United States
Department of
Agriculture

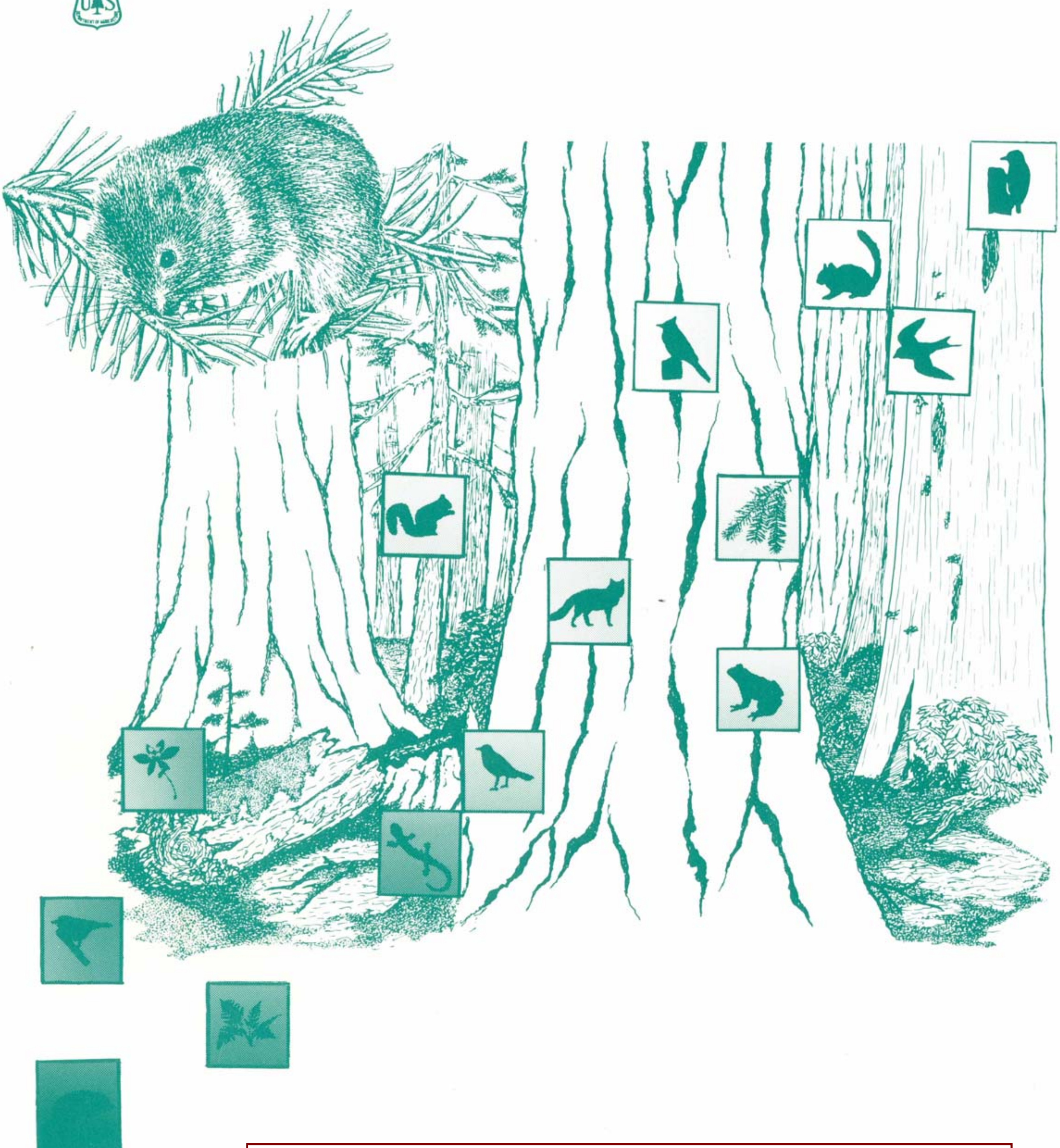
Forest Service

Pacific Northwest
Research Station

General Technical
Report
PNW-GTR-302
September 1992

Habitat Management for Red Tree Voles in Douglas-Fir Forests

Mark H. Huff, Richard S. Holthausen, and Keith B. Aubry



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Biology and Management of Old-Growth Forests

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Keith B. Aubry, Technical Coordinators

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Portland, Oregon
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Abstract

Huff, Mark H.; Holthausen, Richard S.; Aubry, Keith B. 1992. Habitat management for red tree voles in Douglas-fir forests. Gen. Tech. Rep. PNW-GTR-302. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 16 p. (Huff, Mark. H.; Holthausen, Richard. S.; Aubry, Keith. B., tech. coords. Biology and management of old-growth forests).

The relations between arboreal rodents and trees causes the animals to be particularly sensitive to the effects of timber harvesting. Among arboreal rodents, we consider the red tree vole to be the most vulnerable to local extinctions resulting from the loss or fragmentation of old-growth Douglas-fir forests. Red tree voles are nocturnal, canopy dwelling, and difficult to study. The following habitat characteristics are potentially important for this species: tree species, stand development, tree size, moisture conditions, topographic positions, elevation, and stand size. Based on these characteristics, we developed interim management strategies to help sustain or expand existing populations of red tree voles.

Keywords: Arboreal rodents, red tree vole, Douglas-fir, fragmentation, management.

Preface

Information about old-growth Douglas-fir forests and the wildlife species associated with them is critical to forest managers in the Pacific Northwest. Management of these forests has become a major public policy issue. Extremely high levels of concern have been expressed for a broad variety of values associated with old-growth forests, including ecological, social, and religious values as well as commodity values derived from timber production. Forest managers are faced with a need to devise balanced strategies that retain all these values at levels acceptable to the public and consistent with the National Forest Management Act.

