

AN ABSTRACT OF THE DISSERTATION OF

David L. Waldien for the degree of Doctor of Philosophy in Wildlife Sciences  
presented on February 15, 2005.

Title: Population and Behavioral Responses of Small Mammals to Silvicultural and  
Downed Wood Treatments in the Oregon Coast Range.

Redacted for privacy

Abstract approved: \_\_\_\_\_

John P. Hayes

Forest managers are challenged to provide timber revenues and other resources for society while protecting and enhancing components of biodiversity that are often associated with older forests or older forest structure, such as dead wood. We examined small mammal response to timber harvest in stands 8-10 years following group-selection, two-story, and clearcut harvest, how provision of new downed wood influenced small mammals in group-selection and clearcut stands, and use of downed wood by Townsend's chipmunks (*Tamias townsendii*) in group-selection stands.

Densities of adult and reproductive female deer mice (*Peromyscus maniculatus*) were greatest in harvested stands, whereas other measures for deer mice and Townsend's chipmunks (e.g., densities of male deer mice and male chipmunks), and densities of Oregon voles (*Microtus oregoni*) and Pacific shrews (*Sorex pacificus*) were similar among all stand conditions. Density of vagrant shrews (*Sorex vagrans*) was greatest in clearcut stands and decreased with decreasing harvest intensity. Although limited data precluded statistical analysis, abundances of northern flying squirrels (*Glaucomys sabrinus*) and western red-backed voles (*Clethrionomys californicus*) were similar between unharvested control stands and group-selection stands. Within two years following augmentation of downed wood, we did not detect

any response of small mammal populations to the downed wood. Our results suggest that small mammal populations can benefit from alternative silvicultural treatments that retain overstory trees and that stands with areas of closed-canopy forest can provide habitat for species that are more abundant in intact and mature forest conditions (e.g., northern flying squirrels).

In our study of use of wood by Townsend's chipmunks, the model indicating disproportionate use of paths with downed wood by Townsend's chipmunk was 22.6 times more likely than the null model, and a chipmunk was 3.0 times more likely to select locations with downed wood at average wood densities (paths with 26% wood). Chipmunks selected wood that was 1.2 times larger in diameter than randomly available wood and there was no evidence that chipmunks disproportionately used wood that was elevated. Our findings document that downed wood is an important habitat component for Townsend's chipmunks and suggest that downed wood influences movements of chipmunks.

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POPULATION AND BEHAVIORAL RESPONSES OF SMALL MAMMALS TO  
SILVICULTURE AND DOWNED WOOD TREATMENTS IN THE OREGON  
COAST RANGE

by  
David L. Waldien

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Major Professor, representing Wildlife Science

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Dean of the Graduate School

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

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David L. Waldien, Author

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There have been many people involved in this project that it is difficult to find the words to articulate my appreciation for their involvement. The fieldwork was accomplished by a large group of people who willingly embraced (most of the time) the joys and challenges of working with small mammals in the rain and poison oak in the study area. Several people returned for multiple seasons of work even after a full dose of biting animals, poison oak, and my "cheerful" disposition on those days when nothing went right. I thank each person that contributed to this project and I hope they realize that I learned from them just as I hope they learned from me. The field crew included: D. Bailey, D. Bellman, M. Blakely-Smith, A. Burns, F. Cafferata, K. Caruso, M. Cooley, T. Davis, J. DePiero, J. Dundale, R. Emig, J. Faulkner, D. Fish, J. Gambers, P. Graff, R. Hundt, D. Jarkowski, P. Kieper, M. Moore, D. Nagy, F. Nogash, B. McNab, C. Piazza, R. Ripley, J. Saunders, C. Scott, R. Skillen, G. Smith, T. Smith, J. Verschyl, S. Walter, A. Wierk, and M. York. I would especially like to thank E. Beever, J. Faulkner, T. Manning, G. Smith, T. Smith, M. Stoddard, and S. Walter for help me when very large populations exceeded the capabilities of the crew.

I have been privileged to work with a tremendous graduate advisor and committee and their value to me during this process can not be fully expressed. Drs. J. Hayes, D. Luoma, M. Harmon, D. Olson, and A. Skaugsett provided insightful guidance through their interactions, subtle or not so subtle questions or statements, and their reputations for quality work. Although Dr. D. Rosenberg subsequently left Oregon State University and my committee, his insights were invaluable

Friends, colleagues, mentors, and professors were critical in helping me through those periods when one questions all aspects of graduate research. E. Arnett, J. Faulkner, D. Larson, T. Manning, H. Ober, G. Smith, T. Smith, M. Stoddard, S. Walter, J. Weikel, and Drs. R. Anthony, J. Erickson, L. Ganio, C. Maguire, G. Olson and N. Suzuki all tolerated questions ranging from issues in study design and analyses to dealing with challenges balancing the demands of field research, teaching, classes, and family. I could not have completed this project without their support, advice, insight, and occasional pushing or prodding me in “the right” direction.

When I look back over my tenure as a graduate student at Oregon State University, I can identify two people that greatly influenced my current views and approaches to research, learning, and professional work. My graduate advisor, Dr. John Hayes, with his insightful approach to research and steady guidance helped keep me on track (at least most of the time), and Manuela Huso, who was one of the most influential people in my tenure and facilitated my work and efforts in ways that extended beyond her statistical expertise.

Four years of eight month field seasons plus course work, teaching, and everything else that goes into a 6-year Ph.D. program can take a toll on one’s family. My wife Ginger has supported me throughout this project and has been the foundation of support for our family that allowed me to accomplish many things. She even forgave me when I gave her poison oak when she was eight months pregnant with our second child (Words of Wisdom: Do not give pregnant wife poison oak!). The demands have been great and I sincerely appreciate her sacrifices although my actions may not have always demonstrated that appreciation.

## CONTRIBUTION OF AUTHORS

Dr. John P. Hayes contributed to the study design, statistical approach, and assisted in preparation of Chapter 2 and 3 of this document. Manuela M.P. Huso contributed to the study design, statistical approach, and assisted in preparation of Chapter 3 of this document.



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## DEDICATION

To

Dr. Stephen P. Cross

Professor of Biology, Southern Oregon University

I would like to dedicate this body of work to Dr. Steve Cross. Steve has been one person that was a part of all aspects of this work and may never have realized he was involved in my research. The basics he gave me during my undergraduate education have been a strong foundation upon which to build. Many years have passed since I was a naive student in Steve's class but his influence remains. One of his dry, off-the-cuff statements, when asked by an undergraduate student (luckily not me) about what material would be on an exam, was "Just know everything and you will do all right." Fortunately many students heeded his words and we did "all right" on his challenging exams. Although I never did or ever will "know everything," I always plan to keep his words of wisdom close and work to understand all components of the challenges that I may face.

## CHAPTER 1

### INTRODUCTION

In the last decade, one focus of forest management has been protection of older forests to maintain habitat for wildlife and components of biodiversity that are associated with older forests (Thomas et al. 1993, Lehmkuhl et al. 1999). Much of the research on habitat use by small mammals in the Pacific Northwest has addressed differences in communities between older forest (often old-growth) and recently harvested clearcuts (e.g., Hooven 1973, Kirkland 1990, Walters 1991, Mills 1995) or young stands that regenerated following cutting (Rosenberg and Anthony 1992, 1993; Rosenberg et al. 1994; Hayes et al. 1995). Several studies also have examined the influence of stand age ranging from young stands (clearcuts) to old growth on small mammals (e.g., Aubry et al. 1991, Corn and Bury 1991, Gilbert and Allwine 1991, Carter 1993). Only recently has research addressed the responses of wildlife to alternative silvicultural practices (e.g., thinning, group-selection, two-story, and shelterwood harvest systems) (Waters and Zabel 1995, 1998; Von Treba et al. 1998; Lehmkuhl et al. 1999; Suzuki and Hayes 2003), ultimately yielding information on the potential of these harvest practices to provide timber while maintaining habitat for wildlife.

Downed wood has long been recognized as an important habitat component for many species of wildlife (Harmon et al. 1986, Carey and Johnson 1995, Bull et al. 1997, Bunnell et al. 1997, McComb 2003). The functional value of downed wood to vertebrates may be due to the physical structure or the microclimate in and adjacent to downed wood that can vary with the size, species, and stage of decay of downed wood

(Harmon et al. 1986, Hayes and Cross 1987, Tallmon and Mills 1994, Bull et al. 1997, McComb 2003). Downed wood provides substrates for forage and prey items (Maser and Trappe 1984, Hayes et al. 1986, Waters and Zabel 1995, Rambo and Muir 1998, Cazares et al. 1999, Luoma et al. 2003), physical cover for nest or den sites (Maser and Trappe 1984, Thompson 1996, Bull et al. 1997), and travel paths (Hayes and Cross 1987, Barnum et al. 1992, McMillan and Kaufman 1995, McCay 2000).

Recently fallen logs with little decay may not provide the structural conditions required for some species to build a den within the downed wood. Further, wood with little decay also may not provide optimal microclimatic conditions that some species require for den or nest sites and may not offer substrates capable of supporting fungi, bryophytes, or invertebrate populations (Harmon et al. 1986, Bunnell et al. 1997).

However, levels of decay may not detract from some benefits associated with the structure of downed wood (e.g., cover for den and nest sites, travel paths). Although downed wood is thought to influence the behavior, diversity, and abundance of some species of small mammals (Aubry et al. 1991, Carter 1993, Carey and Johnson 1995, Lee 1995, McCay 2000), it may not restrict the abundance or distribution of other species because they are able to exploit alternate microhabitats (Carey and Johnson 1995, Bunnell et al. 1997).

Much of the research on the influence of silvicultural harvest systems and downed wood on small mammals has yielded data that is often inconsistent among studies, perhaps in part due to different habitat component having similar functions. Additionally, use of density and abundance as response measures of small mammal populations may not elucidate the value of downed wood to some species. Another



problem is that most research on associations of small mammals to stand conditions and microhabitat is observational. Although well designed observational studies provide valuable insight into ecological questions, an experimental approach that manipulates specific variables (e.g., overstory canopy cover, downed wood) and attempts to account for other influencing variables (e.g., seasonal influences) allows inference to causality and insight into the context of the results.

Two related studies are presented in this dissertation. In Chapter 2, we present the responses of small mammal populations to silvicultural treatments approximately 8-12 years following harvest and in the first two years following addition of downed wood to the same stands. Specifically, we compare responses of small mammal populations and communities between unharvested control stands and stands that were logged with group-selection, two-story, and clearcut harvest systems. We also examine the response of small mammals to the addition of downed wood in group-selection and clearcut stands. In Chapter 3, we present the effects of downed wood on path selection by Townsend's chipmunks (*Tamias townsendii*) in group-selection stands.

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CHAPTER 2

INFLUENCE OF SILVICULTURAL AND DOWNED WOOD TREATMENTS ON  
SMALL MAMMAL POPULATIONS IN WESTERN OREGON

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**ABSTRACT:** We examined populations of small mammals in three silvicultural treatments (group-selection, two-story, and clearcut harvest) 8-12 years post-treatment and in unharvested forests, and population responses to a downed wood treatment in group-selection and clearcut stands. In general, abundances of species associated with open forest canopies were similar in unharvested stands and all three treatments, with a trend for greater densities in harvested stands. A similar pattern was observed in response to wood treatments, with similar densities of species associated with open canopies in group-selection and clearcut stands. Densities of adult female ( $F_{3,6} = 13.52$ ,  $P < 0.01$ ) and reproductive female ( $F_{3,6} = 5.33$ ,  $P = 0.04$ ) deer mice (*Peromyscus maniculatus*) were greater in harvested stands than in uncut controls. Other measures for deer mice and Townsend's chipmunks (*Tamias townsendii*), and densities of Oregon voles (*Microtus oregoni*) were similar among all stand conditions ( $P > 0.05$ ). Density of vagrant shrews (*Sorex vagrans*) was greatest in clearcut stands and decreased with harvest intensity ( $F_{3,6} = 5.87$ ,  $P = 0.03$ ). Densities of Pacific shrews (*Sorex pacificus*) were similar among all stand conditions ( $F_{3,6} = 1.83$ ,  $P = 0.24$ ), but low numbers of captures in clearcut stands precluded assessment of response to wood treatments. Captures of species associated with closed forest canopies tended to be reduced following harvest, although group-selection stands appear to provide habitat for northern flying squirrels and western red-backed voles whereas two-story and clearcut stands do not. We did not detect statistically significant responses of any species to our wood treatment ( $P > 0.05$ ).

Stands harvested using group-selection maintain habitat for arboreal species and other species that benefit from a closed-canopy forest. Harvest systems that do

not leave adequate numbers of trees will adversely impact species associated with closed forest canopies until the habitat recovers adequately to provide needed resources.

## INTRODUCTION

In many forest types, especially in coniferous forests, even-age harvest systems (e.g., clearcutting) are the primary silvicultural systems used by forest managers (Smith et al. 1997, Kellogg et al. 1996). Past forest management approaches using extensive clearcut harvests have resulted in large expanses of relatively homogeneous young forests with limited numbers of large green trees, snags, and logs that are important legacy structure to many species of wildlife associated with older forests (McComb et al. 1993). Alternatives to clearcut harvest, especially if combined with the maintenance of legacy structures, have the potential to provide timber revenue and maintain and enhance habitat for species associated with older forests or older forest structure (Carey and Curtis 1996, Hayes et al. 1997, McComb et al. 1993, Carey 2001, Carey and Wilson 2001). Forest management can benefit from knowledge of the implications of implementing different harvest systems on timber revenue and on ecological and social objectives and values (Franklin et al. 1997, Tappeiner et al. 1997).

Much of the past research on habitat associations of small mammals in forests in the Pacific Northwest addressed differences in small mammal communities between older forest (often oldgrowth) and recently harvested clearcuts (e.g., Hooven 1973, Kirkland 1990, Walters 1991, Mills 1995) or young stands regenerated following



clearcut harvest (e.g., Rosenberg and Anthony 1992, 1993, Rosenberg et al. 1994, Hayes et al. 1995). Several studies also have examined the responses of small mammals to forest conditions across chronosequences of developmental stages ranging from clearcuts to old growth (e.g., Aubry et al. 1991, Corn and Bury 1991, Gilbert and Allwine 1991). Although this past research provides valuable information on responses of wildlife to clearcut harvest, there is limited information on the response of wildlife to silvicultural approaches that retain intermediate levels forest structure. Responses of wildlife to silvicultural practices, such as shelterwood, two-story, single-tree and group-selection, and thinning, are an emerging information need. To date, few studies have focused on the potential consequences of alternative management approaches on wildlife (e.g., Von Trebra et al. 1998, Waters and Zabel 1998, Aubry et al. 1999, Chambers et al. 1999, Gitzen and West 2002, Suzuki and Hayes 2003) and it is unclear if species have graded or threshold-type responses to different intensities of timber harvest.

Downed wood is an important habitat component for small mammals in forests of the Pacific Northwest (Harmon et al. 1986, Carey and Johnson 1995, Bunnell et al. 1997). Logs provide substrates and habitats for fungi, lichens, and invertebrates that are forage and prey for many species of small mammals (Maser and Trappe 1984, Hayes et al. 1986, Amaranthus et al. 1994, Bunnell et al. 1997, North et al. 1997, Rambo and Muir 1998, Carey et al. 1999, Gomez et. al. in press). Many species use downed wood as physical cover for nest or den sites (Maser and Trappe 1984, Thompson 1996, Bull et al. 1997, McCay 2000) and as travel paths (Barnum et al. 1992, McMillan and Kaufman 1995, McCay 2000, Ucitel et al. 2003, Zollner and

Crane 2003, Chapter 3). Downed wood is a strong predictor of abundance of several species of small mammals (Carey and Johnson 1995, Craig 1995, Lee 1995, Butts and McComb 2000), although there is inconsistency in the response of small mammals to downed wood, likely related to differences in abundances of other habitat features, such as understory vegetation (Carey and Johnson 1995). Information on how small mammal populations respond to downed wood in different contexts (e.g., stand conditions resulting from different harvest systems) can help managers develop silvicultural prescriptions that more fully meet the biological needs of species.

Understanding responses of small mammal to timber harvest generally has been based on observational studies and short-term experiments that examine responses immediately following timber harvest, and there are few experimental studies that have examined responses of wildlife more than a few years following harvest (e.g., Carey 2001). Research evaluating small mammal responses to silvicultural experiments several years after treatment can provide information that may not be readily apparent immediately following harvest on the implications of timber harvest on populations of small mammal. For example, in western Oregon western red-backed voles (*Clethrionomys californicus*) decline in response to thinning treatments immediately following harvest, but populations appear to recover several years after harvest (Carey 2001, Suzuki and Hayes 2003). Insight into potential time lags and changes in trajectories in the responses of species of interest to a treatment can be better interpreted several years following harvest. In contrast, insights from

short-term studies may lead to incorrect conclusions regarding the potential influences of specific silvicultural prescriptions.

