Forest Management and the Dead Wood Resource in Ponderosa Pine Forests: Effects on Small Mammals[1]

Carol L. Chambers[2]

Abstract

Changes in vegetation structure and composition affect habitat for wildlife. Species such as small mammals that are restricted to small home ranges and are relatively immobile may be most affected since it is more difficult to find and move to new habitat. In the southwestern United States, forest management treatments (thinning and prescribed burning) are being implemented to alter structure and function of ponderosa pine *(Pinus ponderosa)* ecosystems and recreate pre-settlement (ca. 1870) tree species composition and size class distribution. These forest restoration treatments will affect the availability of dead wood to wildlife (e.g., prescribed fires may consume dead wood, forest operations may create snags and logs). I live-trapped small mammals in a northern Arizona ponderosa pine forest prior to restoration treatment and found that mouse species (*Peromyscus* species) were associated with some dead wood elements (e.g., Gambel oak *[Quercus gambelii]* snags, ponderosa pine snags, ponderosa pine stumps).

Introduction

Standing dead trees and logs are important components of wildlife habitat. They provide nesting, roosting, feeding, loafing, and storage sites for over 75 species of birds, mammals, reptiles, and amphibians in the Southwest (Degenhardt and others 1996, Rabe 1998, Scott 1979, Scott and Patton 1989). Many of these animals have important ecological roles, such as dispersing seeds and mychorrhizal fungi, helping to control insect populations, and serving as prey for other species (Bergvinson and Borden 1992, Maser and others 1988, Peterson 1980, Ward and Block 1995).

Vertebrate population densities may change in response to change in vegetation structure and composition (see for example, Chambers and others 1999, Scott 1979, Szaro and Balda 1986). Although some wildlife species (birds, large ungulates) are highly mobile and can move to more favorable habitat (assuming it is unoccupied), many species (small mammals, reptiles, amphibians) are often restricted to relatively small areas (i.e., 2 to 20 ha per individual or population) (e.g., Hall and Morrison 1997). Forest management practices may have differential effects on vertebrate populations depending on the scale at which the treatments are applied and the size of habitat used by an organism.

Ponderosa pine forests cover about 3.2 million ha in Arizona and New Mexico (Klemmedson and Smith 1979). These forests appear to be at increasing risk of

---

[1] An abbreviated version of this paper was presented at the Symposium on the Ecology and Management of Dead Wood in Western Forests, November 2-4, 1999, Reno, Nevada.
[2] Associate Professor, School of Forestry, Northern Arizona University, Flagstaff, AZ 86011 (e-mail: Carol.Chambers@nau.edu)

catastrophic fire as a result of 130 years of Euro-American influence. A combination of fire suppression, logging practices, insect infestations, livestock grazing, and a shift towards a warmer and wetter climate has altered the composition of ponderosa pine forests (Cochran and Hopkins 1991, Cooper 1960, Covington and Moore 1994, Grissino-Mayer and Swetnam 2000, Touchan and others 1996). Livestock grazing reduced native grasses and other fine fuels that spread low intensity fires. Grazing also exposed bare mineral soil, which allowed establishment of ponderosa pine seedlings in years following high cone production (Klemmedson and Smith 1979, Touchan and others 1996). Fire suppression has resulted in greater survival of young trees, contributing to forest densities of >3,000 trees/ha in the 1990s compared to 60 trees/ha in 1876 (Mast and others 1999).

