

AN ABSTRACT OF THE THESIS OF

Jeffrey A. Manning for the degree of Master of Science in Wildlife Science presented on September 13, 2002.

Title: Small Mammal Responses to Silvicultural Fuels Treatments in Southwest Oregon.

Abstract approved: ____

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W. Daniel Edge

Despite the belief that fuels management, a form of prescribed fire that reduces accumulated fuels in commercially thinned forests, is necessary to restore forest 'health' in the Pacific Northwest, its effects on wildlife has received little attention in the scientific literature. Because fuels management is supported, funded, and implemented nationwide under the Federal Wildland Fire Management Policy, it is imperative to understand how these management activities affect wildlife. In this field experiment, I used mark-recapture methods to examine community, population, and individual responses of small mammals one year following three fuels-management treatments (lop and scatter, pile, and pile/burn) in three commercially thinned Douglas-fir (*Pseudotsuga menziesii*) forest stands within the Applegate Adaptive Management Area of southwest Oregon.

Fifteen species were captured during two years of study, and I found that fuels treatments did not appear to affect species richness or evenness, nor did they affect population densities and survival of the two most abundant species, deer mouse (*Peromyscus maniculatus*) and western red-backed vole (*Clethrionomys californicus*). In study plots where fuels provided variable distributions and amounts of cover, only deer mice used piled fuels significantly more than available while randomly using fuels that were lopped and scattered. Deer mouse numbers decreased and their home ranges increased with increasing distance from piled fuels. Thus, it appears that although these three fuels treatments do not affect the population density of deer mice in my study area,

piled fuels do affect the distribution and home range size of individuals within these populations, leading to a shift in their local distribution.

I hypothesize that environmental conditions created by the open canopy following thinning in this study may have led to poor-quality forest-floor habitat for small mammals, which could have dampened small mammal community- and population-level responses one year following fuels treatments. I recommend that future studies of wildlife responses to fuels management in the Pacific Northwest consider interactions between commercial thinning, fuels management, and regional climate conditions.

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Small Mammal Responses to Silvicultural Fuels Treatments in Southwest Oregon.

by

Jeffrey A. Manning

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

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 Jeffrey A. Manning, Author

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Dedicated to a wonderful woman and role-model:

Sheila Manning

Thank you for the inspiration and encouragement to follow my dreams!

Small Mammal Responses to Silvicultural Fuels Treatments in Southwest Oregon.

GENERAL INTRODUCTION

The field of fire management has undergone a paradigm shift from fighting fires to using prescribed fire to restore a semblance of the natural fire and ecosystem processes (Brown and Arno 1991, Mutch 1994, Arno 1996). Silvicultural fuels management, hereafter referred to as fuels management, is the use of prescribed fire to burn accumulated fuels (twigs, branches, and stems < 10 cm in diameter) that fall from trees and shrubs following a silvicultural treatment (Harmon and Sexton 1996, Pyne et al. 1996) such as thinning (Walstad et al. 1990). Fuels management is intended to reduce accumulated fuels that make forests vulnerable to wildfire (Wickman 1992, Mutch et al. 1993), and is supported and funded under the Federal Wildland Fire Management Policy (FWFMP) (U.S. Department of Interior [USDI] and U.S. Department of Agriculture [USDA] 2001). Despite the belief that fuels management is necessary to restore forests (Miller and Bigley 1990, USDA 1996), its effects on wildlife has received little attention in the scientific literature and in reports proposing prescribed burning as the primary means for solving forest health problems (Gast et al. 1991, Wickman 1992, Everett et al. 1993, Mutch et al. 1993). Without this information, we cannot fully understand how fuels management affects forest ecosystems. I maintain that managing for improved health of forests, through the application of silvicultural prescriptions that include fuels management, requires management plans that consider the effects of this management activity on wildlife.

The forest floor environment is a key component in the ecology of forest ecosystems, and it is probably more affected by fire than any other component within these systems (Page-Dumroese et al. 1991). If the forest floor environment is viewed only as the annual accumulation of fuels, loss of the forest floor may seem inconsequential, even when fire is used frequently as a means to achieve short-term goals of forest productivity and naturalness (Sackett et al. 1993, Covington et al. 1997). But,

when viewed in terms of biological functions, values, and processes, alteration of the forest floor environment through fuels management may have consequences on wildlife that warrant careful consideration.

Small mammals represent a major assemblage of species that occupy the forest floor environment (Gibbons 1988), and they perform ecological functions in forest systems (Carey and Johnson 1995, Maser 1998:8-13). Some species are known to affect plant community dynamics by consuming seeds and foliage (Brown and Heske 1990, Huntly 1991, Bowers 1993). There is evidence that others influence plant communities by dispersing ectomycorrhizal fungi (Maser and Nussbaum 1978, Tallmon and Mills 1994, Cazares et al. 1999). Finally, small mammals represent a substantial prey-base for forest-dwelling carnivores, reptiles, and raptors (Ingles 1965, Verts and Carraway 1998). Consequently, impacts to small mammals may have cascading effects across the forest environment. In fact, Walstad et al. (1990) suggested that prescribed fire that negatively impacts small mammals could conceivably have a deleterious effect on growth of conifers, especially in xeric sites by reducing the dispersal of ectomycorrhizal fungi.

Silvicultural fuels may function as cover for small mammals by providing breeding, foraging, travel, escape, nesting, shelter, and resting habitat that enhances reproduction and/or survival (Bailey 1984:110-111). Pasitschniak-Arts and Messier (1998) reported that small mammals were more abundant in areas supporting relatively dense nesting cover, Harmon et al. (1986) found small mammals associated with piles of vegetation, and Maser and Sedell (1994) and Steel et al. (1999) showed that small mammals used natural wood piles in riparian areas. In riparian areas, higher numbers of individuals within species and higher species richness were found in natural piles of wood compared to areas without piles (Steel et al. 1999). Orrock et al. (2000) attributed the suitability of southern red-backed vole (*Clethrionomys gapperi*) habitat in the Southern Appalachian Mountains to the abundance of small twigs and branches, similar to that comprised in silvicultural fuels. Manning and Edge (in review) found that deer mouse (*Peromyscus maniculatus*) and creeping vole (*Microtus oregoni*) survival was related to down wood at the scale of micro-sites in the central Oregon Coast Range.

Silvicultural treatments that include fire may directly affect small mammals on the forest floor because they exhibit low vagility (Walstad et al. 1990). Direct causes of death to small mammals due to fire are attributed primarily to asphyxiation, rather than to burning (Chew et al. 1958, Lawrence 1966). Ambient temperatures over 63 °C can directly kill individual small mammals (Howard et al. 1959), and fire effects on habitat can dramatically influence populations (Smith and Fischer 1997). Thus, fire and mechanical activities associated with fuels management likely result in the direct injury and mortality of small mammal individuals as well as habitat alterations that indirectly affect population densities and survival rates.

In managed forests of the Pacific Northwest, silvicultural treatments including prescribed burning removed an average of 34% of down wood and 29% of the forest floor duff (Miller and Bigley 1990). Additionally, the removal of down wood from the forest floor by mechanical activities tied to silvicultural treatments (e.g., drag lining and cable-yarding) has been reported to be deleterious to some small mammals (see Harmon et al. 1986, Freedman et al. 1996 for reviews). After a prescribed fire in central Washington, populations of the Townsend's chipmunk (*Tamias townsendii*) and northern red-backed vole (*Clethrionomys gapperi*) decreased (Hanson 1978). Northern red-backed voles avoided a stand-replacement burn in black spruce (*Picea mariana*) for 1 year, but eventually established a resident population 4 years following the fire (West 1982). On the other hand, populations of pioneer species, such as the deer mouse, may rebound soon after burning (Ream 1981). For instance, Sullivan and Boateng (1996) found that populations of deer mice declined immediately following a burn treatment, but recovered to the control level within 2 months.

Various fuels treatments are available for silvicultural prescriptions (Harmon and Sexton 1996, Pyne et al. 1996), most of which require the use of fire. However, fuels management is limited by local governments to maintain air quality (Fiske and DeBell 1989). Tiedemann et al. (2000) suggested that many of the goals of prescribed fire could be achieved by mechanically managing fuels. They proposed that silvicultural prescriptions could include leaving fuels in place after they are lopped and scattered or by

chipping and scattering them. Also, current treatments that entail piling and burning could be modified to eliminate fire so that piled fuels remain. Such alternative treatments would leave accumulated fuels behind to function as cover for wildlife, but as Tiedemann et al. (2000) expressed, it is imperative that we understand the wildlife response to such fuels treatments before they become incorporated into silvicultural prescriptions.

Fuels treatments can be categorized based on the amount and distribution of cover remaining on the forest floor. The lop-and-scatter treatment described by Tiedemann et al. (2000) provides the greatest amount of cover in a random distribution. Unburned piles of fuel provide cover in randomly distributed clumps, thereby reducing total cover across the forest floor. Treatments that include burning fuels provide the least amount of cover.

Until recently (Kaufman et al. 1982, Schwilk and Keeley 1998, Ford et al. 1999), few studies of wildlife responses to fire investigated effects at the scale of populations, and none explicitly investigated the response of small mammal density and survival to fuels management. As federal land managers implement the Northwest Forest Plan (U.S. Forest Service [USFS] and U.S. Bureau of Land Management [BLM] 1994a) and the FWFMP (USDI and USDA 2001) in the Pacific Northwest, it is crucial to incorporate consideration of small mammal responses to fuels management into forest management plans. The purpose of this study was to determine community, population, and individual responses of small mammals to 3 different fuels treatments 1 year following treatments in commercially thinned Douglas-fir (*Pseudotsuga menziesii*) forests in southwest Oregon.

CRITICAL RESEARCH QUESTIONS

Studies examining the effects of habitat on wildlife should consider ecologically correct scales or risk drawing incorrect conclusions regarding habitat use and quality (Wiens et al. 1986). Morris (1987) and Stapp (1997) suggested that examinations of habitat-specific responses of organisms should use a hierarchical, multiscale approach to yield the most ecologically relevant conclusions. Thus, to examine the effects of fuels

treatments on small mammals, research should focus on responses at the community, population, and individual levels.

Community Responses

Species richness and composition

Down wood provides forest floor structural diversity that may in turn influence small mammal species richness. If fuels provide structural diversity on the floor of managed forests, it could increase ranges of availability within resource dimensions (niches) (Pianka 1969, Schoener 1974) and broaden species distributions (niche breadths) (McCullough 1980, Krebs 1989:371-391), resulting in an increase in species richness at the local scale. Carey et al. (1999) hypothesized that diverse understory vegetation and down wood volumes promote diverse forest-floor small mammal communities, and Wilson and Carey (2000) provided supporting evidence of this. In western Washington, small mammal species richness was greater in riparian sites with natural wood debris piles compared to sites without piles (Steel et al. 1999).

Species evenness

Each species has a unique niche breadth (Hutchinson 1957, McCullough 1980, Krebs 1989:371), and “a species’ niche might be restricted in practice by habitat: parts of a species’ niche ... which are simply not present at a particular location...” (Begon and Mortimer 1986:76). Moreover, increased vertical and horizontal complexity of vegetation and down wood may affect ecological processes, as well as allow coexistence of an abundance of potentially competing species within communities (Carey and Johnson 1995, Carey and Harrington 2001). Increased complexity thus leads to increased stability (*sensu* resilience) in ecological systems (May 1973, van Voris et al. 1980, Tilman 1999). Consequently, fuels treatments that result in heterogeneous habitats due to

incongruent amounts of a habitat component (e.g., fuels cover) may give rise to similar numbers of individuals among species (high species evenness).