We examined responses of small mammals to three silvicultural treatments and to a downed wood treatment 8-12 years following timber harvest in western Oregon. Specifically, we examined responses of small mammal populations to small group-selection (33% of the volume removed in 0.2 ha circular patches), two-story treatment (75% of the volume uniformly removed), and clearcut harvest 8-10 years post-harvest. We also examined the response of small mammals two years following the addition of 5 mature Douglas-fir (*Pseudotsuga menziesii*) trees in group-selection stands and 11 large diameter Douglas-fir logs to clearcut stands 10-12 years post-silvicultural harvest. We predicted that deer mice (*Peromyscus maniculatus*), Oregon voles (*Microtus oregoni*), Townsend's chipmunks (*Tamias townsendii*), and vagrant shrews (*Sorex vagrans*) would increase in harvested treatments (Hooven 1973, Kirkland 1990, Von Trebra et al. 1998, Waters and Zabel 1998) and that responses would be similar in two-story and clearcut stands due to the comparable understory vegetation in these two stand conditions. We hypothesized that northern flying squirrels (*Glaucomys sabrinus*) and western red-backed voles would decrease in harvested stands (Gashwiler 1970, Walters 1991, Mills 1995, Waters and Zabel 1995, 1998), and that populations of these species in group-selection stands would be statistically similar but reduced relative to populations in control stands. We expected to find that small mammals that use downed wood as travel paths (Hayes and Cross 1987, Carter 1993, Chapter 3) or that have home ranges, abundance, or densities that are associated

downed wood (Tallmon and Mills 1994, Lee 1995, Bunnell et al. 1997, Butts and McComb 2000) would increase in abundance in response to the addition of downed wood. We did not expect to observe different responses to the downed wood treatment in the two different stand types examined because of the similarity in wood treatments and the relatively high degree of cover from shrubs and other vegetation in group-selection and clearcut stands.

## **METHODS**

This study was located on the McDonald-Dunn Research Forest at the eastern edge of the Oregon Coast Range in Benton County, Oregon (Townships 10 and 11 South, Range 5 West). Forests in this area are dominated by Douglas-fir, and grand fir (*Abies grandis*), bigleaf maple (*Acer macrophyllum*), Oregon white oak (*Quercus garryanna*), Pacific madrone (*Arbutus menziesii*), Pacific dogwood (*Cornus nuttallii*), red alder (*Alnus rubra*), Oregon ash (*Fraxinus latifolia*), and bitter cherry (*Prunus emarginata*) occur in lesser abundance (Chambers et al. 1999). The study area has an annual average rainfall of 111.8 cm and an average January temperature of 4.4 C and an average July temperature of 19.2 C (Oregon Climate Service 2005).

### **Experimental Design**

Our study was designed as part of a long-term research project examining the response of birds and small mammals to silvicultural treatments (College of Forestry Integrated Research Program [CFIRP]; Chambers et al. 1999). CFIRP is a blocked design with replicated silvicultural treatments within each of three blocks (Saddle,

Peavy, and Dunn blocks). Three silvicultural treatments (small and large group-selection, two-story, and clearcut) were implemented between 1989 and 1991. Each block had at least two replicates of the small group-selection, two replicates of the two-story and clearcut treatments, and one replicate of the unharvested control stands. Small group-selection stands (henceforth referred to as group-selection) had 33% of the volume removed in 0.2 ha circular patches, two-story stands had 75% of the volume uniformly removed, and clearcut stands retained 1.2 green trees/ha. Unharvested control stands did not receive any silvicultural treatment and prior to treatment stands were 90 to 130 years old.

To evaluate influences of silvicultural treatments on small mammals, we randomly selected two group-selection stands from the pool in each of the Saddle and Peavy blocks and used the only two replicates of the group-selection stands in the Dunn block. We used both replicates of the two-story and clearcut stands in each of the Peavy and Dunn blocks and randomly selected a second comparable clearcut within the Saddle block to replace a CFIRP clearcut replicate because it was too small to encompass our trap-grid. We randomly selected a second, non-CFIRP, unharvested control stand in each of the Saddle and Peavy blocks. Because there was not a comparable non-CFIRP unharvested control stand in the Dunn block due to past timber harvest, we divided the unharvested control stand into 2 areas that were separated by a stream and a dirt road; this CFIRP control stand was a coalescence of four similar stand conditions and the stream likely functioned as a barrier to most small mammal movements and thus we believe these two units are functionally

distinct for most small mammals. A total of 24 stands were used in the silvicultural treatment study (Appendix A).

For the wood treatment objective, we randomly identified one of the group-selection and one of the clearcut stands from the stands used in our study in each of the three blocks to receive a downed wood treatment (Appendix A). The other group-selection and clearcut stand per block served as a wood treatment control. Eleven logs were added to one clearcut in each of the three blocks. A helicopter was used to place the logs within the perimeter of the trap grid in February 2001 ( $\bar{x}$  volume per stand =  $45.1 \text{ m}^3$ ,  $\text{SE} = 1.5 \text{ m}^3$ ) and were distributed in three dispersed clumps of 1, 3, and 7 logs in each of three quarters of the trap grid; the fourth quarter did not receive any wood. In one group-selection stand in each block, five trees were felled within 30 m of the perimeter of the trap-grid in March 2001 ( $\bar{x}$  volume per stand =  $54.7 \text{ m}^3$ ,  $\text{SE} = 5.0 \text{ m}^3$ ). The five trees were felled in a manner to distribute them throughout the grid with a portion of the bole of each tree remaining under the remaining overstory trees and a portion landing in the cut patch.

### **Small Mammal Sampling**

An 8 x 10 grid with 10-m spacing between grid points (0.63 ha) was established in each stand; the edge of each grid was  $\geq 35$  m from the edge of the stand. Grids in group-selection stands were randomly placed to sample an area of the stand that approximated the proportions of uncut and cut areas available at the stand-level (approximately 2/3 of the grid was in uncut forest and 1/3 was in patch habitat). Most

grids were >300 m apart, although edges of 4 grids were located ca. 150 m from another grid.

One large, collapsible Sherman live-trap (Model LFA, 8 x 9 x 23 cm; H. B. Sherman Traps, Inc., Tallahassee, Florida, USA) was placed within 1 m of each point on the grids (80 Sherman traps per grid). Starting spring 2000, one Tomahawk live trap (Model 201, 13 x 13 x 41 cm; Tomahawk Live Trap Co., Tomahawk, Wisconsin, USA) was also placed within 1 m of every other station on every other row in each grid (20 Tomahawk traps per grid, 20-m spacing). Traps were baited with a mixture of peanut butter, rolled barley, rolled corn, rolled oats, and cane molasses. Bait was wrapped in wax paper and suspended inside the rear door of Sherman traps to minimize interference of the bait with the operation of the trigger (Stout and Sonenshine 1973) or was placed in the nest box in the rear of the Tomahawk traps. Polyfiber batting was used for bedding material to provide thermal protection to captured animals and traps were covered with waxed cardboard for insulation and protection from rain.

To evaluate the influence of silvicultural treatments, we trapped animals in summer (July and August) and fall (October and November) 1999 and in spring (April and May), summer, and fall in 2000 in control stands and three silvicultural treatments (5 trap sessions total). For the wood treatment objective, we trapped animals in group-selection and clearcut stands in summer and fall 1999 and in spring, summer, and fall 2000-2002 (5 seasons pre-wood addition and 6 seasons post-wood addition; 11 trap sessions total). All trap-grids within a block were sampled simultaneously with an equal capture effort applied within each stand and within each season. Blocks were

sampled in a random order the first season and the order in which blocks were sampled was maintained throughout the duration of the study. Each trap session was preceded by a 3-4 night period during which traps were baited and locked open to reduce potential avoidance of the traps, which can influence capture probabilities and population estimates (Otis et al. 1978). Traps were then set and checked daily starting shortly after sunrise for five consecutive days.

Captured animals were weighed and identified to species, sex, age (adult or juvenile), and reproductive condition. We classified deer mice and Townsend's chipmunks as either adult (deer mice: > 15g, Townsend's chipmunk > 60g) or juvenile. Female deer mice and Townsend's chipmunks were classified as reproductive if they had enlarged mammae (indicating current or recent lactation) and males were classified as reproductive if they had scrotal testes. We did not differentiate age or reproductive classes for other species due to small sample sizes. All individuals were marked with a uniquely numbered ear-tag in each ear, with the exception of shrews (*Sorex* sp.) and shrew-moles (*Neurotrichus gibbsii*), which were marked by clipping a distinct mark in the fur of each individual. Brush rabbits (*Sylvilagus bachmani*), coast moles (*Scapanus orarius*), California ground squirrels (*Spermophilus beecheyi*), and Douglas' squirrels (*Tamiasciurus douglasii*) were not tagged or marked. Live animals were released at the point of capture and dead animals were collected for identification in the laboratory.



## Analyses

We estimated abundance and mean maximum distance moved (MMDM) of all adults (female and males combined), adult female, adult male, reproductive female, and reproductive male deer mice and Townsend's chipmunks on each grid for each season using Program CAPTURE (Otis et al. 1978, Rexstad and Burnham 1992). We used the model selection option in CAPTURE to assist with selection of the most appropriate population estimators. We chose one estimator for use on all grids and seasons for a given species to reduce differences in estimation related to differences in biases among estimators. We selected Pollock's removal estimator (Model  $M_{bh}$ ; Pollock and Otto 1983) for estimates of both species because capture probabilities appeared to be affected by heterogeneity and behavior. Density estimates were calculated based on the effective area trapped, which was estimated by adding one-half the MMDM around the area encompassed by each trap grid (Wilson and Anderson 1985). We used total captures per 0.63 ha (the size of the trap grid) as a naïve estimate of density for each species for which MMDM was not estimated. Densities of reproductive adult male deer mice were not estimated because determination of reproductive condition was problematic.

We calculated the age ratio (number of juveniles per adult female) for deer mice and Townsend's chipmunks as a measure of reproductive output, and calculated the gender ratio (number of adult females to adult males) of deer mice, Townsend's chipmunks, and Trowbridge's shrews (*Sorex trowbridgii*) to as a measure of reproductive capacity.

We used program MARK (White and Burnham 1999) to estimate apparent survival ( $\Phi$ ; an estimate of both mortality and dispersal) of adult deer mice (females and males combined) for each individual stand. *A priori* models were developed based on factors that could influence survival including, seasons, interval length, and pre- and post- wood treatments. We evaluated strength of 9 *a priori* models for the silvicultural objective (Appendix B) and 25 *a priori* models for the wood treatment objective (Appendix C). Small sample sizes can yield imprecise and biased estimates (Lebreton et al. 1992). Therefore for the silvicultural objective, only survival estimates for the spring-summer 2000 time interval from MARK were used in analyses due to relatively few individual animals captured per stand during summer and fall 1999. Likewise, for the wood treatment objective, survival estimates for the first two (summer to fall 1999 and fall 1999 to spring 2000) and last two time intervals (spring to summer 2002 and summer to fall 2002) from MARK were not used in analyses due to relatively few individual animals being captured in each stand during these trap sessions. Survival estimates from the last time interval (summer-fall 2000 or summer-fall 2002) cannot be directly estimated (Lebreton et al. 1992) and were not included in analyses.

We calculated species richness, Shannon's index ( $H'$ ) (Pielou 1975), and Simpson's index ( $D$ ) (Simpson 1949) for each stand sampled within each trap session. Shannon's index is an information statistic and accounts for the evenness in species abundance, whereas Simpson's index is a dominance index and weights the more abundant species in the analyses (Magurran 1988).

We used a repeated measures analysis of variance (RM-ANOVA) or an analysis of variance (ANOVA; Ramsey and Schafer 1997, Steel et al. 1997) to assess differences in densities and survival in relation to silvicultural and wood treatments (PROC MIXED; SAS Institute 1999). We limited our statistical analyses to species that occurred in all three blocks and in  $\geq 50\%$  of the season by replicate combinations. Silvicultural treatments or seasons were excluded from analyses if the species was rarely captured. We examined histograms, normal probability plots, and residual plots (Sabin and Stafford 1990, Steel et al. 1997) to evaluate presence of potential outliers and assumptions of normality, constant variance, and independence of residuals. Data that did not meet these assumptions were log-transformed [ $\ln(Y)$  or  $\ln(Y+1)$ ] for analysis. We used an information-theoretic approach ( $AIC_c$ ) to select a covariance structure (PROC MIXED; SAS Institute 1999). We tested for block by treatment interactions (PROC GLM; SAS Institute 1999) and included block as a fixed effect in the model if an interaction was detected; block was modeled as a random effect if no interaction was identified. Influences of potential outliers on statistical significance and effect sizes were examined by conducting analyses with and without potential outliers; outliers were excluded from analyses only if including them they changed the conclusions of the analysis (Ramsey and Schafer 1997). We used  $\alpha = 0.05$  as a measure of statistical significance.

## RESULTS

During 91,200 trap nights (TN) over the entire study, we had 35,138 captures of 22 species of small mammals (Table 2-1). Deer mice and Townsend's chipmunk

were the most frequently captured species and represented 69.5% and 18.5% of the captures, respectively.

In 55,200 TN (48,000 TN for Sherman traps, 7,200 TN for Tomahawk traps) for the silvicultural treatment objective, we captured 7,005 individuals representing 19 species and 7 families of small mammals in 5 seasons over 2 years (Table 2-1); 1 additional species was captured but not marked and so were not included in the summary of the number of individuals captured. The deer mouse was the most frequently captured species and represented 63% of the individuals captured. Townsend's chipmunk and Trowbridge's shrew were the next most commonly captured species and represented 13% and 9% of the individuals captured, respectively. All shrews combined represented 16% of the individuals captured.

In 63,600 TN (52,800 TN for Sherman traps, 10,800 TN for Tomahawk traps) for the wood treatment objective, we captured 8,023 individuals representing 21 species and 7 families of small mammals in 11 seasons over 4 years (Table 2-1); 4 additional species and 1 additional family were captured but not marked and so was not included in the summary of the number of individuals captured. The deer mouse was the most frequently captured species and represented 54% of the individuals captured. Townsend's chipmunk and Trowbridge's shrew were the next most commonly captured species and represented 16% and 12% of the individuals captured, respectively. All shrews combined represented 19% of the individuals captured.

For the silvicultural and wood treatment objectives combined, we also had 462 captures of 17 non-mammalian vertebrate species; 446 captures of 10 species of birds, 3 captures of 2 species of amphibians, and 13 captures of 5 species of reptiles

Table 2-1. Number of individual small mammals captured for the silvicultural treatment objective (unharvested control stands and three silvicultural treatments over two years and five seasons, 1999-2000) and the wood treatment objective (group-selection and clearcut treatments over four years and 11 seasons, 1999-2002) in western Oregon. NW = no wood added; W = wood added. Individual animals captured in clearcut and group-selection stands in the five seasons of trapping in 1999 and 2000 for the silvicultural objective are also represented in the wood treatment objective as part of the pre-treatment sampling.

Table 2-1.

FAMILY	SPECIES	Silvicultural Treatment					Wood Treatment				
		Control	Group- Selection	Two- Story	Clearcut	Total	Group- Selection		Clearcut		Total
							NW	W	NW	W	
Didelphidae	<i>Didelphis virginiana</i>	0	0	0	0	0	0	0	1	0	1
Dipodidae	<i>Zapus trinotatus</i>	1	4	26	10	41	8	5	26	30	69
Leporidae	<i>Sylvilagus bachmani</i> <sup>1</sup>	0	0	1	0	1	3	2	1	0	6
Muridae	<i>Clethrionomys californicus</i>	16	22	4	0	42	25	35	2	1	63
	<i>Microtus oregoni</i>	29	83	74	137	323	64	109	79	209	461
	<i>Microtus townsendii</i>	0	0	0	0	0	0	0	2	0	2
	<i>Mus musculus</i>	1	0	0	0	1	0	1	0	0	1
	<i>Neotoma cinerea</i>	1	0	0	0	1	0	1	0	0	1
	<i>Neotoma fuscipes</i>	2	15	35	52	104	29	25	127	53	234
	<i>Peromyscus maniculatus</i>	910	1074	1293	1158	4435	1047	1045	1261	1012	4365
Mustelidae	<i>Mustela erminea</i>	4	8	8	11	31	8	5	9	11	33
Sciuridae	<i>Glaucomys sabrinus</i>	27	18	0	0	45	21	36	0	0	57
	<i>Spermophilus beecheyi</i> <sup>1</sup>	0	0	7	12	19	1	1	9	21	32
	<i>Tamias townsendii</i>	98	261	336	208	903	350	336	300	310	1296
	<i>Tamiasciurus douglasii</i> <sup>1</sup>	0	1	0	0	1	13	1	0	0	14
Soricidae	<i>Sorex bairdi</i>	12	24	14	8	58	24	15	4	8	51
	<i>Sorex pacificus</i>	33	74	43	18	168	87	87	7	29	210
	<i>Sorex sonomae</i>	17	37	23	18	95	24	30	10	13	77
	<i>Sorex trowbridgii</i>	195	182	145	111	633	281	251	174	242	948
	<i>Sorex vagrans</i>	5	18	34	80	137	16	25	57	108	206
Talpidae	<i>Neurotrichus gibbsii</i>	4	0	0	0	4	4	1	1	1	7
	<i>Scapanus orarius</i> <sup>1</sup>	0	1	0	0	1	2	1	0	2	5
TOTAL <sup>2</sup>		1355	1822	2029	1799	7005	1967	2002	2049	2005	8023

<sup>1</sup> Represents number of captures because individuals were not marked.