Forest acreage in an "old-growth" stage of development has declined rapidly in the Pacific Northwest since the 1950s. This has caused increasing concern about species' associations with old forests and maintenance of viable populations for the most closely associated species. Decision makers need to know which species show strong associations with old-growth forests and to understand the ecological requirements of those species. Methods and tools are needed to effectively manage and monitor these species and their habitat.

The purpose of this series of publications on the "Biology and Management of Old-Growth Forests" is to summarize the life history characteristics and habitat relations of species showing strong associations with old-growth forests in Washington, Oregon, and northern California and to suggest options for their management. University and Federal scientists collaborating in the USDA Forest Service, Pacific Northwest Research Station, old-growth research program have produced a comprehensive list of associated species. Their technical research results were presented at a symposium in March 1989 in Portland, OR , and published in a book, "Wildlife and Vegetation of Unmanaged Douglas-Fir Forests." We offer this series of management publications as a sequel to that research and to address other issues surrounding the management of late-seral ecosystems. The series is funded by the Wildlife Habitat Relationships Program, Pacific Northwest Region, USDA Forest Service. The goal is to provide timely information to managers so they can make well-informed decisions about the management of old-growth forests.

Mark H. Huff
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Introduction

Rodents routinely using trees to feed, nest, and move through the forest are considered to be arboreal. Six species of arboreal rodents in habit Douglas-fir forests in western Oregon or Washington: the red tree vole, northern flying squirrel, Douglas' squirrel, bushy-tailed woodrat, dusky-foote d woodrat, and Townsends chipmunk (Carey 1991).[1] Ecosystem functions associated with the activities of arboreal rodents include the dissemination of seeds of trees and shrubs, spores of fungi, and nitrogen-fixing bacteria. These rodents also are important prey species for forest predators such as the northern spotted owl, northern goshawk, great horned owl, marten, and bobcat. Due to their obligatory relations with trees, however, arboreal rodents are particularly sensitive to environmental changes resulting from timber harvesting.

Our objectives were (1) to qualitatively evaluate the impact that the loss or fragmentation of old-growth" Douglas-fir forests may have on the six arboreal rodent species listed above, and (2) to develop management strategies for species whose populations are deemed to be at risk from the effects of such habitat alteration. We rated each species by its predicted sensitivity to the loss of old-growth forest habitat and its potential vulnerability to local extirpations. We made this assessment based on each species' reproductive characteristics, abundance, distribution, social behavior, habitat, diet, and other potentially limiting factors. We relied primarily on information presented in a companion publication by Carey (1991) on the biology of arboreal rodents in Douglas-fir forests. We judged that species with high sensitivity ratings should have high priority for development of species-specific management strategies; those with low ratings were given low priority. Although the ratings were based on available data and research results, they represent a qualitative evaluation at the regional level. Ratings may need to be adjusted to reflect local conditions at the Forest, District, or other management level.

Sensitivity Ratings

We rated the red tree vole as the most vulnerable of the arboreal rodents to local extirpations resulting from the loss or fragmentation of old-growth Douglas-fir forests (table 1). This species has a unique life history (Maser and others 1981). Red tree voles select large, live trees with large branches for nest sites and shelter, specializing in Douglas-fir (and to a lesser extent, western hemlock, grand fir, and Sitka spruce); have life history characteristics that prevent rapid population growth; have a restricted geographic distribution limited to western Oregon and northwestern California (fig. 1); and are poor dispersers, which may prevent them from maintaining populations in extensively fragmented landscapes (Carey 1991). Our rating is in agreement with Ruggiero and others (1991), who listed the red tree vole as "closely associated" with old-growth Douglas-fir forests. A designation of closely associated means that red tree vole populations would be expected to decline significantly with a major reduction in old-growth Douglas-fir forests.

Northern flying squirrels and Douglas' squirrels were rated as the second and third most vulnerable species, respectively. These species also have habits making them potentially susceptible to local extirpations, including nesting in large snags or large live trees and a specialized diet. We rated these species substantially lower in management priority than red tree voles because they occupy a much broader range of environmental conditions. Because we consider red tree vole populations to be uniquely vulnerable to

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[1] Scientific names of all species are given at end of text.

[2] Old-growth, mature, and young Douglas-fir forests were classified as forests >200 years, 80 to 195, and 35 to 79, respectively.

Table 1—Ratings of arboreal rodents based on (1) predicted vulnerability *to* local extirpations resulting from the loss or fragmentation of old-growth Douglas-fir forests and (2) the degree of difficulty to inventory and monitor each species

Species	Vulnerability rating[a]	Inventory and monitoring rating[b]
Red tree vole	9	7
Northern flying squirrel	6	9
Douglas' squirrel	5	1
Bushy-tailed woodrat	4	8
Townsends chipmunk	2	1
Dusky-footed woodrat	2	8

[a] Index ranged from 1, low vulnerability, to 10, high vulnerability.
[b] Index ranged from 1, relatively difficult, to 10, relatively easy to inventory or monitor.

