used by western red-backed voles in mature, managed Douglas-fir forests in the southern Oregon Cascades. A greater understanding of habitat components and space used by western red-backed voles are necessary to provide a basis for the management of this species.

My objectives were to: 1) estimate the size of summer home ranges and core areas of male and female adult western red-backed voles, 2) describe temporal movement patterns of male and female adult western red-backed voles, 3) describe specific microhabitat features selected by western red-backed voles within their home ranges, 4) estimate the relationship of home range size to density of selected habitat features, and 5) estimate the relationship between vole abundance and habitat characteristics selected within home ranges. The first two objectives are addressed in Chapter 2 and the last three in Chapter 3.

CHAPTER 2

HOME RANGES OF WESTERN RED-BACKED VOLES IN MATURE CONIFEROUS FORESTS IN SOUTHERN OREGON

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ABSTRACT

Home range and movements of western-red-backed voles (*Clethrionomys californicus*) were estimated using radio-telemetry in 3 mature coniferous forest stands in the southern Oregon Cascades during the summer of 1994 and 1995. Home range and core area size were significantly greater for male red-backed voles than females ($P_{home\ range} = 0.07$, $P_{core} = 0.01$), but did not differ between years ($P > 0.1$). Home range size averaged 0.13 ha (SE = 0.02) for females and 0.74 ha (SE = 0.08) for males. Core area size averaged 0.015 ha for females (SE = 0.002) and 0.173 ha (SE = 0.046) for males. Vole movements between successive, evening telemetry locations averaged 30 m (SE = 5.0) for males and 12 m (SE = 1.2) for females. Females exhibited bimodal patterns of activity, whereas males were active all evening.

INTRODUCTION

Western red-backed voles are endemic to western Oregon and northern California with their distributions restricted to coniferous forests (Ingles 1965, Alexander and Verts 1992). Vole abundance has been documented as greater in old-growth (> 195 years old) (Spies and Franklin 1991) Douglas-fir/western hemlock (*Pseudotsuga menziesii*/*Tsuga heterophylla*) stands than in mature (80-195 years old) (Spies and Franklin 1991) stands (Doyle 1987), and higher in upland regions than in riparian zones (Doyle 1987, 1990; Gomez 1992; McComb et al. 1993). Several studies have shown that red-backed vole populations are reduced or eliminated from sites after clearcut harvesting (Gashwiler 1970; Hooven and Black 1976; Raphael 1988; Mills 1993, 1995). This species disperses spores of mycorrhizal fungi (Maser et al. 1978a, 1978b; Hayes et al. 1986; and Maser and Maser 1988) and is prey for northern spotted owls (*Strix occidentalis caurina*) (Thomas 1990; Forsman 1975, 1980), saw-whet owls (*Aegolius acadicus*) (Forsman and Maser 1970), martens (*Martes americana*) ermines (*Mustela erminea*), long-tailed weasels (*Mustela frenata*) and spotted skunks (*Spilogale gracilis*) (Maser et al. 1981). Western red-backed voles are primarily nocturnal in the Cascades and remain relatively inactive during the daylight hours (Maser et al. 1981, Tallmon and Mills 1994).

Home range is defined as the area traversed by an individual animal in its normal activities of food gathering, mating, and caring for young (Burt 1943). Core areas have been defined as areas of concentrated use within a home range that probably contain the homesites, refuges, and most dependable food sources (Samuel et al. 1985, Seaman and Powell 1990). The core is used more frequently than other areas of the home range, and size is not strictly determined by the total home range size, but rather by the animal's behavior and resource distribution (Samuel et al. 1985, Seaman and Powell 1990). Home ranges for western red-backed voles in old-growth forests are reported to be 0.12 to 0.80 ha for females, and 0.30 to 4.6 ha for males (Hooven 1971, Tallmon and Mills 1994). Data have not been published to document size of home ranges for western red-backed voles in managed, second-growth forests. Further, identification of core areas has not been documented.

Estimation of morphological properties of home range increases our understanding of space use by animals. Size of home range has been related to food density, metabolic needs, and the efficiency of movement (Schoener 1981). The degree of overlap and exclusiveness of home ranges can indicate interspecific competition (Schoener 1981). The size and shape of home ranges when coupled with habitat requirements provide valuable tools for land managers that wish to manage for viable populations of a given species.

I estimated size of home ranges and core areas, and patterns of movement for western red-backed voles in managed, second-growth forests during the summers of 1994 and 1995 in the southern Oregon Cascades. I tested for differences between years in the size of home ranges and core areas to assess whether I could pool the 2 years of data. I hypothesized that males would have larger home ranges than females, like many other polygynous small mammals (Madison 1985; Wolff 1985, 1989). I also hypothesized that males would have larger core areas than females. I compared movements of males and females to detect if there were differences in distances and patterns of movement between gender.

STUDY AREA

The study was conducted in the southern Oregon Cascades in the Umpqua National Forest between 47° 54' and 47° 56' latitude in Douglas County (Figure 2.1 and 2.2). The study sites were located in the mixed-conifer zone (*Pinus-Pseudotsuga-Calocedrus-Abies*) (Franklin and Dyrness 1973) and were between 100 and 130 years in age. The mature coniferous forest stands originated from stand replacement fires and were commercially thinned in the 1970's (Rick Abbott, USDA Forest Service, personal communication). Overstories in the forest stands were dominated by Douglas-fir, with grand fir (*Abies grandis*), western hemlock, ponderosa pine (*Pinus ponderosa*), western white pine (*Pinus monticola*), and silver fir (*Abies concolor*) also present. Common understory shrubs included dwarf Oregon-grape (*Berberis nervosa*), creeping snowberry (*Symphoricarpos mollis*), and western serviceberry (*Amelanchier alnifolia*). A list of plant species found in the study areas is included in Appendix A.

The study area is managed by the United States Department of Agriculture (USDA) Forest Service under current federal forest management plans (USDA Forest Service, and United States Department of Interior (USDI) Bureau of Land Management 1994) and is designated as matrix land (Forest Ecosystem Management Assessment Team (FEMAT) 1993, USDA Forest Service and USDI Bureau of Land Management 1994). The study sites were located in the Diamond Lake Ranger District with elevation ranging from 945 to 1311 m. Climate is characterized by moderate winters and dry summers, and annual precipitation averages 12.2 cm (Franklin and Dyrness 1973). Most of the precipitation falls between October and May with snow cover common between November and March.

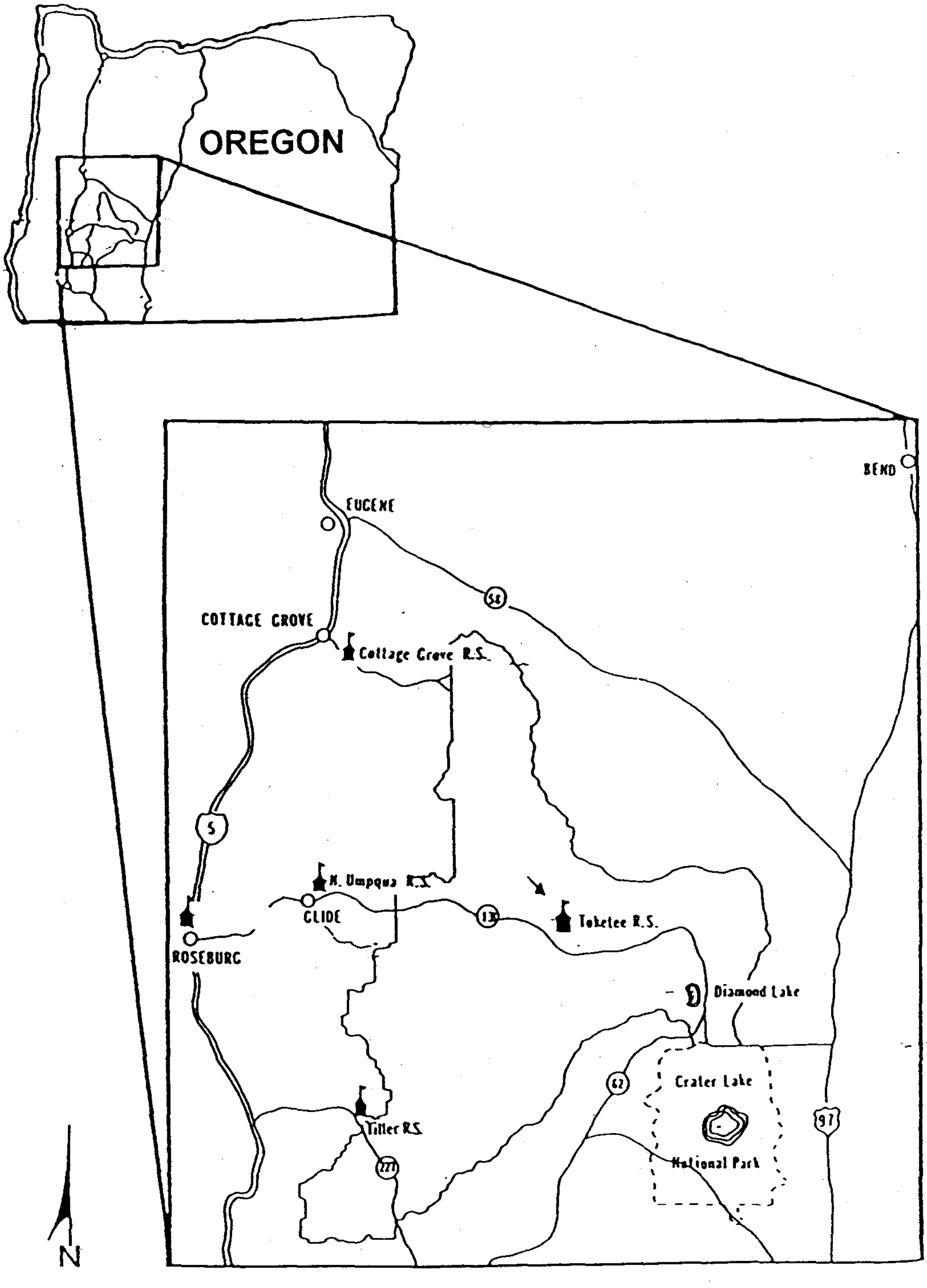

Figure 2.1. Map of study area and vicinity, Umpqua National Forest, Oregon.

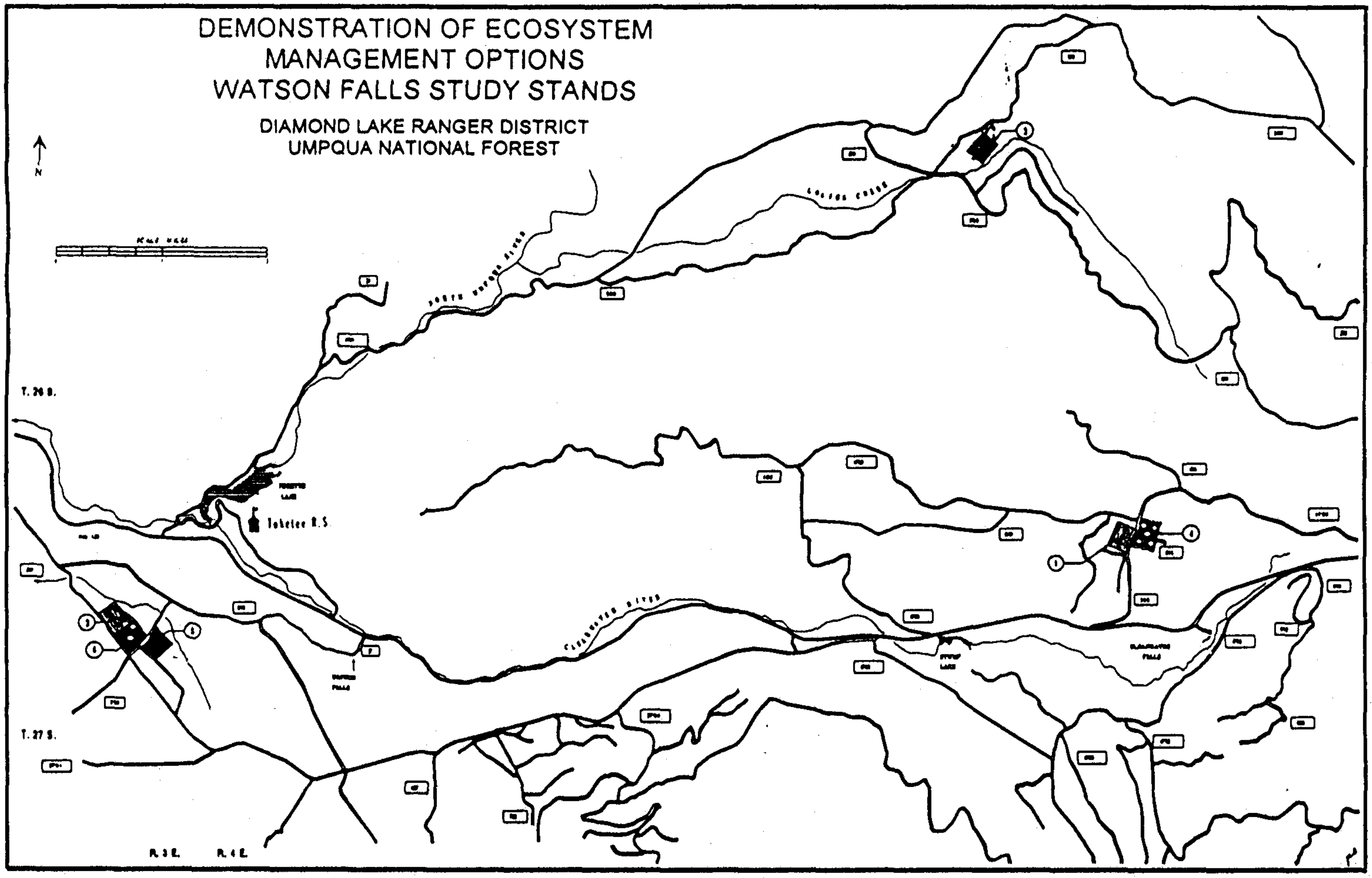

Figure 2.2. Locations of study stands in the Umpqua National Forest, Oregon. Stands are delineated by numbered, shaded rectangles. Radio-telemetry was conducted in stands #1, 5, and 6.

Rainfall totaled 2.2 cm in the summer of 1994, and 3.0 cm in the summer of 1995. Maximum and minimum temperatures during the months of the study averaged 27.8° C and 4.4° C in 1994 and 27.4° C and 6.4° C in 1995, respectively.

I selected 3 commercially thinned stands used in the Demonstration of Ecosystem Management Options (DEMO) project (DEMO 1996). The criteria I used for this selection was an abundance of western red-backed voles and presence of down logs. The stands averaged 16 ha with a minimum distance of 80 m between them. The mean volume of coarse woody debris in a stand was 141.5 m^3/ha (range 94.87 - 188.26 m^3/ha) (Appendix B). Preliminary trapping in these stands yielded an average of 4.0 red-backed vole captures/100 trap nights/stand (range 3.5 - 4.2 captures/100 trap nights/stand) (Amaranthus, M. P., Unpubl. data, USFS, PNW Research Station, Grants Pass, OR). Average basal area, stand age, trees/ha, year thinned, and elevation of individual stands are summarized in Table 2.1.

METHODS

Capture Methods

I live-trapped western red-backed voles within each stand in August and September, 1994 and in July and August, 1995 on a 9 x 8 grid with 20-meter spacing between trap stations. One Sherman live trap (8 x 9 x 23 cm) was placed at each grid point along natural log runways (if present). Traps were baited with fresh apples and oats and polyester batting was added to traps for insulation. I opened the traps at dusk to avoid capturing diurnal species and checked them after sunrise the following morning. All animals captured were identified to species, weighed, and sexed. All animals that were not radio-collared were released at point of capture. Red-backed voles > 20 g in weight were temporarily held in 21.5-liter containers (38 x 30 x 25 cm) with forest litter as bedding and apples for food until all the traps were checked and to allow the voles to recover from possible trap-induced stress.

Table 2.1. Average stand age (yrs), basal area (m^2/ha), trees/ha, elevation (m), and year(s) of thinning for 3 coniferous stands in the Diamond Lake Ranger District, OR.

Stand name	Age	Basal area	Trees/ha	Elevation	Year(s) thinned
Mowich #1	130	43.7	310	1311	1974
Watson Falls #5	100	51.6	382	945	1970, 1978
Watson Falls #6	100	45.4	446	945	1970, 1978

Radio-collaring Procedure

I radio-collared 24 voles in 1994 and 18 in 1995 with 1-gram model MD-2(C) radio-transmitters (Holohil Systems Ltd., Ontario Canada). All of the female red-backed voles were either lactating, pregnant, or in estrus. I was unable to discern the reproductive condition of the male voles. Since it is recommended that telemetry equipment be $\leq$ 5% of the animals body weight (White and Garrott 1990), only voles that were $\geq$ 20 grams were fitted with radios. The radio-collaring procedure required 2 people. One person effectively immobilized the animal by holding it by the tail and allowing its body to rest over their hand. The second person placed the collar around the vole's neck and tightened it securely. Once the fit was assured, the collar was fastened with a metal crimp and rotated so that the radio hung on the ventral surface of the neck, and the whip antenna was trimmed to the length of the animal's back. Each vole successfully collared was toe-clipped for individual identification. I held the voles for at least 15 minutes after collaring to ensure that the animals did not remove their collars and to allow them to recover from handling stress. I put more apple pieces in the container and also offered the voles a dilute mixture of Gatorade and water to prevent dehydration. Once their condition seemed stable, I released the voles at the point of capture. I waited at least 24 hours before tracking the animals to allow them a period of adjustment to the collars.