<sup>2</sup> Does not include captures of California ground squirrels for the silviculture objective or captures of brush rabbits, California ground squirrels, Douglas' squirrels, and coast moles for the wood objective because the number of individuals of these species were not tracked.

(Appendices D and E; Waldien et al. 2004). Most of these captures were in two-story and clearcut stands.

### **Small Mammal Populations**

*Silvicultural Treatment Objective.*—Population densities and gender and sex ratios varied seasonally for all species analyzed ( $P \leq 0.05$ ) except for density of vagrant shrews ( $F_{4,9} = 1.85$ ,  $P = 0.13$ ; Table 2-2 and 2-3). In general, population densities were low for all species in 1999 and elevated in 2000 (Fig. 2-1A).

More deer mice were captured in each type of harvested stands than in unharvested control stands (Table 2-1). Density of adult female ( $F_{3,6} = 13.52$ ,  $P < 0.01$ ) and reproductive female ( $F_{3,6} = 5.53$ ,  $P = 0.04$ ) deer mice differed among silvicultural treatments (Table 2-2), with greatest densities observed in two-story stands and lowest densities in control stands (Table 2-4). There was a significant treatment by time interaction for total density of deer mice ( $F_{12,92} = 1.92$ ,  $P = 0.04$ ; Table 2-2) with greater densities in harvested stands relative to control stands and with greater densities in two-story stands across all seasons (Fig. 2-2). There tended to be lower densities of adult and male deer mice and fewer females per male in control stands than in all three silvicultural treatments (Tables 2-4 and 2-5), although none of these differences were statistically significant ( $P > 0.05$ , Tables 2-2 and 2-3). Conversely, although not statistically significant ( $F_{3,6} = 2.12$ ,  $P = 0.20$ , Table 2-3), the number of juveniles per adult female tended to be lowest in two-story and clearcut stands and greatest in group-selection stands (Table 2-5). Apparent survival of adult deer mice was nearly statistically significantly different among treatments ( $F_{3,6} = 3.95$ ,

Table 2-2. Repeated measures analysis of variance results for species densities for the silvicultural treatment objective (unharvested control stands and three silvicultural treatments over two years and five seasons, 1999-2000) in western Oregon. SVT = silvicultural treatment.

Species	SVT			TIME			SVT x TIME		
	d.f.	F	P	d.f.	F	P	d.f.	F	P
Deer mouse									
Total	3,6	7.00	0.02	4,92	237.51	< 0.01	12,92	1.92	0.04
Adult	3,6	3.74	0.08	4,92	195.84	< 0.01	12,92	1.72	0.08
Female	3,6	13.52	< 0.01	4,92	86.63	< 0.01	12,92	0.88	0.57
Reproductive	3,6	5.53	0.04	4,92	68.43	< 0.01	12,92	1.14	0.34
Male	3,6	2.22	0.19	4,92	206.12	< 0.01	12,92	1.74	0.07
Townsend's chipmunk <sup>1</sup>									
Total	3,6	2.06	0.21	2,52	9.03	< 0.01	6,52	1.39	0.24
Adult	3,6	2.51	0.16	2,52	11.09	< 0.01	6,52	0.77	0.60
Female	3,6	1.82	0.24	2,52	13.83	< 0.01	6,52	0.98	0.45
Reproductive	3,6	0.98	0.46	2,52	8.62	< 0.01	6,52	1.58	0.17
Male	3,6	2.46	0.16	2,52	11.99	< 0.01	6,52	0.79	0.59
Reproductive <sup>2</sup>	3,12	5.12	0.02						
Oregon vole <sup>3</sup>									
Total	3,6	2.13	0.20	3,71	3.55	0.02	9,71	1.78	0.09
Pacific shrew									
Total	3,6	1.83	0.24	4,92	2.47	0.05	12,92	0.74	0.71
Trowbridge's shrew									
Total <sup>4</sup>	3,12	2.14	0.15	4,48	15.11	< 0.01	12,48	3.56	< 0.01
Female <sup>5</sup>	3,12	3.43	0.05	4,48	12.64	< 0.01	12,48	2.61	< 0.01
Male <sup>6</sup>	3,12	2.29	0.13	4,48	13.28	< 0.01	12,48	2.92	< 0.01
Vagrant shrew									
Total	3,6	5.87	0.03	4,92	1.85	0.13	12,92	1.01	0.45

<sup>1</sup> 1999 data excluded due to limited captures.

<sup>2</sup> Measured Spring 2000 only; SVT x BLOCK  $F_{6,12} = 3.55$ ,  $P = 0.03$ .

<sup>3</sup> Summer 1999 data excluded due to limited captures.

<sup>4</sup> SVT x TIME x BLOCK  $F_{24,48} = 3.79$ ,  $P < 0.01$ .

<sup>5</sup> SVT x TIME x BLOCK  $F_{24,48} = 2.40$ ,  $P < 0.01$ .

<sup>6</sup> SVT x TIME x BLOCK  $F_{24,48} = 3.15$ ,  $P < 0.01$ .



Table 2-3. Repeated measures analysis of variance results for gender and age ratios for the silvicultural treatment objective (unharvested control stands and three silvicultural treatments over two years and five seasons, 1999-2000) and for the wood treatment objective (group-selection and clearcut treatments over four years and 11 seasons, 1999-2002) in western Oregon. SVT = silvicultural treatment, WDT = wood treatment, AF:AM = number of adult females per adult male, J:AF = number of juveniles per adult female, and F:M = number of females per male. Age ratio of Townsend's chipmunk and gender ratio for Trowbridge's shrew were not analyzed for the wood treatment objective.

Table 2-3.

	Deer mouse						Townsend's chipmunk						Trowbridge's shrew		
	AF:AM			J:AF			AF:AM			J:AF <sup>1</sup>			F:M <sup>2</sup>		
	d.f.	F	P	d.f.	F	P	d.f.	F	P	d.f.	F	P	d.f.	F	P
<b>Silviculture Treatment</b>															
SVT	3,6	3.95	0.07	3,6	2.12	0.20	3,6	0.38	0.77	3,6	1.26	0.43	3,6	0.44	0.73
TIME	4,92	5.78	<0.01	4,85	22.67	<0.01	2,38	4.61	0.02				4,51	4.42	<0.01
SVT x TIME	12,89	0.97	0.48	12,85	0.82	0.63	6,38	0.75	0.61				12,51	2.57	<0.01
<b>Wood Treatment</b>															
SVT	1,6	0.12	0.74	1,6	12.18	0.01	1,6	1.39	0.28						
WDT	1,6	0.15	0.71	1,6	1.39	0.28	1,6	0.12	0.74						
SVT x WDT	1,6	1.16	0.32	1,6	0.03	0.88	1,6	5.22	0.06						
TIME	10,78	2.47	0.01	10,76	8.07	<0.01	8,51	2.60	0.02						
SVT x TIME	10,78	1.35	0.22	10,76	0.70	0.72	8,51	0.43	0.90						
WDT x TIME	10,78	1.13	0.35	10,76	0.75	0.67	8,51	1.01	0.44						
SVT x WDT x TIME	10,78	0.23	0.99	10,76	0.54	0.86	8,51	1.59	0.15						

<sup>1</sup> 1999 data excluded due to limited captures; measured Spring 2000 only.

<sup>2</sup> SVT x TIME  $F_{12,51} = 2.57$ ,  $P < 0.01$ .

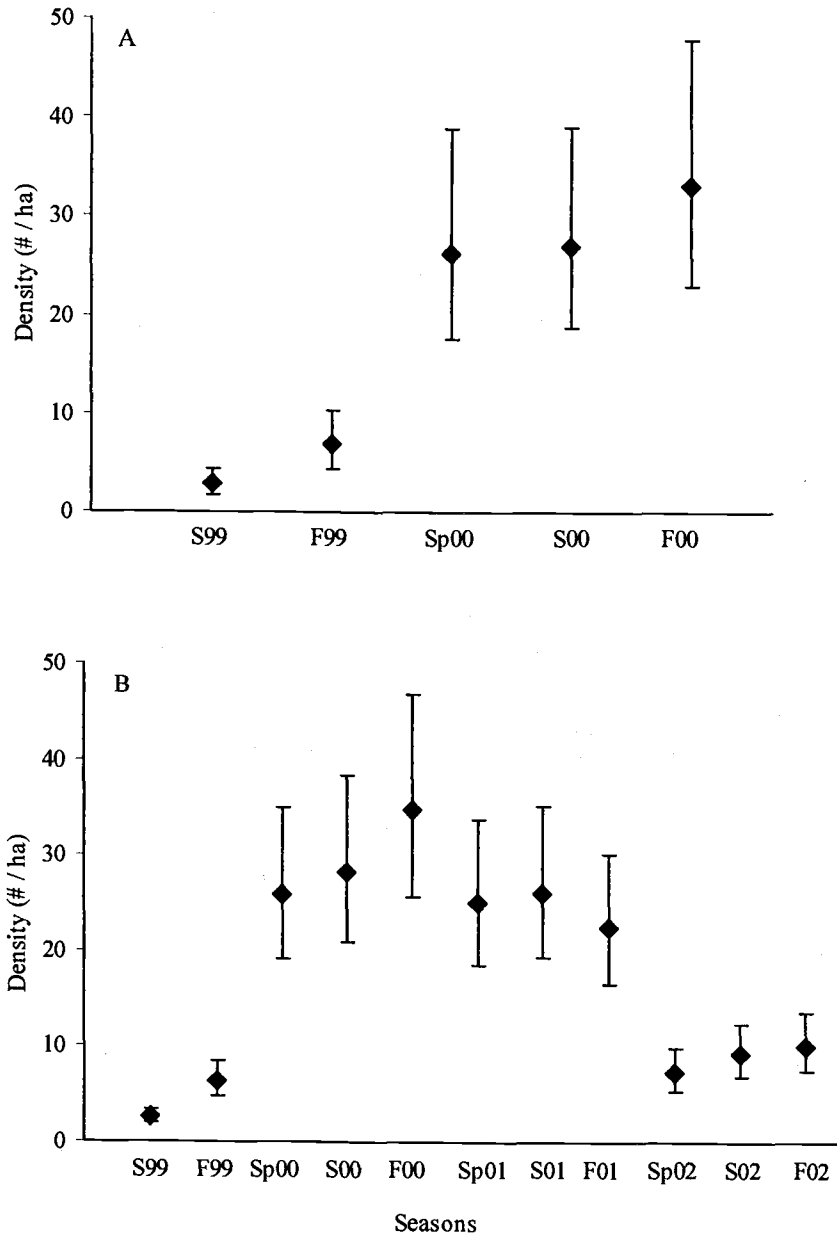


Figure 2-1. Temporal trends in density of adult female deer mice for the A) silvicultural treatment objective and B) the wood treatment objective. S99 = summer 1999, F99 = fall 1999, Sp00 = spring 2000, S00 = summer 2000, F00 = fall 2000, Sp01 = spring 2001, S01 = summer 2001, F01 = fall 2001, Sp02 = spring 2002, S02 = summer 2002, and F02 = fall 2002. In Fig 2-1A, unharvested control, group-selection, two-story, and clearcut stands were trapped S99-F00. In Fig. 2-1B, only group-selection and clearcut stands were trapped and S99-F00 represents a pre-wood treatment period and Sp01-F02 represent a post-wood treatment period.

Table 2-4. Mean densities and standard errors (SE) from the repeated measures analysis of variance model of small mammals from the silvicultural treatment objective (unharvested control, group-selection, two-story, and clearcut stands trapped over five seasons in two years), 1999-2000 in western Oregon. Treatments are ordered left to right based on increased harvest intensity.

Measure	SE	Control	Group-selection	Two-story	Clearcut
		$\bar{x}$	$\bar{x}$	$\bar{x}$	$\bar{x}$
<b>Deer mouse</b>					
Adult	1.25	21.59	29.75	40.22	27.43
Female	1.22	9.03	13.13	21.06	13.35
Reproductive	1.20	5.69	8.27	12.05	8.33
Male	1.24	13.62	16.65	20.75	16.02
<b>Townsend's chipmunk</b>					
Adult	1.82	5.65	13.64	17.30	8.37
Female	1.59	3.15	7.19	8.60	4.96
Reproductive	1.25	1.82	2.53	2.47	1.64
Male	1.78	3.66	7.94	9.62	5.18
Total	1.96	5.86	14.82	18.66	9.74
<b>Oregon vole</b>					
Total	1.39	1.87	3.31	3.50	2.80
<b>Pacific shrew</b>					
Total	1.30	1.92	3.19	2.10	1.51
<b>Vagrant shrew</b>					
Total	1.24	1.15	1.59	2.07	3.26

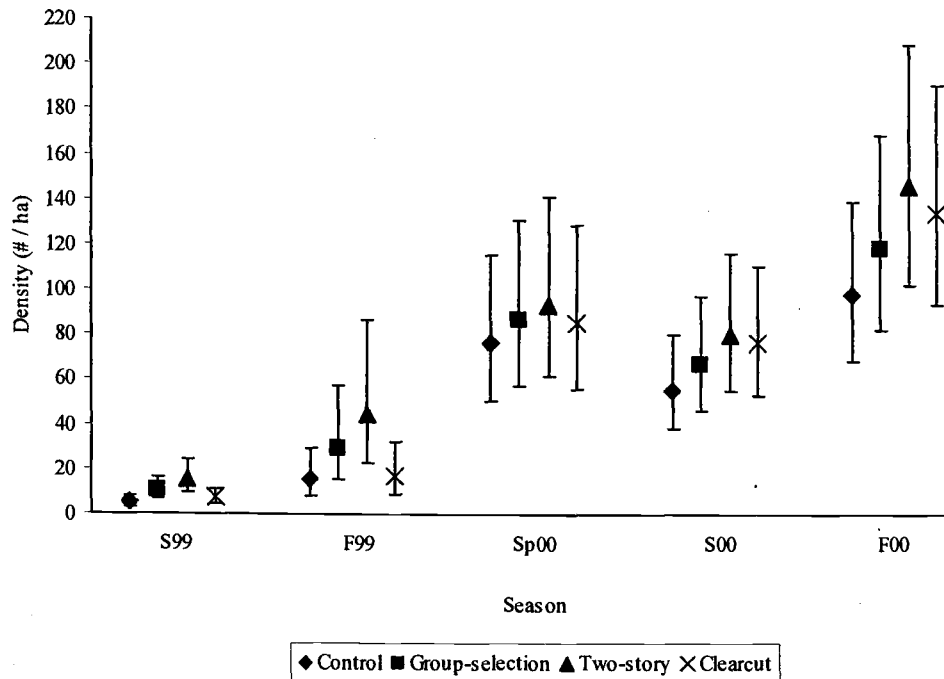


Figure 2-2. Mean densities ( $\pm 1$  SE) of deer mice by season and silvicultural treatment. Estimates are based on 5 seasons of trapping from summer 1999 to fall 2000 in western Oregon. S99 = summer 1999, F99 = fall 1999, Sp00 = spring 2000, S00 = summer 2000, and F00 = fall 2000.

Table 2-5. Mean gender and age ratios and standard errors (SE) from the repeated measures analysis of variance model of small mammals from the silvicultural treatment objective (unharvested control, group-selection, two-story, and clearcut stands trapped over five seasons in two years), 1999-2000 in western Oregon. Treatments are ordered left to right based on increased harvest intensity. Missing data values influenced SE estimates of specific treatments.

Measure	SE	Control	Group-selection	Two-story	Clearcut
		$\bar{x}$	$\bar{x}$	$\bar{x}$	$\bar{x}$
Deer mouse					
F:M	1.05	1.64	1.83	2.06	1.88
J:F <sup>1</sup>	1.11	2.36	2.64	2.09	2.12
Townsend's chipmunk					
F:M <sup>2</sup>	1.15	1.89	2.12	2.12	2.00
J:F <sup>3</sup>	2.52	2.21	2.37	2.37	9.61
Trowbridge's shrew					
F:M <sup>4</sup>	1.19	1.95	2.26	2.30	1.88

<sup>1</sup> SE = 1.12 in control and SE = 1.10 in two-story stands.

<sup>2</sup> SE = 1.17 in control and SE = 1.16 in clearcut stands.

<sup>3</sup> SE = 1.87 in group-selection, SE = 1.80 in two-story, and SE = 2.15 in clearcut stands.

<sup>4</sup> SE = 1.22 in group-selection and SE = 1.20 in clearcut stands.

$P = 0.07$ ), with lower survival in control stands ( $\bar{x} = 0.28$ , 95% CI = 0.22-0.36), higher survival in group-selection stands ( $\bar{x} = 0.38$ , 95% CI = 0.30-0.49), and with the greatest survival in two-story ( $\bar{x} = 0.43$ , 95% CI = 0.34-0.56) and clearcut stands ( $\bar{x} = 0.43$ , 95% CI = 0.33-0.55).