Ecological restoration, using silvicultural tools such as thinning and prescribed burning, may help reestablish structure and function of indigenous ecosystems by recreating pre-settlement (ca. 1870) tree species composition and size class distribution and reestablishing a frequent, low intensity fire regime (Covington and others 1997). However, restoration treatments will affect the availability of dead wood to wildlife. Thinning and pruning may increase log and slash densities. Slash treatments that leave piles or windrows increase habitat for some vertebrates (e.g., small mammals, Goodwin and Hungerford 1979). Prescribed fire may increase or decrease the dead wood resource. Boucher and others (1999), Gaines and others (1958), and Gordon (1996) found that prescribed fire created dead wood; however, live trees killed by fire were predominantly small in diameter and therefore not effective replacements of large logs and snags. Prescribed fires will also incinerate existing snags and logs, removing up to 50 percent of ponderosa pine snags and 60 percent of logs (Gaines and others 1958, Gordon 1996, Horton and Mannan 1986, Randall-Parker and Miller 2002). In addition, Horton and Mannan (1988) found that large (>30 cm dbh) and more decayed ponderosa pine snags were more flammable, and therefore more likely to be lost. This loss of large dead wood may be particularly detrimental to wildlife, because cavity nesters (birds and bats) select larger snags ($\geq$46 cm diameter), large snags persist longer than small snags (Neitro and others 1985, Rabe and others 1998, Scott and Oldemeyer 1983), and replacement of large snags may take a long time (e.g., $\geq$200 years for a ponderosa pine to reach 46 cm dbh under normal stocking, site index 70 [Meyer 1961]). Large snags are often the origin of large logs, so fires may have both immediate and long-term impacts on both standing dead and down wood.

If not incinerated, snags and logs may be altered by fire and their usefulness as wildlife habitat decreased (Gaines and others 1958, Gordon 1996). After a prescribed burn, Gordon (1996) suggested that the utility as habitat of >70 percent of logs in her study was decreased, because logs were charred and case-hardened, making them more difficult for animals to excavate. Most snags fell (50 percent, Gordon 1996), at which point they were considered useful as log habitat. Additional fires might further reduce available dead wood.

What do we know specifically about use of dead wood in the Southwest? I found 41 articles *(table 1)* that described either dynamics of dead wood or use of dead wood as habitat for wildlife in the Southwest. The literature generally focused on ponderosa pine ecosystems (n = 32), although five papers described mixed conifer ecosystems and four papers described dead wood in both forest types. Snag dynamics or use was the most common topic discussed (n = 33). Of these, 11 papers described use of snags by primary or secondary cavity-nesting birds and 10 described other

types of use by wildlife. The remaining 12 papers described snag recruitment and longevity, pre-settlement forest conditions in the Southwest, or effects of prescribed fire on dead wood. Fifteen papers discussed dynamics (n = 6) or wildlife use (n = 9) of logs.

Of the 41 papers discussing dead wood in the Southwest, only 4 (Goodwin and Hungerford 1979, Kyle 2000, Smith and Mannan 1994, Ward and Block 1995) described small mammal use of down wood in ponderosa pine forests. I examined small mammal use of ponderosa pine stands in northern Arizona. My objective was to determine how the availability of standing and down wood and other habitat elements affected abundance of small mammals. The study was conducted in areas scheduled for forest restoration treatments (thinning, prescribed burning). From these data, I have speculated on how restoration may affect dead wood and impact small mammal communities. Following restoration treatments, stands will be resampled and pre- and post-treatment comparisons made.

Table 1—_Dead wood (snags and logs) in the Southwest reference list._

Author(s)	Year	Snags	Logs	Wildlife
Mixed conifer				
Vahle and Patton	1983		X	X
Conway and Martin	1993	X		X
Franzreb	1978	X		X
Franzreb and Ohmart	1978	X		X
Li and Martin	1991	X		X
Ponderosa pine				
Goodwin and Hungerford	1979		X	X
Smith and Mannan	1994		X	X
Ward and Block	1995		X	X
Smith	1996		X	X
Covington and Sackett	1984		X	
Graham and others	1994		X	
Balda and others	1983	X		X
Crocker-Bedford	1993	X		X
Cunningham and others	1980	X		X
Dwyer	2000	X		X
Hay and Guntert	1983	X		X
Horton and Mannan	1988	X		X
Keller	1992	X		X
Rabe and others	1998	X		X
Reynolds and others	1992	X		X
Scott	1978	X		X
Scott	1979	X		X
Szaro and Balda	1986	X		X
Brawn and Balda	1988	X		X
Ffolliot	1983	X		
Mast and others	1999	X		
Miller and Benedict	1994	X		
Pearson	1937	X		
Scott and Oldemeyer	1983	X		
Wadsworth	1943	X		