Population Responses

Survival

Few studies have examined the influence of down wood cover on small mammal survival (Manning and Edge in review). Small mammals have likely adapted to use cover in ways that enhance their reproduction and/or survival (Bailey 1984), although Cox et al. (1997) did not detect a significant effect of supplemental cover on survival of two leporids in Wisconsin. Fuels provide structural diversity that may function as cover on the forest floor that can influence survival of small mammals.

Density

Population abundance has been the most extensively investigated population parameter relative to prescribed fire (Lyon et al. 2000), but most of the literature describing effects of fire on small mammal populations deals primarily with stand-replacement and mixed-severity fires (Ream 1981); none have examined effects of fuels management. While responses to fire can be positive or negative (Ream 1981), studies have shown a positive relationship between vegetation cover and the presence (Butts and McComb 2000) and abundance (Sullivan 1980) of some small mammals.

Individual Responses

Fuels use

Various types of down wood cover are widely sited for their use by small mammals (Hayes and Cross 1987, Maser et al. 1978, Steel et al. 1999). Logs are used more than they are available by western red-backed voles (*Clethrionomys californicus*)

(Tallmon and Mills 1994), and higher numbers of small mammals have been reported to occur in piles of wood debris compared to areas without piles in riparian areas (Steel et al. 1999). Nonetheless, no studies have examined small mammal responses to different amounts of and distances from fuel piles.

Distance from unburned fuel piles

By providing foraging, travel, escape, shelter, and resting habitat for small mammals (Bailey 1984:111), fuels may influence ecological processes such as competition, predation, and variations in food resources that effect individuals at the microhabitat scale (Doyle 1987). These processes are known to influence animal numbers as well as home range size (Morrison et al. 1998). If small mammals use unburned piles differently than expected by chance (acceptance of the fuels-use hypothesis for unburned piles), then small mammal locations and home range sizes should be a function of distance from unburned piles.

SMALL MAMMAL RESPONSES TO SILVICULTURAL FUELS TREATMENTS IN SOUTHWEST OREGON.

INTRODUCTION

The field of fire management has undergone a paradigm shift from fighting fires to using prescribed fire to restore a semblance of the natural fire and ecosystem processes (Brown and Arno 1991, Mutch 1994, Arno 1996). Silvicultural fuels management, hereafter referred to as fuels management, is the use of prescribed fire to burn accumulated fuels (twigs, branches, and stems < 10 cm in diameter) that fall from trees and shrubs following a silvicultural treatment (Harmon and Sexton 1996, Pyne et al. 1996) such as thinning (Walstad et al. 1990). Fuels management is intended to reduce accumulated fuels that make forests vulnerable to wildfire (Wickman 1992, Mutch et al. 1993), and is supported and funded under the Federal Wildland Fire Management Policy (FWFMP) (U.S. Department of Interior [USDI] and U.S. Department of Agriculture [USDA] 2001). Despite the belief that fuels management is necessary to restore forests (Miller and Bigley 1990, USDA 1996), its effects on wildlife has received little attention in the scientific literature and in reports proposing prescribed burning as the primary means for solving forest health problems (Gast et al. 1991, Wickman 1992, Everett et al. 1993, Mutch et al. 1993). Without this information, we cannot fully understand how fuels management affects forest ecosystems.

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Silvicultural fuels may function as cover for small mammals by providing breeding, foraging, travel, escape, nesting, shelter, and resting habitat (Bailey 1984:111) that are important in the life histories of these species. Pasitschniak-Arts and Messier (1998) reported that small mammals were more abundant in areas supporting relatively dense nesting cover, Harmon et al. (1986) found small mammals associated with piles of vegetation, and Maser and Sedell (1994) and Steel et al. (1999) showed that small mammals used natural wood piles in riparian areas. Orrock et al. (2000) attributed the suitability of southern red-backed vole (*Clethrionomys gapperi*) habitat in the Southern Appalachian Mountains to the abundance of small twigs and branches, similar to that comprised in silvicultural fuels. Manning and Edge (in review) found that deer mouse (*Peromyscus maniculatus*) and creeping vole (*Microtus oregoni*) survival was related to down wood at the scale of micro-sites in the central Oregon Coast Range.

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Until recently (Kaufman et al. 1982, Schwilk and Keeley 1998, Ford et al. 1999), few studies of wildlife responses to fire investigated effects at the scale of populations, and none have explicitly investigated the response of small mammal density and survival to fuels management. As federal land managers implement the Northwest Forest Plan (U.S. Forest Service [USFS] and U.S. Bureau of Land Management [BLM] 1994a) and the FWFMP (USDI and USDA 2001) in the Pacific Northwest, it is crucial to incorporate consideration of small mammal responses to fuels management into forest management plans. The purpose of this study was to determine community, population, and individual responses of small mammals to 3 different fuels treatments 1 year following treatments in

commercially thinned Douglas-fir (*Pseudotsuga menziesii*) forests in southwest Oregon. I predicted that small mammal species richness, evenness, survival, and densities would be highest where fuels treatments provide the greatest amount of cover. I hypothesized that small mammals would use trap sites with high fuels cover or unburned piles greater than expected by chance, sites with intermediate levels of fuels cover equal to expected, and sites with low amounts of cover less than expected. Lastly, I predicted that if small mammals used unburned piles greater than expected by chance, their numbers would be highest and home ranges smallest at sites closest to unburned piles, and if they used unburned piles significantly less than expected, numbers would be lowest and home ranges largest at sites closest to piles.

STUDY AREA

This study was conducted in 3 forest stands located on public lands administered by the Bureau of Land Management (BLM) in the Applegate Adaptive Management Area (AAMA), 17 km southwest of Medford, Oregon (Figure 1). The AAMA lies on the eastern escarpment of the Siskiyou Mountains within the Klamath Mountains Geological Province, which straddles the Oregon-California border (Franklin and Dyrness 1988). Unlike temperate ecosystems to the north, the Klamath Province lies within the mediterranean systems more characteristic of California. A higher diversity of plant species, reduced forest structure, and lower process rates (particularly disturbance processes) occur relative to the temperate, northerly provinces (Franklin and Dyrness 1988). Soils in the study area are reddish-brown loams with clay loam subsoils (Franklin and Dyrness 1988). Topography is deeply folded and faulted, with elevations ranging from 600-1,200 m.

The climate is hot and dry, with annual precipitation ranging from 60-170 cm, most (> 80%) of which falls during winter (Verts and Carraway 1998:23). Cold air masses provide snow and rainfall during winter, and tropical storms are a source of summer rainfall (Franklin and Dyrness 1988). The average minimum and maximum

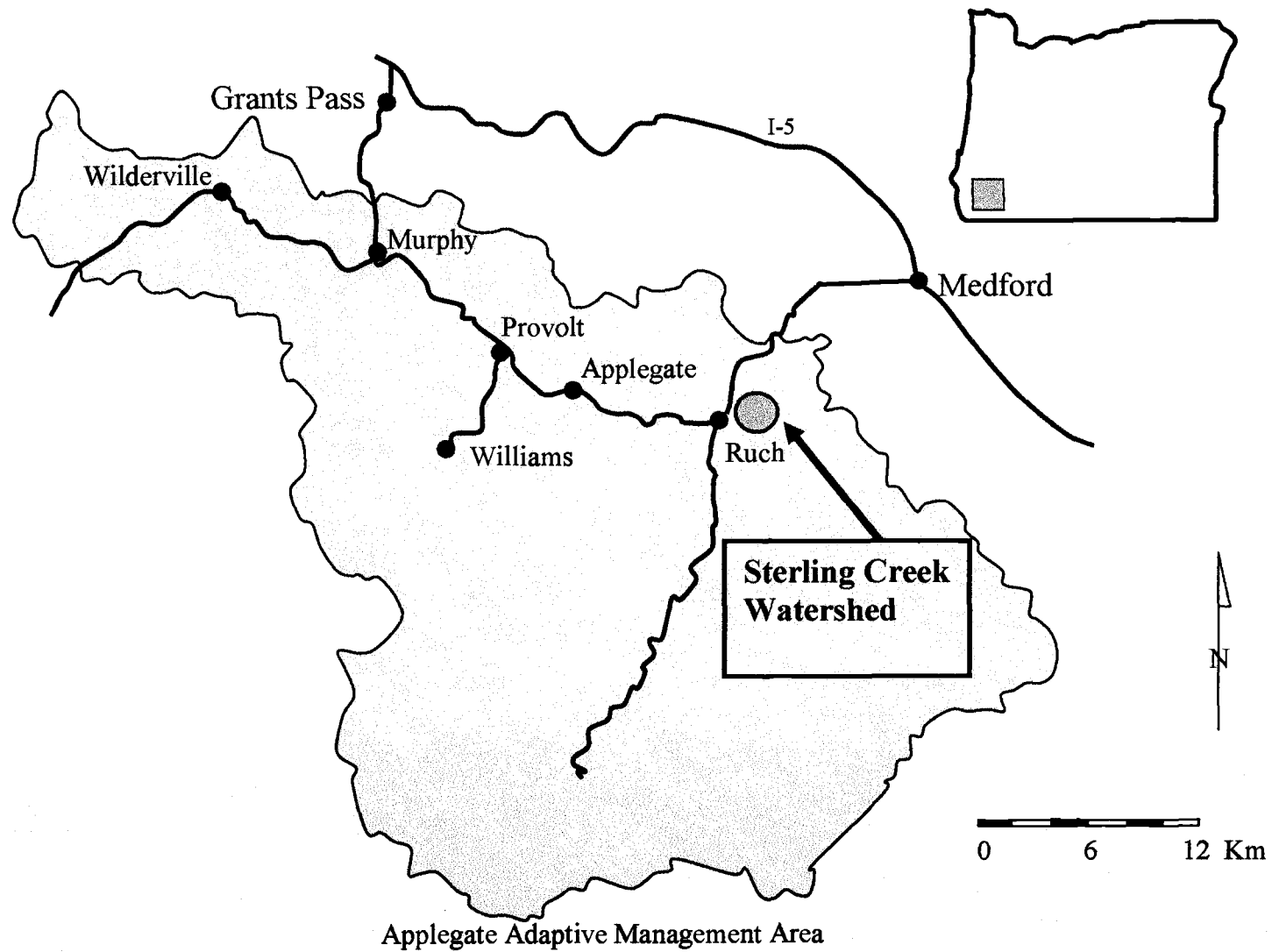


Figure 1. Study area for small mammal silvicultural fuels study in Jackson County, Oregon.

daily temperatures during the 1999 summer season were 10.7 °C and 31.4 °C respectively; in 2000 they were 10.9 °C and 29.6 °C.

The 3 forest stands studied were located in Armstrong, lower Deming, and upper Deming gulches within the Sterling Creek Watershed (Figure 1) and lie within the Province's mixed-evergreen zone (Franklin and Dyrness 1988). This zone is characterized by tanoak (*Lithocarpus densiflorus*), canyon live oak (*Quercus chrysolepis*), madrone (*Arbutus menziesii*), Douglas-fir, sugar pine (*Pinus lambertiana*), and Jeffrey pine (*Pinus jeffreyi*) (Franklin and Dyrness 1988). Presently, forest management practices in the study area include thinning through the selective removal of trees and shrubs and the reintroduction of fire (USFS and BLM 1994a, 1994b).