Radio-tracking Procedure

Radio-tracking was conducted during August and September, 1994 and July and August, 1995 using a model TR-2 Telonics receiver (Telonics, Telemetry-Electronics Consultants; Mesa, Arizona) and a hand-held 4-element H-antenna. Radio frequencies ranged from 164.097 to 164.973. From preliminary radio-tracking sessions, I determined that the activity of voles was greatest between dusk and dawn. Subsequent effort was concentrated during this period and hourly locations were taken on each vole every 2 to 3 days for up to 1 month or until the radio-signal was lost. Voles were located initially by obtaining a radio signal from 40 to 200 meters away. The animal was then approached to within 5 meters with the antenna attached, and then the animal was approached until it could be detected with only the coaxial cable. After the animal was located, a second person walked to 2 nearby grid points and took a distance and compass bearing on the animal's location (in effect, triangulating on the animal). I ensured that the angle between the 2 azimuths was between 60 and 120° to minimize possible error when converting azimuth intersections to UTM coordinates. I estimated my accuracy to be within approximately 2 meters of the vole's actual location by locating inert radios at the beginning of the study and by locating numerous slipped collars and dead radio-collared voles throughout the study.

Data Analysis

Home Range

Telemetry locations were analyzed using program CALHOME (Kie et. al. 1996). To determine the minimum number of telemetry locations required for home range analysis, I plotted each animal's home range size against number of telemetry locations in 5 location increments (Appendix C). An inflection point on the curve (visually estimated) indicated that an asymptote was reached. Asymptotes for individual voles were averaged among all animals. An asymptote was reached, on average, at 35 locations (range 25 - 60 locations, SE = 1.6), therefore only animals that had a minimum of 35 locations were used in the home range analysis. Tests for independence of observations were run using three indices of serial correlation: t^2/r^2 (the time to independence, Schoener 1981), ψ (psi, Swihart and Slade 1985a), and γ (gamma, Swihart and Slade 1986). Data were considered serial correlated when $t^2/r^2 < 1.6$, or > 2.4, $\psi > 0.6$, and/or $\gamma > 0.3$ (Swihart and Slade 1985b, 1986, 1987).

The adaptive kernel method (Whorton 1989, 1995) was used to estimate home range and core area size. This method is a non-parametric technique for analyzing spatial patterns of use in home range data (Whorton 1989). Utilization distributions are estimated by the adaptive kernel probability density function and describe the relative amount of time that an animal spends in any one place (Seaman and Powell 1990, 1996). Probability contours are home range boundaries that encompass a selected percentage of total space used by an animal (Seaman and Powell 1996). I used 95% utilization distributions to estimate home range size. The utilization distributions were converted into 95% probability contour estimates of home range size using a 30-cell x 30-cell grid. I modified the methods used by Clutton-Brock et al. (1982) and Samuel et al. (1985) to estimate core areas for each vole. I plotted utilization distributions vs. home range size and looked for a point of transition on the curve (Figure 2.3). The transition point represented the split between areas of heavily used portions of the home range (cores) and occasionally used areas. Probability contour estimates used to generate core areas ranged from 45-75% and reflected individual habitat use patterns of the voles. I used least squares cross-validation (lscv) to select a smoothing parameter for this analysis (Whorton 1989, 1995; Kie et al. 1996; Seaman and Powell 1996). Criteria for selecting a smoothing parameter included small lscv scores, continuity of polygons, and reduction of "white space" around location points (tighter fit of contours). An adaptive kernel estimator with $0.60h_{lscv}$ for the smoothing parameter (h = specified value of the smoothing parameter by CALHOME) met these criteria and best represented the observed spatial configuration patterns of red-backed voles in my study.

I used a one-way analysis of variance, blocking on stands, to compare female home range and core area size between years (SAS Institute Inc. 1987). I ran a power analysis to determine the power of this test. Power was considered adequate when $\beta \leq 0.20$. Dispersal out of the detectable range of the radios and high mortality of collared males resulted in small sample sizes ($n_{1994} = 2$, $n_{1995} = 3$). This prohibited me from using standard statistical tests, therefore I used 90% confidence intervals to evaluate male home range and core area size by year. I used one-way analysis of variances, blocking on stands, to compare home range size between sexes, and core area size between sexes. To increase the power of detecting a difference, and to reduce the probability of making a type II error, I used an alpha level of 0.10 for all statistical analyses.

Movement Patterns

Western red-backed vole movements were defined as the distance traveled

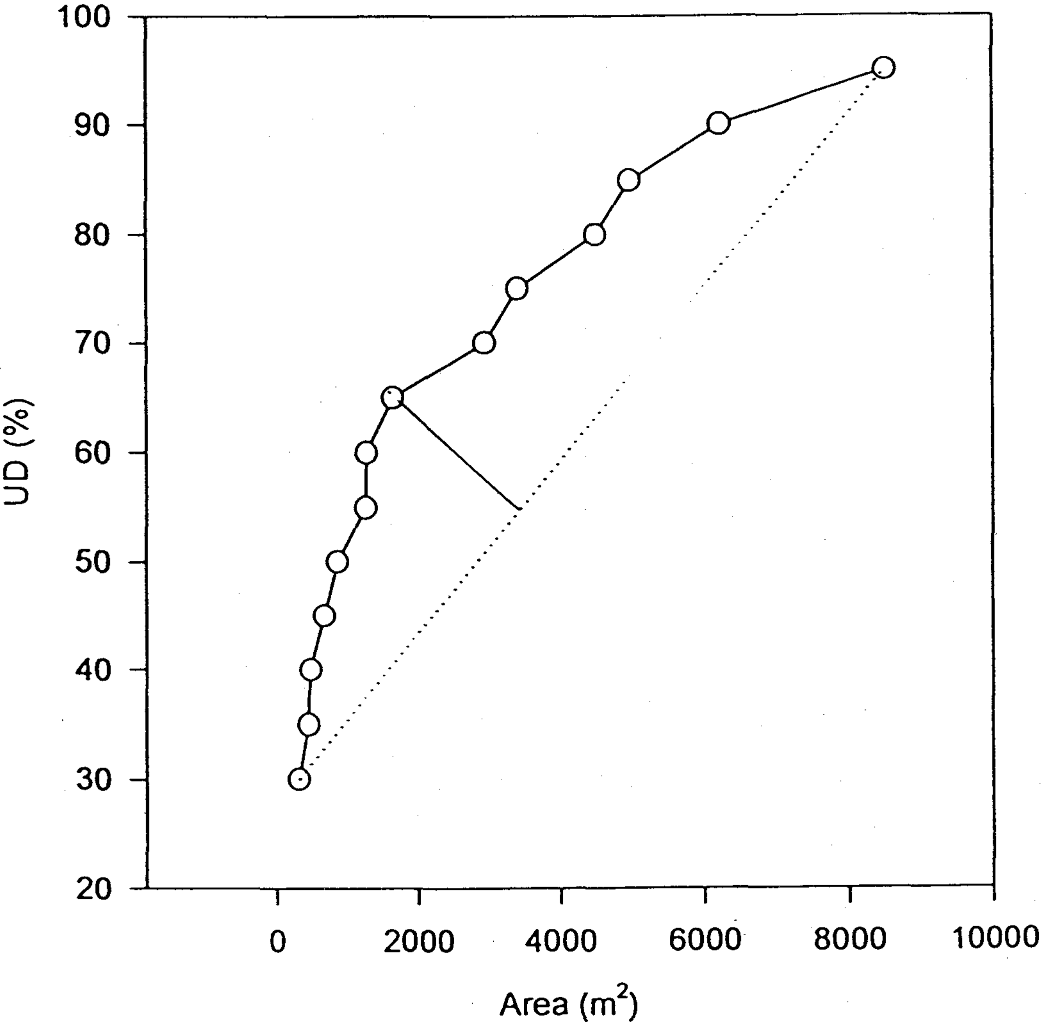

Figure 2.3. Utilization distributions (UD) vs. home range size (m^2). The core area UD (65) was determined by identifying the point of transition on the curve. The transition point represents the split between areas of heavily used portions of the home range (cores) and occasionally used areas.

between consecutive hourly observations. I averaged movement data for each hour sampled, from full tracking periods (2 to 4 weeks) for each animal. I plotted movement averages for each sex to detect trends. I calculated mean hourly distances moved per 8-hour telemetry period for individuals of each sex, averaged these values among voles, and pooled the data between the 2 years sampled. A two-sample t-test for unequal variances was used to compare means between sexes with alpha = 0.10 (SAS Institute Inc. 1987).

RESULTS

Home Range

Home ranges of red-backed voles tended to be elliptical or irregular in shape (Figure 2.4 and 2.5). Males had significantly larger home ranges than females ($P = 0.07$, $F = 79.75$, 1,1 df; Table 2.2). Male red-backed voles had an average home range size of 0.741 ha (range 0.521 - 0.961 ha), whereas female voles had a mean home range size of 0.135 ha (range 0.034 - 0.322 ha). Over half of the animals analyzed showed significant serial correlation among locations (average $t^2/r^2 = 1.22$, SE = 0.152; $\psi = 1.06$, SE = 0.186; $\gamma = 0.357$, SE = 0.057). I did not modify the data to eliminate serial correlation thus reported home range estimates may be underestimated.

Home range size of females did not differ between years ($P = 0.455$, $F = 0.85$, 1,2 df; Table 2.2). Ninety percent confidence intervals for size of home ranges for males during 1994 and 1995 overlapped, as did those for females, thus I was not able to reject the null hypothesis that means did not differ between years. Because of my small sample size, I had very little power to test this hypothesis ($\beta = 0.50$ for females, ES = 0.80, n = 9; $\beta > 0.90$ for males, ES = 0.80, n = 2) (Cohen 1988). To increase my sample size and power for the analysis of home range size, I pooled the data between years.

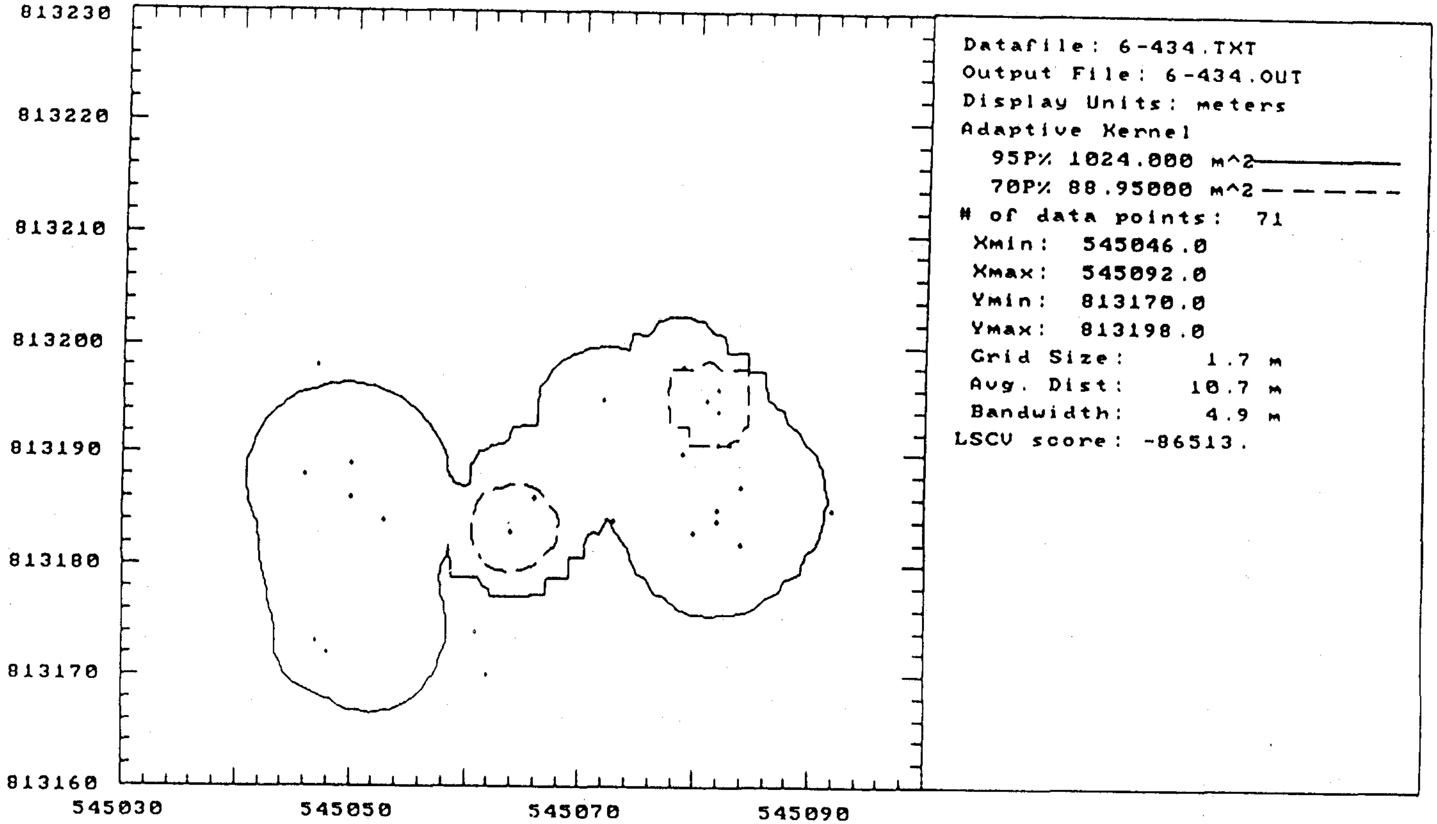

Figure 2.4. Representative home range configuration of a female western red-backed vole in the southern Oregon Cascades, 1995. The plot is of vole 6-434, stand #1. The outer solid line delineates the 95% probability contour. The area inside this contour = 1024 m^2. The two ellipses delineated by the dashed lines represent core areas. Total core area = 88.95 m^2. Xmin and Xmax are the minimum and maximum UTM coordinates on the X axis (m). Ymin and Ymax are the minimum and maximum UTM coordinates on the Y axis (m). Grid size is the size of each grid in the 30-cell by 30-cell grid used to determine the adaptive probability density function. Avg. Dist. is the average distance moved between successive telemetry locations. Bandwidth is the smoothing parameter determined by Least Squares Cross Validation (LSCV).

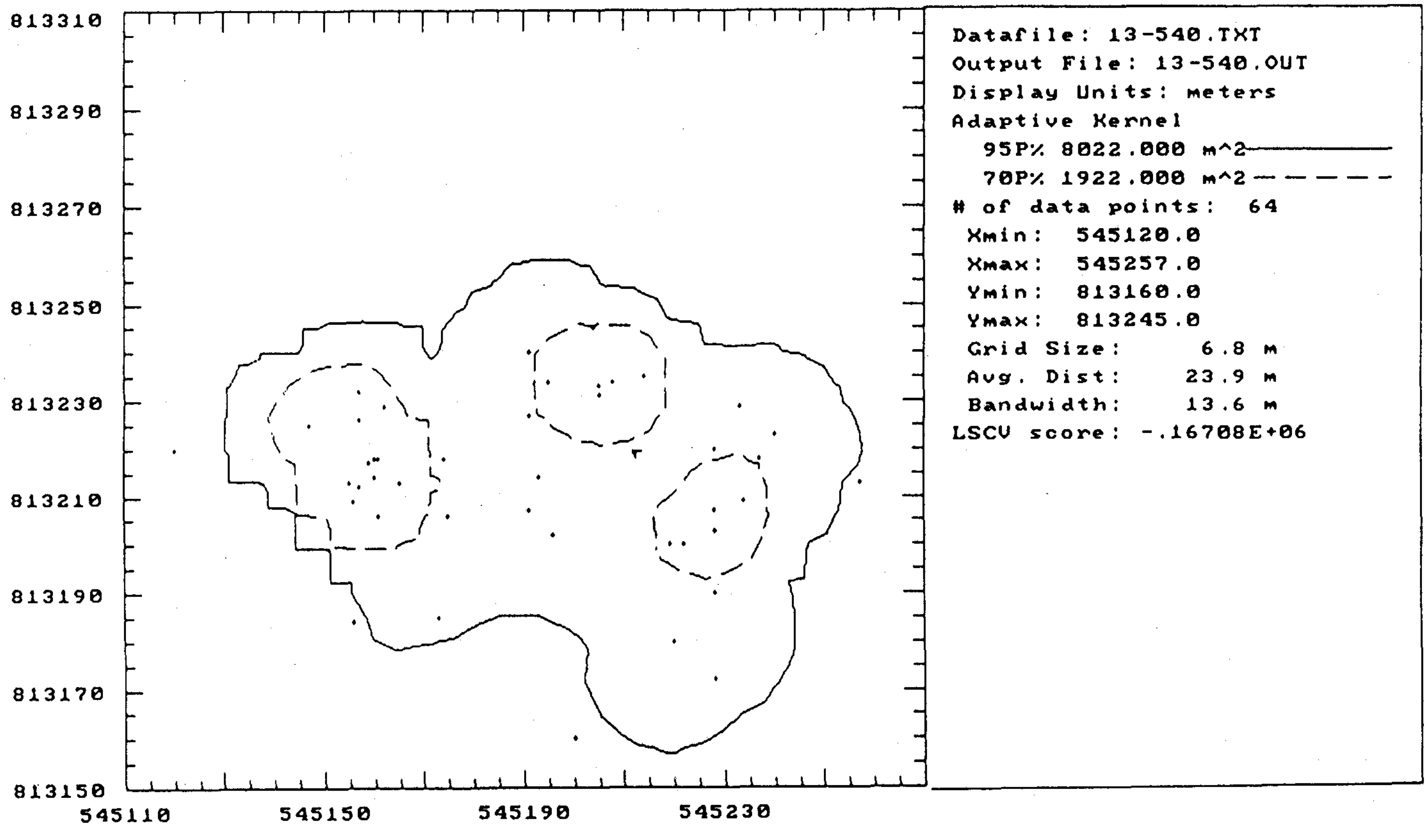

Figure 2.5. Representative home range configuration of a male western red-backed vole in the southern Oregon Cascades, 1995. The plot is of vole 13-540, stand #1. The outer solid line delineates the 95% probability contour. The area inside this contour = 8022 m^2. The three ellipses delineated by the dashed lines represent core areas. Total core area = 1922 m^2. Xmin and Xmax are the minimum and maximum UTM coordinates on the X axis (m). Ymin and Ymax are the minimum and maximum UTM coordinates on the Y axis (m). Grid size is the size of each grid in the 30-cell by 30-cell grid used to determine the adaptive probability density function. Avg. Dist. is the average distance moved between successive telemetry locations. Bandwidth is the smoothing parameter determined by Least Squares Cross Validation (LSCV).