(*table 1* continued) Author(s)	Year	Snags	Logs	Wildlife
Block and Finch	1997	X	X	X
Germaine	1999	X	X	X
Kyle	2000	X	X	X
Covington and Moore	1994	X	X	
Covington and others	1997	X	X	
Gaines and others	1958	X	X	
Gordon	1996	X	X	
Mixed conifer and ponderosa pine				
Mollohan and others	1989		X	X
Balda	1975	X		X
Dahms and Geils	1997	X		
Ganey	1999	X		

Methods

Study Area

I live-trapped small mammals at Mt. Trumbull, in the Arizona Strip north of the Colorado River, in northern Arizona (latitude $36^o 22'$ 0", longitude $113^o 11'$ 0"). The study area ranged from 2,055 to 2,277 m in elevation. Tree density averaged 1,642 trees per ha, with ponderosa pine dominating (ponderosa pine averaged 90 percent of stand basal area). Gambel oak, pinyon pine *(Pinus edulis),* Utah juniper *(Juniperus osteosperma),* and New Mexican locust *(Robinia neomexicana)* comprised the remaining 10 percent basal area. Log density averaged 6.4/ha, 51.0, 1.6, 107.6, respectively, for large (>50 cm diameter) and small ($\leq$50 cm) ponderosa pine logs; large (>15 cm diameter) and small ($\leq$15 cm) Gambel oak logs. Snag density averaged 1.6/ha, 40.3, 7.8, and 216.6, respectively, for large and small ponderosa pine snags; large and small Gambel oak snags.

Small Mammal and Habitat Sampling

I established trapping grids within five 32-ha experimental restoration units. Each unit consisted of two stands: one treatment and one control, approximately equal in size. Treatment stands were to be harvested in 1999; I sampled all stands prior to harvest in July 1998.

I established a 10 x 10 trapping grid (4 ha grid) centered in each 16-ha stand (n = 10 grids). Grid points were placed 20 m apart. At each point on the trapping grid, I placed one Sherman live trap (8 x 8 x 23 cm). Traps were baited with a peanut heart and seed mix. Traps were set for four to five consecutive nights (until recapture rates were >80 percent) and checked daily. Traps were closed during the day to prevent capture of diurnal animals and reopened approximately 1 hour before dusk.

Units 1, 2, and 3 were sampled July 11-15, 1998. Units 4 and 5 were sampled July 26-29, 1998. All animals were weighed, measured (total body length, lengths of tail, ear, and right hind foot), ear-tagged with a unique number, and released at the point of capture.

I obtained vegetation and habitat data for each stand from the Northern Arizona University School of Forestry Ecological Restoration Institute. These data were collected June through August 1998 for a subset of trap stations (12 to 16 trap stations systematically distributed in each grid to equally sample throughout the trapping grid). Overstory data (tree density, basal area, canopy cover, snags, logs, stumps) were measured on a 0.04 ha plot and shrubs were measured on a 0.01 ha plot centered on each trap station location *(table 2)*. Other understory habitat features (grasses, forbs, mosses, lichens) were measured by point intercept along a 50-m line transect (166 points per transect) and their frequency per trap station calculated *(table 2)*.

Table 2—*Habitat variables used in developing habitat relationships models for small mammal species (deer mouse, pinyon mouse, brush mouse) at Mt. Trumbull, Arizona, June–August 1998.*