The greatest numbers of individual Townsend's chipmunks were captured in two-story stands whereas the fewest were captured in unharvested control stands (Table 2-1). Reproductive males were primarily captured spring 2000 and their densities differed among blocks and silvicultural treatments (Block x Treatment;  $F_{6,12} = 3.55$ ,  $P = 0.03$ ). In general, greater densities of reproductive male chipmunks were encountered in harvested stands than in control stands in the Peavy block, whereas low densities of chipmunks were encountered across all stands in the Dunn and Saddle blocks (Fig. 2-3). Juvenile chipmunks were captured primarily in spring 2000 and the number of juveniles per adult female did not differ among silvicultural treatments ( $F_{3,6} = 1.26$ ,  $P = 0.43$ , Table 2-3); roughly four times more juveniles per adult female were captured in clearcut stands than in the other stands, but differences were not statistically significant because of high variances (Table 2-5). The sex ratio and all other density measures for Townsend's chipmunks did not differ statistically among treatments ( $P > 0.05$ , Tables 2-2 and 2-3) and exhibited similar patterns, with the greatest density and the most females per male in two-story stands and the lowest in control stands (Tables 2-4 and 2-5).

The greatest numbers of individual Oregon voles were captured in clearcut stands, whereas unharvested control stands had the fewest individuals captured (Table

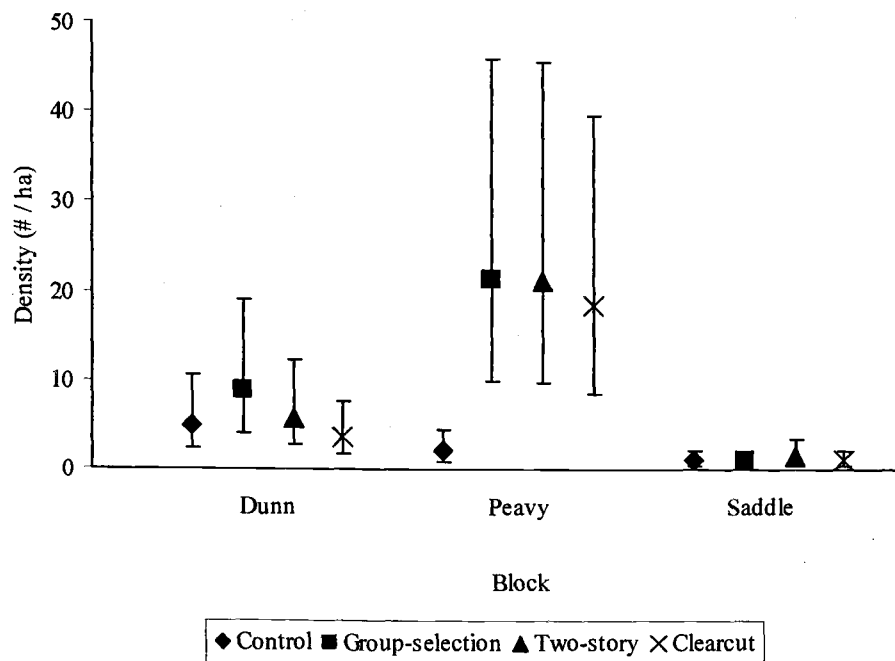


Figure 2-3. Mean density ( $\pm 1$  SE) of reproductive male Townsend's chipmunks by block and silvicultural treatment. Estimates are based on 5 seasons of trapping from summer 1999 to fall 2000 in western Oregon.



2-1). However, Oregon vole density did not differ statistically among silvicultural treatments ( $F_{3,6} = 2.13$ ,  $P = 0.20$ , Table 2-2 and Table 2-4).

The three species of shrews with sufficient data for analysis responded differently to silvicultural treatment. Densities of vagrant shrews differed among silvicultural treatments ( $F_{3,6} = 5.87$ ,  $P = 0.03$ , Table 2-2) with densities increasing with harvest intensity (Table 2-4). Conversely, densities of Pacific shrews (*Sorex pacificus*) were similar among silvicultural treatments ( $F_{3,6} = 1.83$ ,  $P = 0.24$ ; Table 2-2), but tended to be greatest in group-selection stands (Table 2-4). There was a significant treatment by time by block interaction for total density ( $F_{24,48} = 3.79$ ,  $< 0.01$ ) and densities of female ( $F_{24,48} = 2.4$ ,  $< 0.01$ ) and male ( $F_{24,48} = 3.15$ ,  $< 0.01$ ) Trowbridge's shrews. The gender ratio for Trowbridge's shrew had a significant treatment by time interaction ( $F_{12,51} = 2.57$ ,  $P < 0.01$ , Table 2-3) with no general trend among silvicultural treatments apparent through time (Fig. 2-4).

Species richness varied seasonally ( $F_{4,92} = 10.28$ ,  $P < 0.01$ ) but did not differ among silvicultural treatments ( $F_{3,6} = 1.05$ ,  $P = 0.44$ , Table 2-6). Within years, species richness was greatest in summer and lowest in the fall (Fig. 2-5). Shannon's index (Treatment x Block,  $F_{6,12} = 6.01$ ,  $P < 0.01$ ) and Simpson's index (Treatment x Time x Block,  $F_{24,47} = 2.47$ ,  $P < 0.01$ ) were spatially and temporally variable (Table 2-6) with no general trend among silvicultural treatments apparent through time.

*Wood Treatment Objective.*—Population densities and other measures varied seasonally for all species analyzed ( $P \leq 0.05$ ) except for densities of Pacific ( $F_{10,40} = 1.61$ ,  $P = 0.14$ ) and vagrant shrews ( $F_{10,40} = 1.47$ ,  $P = 0.19$ ; Table 2-7). In general,

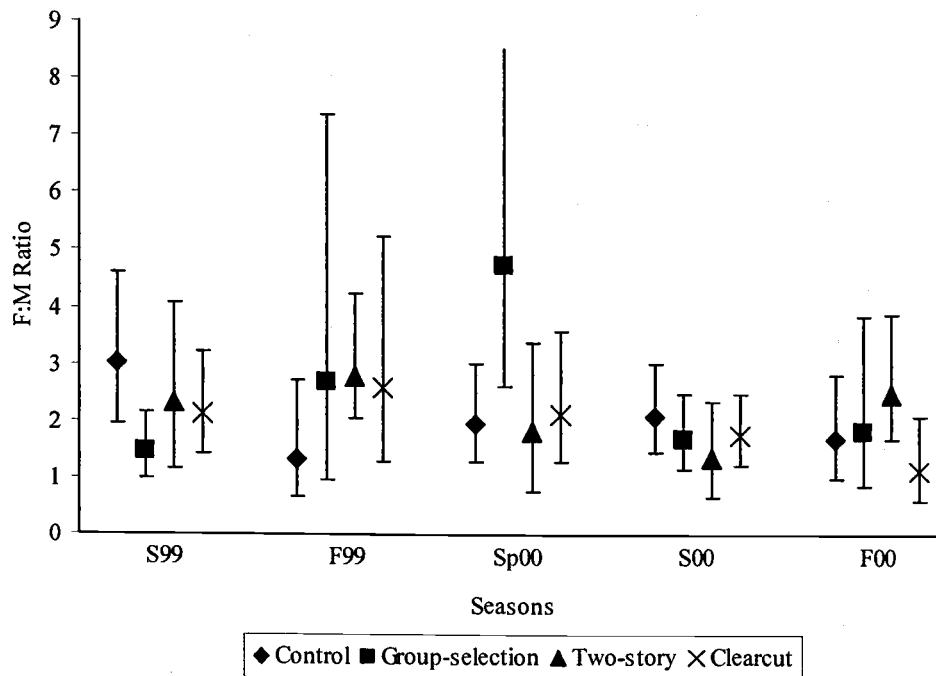


Figure 2-4. Mean gender ratio ( $\pm 1$  SE) of Trowbridge's shrews by season and silvicultural treatment. Estimates are based on 5 seasons of trapping from summer 1999 to fall 2000 in western Oregon. S99 = summer 1999, F99 = fall 1999, Sp00 = spring 2000, S00 = summer 2000, and F00 = fall 2000.

Table 2-6. Repeated measures analysis of variance results for species richness and diversity measures for the silvicultural treatment objective in unharvested control stands and three silvicultural treatments over two years and five seasons, 1999-2000 and the wood treatment objective in group-selection and clearcut treatments over four years and 11 seasons, 1999-2002 in western Oregon. SVT = silvicultural treatment and WDT = wood treatment.

	Species Richness			Shannon (H')			Simpson (D)		
	d.f.	F	P	d.f.	F	P	d.f.	F	P
<b>Silviculture Treatment</b>									
SVT	3,6	1.05	0.44	3,12	2.59	0.10	3,12	2.85	0.08
TIME	4,92	10.28	<0.01	12,47	9.08	<0.01	12,47	19.71	<0.01
SVT x TIME	12,92	0.62	0.82	4,47	1.80	0.08	4,47	2.87	<0.01
<b>Wood Treatment</b>									
SVT	1,6	5.09	0.06	1,6	8.27	0.03	1,6	2.72	0.15
WDT	1,6	0.18	0.69	1,6	1.80	0.23	1,6	0.16	0.71
SVT x WDT	1,6	0.07	0.80	1,6	0.11	0.75	1,6	0.88	0.38
TIME	10,80	4.99	<0.01	10,80	8.85	<0.01	10,80	8.34	<0.01
SVT x TIME	10,80	0.19	0.99	10,80	0.61	0.80	10,80	1.23	0.29
WDT x TIME	10,80	1.95	0.05	10,80	1.39	0.20	10,80	0.18	0.99
SVT x WDT x TIME	10,80	0.24	0.99	10,80	0.27	0.99	10,80	1.48	0.16

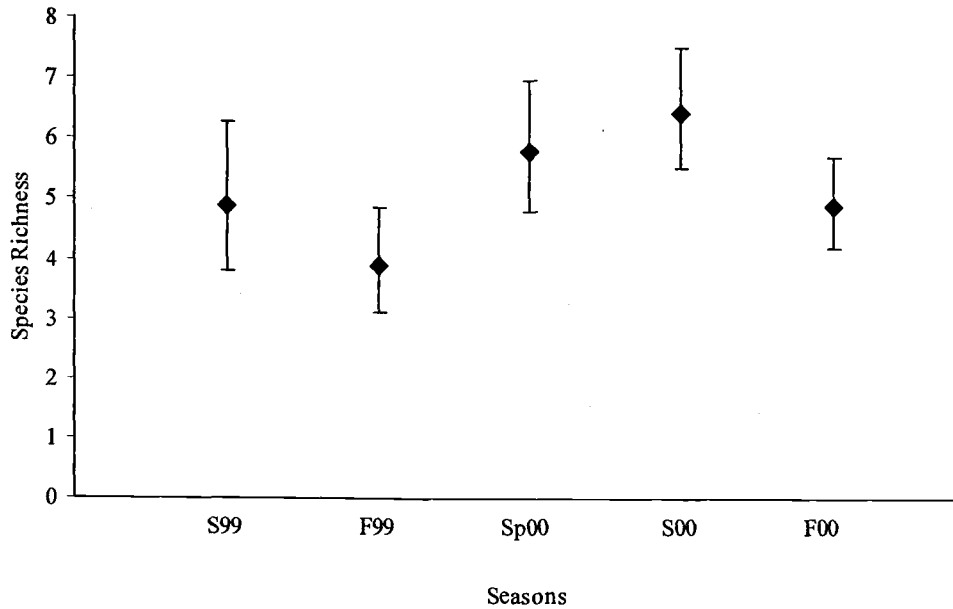


Figure 2-5. Mean species richness ( $\pm 1$  SE) for the silvicultural treatment objective. Estimates are based on 5 seasons of trapping from summer 1999 to fall 2000 in unharvested control, group-selection, two-story, and clearcut stands in western Oregon. S99 = summer 1999, F99 = fall 1999, Sp00 = spring 2000, S00 = summer 2000, and F00 = fall 2000.

Table 2-7. Repeated measures analysis of variance results for species densities for the wood treatment objective in group-selection and clearcut treatments over four years and 11 seasons, 1999-2002 in western Oregon. SVT = silvicultural treatment and WDT = wood treatment.

Table 2-7.

Species	SVT			WDT			WDT x SVT			TIME			SVT x TIME			WDT x TIME			SVT x WDT x TIME			
	d.f.	F	P	d.f.	F	P	d.f.	F	P	d.f.	F	P	d.f.	F	P	d.f.	F	P	d.f.	F	P	
Deer mouse																						
Total	1,6	0.02	0.90	1,6	0.01	0.92	1,6	0.04	0.84	10,80	179.10	<0.01	10,80	1.77	0.80	10,80	0.78	0.64	10,80	2.09	0.03	
Adult	1,6	0.52	0.50	1,6	<0.00	0.98	1,6	0.19	0.68	10,80	41.99	<0.01	10,80	1.39	0.20	10,80	0.63	0.79	10,80	0.73	0.69	
Adult Female	1,6	0.75	0.42	1,6	0.03	0.88	1,6	0.03	0.87	10,80	38.69	<0.01	10,80	0.99	0.46	10,80	0.82	0.61	10,80	0.77	0.65	
Reproductive Female	1,6	0.24	0.64	1,6	1.28	0.30	1,6	0.17	0.70	10,80	28.58	<0.01	10,80	0.86	0.57	10,80	1.47	0.17	10,80	2.02	0.04	
Adult Male	1,6	0.72	0.43	1,6	0.02	0.90	1,6	0.01	0.92	10,80	35.06	<0.01	10,80	1.76	0.08	10,80	0.59	0.82	10,80	0.56	0.84	
Townsend's chipmunk <sup>1</sup>																						
Total	1,6	1.20	0.32	1,6	0.06	0.82	1,6	0.76	0.42	8,64	2.58	0.02	8,64	0.23	0.98	8,64	0.27	0.97	8,64	1.50	0.18	
Adult	1,6	1.31	0.30	1,6	0.05	0.84	1,6	0.70	0.43	8,64	3.98	<0.01	8,64	0.22	0.99	8,64	0.45	0.89	8,64	1.92	0.07	
Adult Female	1,6	0.73	0.43	1,6	0.02	0.89	1,6	1.51	0.26	8,64	5.11	<0.01	8,64	0.51	0.84	8,64	0.58	0.79	8,64	2.02	0.06	
Reproductive Female <sup>2</sup>	1,6	1.88	0.22	1,6	<0.00	0.96	1,6	0.13	0.73	5,40	10.48	<0.01	5,40	0.37	0.87	5,40	0.39	0.85	5,40	1.16	0.35	
Adult Male	1,6	2.07	0.20	1,6	0.01	0.93	1,6	0.12	0.75	8,64	5.62	<0.01	8,64	0.21	0.99	8,64	0.36	0.94	8,64	0.62	0.76	
Reproductive Male <sup>3</sup>	1,6	0.79	0.41	1,6	0.02	0.91	1,6	0.01	0.93	2,16	7.08	<0.01	2,16	0.11	0.89	2,16	3.07	0.07	2,16	3.71	0.05	
Pacific shrew <sup>4</sup>																						
Total				1,2	0.01	0.95				10,40	1.61	0.14				10,40	0.31	0.97				
Trowbridge's shrew																						
Total	1,6	2.45	0.17	1,6	0.04	0.85	1,6	0.53	0.49	10,80	7.93	<0.01	10,80	1.07	0.40	10,80	0.46	0.91	10,80	0.19	0.99	
Female	1,6	1.64	0.25	1,6	0.44	0.53	1,6	1.35	0.29	10,80	6.83	<0.01	10,80	1.56	0.13	10,80	0.49	0.89	10,80	0.59	0.82	
Male	1,6	4.04	0.09	1,6	0.01	0.91	1,6	0.02	0.89	10,80	6.76	<0.01	10,80	1.26	0.27	10,80	0.62	0.80	10,80	0.36	0.96	
Vagrant shrew <sup>5</sup>																						
Total				1,2	0.99	0.42				10,40	1.47	0.19				10,40	1.06	0.41				

<sup>1</sup> 1999 data excluded due to limited captures.

<sup>2</sup> Analyzed Spring and Summer 2000-2002 only.

<sup>3</sup> Analyzed Spring 2000-2002 only.

<sup>4</sup> Analyzed group-selection stands only.

<sup>5</sup> Analyzed clearcut stands only.

densities of adult female deer mice were low in 1999, elevated in 2000 and 2001, and decreased through 2002 (Fig. 2-1B); similar patterns were observed for all other species.

Although more deer mice were captured in clearcut stands than in group-selection stands, there were no apparent differences in captures related to the wood treatment (Table 2-1). The number of juveniles per adult female was greatest in group-selection stands ( $F_{1,6} = 12.18$ ,  $P = 0.01$ ), with no difference related to the wood treatment ( $F_{1,6} = 0.15$ ,  $P = 0.71$ , Tables 2-3 and 2-8). All density measures of deer mice and gender ratios did not differ ( $P > 0.05$ ) between the silvicultural or wood treatments (Tables 2-3, 2-7, and 2-8), with slightly greater densities in clearcut stands (Table 2-9). There was a silvicultural treatment by wood treatment by time interaction for total density ( $F_{10,80} = 2.09$ ,  $P = 0.03$ ) and density of reproductive female deer mice ( $F_{10,80} = 2.02$ ,  $P = 0.04$ ; Table 2-7), with no clear pattern in density between silvicultural or downed wood treatments. Apparent survival of adult deer mice was not statistically different between silvicultural ( $F_{1,6} = 0.29$ ,  $P = 0.61$ ) or wood treatments ( $F_{1,6} = 0.80$ ,  $P = 0.41$ ), but did differ among time intervals ( $F_{5,36} = 10.37$ ,  $P < 0.01$ ), with the lowest survival estimated for the over winter time intervals (fall to spring; Fig. 2-6).