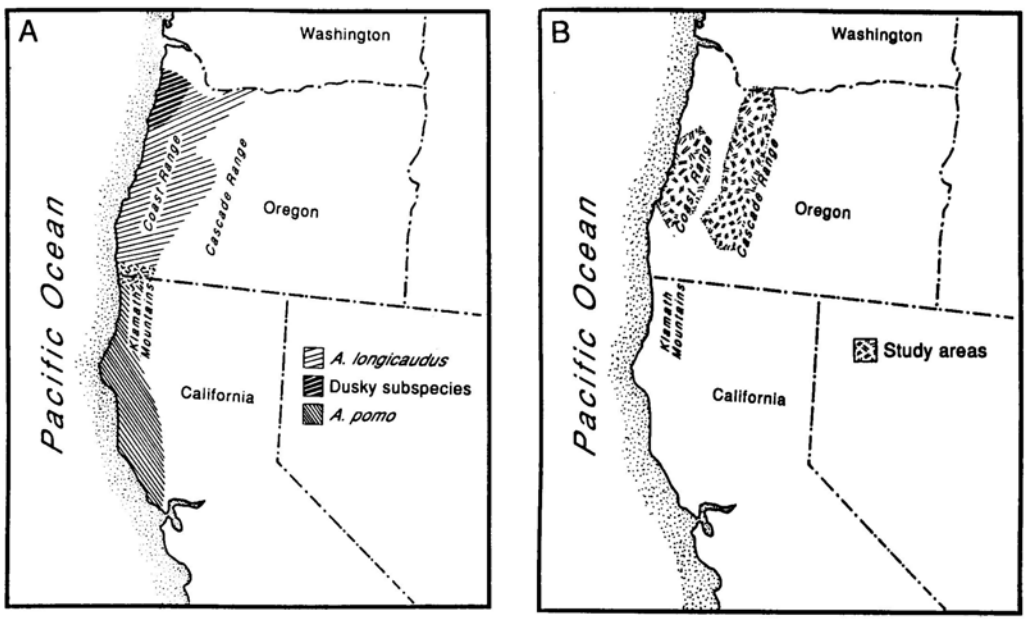

Figure 1—A. Geographic distribution of the red tree vole complex. B. Study areas where red tree voles were collected from 1984 to 1986.

the alteration of old-growth Douglas-fir forest habitat, the focus in this paper is the red tree vole. Management strategies for other arboreal rodents will be developed in subsequent papers on prey species of the northern spotted owl and on seed-eating birds and mammals in winter.

To develop management strategies, we again relied primarily on information from Carey (1991). We recommend that biologists and managers become familiar with background information presented there before attempting to implement any management strategy. Unpublished data on red tree voles[3] and on landscape characteristics associated with the distribution of red tree voles[4] also were used to develop this paper.

As Carey (1991) points out, limited information is available on the ecology of red tree voles and other arboreal rodents in the Pacific Northwest. These recommendations coincidentally may need to be amended as additional data become available. It may be decades before we understand enough about the ecology of red tree voles to reliably predict the effects of forest management on their populations; meanwhile, the information presented here offer managers a basis for initiating management strategies to maintain viable populations of this unique mammal.

Developing Interim Management Strategies

Background Information

The red tree vole is the least studied of the arboreal rodents occurring in Douglas-fir forests in the Pacific Northwest (Carey 1991). They are nocturnal and canopy dwelling, which makes them extremely difficult to observe and capture. Most of what is known comes from anecdotal observations and a few limited studies (for example, Corn and Bury 1986, Corn and others 1988, Gillesberg and Carey 1991, Maser 1965; see Carey 1991 for additional references). There is no information on their longevity, demography, or population density.

During studies of small mammal communities and vegetation characteristics in the Oregon Cascade and Coast Ranges from 1984 to1986 (Aubry and others 1991, Corn and Bury 1991, Gilbert and Allwine 1991), red tree voles were captured in pitfall traps in 18 of 99 stands sampled. Pitfall traps were used to sample small mammals occurring on the forest floor, so captures of red tree voles were unexpected (Corn and Bury 1986). No more than two individuals were captured in' any stand. Despite the limitations, no other data are available to describe the types of stands and landscapes inhabited by red tree voles over a broad geographic area. We characterized the habitat attributes of each stand and the landscape in which it occurred.[5]

To describe the characteristics of each landscape, we measured (1) percentage of late seral forest, old-growth forest (a subset of late-seral forest), clearcuts within a 1,300-foot "buffer" area around the perimeter of each study stand; and (2) total area of late-seral and old-growth forest and total area of clearcut within a 5,000-acre circular landscape surrounding each study stand (radius= 1.58 miles). Methods for characterizing these

[3] Unpublished data. On file with: Wildlife Ecology Team, Pacific Northwest Research Station, 3625 93d Ave., Olympia, WA 98512.

[4] Lehmkuhl, John L. Unpublished data. On file with: Pacific Northwest Research Station, 3625 93d Ave., Olympia, WA 98512.

[5] Spies, Tom A.; Lehmkuhl, John L Unpublished data. On file with: Pacific Northwest Research Station, 3625 93d Ave., Olympia, WA 98512.

variables are described in Lehmkuhl and others (1991). Forested areas were delineated into homogeneous patches by using aerial photographs, with each patch classified according to its successional stage. Each successional stage was identified by using aerial photo templates calibrated according to characteristics of tree crown diameters and canopy shape, levels, closure, and texture. Templates were validated and refined by sampling vegetation in 10 percent of the patches selected at random. Patches were classified as late seral or old growth if tree dominance values (combination of tree frequency and basal area; see Mueller-Dombois and Ellenberg 1974) were highest in the size classes >20 inches d.b.h. (diameter at breast height) or >32 inches d.b.h., respectively. Open patches created from timber harvesting were classified as clearcuts if tree dominance values were highest in the size class <10 inches d.b.h.

To identify potentially important habitat variables, we compared values for each habitat attribute in stands where red tree voles were captured with those in randomly selected stands where red tree voles were not captured. Differences were tested with nonparametric Mann-Whitney *U*-tests (Siegel 1956). Although the sample size was small and the power of this analysis is weak, it provided a quantitative basis for identifying specific habitat characteristics that may be associated with the presence of red tree voles. We caution that recommendations derived from this information are interim and may be modified as further information becomes available.

Using our results and available Information (Carey 1991), we selected several habitat attributes believed potentially important to red tree voles: tree characteristics (tree species, size, density, and basal area), stand characteristics (stand development and size), landscape characteristics (degree of fragmentation and buffer and landscape composition), and topographic features (topographic-moisture condition, topographic position, and elevation).