Variable	Definition
Understory	
Lichen	Percentage of lichen and moss cover
Litter	Percentage of litter cover
Forb	Percentage of forb cover
Grass	Percentage of grass cover
Shrub	Percentage of woody plant (shrubs and trees <1.4 m) cover
Logs	Number of logs > 0.15 m long by species (ponderosa pine, Gambel oak, New Mexican locust, Utah juniper) and size class (for ponderosa pine: small ≤50 cm diameter, large >50 cm diameter; for Gambel oak, small ≤15 cm diameter, large >15 cm diameter; size classes were not created for New Mexican locust or Utah juniper)
Stumps	Number of stumps by species (ponderosa pine, Gambel oak, New Mexican locust, Utah juniper) and size class (for ponderosa pine: small ≤50 cm diameter, large >50 cm diameter; for Gambel oak, small ≤15 cm diameter, large >15 cm diameter; size classes were not created for New Mexican locust or Utah juniper)
Overstory	
Basal area	Basal area (m²/ha) for all live trees combined and for each tree species (ponderosa pine, Gambel oak, New Mexican locust, Utah juniper, pinyon pine)
Live trees	Number of live trees by species (ponderosa pine, Gambel oak, New Mexican locust, Utah juniper) and size class (for ponderosa pine: small ≤50 cm diameter, large >50 cm diameter; for Gambel oak, small ≤15 cm diameter, large >15 cm diameter; size classes were not created for New Mexican locust, or Utah juniper) and decay condition (1 = live tree, no sign of decay, 2 = live tree, declining, some evidence of decay (e.g., dead branches)
Snags	Number of snags by species (ponderosa pine, Gambel oak, New Mexican locust, Utah juniper), size class (for ponderosa pine: small ≤50 cm diameter, large >50 cm diameter; for Gambel oak, small ≤15 cm diameter, large >15 cm diameter; size classes were not created for New Mexican locust, or Utah juniper), and decay condition (3 = recent snag, 4 = loose bark snag, 5 = snag without bark remaining, 6 = snag broken above 1.4 m)

Live trees and snags or partial snags were classified into decay classes. Decay class 1 was a live tree with no evidence of dead branches. Decay class 2 was a live tree with dead branches (declining), decay class 3 was a recent snag, decay class 4 was a snag with loose bark, decay class 5 was a snag with no bark remaining.

Statistical Analyses

Stand-Level Analyses

I calculated capture rates per stand (number of animals per 100 trap nights [TN]) *(table 3)* for each *Peromyscus* species. I averaged overstory and understory variables for each stand. Habitat variables that were not normally distributed or with unequal variance were transformed by taking the square root of the variable or by using $\log_{10}$(variable + 1) (Sabin and Stafford 1990).

I reduced the number of habitat variables for multiple linear regression to adjust for small sample sizes. For each mouse species, I developed models using subsets of ≤3 habitat variables. I used Spearman correlations to determine univariate relationships between each species of *Peromyscus* and habitat variables that were selected in multivariate models (SAS Institute Inc. 1985) (Spearman correlations: R > 0.6, $P \le 0.05$ for deer mouse, R > 0.5, $P \le 0.1$ for brush mice, and R > 0.7, $P \le 0.03$ for pinyon mice).

I used stepwise linear regression analysis to identify habitat variables that, in combination, were associated with small mammal capture rates (Sokal and Rohlf 1981, SAS Institute Inc. 1985). I used Akaike's Information Criterion (AIC) to select models with predictive power that used the fewest variables; low AIC values are associated with models that give the best fit of data. To select the best model, I compared AICd values (relative AIC value for each model, calculated by taking the difference between the model with lowest AIC value). If AICd values were < 4, models were assumed equally effective in predicting presence of the animal species and the most parsimonious model selected (Burnham and Anderson 1998:43-48).

Table 3—*Capture rates (number of animals per 100 trap nights [TN]) for deer mouse* (Peromyscus maniculatus), *brush mouse* (P. boylii), *and pinyon mouse* (P. truei) *at Mt. Trumbull, Arizona, July 1998. For stand, C represents the control unit (will not be thinned or burned) and T represents the treatment unit (untreated at the time of data collection).*

	Capture Rate (number/100 TN)		
Stand	**Deer Mouse**	**Brush Mouse**	**Pinyon Mouse**
1C	3.0	4.8	0.0
1T	3.6	5.8	0.6
2C	4.4	0.0	0.4
2T	12.0	1.0	0.0
3C	2.6	0.0	0.0
3T	2.6	0.2	1.2
4C	1.3	0.0	4.8
4T	0.8	0.5	5.0
5C	0.3	0.0	3.8
5T	0.5	0.8	2.8

Trap Station Analyses

I averaged values for each habitat variable by trap station and used these data to develop habitat association models. I used logistic regression as a means of selecting variables that separated trap stations used by small mammals from unused trap stations. I conducted separate analyses for each mouse species (deer mouse, brush mouse, pinyon mouse). I used the Hosmer and Lemeshow goodness-of-fit test to determine whether the distribution of probabilities produced by my model(s) fit the logistic probability distribution (SAS Institute, Inc. 1990).