The greatest numbers of individual Townsend's chipmunks were captured in group-selection stands, with no apparent differences in captures related to the wood treatment (Table 2-2). We did not identify any responses of chipmunks to either silvicultural or downed wood treatments (Tables 2-3 and 2-7). Density of

Table 2-8. Mean gender and age ratios and standard errors (SE) from the repeated measures analysis of variance model of small mammals from the wood treatment objective in group-selection and clearcut treatments over four years and 11 seasons, 1999-2002 in western Oregon. Missing data values influenced SE estimates of specific treatments.

Measure	SE	Group-selection		Clearcut	
		NW	W	NW	W
		$\bar{x}$	$\bar{x}$	$\bar{x}$	$\bar{x}$
Deer mouse					
F:M	1.05	1.83	1.78	1.78	1.89
J:F <sup>1</sup>	1.08	2.74	2.56	2.18	1.99
Townsend's chipmunk					
F:M <sup>2</sup>	1.08	1.84	1.58	1.69	2.06

<sup>1</sup> SE = 1.07 in group-selection NW stands.

<sup>2</sup> SE = 1.09 in clearcut NW stands.



Table 2-9. Mean densities and standard errors (SE) from the repeated measures analysis of variance model of small mammals from the wood treatment objective in group-selection and clearcut treatments over four years and 11 seasons, 1999-2002 in western Oregon.

Measure	SE	Group-selection		Clearcut	
		NW	W	NW	W
		$\bar{x}$	$\bar{x}$	$\bar{x}$	$\bar{x}$
<b>Deer mouse</b>					
Adult	1.21	31.21	29.13	32.78	35.42
Female	1.17	13.42	12.73	15.00	15.02
Male	1.21	16.90	16.81	19.37	18.73
<b>Townsend's chipmunk</b>					
Adult	1.69	25.09	19.51	11.33	17.27
Female	1.52	11.61	8.05	5.74	9.13
Reproductive	1.47	4.73	4.32	2.85	3.21
Male	1.64	13.75	12.63	7.46	8.66
Total	1.73	26.92	20.74	11.98	18.93
<b>Oregon vole</b>					
Total	1.34	2.43	3.88	2.69	2.88
<b>Pacific shrew<sup>1</sup></b>					
Total	1.33	3.26	3.16		
<b>Trowbridge's shrew</b>					
Female	1.14	5.16	4.83	3.73	4.76
Male	1.19	5.04	4.81	3.45	3.47
Total	1.18	9.54	8.76	6.59	7.66
<b>vagrant shrew<sup>2</sup></b>					
Total	1.32			2.81	4.17

<sup>1</sup> Group-selection stands only.

<sup>2</sup> Clearcut stands only.

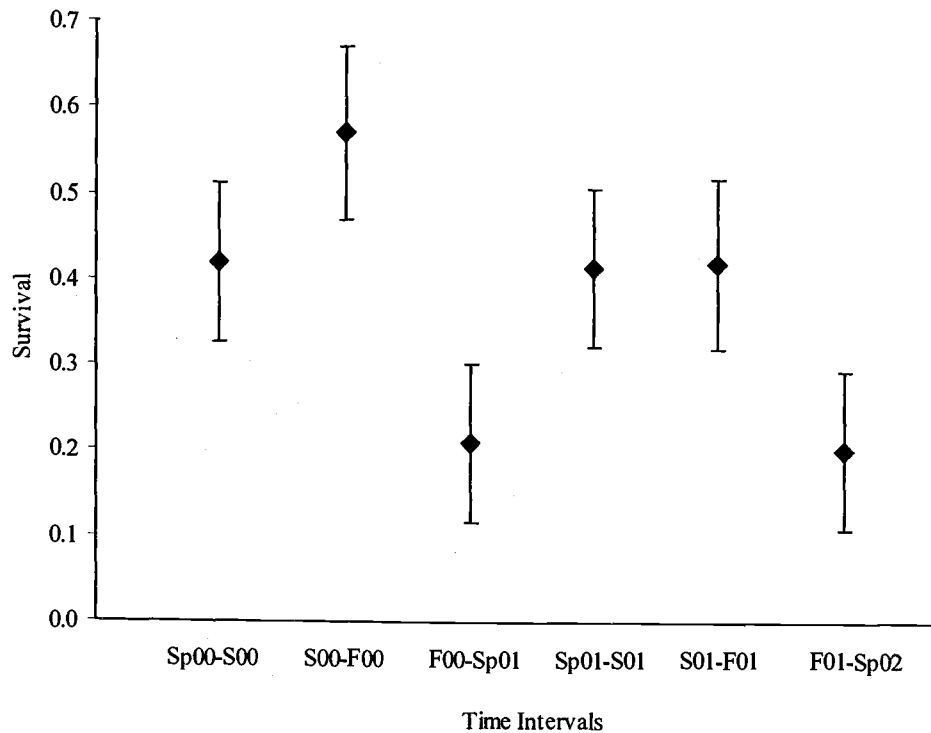


Figure 2-6. Apparent survival estimates ( $\pm 1$  SE) of adult deer mice from the wood treatment objective in group-selection and clearcut treatments over four years and 11 seasons, 1999-2002 in western Oregon. Estimates are from group-selection and clearcuts with and without downed wood. Sp00-S00 = spring to summer 2000, S00-F00 = summer to fall 2000, F00-Sp01 = fall 2000 to spring 2001, Sp01-S01 = spring to summer 2001, S01-F01 = summer to fall 2001, and F01-Sp02 = fall to spring 2002. Downed wood was added to three group-selection stands and 3 clearcut stands during interval F00-Sp01

reproductive males had a silvicultural treatment by wood treatment by time interaction ( $F_{2,16} = 3.71, P = 0.05$ ), with no interpretable differences among treatments or over time. Although densities of females ( $F_{8,64} = 1.92, P = 0.07$ ) and reproductive females ( $F_{8,64} = 2.02, P = 0.06$ ) was nearly statistically significant (Table 2-7), we did not observe any interpretable trends among treatments or time. The silvicultural by wood treatment interaction for gender ratio also was nearly statistically significant ( $F_{1,6} = 5.22, P = 0.06$ , Table 2-5) and the most females per male were captured in group-selection stands without downed wood, whereas in clearcut stands more females per male were captured in stands with downed wood (Table 2-8). Differences for all other density measures of Townsend's chipmunks were not statistically significant ( $P > 0.05$ , Table 2-7), and all other density measures exhibited a similar pattern, with the greatest density in group-selection stands (Table 2-9).

The three species of shrews with sufficient data for analysis had different responses to silvicultural treatments. Vagrant shrews only had an adequate distribution in captures for analysis in clearcut stands (Table 2-1), and in these stands densities did not differ with wood treatment ( $F_{1,2} = 0.99, P = 0.42$ , Table 2-7). However, in general, densities of vagrant shrews tended to be greater in clearcuts with wood than in clearcuts without wood (Table 2-9). Pacific shrews only had an adequate data for statistical analysis in group-selection stands (Table 2-1) and their density did differ with wood treatment ( $F_{1,2} = 0.01, P = 0.95$ , Table 2-7). Densities of Trowbridge's shrew were similar between silvicultural and wood treatments (Tables 2-7 and 2-9).

Species richness, Shannon's indices, and Simpson's indices varied temporally ( $P < 0.01$ ; Table 2-6). Although there was a wood treatment by time interaction for species richness ( $F_{10,80} = 1.95$ ,  $P = 0.05$ ), the number of species captured differed between wood treatments only during fall 1999 when captures were very low. Therefore, we interpreted the nearly significantly silvicultural treatments effect ( $F_{1,6} = 5.09$ ,  $P = 0.06$ ). On average, more species were captured in group-selection stands ( $\bar{x} = 6.55$ ,  $SE = 1.14$ ) than in clearcut stands ( $\bar{x} = 5.32$ ,  $SE = 1.14$ ). As measured by Shannon's index, species diversity was greater in group-selection stands ( $\bar{x} = 2.21$ ,  $SE = 1.05$ ) than in clearcut stands ( $\bar{x} = 2.01$ ,  $SE = 1.05$ ) and were similar between the wood treatments (No Wood  $\bar{x} = 2.06$ ,  $SE = 1.05$ ; Wood  $\bar{x} = 2.15$ ,  $SE = 1.05$ ) (Table 2-6). As measured by Simpson's Index, diversity was similar between silvicultural treatments (Group-selection  $\bar{x} = 1.38$ ,  $SE = 1.03$ ; Clearcut  $\bar{x} = 1.43$ ,  $SE = 1.03$ ) and wood treatments (No Wood  $\bar{x} = 1.41$ ,  $SE = 1.03$ ; Wood  $\bar{x} = 1.40$ ,  $SE = 1.03$ ) (Table 2-6).

*General Patterns.*—Although analyses were not conducted on several species due to limited captures or absence of a species in a block, general patterns in number of captures were evident. In the silvicultural treatment objective, numbers of captures of northern flying squirrels were similar between group-selection and control stands and flying squirrels were not captured in two-story and clearcut stands (Table 2-1). A similar pattern was noted for the western red-backed voles, in which the numbers of captures were similar in group-selection and control stands, reduced in two-story, and absent in clearcut stands. A similar pattern also was noted for northern flying

squirrels and western red-backed voles in the wood treatment objective. In the wood treatment objective, Douglas' squirrels only were captured in group-selection stands and Baird's shrews (*Sorex bairdi*) and fog shrews (*Sorex sonomae*) were captured more often in group-selection stands than in clearcuts. Conversely, the number of captures of California ground squirrels, dusky-footed woodrats (*Neotoma fucipes*), and Pacific jumping mice (*Zapus trinotatus*) tended to be greatest in two-story and clearcut stands and relatively few or no individuals of these species were captured in control or group-selection stands in the silvicultural treatment objective (Table 2-1); a similar pattern was noted for these species in the wood treatment objective. In the wood treatment objective, the greatest numbers of Oregon voles were captured in clearcut stands and although wood treatment stands appeared to have greater captures than stands without wood for both silvicultural treatments (Table 2-1), these differences were present in the stands prior to the wood treatment and thus are likely to be an artifact.

## DISCUSSION

Our study is one of the first to examine small mammal response to silvicultural harvest systems other than clearcut and thinning several years post-harvest. Although forest management has benefited tremendously from insights yielded from studies that examined short term-responses to treatments, the more complete understanding of the implications of management decisions through time that results from studies such as ours can provide managers with greater confidence in their decisions. Further, some species may not respond for several years following treatments (Hallet et al. 2003);

slow changes in the quality and quantity of specific resources may not elicit cascading effects in species numbers until the resources have adequately changed to influence species demographics.

### **Response to Silvicultural Treatments**

Densities and abundances of several species of small mammals (e.g., deer mouse, dusky-footed woodrat, Oregon vole, Pacific jumping mouse, Townsend's chipmunk, and vagrant shrew) tended to be greater in stands 8-12 years post-harvest relative to control stands, or were similar among all stand conditions. Our results are consistent with those of previous studies and with what is known of the natural histories of these species. For example, deer mice were more abundant in shelterwood stands (39-60 trees/ha) than in control stands in northern California (Waters and Zabel 1998), but deer mouse populations were similar between shelterwood stands (30% and 50% basal area harvested) and control stands in British Columbia (Von Trebra et al. 1998). Further, Oregon voles, Pacific jumping mice, and vagrant shrew populations increased in response to clearcut harvest (Hooven 1973, Hooven and Black 1976) and thinning (Carey and Wilson 2001, Larson 2001, Suzuki and Hayes 2003). Although Townsend's chipmunks occur in many habitats (Doyle 1990, Hayes et al. 1995, Gomez and Anthony 1998) and densities in some regions are greatest in older forests (Rosenberg and Anthony 1993, Carey 1995, Carey 2000), populations also increased following thinning of young forests (Carey 2001, Carey and Wilson 2001, Larson 2001).

The general increase in populations of many species following timber harvest likely reflects a relationship with the productivity of understory vegetation (e.g., shrubs and herbaceous vegetation) and changes in overstory canopy as a result of timber harvest (Hayes et al. 1995, Carey 2001, Carey and Wilson 2001, Suzuki and Hayes 2003). Understory vegetation often responds to increased light and other resources released by decreased competition with trees as a result of timber harvest (Halpern 1989, Carey and Curtis 1996, Hayes et al. 1997, Thysell and Carey 2000, Suzuki and Hayes 2003) and provides protective cover, complex habitats, and a greater abundance and diversity of food resources for small mammals (Rosenberg and Anthony 1993, Carey 1995, Carey and Johnson 1995, Hayes et al. 1995, Carey 2001). Increased availability of resources (e.g., food) promotes greater densities of small mammal populations until another resource became limiting (e.g., den sites in snags) or until food resources again limits the size of the population (Barbour et al. 1987, Carey 2002).

In general, northern flying squirrels and western red-backed voles are most abundant in older forests, although they do occur in younger forests (Gomez and Anthony 1998, Rosenberg et al. 1994), particularly those with legacy structures (e.g., large snags and logs) that can provide dens, nests sites, and protected travel paths (Tallmon and Mills 1994, Thompson 1996, Carey 2001, Carey and Wilson 2001, Ucitel et al. 2003). Although we had few captures of northern flying squirrels and western red-backed voles, our data suggest that two-story and clearcut stands 8-12 years post-harvest do not provide adequate habitat to support populations of either species. Similarly, in other studies in the Pacific Northwest flying squirrels and red-

backed voles were rarely captured in clearcuts and were more abundant in uncut forest (Hooven and Black 1976, Martell 1983, Moses and Boutin 2001, Klenner and Sullivan 2003). Decreased numbers of northern flying squirrels and western red-backed voles to clearcut and two-story harvest systems are likely linked to reduction of critical resources following timber harvest. Removal of most of the overstory trees and snags reduces or eliminates sites where flying squirrels establish nests and dens (Carey et al. 1997, Feen 1997). Further, removal of the majority of the overstory trees changes the microclimate, which in turn can negatively impact abundance and diversity of hypogeous fungi (Luoma et al. 2003); sporocarps of hypogeous fungi are primary food of northern flying squirrels and western red-backed voles (Maser et al. 1985, Hayes et al. 1986, Luoma et al. 2003, Gomez et al. *In Press*).

### **Response to Downed Wood Treatments**

The lack of a clear response of small mammal populations to our downed wood treatment is not surprising given the lack of decay in the recently added wood. Similarly, Moses and Boutin (2001) did not detect a change in populations of deer mice and red-backed voles (*C. gapperi*) to supplemented downed wood immediately following timber harvest. Although downed wood with little decay is used by small mammals as travel paths (Chapter 3), many of the benefits of downed wood to small mammals are related to the level of decay in the wood (Harmon et al. 1986). Decayed wood provides more substrates for fungi, lichens, and invertebrates that are, in turn, forage and prey to many species of small mammals (Maser and Trappe 1984, Hayes et al. 1986, Bunnell et al. 1997, North et al. 1997, Rambo and Muir 1998). Moreover,



heavily decayed logs and stumps are used by small mammals as den sites (Tallmon and Mills 1994, Thompson 1996, McCay 2000). With time, small mammal populations may increase due to the long-term presence of this physical structure and increased decay in the downed wood (Moses and Boutin 2001).

### **Management Implications**

Management of forests for wildlife and timber requires information regarding how species respond to different harvest systems so that management goals can be met. Removal of too much of the overstory from a stand can result in reduced numbers of species that need a fairly contiguous overstory. In our study, there appears to be steeply graded responses or perhaps threshold responses for northern flying squirrels and western red-backed voles. If in fact there is a threshold, our data suggest that it lies between the group-selection treatment (ca. 33% of the canopy removed) and the two-story treatment (ca. 75% of the canopy removed). Northern flying squirrels and western red-backed voles were either not captured or were rarely captured in two-story and clearcut stands.

Conversely, abundances of other species increase with timber harvest and appear to have graded response to the silvicultural treatments. Dusky-footed woodrats were nearly absent in the unharvested control stands, had increased abundances in group-selection stands, and were most abundant in two-story and clearcut stands. Species such as deer mice and Townsend's chipmunks are more ubiquitous in their distribution (Hallet et al. 2003) and also appear to have more of a graded response

among the treatments, generally with greater numbers captured in two-story and clearcut stands relative to unharvested control stands.

We found evidence that several species of small mammals occur in greater abundances in two-story stands than in clearcuts. The retention of dispersed overstory trees in two-story stands provides not only den and nest sites but also increased foraging habitat related to the residual trees through time (Chambers et al. 1999, Luoma et al. 2003); these resources are absent or very limited in clearcuts due to the lack of residual trees. Fungal diversity is greater within the dripline of green-trees in open stand conditions (e.g., two-story stands), which provides not only more diverse fungal food resources, but also on-site genetic sources of fungi for the new stand (Stockdale 2000, Luoma et al. 2003).