After thinning, 3 primary categories of tree densities are present in the study area (BLM 1996), the most prevalent being 124 trees/ha after the density of overstory trees was reduced by 37-43%. After thinning, Douglas-fir and madrone were the dominant trees and snowberry (*Symphoricarpus albus*), trailing snowberry (*Symphoricarpus mollis*), ocean spray (*Holodiscus discolor*), and poison oak (*Toxicodendron diversilobum*) were the dominant woody shrub species. Physiognomy of understory vegetation varied within stands due to scarring, uprooting, and clearing caused by thinning. Ten native species characterize the mammalian fauna across the Province, 6 of which are small mammals (Verts and Carraway 1998:28).

The fire regime in the study area has been altered, with 5 fire cycles being eliminated through fire suppression (Thomas and Agee 1986). This has led to high volumes of vegetation and dead wood on the forest floor compared to a century ago (BLM 1996). Following thinning in the study area, fuels are commonly hand-piled and burned (hereafter referred to as burned piles) when fuels are >26 kg/ha, broadcast burned when <26 kg/ha occur, or lopped and scattered when volumes are much lower (G. Chandler, BLM, pers. comm.). Pile dimensions are roughly 3 m in diameter and 1-2 m in height, and densities range from 12-37 piles/ha; piles are burned in the spring and fall. Burned piles and lop and scatter are the 2 most commonly used methods of treating fuels in the study area.

METHODS

Experimental Design

I used a randomized complete block design (RCBD; Sokal and Rohlf 1981:348) to compare responses of small mammals to 2 methods of fuels management (burned and unburned piles) plus a control treatment of lop and scatter fuels following thinning. Three Douglas-fir forest stands (blocks) were randomly selected along an elevation-climatic gradient from cool and moist low-elevations to warm and dry high-elevation forests where they were thinned to 124 trees/ha. Thus, I sampled along a range of conditions within the most prevalent of the 3 categories of tree densities in the study area (BLM 1996). Additionally, blocks were selected that were ≥ 5.1 ha and ≥ 130 m wide to ensure that each could support 3 0.8-ha study plots, each with a ≥ 20 -m buffer, providing a total of 9 study plots.

Each plot contained a 9 x 11 grid of trap stations spaced at 10-m intervals. Spacing was based on 4 trap stations per home range (Otis et al. 1978, White et al. 1982) for the California vole [*Microtus californicus*]; Ostfeld 1986, Verts and Carraway 1998:311-317), which was expected to have the smallest home range size in the study area. To minimize direct (Murcia 1995) and indirect (reviewed in Kremsater and Bunnell 1999) effects of habitat edges on small mammals (Mills 1995), study plots were buffered from streams, roads, adjacent treatment areas, and forest-stand boundaries by ≥ 20 m.

Fuel Treatments

Blocks were thinned with chain saws in April 1999 using draglines and skip loaders. Disturbance to surface soils and understory vegetation was assumed to be similar across experimental units. I randomly allocated the 3 fuels treatments to each study plot within a block without replacement. Fuels were hand-piled in October and burned in November 1999. The density of piles remaining in the unburned pile treatment ranged from 22-42/ha. The lop and scatter treatment represented baseline conditions

before fuels were treated after thinning in all experimental units, and was considered a fuels treatment control.

Animal Sampling

I used mark-recapture methods (White et al. 1982) conforming to Pollock's robust design (Pollock 1982, Pollock et al. 1990) to sample small mammals under 2 conditions during summer because this season is generally when small mammal populations in the study area exhibit peak reproduction and densities. The conditions were: (1) before fuels treatments (5 4-day trapping sessions separated by 4 10-day survival intervals, 28 June to 30 August 1999) and (2) 8 months after treatments (5 4-day trapping sessions with 4 10-day survival intervals, 24 June to 22 August 2000). Sampling before fuels were treated provided a population-level baseline so that differences in geographic variation among the study plots prior to treatments would be accounted for in determining treatment effects.

One Sherman live-trap (7.6 x 8.9 x 22.9-cm) covered with a cardboard shelter was placed at each of the 99 trap sites within a study plot. Traps were locked open and prebaited with whole rolled oats and raw sunflower seeds for 7-10 days before each trapping session to increase capture rates (White et al. 1982). During sampling, traps were supplied with bait and polyester batting. Trapping involved setting traps in the evening, checking them in the morning, and closing them during the day to reduce mortality due to extreme daytime temperatures. Newly captured animals were marked with individually numbered Monel fingerling tags (National Band and Tag Co., Newport, Kentucky) in 1 ear, and identification of recaptures was recorded. Captured animals, except shrews (identified to genus; *Sorex* spp.) and chipmunks (*Tamias* spp.) were identified to species, gender, reproductive condition (scrotal, non-scrotal, pregnant, non-pregnant), and age class (adult, juvenile) and released at the capture site. Capturing and handling conformed to the guidelines established by the American Society of

Mammalogists (1998) under a protocol approved by Oregon State University, Institutional Animal Care and Use Committee.

Habitat Sampling

Although the lopped and scattered fuels represented the baseline condition across all 9 experimental units during the pre-treatment period, the initial amounts of understory vegetation and fuels were expected to vary among sampling plots. Because thinning may produce undesirable, unintended consequences for plant communities and small mammals (Carey 2000, Thysell and Carey 2000, Wilson and Carey 2000), I suspected that these initial amounts might influence the magnitude of the response by small mammals after fuels were treated. Thus, I sampled herb/grass and woody shrub cover before and after treatments and fuel volumes before treatments in each plot.

I used point intercepts at 3-m intervals along 3 evenly spaced 100-m line transects to sample vegetation in each plot (Bonham 1989). Herb/grass and shrub cover was calculated as percent cover (no. of points present / 99 points x 100) at the plot-level.

Fuels were sampled along 15 evenly spaced 12-m sampling line-intercepts that extended out in random directions from the vegetation transects following methods described by Brown (1974), and volumes (m^3/ha) were calculated at the plot-level. This method did not result in an asymptotic relationship between fuel volume and the number of line-intercepts, suggesting that higher volumes were present than recorded. Thus, I considered fuel volumes as an index of relative difference among study plots.

I recorded percent cover of lopped and scattered fuels and the presence of unburned piles at trap sites in the 3 plots that received the unburned pile treatment. I recorded this information in these plots because only they had they a combination of unburned piles and some residual lopped and scattered fuels that were not treated. I divided the 100 m^2 square area centered on each trap into 4 quadrants, and used percent cover classes to visually estimate fuels cover (Daubenmire 1959): Class 1 (0% lopped and scattered), Class 2 (1-25% lopped and scattered), Class 3 (26-50% lopped and

scattered), Class 4 (51-75% lopped and scattered), and Class 5 (76-100% lopped and scattered). Sites with unburned piles were assigned to Class 6. I also measured distance (m) from each trap site to the nearest unburned pile as a continuous variable. I averaged fuels cover-class estimates (%) for each trap site, rather than using the cover class midpoints (%), because this approach approximates an arcsine-square-root transformation of the data, improving normality and homogeneity of variances among cover classes (Muir and McCune 1988).

DATA ANALYSES

I followed a 2-step process for analyzing treatment effects on community- and population-level responses. First, I estimated the richness and evenness of species and survival and density of populations within study plots before and after treatments, and then used these estimates in replication-based testing of treatment effects where statistical inferences could be made based on my experimental design. I also analyzed the response of individuals within a species to the amount and distribution of fuels.

Community Responses

Species richness and composition

I used the rarefaction method (Sanders 1968) to compute a single estimate of species richness for pre- and post-treatment periods in each study plot. The rarefaction method standardizes sample sizes to overcome the problem of comparing communities with different sample sizes (Sanders 1968). Because the rarefaction method is restricted by the inability to extrapolate its curves beyond the number of species in the sample (Krebs 1989:335), I used the fewest observed number of species among study plots as a standard for estimating richness so that comparisons were possible. Estimates of species richness were computed using Program RAREFACT (Krebs 1989:569-571).

Species evenness

Species evenness was estimated for pre- and post-treatment periods in each study plot using the V' Evenness Measure (Hurlbert 1971). The V' Evenness Measure calculates evenness by dividing a diversity index by the maximum possible index of diversity, given S species and N individuals (Krebs 1989:363). I used the reciprocal of Simpson's diversity index to calculate the V' Evenness Measure (Williams 1964, MacArthur 1972, Krebs 1989:363-367) because it is a *Type II* index sensitive to changes in the more abundant species (Peet 1974). I used program DIVERS (Krebs 1989:581-584) to obtain estimates of species evenness.

Population Responses

Survival

I used mark-recapture analysis to estimate apparent survival rates (Φ) of each small mammal species separately in each plot. Species that had low numbers of first captures and recaptures were excluded because small sample sizes can lead towards biased, imprecise estimates (Lebreton et al. 1992). Small sample sizes in the remaining species (see Results) did not allow for using Pollock's robust design model (Pollock 1982, Pollock et al. 1990) or partitioning data among age classes, reproductive conditions, or gender. This led to combining adult, juvenile, male, and female animals and estimating parameters as if all animals were the same age and sex. I fit Cormack-Jolly-Seber models (Cormack 1964, Jolly 1965, Seber 1965) available in program MARK (White and Burnham 1999) to the mark-recapture data by considering animals captured at least once in a study plot during a biweekly trapping session as present. In mark-recapture studies of geographically open animal populations, the estimate of apparent survival probability reflects both mortality and emigration (e.g., Lebreton et al. 1992), hence Φ is the probability that the animal is alive and remains on the study area to be available for recapture.

I developed 4 *a priori* models to estimate survival rates for each study plot and treatment period (See RESULTS). Each survival model represented an alternative hypothesis for testing whether or not probabilities of apparent survival and recapture (P) varied through time. My most general structure of survival and recapture parameters was time-specific probabilities, denoted as $\Phi(t)$, $P(t)$ = survival and recapture probabilities varied with time. I assessed goodness-of-fit for the global model using 1,000 bootstrap simulations in program MARK (White and Burnham 1999) to evaluate the likelihood of the observed deviance (White and Burnham 1999). Model selection was carried out for each study plot and treatment period separately and was based on Akaike weights (w) using the small-sample corrected Akaike's Information Criterion (AICc) (Akaike 1973, Burnham and Anderson 1998:221).

Density

Information from the 5 biweekly trapping sessions was used to estimate population abundance (N_t) for each 4-day trapping session using mark-recapture data and program CAPTURE (Rexstad and Burnham 1992). Births, deaths, emigration, and immigration are considered to be negligible during this period (White et al. 1982); therefore, the design was intended to meet the assumptions of closed population estimation procedures.

My sample sizes for each species were too small to carry out the model selection procedure in CAPTURE (Otis et al. 1978, Rextad and Burnham 1992). I used the jackknife estimator (Burnham and Overton 1978, 1979) for all plots because it is recommended for estimating population size (Otis et al. 1978, White et al. 1982), frequently used (Greenwood et al. 1985, Hallett et al. 1991, Rosenberg and Anthony 1992, 1993), considered 1 of the most robust estimators for closed populations (Otis et al. 1978), and was found to be less biased and variable than the moment estimator when few animals were captured >2 times (Chao 1988, 1989, Rosenberg et al. 1995), as was the case in this study. I used the first-order jackknife estimator because the jackknife

selection procedure in CAPTURE is sensitive to the number of new captures and recaptures when sample sizes are small (Rosenberg et al. 1995).