Results

I captured 270 individuals of 3 species during the trapping period: 135 deer mice (50 percent of captures), 74 pinyon mice (27 percent of captures), and 61 brush mice (23 percent of captures). Deer mice were more abundant in units 1, 2, and 3. Brush mice were most abundant in unit 1. Pinyon mice were most abundant in units 4 and 5 *(table 3)*.

Stand-Level Analyses

Models with two regressors were strongest predictors of deer mouse and pinyon mouse habitat use based on AICd values. For brush mouse, there was no difference between the 1- and 2-variable models based on AICd values *(table 4)*.

Large Gambel oak trees and small ponderosa pine snags explained 87 percent of the variation in deer mouse abundance ($F = 24.3$, $df = 2, 9$, $P < 0.0007$). Deer mice were positively correlated with large Gambel oaks ($R = 0.64$, $P = 0.05$) *(fig. 1A)* and negatively correlated with small ponderosa pine snags ($R = -0.74$, $P = 0.01$) *(fig. 1B)*.

Table 4—*Stepwise linear regression models developed to explain differences in habitat use at the stand level by deer mice, brush mice, and pinyon mice, Mt. Trumbull, Arizona, 1998.[1]*

Species	Habitat Variable	Partial R^2	Model R^2	AIC	AICd
Deer	>15 cm dbh Gambel oak trees	0.62	0.62	18.0	9.2
mouse	<50 cm dia. ponderosa pine snags	0.26	0.87	**8.8**	0
Brush	>50 cm dia. ponderosa pine stumps	0.37	0.37	13.5	2.6
mouse	Lichen and moss cover	0.23	0.61	10.9	0
Pinyon	Juniper species basal area	0.90	0.90	-6.1	4.9
mouse	Ponderosa pine basal area	0.05	0.95	**-10.9**	0

[1]Akaike's Information Criterion (AIC) was used to select models with predictive power using fewest variables; lowest AIC values are associated with models that give the best fit of data (best model is depicted in bold typeface, if not indicated in bold typeface, either model is equally acceptable). AICd is the relative AIC value for each model, calculated by taking the difference between the model with lowest AIC value.

Basal area of juniper and ponderosa pine trees explained 95 percent of the variation in pinyon mouse abundance (F = 67.2, df = 2, 9, P = 0.0001) *(table 4)*. Pinyon mice were positively correlated with juniper basal area (R = 0.85, *P* = 0.002) *(fig. 1C)* and ponderosa pine basal area (R = 0.71, P = 0.02) *(fig. 1D)*.

Large ponderosa pine stumps explained 37 percent of the variation in brush mouse abundance (F = 4.8, df = 1, 9, *P* = 0.06) *(table 4)*. Brush mice abundance was negatively correlated with large ponderosa pine stump density (R = -0.61, *P* = 0.06) *(fig. 1E)*. Lichen cover was not significantly correlated with brush mouse abundance (R = 0.15, *P* = 0.7), and it did little to explain more variation in mouse abundance (based on AICd values) when included in the multiple regression model *(table 4)* (F = 5.4, df = 2, 9, *P* = 0.04).

Trap Station Analyses

Of 143 trap stations with vegetation data, I captured deer mice at 14 stations, pinyon mice at 12 stations, and brush mice at 6 stations. Combining all species, I captured mice at 29 of 143 trap stations.