Tree Characteristics

Tree species—Red tree voles are found almost exclusively in forests having Douglas-fir in the canopy. Douglas-fir needles are the primary food of red tree voles, but they also will eat needles of grand fir, Sitka spruce, and western hemlock. Red tree voles also preferentially select Douglas-firs for nesting. Thus, the presence of live Douglas-fir trees is a key characteristic for identifying potential habitat for red tree voles.

Tree density, basal area, and size—Little is known about the numbers and sizes of Douglas-fir trees or the related structural characteristics needed to sustain local populations of red tree voles. High densities of Douglas-fir were negatively associated with red tree voles in four late-seral Douglas-fir stands in the southern Oregon Coast Range (Gillesberg and Carey 1991). In that study area, the stands with the highest density (and smallest diameters) of Douglas-fir trees had 1.2 to 2.3 times fewer nests per tree than the stand with the lowest density of Douglas-fir trees. Gillesberg and Carey (1991) hypothesized that as the size of a tree and its branches increase, the amount of suitable space for nests on branches also will increase; and, as nest space increases, the more likely that the tree will be used by red tree voles. They found that both the mean diameter and height of trees containing red tree vole nests are significantly greater than for trees without nests ($P < 0.05$). Average diameter and height of trees with nests were 39 inches and 171, feet, respectively, whereas trees without nests were 31 inches and 144 feet. Only merchantable size-class trees (>10 inches d.b.h.) were sampled, We compared the structural attributes of stands with red tree vole captures to those where voles were not captured. The attributes we examined were total density and cover of Douglas-fir, density of large trees (>39 inches d.b.h.),[6] and maximum tree height. Tree cover was inferred by calculating tree basal area. Tree basal area is a reasonable approximation of tree biomass and foliar capacity and can be used to asses the developmental status of a stand (Mueller-Dombois and Ellenberg 1974).

Although values were highly variable, the density of Douglas-fir trees generally was lower in stands where red tree voles were captured than in stands where they were not captured (table 2). The median densities of Douglas-fir in stands where red tree voles were captured in the Oregon Cascade and Coast Ranges were 28 and 32 trees per acre, respectively. The average basal areas of Douglas-fir trees within stands classified as old growth in the Oregon Cascade and Coast Ranges were 514 and 475 square feet per acre, respectively (table 2). There were no differences in Douglas-fir basal area between stands with and without red tree vole captures.

In the Oregon Cascades, the density of large trees was nearly four times greater in stands with (15/acre) than without (4/acre) red tree voles (table 2). Similarly, stands with red tree voles in the Oregon Coast Range also tended to have higher densities of large trees (mean=IO/acre), although the differences were not as strong as in the Cascades. For both provinces combined, the stands with red tree voles had a mean of 12 large Douglas-fir per acre, whereas those without had significantly fewer (6/acre; P=0.02).

Maximum tree height of the stands classified as old growth where red tree voles were captured was >160 feet In all but one stand. The median maximum tree height of these stands was about 180 feet In both the Oregon Cascade and Coast Ranges (table 2), Greater differences again were observed In the Cascades between stands where red tree voles were and were not captured than In the Coast Range, In both provinces, however, maximum tree heights generally were higher in stands where red tree voles were captured (table 2).

The presence of Douglas-fir clearly is important to maintalning viable populations of red tree voles, Even though basal area and density were highly variable among stands, the basal area of Douglas-fir was >40 percent of the total stand basal area in 15 of the 18 stands where red tree voles were captured. It seems reasonable to conclude that stands with many large, tall Douglas-firs provide high-quality habitat for red tree voles. If one objective is to retain the most productive habitat for red tree voles within multiplsuse planning areas, we suggest preserving stands having the highest density of trees 139-inch diameter and >160 feet tall. The mean or median densities of large trees occurring in stands where red tree voles were captured in the Oregon Cascade and Coast Ranges (table 2) provide useful reference points for developing management prescriptions.

[6] Research results on the density of trees within diameter classes were available only in the following size classes: 2 to 3.5 inches, 4 to 9.5, 10 to 19.5, 20 to 38.5, 39 to 58.5, and >59. The tree size and density criterion identlfied by the Old-Growth Definition Task Qroup (1986) to qualify as old-growth Douglas-fir forests was > 8 trees > 32 inches In dlameter per acre. This criterion does not correspond to the density slze-classes information avallable for developlng management strategies used in the paper.

Table 2—Mean, median, and range of vegetation and landscape variables of stands sampled for red tree voles in the Oregon Cascades Range (n=8) and Oregon Coast Range (n=10)[a]