I computed estimates of absolute density rather than relative abundance because only the former provides a number of animals per standardized unit area desired for comparisons (Krebs 1989:11-12), such as among fuels treatments. I did not have the large sample sizes necessary for using the nested-subgrid routine in program CAPTURE (Otis et al. 1978, Rexstad and Burnham 1992) to compute density estimates (Appendix 1); thus, I used $\frac{1}{2}$ the mean maximum distance moved (MMDM) output from program CAPTURE (Otis et al. 1978, Rexstad and Burnham 1992) to estimate density using the effecting trapping area (Dice 1938, 1941, Wilson and Anderson 1980). Although the boundary strip width is often correlated with the number of recaptures (Stickel 1954, Tanaka 1972), sufficient numbers of captures in live traps can give average estimates of observed-range length and home range similar to those from radiotracking (Desy et al. 1989). Additionally, density estimates obtained by the MMDM are less biased than naive estimates (Wilson and Anderson 1985).

Replication-based testing of treatment effects

I estimated community and population responses within each plot separately to minimize bias and maximize precision, and used them in replication-based testing of treatment effects where statistical inferences could be made based on my experimental design. The replicated study design used the before and after treatment conditions to avoid the masking of treatment effects by pre-existing geographic variation.

The design had 3 replicates (blocks) with 3 treatments per replicate. In the most general case where within-plot modeling provided separate estimates for each biweekly trapping session (time effects) before and after treatments, I used a RCBD model where treatments and treatment periods were main effects, study plots were in randomized blocks (Littell et al. 1996:2-13), and the biweekly trapping sessions were repeated measures through time within each study plot (Littell et al. 1996:87-134). For models

based on parameter estimates that were found to vary among biweekly periods in my within-study-plot analysis, I used AICc to compare 4 variance-covariance matrix structures for each parameter (Littell et al. 1996:92-102), and determined that the first order autoregressive covariance structure was the appropriate matrix structure for each model. After each model was run with the appropriate matrix structure, I removed non-significant ($P > 0.25$) interaction terms between main effects and reran the reduced model.

For parameters that did not have biweekly estimates within plots (e.g., species richness and evenness), I used the difference between estimates obtained before and after treatments as response variables. I suspected that the magnitude of the difference before and after treatments among plots may be attributed to variation in the before-treatment estimates of the corresponding parameter and the amounts of herb/grass cover and fuels volume that were uncontrollable in the experimental design. Fuel volumes were negatively correlated with herb/grass cover ($P = 0.01$, $R^2 = -0.79$) and shrub cover ($P = 0.08$, $R^2 = -0.61$); thus, I only used the initial fuels volumes and parameter estimates from before treatments as covariates in an analysis of covariance (ANCOVA; Steel et al. 1997:429-459). Where no relationship occurred between fuels treatments and both covariates, I used a RCBD model as a reduced model to test for treatment effects.

I transformed western red-backed vole density using $\log_{10}(x+1)$ to correct for unequal variances. For all other analyses, untransformed estimates were used because assumptions of normality and constant variance were met. I tested for main effects and interactions with covariates using standard F -tests (Steel et al. 1997). All significance levels were set at $\alpha = 0.1$ to balance Type I and Type II errors because population experiments often result in sampling error and heterogeneity in animal abundance that contribute to a large error variance (Skalski and Robson 1992), resulting in low power (Schauber and Edge 1999). I used the PROC MIXED procedure in SAS 8.01 (SAS Institute Inc. 2000) for replication-based testing of treatment effects on community and population parameters and included the blocking effect in all models.

Individual Responses

Fuels use

I used the Bonferroni utilization test (Neu et al. 1974) to evaluate small mammal use of the 6 fuels cover categories recorded in the 3 plots that received the unburned pile treatment. This statistical procedure tests for significant differences between expected and observed frequency data, while adjusting for unequal sample sizes among the categories. The expected values were the number of stations in each fuels cover category, and observed values were the total number of individuals of a species captured at stations within each category. I used the total number of individuals captured at stations and restricted the number of categories to the 6 fuels categories to avoid Type II errors that can occur from small sample sizes or a large number of resource categories (Aldredge and Ratti 1986). The significance level was held at 0.1.

Distance from unburned fuel piles

I used simple linear regression to examine the relationship between distance from unburned piles (independent variable) and the average number of individuals captured. Because I was interested in portraying the general underlying biological pattern, I smoothed these data by calculating the average number of individuals captured in traps within each 1-m trap-distance interval (Velleman and Hoaglin 1981). This method provides an average number of individuals captured at 1-m intervals, and is thus not influenced by unequal numbers of traps at each interval.

Simple linear regression was also used to examine the relationship between distance from unburned piles and MMDM. I used MMDM as an index of average home range size for animals captured ≥ 2 times because home ranges calculated from trapping grid data are significantly correlated with radiotelemetry-derived home ranges (Ribble et al. 2002), and MMDM is comparable to Dice's (1938, 1941) method of estimating the diameter of an average home range. I smoothed these data by calculating the average MMDM among all individuals captured in traps within each 1-m trap-distance interval

(Velleman and Hoaglin 1981). In both analyses, R^2 -values were used as an indication of the percentage of variation explained by the independent variable, and linear and \log_{10} models were fitted to the data to determine the form of the relationship. Regression analysis was carried out using the PROC REG procedure in SAS 8.01 (SAS Institute Inc. 2000).

RESULTS

My field experiment was based on a randomized block design with blocks randomly selected along a range of conditions within the most prevalent of the 3 categories of tree densities in the study area (BLM 1996). Although not significant (all P -values > 0.195), blocking was effective in that blocks explained some of the variation in all of the community- and population-level analyses (all F -values > 1.43).

Fuels Treatments

Herb/grass cover ranged from 35 to 71% among plots before and 48.4 to 84.7% after treatments, and shrub cover ranged from 19.2 to 65.5% before and 17.1 to 67.3% after (Table 1). Fuel volumes varied from 4.8-10.7 m³/ha before treatments (Table 1), indicating that some plots had roughly twice the volume of fuels. Burned and unburned pile treatments reduced fuel volumes within study plots as much as 83%. Additionally, unburned piles produced clumped distributions with densities ranging from 22 to 42 piles/plot. Burned piles also caused qualitative changes in the soils and understory vegetation. Burned piles left a patch of forest floor containing no organic matter, little understory vegetation, and a high amount of ash. Understory vegetation cover increased in all plots by August 2000, although the burned patches of forest floor in the burned pile treatment plots remained barren.

Table 1. Vegetation cover and fuels volume prior to fuels treatments in 9 study plots (3 replicate study plots per treatment) in the Applegate Adaptive Management Area, Jackson County, Oregon 1999-2000.

Fuels treatment	Replicate no.	Before treatment			After treatment	
		Herb/grass cover (%)	Shrub cover (%)	Fuels volume (m ³ /ha)	Herb/grass cover (%)	Shrub cover (%)
Lop and scatter	1	43.1	19.4	10.5	65.1	21.2
Lop and scatter	2	60.0	60.4	6.7	53.7	64.1
Lop and scatter	3	46.3	65.5	8.0	58.6	67.3
Unburned pile	1	45.9	19.2	7.9	52.5	17.1
Unburned pile	2	34.9	42.4	10.7	60.0	53.5
Unburned pile	3	37.8	35.9	9.8	48.2	35.9
Burned pile	1	55.3	26.5	8.7	84.7	37.5
Burned pile	2	53.3	65.5	4.8	74.1	59.4
Burned pile	3	71.2	49.0	5.4	66.3	59.6

Community Responses

Species richness and composition

I captured 593 individual small mammals representing 15 species (Appendix 1). Species richness ranged from 4.61 to 6.90 species among plots during the pre-treatment period. I used a single estimate of species richness in each treatment period in the ANCOVA model to test if fuels treatments were a determinant of species richness. I did not detect interactions between the change in species richness and initial species richness or fuels volume (all $P > 0.21$, Appendix 2). I found no significant difference in richness among treatments ($F_{2,4} = 1.32$, $P = 0.36$ and overlapping 90% confidence intervals, Figure 2). Thus, I found no evidence to support my hypothesis that species richness would be higher where fuel treatments provided the greatest amount of cover across the forest floor.

Although the change in species richness was similar among treatments, species composition changed between treatment periods for each treatment (Appendix 1). In the lop and scatter treatment plots, the creeping vole and California ground squirrel (*Spermophilus beecheyi*) were present only before fuels were treated, whereas the northern flying squirrel (*Glaucomys sabrinus*) and shrews were captured only after treatments. In the burned pile treatment plots, the California ground squirrel was captured only before treatments, and the dusky-footed woodrat (*Neotoma fuscipes*), piñon mouse (*Peromyscus truei*), and shrews were present only after treatments. I also found that the harvest mouse (*Reithrodontomys megalotis*) was absent and the northern flying squirrel, shrew-mole (*Neurotrichus gibbsi*), and shrews were present after fuels were treated in the unburned pile treatment plots. Shrews were the only species absent from all treatments before treatments but occurred in high numbers (28-30 total captures) in all treatments after treatments.

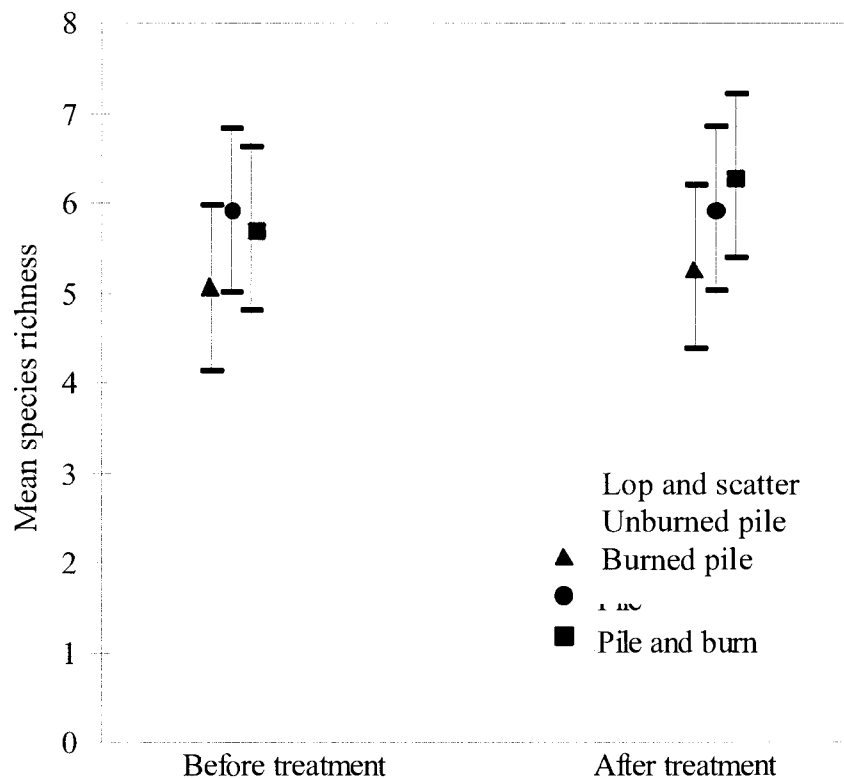


Figure 2. Small mammal species richness before and after 3 silvicultural fuels treatments in the Applegate Adaptive Management Area, Jackson County, Oregon, 1999-2000. Vertical bars represent 90% confidence intervals around mean species richness based on the rarefaction method (Sanders 1968).

Species evenness

High species evenness before fuels were treated (V' ranging from 0.75 to 0.84 among plots) suggested that individuals were evenly distributed among species in all plots. The deer mouse ($n = 243$ individuals) and western red-backed vole (*Clethrionomys californicus*) ($n = 120$ individuals) were the most common species accounting for 41% and 20% of all individuals captured, respectively. Shrews were present only after fuels were treated with 87 total captures. Chipmunks were less common, with 54 total captures. Evenness did not vary with any of the covariates ($P > 0.16$, Appendix 3), nor did I detect a difference among treatments with the randomized block design model ($F_{2,4} = 0.31$, $P = 0.75$, Appendix 3, Figure 3). The similarity in species evenness among treatments did not conform to my prediction that evenness would be lowest where fuels treatments provided the lowest amount of horizontal cover across the forest floor.