Table 2.2. Western red-backed vole home range and core area size (mean and standard error, ha) and minimum and maximum number of average telemetry locations/animal in the southern Oregon Cascades, 1994 and 1995. *n* = number of animals, 95% = the probability contour estimate of home range size, SE = standard error, Core area = the probability contour estimate (range 45-75%) of total core area size. Total core area size = the sum of 1 or more core areas.

		Adaptive Kernel Probability Contour Area				# Locations	
Year	*n*	95%	SE	Core Area	SE	Min.	Max.
1994							
Female	10	0.120	0.027	0.014	0.003	35	71
Male	2	0.581	0.060	0.124	0.036	35	64
1995							
Female	8	0.153	0.017	0.017	0.002	48	111
Male	3	0.847	0.057	0.206	0.074	62	64
Pooled Mean							
Female	18	0.135	0.017	0.015	0.002	35	111
Male	5	0.741	0.075	0.173	0.046	35	64

Core Areas

Home ranges contained 1 to 2 core areas for females (Figure 2.4) and 2 to 3 for males (Figure 2.5). Males had larger core areas than females ($P = 0.01$, $F = 4026$, 1,1 df; Table 2.2). Average core area size for males was 0.173 ha (range 0.086 - 0.340 ha) and 0.015 ha for females (range 0.003 - 0.036 ha). Utilization distributions for core areas averaged 65% for males (range 55 - 75%) and 57% for females (range 45 - 75%, Appendix D).

Core area size of females did not differ between years ($P = 0.538$, $F = 0.54$, 1,2 df, Table 2.2). Ninety percent confidence intervals for size of core areas for males during 1994 and 1995 overlapped, as did those for females, thus I was not able to reject the null hypothesis that means did not differ between years. Because of my small sample sizes, I had very little power to test this hypothesis ($\beta = 0.50$ for females, ES = 0.80, $n = 9$; $\beta > 0.90$ for males, ES = 0.80, $n = 2$) (Cohen 1988). To increase my sample size and power for the analysis of core area size, I pooled the data between years.

Movement Patterns

Red-backed vole movement patterns varied over a nocturnal 8-hour sampling period. Average distance moved between sequential telemetry locations was greater for males than for females ($P = 0.006$, $t = 4.55$, df = 4; Figure 2.6). Distance moved averaged 29.7 m for males (SE = 5.0, $n = 5$) and 11.7 m for females (SE = 1.2, $n = 18$). Both male and female voles traveled the greatest distances soon after sunset. Male activity peaked immediately after sunset and their movements declined throughout the rest of the evening. Males were least active after 0400 hours but still more active than females. Females had 2 peaks of activity: 1 immediately after sunset and another within 2 hours of sunrise. Females were relatively inactive between midnight and 0200 hours.

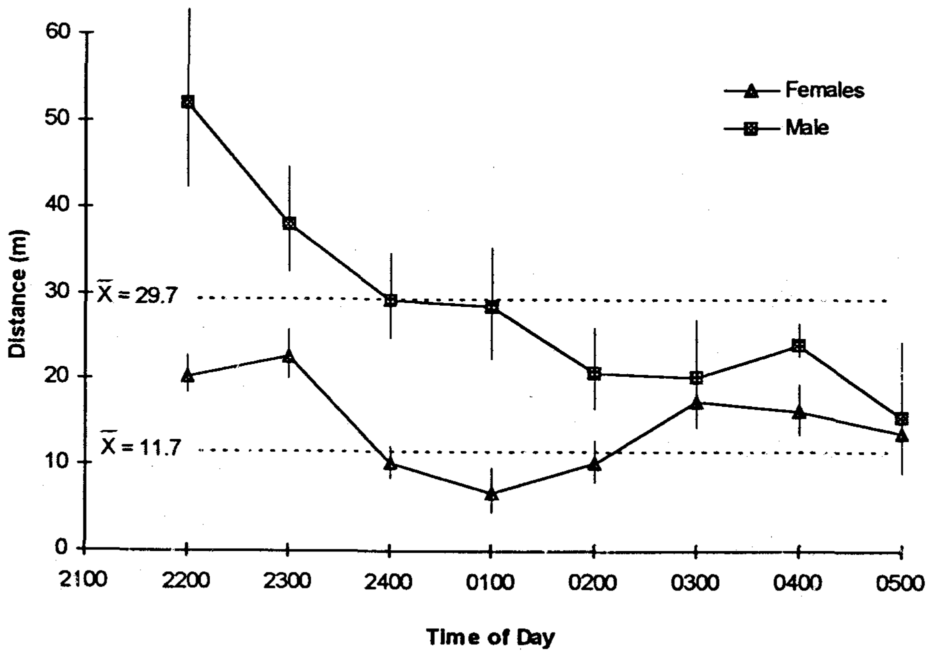

Figure 2.6. Western red-backed vole average hourly movements between sequential locations from dusk to dawn in mature coniferous forests of southern Oregon, 1994-1995. Hours on the x-axis represent temporal movement within the last hour. Error bars represent one standard error.

DISCUSSION

Home Range Size

Few data have been collected on home range of western red-backed voles. Tallmon and Mills (1994) reported summer home range sizes from radio-telemetry of 0.12 ha for females (range 0.11 - 0.14, n = 2) and 0.30 ha for males (range 0.26 - 0.34, n = 2) in a remnant old-growth stand in southwestern Oregon. The estimates of size of home range for females were similar to mine, but Tallmon and Mills' (1994) estimates of size of home range for males were much smaller than mine. Tallmon and Mills' (1994) results were based on the harmonic mean method of home range analysis and a minimum location requirement of only 17, therefore their estimates are likely underestimates of home range size. Home range was determined with the use of live trapping by Hooven (1971) and averaged 4.6 ha for males (n = 12), and 0.8 ha for females (n = 8) in old-growth forests in the western Oregon Cascades. Home range estimates based on trapping records are only an index to size and may indicate a larger home range than really exists (Burt 1943). Furthermore, live-trapping with bait potentially may draw animals away from areas of normal use and could introduce bias (overestimates) into home range estimates. Because of the different methods of data collection and analysis used by these researchers, comparisons of my home range results with data from other studies may be misleading.

Home range estimation assumes independence of observations (Swihart and Slade 1985a). Analysis of serially correlated data produces underestimates of size of home range. Over half of the red-backed voles in my study showed some degree of serial correlation. Although the telemetry locations are not statistically independent, they are biologically important for defining core areas. When significant autocorrelation exists, it is suggested that locations be dropped until the correlation no longer persists. Reduction of sample size, however, reduced my ability to describe spatial use (core area estimates became smaller) and resulted in sample sizes that fell below my minimum sample size requirement (35). Short life-spans of radio-collars for small mammals inhibit the ability to gather large numbers of locations, so every location is important when estimating home range and core area size. Therefore, I decided to use the maximum number of locations and accept the effects of serial correlation on size of home range.

Home ranges reported in my study are for 2 to 4 week periods and summer use only. Longer tracking periods will likely result in larger sizes of home range. Seasonal variation in food and cover also will likely affect size of home range. Truffles are lower in abundance in the summer than in the spring or fall (Luoma 1988) and may effect patterns of movement and size of home range for voles. Bondrup-Nielson and Karlsonn (1985) have found Inverse relationships between food quantity and home range size for Gapper's red-backed voles (*Clethrionomys gapperi*) and thus variations seen in home ranges among individuals in this study (range 0.52 - 0.96 ha for males; 0.03 - 0.32 ha for females) also could be explained by food availability.

I found male western red-backed voles to have larger home ranges than females. Males are promiscuous and are presumed to be competing for estrus females, so their home ranges are often large enough to include those of several sexually mature females (Gipps 1985, and Wolff 1989) as well as ample food and cover resources. Females spend much of their time caring for young and perhaps have ample food and cover nearby. Bondrup-Nielson (1985) hypothesized that since the food source of red-backed voles is scattered or patchy, the mature females must be territorial to ensure an adequate food supply for themselves and their offspring. Territorial behavior also may function to protect young from infanticide (Wolff 1986, 1989). Territorial behavior causes a non-overlapping distribution of home ranges of females that may not be as readily defended by males than if the home ranges were clumped. This results in large home ranges of males that overlap home ranges of females to ensure optimal mating (Bondrup-Nielson 1985).

Core Areas

Home ranges of red-backed voles tended to be elliptical or irregular in shape with 1 or more centers of activity. Males had more than 1 core area in their home ranges, suggesting multi-modal home range use. Position of female home ranges may help explain this pattern for males (Bondrup-Nielson 1985); males may move into different female home ranges as females come into estrus. Females often, but not always, had more than 1 core area. One possible explanation for a second core area is that the females move their young to new nests periodically before weaning; this is a common phenomenon in other rodents (Wolff 1989). A second explanation could be that the females change nest sites between litters. Red-backed voles undergo post-partum estrus, thus it is likely that they need to build a new nest for an upcoming litter while they are still weaning a present litter. An explanation for multiple core areas relating to both male and female red-backed voles is that they are known to cache truffles, their main food source (Ure and Maser 1982, Clarkson and Mills 1995). Distribution or depletion of truffle caches may cause males and females to change core areas. Males also had larger core areas than females which can be accounted for by their larger home range size or caused by overlap of home ranges with other males (Bondrup-Nielson 1985). Males can probably afford to have large core areas and home ranges since they do not actively defend territories (Bondrup-Nielson 1985).

Movements

Distances moved between successive locations were greater for males than for females, which is explained by larger sizes of home range for males. Patterns of movement also differed between the 2 sexes. The females exhibited bimodal patterns of nocturnal movement with post-dusk and pre-dawn peaks. The rest of the night females were relatively inactive. Males were active all evening, moving greater distances in the early hours than during later hours. They did not exhibit a second peak in activity before dawn as did the females, but they were still more active than females at that time. All of the females that I followed were either lactating, pregnant, or in estrus. Lactating voles probably spent most of their time in their nests, nursing their young. The 2 periods of activity were short in distance and time, and probably enabled them to secure sufficient resources to support them through the night. The territorial nature of female red-backed voles (Bondrup-Nielson 1985, Gipps 1985) is a second hypothesis of why females do not move very far from their core areas. These females still may have some of their sub-adult offspring in their home ranges, thus their short movements could be explained by territory defense and their small core area size. Males, on the other hand are not as territorial as females and spend much of their time in search for mating opportunities and resources (Gipps 1985). Although the temporal pattern of movements for males was highly variable, a trend of reduced activity from dusk to dawn was still evident.

SUMMARY

During the summer season, male red-backed voles had larger home ranges and core areas than did females. This may be attributed to territorial and reproductive behavior of the females and reproductive behavior of the males. Female red-backed voles frequently and males always had > 1 core area. Females had 2 peaks of activity whereas the males were active throughout the evening. The differences in reproductive strategies between male and female voles may have caused differences in temporal patterns of activity.

This study was limited by the small number of voles and stands sampled, the time of year sampling was completed, and to the southern Oregon Cascades. Home range studies should be conducted on larger sample sizes, over more than 1 season and longer time periods, in multiple years, and in greater geographic ranges. The limited life-span of small radio-transmitters makes it difficult to study these animals for more than one month, unless voles can be recaptured and recollared. Red-backed vole density and home range overlap need to be collected to understand the effect of density on home range size and use. Further research is needed to assess reproductive rates, survival, dispersal, and fitness of western red-backed voles in various habitat types so that questions about resource selection and habitat needs can be addressed. Home range size also should be estimated in relation to food availability. Dispersal capabilities of this species through fragmented landscapes needs to be determined to address theories of population and genetic isolation. Data on home range size should be combined with habitat data in order to make management decisions that provide for this species' persistence.

CHAPTER 3

HABITAT ASSOCIATIONS OF WESTERN RED-BACKED VOLES IN MATURE CONIFEROUS FORESTS IN SOUTHERN OREGON

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ABSTRACT

Radio-telemetry and pitfall trapping were used to identify habitat used by western red-backed voles in mature coniferous forests in the southern Oregon Cascades. Night-time home ranges and core areas were estimated for 12 red-backed voles in 1994 and 11 in 1995. Of the home ranges estimated in 1994, vegetative components and habitat features were measured within vole core areas and compared to measurements taken randomly in the remainder of the home ranges. Associations of vole abundance with coarse woody debris volume and organic soil depth were estimated. Nest sites of red-backed voles were located and described. Organic soil depth and volume of medium-sized, highly decayed logs effectively distinguished core areas from the rest of the vole's home range ($P < 0.05$). Trapping data revealed an inverse relationship between the abundance of voles and volume of small and medium decayed logs on a stand level ($P < 0.10$) in 1994, but no such relationships were detected in 1995. No consistent relationships were detected between capture rate per trap station and volume of logs in 1994 or 1995. No correlations were detected between capture rates and organic soil depth at the stand or the trap station-level. Nest sites of red-backed voles were found within highly decayed logs. Because of the assumptions and biases associated with trapping data, the telemetry-based habitat associations detected in my study are stronger than those based on capture data. Silvicultural prescriptions in coniferous forest stands that provide deep organic layers and high down log volumes should be conducted when managing future populations of western red-backed voles.

INTRODUCTION

Western red-backed voles are endemic to western Oregon and northern California with their distributions restricted to coniferous forests (Ingles 1965, Alexander and Verts 1992). They disperse mycorrhizal fungi (Maser et al. 1978a, 1978b; Hayes et al. 1986; and Maser and Maser 1988) and are food for many avian and mammalian species, such as northern spotted owls (*Strix occidentalis*)

(Forsman 1975, 1980; Thomas 1990) and martens (*Martes americana*) (Maser et al. 1981).

Most previous associations between western red-backed voles and aspects of their habitat have been estimated based on abundance estimates from live- or removal-trapping. Vole abundance has been documented as higher in old-growth (> 195 years old) (Spies and Franklin 1991) Douglas-fir/western hemlock (*Pseudotsuga menziesii*/*Tsuga heterophylla*) stands than in mature (80-195 years old) (Spies and Franklin 1991) stands (Doyle 1987), and higher in upland regions than in riparian zones (Doyle 1987, 1990; Gomez 1992; McComb et al. 1993). Most investigators have suggested that western red-backed voles occur more frequently in mature and old-growth forests than in younger forests (Raphael 1988, Ruggiero et al. 1991, Rosenberg et al. 1994), although some investigators have detected no difference in abundance between young and older forests (Aubry et al. 1991, Corn and Bury 1991, Gilbert and Allwine 1991). Several studies have shown that red-backed vole populations are reduced or eliminated from sites after clearcut harvesting (Gashwiler 1959, 1970; Hooven and Black 1976; Raphael 1988; Mills 1993, 1995). Gashwiler (1959) reported that red-backed voles were eliminated from clearcuts only after the areas were burned, suggesting, as many trapping studies have, that red-backed voles are closely associated with logs (Tevis 1956; Maser et al. 1981; Hayes and Cross 1987; Raphael 1988; Gilbert and Allwine 1991; Mills 1993, 1995). In addition to an abundance of decaying logs, habitats used by western red-backed voles have also been characterized as having a high percentage of coniferous canopy cover, lichens, and a low cover of deciduous trees and ferns (Doyle 1987). Gomez (1992) and Rosenberg et al. (1994) indicated that the forest organic layer was important to western red-backed voles in the Oregon Coast Range and Cascade Mountains, respectively. Only 1 radio-tracking study has been published on western red-backed voles (Tallmon and Mills 1994), and their results also suggested that decayed logs were associated with areas used by red-backed voles. The well-decayed fallen logs in closed-canopy forests create an optimal environment for hypogeous fungal sporocarps, the primary diet component for red-backed voles (Ure and Maser 1982, Hayes et al. 1986, Maser and Maser 1988).

Past and recent forest management practices in the Pacific Northwest have reduced the volume and changed the characteristics of coarse woody debris (CWD) in managed stands (Spies et al. 1988). Forest rotation lengths under 100 years, which are typical of most managed forest lands, keep natural accumulations of CWD low (Spies et al. 1988, USDA Forest Service and USDI Bureau of Land Management 1994). Clearcutting and slash burning also greatly reduce the volume and depth of the organic layer on the forest floor (McNabb and Cromack 1990, McNabb and Swanson 1990). Shallow depth of organic soil and low volumes of CWD may help explain why western red-backed voles are not common in recent clearcuts following prescribed burning (Tevis 1956; Gashwiler 1959, 1970; Hooven and Black 1976; Rosenberg et al. 1994). Broadcast burning can reduce organic soil depth by consuming organic matter, volatilizing nutrients, and increasing erosion (McNabb and Cromack 1990, McNabb and Swanson 1990). Some burning practices include the removal of CWD prior to burning to reduce fire intensity (McNabb and Cromack 1990). Forest thinning and broadcast burning have been found to negatively effect the composition of hypogeous ectomycorrhizal fungi (Waters et al. 1994). Xeric soil conditions, often a result of clearcut logging, also have been associated with low truffle and vole abundance (Luoma 1988, Clarkson and Mills 1994, Mills 1995). State and private management activities in Oregon, which prescribe clearcutting and the removal of existing snags and non-decayed logs (Oregon Department of Forestry 1995a, 1996), greatly reduce the amount of CWD encountered under natural conditions (Spies et al. 1988). The remaining debris from these activities is relatively small in diameter and decays rapidly. Continued use of this regeneration system could result in lower abundance and/or genetic diversity of red-backed voles in the Pacific Northwest (Raphael 1988; Mills 1993, 1995; Rosenberg et al. 1994).