Dynamic approaches to management of downed wood are needed if the goal is to provide downed wood in an area through time rather than an approach that provides minimum quantities at one point in time (Harmon 2001). Although we did not detect changes in species densities to our downed wood treatment, many species of small mammals use downed wood in forests (Harmon et al. 1986, Carey and Johnson 1995, Bunnell et al. 1997, Chapter 3). One value of downed wood to small mammal populations is cover (Carey and Johnson 1995), which also can be provided by vegetation and other structures (McComb 2003). The functional redundancy of downed wood with vegetation may contribute to the lack of response of small mammals in our study. The group-selection and clearcut stands that received the downed wood treatments had relatively high levels of understory vegetation, which provides both cover and food sources for many species. Under these conditions, one

may not expect to see short-term responses of small mammals to the addition of downed wood with little decay to the system (McComb 2003).

Social, economic, and biological factors often work in concert to shape management approaches (Curtis 1998). At broader spatial scales, a diverse set of harvest systems will likely provide a range of habitat conditions capable of supporting broad wildlife communities (Martin and McComb 2003). At the stand scale, our data suggest that group-selection and two-story harvest systems offer alternative management options to clearcut harvest to balance tradeoffs between ecological goals, while providing timber revenues (Kellogg et al. 1996). The maintenance of overstory trees in two-story stands provides many resources that are not available in clearcuts and likely contributes to greater abundances of animals relative clearcuts.

Alternatively, forests with gaps yield diverse conditions that can maintain forest species (Klenner and Sullivan 2003), and if gaps are adequately large, populations of early-successional species or gap specialists may increase in abundance (Chambers et al. 1999, Gitzen and West 2002). Response of small mammals to variable density thinning with gaps likely would be similar to the responses we saw to group-selection harvest because it can yield similar stand conditions that can maintain populations of northern flying squirrels and western red-backed voles through time (Carey 2001). Stands that result from group-selection harvest systems also has the potential to benefit the northern spotted owl (*Strix occidentalis*) because these stands potentially provide nesting and foraging habitat, and offer a greater diversity of prey (e.g., dusky-footed woodrat and northern flying squirrel) than what is typically found in either older forests or young clearcuts.

### Scope and Inference

Our study was limited to three silvicultural harvest systems 8-12 years post-harvest and downed wood 2 years post-treatment in 100-130 yr old Douglas-fir forests on the west slope of the Oregon Coast Range. Strongest inference extends to similar harvest systems and downed wood treatments in comparable forests and should be applied with caution to substantially younger or older Douglas-fir forests or dramatically different harvest systems. Further, our study area has relatively high levels of exotic plant species (e.g., Himalayan blackberry [*Rubus discolor*] and grasses [*Brachypodium*, *Bromus*, *Dactylis*]) that readily invade disturbed areas and influence the availability of resources within stands, possibly influencing patterns we observed in small mammals relative to the different treatments. However, we believe our results can be applied to coniferous forests of similar structure in other regions given the general consistency of our results with current knowledge of the natural history of each species.

The availability of resources at larger spatial scales and within adjacent habitats can influence patterns observed at small spatial scales (Hayes et al. 2003, Martin and McComb 2003). Our study was designed to sample the small mammals within a stand while limiting, not eliminating, the influence of adjacent forest stands. Our research was conducted at a spatial scale of 5.5-17.8 ha that is within the range of typical harvest units with the Pacific Northwest. Our sampling likely reflects independent sub-sampling within discrete forest stands from relatively continuous small mammal populations in our study area; <1% of captured animals were detected

in adjacent trap-grids throughout our four year study. Further, grid size, trap spacing, and types of traps can influence results of small mammal trapping studies (Williams et al. 2002). Based on home range sizes of species captured, our study design probably was most appropriate for deer mice and voles whereas larger home ranges of Townsend's chipmunks and northern flying squirrels likely influenced patterns in our data. We caution that the limited number of replicates, in conjunction with highly variable populations through time, likely limited our ability to detect some patterns.

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CHAPTER 3

USE OF DOWNED WOOD AS TRAVEL PATHS  
BY TOWNSEND'S CHIPMUNKS (*TAMIAS TOWNSENDII*)  
IN WESTERN OREGON

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**ABSTRACT:** Dead wood is an important habitat component for small mammals and is hypothesized to be used by many species as travel paths. We examined the use of downed wood in path selection by 41 Townsend's chipmunks (*Tamias townsendii*) in coniferous forests of western Oregon with the spool-and-line method. Chipmunk paths averaged 84.6% (SD = 6.2%) surficial, 14.9% (SD = 7.0%) arboreal, and 0.5% (SD = 0.9%) subterranean; 50.4% (SD = 4.1%) of the surficial trail was associated with downed wood and 78.6% (SD = 10.0%) of this use was on top of logs. We evaluated the likelihood of different *a priori* models regarding gender- and season-specific differences and if the quantity of wood in the environment influenced selection using an information-theoretic approach. All but one chipmunk disproportionately selected paths with downed wood relative to its availability and the model indicating that quantity of wood in the environment influenced path selection was 22.6 times more likely than the null model. Disproportionate use of wood was observed across the full range of our data but decreased with increasing availability of wood. At average wood densities (paths with 26% wood), a chipmunk was 3.0 times more likely to select locations with downed wood than locations without downed wood (95% CI = 2.5-3.5). Chipmunks selected wood that averaged 1.2 times larger in diameter than randomly available wood (95% CI = 1.1-1.3) and there was no evidence that chipmunks disproportionately used wood that was elevated off the surface of the ground (Odds Ratio 95% CI = 0.8-1.5). We did not detect any differences in selection of downed wood, size of downed wood, or elevated wood based on gender or season, and the amount of wood in the environment did not appear to influence selection of size of wood or if it was elevated (Evidence Ratio, ER < 3.9). Our findings document

that Townsend's chipmunks preferentially use downed wood in western Oregon forests, and that downed wood influences how chipmunks move through an area and may influence fitness or survival of individual chipmunks.

## INTRODUCTION

Habitat selection studies can provide useful insight for effective management of habitats for wildlife. Approaches to examine resource selection by small mammals often are limited to comparisons of density or abundance and where possible alternate measures, such as fitness and survival, also should be used when evaluating habitat quality for a species to provide a more complete understanding of the importance of a habitat or habitat component (Van Horne 1983). Unfortunately, data on fitness, reproductive condition, and survival can be difficult to obtain for many species in field settings (McCravy and Rose 1992). Further, identifying patterns of microhabitat use of small mammals by traps can be problematic because the presence of bait can influence resource selection (Douglass 1989; Manville et al. 1992). In contrast, path selection using powder tracking (Lemen and Freeman 1985) or spool-and-line (Boonstra and Craine 1986) provides a direct measure of resource selection by a species. Path selection studies can be used to evaluate selection for specific resources (e.g., downed wood) without potential biases from the presence of baited traps (Douglass 1989; Manville et al. 1992). Further, evaluation of path selection can provide a finer resolution to assess use of habitat than typically obtained through trapping or radio telemetry (Mullican 1988; McShea and Gilles 1992).

Dead wood on the forest floor is an important habitat component for small mammals (Harmon et al. 1986; Carey and Johnson 1995; Bunnell et al. 1997). Logs serve as substrates and environments for fungi, lichens, and invertebrates, which provide forage and prey items to many species (Maser and Trappe 1984; Hayes et al. 1986; Bunnell et al. 1997; North et al. 1997; Rambo and Muir 1998; Evans et al. 2003). Use of downed wood as physical cover for nests or dens (Maser and Trappe 1984; Thompson 1996; Bull et al. 1997; McCay 2000) and travel paths (Barnum et al. 1992; McMillan and Kaufman 1995; McCay 2000; Ucitel et al. 2003; Zollner and Crane 2003) has been documented for some species, although the value of dead wood to many species is unknown.

Townsend's chipmunk (*Tamias townsendii*) is a common sciurid in coniferous forests of the Pacific Northwest that is prey for diurnal predators and disperses mycorrhizal fungal spores (Carey 1995; Hayes et al. 1995; Verts and Carraway 1998). This species can be abundant in riparian areas and upland habitats as well as across a range of stand ages and conditions (Doyle 1990; Rosenberg and Anthony 1993; Carey 1995; Hayes et al. 1995; Carey 2000). Although much is known about general habitat associations of Townsend's chipmunks, little is known about their association with downed wood at the individual or population level.

Our objective was to examine the influence of downed wood on path selection of Townsend's chipmunk in conifer forests. Specifically, we examined if chipmunks selected paths based on the presence and characteristics of downed wood. Further, we examined if use of downed wood differed between females and males, between

summer and fall, and with the quantity of wood in the environment. We also examined data for differences in how females and males utilize downed wood for movement and how selection of downed wood as travel paths may change with the amount of wood in the environment. Given the importance of downed wood to path selection of eastern chipmunks (*Tamias striatus*; Zollner and Crane 2003), shrews (*Sorex* sp.; Craig 1995), mice (*Peromyscus* sp.; Barnum et al. 1992; Carter 1993; McMillan and Kaufman 1995; McCay 2000), and Gapper's red-backed voles (*Clethrionomys gapperi*; Ucitel et al. 2003), we hypothesized that Townsend's chipmunks would disproportionately select paths with downed wood. Further, because populations, home ranges, and habitat selection of individual small mammals are sometimes related to stage of decay, size, and other characteristics of downed wood (Hayes and Cross 1987; Tallmon and Mills 1994; Carey and Johnson 1995; Thompson 1996; McCay 2000), we hypothesized that chipmunks would select larger diameter wood and wood that was elevated because it can provide paths under the logs that could function as protective cover (Hayes and Cross 1987). Finally, we hypothesized that use of downed wood would be greater after deciduous leaves had fallen in the fall because downed wood may facilitate rapid and silent movements through areas with dry deciduous leaf cover (Fitzgerald and Wolff 1988; Roche et al. 1999).

## MATERIALS AND METHODS

*Study Area.*—The study was conducted on the Oregon State University McDonald-Dunn Research Forest at the eastern edge of the Oregon Coast Range in Benton County, Oregon (Townships 10 and 11 South, Range 5 West). Forests in this area are dominated by Douglas-fir (*Pseudotsuga menziesii*) with minor amounts of grand fir (*Abies grandis*), bigleaf maple (*Acer macrophyllum*), Oregon white oak (*Quercus garryana*), Pacific madrone (*Arbutus menziesii*), Pacific dogwood (*Cornus nuttallii*), red alder (*Alnus rubra*), Oregon ash (*Fraxinus latifolia*), and bitter cherry (*Prunus emarginata*) (Chambers 1996). We tracked Townsend's chipmunks in stands in which one third of the stand volume was removed in 0.2 ha circular clearcut patches between 1989 and 1991 (Chambers et al. 1999). Stands were 90 to 130 yr old prior to harvest, were 8-12 ha in size, and were part of the Oregon State University College of Forestry Integrated Research Program (CFIRP) (Chambers 1996).

*Field Methods.*—We trapped chipmunks in each of six stands in July (summer) and September (fall) 2001. One trap grid was randomly located within each stand so that it encompassed an area that approximated stand-level proportions of uncut (ca. 2/3 of the grid) and cut (ca. 1/3 of the grid) forest and had a buffer of at least 35 m between the grid and the edge of the stand. Within each stand, we set 40 Sherman live-traps (Model LFA, 8 x 9 x 23 cm, H. B. Sherman Traps, Inc., Tallahassee, Florida, USA) in four rows of 10 traps; traps were 10 m apart within a row and rows were 20 m apart. Traps were baited with a mixture of peanut butter, rolled barley, rolled corn, rolled oats, and cane molasses and the bait was wrapped in wax paper and suspended inside the rear door of each trap (Stout and Sonenshine 1973). Each trap

was covered with a waxed milk-carton sleeve for insulation and protection from rain and direct sunlight. Polyfiber batting was used for bedding to provide additional thermal protection for captured animals. Traps were set in the morning and checked every 2-4 hr to minimize the time chipmunks were in traps prior to tracking. In September, we also set traps in the evening and checked them the following morning.

We evaluated path selection of adult female and male Townsend's chipmunks with the spool-and-line technique (Boonstra and Craine 1986; Key and Woods 1996). We wrapped each spool in parafilm to keep the thread dry and taped a spool to the dorsal side of the base of each chipmunk's tail with two small pieces of duct tape. A third piece of tape was placed over the leading edge of the spool to reduce the chance that the thread would get caught on the spool. Spools weighed ca. 2.9 g after attachment and comprised < 5% of a chipmunk's mass; threads had a maximum length of ca. 150 m.

We attached spools to chipmunks in the field and secured the leading end of the thread to a stationary object at the trap station; the trailing end of the thread was marked with red ink to allow positive identification of the end of the trail. To standardize release, each chipmunk was returned to the trap and allowed to calm down for a few minutes. The trap then was placed on the ground in its original position, oriented in a random direction, and locked open. The animal was allowed to exit the trap of its own accord. After opening the trap, everyone immediately left the study site by the most direct manner along a path that avoided potential encounters with the chipmunk. Observations suggested that the thread was fully deployed within 2-3 hrs of release. In most cases, paths were located >4 hr later the same day or on the

following day, depending upon time of release. Our observations suggest that paths selected by chipmunks with spools reflect normal path selection behavior of chipmunks and were not strongly influenced by presence of the spool or reflected escape behavior associated with release from a live-trap.

We measured habitat use along each path and categorized trail segments as arboreal, subterranean, or surficial. We defined an arboreal trail segment as a portion of the trail where the string was suspended in vegetation or ascended into the canopy and portions of the trail where the string was underground was defined as a subterranean trail segment. Portions of the path that were neither arboreal nor subterranean were considered surficial trail segments. To determine extent of arboreal and subterranean use, the string was cut at the points where it left and returned to the surface. The string was then collected and the total length measured. In one case, subterranean string was broken during collection and thus the measured length represents a conservative estimate of subterranean use. All string was removed from the field to minimize risk of injury or death to other animals by entanglement with the string (Loefering 1997).

We evaluated use of downed wood by comparing presence of wood at 0.5 m radius circular plots along the path (hereafter called "used plots") and at randomly selected points adjacent to the path (hereafter called "random plots"). The first used plot was centered on the string 2 m from the release point, and additional plots were centered at 2-m intervals until the end of the path. Random plot centers were centered 1 m along a random compass heading from a point on the path. The first point on the path used to establish random plots was located 1 m from the release point, and

additional random plots were established at 2-m intervals along the path. If a selected random plot overlapped with a used plot, an alternate random compass bearing was selected. A plot was defined as being associated with downed wood if any part of the plot included any portion of any downed wood  $\geq 1.0$  m in length having a diameter  $\geq 10$  cm. These criteria were based on the assumption that a Townsend's chipmunk perceives and uses downed wood at this distance and of this size as cover or to facilitate movement. For each piece of wood meeting these criteria, we recorded the type (conifer or hardwood), diameter (cm, maximum in plot), and decay stage (hard or soft) of the wood, and whether it was elevated off the ground within the plot. The limited distribution of data for type of wood (mostly conifer) and decay stage (mostly "hard") in plots precluded meaningful analyses and these data are not discussed further.

In used plots with more than one piece of wood, we restricted analysis to the piece of wood that was closest to the string. In random plots with more than one piece of wood, we used the piece of wood with the greatest diameter in statistical analyses. We also determined the type of use (top, underneath, inside, and beside) and measured distance from the path to the wood out to 50 cm; these data were not measured for random plots. We defined the path to be on top of the log was when the string was on either the top or side of the log, underneath the log was when the string was on the ground directly under the log or beneath the overhang of the log, beside the log was when the string was on the ground at any point outside the overhang of the log, and inside the log if the string was in a cavity in the wood or beneath exfoliating bark.



*Analytical Methods.*—We developed three models to evaluate how the availability of wood, diameter of wood, and whether or not the wood was elevated influenced path selection by chipmunks. We first evaluated a model to determine if chipmunks disproportionately selected plots with wood along a path (availability model). For this model, information on presence of wood in each used and random plot was used. We used logistic regression to estimate the relative odds that a plot that contained wood was a function of whether or not it was on a chipmunk's path. We estimated the odds of a plot containing wood if it was on the path relative to it simply being available for each chipmunk individually using PROC GENMOD in SAS (SAS Institute 1999). We then evaluated a model to examine influences of diameter of wood on use by chipmunks based on data from used and random plots that contained wood (diameter model). We used linear regression to estimate the difference in diameters of wood between used and random plots for each chipmunk individually using PROC MIXED in SAS (SAS Institute 1999). Finally, we evaluated a model to determine the influence of wood being elevated off the ground on use of wood by chipmunks (elevated model). We used logistic regression to estimate the odds of a plot containing an elevated piece of wood as a function of whether or not it was on a chipmunk's path. Because there were very few or no used or random plots with elevated wood for 17 chipmunks, this analysis was based on the 25 chipmunks for which adequate data were available (16 males and 9 females, and 6 summer and 19 fall trials). Odds of a plot with wood containing elevated wood were estimated for each of these 25 chipmunks individually using PROC GENMOD in SAS (SAS Institute 1999).