	Oregon Cascade Range								Oregon Coast Range								Provinces Combined						
	Stands with captures				Stands without captures[e]				Stands with captures				Stands without captures				Stands with captures		Stands without captures		P-value[f]		
Variable	Mean	Med[b]	Min[c]	Max[d]	Mean	Med	Min	Max	Mean	Med	Min	Max	Mean	Med	Min	Max	Mean	Med	Mean	Med	Cas[g]	Coa[h]	All[i]
Density of Douglas-fir (per acre)	53	28	4	160	120	112	7	290	59	32	6	233	68	47	15	185	56	30	92	60	0.25	0.29	0.11
Percentage density Douglas-fir	26	20	3	69	26	39	6	98	32	17	5	82	40	32	10	78	29	18	44	33	.18	.22	.07
Basal area of Douglas-fir (ft^2/acre)	514	476	177	1117	393	382	178	637	475	482	338	623	539	507	309	753	492	476	470	469	.44	.41	.83
Percentage basal area Douglas-fir	55	63	22	87	55	60	28	100	69	67	82	96	78	78	56	97	63	64	72	76	.70	.33	.36
Density of trees 20-39 in d.b.h.	22	22	10	31	32	26	9	69	14	11	8	30	22	20	5	40	18	16	27	22	.66	.10	.12
Density of trees >39 in d.b.h.	15	12	2	33	4	1	0	12	10	10	0	15	7	6	0	18	12	10	6	4	.03	.22	.02
Density of trees >39-59 in d.b.h.	12	9	1	30	3	1	0	12	8	9	0	13	6	5	0	14	10	9	5	4	.06	.32	.03
Density of trees >59 in d.b.h.	2	2	0	7	0	0	0	1	2	2	0	5	2	0	0	5	2	2	1	0	.03	.42	.03
Maximum tree height (ft)	173	179	130	215	146	152	111	171	183	182	111	232	173	167	110	241	178	181	160	154	.10	.56	.10
Stand size (acres)	1256	1145	220	2543	1163	1045	43	2993	475	318	75	1280	831	518	118	1608	822	649	988	585	.50	.17	.79
Percentage buffer[j] in clearcut[k]	23	22	8	47	22	19	5	66	37	35	18	61	42	42	9	90	31	28	32	22	.31	.74	.44
Percentage buffer in old growth[l]	17	15	3	36	28	19	4	64	8	7	0	28	9	6	0	34	12	8	18	10	.21	.76	.31
Percentage buffer in late seral[m]	42	38	21	75	42	37	10	74	25	26	1	51	13	10	3	36	32	33	27	20	.92	.17	.36
Landscape area[n] in clearcut	691	649	385	1153	815	865	190	1710	1251	1354	505	1845	1456	1363	550	2875	1002	860	1155	926	.56	.68	.58
Landscape area in old growth	1173	856	430	2668	1351	1645	255	2260	959	1129	328	1543	879	613	40	1968	1054	1035	1101	1065	.70	.81	.68
Landscape area in late seral	2946	2923	2270	3620	2789	3150	898	4033	1554	1489	803	2598	1197	1088	85	2180	2173	2176	1946	1713	.77	.17	.55
Elevation (ft)	2751	2837	1856	4212	2899	2808	2001	3900	1427	1151	902	2572	1137	1102	282	1689	2016	1912	1966	1689	.53	.57	.96
Macrotopography[o]	2	2	1	4	3	3	2	4	3	3	2	4	3	3	2	4	3	3	3	3	.25	.62	.21
Topographic shape[p]	1	2	0	3	2	4	0	4	2	2	0	4	1	2	1	3	2	2	2	2	.03	.59	.26

[a] Data were from studies of small mammals and vegetation characteristics from 1984 to 1986.
[b] Median.
[c] Minimum.
[d] Maximum.
[e] 8 stands in the Oregon Cascade Range and 10 stands in the Coast Range were selected randomly from 46 and 35 stands, respectively, where red tree voles were not captured.
[f] P-values are for tests of independence between detected and undetected stands using Mann-Whitney *U*-test; *P*-values ≤0.19 are underlined.
[g] Oregon Cascade Range.
[h] Oregon Coast Range.
[i] Oregon Cascade and Coast Ranges combined.
[j] Buffer is defined as a 1,300-foot strip around the perimeter of a stand.
[k] All areas with trees <10 in d.b.h. that had been felled and cleared were classified as a clearcut.
[l] All forested areas with trees >32 in d.b.h. were classified as old growth.
[m] All forested areas with trees >20 in d b.h. and undisturbed riparian areas were classified as late-seral forest.
[n] A landscape was defined as a 5,000-acre area; within each landscape the amount of area in clearcut, late-seral, and old-growth forest was determined.
[o] Macrotopography refers to the topographic position of a stand where 1=valley 2=lower 1/3 of slope, 3=middle 1/3, and 4=upper 1/3.
[p] Topographic shape refers to the general horizontal shape of the terrain where 0=extreme concavity to 4=extreme convexity.

Stand Characteristics

Stand development— Carey (1991) identifies optimal habitat (that is, the habitat where a species is found with greatest frequency and in greatest densities) for red tree voles to be old-growth Douglas-fir forests. Red tree voles were captured from the Oregon Cascade and Coast Ranges in 28 percent of the old-growth stands surveyed but in only 5 percent of the unmanaged young and mature stands (see footnotes 2 and 3). Because young and mature stands represented nearly percent of total stands surveyed, the likelihood was very small ($P < 0.001$) that red tree voles were captured in five times as many old-growth stands through chance alone. Aubry and others (1991) also classify red tree voles as closely associated with old-growth forests in both the Oregon Cascade and Coast Ranges. They found that red tree voles occur in old-growth forests significantly more often than in younger forests and suggest that the age of an old-growth forest or parameters associated with age (for example, old-growth structures such as large live trees) are important habitat components.

About 67 percent of the old-growth stands with red tree voles were ≥300 years old. The mean ages were 420 and 340 years in the Oregon Cascade and Coast Ranges, respectively. Red tree voles were captured in the oldest stands surveyed in Oregon, which were estimated at 525 years old. The youngest stand in which red tree voles were captured was 62 years old; it was in the southern Oregon Coast Range and did not have features characteristic of stands classified as old growth (see Old-Growth Definition Task Group 1986). These results and those of other studies (for example, Johnson and George 1991, Maser 1965) demonstrate that red tree voles can inhabit stands younger than old growth. These younger forests are most likely sinks rather than sources, however (Carey 1991); thus they are unlikely to provide for population persistence of red tree voles over the long term.

Stand size— Providing stands large enough to sustain red tree vole populations is unquestionably a crucial factor in managing for this species. Mammalogists have observed that red tree vole populations quickly diminish or disappear where logging is widespread. Nothing is known, however, about what effect stand size may have on red tree vole persistence. Stand size is a difficult factor to isolate because it interacts with many other factors. The effect of stand size can be influenced, for example, by the number of suitable tree species within a stand; the position of the stand in the landscape; and the amount, type, and level of disturbance outside and within a stand.