Recent changes in policy for management of federal forests in the Pacific Northwest, prompted by growing concerns over the maintenance of animal and plant biodiversity (Forest Ecosystem Management Assessment Team (FEMAT) 1993), have resulted in silvicultural alternatives to clearcutting that promote development of late-successional habitat features (large trees and logs, snags, and multilayered stands). Although red-backed voles are not threatened or endangered, they are recognized in the FEMAT (1993) report and in the Record of Decision (USDA Forest

Service and USDI Bureau of Land Management 1994) for their role in fungi-dispersal, as a prey base for raptors and carnivores, their use of decayed logs, and for their association with late-successional forests. Under federal guidelines, snags and large down logs are to be retained to provide habitat for organisms that use these structures, and single or groups of green trees are to be distributed to provide future supplies of down wood (USDA Forest Service and USDI Bureau of Land Management 1994). Provisions of these late-successional features will likely aid in the distribution of habitat for red-backed voles (FEMAT 1993).

I used a combination of radio-tracking and live- and removal-trapping to identify habitat associations of western red-backed voles in mature coniferous forests in the southern Oregon Cascades. My objective was to identify specific features of the habitat selected by western red-backed voles within their home ranges in mature, second-growth forests. I compared 28 habitat variables that were measured in home ranges to detect if there were any differences in habitat between core and random areas. Based on previous research on red-backed voles, I hypothesized that volume of decayed logs would be greater in core areas than in random areas. I further hypothesized that home range size would be dependent on volume of down wood. My second objective was to determine habitat associations based on individual captures of red-backed voles. I wished to determine if 1) the number of captures/stand was correlated with average volume of logs and depth of organic litter in each stand, 2) the number of captures/trap station was correlated with the volume of logs and depth of organic litter at each capture location, and 3) the number of logs and depth of organic litter were greater at trap stations where voles were captured compared to trap stations where they were not captured. I predicted that capture rates of western red-backed voles would be positively correlated with levels of CWD.

STUDY AREA

The study was conducted in the southern Oregon Cascades in the Umpqua National Forest between 47° 54' and 47° 56' latitude in Douglas County (see

Chapter 2 Figure 2.1 and 2.2). The study sites were located in the mixed-conifer zone (*Pinus-Pseudotsuga-Calocedrus-Abies*) (Franklin and Dyrness 1973), and were between 100 and 130 years in age. The mature coniferous forest stands originated from stand replacement fires and were commercially thinned in the 1970's (Rick Abbott, USDA Forest Service, personal communication). Overstories in the forest stands were dominated by Douglas-fir, with grand fir (*Abies grandis*), western hemlock, ponderosa pine (*Pinus ponderosa*), western white pine (*Pinus monticola*), and silver fir (*Abies concolor*) also present. Common understory shrubs included dwarf Oregon-grape (*Berberis nervosa*), creeping snowberry (*Symphoricarpos mollis*), and western serviceberry (*Amelanchier alnifolia*). A list of plant species found in the study areas is included in Appendix A.

The study area is managed by the United States Department of Agriculture (USDA) Forest Service under the current federal forest management plan (USDA Forest Service and United States Department of Interior (USDI) Bureau of Land Management 1994) and is designated as matrix land (FEMAT 1993, USDA Forest Service and USDI Bureau of Land Management 1994). The study sites were located in the Diamond Lake Ranger District with elevation ranging from 945 to 1311 m. Climate is characterized by moderate winters and dry summers, and annual precipitation averages 12.2 cm (Franklin and Dyrness 1973). Most of the precipitation falls between October and May with snow cover common between November and March. Rainfall totaled 2.2 cm in the summer of 1994, and 3.0 cm in the summer of 1995. Maximum and minimum temperatures during the months of the study averaged 27.8° C and 4.4° C in 1994 and 27.4° C and 6.4° C in 1995, respectively.

I selected 3 commercially thinned stands for the radio-telemetry work out of 6 that were used in the Demonstration of Ecosystem Management Options (DEMO) project (DEMO 1996). The criteria I used for this selection was an abundance of western red-backed voles and presence of down logs. All 6 stands were used for small mammal trapping as part of the wildlife component of the DEMO project (Lemkuhl et al. 1996). The stands averaged 16 ha with a minimum distance of 80 m between them. The mean volume of coarse woody debris in a stand was 141.5 m^3/ha (range 94.87 - 188.26 m^3/ha; unpublished data collected for the DEMO vegetation study, Halpern 1996). Preliminary trapping in these stands yielded an average of 4.0 red-backed vole captures/100 trap nights/stand (range 3.5 - 4.2 captures/100 trap nights/stand) (Amaranthus, M. P., Unpubl. data, USFS, PNW Research Station, Grants Pass, OR). Average basal area, stand age, trees/ha, year thinned, and elevation of individual stands are summarized in Table 3.1.

METHODS

Radio-tracking

Twenty-four red-backed voles were captured with Sherman live traps in the summer of 1994 and 18 in the summer of 1995. The voles were radio-tagged with 1-gram model MD-2(C) radio-transmitters (Holohil Systems Ltd., Ontario Canada). Radio tracking was conducted during August and September, 1994 using a model TR-2 Telonics receiver (Telonics, Telemetry-Electronics Consultants; Mesa, Arizona) and a hand-held 4-element H-antenna. Hourly locations were taken on each vole from dusk to dawn, every 2 to 3 days for up to 1 month, or until the radio-signal was lost. Voles were located initially by obtaining a radio signal from 40 to 200 meters away. The animal was then approached to within approximately 5 meters with the antenna, and then approached until it could be detected with only the coaxial cable. After the animal was located, a second person walked to 2 nearby grid points and took a distance and compass bearing on the animal's location (in effect, triangulating on the animal). To minimize possible error when converting azimuth intersections to UTM coordinates, I ensured that the angle between the 2 azimuths was between 60 and 120°. I estimated my accuracy to be within approximately 2 meters of the vole's actual location by locating inert radios at the beginning of the study and by locating numerous slipped collars and dead radio-collared voles throughout the study. I recorded presence of logs and a brief description of vegetation at each animal location. Home range and core areas were estimated from telemetry locations to determine location of habitat plots (methods described in the data analysis section).

Table 3.1. Average stand age (yrs), basal area (m^2/ha), trees/ha, elevation (m), and year(s) of thinning for 6 coniferous stands in the Diamond Lake Ranger District, OR.

Stand name	Age	Basal area	Trees/ha	Elevation	Year(s) thinned
Mowich #1[a]	130	43.7	310	1311	1974
Watson Falls #2	100	36.1	502	945	1970, 1978
Loafer Creek #3	100	47.7	389	1160	1974
Mowich #4	130	60.3	355	1311	1974
Watson Falls #5[a]	100	51.6	382	945	1970, 1978
Watson Falls #6[a]	100	45.4	446	945	1970, 1978

[a]Stand used in radio-telemetry study.

Many voles throughout my study had stopped moving and I presumed that they were dead or without collar. I searched for these animals and as a result, I located nest sites of 6 red-backed voles. I positively identified nests by the presence of a slipped radio-collar or a dead radio-collared vole in a nest. I measured dimensions of the nests and described their substrate and material.

Trapping

Trapping occurred in October 1994 and 1995 as part of the DEMO wildlife study (Lemkuhl et al. 1996). Six stands were used; 3 from the radio-telemetry study, plus 3 in the near vicinity (Figure 2.2 Chapter 2, Table 3.1). In each 16-ha stand, 63 pitfall-traps (2 number 10 cans, stacked and joined with duct tape) were placed at 40-m intervals on a 7 x 9 small mammal trapping grid. Pitfall traps were buried flush with the ground along logs, snags or other natural drift fences and were located within 3 m of the grid points. In 1994, live-trapping techniques were used. The traps were baited with a mixture of oats, peanut butter and molasses to provide food during confinement and were furnished with polyester-batting and nest boxes to reduce the risk of death from hypothermia. We trapped each stand for 2 weeks in October. Traps were opened for 4 consecutive days, closed for 3, and then opened for another 4 days for a total of 8 days and 504 trap nights for each stand. Traps were checked daily for red-backed voles and the voles were individually toe-clipped to distinguish recaptures. In 1995, removal-trapping was used. The pitfall traps were filled with 2.5 cm of water and opened for 28 consecutive days (1764 trap nights/stand). Traps were checked weekly and animals were removed and later dissected for species and sex identification, and reproductive status.

Habitat Sampling

Habitat Plots within Home Ranges

From mid-June to late-July in 1995 I measured 28 habitat variables at 19 core areas and 38 random areas within home ranges of red-backed voles (10 female and 2 male) that were radio-tracked in the summer of 1994 (Table 3.2). For

Table 3.2. Habitat variables measured in plots centered on western red-backed vole home range core and random areas in 3 mature Douglas-fir stands in the Umpqua National Forest, Oregon, 1995. Decay classes of logs follow those defined by Fogel et al. (1973) and revised by Sollins (1982).

Variable	Variable Definition
Logs[a]	
All logs	conifer m^3/ha, all size and decay classes combined
Soft small logs[b]	conifer m^3/ha, 10 - 19.9 cm diameter, decay class 4 & 5
Soft medium logs[b]	conifer m^3/ha, 20 - 29.9 cm diameter, decay class 4 & 5
Soft large logs[b]	conifer m^3/ha, $\geq$ 30.0 cm diameter, decay class 4 & 5
All soft logs	conifer m^3/ha, $\geq$ 10.0 cm diameter, decay class 4 & 5
Hard small logs[b]	conifer m^3/ha, 10 - 19.9 cm diameter, decay class 1 - 3
Hard medium logs[b]	conifer m^3/ha, 20 - 29.9 cm diameter, decay class 1 - 3
Hard large logs[b]	conifer m^3/ha, $\geq$ 30.0 cm diameter, decay class 1 - 3
All hard logs	conifer m^3/ha, $\geq$ 10.0 cm diameter, decay class 1 - 3
Understory Cover[a]	
Conifer saplings	% cover of understory conifer saplings (< 5.0 cm dbh,)
Hardwoods	% cover of understory hardwoods (< 5.0 cm dbh)
Tall shrubs	% cover of tall shrubs (< 5.0 cm dbh and > 30 cm height)
Tall shrub and understory tree layer[b]	% cover of conifer saplings, hardwoods, and tall shrubs (< 5.0 cm dbh)
Ground Surface Conditions[c]	
Soil	% cover of exposed soil
Stone	% cover of stone (> 7 cm length and width)
Fine litter[b]	% cover of fine litter (< 5 cm width)
Coarse litter[b]	% cover of coarse litter (> 5 cm width)
Stump	% cover stumps
Tree base	% cover of live tree base or exposed roots
Organic soil depth[b]	depth (mm) of organic litter layer (needles, leaves, twigs, and humus)

Table 3.2, continued.

Variable	Variable Definition
Herbaceous Cover[c]	
Lichens	% cover of lichens
Bryophytes	% cover of mosses
Low forbs	% cover of forbs (height < 10 cm)
Tall forbs	% cover of forbs (height $\geq$ 10 cm)
Low shrubs	% cover of shrubs (height $\leq$ 30 cm)
Herbaceous layer[b]	% cover of low and tall forbs, and low shrubs combined
Ferns	% cover of ferns
Grass	% cover of grasses
Overstory Cover	
Overstory canopy[b]	% cover of overstory conifer canopy

[a]Variables measured using the line intercept method.
[b]Variables included in the logistic regression analysis.
[c]Variables measured at each Daubenmire (1988) microplot.

every estimated core area, 2 areas were located randomly within home ranges. Number of habitat plots sampled within each animal's home range was dependent upon the number of core areas per home range (e.g. if an animal had one core area, I sampled habitat at one core area and two random areas within the home range). Measurements were taken within 0.06-ha circular habitat sampling plots which were centrally positioned over each animal's core and random areas (Figure 3.1).

Habitat Plots at Trap Stations

Additional circular habitat plots were systematically established at grid points in each of the 6 small mammal trapping grids (Figure 3.1) (Halpern 1996). Thirty-two trap stations were sampled for habitat in stand #1, 2, 3, and 6; 37 trap stations were sampled in stand #4; and 62 were sampled in stand #5. Log volume (3 decay and diameter classes) and organic soil depth were measured in these plots (Table 3.2).

Habitat Sampling Methods

Four 6-meter transects were arranged in each cardinal direction within each circular habitat plot (Figure 3.1). I used the line-intercept method (Daubenmire 1988) to sample down logs, tall shrubs, conifer saplings, and hardwoods in each plot. Diameter, length, and decay class were recorded for each log intercepted. Decay classes of logs follow those defined by Fogel et al. (1973) and revised by Sollins (1982), (ranging from 1 to 5, with 1 being in the earliest stages of decay {hard} and 5 being in the latest stages of decay {soft}). I recorded linear cover and height estimates for each tall shrub, sapling and hardwood intercepted.

Daubenmire (1988) microplots (0.2 m x 0.5 m) were placed at 1-meter intervals along the line transects (24 microplots per plot) (Figure 3.1). Ground surface conditions, herbaceous cover, and organic soil depth were estimated for each microplot. Cover was estimated visually to the nearest percent for ground surface and herbaceous variables, and organic soil depth was measured to the nearest mm. Canopy cover was measured ocularly, through a 4.1-cm diameter cylinder, within microplots at both ends of the transects (8 measurements per plot)

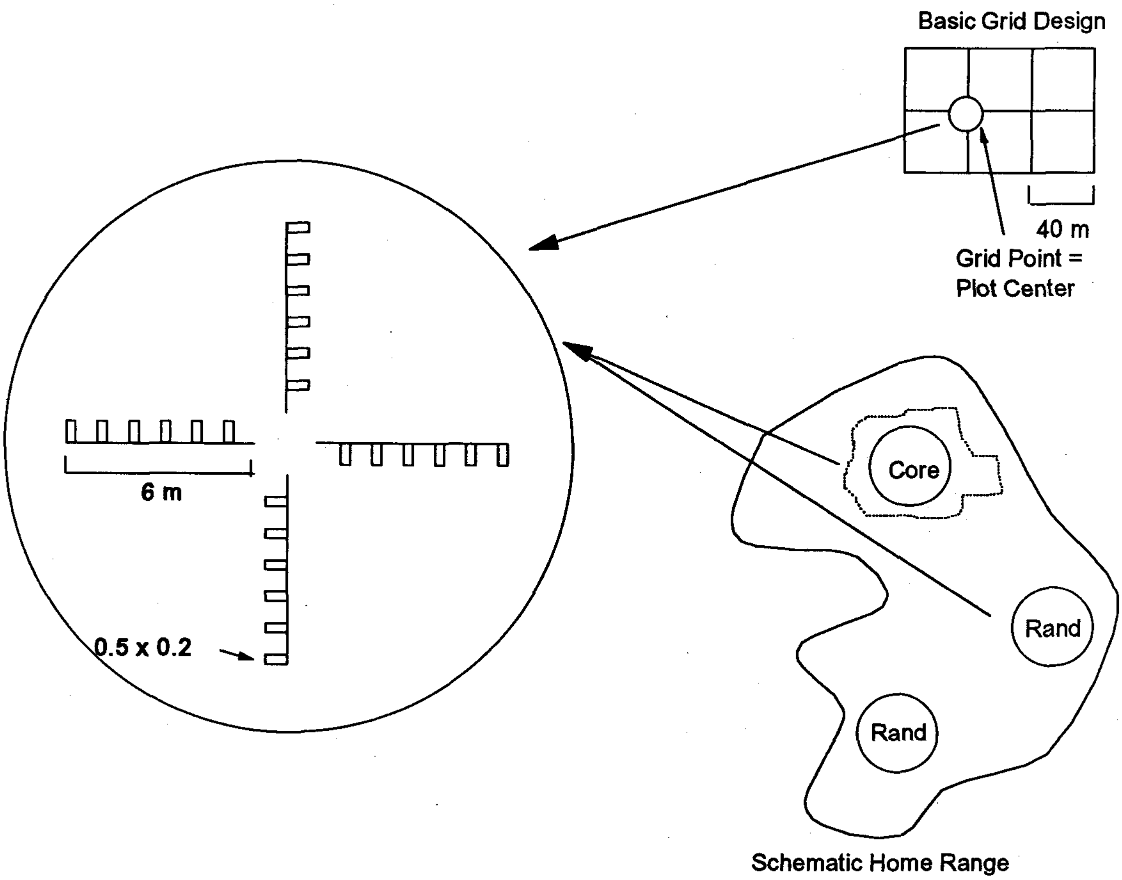

Figure 3.1. Habitat plot and transect layout for habitat sampling in the southern Oregon Cascades. Tall shrubs and understory tree cover, and coarse woody debris were sampled along each 6 m line transect. Ground surface conditions and herb cover were measured at each Daubenmire (1988) microplot. Plots were centered within home range core and selected random areas and at alternative grid points (trap stations) within small mammal trapping grids.

and the accuracy of the estimates were checked with a moosehorn densiometer for every 5th plot.

Data Analysis

Habitat Variables

Volume per hectare of down logs was computed using the formula

$$V = \pi^2 \Sigma d^2 / 8L$$

where V is the volume, d is the diameter of the log, and L is the transect length (Van Wagner 1968, Harmon et al. 1986, Harmon and Sexton 1996). Linear coverage estimates were computed using the formula

$$\textit{Linear Cover (\%)} = li / L * 100$$

where li = the sum of the intercept lengths for habitat variable i, and L = Total length of all transects sampled (Brower et al. 1989). I determined mean coverage of habitat variables, log volume, and organic soil depth per plot by averaging data for 4 line transects within the plot.

Home Range and Core Areas

Home range and core area configurations were estimated using the adaptive kernel method and program CALHOME (Kie et al. 1996) for each animal with $\geq$ 35 telemetry locations. Home ranges were estimated at the 95% utilization level whereas core areas were identified individually for each home range at a range of utilization levels (45 - 75%) (see Chapter 2 for details). I used least squares cross-validation (lscv) to select a smoothing parameter for this analysis (Whorton 1989, 1995; Kie et al. 1996; Seaman and Powell 1996). I used an adaptive kernel estimator with $0.60h_{lscv}$ for the smoothing parameter (h = specified value of the smoothing parameter by CALHOME), which best represented the observed spatial configuration patterns of red-backed voles in my study.

Home Range Habitat

I only had enough locations to estimate home ranges and core areas for 2 males in 1994. Because of this small sample, I only analyzed habitat associations for female voles.