We refined the availability, diameter, and elevated models to examine whether there was a systematic influence of gender, season, or quantity of wood in the environment (as estimated by the data from the random plots) on the values of the estimated parameters (Meredith and Stehman 1991). We used an information-theoretic approach (Burnham and Anderson 2002) to evaluate the relative importance of these three *a priori* models and a null model. The four possible competing models were:

1. Null model: the estimated parameter was not a function of gender, season, or wood quantity,
2. Gender model: the estimated parameter differs between males and females,
3. Season model: the estimated parameter differs between summer and fall, and
4. Wood quantity model: the estimated parameter changes with amount of wood in the environment.

We ranked models using Akaike's Information Criterion for small sample sizes ( $AIC_c$ ) for each base model;  $AIC_c$  was calculated with PROC MIXED (SAS Institute 2004). We calculated  $\Delta AIC_c$  as the difference between the best model (model with the smallest  $AIC_c$ ) and each of the other models for each base model. Models with  $\Delta AIC_c$  values  $\leq 2.0$  were interpreted to be strongly competing, models with  $\Delta AIC_c$  values between 2.0 and 4.0 were considered to be moderately competing, and models with  $\Delta AIC_c$  values  $> 4.0$  were considered to be weakly competing or not competing models (Burnham and Anderson 2002). We computed Akaike weights ( $w$ ) for each model to provide an estimate of the relative importance of each model given the data

(Burnham and Anderson 2002). We calculated evidence ratios (ER) as a ratio of  $w$  of each of the models to the best model; evidence ratios are measures of the strength of support of best model relative to other models of interest (Burnham and Anderson 2002). We interpreted models with  $ER > 7.4$  as strong evidence that the best model is the better model, those with ER between 2.7 and 7.4 as moderate evidence that the best model is the better model, and those with  $ER < 2.7$  as weak evidence that the best model is the better model (Burnham and Anderson 2002).

## RESULTS

We tracked 41 Townsend's chipmunks for a total of 5,093 m. Paths of four additional individuals were excluded from all analyses because spools were shed by chipmunks within 55 m of the release point (3 trails) or because the string broke and was obviously disrupted (1 trail). Mean trail length was 124.2 m (SD = 8.1 m) and averaged 84.6% (SD = 6.2%) surficial, 14.9% (SD = 7.0%) arboreal, and 0.5% (SD = 0.9%) subterranean (Table 3-1). Minor differences were apparent between females and males and between the summer and fall seasons. A mean of 50.4% (SD = 4.1%) of the average surficial chipmunk path was within 50 cm of downed wood (Table 3-1), and a mean of 54.5% (SD = 6.1%) of this use was on top, inside, or underneath downed wood. Examining level of wood use in 10-cm bands from the log out to 50 cm indicated that use was similar among distance classes, but reduced relative to use directly at the log (Fig. 3-1). On average, 78.6% (SD = 10.0%) of the use directly associated with downed wood was on top of logs (Fig. 3-2).

Table 3-1. Average path characteristics of 41 Townsend's chipmunks in western Oregon, 2001. The wood present category represents data only from surficial plots.

	Summer				Fall				Total	
	Female (n = 4)		Male (n = 6)		Female (n = 9)		Male (n = 22)		(n = 41)	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Length (m)	114.5	7.5	121.2	8.8	133.0	11.1	128.0	9.3	124.2	8.1
Surficial (%)	93.1	6.0	78.8	18.6	84.9	8.3	81.6	4.7	84.6	6.2
Arboreal (%)	5.0	6.2	21.2	18.6	15.1	8.3	18.3	4.6	14.9	7.0
Subterranean (%)	1.9	3.2	0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.9
Wood										
On Path (%)	55.8	14.0	46.2	14.6	50.8	8.4	48.9	8.2	50.4	4.1
Random (%)	31.2	19.5	24.1	11.3	31.3	9.7	23.9	5.8	27.6	4.2

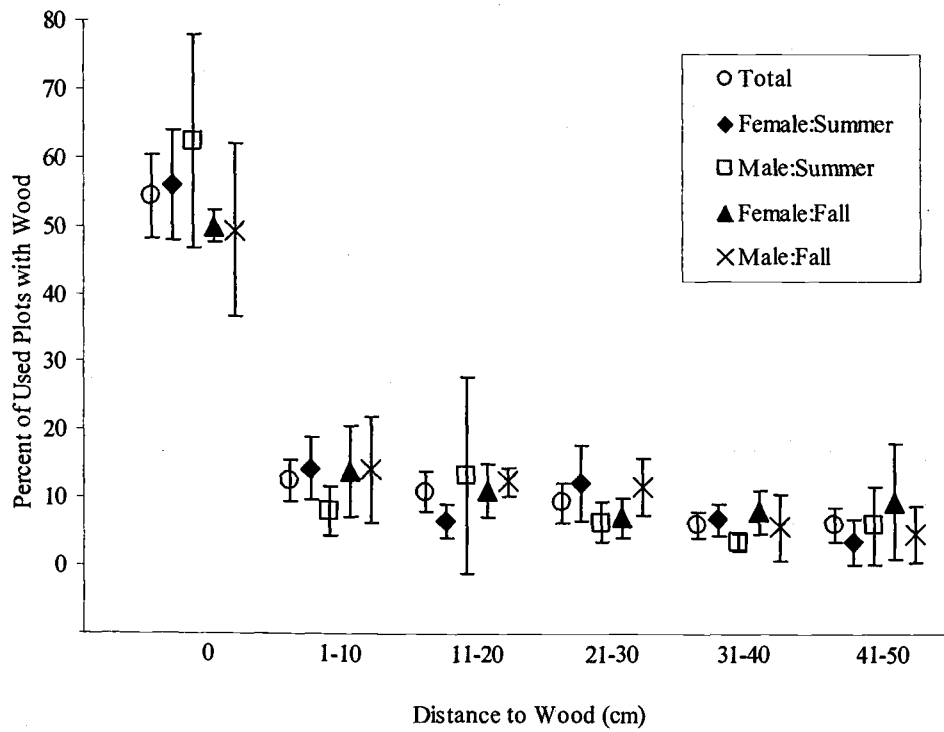


Figure 3-1. Pattern of use of downed wood ( $\bar{x} \pm 1$  SD) by 41 Townsend's chipmunks in western Oregon, 2001. Data are based on used plots with wood present.

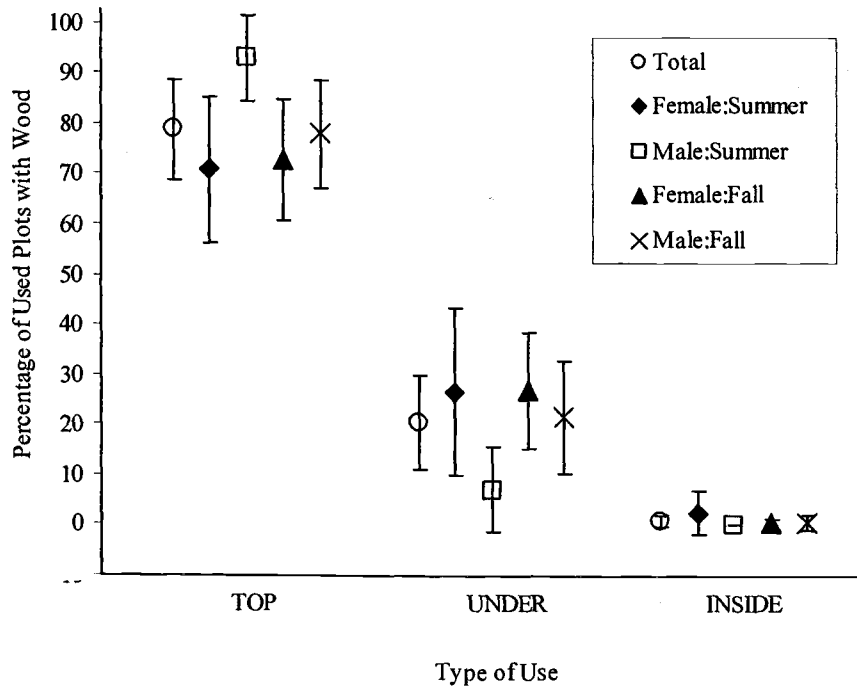


Figure 3-2. Types of use of downed wood ( $\bar{x} \pm 1$  SD) by 41 Townsend's chipmunks in western Oregon, 2001. Data are based on used plots with wood present and located 0 cm from the string.

In all but one case, Townsend's chipmunks disproportionately selected plots with downed wood (Fig. 3-3). There was strong evidence that chipmunks disproportionately selected paths with wood (availability model) and that the quantity of wood in the environment influenced path selection; the closest competing model (null model) had a  $\Delta AIC_c$  value of 6.24 and an ER of 22.6 (Table 3-2). At average wood densities (26% of path), a used plot was 2.99 times more likely to be associated with downed wood (95% CI = 2.53-3.53) and a decrease of 10% of wood in the environment results in an increase in the relative odds of wood use between 6% and 36%. We found no clear evidence that use of wood differed with gender (ER = 51.2) or season (ER = 39.3) (Table 3-2).

Downed wood in used plots averaged 1.23 times larger in diameter than wood in random plots (diameter model; 95% CI = 1.14-1.34). We found no clear evidence for differences in patterns of use with gender (ER = 1.0), season (ER = 2.3), or quantity of wood in the environment (ER = 3.9) because the null model was a competing model ( $\Delta AIC_c$  = 0.66, ER = 1.4) (Table 3-2).

On average, 45% of the wood was elevated both in used and random plots; the relative odds of wood being elevated on a path was 1.05 times that found in random plots (elevated model; 95% CI = 0.75-1.47). We found no clear evidence that the relative odds of elevated wood on the path versus randomly available wood varied with gender (ER = 2.3), season (ER = 3.4), or quantity of wood in the environment (ER = 2.2) and the null model was the best model (Table 3-2).

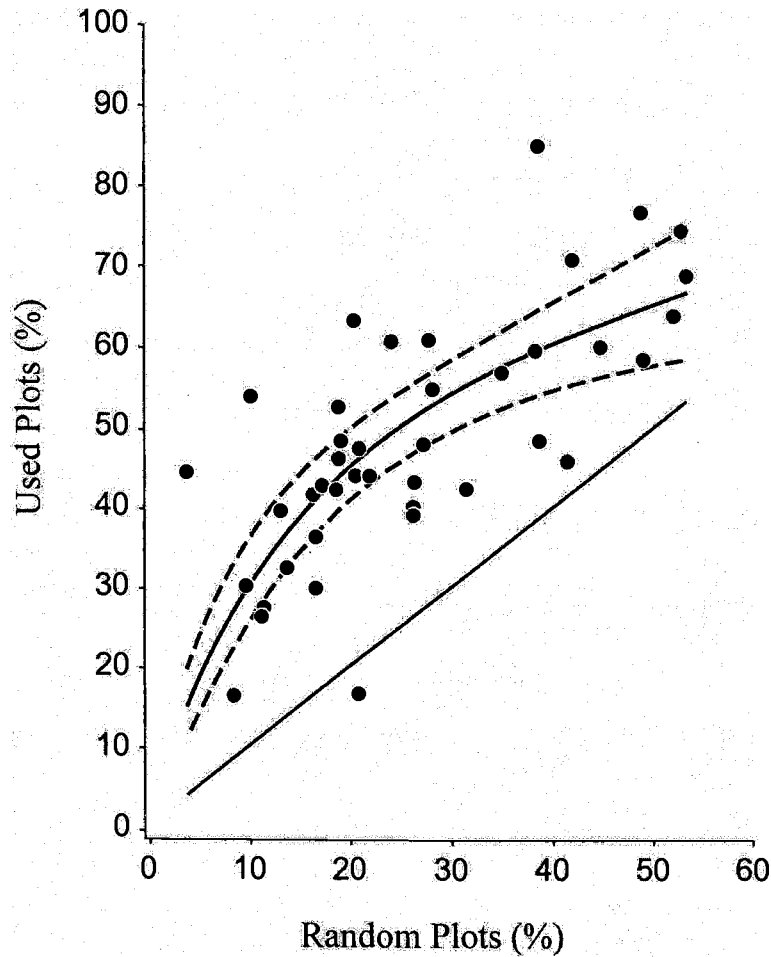


Figure 3-3. Percentage of used versus random plots with downed wood for 41 Townsend's chipmunks in western Oregon, 2001. Each point represents data for an individual chipmunk. The diagonal solid line represents equal percentage of used and random plots having wood. Values located below this line indicate a greater percentage of random plots with wood than used plots; values above the line indicate a greater percentage of used plots with wood than random plots. The curved solid line represents the predicted probability and the curved dashed line a 95% CI of a chipmunk's path having wood.



Table 3-2. Results of model comparisons using  $AIC_c$  to evaluate how wood availability, diameter, and elevated status influenced path selection by 41 chipmunks in western Oregon, 2001. The analyses for wood diameter and wood elevated were conditioned only on data points with wood.

Model	<i>a priori</i> Models	Number of Parameters	$\Delta AIC_c$	$w$	Evidence ratio
Availability	Wood Quantity	3	0.00	0.918	1.0
	Null	2	6.24	0.041	22.6
	Season	3	7.34	0.023	39.3
	Gender	3	7.87	0.018	51.2
Diameter	Gender	3	0.00	0.416	1.0
	Null	2	0.66	0.299	1.4
	Season	3	1.70	0.178	2.3
	Wood Quantity	3	2.70	0.108	3.9
Elevated	Null	2	0.00	0.461	1.0
	Wood Quantity	3	1.62	0.205	2.2
	Gender	3	1.68	0.199	2.3
	Season	3	2.46	0.135	3.4

## DISCUSSION

Our study is the first to document the importance of downed wood in path selection by Townsend's chipmunks and contributes to the growing knowledge base that downed wood is selected as travel paths by many species of small mammals including mice (Barnum et al. 1992; Carter 1993; McMillan and Kaufman 1995; McCay 2000), shrews (Craig 1995), Gapper's red-backed voles (Ucitel et al. 2003), and eastern chipmunks (Zollner and Crane 2003). Interestingly, downed wood influences path selection and habitat use by individual Townsend's chipmunks even though Townsend's chipmunk populations do not consistently seem to respond to downed wood in the environment (Morrison and Anthony 1989; Doyle 1990; Rosenberg and Anthony 1993; Carey 1995; Hayes et al. 1995; Carey 2000; Chapter 2). Similarly, eastern chipmunks select downed wood as travel paths (Zollner and Crane 2003) although populations do not appear to respond to downed wood (Dueser and Shugart 1978). The relationship of abundance, density, and demographics of populations with downed wood may be difficult to observe in Townsend's chipmunks because their populations are variable through space and time (Chapter 2). Downed wood may convey benefits to individual animals through increased survival (Manning and Edge 2004), reproduction, or fitness, which could translate to benefits to populations but may be difficult to measure in the field.

The importance of large wood (e.g., diameter and length) has been observed in several species of small mammals. The disproportionate use of larger diameter wood by Townsend's chipmunks in this study is similar to that observed for white-footed mice (*Peromyscus leucopus*; Barnum et al. 1992) and western red-backed voles

(*Clethrionomys californicus*; Hayes and Cross 1987). Although it is not clear why animals select larger wood, it has been hypothesized that large wood provides better navigational cues (Barry and Francq 1980; McCay 2000) or protective cover (Hayes and Cross 1987). Alternatively, larger logs may offer more contiguous movement paths and cover over broader expanses.

The lack of clear evidence of disproportionate use of elevated wood by Townsend's chipmunks is inconsistent with our hypothesis, and may partially be a function of the limited availability of elevated downed wood in our study area. Chipmunks regularly used tops of logs as travel paths, suggesting overhead cover may not be a primary function of downed wood to chipmunks. Further, the overhang from non-elevated large diameter logs, which is hypothesized to be important cover for western red-backed voles (Hayes and Cross 1987), could provide the protection we hypothesized to be associated with elevated wood. Non-elevated small diameter wood was relatively more abundant in our study area and was used by chipmunks but likely offers limited opportunities for chipmunks to use the overhang of the logs. The small size of the overhang on non-elevated small diameter logs likely is too small for chipmunks to use efficiently.

The lack of difference in use of downed wood by chipmunks between the summer and fall is counter to our hypothesis of greater use of downed wood in the fall to avoid moving across fallen leaves. One plausible explanation is that the relatively short trails we encountered encompassed different behaviors (e.g., escape, foraging) that were not directly related to rapid and silent movement through an area. The

functional role of downed wood to animals escaping from threats likely remains relatively constant among seasons and use of downed wood, as an immediate escape path, would vary for each chipmunk due to local availability and distribution of downed wood. Further, rainstorms in the fall resulted in wet substrates during much of the fall sampling and areas with relatively high levels of deciduous vegetation that had lost its leaves in the fall during our study were rather limited because conifer trees dominate our study area (Chambers 1996). Therefore, increased use of downed wood by chipmunks in the fall to avoid movement across dry leaves (Fitzgerald and Wolff 1988; Roche et al. 1999) may not have been necessary. Conversely, the relatively small sample size may have reduced our ability to detect seasonal differences in path selection.