Red tree voles were captured in stands ranging in size from 75 to 2,500 acres in the Oregon Cascade and Oregon Coast Ranges (table 2). The median stand size was substantially larger in the Oregon Cascade Range (1,145 acres) than in the Oregon Coast Range (318 acres). In general, only relatively small stands were available for sampling in the Coast Range, because those forests have been subjected to more intense logging pressure over the last century and catastrophic wildfire has occurred more frequently there than in the Cascades (Carey and others 1991, Huff and Raley 1991, Juday 1976).

We detected no differences in stand size between stands with and without tree voles in the Oregon Cascade Range (table 2). Red tree voles were captured in 22 percent of the 79 study stands >100 acres but in only 1 percent of the 12 stands <100 acres. They were not captured in stands <75 acres. Although speculative, it seems reasonable that red tree voles would benefit from the retention of stands substantially larger than 75 acres.

Topographic Features

Aspect, shape, and moisture condition—Suitable habitat for red tree voles has been described as mesic forest providing relatively high levels of moisture from fog, precipitation, or permanent ground water (Johnson and George 1991). We suspect that free water in the tree canopy is a critical habitat component for red tree voles. Red tree voles probably obtain most of their water from consuming conifer needles and licking moisture off the surface of vegetation.

Red tree voles may avoid dry environments because free water in tree canopies is limited during certain times of the year. In the Oregon Cascade Range, red tree voles were captured in 33 percent of the old-growth stands classified as wet (n=12) or mesic (n=9) but were not captured in any classified as dry (n=7) (table 2).[7] In the Oregon Coast Range, however, red tree voles were captured in a broader range of moisture conditions, including half of the dry stands (n=8), as well as 40 and 19 percent of the wet (n=5) and mesic (n=16) stands, respectively.

Two important factors influencing site moisture conditions are shape and aspect. For example, topographic profiles from concave to flat in shape collect and retain surface moisture better than a convex topography. Red tree voles were captured more often in stands with a concave to flat topography, especially in the Oregon Cascades (table 2, topographic shape). Stand aspect was highly variable among stands where red tree voles were captured in both the Oregon Cascade and Coast Ranges.

Old-growth stands occurring in mesic or wet locations, especlally in topographic depressions where fog lingers, seem to be the most suitable for red tree voles. The vegetative characteristics associated with mesic to wet stands are described in Franklin and Dyrness (1973) and Spies and Franklin (1991). As moisture available to plants increases, however, the density of Douglas-fir often decreases. A low amount of Douglas-flr would be expected to reduce habitat suitability for red tree voles. Consequently, both the vegetative composition of a slte and its moisture condition should be considered.

Elevation—The elevational limits of red tree voles are not known. Available information indicates that they Inhabit mid- to low-elevation forests, from sea level to below 3,000 to 4,000 feet. The geographic distribution of red tree voles and Douglas-fir In Oregon and California are virtually identical. Thus, red tree voles are probably limited to the elevational range of Douglas-fir.

Red tree voles were captured at 4,200 feet in the southern Oregon Cascade Range, but they may inhabit such high elevations only in the southern portion of their range. In the central and northern Oregon Cascades, the highest elevation where red tree voles were captured was 3,200 feet; in the Coast Range, it was 2,575 feet. Most captures were from 1,000 to 3,000 feet; the lowest was 900 feet (table 2). Red tree voles also are known to inhabit forests near sea level along the coast of Oregon and California (Johnson and George 1991).

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[7] A subjective classification of site molsture conditions was based on field observations of soils, understory plant communitlee, and physiography. Plant species that characterize the moisture claese (wet, mesic, and dry) are discussed briefly by Spies and Franklin (1991).

Landscape Characteristics

Forest fragmentation usually refers to the loss of old forests and the resulting isolation of remaining patches due to human-caused disturbances, such as timber harvest (Harris 1984, Lehmkuhl and others 1991). As forests are fragmented, a complex mosaic develops that is composed of recently cut patches and different-aged forests scattered over the landscape. Only recently have the effects of fores t fragmentation on wildlife populations been recognized and studied. No attempt yet has been made to examine the effects of forest fragmentation on red tree voles, and our analyses provided no new insigms. The amounts of area in clearcuts, old growth, and late-seral forest within 1,300-foot buffers and 5,000-acre landscapes surrounding stands with red tree voles were not significantly different from those around stands without red tree voles (table 2).

Other Factors

Two subspecies of red tree voles are recognized: red *(Arborimus longicaudus longicaudus)* and dusky *(A. l. silvicola)* (Johnson 1968). The dusky subspecies is found in only two counties in the north and central portions of the Oregon Coast Range (fig. 1). Because this range is extremely restricted, managers and biologists should take special precautions to provide suitable habitat within this geographic area.

Johnson and George (1991) propose a new species, A. porno (no common name), for tree vole populations in California, which are isolated geographically from the Oregon pqulations by the Klamath Mountains (fig. 1). Based on their well-documented research, it is likely that all California populations of tree voles will be recognized as A. *porno.* More zoogeographic and ecological studies will be needed to describe the distribution and ecology of A. *porno* in the Klamath Mountains (Johnson and George 1991).

Evaluating Habitat Suitabillty

Information limitations—Below we suggest some ways for blologlsts and resource managers to evaluate habitat for red tree voles. Existing ecological information on red tree voles does not lend itself to precise predictions about habitat requirements, and we cannot be sure that management actions will provlde for the persistence of red tree voles. To proactively address legal mandates, however, management plans should be developed for red tree voles despite this uncertainty. Our habitat evaluation procedure is based on both existing data and educated guesses. The objective here is to determine which forested areas have the highest likelihood of providing suitable habitat for red tree voles.

Our description of suitable red tree vole habitat can be applied with highest confidence to areas within the geographic distribution of red tree voles In the Oregon Cascade and Coast Ranges (fig. 1). The extent to which this may apply in other geographic areas where red tree voles occur is unknown.