Population Responses

Population responses were modeled only for the deer mouse and western red-backed vole because samples from the other 13 species were insufficient. Combined, these two species represented 76% of all captures and recaptures ($n = 2,596$), of which the deer mouse represented 59% ($n = 1,538$).

Survival

Survival was modeled only for deer mice because it was the only species that was present in all replicates of each treatment. High recapture probabilities resulted in precise estimates of deer mouse survival (Table 2). The survival models with the highest likelihoods were those that constrained recapture probabilities and apparent survival rates to be constant among trapping sessions (all $w_i > 0.44$, Table 2). High recapture probabilities in study plots before ($P > 0.77$) and after ($P > 0.81$) treatments provided

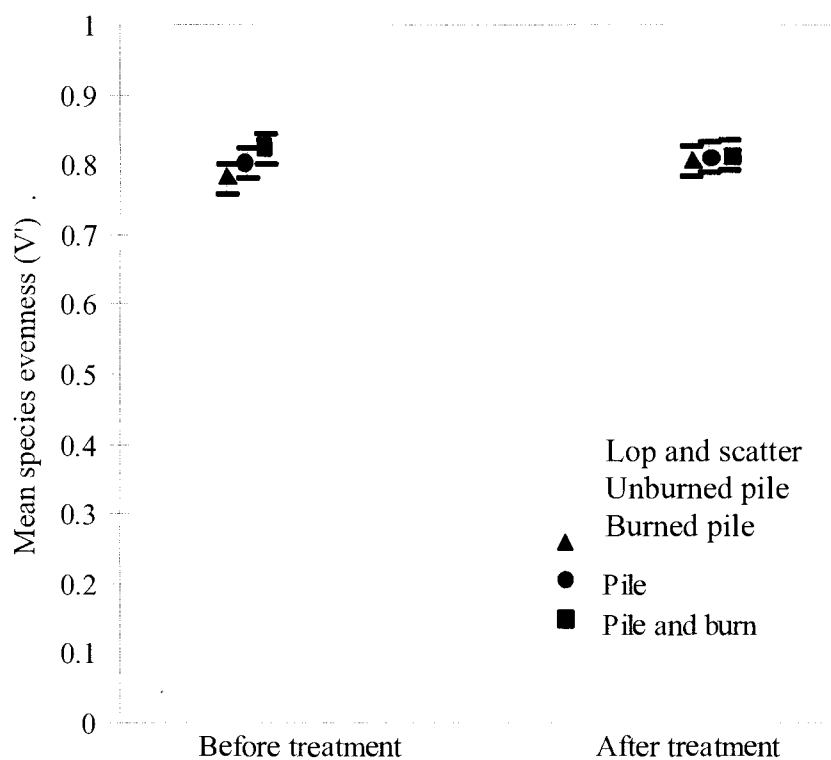


Figure 3. Small mammal species evenness before and after 3 silvicultural fuels treatments in the Applegate Adaptive Management Area, Jackson County, Oregon, Oregon 1999-2000. Vertical bars represent 90% confidence intervals around mean species evenness based on the inverse of Simpson's diversity index (Hurlbert 1971).

Table 2. Model description for best models and results of survival analyses for the deer mouse in response to 3 silvicultural fuels treatments in the Applegate Adaptive Management Area, Jackson County, Oregon 1999-2000.

Silvicultural treatment (before and after, replicate no.)	Model ^a	AICc Weight (w _i) ^b	ϕ	SE
Lop and scatter (before, rep 1)	$\Phi(.), P(.)$	0.858	0.839	0.066
Lop and scatter (before, rep 2)	$\Phi(.), P(.)$	0.916	0.667	0.086
Lop and scatter (before, rep 3)	$\Phi(.), P(.)$	1.000	1.000	0
Lop and scatter (after, rep 1)	$\Phi(.), P(.)$	0.974	0.591	0.105
Lop and scatter (after, rep 2)	$\Phi(.), P(.)^c$	0.453	0.834	0.069
Lop and scatter (after, rep 3)	$\Phi(.), P(.)$	0.993	0.946	0.067
Unburned pile (before, rep 1)	$\Phi(.), P(.)$	0.951	0.759	0.085
Unburned pile (before, rep 2)	$\Phi(.), P(.)$	0.957	0.808	0.077
Unburned pile (before, rep 3)	$\Phi(.), P(.)^d$	0.442	0.700	0.145
Unburned pile (after, rep 1)	$\Phi(.), P(.)^d$	0.529	0.745	0.090
Unburned pile (after, rep 2)	$\Phi(.), P(.)$	0.919	0.793	0.095
Unburned pile (after, rep 3)	$\Phi(.), P(.)$	0.760	0.945	0.149
Burned pile (before, rep 1)	$\Phi(.), P(.)$	0.939	0.857	0.076
Burned pile (before, rep 2)	$\Phi(.), P(.)$	0.935	0.760	0.085
Burned pile (before, rep 3)	$\Phi(.), P(.)$	0.881	0.827	0.091
Burned pile (after, rep 1)	$\Phi(.), P(.)$	0.919	0.705	0.089
Burned pile (after, rep 2)	$\Phi(.), P(.)$	0.842	0.833	0.068
Burned pile (after, rep 3)	$\Phi(.), P(.)$	0.958	0.810	0.087

^a Based on comparing 4 models using Akaike weights (Burnham and Anderson 1998): 1) $\Phi(.), P(.)$ with 2 parameters, H_0 : survival and recapture probability constant among individuals; 2) $\Phi(t), P(.)$ with 5 parameters, H_0 : survival varied with time and common recapture probability; 3) $\Phi(.), P(t)$ with 5 parameters, H_0 : survival constant and recapture probability varied with time; and 4) $\Phi(t), P(t)$ with 8 parameters, H_0 : survival and recapture probability varied with time, model $\Phi(.), P(.)$ constantly had the highest likelihood.

^b Akaike's weights, an estimate of the likelihood of the model within the set of models considered (Burnham and Anderson 1998), based on the small-sample size corrected Akaike Information Criterion (AICc).

^c Selected this model over competing model $\Phi(t), P(.)$, based on Principle of Parsimony (Burnham and Anderson 1998).

^d Selected this model over competing models $\Phi(t), P(.)$ and $\Phi(t), P(t)$, based on Principle of Parsimony (Burnham and Anderson 1998).

evidence that most marked deer mice were observed if present in study plots. I found that apparent survival rates of deer mice ranged from 0.59 (± 0.11 SE) to 1.0 (± 0 SE) among plots before treatments and 0.705 (± 0.09 SE) to 0.96 (± 0.15 SE) after treatments (Table 2).

The lack of time effects within treatment periods still allowed for using the change in survival from before to after treatments for testing my hypothesis of primary interest. Based on the inference of no time effects on apparent deer mouse survival within treatment periods, I used the single survival estimate in each treatment period in the ANCOVA model. Initial survival rates did not affect the magnitude of change in survival between before- and after-treatment periods (all P -values for interactions between the change in survival and the fuels volume > 0.44 , Appendix 4). I found no difference in deer mouse survival among treatments ($F_{2,4} = 0.78$, $P = 0.52$ and overlapping 90% confidence intervals, Figure 4) in using the reduced randomized block design model. The relationship between mean deer mouse survival and fuels cover did not conform to my prediction that treatments would be a determinant of survival, and that survival would be higher where fuels treatments provided the greatest amount of cover across the forest floor.

Density

I used the biweekly density estimates derived from combining the age classes and gender in the within-plot modeling for estimating deer mouse and western red-backed vole densities. For the deer mouse, I found no effect of treatment by treatment period and biweekly session ($F_{8,24} = 0.54$, $P = 0.82$), treatment by treatment period ($F_{2,6} = 0.26$, $P = 0.78$), treatment by biweekly session ($F_{8,24} = 0.48$, $P = 0.86$), or treatment period by biweekly session ($F_{4,24} = 0.83$, $P = 0.52$) interactions on density based on the randomized block design model with repeated measures. After removing these interactions from the model, I detected no effect of treatments ($F_{2,6} = 0.60$, $P = 0.58$) or treatment period

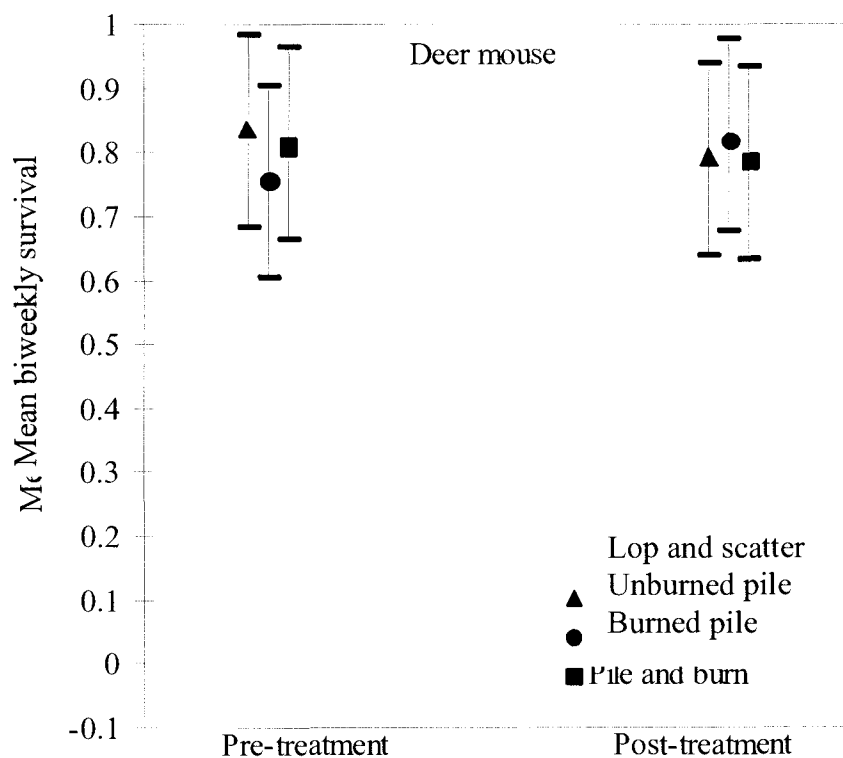


Figure 4. Mean biweekly survival of the deer mouse before and after 3 silvicultural fuels treatments in the Applegate Adaptive Management Area, Jackson County, Oregon 1999-2000. Vertical bars represent 90% confidence intervals.

($F_{1,8} = 0.00$, $P = 0.95$), though density differed between biweekly sessions ($F_{4,32} = 3.32$, $P = 0.02$, Appendix 5), with density increasing nearly 80% through time (Figure 5). Thus, I found no evidence to support my hypothesis that deer mouse density would be greatest where fuels treatments provided the highest amount of cover across the forest floor.

The western red-backed vole was absent from two study plots before and after treatments. Based on the randomized block design model with repeated measures, there was no effect of treatment by treatment period and biweekly session ($F_{8,24} = 0.24$, $P = 0.98$), treatment by treatment period ($F_{2,6} = 0.34$, $P = 0.72$), or treatment by biweekly session ($F_{8,24} = 0.61$, $P = 0.76$) interactions on western red-backed vole density. After removing these interactions from the model, I found evidence that the treatment period by biweekly session interaction was significant ($F_{4,32} = 2.16$, $P = 0.09$, Appendix 6). Western red-backed vole densities steadily increased throughout the before treatment sampling period, whereas an overall decline occurred after treatments (Figure 6). I found no evidence to support my hypothesis that fuels treatments were a determinant of western red-backed vole density.