Our observations that individual chipmunks use the tops of logs is consistent with the hypothesis that small mammals use downed wood as travel paths to facilitate rapid and relatively silent movement between areas (Fitzgerald and Wolff 1988; Roche et al. 1999). The use of tops of logs as paths also is known for cotton mice (*P. gossypinus*; McCay 2000), white-footed mice (McMillan and Kaufman 1995), and Gapper's red-backed voles (Ucital et al. 2003). Although the use of logs in this manner may reduce audible noise detectable by many predators (Roche et al. 1999) and reduce predation risks from auditory orienting predators (Fitzgerald and Wolff 1988; Roche et al. 1999), use of tops of logs also places individuals in locations where they may be subject to greater predation pressure by aerial predators.

Although reasons underlying use of downed wood generally are not readily apparent from tracking data collected with the spool-and-line technique or similar methods (e.g., powder tracking; Lemen and Freeman 1985), the variable patterns in type of use of downed wood by Townsend's chipmunks in our study (i.e., movement on top of, under, inside, and beside logs) suggests that downed wood serves many functions to individual chipmunks (e.g., cover and concealment, foraging, movement, navigation) and that the primary function likely changes with context over short distances or periods of time. Observed patterns of chipmunk paths suggested rapid movement through areas (straight paths on top of logs), foraging behavior (convoluted paths associated with or on downed wood and shrubs), and perhaps orientation (repeated use of downed wood that was followed by major changes in the direction of travel).

While chipmunks and other small mammals may benefit in several ways by selecting paths on or near downed wood (Zollner and Crane 2003), the benefits of downed wood to small mammals may be reduced because predators of small mammals also are known to forage or select paths near downed wood (Buskirk and Zielinski 2003). Marten (*Martes americana*) use logs as den and resting sites (Spencer 1987; Buskirk et al. 1989) and as access routes to subnivian nests and dens in snow (Sherbourne and Bissonette 1994; Bunnell et al. 1997). Paths of three ermine (*Mustela ermineae*) that were tracked in our study area with the spool-and-line technique selected paths on, in, and near downed wood (D. L. Waldien, unpublished data) and the pattern of movement suggested that the ermine were actively searching

the downed wood and areas near wood as they traveled through the area. The size and morphology of ermine allow them to readily exploit habitats utilized by potential prey (Simms 1979) and benefits of downed wood as cover to chipmunks or other small mammals from ermine likely would be reduced. However, small hollows and crevices in downed wood can provide protection to small mammals from predators too large to access the hollow (Spencer and Zielinski 1983).

Information on the importance of downed wood at larger spatial and temporal scales for Townsend's chipmunks is lacking. Studies of minimum thresholds of downed wood needed to elicit a response by chipmunks and upper limits where chipmunks no longer appear to respond to downed wood are needed. Studies that examine the importance of downed wood to chipmunks across multiple spatial scales could include how downed wood influences movement through an area, selection of an area, and population level responses. Understanding the functional value of downed wood to Townsend's chipmunks and other species of small mammals at individual and population levels is needed to better understand their behavior and ecology and would facilitate effective conservation and management.

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## CHAPTER 4

### CONCLUSIONS

Selection of specific harvest systems during forest management operations influences habitat conditions and establishes new trajectories for wildlife in the area impacted by management. Several species of small mammals (e.g., deer mice, Townsend's chipmunks, and vagrant shrews) had either neutral or positive responses to the removal overstory trees 8-10 years post-harvest, likely a result of increased resources (e.g., shrubs and herbaceous vegetation). Conversely, species that generally have greater abundances in older forests or in forest with relatively intact overstory canopies (e.g., northern flying squirrel and western red-backed voles), appear to be maintained in the group-selection treatments but were either reduced or were not captured in clearcut and two-story treatments where most of the overstory trees were removed. The loss of critical resources to northern flying squirrels and western red-backed voles, such as trees and snags, in clearcut and two-story treatments likely impacted their populations. Northern flying squirrels establish nests and dens in trees and snags and the removal of the overstory canopy not only removed these resources but also influenced the microclimate within the stand, which in turn negatively impacts the abundance and diversity of hypogeous fungi which are primary food of northern flying squirrels and western red-backed voles.

Small mammal populations did not respond to downed wood in group-selection and clearcut stands. The lack of response of small mammal populations to downed wood is not surprising given the lack of decay and newness of the wood to the forest. Relatively high levels of vegetation was present in the group-selection and

clearcut stands that received downed wood, which provides not only cover but also food sources for many species. Populations of small mammals may not respond to the addition of downed wood under these conditions. The value of downed wood to small mammal populations will likely increase as the wood decays and likely will provide increased quality and quantity of resources with time. However, Townsend's chipmunks selected paths with downed wood and larger diameter wood than what was available demonstrating that downed wood can be important to individual animals although populations may not appear to respond to the downed wood.

Group-selection harvest systems, combined with dynamic approaches to managing downed wood in an area, offers a management option to balance tradeoffs in economic and ecological terms and have the potential to provide habitat for many species of small mammals through time. Gaps in forest canopies, if adequately large, provide habitat for populations of early-successional species (e.g., dusky-footed woodrat, Oregon vole) whereas the intact forest provides habitat for species that benefit from an overstory canopy. The assumption that a species has a continuous response curve to overstory canopy may result in precipitous declines in priority species if in fact there are critical thresholds in how a species responds to important resources (e.g. contiguous overstory). A comprehensive management plan for small mammal communities will include the use different harvest systems in different areas to meet site-specific objectives. Both two-story and group-selection harvest systems appear to be viable alternatives to clearcut harvest systems that will allow timber extraction and maintain different levels of habitat for species.

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APPENDICES

APPENDIX A. Oregon State University College of Forestry MacDonald-Dunn Research Forest stand numbers for stands used in this research project by block with silvicultural and wood treatment designations.

Block	CFIRP Number	Forest Number	Stand Condition	Wood Treatment	
Saddle	S2	60206	two-story		
	S3	60208	group-selection	yes	
	S6	60208	group-selection		
	S7	60209	two-story		
	S8	60512	clearcut	yes	
	S11		060505, 060503, and 060507	control	
			60504	control	
			71117	clearcut	
	Peavy	P1	40608	control	
		P2	41708	clearcut	yes
P3		41709	group-selection	yes	
P4		41809	two-story		
P9		42109	group-selection		
P10		42110	two-story		
P11		42111	clearcut		
			50605	control	
Dunn	D1	30824	two-story		
	D3	30713	clearcut	yes	
	D5 <sup>1</sup>	030504, 030509, 030701, and 030703		control	
	D7	30609	group-selection	yes	
	D8	30610	two-story		
	D9	30611	clearcut		
	D11	30312	group-selection		

<sup>1</sup> D5 was divided into two separate stands at the road and adjacent stream which bisected the stand.

APPENDIX B. *A priori* models examined in survival analysis for adult deer mice for the silvicultural treatment objective (unharvested control stands and three silvicultural treatments over two years and five seasons, 1999-2000) in western Oregon. Time intervals are: 1 = summer to fall 1999, 2 = fall 1999 to spring 2000, 3 = spring to summer 2000, 4 = summer to fall 2000.

Model	Probability of Survival	Probability of Capture
$\Phi (.) P (.)$	Constant through time	Constant through time
$\Phi (.) P (t)$	Constant through time	Varies with time
$\Phi (.) P (SU WI SPSU)$	Constant through time	$1 \neq 2 \neq (3,4)$
$\Phi (t) P (.)$	Varies with time	Constant through time
$\Phi (t) P (t)$	Varies with time	Varies with time
$\Phi (t) P (SU WI SPSU)$	Varies with time	$1 \neq 2 \neq (3,4)$
$\Phi (SU WI SPSU) P (.)$	$1 \neq 2 \neq (3,4)$	Constant through time
$\Phi (SU WI SPSU) P (t)$	$1 \neq 2 \neq (3,4)$	Varies with time
$\Phi (SU WI SPSU) P (SU WI SPSU)$	$1 \neq 2 \neq (3,4)$	$1 \neq 2 \neq (3,4)$

APPENDIX C. *A priori* models examined in survival analysis for adult deer mice for the wood treatment objective (group-selection and clearcut treatments over four years and 11 seasons, 1999-2002) in western Oregon. Time intervals are: 1 = summer to fall 1999, 2 = fall 1999 to spring 2000, 3 = spring to summer 2000, 4 = summer to fall 2000, 5 = fall 2000 to spring 2001, 6 = spring to summer 2001, 7 = summer to fall 2001, 8 = fall 2001 to spring 2002, 9 = spring to summer 2002, 10 = summer to fall 2002. Pre-wood treatment time intervals include 1-4, and post-wood treatment include 5-10.

APPENDIX C.

Model	Probability of Survival	Probability of Capture
Phi (.) P (.)	Constant through time	Constant through time
Phi (.) P (SU99 PRE POST SEAS)	Constant through time	1 ≠ 2 ≠ 3 ≠ 4 ≠ (5,8) ≠ (6,9) ≠ (7,10)
Phi (.) P (SU99 SEAS)	Constant through time	1 ≠ (2,5,8) ≠ (3,6,9) ≠ (4,7,10)
Phi (.) P (SU99 WI SPSU)	Constant through time	1 ≠ (2,5,8) ≠ (3,4,6,7,9,10)
Phi (.) P (t)	Constant through time	Varies with time
Phi (SU99 PRE POST SEAS) P (.)	1 ≠ 2 ≠ 3 ≠ 4 ≠ (5,8) ≠ (6,9) ≠ (7,10)	Constant through time
Phi (SU99 PRE POST SEAS) P (SU99 PRE POST SEAS)	1 ≠ 2 ≠ 3 ≠ 4 ≠ (5,8) ≠ (6,9) ≠ (7,10)	1 ≠ 2 ≠ 3 ≠ 4 ≠ (5,8) ≠ (6,9) ≠ (7,10)
Phi (SU99 PRE POST SEAS) P (SU99 SEAS)	1 ≠ 2 ≠ 3 ≠ 4 ≠ (5,8) ≠ (6,9) ≠ (7,10)	1 ≠ (2,5,8) ≠ (3,6,9) ≠ (4,7,10)
Phi (SU99 PRE POST SEAS) P (SU99 WI SPSU)	1 ≠ 2 ≠ 3 ≠ 4 ≠ (5,8) ≠ (6,9) ≠ (7,10)	1 ≠ (2,5,8) ≠ (3,4,6,7,9,10)
Phi (SU99 PRE POST SEAS) P (t)	1 ≠ 2 ≠ 3 ≠ 4 ≠ (5,8) ≠ (6,9) ≠ (7,10)	Varies with time
Phi (SU99 SEAS) P (.)	1 ≠ (2,5,8) ≠ (3,6,9) ≠ (4,7,10)	Constant through time
Phi (SU99 SEAS) P (SU99 PRE POST SEAS)	1 ≠ (2,5,8) ≠ (3,6,9) ≠ (4,7,10)	1 ≠ 2 ≠ 3 ≠ 4 ≠ (5,8) ≠ (6,9) ≠ (7,10)
Phi (SU99 SEAS) P (SU99 SEAS)	1 ≠ (2,5,8) ≠ (3,6,9) ≠ (4,7,10)	1 ≠ (2,5,8) ≠ (3,6,9) ≠ (4,7,10)
Phi (SU99 SEAS) P (SU99 WI SPSU)	1 ≠ (2,5,8) ≠ (3,6,9) ≠ (4,7,10)	1 ≠ (2,5,8) ≠ (3,4,6,7,9,10)
Phi (SU99 SEAS) P (t)	1 ≠ (2,5,8) ≠ (3,6,9) ≠ (4,7,10)	Varies with time
Phi (SU99 WI SPSU) P (.)	1 ≠ (2,5,8) ≠ (3,4,6,7,9,10)	Constant through time
Phi (SU99 WI SPSU) P (SU99 PRE POST SEAS)	1 ≠ (2,5,8) ≠ (3,4,6,7,9,10)	1 ≠ 2 ≠ 3 ≠ 4 ≠ (5,8) ≠ (6,9) ≠ (7,10)
Phi (SU99 WI SPSU) P (SU99 SEAS)	1 ≠ (2,5,8) ≠ (3,4,6,7,9,10)	1 ≠ (2,5,8) ≠ (3,6,9) ≠ (4,7,10)
Phi (SU99 WI SPSU) P (SU99 WI SPSU)	1 ≠ (2,5,8) ≠ (3,4,6,7,9,10)	1 ≠ (2,5,8) ≠ (3,4,6,7,9,10)
Phi (SU99 WI SPSU) P (t)	1 ≠ (2,5,8) ≠ (3,4,6,7,9,10)	Varies with time
Phi (t) P (.)	Varies with time	Constant through time
Phi (t) P (SU99 PRE POST SEAS)	Varies with time	1 ≠ 2 ≠ 3 ≠ 4 ≠ (5,8) ≠ (6,9) ≠ (7,10)
Phi (t) P (SU99 SEAS)	Varies with time	1 ≠ (2,5,8) ≠ (3,6,9) ≠ (4,7,10)
Phi (t) P (SU99 WI SPSU)	Varies with time	1 ≠ (2,5,8) ≠ (3,4,6,7,9,10)
Phi (t) P (t)	Varies with time	Varies with time

APPENDIX D. Ancillary captures of non-mammalian species for the silvicultural treatment objective (unharvested control stands and three silvicultural treatments over two years and five seasons, 1999-2000) in western Oregon.

Species		Group- Control	Two- Selection	Two- story	Clearcut	Total
<b>Aves</b>						
<i>Aphelocoma californica</i>	western scrub jay	0	0	2	0	2
<i>Catharus ustulatus</i>	Swainson's thrush	0	0	1	1	2
<i>Cyanocitta stelleri</i>	Steller's jay	3	4	1	1	9
<i>Junco hyemalis</i>	dark-eyed junco	2	0	0	1	3
<i>Melospiza melodia</i>	song sparrow	0	7	68	33	108
<i>Pipilo maculatus</i>	spotted towhee	0	4	103	48	155
<i>Thryomanes bewickii</i>	Bewick's wren	0	0	1	1	2
<i>Troglodytes troglodytes</i>	winter wren	1	0	1	1	3
<i>Zonotrichia atricapilla</i>	golden-crowned sparrow	0	0	1	0	1
<i>Zonotrichia leucophrys</i>	white-crowned sparrow	0	0	0	8	8
	Species not recorded	0	0	17	6	23
	Total	6	15	195	100	316
<b>Amphibia</b>						
<i>Hyla regilla</i>	Pacific tree frog	0	1	0	0	1
<i>Taricha granulosa</i>	rough skinned newt	0	0	1	1	2
	Total	0	1	1	1	3
<b>Reptilia</b>						
<i>Charina bottae</i>	rubber boa	0	0	1	0	1
<i>Elgaria multicarinata</i>	southern alligator lizard	0	0	0	1	1
<i>Pituophis melanoleucus</i>	gopher snake	0	1	0	0	1
<i>Sceloporus occidentalis</i>	western fence lizard	0	1	2	6	9
<i>Thamnophis</i> spp.	garter snake	0	1	0	0	1
	Total	0	3	3	7	13
<b>Grand Total</b>		<b>6</b>	<b>19</b>	<b>199</b>	<b>108</b>	<b>332</b>

Appendix E. Ancillary captures of non-mammalian species for the wood treatment objective in group-selection and clearcut treatments over four years and 11 seasons, 1999-2002 in western Oregon.

Species		Group- Selection	Clearcut	Total
<b>Aves</b>				
<i>Aphelocoma californica</i>	western scrub jay	0	2	2
<i>Catharus ustulatus</i>	Swainson's thrush	0	1	1
<i>Cyanocitta stelleri</i>	Steller's jay	18	14	32
<i>Junco hyemalis</i>	dark-eyed junco	0	2	2
<i>Melospiza melodia</i>	song sparrow	32	62	94
<i>Pipilo maculatus</i>	spotted towhee	14	113	127
<i>Thryomanes bewickii</i>	Bewick's wren	0	1	1
<i>Troglodytes troglodytes</i>	winter wren	0	1	1
<i>Zonotrichia atricapilla</i>	golden-crowned sparrow	-	-	-
<i>Zonotrichia leucophrys</i>	white-crowned sparrow	0	13	13
Species not recorded		0	6	6
Total		64	215	279
<b>Amphibia</b>				
<i>Hyla regilla</i>	Pacific tree frog	1	0	1
<i>Taricha granulosa</i>	rough skinned newt	1	1	2
Total		2	1	3
<b>Reptilia</b>				
<i>Charina bottae</i>	rubber boa	-	-	-
<i>Elgaria multicarinata</i>	southern alligator lizard	0	1	1
<i>Pituophis melanoleucus</i>	gopher snake	1	0	1
<i>Sceloporus occidentalis</i>	western fence lizard	1	7	8
<i>Thamnophis</i> spp.	garter snake	1	1	2
Total		3	9	12
<b>Grand Total</b>		<b>69</b>	<b>225</b>	<b>294</b>