Trap stations with the highest probability of deer mice capture had higher forb cover, higher live tree basal area, and higher densities of small (<15 cm dbh) Gambel oak live trees or recent snags (decay class 2 or 3). Pinyon mice were captured at trap stations with higher pinyon pine basal area, small (<15 cm dbh) Gambel oak trees, and <50 cm diameter ponderosa pine stumps. There was a higher probability of brush mouse capture at trap stations with lichen cover, >50 cm dbh ponderosa pines, and <15 cm dbh Gambel oak trees or recent snags (decay class 2 or 3).

Discussion

Habitat Associations of Small Mammals

The deer mouse is one of the most widespread rodents. In the Southwest, it is common in forest types from high elevation spruce/fir *(Picea/Abies)* forests to ponderosa pine forests. Pinyon and brush mice are more selective of habitat. Brush mice occur in areas with dense rock and shrub cover, usually in pinyon-juniper, riparian, oak, and pine-oak woodlands (Goodwin and Hungerford 1979, Ward and Block 1995). Pinyon mice occur in pinyon-juniper and xeric oak woodlands (Cranford 1982, Morrison and Hall 1998).

Ward and Block (1995) described habitat associations of deer mice in ponderosa pine/Gambel oak forests of northern Arizona. They found that deer mice used more open sites with less shrub and midstory canopy, and smaller densities of Gambel oak. They also found deer mice used sites with more slash piles and greater litter depth. Goodwin and Hungerford (1979) found that deer mice were correlated with stump and log density. They found that mice hid in larger logs or stumps, fallen logs created spaces for nesting, and that mice also nested inside bark that had separated from stumps and logs. At the stand level, I found deer mice were more abundant in areas with higher densities of large Gambel oak. Deer mice were less abundant in stands with high densities of small ponderosa pine snags. Small ponderosa pine snags were correlated with high densities of live ponderosa pine (R = 0.71, *P* = 0.02); deer mice were therefore less abundant in dense ponderosa pine stands. At the trap station level, deer mice were more abundant in areas with high forb cover and live tree basal area.
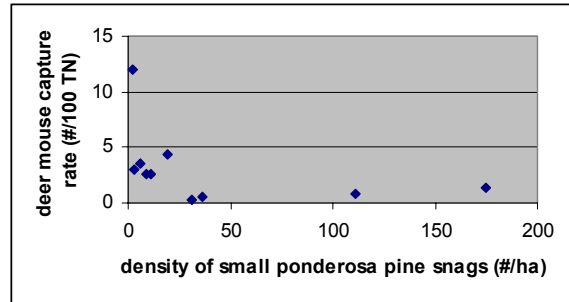
Gambel oak was an important predictor of deer mouse density. Because deer mice are generalists positively correlated with Gambel oak and negatively correlated with high densities of ponderosa pine, I hypothesize that deer mice will continue to increase in density in treated units for several years following treatment; then populations will stabilize.
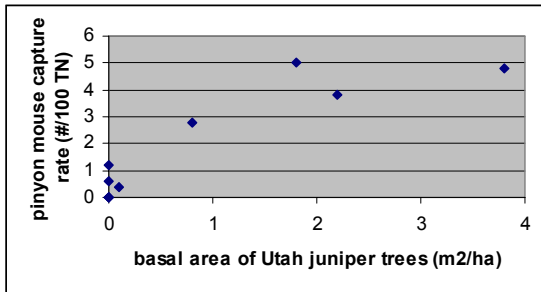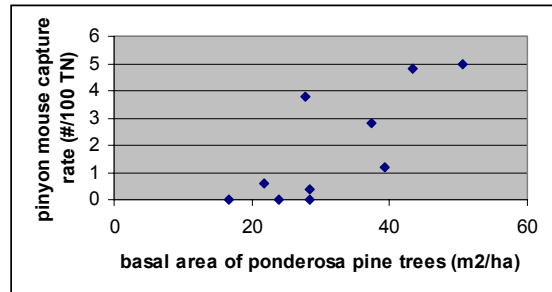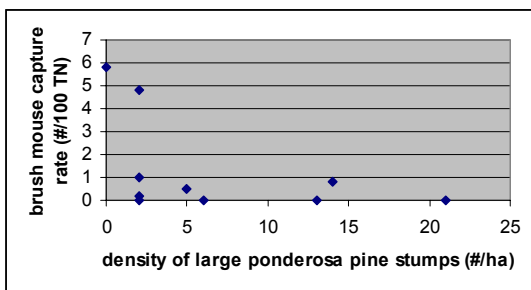
A.
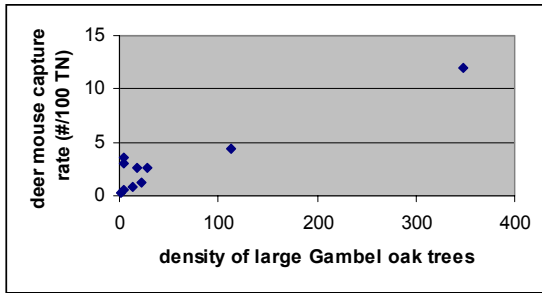
B.