Individual Responses

Fuels use

After comparing expected to observed proportions of deer mice with simultaneous 90% confidence intervals for each of the 6 fuels cover categories, I found evidence that the deer mouse used trap sites with unburned piles significantly more than expected. This supported my hypothesis that use would be more than expected for stations having unburned piles, although I also found that deer mice used stations with 76-100% lopped and scattered fuels cover significantly less than expected (Figure 7), while randomly using the remaining cover types. Significantly low use of sites with the greatest amount of lopped and scattered cover by deer mice represented the opposite response that I hypothesized.

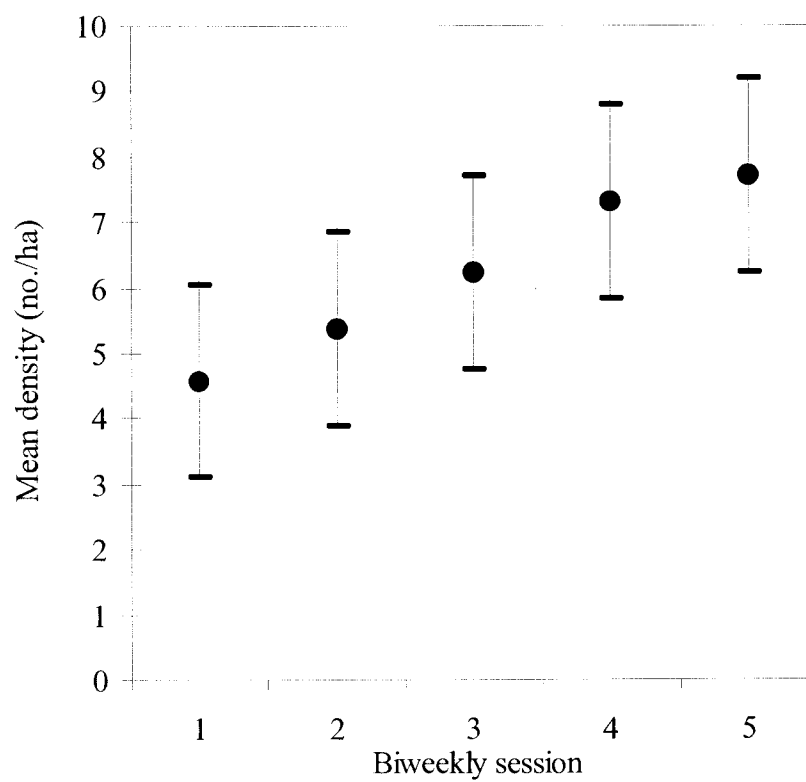


Figure 5. Mean deer mouse density during 5 biweekly sampling periods in the Applegate Adaptive Management Area, Jackson County, Oregon, 1999-2000. Vertical bars represent 90% confidence intervals.

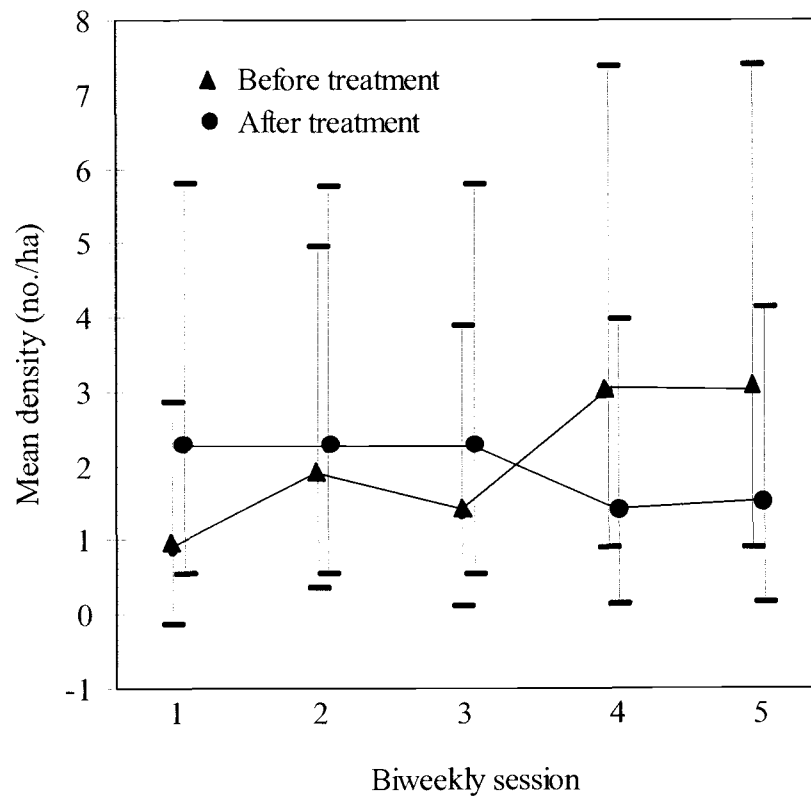


Figure 6. Mean western red-backed vole density before and after 3 silvicultural fuels treatments in the Applegate Adaptive Management Area, Jackson County, Oregon, 1999-2000. Vertical bars represent 90% confidence intervals.

I found some evidence that the western red-backed vole avoided stations lacking fuels cover (Figure 7); however, this may have been due to the small number of stations ($n = 3$) supporting this cover category. With such few stations in a category, random use of stations could produce the same result. The western red-backed vole therefore appeared not to respond to fuels cover categories, which led to rejection of my *a priori* hypothesis.

Distance from unburned fuel piles

The evaluation of the effects of distance from unburned piles was limited to the deer mouse because only it had a significant difference in the use of unburned piles (Figure 7). The \log_{10} regression model explained nearly twice the amount of variation in average numbers of deer mice at trap sites ($R^2 = 0.60$; Figure 8) as the linear model, and indicated that deer mice significantly ($P = 0.001$) declined with distance from the nearest unburned pile. The average number of deer mice at trap stations declined by 50% at a distance of 7 m from unburned piles, and steadily declined, though at a lesser rate, at greater distances (Figure 8).

Distance from unburned piles also significantly affected deer mouse home range size, with the linear model ($P = 0.009$, $R^2 = 0.54$, Figure 8) explaining 3% more variation in home range size than the Log_{10} model. Based on the linear model, the home range index doubled every 5-m increment away from piles (Figure 8). In other words, the home range of deer mice captured at stations 5 m from the nearest unburned pile was twice as large as that of mice captured at stations roughly 1-m away from piles (Figure 8). These results supported my prediction that small mammal numbers would be greatest and home ranges smallest at sites closest to piles.

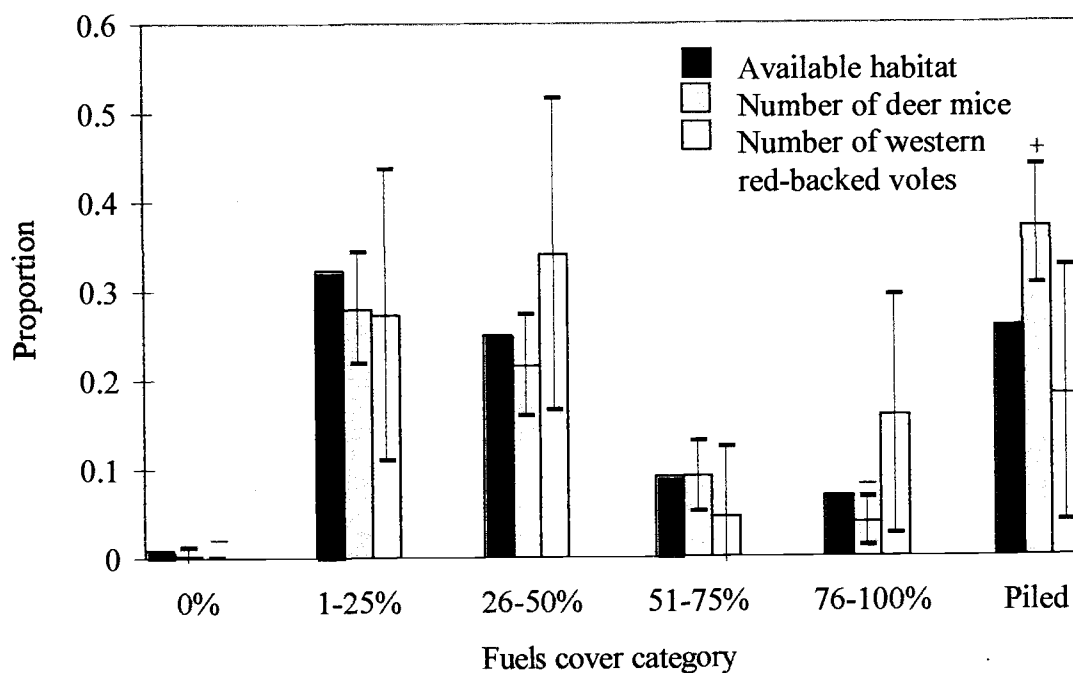


Figure 7. Proportions of available habitat and total individuals of the deer mouse and western red-backed vole within 6 silvicultural fuels cover categories in the Applegate Adaptive Management Area, Jackson County, Oregon 2000. Vertical bars represent 90% confidence intervals for individual fuels cover categories. Cover categories are percent cover by lopped and scattered fuels (%) and cover provided by unburned piles (Piled). Pluses (+) indicate that a species used fuels category significantly ($P \leq 0.1$) more than expected, and minuses (-) indicate significantly less use than expected, based on the Bonferroni utilization test (Neu et al. 1974).

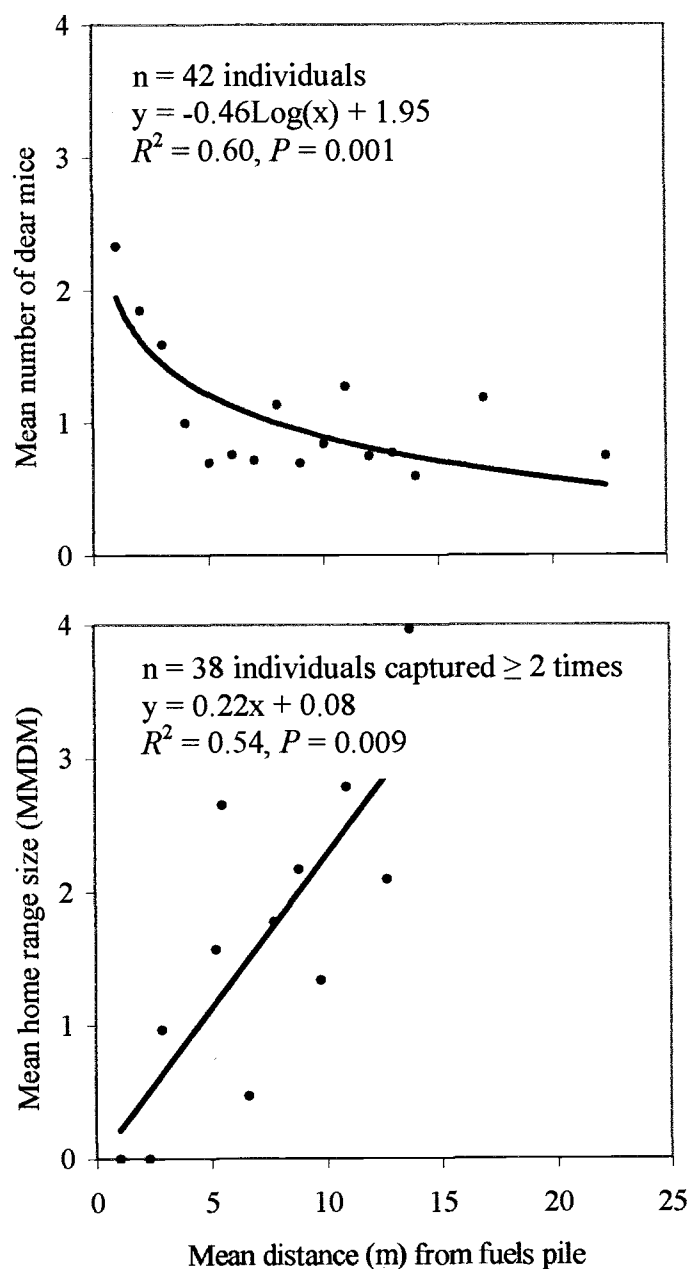


Figure 8. Relationship between distance from unburned piles and mean number of individuals (top) and mean home range size (bottom) of deer mice in the Applegate Valley Adaptive Management Area, Jackson County, Oregon 2000. Mean maximum distance moved (MMDM; Otis et al. 1978) is considered to be an index of the average diameter of a home range (Dice 1938, 1941) and was based on all individuals occupying trap stations at the corresponding nearest distance from an unburned pile.