Habitat coverage, organic soil depth, and log volume values were ranked within stands using the Friedman's Rank Sum procedure (SAS Institute Inc. 1990) and compared between core area plots and random plots using a one-way analysis of variance for block designs (SAS Institute Inc. 1987). To increase the power of my statistical tests, and to reduce the probability of making a type II error, all tests were conducted using alpha = 0.10.

Conditional logistic regression for matched case-control studies was used to evaluate the effectiveness of 12 habitat variables (Table 3.2) in separating core areas from random areas (Breslow and Day 1980, SAS Institute Inc. 1992, Manly 1993). The response variable for this analysis was the plot type (core or random) and the explanatory variables were the mean values of microhabitat characteristics collected at each circular plot sampled. Because random areas were dependent on the location of core areas, I effectively matched on voles, thus I stratified on vole in the regression model. The regression procedure in SAS (PHREG) took into account the 2:1 ratio of random to core plots by averaging the variables of the random plots (SAS Institute 1992). Stepwise logistic regression was used to analyze data, and a significance level ≤ 0.10 was used to enter variables into the models.

One variable, organic soil depth, was confounded with plot type. Organic soil depth was higher in all of the use categories (core areas) than in the random plots and was thus completely partitioned. This type of analysis was not designed for such a consistent effect between case and control and thus maximum likelihood estimates could not be computed. Because of the nature of this variable, my small sample size, and large number of predictor (explanatory) variables, I could not estimate other parameters in the presence of organic soil depth. For exploratory purposes, I ran the conditional logistic regression model without organic soil depth.

I used Spearman's rank-order correlation analysis (SAS Institute Inc. 1990) to test for relationships between home range or core area size and average log volume computed for individual home ranges in 1994. Correlation analyses were not run for habitat variables other than log volume since hypotheses regarding home range size and other habitat variables were not developed *a priori*.

<u>Telemetry Locations</u>

I calculated the percentage of red-backed vole telemetry locations within 1 m of 1 or more logs of any stage of decay for males and females individually and combined in 1995. Logs also were segregated into 3 decay categories for these analyses: soft logs indicated the presence of decay class 4 and/or 5 logs; hard logs indicated the presence of decay class 1, 2, and/or 3 logs; and soft and hard logs indicated the presence of both soft and hard logs within one meter of the telemetry location.

<u>Habitat and Capture Data at Trap Stations</u>

Stand Level Captures

I estimated the number of individual red-backed voles captured per trap station by sex and stand for each year sampled. Recaptures of individuals at a given trap station were discounted. I converted the data to number of captures per 100 trap nights per stand for each year sampled. Differences in trapping methodology prohibited testing for year effects or pooling the data between years. I estimated mean log volume and organic litter depth for each stand from the habitat data sampled at trap stations (Appendix B). A comparison of log volume by sex detected no difference between gender ($P > 0.10$, 1,5 df), thus I combined male and female capture for all capture-related analyses. I used Spearman's rank-order correlation analysis (SAS Institute Inc. 1990) to assess whether the capture rate per stand was correlated with average log volume and organic soil depth in each stand. I ran a power analysis to determine the power of this test. Power was considered adequate when $\beta \leq 0.20$.

Trap Station Level

I estimated the number of red-backed voles captured per trap station for each stand in 1994 and 1995. I used Spearman's correlation analysis to assess whether the number of captures per trap station per stand was correlated with average log volume and organic soil depth at each capture site.

A one-way analysis of variance, blocking on stands, was used to test for differences in CWD volume and organic soil depth between plots where voles were and were not captured during the trapping session. The mean values of the habitat variables were ranked within stands using the Friedman's Rank Sum Procedure (SAS Institute Inc. 1990).

I discounted captures at trap stations that had not been sampled for logs and organic soil depth for all analyses at the trap station level. I ran power analyses to determine the power of these tests. Power was considered adequate when $\beta \leq 0.20$.

RESULTS

Home Range Habitat

I identified 11 habitat variables that differed significantly between random and core areas (Table 3.3). The volume of small, medium, and large soft logs was significantly greater in core areas than in random areas. Coarse litter cover also was significantly greater in core areas than in random areas. Depth of organic soil was highly correlated with vole use and was significantly greater in core areas than random areas. Percent cover of fine needle litter, bare soil, tall shrubs and forbs was significantly greater in random areas than in core areas.

I identified 1 main effect using conditional logistic regression; female voles selected areas with deep organic soil (Table 3.4). Because of the consistent difference between organic soil depth in core versus random areas discussed earlier, I was not able to report an exact P-value from the logistic regression, although the rank-sum P-value (0.0001) was evidence of it's significance (Table 3.3). From the exploratory analysis where the logistic regression was run without organic soil depth, I identified medium-diameter, soft logs as a significant variable (Table 3.5).

Table 3.3. Mean habitat characteristics ($\overline{X}$) and standard errors (SE) within western red-backed vole core and random areas in 3 mature Douglas-fir stands in the Umpqua National Forest, Oregon, 1994. P is the probability of detecting a difference between core and random areas using a one-way ANOVA with ranked means, blocking on stands. F is the test statistic with 1,5 df. Original means are reported.

Habitat variable[a]	Core		Random		P-Value
	$\overline{X}$	SE	$\overline{X}$	SE	P > |t|
Log Volume (m^3/ha) by decay and diameter					
All logs	236.8	40.49	119.7	22.69	0.013[b]
Soft small logs	24.9	4.57	11.9	1.96	0.020[b]
Soft medium logs	38.9	10.32	7.5	2.49	0.020[b]
Soft large logs	83.7	28.99	29.8	10.76	0.032[b]
All soft logs	152.5	33.58	49.2	11.36	0.004[b]
Hard small logs	15.4	3.15	15.0	2.19	0.979
Hard medium logs	13.3	5.67	9.9	2.94	0.350
Hard large logs	55.6	20.50	45.6	18.68	0.620
All hard logs	84.3	25.38	70.5	19.26	1.000
Understory Cover (%)					
Conifers	19.6	4.11	18.4	2.66	1.000
Hardwoods	2.9	1.76	1.7	0.56	0.219
Tall shrubs	3.9	1.08	6.3	1.55	0.082[d]
Tall shrub and understory tree layer	24.2	4.11	25.7	2.44	0.514
Ground Surface Conditions (% cover)					
Soil	0.6	0.51	0.5	0.23	0.025[b]
Stone	< 0.1	0.04	< 0.1	0.003	0.956
Fine litter	86.1	1.35	90.1	0.83	0.047[d]
Coarse litter	12.3	1.40	9.0	0.83	0.075[c]
Stump	0.3	0.20	0.4	0.23	0.364

Table 3.3, continued.

Habitat variable[a]	Core		Random		P-Value
	$\bar{X}$	SE	$\bar{X}$	SE	P > |t|
Ground Surface Conditions (% cover)					
Tree base	2.0	0.57	1.7	0.36	0.769
Organic soil depth	42.3	3.09	21.9	1.00	0.0001[b]
Herbaceous Cover by Growth Form (%)					
Lichens	2.0	0.26	1.9	0.31	0.815
Bryophytes	28.2	4.97	33.7	3.58	0.335
Low forbs	23.0	1.76	22.7	1.08	0.723
Tall forbs	23.7	2.91	28.6	2.11	0.049[d]
Low shrubs	23.9	2.21	24.5	1.31	0.360
Ferns	0.5	0.34	1.0	0.57	0.428
Grass	2.0	0.29	3.1	0.74	0.144
Herbaceous Cover (%)					
Herbaceous layer	66.5	3.09	70.9	2.05	0.135
Overstory (% cover)					
Overstory canopy	75.8	2.10	68.5	2.95	0.111

[a]See Table 3.2 for descriptions of habitat variables.
[b]Significantly greater in Core areas (Friedman's Rank Sum Test; $P \leq 0.05$).
[c]Significantly greater in Core areas (Friedman's Rank Sum Test; $P \leq 0.10$).
[d]Significantly greater in Random areas (Friedman's Rank Sum Test; $P \leq 0.05$).

Table 3.4. Results of conditional logistic regression analyses used to evaluate the effectiveness of 12 habitat variables in separating red-backed vole core areas from random areas in the southern Oregon Cascades, 1994. Chi-square is the test-statistic for the analysis based on 10 degrees of freedom and P is the probability of detecting a difference between core and random areas.

Habitat Variables[a]	Chi-square	P
Organic soil depth	> 28.00	< 0.0001 [b]
Soft small logs	0.00	0.9996
Soft medium logs	0.00	0.9996
Soft large logs	0.00	0.9996
Hard small logs	0.00	0.9996
Hard medium logs	0.00	0.9996
Hard large logs	0.00	0.9996
Fine litter	0.00	0.9996
Coarse litter	0.00	0.9996
Canopy	0.00	0.9996
Saplings	0.00	0.9996
Herbs	0.00	0.9996

[a]See Table 3.2 for a description of habitat variables.
[b]Habitat variable significantly separates core areas from random areas.

Table 3.5. Results of the exploratory conditional logistic regression analyses run without organic soil depth used to evaluate the effectiveness of 11 habitat variables in separating red-backed vole core areas from random areas in the southern Oregon Cascades, 1994. Chi-square is the test-statistic for the analysis based on 10 degrees of freedom and P is the probability of detecting a difference between core and random areas.

Habitat Variables[a]	Chi-square	P
Soft small logs	1.06	0.303
Soft medium logs	4.42	0.036 [b]
Soft large logs	1.64	0.201
Hard small logs	0.92	0.342
Hard medium logs	0.77	0.380
Hard large logs	1.40	0.237
Fine litter	1.84	0.174
Coarse litter	0.60	0.440
Canopy	1.80	0.180
Saplings	1.29	0.257
Herbs	0.19	0.666

[a]See Table 3.2 for a description of habitat variables.
[b]Habitat variable significantly separates core areas from random areas.

Home range size was inversely related to volume of small soft logs (P = 0.036, rho = -0.664, n=10) and positively correlated with volume of medium (P = 0.041, rho = 0.652, n=10) and large hard logs (P = 0.007, rho = 0.79, n=10). Core area size also was positively correlated with volume of medium and large hard logs (P = 0.040, rho = 0.654; P = 0.081, rho = 0.577, n=10).

Telemetry Locations

Of the 746 telemetry locations of voles from 1995, 80% coincided with down logs. Ninety-six percent of the male locations (n = 190), and 75% of the female locations (n = 556) coincided with 1 or more down logs. Sixty-four percent of the male locations coincided with soft logs, 13% with hard logs, and 18% with both soft and hard logs. For females, 47% of the locations coincided with soft logs, 14% with hard logs, and 14% with both soft and hard logs. When voles were not found near logs, they were usually in close proximity to tree or snag bases, or underneath western serviceberry, all of which tended to be associated with a thick litter layer.

Nest Sites

I found nest sites for 6 female red-backed voles. Five out of the six sites were located underground in decay class 4 and 5 logs, 7 - 28 cm below the topsoil layer. Nest sites were typically covered by a layer of needle litter. I found burrow entrances and fecal chambers within the substrate. The remaining nest was located above-ground at the base of a tree under large pieces of sloughed bark.

Nest dimensions ranged from 9 - 14 cm in length and 10 - 18 cm in width. All nests were composed of moss, leaves, woody debris, and needle litter. Four of the nests contained varying quantities of synthetic polyester fiber which was used in traps as an insulator during the trapping session.

Red-backed Vole Captures

A total of 289 western red-backed voles was captured in 1994 (9.6 captures/100 trap nights/stand) and 213 in 1995 (2.0 captures/100 trap nights/stand) (Tables 3.6 & 3.7).

Stand Level

In 1994, there was an inverse relationship between number of red-backed vole captures per 100 trap nights/stand and the average volume of small and medium soft logs (Table 3.8). There was no detectable correlation between capture rate of voles and volume of hard logs. In 1995, I detected no relationship between capture rate and volume of coarse woody debris (Table 3.8). I detected no correlation between capture rate and organic soil depth for either year sampled. Because of the small number of stands sampled, there was not enough power to detect correlations for either year sampled ($\beta = 0.88$, $\rho = 0.3$, n = 6).

Trap Station Level

Correlations

I detected no correlation between capture rate and organic soil depth in any of the stands for either year sampled (Table 3.9 and 3.10). I detected no consistent trends between the capture rate per trap station and volume of logs among the 6 stands for either year sampled (Table 3.9 and 3.10). Power to detect correlations in each stand ranged from 50 - 75% ($\beta = 0.50$, $\rho = 0.3$, n = 32; $\beta = 0.43$, $\rho = 0.3$, n = 37; $\beta = 0.25$, $\rho = 0.3$, n = 62).

In 1994, there was a negative correlation between number of voles captured per trap station and volume of small and medium hard logs in stand #1. In stand #5, there was a negative correlation between number of voles captured per trap station and volume of large soft logs, and small hard logs. I detected no relationships between capture rate and volume of logs for the other 4 stands (Table 3.9).

In 1995, there was a negative correlation between the number of voles captured per trap station and volume of medium, large, and soft logs, and a positive

Table 3.6. Western red-backed vole captures[a] in 6 mature Douglas-fir stands in the Umpqua National Forest, Oregon, Fall 1994.

Stand	Total individuals	Relative abundance[b]	Females	Males	Sex ratio[c]
Mowich #1	37	7.3	22	15	1.5
Watson Falls #2	69	13.7	31	38	0.8
Loafer Creek #3	17	3.4	9	8	1.1
Mowich #4	25	5.0	16	69	1.8
Watson Falls #5	70	13.9	39	31	1.3
Watson Falls #6	71	14.1	34	34	0.9
Total	289	9.6	151	138	1.1

[a]Individuals captured from live pitfall trapping (number of trap nights = 504/stand for 8 days of trapping).
[b]Relative abundance = number of captures/100 trap nights/stand.
[c]Sex ratio = ratio of female to male red-backed voles.

Table 3.7. Western red-backed vole captures[a] in 6 mature Douglas-fir stands in the Umpqua National Forest, Oregon, Fall 1995.

Stand	Total individuals	Relative abundance[b]	Females	Males	Sex ratio[c]
Mowich #1	51	2.9	26	25	1.0
Watson Falls #2	52	2.9	24	28	0.9
Loafer Creek #3	18	1.0	9	9	1.0
Mowich #4	26	1.5	11	15	0.7
Watson Falls #5	50	2.8	27	23	1.2
Watson Falls #6	16	0.9	7	9	0.8
Total	213	2.0	104	109	1.0

[a]Individuals captured from removal pitfall trapping (number of trap nights = 1764/stand for 28 days of trapping).
[b]Relative abundance = number of captures/100 trap nights/stand.
[c]Sex ratio = ratio of female to male red-backed voles.

Table 3.8. Spearman's Rank Correlation Coefficients (ρ), and observed significance levels (P) for correlations of individual male and female western red-backed vole captures per stand (n = 6) with stand average log volume and organic soil depth in the Southern Cascades, 1994 and 1995.

Habitat variable[a]	Number of individuals captured/stand, 1994[b]		Number of individuals captured/stand, 1995[c]	
	ρ	P	ρ	P
Soft small logs	- 0.771	0.072[d]	- 0.203	0.700
Soft medium logs	- 0.886	0.019[d]	0.000	1.000
Soft large logs	- 0.257	0.623	0.116	0.827
Hard small logs	- 0.486	0.329	- 0.464	0.354
Hard medium hard logs	- 0.486	0.329	0.174	0.742
Hard large hard logs	- 0.086	0.872	- 0.145	0.784
Organic soil depth	0.125	0.814	0.406	0.425

[a]See Table 3.2 for a description of habitat variables.
[b]Number of trap nights/stand = 504.
[c]Number of trap nights/stand = 1764.
[d]Significant negative correlation.

Table 3.9. Spearman's Rank Correlation Coefficients (ρ), and observed significance levels (P) for correlations of number of western red-backed vole captures per trap station with plot-level average log volume and organic soil depth in the Southern Oregon Cascades, 1994. Captures are from 504 trap nights/stand.

Habitat Variable[a]	Stand 1 (n = 32)		Stand 2 (n = 32)		Stand 3 (n = 32)		Stand 4 (n = 37)		Stand 5 (n = 62)		Stand 6 (n = 32)	
	ρ	P	ρ	P	ρ	P	ρ	P	ρ	P	ρ	P
Soft small logs	- 0.064	0.728	- 0.124	0.498	0.095	0.606	0.236	0.159	0.033	0.803	- 0.142	0.438
Soft medium logs	0.117	0.525	- 0.156	0.391	0.028	0.880	0.208	0.218	- 0.050	0.697	0.039	0.834
Soft large logs	- 0.097	0.597	0.202	0.265	0.071	0.699	- 0.037	0.829	- 0.320	0.011 [b]	- 0.015	0.935
Hard small logs	- 0.416	0.018 [b]	- 0.191	0.294	0.092	0.616	0.168	0.321	- 0.438	0.0003 [b]	0.203	0.266
Hard medium logs	- 0.334	0.061 [b]	0.008	0.966	- 0.103	0.571	0.071	0.677	- 0.109	0.396	0.041	0.822
Hard large logs	- 0.061	0.738	- 0.196	0.281	- 0.251	0.166	0.169	0.317	0.047	0.714	0.138	0.450
Organic soil depth	- 0.059	0.750	0.305	0.305	- 0.087	0.637	- 0.149	0.378	0.109	0.394	0.025	0.893

[a]See Table 3.2 for a description of habitat variables.
[b]Significant negative correlation.

Table 3.10. Spearman's Rank Correlation Coefficients (ρ), and observed significance levels (P) for correlations of number of western red-backed vole captures per trap station with plot-level average log volume and organic soil depth in the Southern Oregon Cascades, 1995. Captures are from 1764 trap nights/stand.