C.

D.

E.

Figure 1—Spearman correlations for habitat variables that were used in multiple linear regression models for deer mouse (A and B), pinyon mouse (C and D), and brush mouse (E). Capture rate is standardized as number of individuals captured per 100 trap nights (#/100 TN). Large Gambel oak were >15 cm diameter. Small ponderosa pine snags were $\leq$50 cm dbh; large ponderosa pine stumps were >50 cm diameter.

Ward and Block (1995) found brush mice more abundant in areas with steeper slopes, low vegetation cover, sparse tree canopy cover, greater Gambel oak basal area, greater Gambel oak tree and shrub density, greater log volume, and less ponderosa pine basal area. Goodwin and Hungerford (1979) found high densities of brush mice along rocky slopes. These animals used windrowed slash piles. Goodwin and Hungerford (1979) also found that brush mice were much less abundant in areas of pure ponderosa pine or in mixed pine-juniper forest. I found few correlations between brush mice and habitat variables. The regression model I developed for brush mice explained less variation than models developed for pinyon and deer mice. Brush mice were negatively correlated with large ponderosa pine stump density. Brush mice were captured most frequently at Mt. Trumbull in an area with rocky basalt-derived soils adjacent to a recent (~6,000 BP) lava flow. I found large ponderosa pine stumps were negatively correlated with large ponderosa pine trees (R = -0.55, P = 0.10), which may indicate that brush mice were using more open sites. Lichen cover (likely an indicator of rock cover), large ponderosa pine and small Gambel oak trees were predictors of brush mouse habitat at the trap-station level, indicating their use of more open, brushy, rocky habitats. I hypothesize that brush mice populations will remain stable or slightly increase following harvest treatment since they are less reliant on overstory cover but use shrub and rock cover for habitat. Shrubs will likely increase on treated units; rock cover will not change.

I found no studies that documented habitat use of pinyon mice in ponderosa pine forests. I found that pinyon mice were associated with Utah juniper and ponderosa pine basal area. Pinyon mice were captured most frequently in stands with high densities of small diameter trees. These sites were lower in elevation, with higher densities of Utah juniper and pinyon pine. At the trap-station level, pinyon mice were captured in areas with high pinyon pine density, and high abundance of small Gambel oak trees and small ponderosa pine stumps. Suppression mortality may have resulted in high densities of small logs on the forest floor in these stands, but high densities of down wood may not necessarily be the cause of pinyon mouse habitat use. Other factors, such as the presence of pinyon pine and Utah juniper, may have been more important influences in use of habitat by pinyon mice. I hypothesize that pinyon mice populations will decline following harvest since pinyon mice are associated with high density of small diameter trees.

I found associations between habitat elements and relative abundance for each *Peromyscus* species; however, in most cases there was little consistency between the trap-station analyses and the stand-level comparisons. Multiple linear regression and logistic regression examine habitat relationships at different scales, so these results are not necessarily surprising (Block and others 1998).