DISCUSSION

Management plans intended to improve forest health typically incorporate fuels management into silvicultural treatments to reduce future risk of fire. There are various methods available for fuels management, and selection of treatments is based on the amount of fuels. When fuel levels are high, as was the case in several forest stands in the AAMA, managers propose piling and burning. Mid levels are managed by broadcast burning, and low levels dictate leaving fuels in the lopped and scattered condition. Tiedemann et al. (2000) recently proposed modifying these treatments by leaving fuels in place, and an alternative to piling and burning might be to leave piles unburned. The assumption that managers make when proposing a fuels treatment is that the available methods have similar effects on wildlife, including small mammals. Nevertheless, because fuels provide cover that may satisfy some of the life history requirements of many small mammals (Bailey 1984:110-124), lop and scatter, unburned pile, and burned pile treatments result in varying amounts and distributions of cover that may affect small mammal communities, populations, and individuals differently. I found that fuels treatments did not affect small mammal species richness and evenness and deer mouse and western red-backed vole survival or densities. However, I demonstrated that deer mice used unburned piles significantly more than they were available, and their numbers were negatively and home range sizes positively correlated with distance from piles

Community Responses

Species richness and composition

Community composition and richness of species I observed in the study area were characteristic of small mammal communities in the Klamath Mountains Geological Province (Verts and Carraway 1998:28). However, I found that varying amounts of horizontal fuels cover associated with lop and scatter, unburned pile, and burned pile treatments did not affect small mammal species richness. Steel et al. (1999) found a

higher richness of small mammal species at debris piles compared to reference sites in riparian areas of Washington. The lack of agreement between their study and mine may be due to different habitats and sizes of experimental units. For instance, Steel et al. (1999) considered wood debris piles and barren reference sites as experimental units within a riparian system, whereas I measured community responses in study plots within upland forests. My larger experimental units provided variable habitat conditions within each study plot where, as Wilson and Carey (2000) hypothesized, some substitutability in protective cover between down wood and other sources of cover like shrubs may occur and thus minimize the effects of reduced cover in burned pile treatment plots.

Treatment replicates and sampling periods contained incomplete communities, and species composition varied among them. The apparent absence of the creeping vole in the lop and scatter treatment plots during the post-treatment period was unexpected. The creeping vole is generally associated with dense herb and grass cover in clear-cuts, edges of timber, and abandoned brushlands (Goertz 1964, Gashwiler 1970, Hooven 1973, Pettecrew and Sadleir 1974, Hooven and Black 1976, Sullivan 1980). Thus, its absence from the lop and scatter treatment plots suggest that the structural diversity provided by fuels in these plots may not have increased the vole's niche breadth, but rather may have reduced the grass and herb vegetation to unsuitable levels. Another explanation may be that habitat relationships of the creeping vole might be tempered by the abundance of the red-backed vole through inter-specific competition (Carey and Harrington 2001) in the absence of fuels treatments.

Although the western harvest mouse was present in low numbers, its apparent elimination from the unburned pile treatment plots and its reduction in the number of captured individuals by 66% in the post-treatment period in the burned pile treatment plots were not a surprise. This species is dependent on thick grass and weeds for building birdlike nests above the ground (Ingles 1965), and these 2 methods of fuels management result in higher amounts of disturbance and loss of understory vegetation compared to the lop and scatter treatment. Piling fuels in my study plots reduced and destroyed understory vegetation, which may have led to unsuitable nesting habitat conditions for

the western harvest mouse during the post-treatment period. Although my study did not investigate effects of fuels management beyond 1 year after treatments, I predict that an increase in understory vegetation in subsequent years may lead to increased habitat suitability for the western harvest mouse.

Shrews were absent from all stands during the pre-treatment period, but common in the post-treatment period. These species may be directly tied to biological activity at the soil-litter interface (Wilson and Carey 2000) rather than to fuel volumes and distributions on the forest floor. The extensive amount of disturbance to the forest floor during commercial thinning may have disrupted the soil-litter component contributing to the absence of shrews immediately following this activity.

Species evenness

The similarity in species evenness among treatments did not coincide with my expectation that evenness would vary among treatments because they differed in regards to the amount of horizontal fuels cover. I predicted that the relatively low amount of horizontal fuels cover in the burned pile treatment plots would correspond to homogeneous amounts of cover across the forest floor and would promote low species evenness.

Fuel volumes and distributions did vary among my treatments, thus the similarity in evenness suggests that (1) fuels volume, cover, and distribution does not affect species evenness in forest-floor small mammal communities, (2) other habitat components are providing heterogeneous habitats that provide for the similar numbers of individuals among species, or (3) problems with evenness measures (Pielou 1969, Sheldon 1969) may have masked differences.

Population Responses

Survival

My results suggest that small mammal survival did not differ greatly among lop and scatter, unburned pile, and burned pile silvicultural fuels treatments. Although the power of some of my tests were low, neither the results of this experiment nor anecdotal observations made during fieldwork have convinced me that fuels treatments differentially effected survival of small mammals. The lack of significant differences among treatments in regards to survival may be due to the low degrees of freedom in the replication-based testing and because the small sample sizes resulted in high amounts of variation among replicates. Another source of high variation among replicates, which also led to low estimates of survival was the absence of individuals in some replicates. For instance, western red-backed voles were absent from 1 replicate in each treatment, resulting in a survival rate of zero in those replicates. However, the failure to detect differences may also be because some small mammal species, including the deer mouse, may respond to the distribution of down wood cover at the scales of individuals and micro-sites (10 m²) rather than at the scales of populations and plots (1-ha; Manning and Edge in review), the latter of which were used in this experiment. Furthermore, Carey et al. (1999) proposed that small mammals respond to a diversity of vegetation conditions and down wood that are arranged in close juxtaposition in a fine-scale mosaic. Thus, survival rates at the population level may not be an appropriate measure of deer mouse and western red-backed vole responses to the treatments used for fuels management.

Density

The absence of a treatment effect on densities of deer mice and western red-backed voles was inconsistent with the findings of Sullivan (1980), Morrison and Anthony (1989), Carey and Johnson (1995), and Butts and McComb (2000), who found that small mammal abundance was related to the amount of vegetation and down wood. Although I did not sample animals within piles, I frequently observed deer mice escaping

under unburned piles after being released at capture sites, which appears to lend support to Steel et al.'s (1999) conclusion that piles of wood in riparian habitats of western Washington may provide valuable resources to small mammals. But, the absence of a treatment effect on deer mice and western red-backed vole population densities suggests that high use of unburned piles may not translate into higher population densities. At high densities per ha, deer mice home ranges overlap 14-37%, intraspecific and interspecific territorial aggressive interactions occur frequently, and conspecific females are excluded from territories by aggressive behavior because they frequently kill unprotected young (Wolf 1989). Given the higher numbers of deer mice I found close to unburned piles, I postulate that piles occurring at densities similar to those found in my study area may provide an uneven distribution of animals within forests, though the overall population density may not deviate from populations found in similar habitats lacking piles. At higher densities of piles, the number of animals may possibly become higher and more evenly distributed.

The increase in deer mouse density over time was anticipated due to recruitment into the populations through births and migration during the summer sampling periods. Additionally, the quality of habitat in terms of vegetation cover and forage (seeds, herbs, grasses, and fungi) generally increased through summer. The interactive effect of treatment and biweekly periods on western red-backed vole density may have been due to their capture frequencies being positively related to the amount of weekly rainfall and negatively related to minimum ambient temperatures (Maguire 1999). I detected nearly twice the amount of rainfall during the last 3 biweekly sessions of the pre-treatment period when red-backed vole densities increased compared to the post-treatment period when densities decreased.

I suspect that for both species, the temporal variation among biweekly periods may have confounded or obscured effects of treatments, although other causes may have contributed to this. For instance, MMDM was used for computing population density, and this statistic is positively related to the number of recaptures (Stickel 1954, Tanaka 1972). Additionally, density may not be a good indicator of the quality of habitat (Van

Horn 1983). Fuels may also afford concealment for predators and may offset the benefits of cover (Bailey 1984:111). I also suspect that baited traps may provide supplemental food that can cause immigration into the study plots (Younger 2002), thus increasing small mammal population density beyond that directly effected by fuels treatments. Moreover, high amounts of subsidized food may increase predators leading to an interactive effect between food availability and predators on density of small mammals (Younger 2002).

Individual Responses

Fuels use

Although community- and population-level responses did not differ among the 3 fuels treatments, it was not surprising to find patterns of fuels use within plots. Most studies that link the distribution of small mammals to the distribution of down wood (e.g., Doyle 1987, Tallmon and Mills 1994, Bowman et al. 2000, Butts and McComb 2000) have done so at the scale of microhabitats, and microhabitat associations may not translate across scales (Wiens et al. 1986). For instance, Manning and Edge (in review) examined small mammal survival as a response to down wood at 3 spatial scales, the smallest being individual home ranges, and concluded that survival was related to the amount of down wood only at that small scale. However, Bowman et al. (2000) hypothesized that the lack of relationships between small mammal abundance and down wood at the individual log and stand scales reflected the broad niches and variable responses of many small mammal species to forest management.

I found that deer mice used individual unburned piles significantly more than they were available compared to the other 5 fuels cover categories. Their inconsistent use of high amounts of lopped and scattered fuels compared to the high amounts of cover afforded by unburned piles indicate that my hypothesis of greater than expected use of these 2 cover categories was too general. This leads me to believe that piles left behind in thinned forests might provide habitat components for deer mice that are unique from

lopped and scattered fuels. Steel et al. (1999) captured more small mammals in naturally occurring wood piles compared to reference sites, and concluded that piles were used over the breeding season. Cox et al. (1997) however did not find that the presence of brush piles influenced survival of the considerably larger snowshoe hare (*Lepus americanus*) and cottontail rabbit (*Sylvilagus floridanus*). Based on the significant use of unburned piles by deer mice, I conclude that piled fuels may be important habitat components in thinned forests that are worthy of further research.

Because the western red-backed vole exhibits microhabitat preferences (Doyle 1987), I was surprised to find that they randomly used all 6 categories of fuels cover. This random use implies that the amount or distribution of fuels did not affect their presence at stations in the unburned pile treatment plots. Down wood (Hayes and Cross 1987, Tallmon and Mills 1994), and depth of organic soil have been reported to contribute to the quality of habitat for western red-backed voles (Rosenberg et al. 1994), although I was unable to consider logs because my experiment was not intended to separate such associations.