Habitat Variable[a]	Stand 1 (n = 32)		Stand 2 (n = 32)		Stand 3 (n = 32)		Stand 4 (n = 37)		Stand 5 (n = 62)		Stand 6 (n = 32)	
	ρ	P	ρ	P	ρ	P	ρ	P	ρ	P	ρ	P
Soft small logs	- 0.128	0.488	0.101	0.581	- 0.081	0.661	0.166	0.328	0.098	0.447	- 0.272	0.132
Soft medium logs	- 0.489	0.005[b]	0.139	0.449	- 0.070	0.705	0.061	0.720	- 0.085	0.507	- 0.121	0.509
Soft large logs	- 0.350	0.049[b]	- 0.115	0.532	0.206	0.259	- 0.008	0.963	- 0.176	0.168	- 0.151	0.410
Hard small logs	0.359	0.043[c]	0.039	0.833	- 0.064	0.727	- 0.077	0.647	- 0.099	0.442	- 0.266	0.141
Hard medium logs	0.115	0.531	0.115	0.529	0.092	0.615	- 0.104	0.542	0.064	0.619	- 0.198	0.277
Hard large logs	0.196	0.281	0.201	0.269	0.098	0.594	0.087	0.609	- 0.114	0.374	- 0.038	0.835
Organic soil depth	0.181	0.321	- 0.175	0.337	- 0.221	0.223	0.266	0.112	- 0.113	0.377	- 0.177	0.333

[a]See Table 3.2 for a description of habitat variables.
[b]Significant negative correlation.
[c]Significant positive correlation.

Table 3.11. Test of the hypothesis that there was no difference in mean log volume and organic soil depth between trap stations where western red-backed voles were and were not captured using a one-way analysis of variance, blocking on stands, in the Southern Oregon Cascades, 1994 and 1995. Data were ranked within stands using the Friedman's Rank Sum test. F is the test statistic based on 1, 5 degrees of freedom and P is the probability of rejecting the null hypothesis.

Habitat Variable[a]	1994		1995	
	F	P > F	F	P > F
Soft small logs	0.71	0.437	0.56	0.490
Soft medium logs	1.40	0.289	1.25	0.314
Soft large logs	0.00	1.000	2.76	0.158
Hard small logs	1.30	0.258	0.68	0.449
Hard medium logs	0.11	0.750	1.67	0.253
Hard large logs	0.00	1.0000	0.40	0.555
Organic soil depth	0.05	0.825	0.00	1.000

[a]See Table 3.2 for a description of habitat variables.

correlation between the number of voles captured per trap station and small hard logs in stand #1. I detected no relationships between capture rate and volume of logs for the other 5 stands (Table 3.10).

Capture Sites vs. Non-capture Sites

In 1994 and 1995, neither organic soil depth nor log volume of any size or decay stage differed between plots where voles were and were not captured (Table 3.11). Power to detect relationships between capture sites was low ($\beta > 0.54$, ES = 0.8, n = 6).

DISCUSSION

Habitat within Home Ranges

There was an inverse relationship between size of home range and volume of small soft logs. This suggests that the greater the volume of small decayed wood the smaller the living area used by red-backed voles. If decayed woody debris is a limiting factor for voles, as Tallmon and Mills (1994) suggest, and if decayed logs are sparse and/or clumped in a given area, then I would hypothesize that the voles would need larger home range areas than would be required if the logs were more evenly dispersed. The close association of hypogeous fungi with decayed logs (Hayes and Cross 1987, Luoma 1988, Tallmon and Mills 1994) and the clumped distribution of some truffle species (Waters J. R., Unpubl. data, USFS PSW Research Station, Arcata, CA) also may help explain this relationship. Bondrup-Nielson and Karlsonn (1985) have found similar inverse relationships between home range size and food quality and quantity for Gapper's red-backed vole (*Clethrionomys gapperi*). The positive association of medium and large hard logs with size of home range and core areas suggests that although the voles use these logs in their daily activity, the size of home range is not dependent on volume of hard logs. It is likely that these hard logs are used as travel corridors and cover (Hayes and Cross 1987, Tallmon and Mills 1994).

The depth of the organic soil layer was the habitat variable that best separated used areas from available areas. Organic soil depth was found to be positively correlated with red-backed vole abundance in both the Oregon Coast and Cascade Ranges by Gomez (1992) and Rosenberg et al. (1994) respectively. Shallow organic soil depth may explain why Tevis (1956), Gashwiler (1959 and 1970), and Hooven and Black (1976) found only limited numbers of red-backed voles in recent clearcuts following prescribed burning.

Log volume also was found to be significant in separating high vole-use areas from low use areas. Red-backed vole capture rates have been positively associated with logs by Doyle (1987), Hayes and Cross (1987), and Tallmon and Mills (1994). I found a greater volume of small, medium, and large soft logs in core areas than in random areas when I examined all of the habitat variables separately. When I combined the variables (excluding organic soil depth), the data indicated that voles were selecting highly decayed, medium diameter logs. Maser et al. (1979) suggested that large logs were more useful to small mammals because they provide more cover than smaller logs. Maser and Trappe (1984) and Harmon et al. (1986) suggest that size of logs also may determine the duration of use because larger coarse woody debris generally lasts longer than smaller coarse woody debris. Hayes and Cross (1987) found that red-backed voles select large logs over small logs. The frequency of large decayed logs was low in my study stands which perhaps was not enough to substantiate selection for large logs.

Hayes (1983), Doyle (1987, 1990), and Gomez (1992) found positive associations of western-red-backed vole abundance estimates with overstory canopy cover. Hayes (1983), Doyle (1990), Gomez (1992), and Rosenberg et al. (1994) found positive associations of western-red-backed vole capture rates with snag density. Hayes (1983) also found positive associations of western-red-backed vole abundance estimates with overstory and understory tree density. I did not find a significant difference in canopy cover between core areas and random areas within vole home ranges, nor in percent cover of live tree bases and stumps. The lack of difference in canopy cover in my study may be because of the small range of differences that I encountered in my study stands. All of the stands used in my study were in the same seral stage and had little variation in overstory cover. Study stands used by Hayes (1983), Doyle (1990) and Gomez (1992) included more than one seral stage thus they had a greater range of canopy cover values and a greater chance of detecting a difference. I did not measure density of trees and snags in my study, and perhaps it would have been a better measurement than cover. Tree and snag density may contribute to the forest litter layer through needle loss and decay, and may have a significant influence on location of vole core areas.

Telemetry Locations

Tallmon and Mills (1994) found 98% of vole locations were associated with downed logs and that red-backed voles preferentially used decay class 3, 4, and 5 logs. When I combined all vole locations, 80% coincided with down logs, with 66% of the locations coinciding with decay class 4 and 5 logs.

Nest Sites

Lichens have been documented as being used by western red-backed voles as nest building material by Doyle (1987) and Ure and Maser (1982). The nests that I found were constructed from lichens, and other organic and inorganic materials. Ure and Maser (1982) found that red-backed voles supplement their truffle diet with lichens. Perhaps lichens in vole's nests could couple as a food source when resources are scarce. Hayward and Rosentreter (1994) suggested that northern flying squirrels (*Glaucomys sabrinus*) used lichens in their nests as food caches during winter months. Red-backed vole nest sites have been found in underground burrows or under organic debris (Stephens 1906). The majority of the nests found in my study were subterranean and located within highly decayed logs. This further emphasizes the importance of decayed logs for red-backed voles. Not only do logs provide an area permeable to excavation, but they also provide thermal protection and an environment in which hypogeous fungi can fruit, and thus a convenient food source for lactating female voles.

Habitat Associations from Capture Data

Stand Level

Neither organic soil depth nor log volume were important factors influencing vole capture rate at the stand level. In 1994, there was an inverse relationship between capture rate and volume of decayed logs, whereas in 1995, no relationships were detected. No correlations were detected between western red-backed vole captures and dead wood abundance in recent studies by Corn et al. (1988), Gomez (1992), McComb et al. (1993), and Rosenberg et al. (1994). In fact, Corn et al. (1988) reported a negative association between captures and biomass of decay class 1 and 2 logs. Gomez (1992) and Rosenberg et al. (1994) did, however, find a positive association of red-backed vole captures with depth of organic soil layer. The lack of correlation of captures with coarse woody debris and organic soil depth on a stand level in my study may be a reflection of the scale at which voles select habitat. The scale at which red-backed voles select habitat is probably much smaller than the scale that was sampled by trapping. At a stand level, coarse woody debris and organic soil depth may not be influencing the population; another resource such as food or mates may be influencing their habitat use. Another probable explanation for the lack of correlation of captures with coarse woody debris and organic soil depth on a stand level in my study is because I did not have sufficient statistical power to conduct this analysis.

Trap Station Level

Red-backed vole captures on an individual trap station level yielded no consistent results among stands or between years. Overall, no relationships were detected between vole capture rates and volume of logs and depth of organic soil for either year sampled. The scale of this analysis should have enabled the detection of small grain responses of voles, but perhaps the low power of the test inhibited any detection of relationships. The ability to detect a relationship between capture rate and habitat variables at a trap station level was also limited to the capture stations that were sampled for habitat. Many captures were discounted because no habitat data were collected, which likely made it more difficult to detect a relationship. For exploratory purposes, I combined the log diameter classes to see if I could detect any relationships, but I did not. The inferences from the trap station level correlation analyses are limited to the individual stands, thus the analysis at the stand level is probably more meaningful.

Distribution of logs in the stands may influence capture rate at the stand and trap station level. The average log volume in all decay classes was higher in home range core areas than in the stands. This suggests that logs have clumped distributions. Thus if voles are dependent on logs for cover, they may be more abundant where log volume is higher. Furthermore, Waters J.R. (Unpubl. data, USFS PSW Research Station, Arcata, CA) found that distribution of individual truffle species was clumped in old-growth and mature fir (Abies spp.) stands in northeastern California. It is possible that truffle distributions are clumped in my study stands as well. The possible aggregation of logs and truffles in my study stand, and the fact that mature forests have a relatively low volume of CWD compared to old-growth and young forests (Spies et al. 1988, Spies and Franklin 1991) could explain the lack of association of vole captures with log volume.

Certain limitations exist when trying to estimate habitat use from trapping, therefore, caution must be used when making inferences from trapping studies. Because trap locations are limited to above-ground areas, capturing animals traveling under or in soft logs is difficult (Hayes and Cross 1987). A captured animal only indicates that an animal has visited an area; it does not reveal the intensity of use during the trapping period. Additionally, baited traps may attract animals to the traps away from their intended path of travel and thus their presence in a trap could be merely incidental (Hayes and Cross 1987). The number of locations where an animal can be captured also is limited to the number and placement of the traps, whereas the number of telemetry locations that an animal can be detected is infinite. Trapping data also assumes equal capture probability of animals, an assumption that is often violated (White et al. 1982). It is possible that lactating female voles have lower capture probability than estrus females, thus trapping data will not yield habitat associations that are representative of the whole population. Conversely, telemetry-based data will allow for equal detectability of individuals, assuming a representative sample of the population is radio-collared. Because of the limitations of trapping data and the advantages that telemetry data provide, my strongest data is telemetry-based. The telemetry-based data probably describes the habitat associations exhibited by western red-backed voles more accurately than the trapping data.

Logs in different stages of decay are used for different purposes by red-backed voles (Maser et al. 1979, Thomas 1979, Hayes and Cross 1987). My telemetry-based data do not show any selection of logs in early stages of decay. Decay stages of logs may not be as important to animals moving through a stand as long as they have some logs for cover. The larger volume of soft logs over hard logs in the study stands may partially explain why voles were located more frequently in the vicinity of soft logs, but the association of truffles with highly decayed logs is also a likely explanation (Maser et al. 1979, Maser and Trappe 1984, Harmon et al. 1986, Clarkson and Mills 1994, Amaranthus et al. 1994, Waters J. R., Unpubl. data, USFS PSW Research Station, Arcata, CA).

Truffles

The significance of organic soil depth as a habitat variable differentiating used from unused sites could be related to the abundance of truffles. Red-backed voles often forage in the organic layer of soil (Maser et al. 1981), and organic soil depth has been found to be associated with truffle abundance in northeastern California mature fir stands (Waters J. R., Unpubl. data, USFS PSW Research Station, Arcata, CA) and in mesic old-growth Douglas-fir stands in the central Cascade Mountains in Oregon (Luoma 1988). A tendency for forest floor depth to increase with coarse woody debris cover also has been observed in the central Cascades (Luoma 1988). Distribution of hypogeous sporocarps of mycorrhizal fungi explained the distribution of red-backed voles in remnants of old-growth forests in southwest Oregon (Mills 1995). The predominance of truffles in the diet of red-backed voles in my study sites (Amaranthus, M. P., Unpubl. data, USFS, PNW Research Station, Grants Pass, OR; Appendix E) further emphasizes their importance.

Fungal sporocarps in the Basidiomycetes family accounted for 86% of the total diet of western red-backed voles in the Oregon Coast Range and 64% of the total diet in the Oregon Cascade Range (Ure and Maser 1982). There was significant seasonal variation in truffle consumption in the Cascade, but not in the Coast Range (Ure and Maser 1982). Fruticose lichens comprised the second largest food class and comprised the greatest proportion of vole diets during the winter months. Approximately 75% of the fall diet of red-backed voles in my study stands were composed of hypogeous fungi with a large component consisting of 2 genera of truffles, *Rhizopogon* and *Truncocolumella* (Luoma, D. L., Unpubl. data, Oregon State University, Corvallis, OR). Plant material, including lichens, comprised the second largest component of the diet (Luoma, D. L., Unpubl. data, Oregon State University, Corvallis, OR). These 2 genera of fungi also have been found to occur in greater biomass compared to other truffle and mushroom genera in the stands where my study was conducted (Amaranthus, M. P., Unpubl. data, USFS, PNW Research Station, Grants Pass, OR). and many species of *Rhizopogan* are found only in mature forests underneath CWD (Amaranthus et al. 1994). Hayes et al. (1986) also found *Rhizopogon* to be the most frequently occurring truffle genus in red-backed vole fecal pellets in the Cascade range of southwestern Oregon. Hayes (1983) found the greatest diversity of truffle species were consumed by voles in August. Hayes et al. (1996) also found that maximum fungus consumption occurred during late summer, the period when truffles are scarce (Luoma 1988), thus food caches are probably common for voles (Ure and Maser 1982, Clarkson and Mills 1994).

Statistical Inferences

This study was conducted in the southern Oregon Cascades and is applicable to mature, mixed-coniferous forests in this region. The habitat associations described in this study represent summer (telemetry-based) and fall (capture-based) use and may only be significant in the seasonal context of this study. At periods when truffle abundance is low (winter), a shift in diet to lichens (Ure and Maser 1982) also may cause a shift in habitat to accommodate foraging needs. Thus habitat relationships estimated in my study may not represent relationships during the winter. Documenting habitat associations in all seasons, in more than one seral stage, and in larger geographic regions would provide better information for the management of this species.

CONCLUSIONS & MANAGEMENT IMPLICATIONS

Depth of the forest organic soil layer was the most significant habitat variable used to describe red-backed vole core areas in this study. Decayed logs also were found associated with vole core areas, nest sites, and individual capture sites. The association of truffles with deep organic soil layers (Waters J. R., Unpubl. data, USFS PSW Research Station, Arcata, CA) and decayed logs (Clarkson and Mills 1994, Waters J. R., Unpubl. data, USFS PSW Research Station, Arcata, CA), and their substantial contribution to red-backed vole diets (Ure and Maser 1982, Amaranthus, M. P., Unpubl. data, USFS, PNW Research Station, Grants Pass, OR) are likely explanations for the prevalence of these habitat features within western red-backed vole home ranges. If management of viable populations of western red-backed voles is an objective, silvicultural prescriptions that will provide deep organic soil layers and large volumes of logs in future stands should be conducted in early seral stage forests.

Recent policy changes in federal forest management in the Pacific Northwest (FEMAT 1993) will likely meet the habitat needs of red-backed voles. I predict that late-successional reserves and wilderness areas under alternative 9 will meet the future habitat needs of western red-backed voles (USDA Forest Service, and USDI Bureau of Land Management 1994). Adaptive Management Areas, depending on their objectives, also have the potential for providing red-backed vole habitat. The federal standards and guidelines for the matrix lands (USDA Forest Service, and USDI Bureau of Land Management 1994) exceed those required for state and private land owners (Oregon Department of Forestry (ODF) 1995a, 1995b, 1996), but still may not meet the requirements of red-backed voles. Retention of 38.5 m^3/ha of logs $\geq$ 50.8 cm diameter and 4.9 m long are required under current matrix guidelines. Only 18 m^3/ha of the logs are required to be left on the ground; the remainder can be retained as snags. The average volume of CWD on the ground in red-backed vole home range core areas in my study was more that 5 times as great as the total log requirements and more than 13 times as great as the down log requirements. The average log volume for all of my study stands combined also greatly exceeds the minimum federal requirements. Although the diameter of logs required federally exceed those used by red-backed voles in my study, the overall volume guidelines probably won't meet the requirements of red-backed voles. To meet the down log requirements suggested by my study results, I recommend distributing logs in 236 m^3/ha patches over approximately 20% of a given management area. If the logs are retained within forest patches, I also recommend that sufficient logs be left in open areas to provide runways and cover. These logs will potentially function as corridors among forest patches while the early seral forest matures.

Retention of fine and coarse woody debris over the mineral soil effectively prevents or limits most surface erosion following prescribed burning (McNabb and Swanson 1990) and potentially provides habitat for red-backed voles. Surface organic material (needle and leaf litter, duff, and down wood) is managed under the federal forest management standards and guidelines to maintain soil productivity (USDA Forest Service, and USDI Bureau of Land Management 1994). In the Umpqua National Forest, 65 - 85% minimum ground cover is required after all ground-disturbing activities (USDA Forest Service Umpqua National Forest Plan 1990 as amended by the Record of Decision USDA Forest Service, and USDI Bureau of Land Management 1994). To meet these requirements, broadcast burning is restricted to the spring, and/or pile burning is used in the winter when duff moisture levels are high (USDA Forest Service 1996). Some of the surface layer of litter is still burned or singed with these methods, but if properly conducted, I predict that low intensity burns should maintain an adequate litter depth for truffles to develop and voles to burrow and forage.