Habitat suitability classes— We recommend examining seven attributes to evaluate habitat for red tree voles (fig. 2). The seven habitat attributes are tree characteristics-basal area of Douglas-fir, density of live trees >39 inches d.b.h., and maximum height of live trees; stand characteristics—stand age and size; and topographic features-moisture class and elevation. We split each attribute into two to four suitability classes, ranging from highly suitable to unsuitable. Criteria used to develop these suitability classes were derived primarily from the means, medians, and minimums shown in table 2 and from other research results reported in this paper.

Inventory and habitat databases—Forest inventory information currently available to Ranger Districts and National Forests include, for example, total resource inventory, vegetative resource surveys, and mature and Overmature inventories (Holthausen and Marcot 1991) The first step in using these databases is to determine what kind of

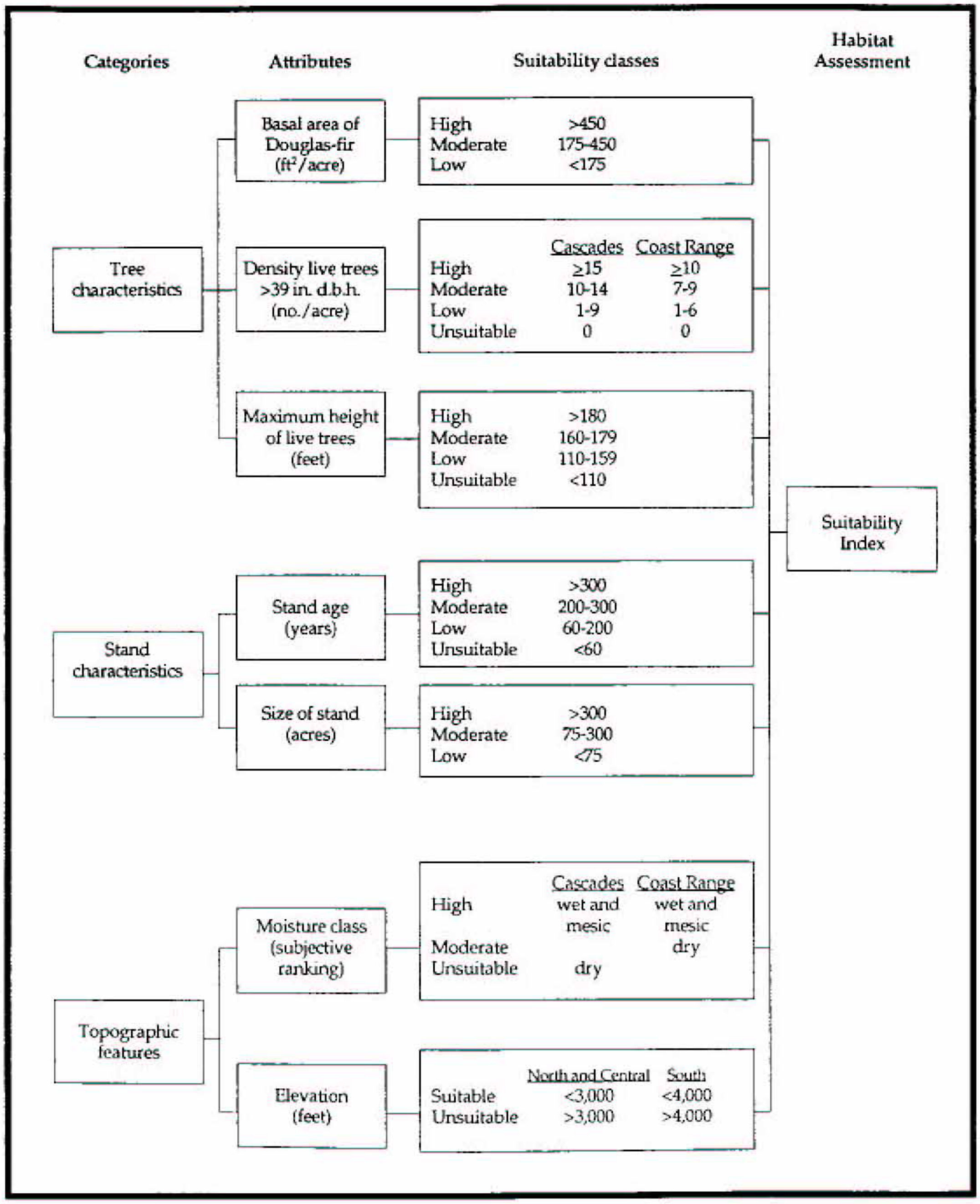

Figure 2—Attribute categories, types, and suitability classes used to evaluate habitat for red tree voles.

information is available for the seven habitat attributes. Next, standards for acceptable precision and resolution (scale) of the databases have to be addressed. Assessments can be accomplished with less than the seven recommended attributes, if the data corresponding to some of the attributes are insufficient, unacceptable, or too difficult to analyze.

It is important to classify the land base into units from which assessments and comparisons can be made. Homogeneous units or stands delineated by seral development, natural disturbance patterns, vegetation and soil types, or harvesting activities usually are obtained easily from existing databases.

Attribute weighting—Attributes can be treated equally or be weighted preferentially during the habitat evaluation process. Professional judgment plays an important role in how attributes are treated. Some factors to consider include comparing the quality of the information among attributes, the strength of associations among attributes and animal abundance or presence (for example, *P*-values in table 2), and the relative importance of an attribute to the survival and reproduction of a species (see table 3) . Because the management precision, strength of association, and importance to survival and reproduction of these attributes are largely fixed, it is primarily information quality that will determine the weightings to be applied in each situation. Attribute weights based on a hypothetical ranking are shown in table 3.