Distance from unburned fuel piles

The individual response by deer mice to distances from unburned piles also suggests that piles may function as an important habitat component in thinned forests. The decline in deer mouse numbers at greater distances from unburned piles provides strong evidence that the distribution of deer mice coincided with the distribution of piles. Steel et al. (1999) found a high abundance of deer mice in piles of wood compared to surrounding barren cobble bars in riparian floodplains regardless of distance from the forest edge. In my study, the unburned pile treatment provided a distribution of cover comparable to that described by Steel et al. (1999) in that areas of the forest floor in between piles had relatively low amounts of fuels cover.

The positive relationship between average deer mouse home range and distance from unburned piles suggest that mice satisfy their habitat requirements within small

home ranges juxtaposed within close proximity to piles, whereas at greater distances, they may need to occupy relatively larger home ranges to achieve the same habitat requirements. This pattern of increasing home range size with increasing distance from piles would appear to favor higher densities in unburned pile treatment plots compared to lop and scatter and burned pile plots, although I did not find this to be the case. My findings suggest that deer mouse densities are similar in both treatments, but the type of treatment may influence their distribution (e.g., mice may be in a clumped distribution in unburned pile treatment plots), with the greatest variability among home ranges occurring in unburned pile treatment plots.

The variation in individual responses did not translate up to population- and community-levels, and it is unclear from this study how these individual responses might affect individual fitness or populations and communities beyond 1 year following fuel treatments. The lack of treatment effects on community and population parameters may have been due in part to the small sample sizes in this study. However, another explanation is that environmental conditions created by the open canopy following thinning in all 3 blocks may have led to poor-quality forest-floor habitats for small mammals. Specifically, the open canopy condition following thinning may have allowed extreme solar radiation to penetrate the previously closed-canopy and reach the forest floor environment, thereby creating relatively xeric environmental conditions. Thinning may therefore destabilize the thermally constant environments of moist substrates found on the forest floor (Hack and Goodlett 1960). Thinning also disturbs understory shrub vegetation that is believed to contribute to sheltered, thermally stable microclimates during temperate seasons (Orrock et al. 2000), like the summer periods I sampled in. These abrupt changes to forest floor environments may be deleterious to some small mammal species, such as the red-backed vole that occupies areas with increased cover and minimal solar irradiance (Orrock et al. 2000). Because the abundance and diversity of understory vegetation are determined by the interaction of canopy closure and site conditions (Spies 1991), thereby influencing small mammal communities (see Carey and Johnson 1995 for a review), conditions created by opening the forest canopy in my study

sites may have led to dampening the influence of treatments at the community and population levels. Thus, although commercial thinning has been considered a potential method to enhance wildlife habitat (McComb et al. 1993, Bailey 1996, Hayes et al. 1997), I recommend that future studies of wildlife responses to fuels management in the Pacific Northwest consider interactions between commercial thinning, fuels management, and regional climate conditions.

MANAGEMENT RECOMMENDATIONS

Small mammal responses to fuels management following commercial thinning in the AAMA were apparent only for the deer mouse at the individual level. Similar population densities and survival rates among treatments indicate that individual deer mice likely reached their basic biological needs through the establishment and variable size of home ranges within treatment areas. All other species showed no difference in response among fuel treatments. This suggests that the 3 fuel treatments provided adequate amounts of cover for small mammal communities and populations of most species to persist for at least 1 year following treatments. Deer mice represent nearly half of the individuals that comprise the small mammal community in the AAMA, which is typical for this ubiquitous species. Consequently, silvicultural practices and fuels management actions in the AAMA should be directed towards managing fuels with the intent of conserving small mammals, including the deer mouse.

Deer mouse and western red-backed vole populations demonstrated a similar lack of response to the 3 fuels treatments tested here, suggesting that the 3 treatments will not affect populations of both species. However, my hypothesis that extreme environmental conditions after commercial thinning leads to a dampening of the influence of treatments at the community and population levels raises concerns that conditions resulting from thinning may interact with on-the-ground fuel treatments across the varied climatic conditions of the Pacific Northwest. This study focused on the short-term effects and on

the most abundant thinning condition only during summer. Consequently, it did not include multi-year responses or the full range of habitat and seasonal conditions in the AAMA. Thus, until further studies of wildlife responses to fuels management in the Pacific Northwest consider such interactions between thinning, fuels management, and regional climate conditions, my results should be applied cautiously to other forests of different location, age, composition, and thinning prescriptions in the AAMA.

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APPENDICES

Appendix 1. Number of individual small mammals captured among three silvicultural fuels treatments before and after 3 fuels treatments in 9 trapping grids (3 replicate grids per treatment) in the Applegate Adaptive Management Area, Jackson County, Oregon 1999-2000.

Species	Lop and Scatter		Burned Pile		Unburned Pile		Total
	Before treatment ^a	After treatment	Before treatment	After treatment	Before treatment	After treatment	
<i>Clethrionomys californicus</i>	16	20	29	20	24	11	120
<i>Glaucomys sabrinus</i>	0	1	0	0	0	1	2
<i>Microtus californicus</i>	5	1	4	8	4	7	29
<i>Microtus oregoni</i>	3	0	2	2	3	5	15
<i>Neotoma fuscipes</i>	0	0	0	2	0	0	2
<i>Neurotrichus gibbsi</i>	0	0	0	0	0	5	5
<i>Peromyscus maniculatus</i>	36	34	40	45	46	42	243
<i>Peromyscus truei</i>	1	4	0	1	1	1	8
<i>Reithrodontomys megalotis</i>	4	8	6	2	5	0	25
<i>Sorex</i> spp.	0	28	0	30	0	29	87
<i>Spermophilus beecheyi</i>	2	0	1	0	0	0	3

Appendix 1. Continued.

<i>Tamias</i> spp.	8	5	7	6	15	13	54
Total	75	101	89	116	98	114	593

^a Before treatment trapping grids were geographically the same as after treatment grids within each fuels treatment.

Appendix 2. Type 3 *F*-test results and *P*-values for fixed effects of silvicultural fuels treatments on small mammal richness¹ in the Applegate Adaptive Management Area, Jackson County, Oregon 1999-2000.

Effect	Num df	Den df	<i>F</i>	<i>P</i>
(ANCOVA H_0 : Slopes are equal to zero with increasing initial richness)				
Fuels treatment	1	3	2.48	0.4297
Initial richness x Fuels treatment ²	1	3	2.48	0.4293
(ANCOVA H_0 : Slopes are non-zero and similar with increasing initial richness)				
Fuels treatment	1	2	3.56	0.3511
Initial richness	1	1	0.00	0.9712
Initial richness x Fuels treatment	1	2	3.58	0.3502
(ANCOVA H_0 : Slopes are equal to zero with increasing fuels volume)				
Fuels treatment	1	3	3.14	0.3990
Fuels vol. x Fuels treatment	1	3	3.53	0.3694
(ANCOVA H_0 : Slopes are non-zero and similar with increasing fuels volume)				
Fuels treatment	1	2	4.56	0.3143
Fuels vol.	1	1	0.92	0.5139
Fuels vol. x Fuels treatment	1	2	4.55	0.3148
(RCBD H_0 : Fuels treatment means are equal)				
Fuels treatment	2	4	1.32	0.3626

¹ Species richness calculated using rarefaction method (Sanders 1968).

² Interaction between initial fuels volume and silvicultural fuels treatment.

Appendix 3. Type 3 *F*-test results and *P*-values for fixed effects of silvicultural fuels treatments on small mammal evenness (*V'*)¹ in the Applegate Adaptive Management Area, Jackson County, Oregon 1999-2000.

Effect	Num df	Den df	<i>F</i>	<i>P</i>
(ANCOVA <i>H</i> ₀ : Slopes are equal to zero with increasing initial evenness)				
Fuels treatment	1	3	10.70	0.2202
Initial evenness x Fuels treatment ²	1	3	10.56	0.2216
(ANCOVA <i>H</i> ₀ : Slopes are non-zero and similar with increasing initial evenness)				
Fuels treatment	1	2	2.30	0.4229
Initial evenness	1	1	0.00	0.9771
Initial evenness x Fuels treatment	1	2	2.30	0.4228
(ANCOVA <i>H</i> ₀ : Slopes are equal to zero with increasing fuels volume)				
Fuels treatment	1	3	3.29	0.3801
Fuels vol. x Fuels treatment	1	3	3.36	0.3764
(ANCOVA <i>H</i> ₀ : Slopes are non-zero and similar with increasing fuels volume)				
Fuels treatment	1	2	0.15	0.8799
Fuels vol.	1	1	8.25	0.2133
Fuels vol. x Fuels treatment	1	2	0.10	0.9104
(RCBD <i>H</i> ₀ : Fuels treatment means are equal)				
Fuels treatment	2	4	0.31	0.7528

¹ Species evenness calculated using the *V'* evenness measure (Hurlbert 1971).

² Interaction between initial fuels volume and silvicultural fuels treatment.

Appendix 4. Type 3 *F*-test results and *P*-values for fixed effects of silvicultural fuel treatments on biweekly deer mouse survival in the Applegate Adaptive Management Area, Jackson County, Oregon 1999-2000.

Effect	Num df	Den df	<i>F</i>	<i>P</i>
(ANCOVA H_0 : Slopes are equal to zero with increasing initial survival)				
Fuels treatment	1	3	2.09	0.4614
Initial survival x Fuels treatment ¹	1	3	2.22	0.4499
(ANCOVA H_0 : Slopes are non-zero and similar with increasing initial survival)				
Fuels treatment	1	2	0.52	0.6998
Initial survival	1	1	0.74	0.3037
Initial survival x Fuels treatment	1	2	0.49	0.7092
(ANCOVA H_0 : Slopes are equal to zero with increasing fuels volume)				
Fuels treatment	1	3	1.92	0.4771
Fuels vol. x Fuels treatment	1	3	2.30	0.4430
(ANCOVA H_0 : Slopes are non-zero and similar with increasing fuels volume)				
Fuels treatment	1	2	1.13	0.5545
Fuels vol.	1	1	2.27	0.3730
Fuels vol. x Fuels treatment	1	2	1.39	0.5141
(RCBD H_0 : Fuels treatment means are equal)				
Fuels treatment	2	4	0.78	0.5185

¹ Interaction between covariate and silvicultural fuels treatment.

Appendix 5. Type 3 *F*-test results and *P*-values for fixed effects of silvicultural fuels treatments in the RCBD analysis on deer mouse density (no./ha) in the Applegate Adaptive Management Area, Jackson County, Oregon 1999-2000.

Effect	Num df	Den df	<i>F</i>	<i>P</i>
Fuels treatment	2	6	0.60	0.5807
Treatment periods ¹	1	8	0.00	0.9533
Biweekly periods	4	32	3.32	0.0219

¹ Pre- and post-treatment periods

Appendix 6. Type 3 *F*-test results and *P*-values for fixed effects of silvicultural fuels treatments in the RCBD analysis with repeated measures on western red-backed vole density (no./ha) in the Applegate Adaptive Management Area, Jackson County, Oregon 1999-2000.

Effect	Num df	Den df	<i>F</i>	<i>P</i>
Fuels treatment	2	6	0.11	0.8960
Treatment periods ¹	1	8	0.00	0.9957
Biweekly periods	4	32	0.70	0.5958
Treatment periods x Biweekly periods ²	4	32	2.16	0.0964

¹ Pre- and post-treatment periods

² Interaction between treatment periods (pre and post) and biweekly periods.