Prescribed fire, both broadcast and pile burning, is used on state and private lands for site preparation and/or to reduce fire hazards, but there are no minimum ground cover requirements under the Oregon Forest Management Act (ODF 1995a, 1995b, 1996). Smoke management has led to more pile burning and utilization of debris (ODF 1996). If the chip and/or pulp market is profitable, wood $\geq$ 2.5 cm in diameter will be utilized, and the intensity and volatility of the prescribed fire will be reduced (Conrad Toll, ODF, personal communication). The combination of short rotation times and the utilization of woody debris on state and private lands could potentially reduce litter depth and not allow for much natural accumulation or future deterioration of organic material above the mineral soil. Thus I suspect that organic litter depth on state and private lands may fall below that needed by western red-backed voles. Therefore, I recommend managing for minimum ground cover requirements similar to requirements used on federal lands to provide habitat for red-backed voles.

CHAPTER 4

CONCLUSIONS

Western red-backed voles selected areas with deep organic soil and medium-sized, highly decayed logs within their summer home ranges in the southern Oregon Cascades. These habitat features are closely related to abundance of truffles, which made up a substantial portion of the vole's diet in this region. Neither herbaceous nor canopy cover effected intensity of home range use. Home range size was larger for male red-backed voles than for females, but there was no detectable annual size difference in these stands even though vole abundance varied between years.

This study was observational, and thus cause and effect cannot be demonstrated and inferences cannot be made outside of the subpopulation studied and season sampled. My results indicate that deep organic soil layers and coarse woody debris are associated with areas used by western red-backed voles. To better understand the need for these habitat features, manipulative experiments that would test for the presence and reproductive fitness of voles, and intensity of use of areas with and without these specific habitat features would have to be conducted. Unfortunately, the logistics of such experiments prove difficult and expensive, thus it is difficult to positively demonstrate the requirement of particular habitat features for red-backed voles.

Additional research on seasonal and temporal variations in home ranges across larger geographic areas and for both sexes is needed for more accurate descriptions of home range and core areas size. Further research on western red-backed voles in the Pacific Northwest should be focused on foraging, reproductive fitness, and dispersal and survival of voles across a variety of forest seral stages and ages. Until the detection range of radio-transmitters is increased, dispersal studies will not be possible. An integrated study which would document vole diet, truffle abundance, and truffle distribution in relation to decayed log distribution and organic litter depth would enable exploration of resource preference theories.

Furthermore, habitat manipulation through silvicultural practices should continue to be tested and monitored to promote a greater understanding of the effect of structural habitat features on vole abundance and fitness.

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APPENDICES

Appendix A. Plant species found in 6 mature Douglas-fir stands in the Umpqua National Forest, Oregon, 1994-95.

Genus and species	Common name
Abies concolor	silver fir
Abies grandis	grand fir
Abies magnifica shastensis	Shasta red-fir
Achillea millefolium	common yarrow
Actaea rubra	baneberry
Achlys triphylla	vanilla leaf
Adenocaulon bicolor	Pathfinder
Agrostis scabra	bentgrass
Amelanchier alnifolia	western serviceberry
Anemone deltoidea	three-leaf anemone
Anemone lyallii	Lyall anemone
Anaphalis margaritacea	common pearly ever-lasting
Aquilegia formosa	Sitka columbine
Arenaria macrophylla	bigleaf sandwort
Arctostaphylos nevadensis	pinemat manzanita
Asarum caudatum	western wild ginger
Asarum hartwegi	marbled wild ginger
Athyrium filix-femina	lady fern
Berberis nervosa	dwarf Oregon grape
Blechnum spicant	deer fern
Bromus spp.	bromes
Bromus vulgaris	Columbia brome
Carex concinnoides	northwest sedge
Carex deweyana	sedge
Carex spp.	sedges
Campanula scouleri	souler's harebell
Chimaphila menziesii	little princess pine
Chimaphila umbellata	princess pine
Circaea alpina	night shade
Cirsium arvense	Canadian thistle
Cirsium vulgare	bull thistle
Claytonia umbellata	spring beauty
Clintonia uniflora	queen's cup
Collomia heterophylla	varied-leafed collomia
Coptis laciniata	cutleaf goldthread
Cornus canadensis	bunchberry
Coptis laciniata	cutleaf gold thread

Appendix A, continued.

Genus and species	Common name
Corallorhiza maculata	spotted coral root
Cornus nuttallii	Pacific dogwood
Disporum hookeri	fairy bells
Dryopteris austriaca	mountain wood fern
Elymus glaucus	blue wild rye
Epilobium angustifolium	fireweed
Epilobium spp.	willow herbs
Festuca idahoensis	Idaho fescue
Festuca occidentalis	western fescue
Festuca subulata	fescue
Festuca subuliflora	crinkle awn fescue
Fragaria spp.	strawberrys
Fragaria vesca	strawberry
Fragaria virginiana	strawberry
Galium boreale	northern bedstraw
Galium oreganum	Oregon bedstraw
Galium triflorum	fragrant bedstraw
Gaultheria ovatifolia	slender salal
Gaultheria shallon	salal
Goodyera oblongifolia	rattlesnake plantain
Habenaria spp.	bog-orchids
Habenaria unalascensis	Alaska bog-orchid
Hemitomes congestum	gnome plant
Hedysarum sulphurescens	sweetvetch
Hieracium albiflorum	fringed pinesap
Horkelia fusca	horkelia
Hypericum perforatum	Kalamath weed
Hypopitys monotropa	fringed pine sap
Iris spp.	irises
Juncus spp.	rushes
Linnaea borealis	western twin flower
Listera caurina	northwest listera
Listera cordata	northern listera
Lonicera ciliosa	trumpet honeysuckle
Lonicera conjugialis	Honeysuckle
Lotus corniculatus	deervetch
Lotus formosissimus	deervetch

Appendix A, continued.

Genus and species	Common name
Lotus micranthus	small flowered deervetch
Lonicera hispidula	hairy honeysuckle
Lotus purshianus	deervetch
Lotus spp.	deervetches
Luzula campestris	field woodrush
Luzula parviflora	small flowered wood rush
Madia gracilis	tarweed
Melica spp.	melics
Melica subulata	Alaska oniongrass
Mitella spp.	mitreworts
Montia perfoliata	miner's lettuce
Osmorhiza chilensis	mountain sweet root
Oxalis oregonia	Oregon oxalis
Pachistima myrsinites	Oregon boxwood
Pedicularis racemosa	leafy lousewort
Penstemon subglaber	penstemon
Phlox spp.	phloxes
Pinus monticola	limber pine
Pinus ponderosa	ponderosa pine
Pleuricospora fimbriolata	Sierra sap
Polystichum munitum	western sword fern
Potentilla gracilis	northwest cinquefoil
Prunus emarginata	bittercherry
Prunella vulgaris	self-heal
Pseudotsuga menziesii	Douglas-fir
Pteridium aquilinum	braken fern
Pyrola picta	white vein pyrola
Pyrola secunda	one-sided pyrola
Ranunculus uncinatus	buttercup
Rhamnus purshiana	cascara
Rubus spp.	berrys
Rubus lasiococcus	dwarf bramble
Rubus nivalis	snow bramble
Rubus ursinus	Pacific blackberry
Satureja douglasii	yerba buena
Senecio bolanderi	Bolander's groundsel
Senecio spp.	groundsels

Appendix A, continued.

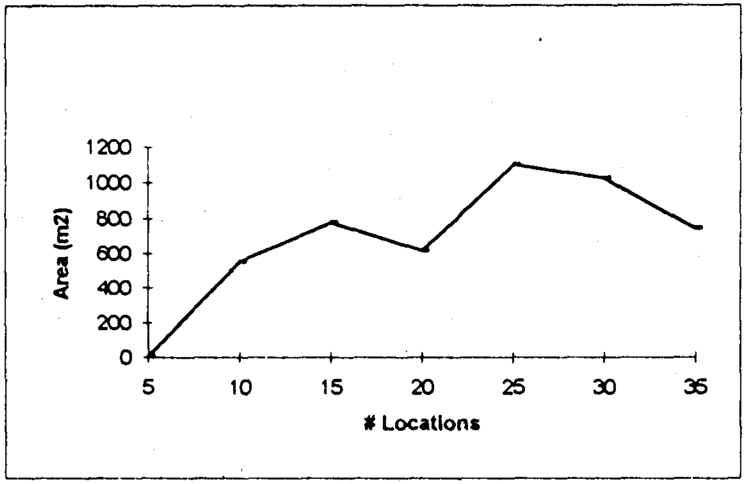
Genus and species	Common name
Silene montana	campion
Smilacina racemosa	western false Solomon's seal
Smilacina stellata	starry false Solomon's seal
Stellaria media	chickweed
Symphoricarpos mollis	creeping snowberry
Synthyris reniformis	snow-queen
Taxus brevifolia	Pacific yew
Tiarella trifoliata	three-leafed coolwort
Tiarella trifoliata unifoliata	cool-wort foamflower
Trientalis latifolia	star flower
Trillium ovatum	wood lily (trillium)
Trifolium repens	white clover
Trisetum canescens	tall trisetum
Tsuga heterophylla	western hemlock
Tsuga mertensiana	mountain hemlock
Vaccinium scoparium	grouseberry
Vancouveria hexandra	inside out flower
Viola glabella	wood violet
Viola orbiculata	round-leafed violet
Viola spp.	violets
Whipplea modesta	whipplevine

Appendix B. Mean log volume (m^3/ha) (SE) by decay and diameter categories[a] in 6 mature Douglas-fir stands in the Umpqua National Forest, Oregon, 1994-95.

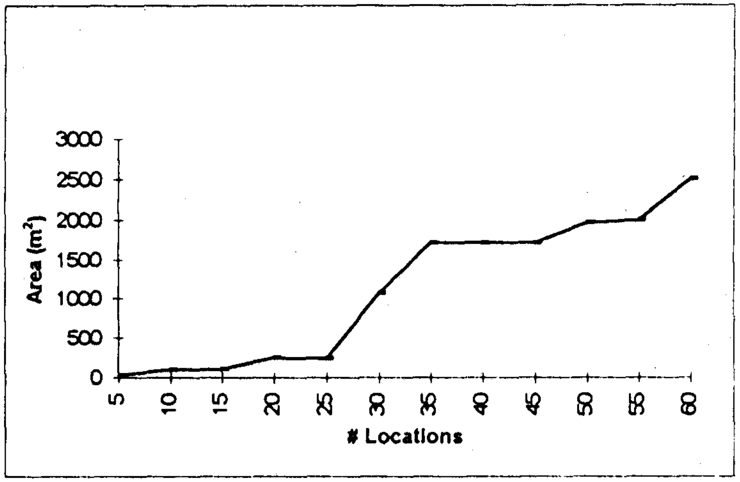
Stand number	Soft small logs	Soft medium logs	Soft large logs	All soft logs	Hard small logs	Hard medium logs	Hard large logs	All hard logs	All logs
1[b]	21.87 (3.3)	31.5 (6.1)	47.9 (12.8)	99.1 (19.7)	15.7 (3.1)	18.5 (4.0)	53.0 (15.6)	81.3 (11.9)	180.3 (25.8)
2	8.01 (2.7)	6.8 (3.2)	9.2 (6.4)	30.6 (10.0)	10.0 (2.6)	3.2 (1.5)	11.1 (5.7)	31.3 (8.0)	61.9 (14.4)
3	31.2 (4.0)	47.4 (8.2)	48.9 (9.9)	88.7 (12.7)	20.5 (2.6)	25.6 (6.2)	17.0 (6.3)	97.4 (16.3)	186.1 (23.2)
4	16.8 (3.3)	30.9 (5.7)	53.0 (12.5)	73.6 (12.7)	12.4 (2.13)	16.3 (3.9)	36.9 (13.0)	86.8 (17.4)	160.5 (20.5)
5[b]	16.6 (1.8)	17.7 (2.7)	59.0 (17.5)	83.4 (17.7)	11.9 (1.6)	19.1 (3.4)	25.0 (9.0)	57.9 (7.5)	141.4 (17.9)
6[b]	14.4 (2.1)	4.2 (1.6)	35.0 (17.2)	71.3 (31.7)	14.2 (3.1)	9.6 (3.4)	17.3 (10.2)	49.1 (14.0)	94.9 (32.9)
Pooled	17.3 (1.9)	23.3 (2.7)	25.8 (3.3)	75.5 (7.8)	25.5 (4.9)	27.6 (4.2)	22.12 (2.83)	66.4 (5.2)	141.5 (9.5)

[a]See Table 3.2 for a description of log variables.
[b]Used in radio-telemetry study.

Appendix C. Number of telemetry locations in 5 location increments plotted against home range area (m^2) to detect minimum number of locations required to estimate home range size. Asymptotes (the number of locations at which the curve begins to level) were visually estimated for each animal. The apparent decrease in the size of home ranges for some of the voles with the addition of telemetry locations is a function of the Adaptive Kernel estimator. Addition of data points in the same location will draw the contours in, thus reducing the 95% probability contour estimate.

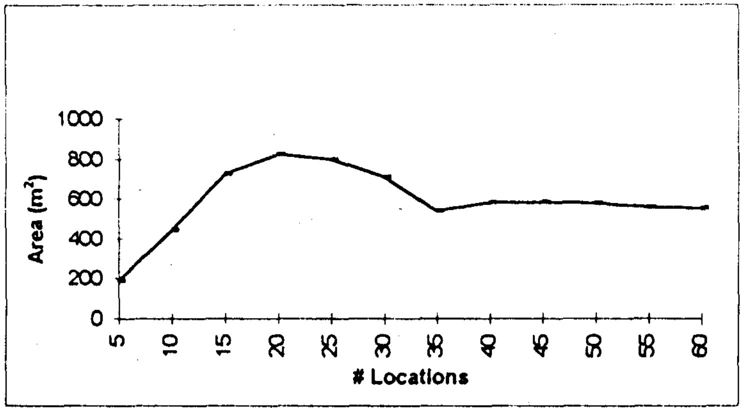


C-1. Female vole 7-097, Stand #5, 1994.

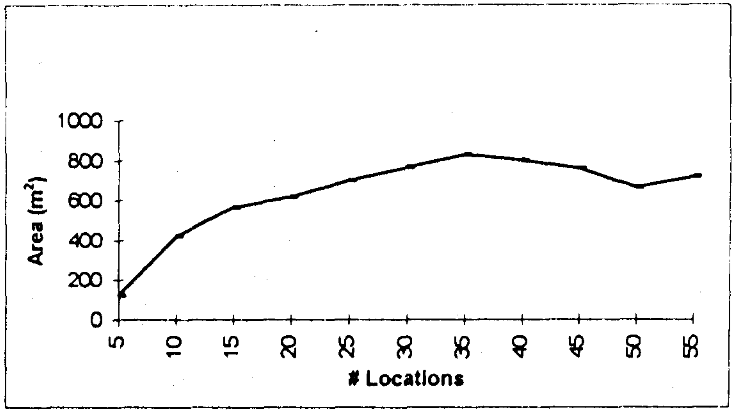


C-2. Female vole 8-573, Stand #5, 1994.

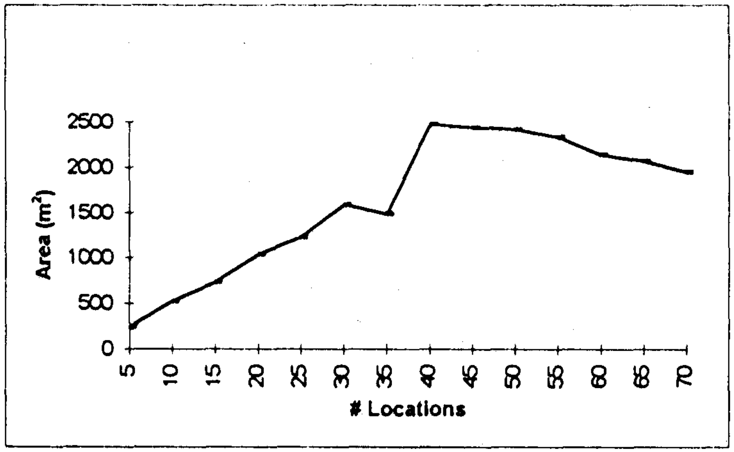
Appendix C., continued.



C-3. Female vole 10-158, Stand #5, 1994.



C-4. Female vole 20-275, Stand #5, 1994.

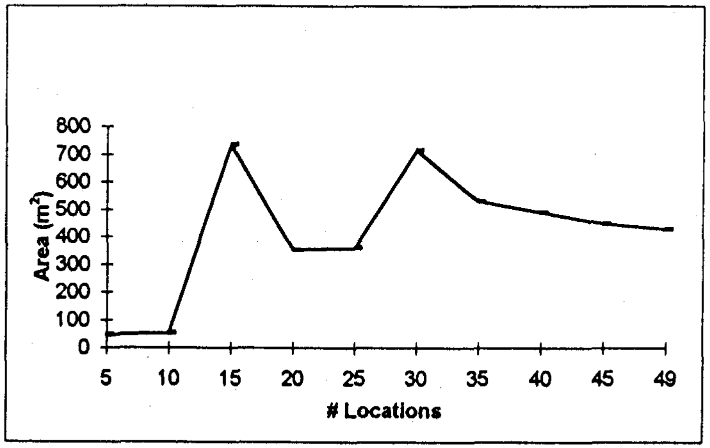


C-5. Female vole 1-256, Stand #6, 1994.

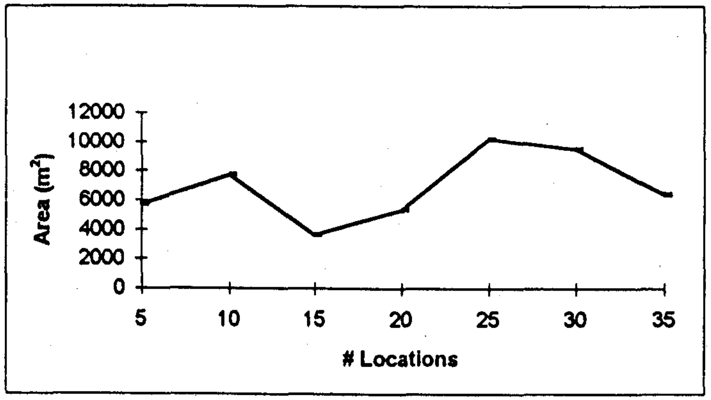
C-6. Female vole 5-126, Stand #6, 1994.