Stand ratings—Each attribute can be rated as high, moderate, low, or unsuitable within each stand by using the suitability classes shown in figure 2. To accomplish this, attribute information must be obtained from forest vegetation and other resource databases. Developing a matrix of individual stands by attribute ratings can help display the rating information for further analysis. At this point, various strategies can be used to compare stands. These may include separating stands into groups with similar attribute ratings (for example, placing stands that rate in the high category for all attributes in one group) or developing a scoring scheme to rate and rank stands by attributes (discussed below).

One quick approach to grouping stands with similar attribute ratings is to separate stands into two groups: (1) stands with at least one attribute rated as low suitability or unsuitable, and (2) stands with all attributes rated as moderate or highly suitable. The strategy here is to provide rapid identification of stands either likely or unlikely to be considered in a management plan for the red tree vole. Although it would be prudent to concentrate further analyses on only the stands with attributes rated as moderate or highly suitable, opportunities may arise when stands having ratings of low suitabiltty should be retained to provide critical links among highly suitable forest patches, or when conditions in a stand rated as having low suitability are expected to change over time to provide suitable habitat.

The objective of scoring attributes is usually to rank stands numerically. This often is accomplished by adding together the scores of the individual attributes to obtain one score for each stand. Scores for each attribute could be developed as follows: high suitability=3, moderate=2, low=I, and unsuitable=O (see fig. 2). After the scores are summed for each stand, they are ordered to determine their relative rank. Weights given to attributes also will influence the final rank of each stand. A limitation to this approach is that decisions are based on final rankings alone, without full consideration of the attributes characterizing the variation among stands. Because the information used to select these criteria is limited, it may be wise to retain stands with a variety of high and moderate suitability ratings among the attributes, rather than retaining only stands with the highest scores.

Spatial relations—Spatial considerations that are beyond the scope of this paper also can be examined. Some things to consider are the focal points of suitable patches, interconnectiveness among suitable habitat patches, extent and degree of forest fragmentation, and proposed harvesting activities within areas.

Table 3—Weights of habitat attributes for red tree voles

Attributes	Management precision[c]	Strength of association[d]	Survival and reproduction[e]	Information quality[f]	Attribute weight[g]
	Attribute weight considerations[a,b]				
Basal area of Douglas-fir	10	6	7	10[h]	1.25
Density of live trees >39 inches d.b.h.	10	8	8	10	2.0
Maximum tree height	8	8	5	5	1.25
Stand age	7	10	9	6	1.5
Stand size	8	4	7	8	1.0
Moisture class	5	5	8	4	1.0
Elevation	10	8	9	9	2.0

[a] Attribute weights of management precision, strength of association, and effects on survival and reproduction are fixed and independent of vegetation databases.
[b] Relative scale is 1-10.
[c] Refers to how precisely an attribute can be measured and applied.
[d] Refers to strength of the relation (for example, correlation) between the abundance or presence of red tree voles and the habitat attribute.
[e] Refers to the relative importance of an attribute to the survival and reproduction of red tree voles.
[f] Refers to the relative quality of the information available within the database used to rate the attributes; quality is judged by such factors as precision, extent, and intensity.
[g] Attribute weight scale is 1.0 to 2.0.
[h] These hypothetical ratings of information quality were done without examining an inventory database.

The first step to evaluating spatial relations using GIS (Geographic Information Systems) is to produce individual layers for each attribute that show the geographic distribution of suitability classes. These layers will provide a landscape-level reference map of suitable stands for red tree voles that can provide the basis for further spatial analyses. Even though maps convey valuable information, too many maps can make interpretation and decision making awkward. To alleviate this, combine maps into broad categories, such as tree characteristics, stand characteristics, or topographic features (see fig. 2), to produce multiattribute map overlays.

Forest plans and final recommendations—Before biologists or resource managers can make management recommendations for red tree voles, it is essential to examine how proposed management strategies would be implemented relative to Forest plans. Information gathered during the habitat assessment process should help in designing a range of management alternatives.

Scientific Names

Common Name	Scientific name
Mammals:	
Bobcat	*Felis rufus*
Bushy-tailed woodrat	*Neotoma cinerea*
Douglas' squirrel	*Tamiasciurus douglasii*
Dusky-footed woodrat	*Neotoma fuscipes*
Marten	*Martes americana*
Northern flying squirrel	*Glaucomys sabrinus*
Red tree vole complex—	
Red subspecies	*Arborimus longicaudas longicaudas*
Dusky subspecies	*Arborimus longicaudas silvicola*
California species	*Arborimus pomo*
Townsend's chipmunk	*Tamias townsendii*
Birds:	
Great horned owl	*Bubo virginianus*
Northern goshawk	*Accipiter gentilis*
Northern spotted owl	*Strix occidentalis*
Plants:	
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
Grand fir	*Abies grandis* (Dougl. ex D. Don) Lindl.
Sitka spruce	*Picea sitchensis* (Bong.) Carr.
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.

Acknowledgments

The pen and ink drawing was done by wildlife artist, Brigitta Van der Raay. We thank Charles Meslow and Murray Johnson for their thoughtful comments on earlier drafts of this paper.

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*U.S. GOVERNMENT PRINTING OFFICE. 1992-691-000/60050

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The relations between arboreal rodents and trees causes the animals to be particularly sensitive to the effects of timber harvesting. Among arboreal rodents, we consider the red tree vole to be the most vulnerable to local extinctions resulting from the loss or fragmentation of old-growth Douglas-fir forests. Red tree voles are nocturnal, canopy dwelling, and difficult to study. The following habitat characteristics are potentially important for this species: tree species, stand development, tree size, moisture conditions, topographic positions, elevation, and stand size. Based on these characteristics, we developed interim management strategies to help sustain or expand existing populations of red tree voles.

Keywords: Arboreal rodents, red tree vole, Douglas-fir, fragmentation, management.

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