Appendix C., continued.

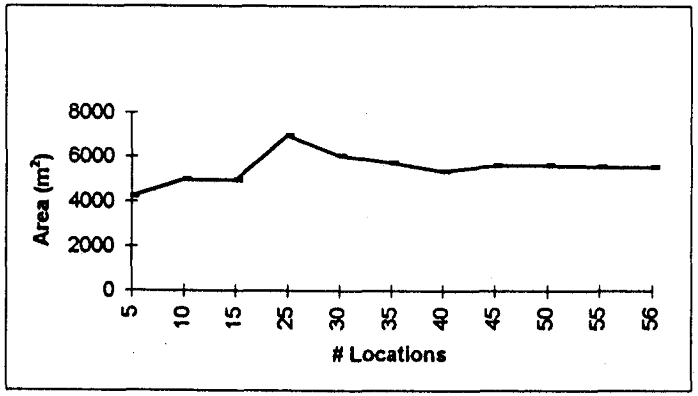
C-7. Female vole 6-076, Stand #6, 1994.



C-8. Female vole 50-540, Stand #1, 1994.

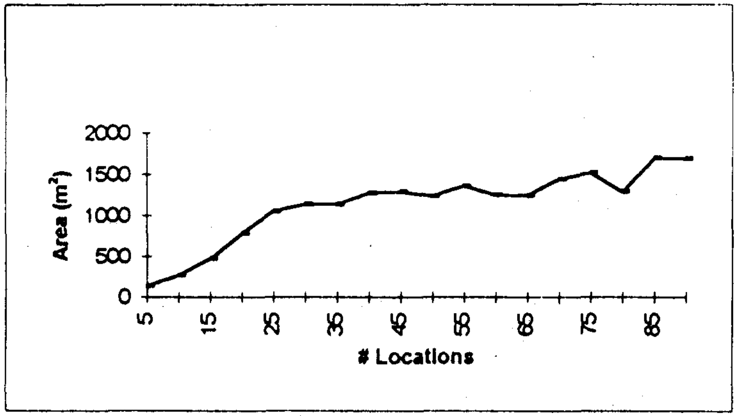


C-9. Male vole 1-629, Stand #5, 1994.

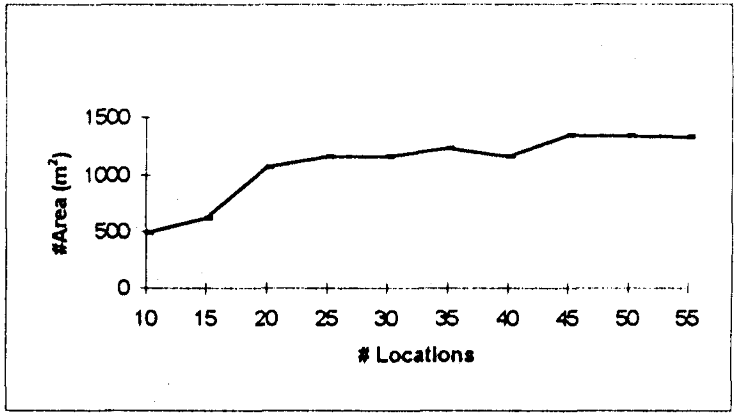


C-10. Male vole 3-386, Stand #5, 1994.

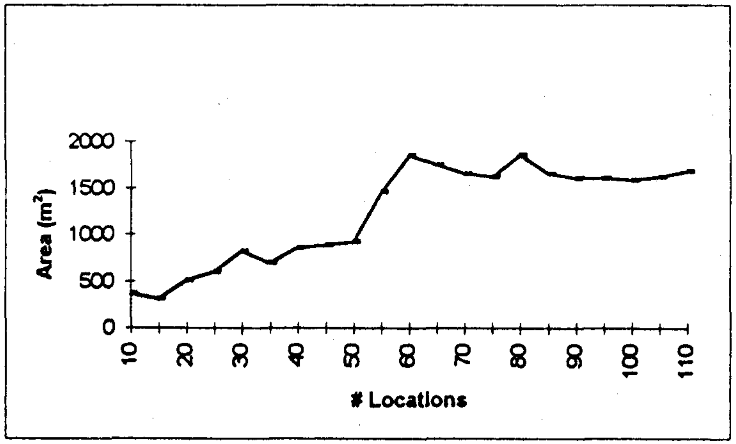
Appendix C., continued.



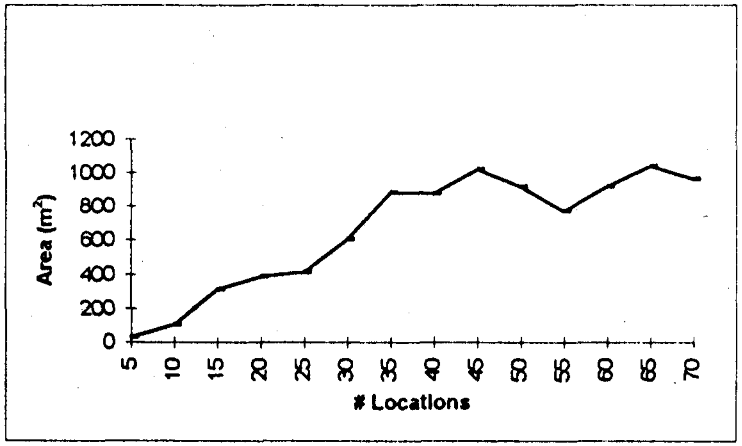
C-11. Female vole 1-989, Stand 5, 1995



C-12. Female vole 4-214, Stand 5, 1995

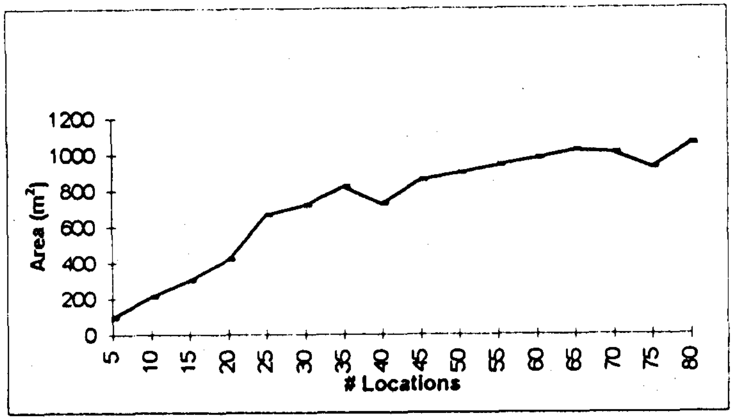


C-13. Female vole 5-517, Stand 5, 1995

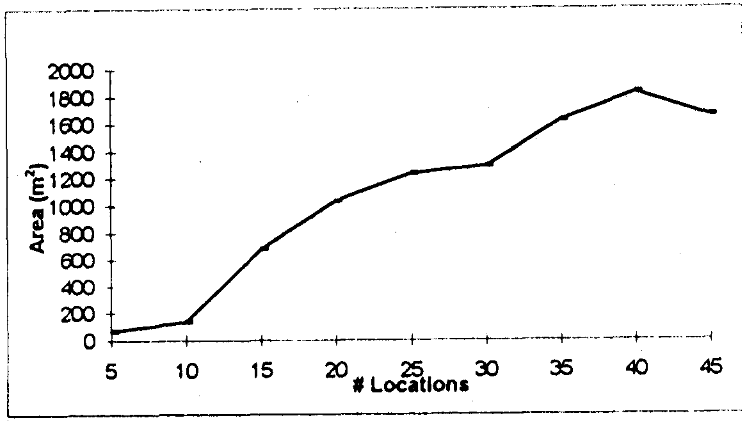


C-14. Female vole 6-434, Stand 1, 1995

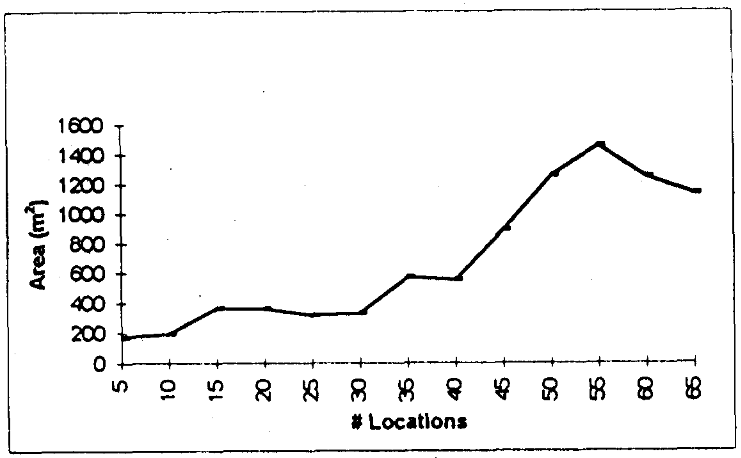
Appendix C., continued.



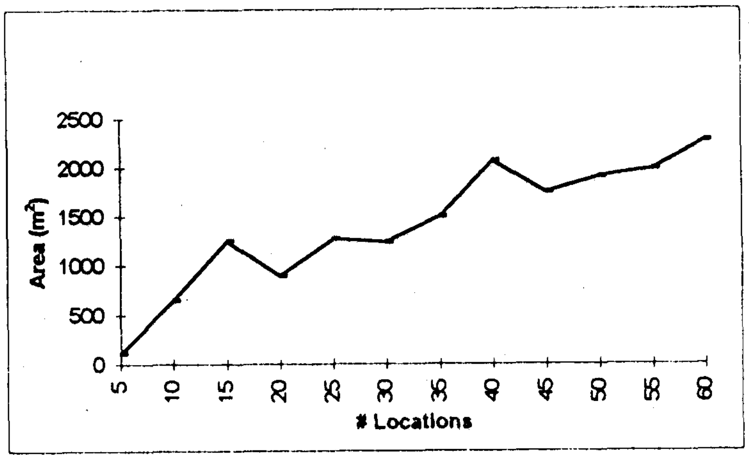
C-15. Female vole 7-257, Stand 1, 1995



C-16. Female vole 10-808, Stand 1, 1995

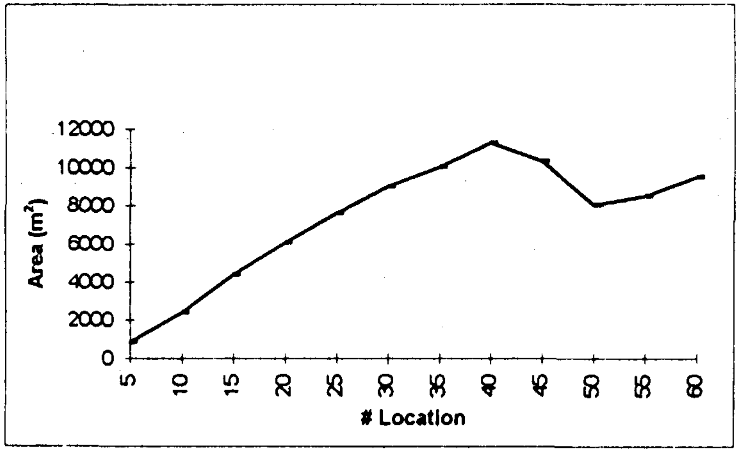


C-17. Female vole 18-755, Stand 6, 1995

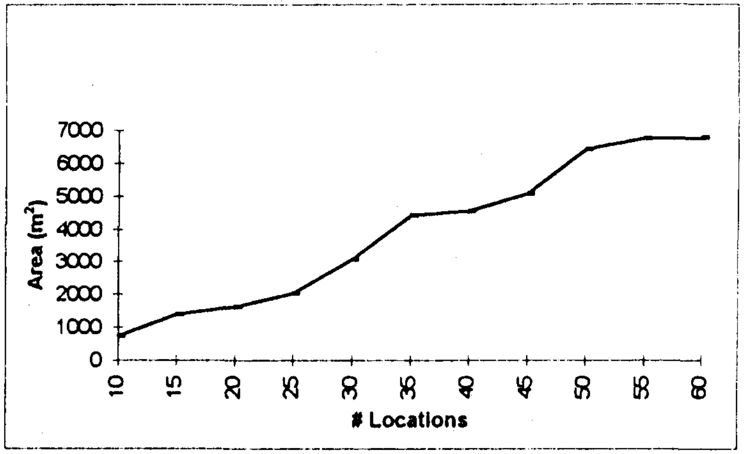


C-18. Female vole 14-973, Stand 6, 1995

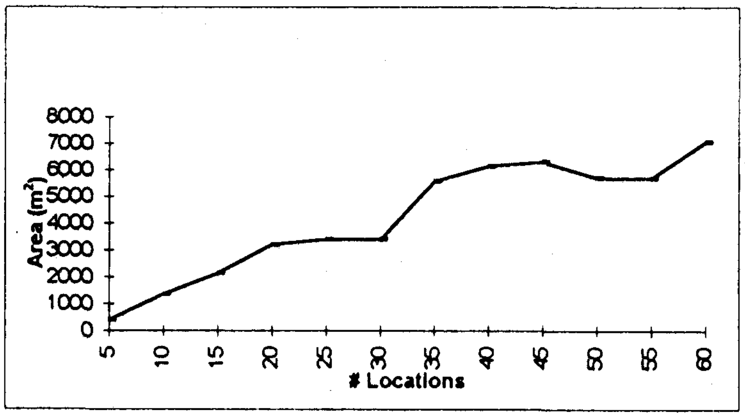
Appendix C., continued.



C-19. Male vole 9-699, Stand 1, 1995



C-20. Male vole 11-077, Stand 1, 1995

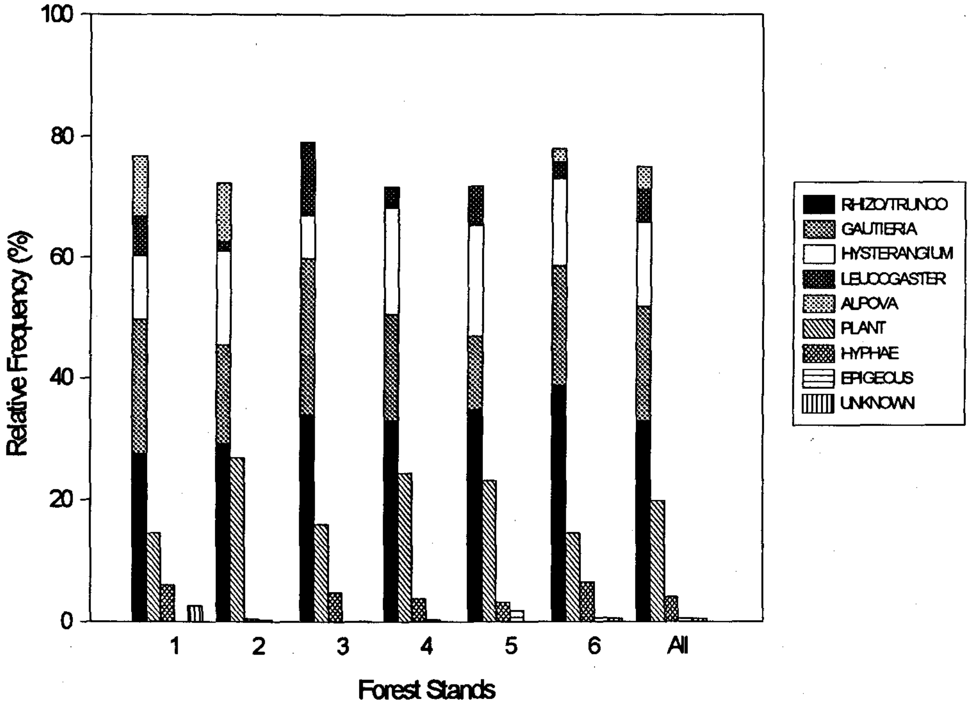


C-21. Male vole 13-540, Stand 1, 1995

Appendix D. Home range and core area sizes (ha) for individual male and female western red-backed voles in 3 coniferous stands in the southern Oregon Cascades, 1994-95.

Year	Sex[a]	Stand	Vole ID	Home range[b]	No. locations[c]	Core area	UD (%)[d]
1994	F	1	1-196	0.101	39	0.009	50
			3-517	0.322	38	0.036	45
			50-540	0.034	49	0.006	60
		5	7-097	0.074	35	0.008	60
			8-573	0.196	60	0.014	60
			10-158	0.047	60	0.011	60
			20-275	0.069	55	0.003	55
		6	1-256	0.142	71	0.025	50
			5-126	0.139	49	0.020	45
			6-076	0.079	43	0.007	55
1994	M	5	1-629	0.641	35	0.160	65
			3-386	0.521	56	0.088	60
1995	F	1	6-434	0.095	71	0.009	70
			7-257	0.106	80	0.007	60
			10-808	0.201	48	0.022	65
		5	1-989	0.181	91	0.015	55
			4-214	0.132	56	0.014	45
			5-517	0.169	111	0.025	55
		6	14-973	0.227	60	0.025	60
			18-755	0.114	68	0.020	70
1995	M	1	9-699	0.961	62	0.340	55
			11-077	0.779	64	0.086	75
			13-540	0.802	64	0.192	70

[a]F = female. M = male.
[b]Home ranges represent 95% utilization distributions (UD).
[c]Number of telemetry locations used in home range estimation
[d]Individual core area UD's.



Appendix E. Relative frequency of fungal spores and other food items in western red-backed vole fecal pellets in 6 forest stands in the southern Oregon Cascades, Fall 1994. The first column for each stand includes a combination of 3 or more truffle species identified in vole fecal samples, and the remaining columns depict non-truffle components of the diet. Rhizo/Trunco = a combination of spores from *Rhizopogon* and *Truncolumella* truffle species (they are not distinguishable by spores alone). Plant = plant material, including lichens. Epigeous = spores from 3 above-ground mushroom families. Data were provided by the Forest Sciences Laboratory, Dept. of Forest Science, OSU.