Importance of Dead Wood and Effects of Forest Management on Dead Wood

The models that I developed to predict the presence of *Peromyscus* species included elements of dead wood. However, there were no consistent patterns of dead wood use at the two spatial scales (trap-station level and stand-level) I examined. Either strong patterns of use of dead wood by these species are different at different spatial scales, do not exist, or I could not detect them because of small sample sizes.

Deer mice are considered habitat generalists, so they may use elements of dead wood opportunistically. Brush mice and pinyon mice may be more specialized in

their use of habitat than deer mice, but they also appear able to use a variety of habitats. When we released animals, they frequently used stumps or logs as escape cover, and I expect they also used these sites as nesting and feeding sites. However, I could not provide convincing evidence to link dead wood and *Peromyscus* species. In the Pacific Northwest, Butts and McComb (2000) and Maser and others (1981) suggested that other forms of cover (for example, fern cover) might replace logs as protective cover. This might also be the case in the Southwest, with animals using areas with shrubs or rocky substrates for hiding cover. If mice use logs as movement pathways (e.g., we observed pinyon mice running beside or on top of large [>50 cm diameter] down wood), logs may not be as readily replaced by other forms of cover.

Snags have been more studied than down wood. The importance of snags is well documented in the Southwest and in other forest ecosystems. Some species (e.g., cavity nesters) must use snags or live trees with decay; without them they lack breeding sites. Artificial devices (boxes) can be used by some species as substitutes; however, these are often costly to set up and maintain.

How might forest management affect dead wood? Live trees may be retained to use as replacement snags and logs in the future. During thinning operations, large snags and logs can be protected. Down wood can be added by piling or windrowing slash, or by felling trees. However, slash piles break down quickly and their structure changes. Slash piles may be useful as cover for only a short period of time, until the wood begins to decay and collapses and no longer provides air spaces and movement corridors (W. Block, Project Leader, Rocky Mountain Research Station, Flagstaff, Arizona, pers. comm.). The effects of prescribed fires on dead wood are less predictable. Fire can create dead wood by killing live trees, or it can remove dead wood by incinerating snags and logs. Attempts to clear debris around snags and logs to protect them during prescribed burning has had mixed success; often a large portion of the dead wood is incinerated. Continuation of these studies will help clarify the effects of forest management treatments on dead wood and habitat relationships of these *Peromyscus* species.

Acknowledgments

References

Balda, R. P. 1975. **The relationship of secondary cavity nesters to snag densities in western coniferous forests.** Flagstaff, AZ: Northern Arizona University; Albuquerque, NM: USDA Forest Service, Southwest Reg. Wildl. Hab. Tech. Bull. #1; 37 p.

Balda, R. P.; Gaud, W. S.; Brawn, J. D. 1983. **Predictive models for snag nesting birds.** Davis, J. W.; Goodwin, G. A.; Ockenfels, R. A., technical coordinators. Snag habitat management: proceedings of the symposium; Flagstaff, AZ. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, USDA Forest Service; 216-222.

Bergvinson, D. J.; Borden J. H. 1992. **Enhanced woodpecker predation on the mountain pine beetle, Dendroctonus ponderosae Hopk., in glyphosate-treated lodgepole pines.** Can. Ent. 124: 159-165.

Block, W. M.; Finch, D. M. 1997. **Songbird ecology in southwestern ponderosa pine forests.** Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, USDA Forest Service.

Block, W. M.; Morrison, M. L.; Scott, P. E. 1998. **Development and evaluation of habitat models for herpetofauna and small mammals.** Forest Science 44: 430-437.

Boucher, P. F., Block, W. M.; Benavidez, G. V.; Wiebe, L. E. 1999. **Implementing the expanded prescribed fire program on the Gila National Forest, New Mexico: Implications for snag management.** Tall Timbers Fire Conference 20: 374-379.

Brawn, J. D.; Balda, R. P. 1988. **Population biology of cavity nesters in northern Arizona: do nest sites limit breeding densities?** Condor 90: 61-71.

Burnham, K. P.; Anderson D. R. 1998. **Model selection and inference.** New York: Springer-Verlag, Inc.; 353 p.

Butts, S. R.; McComb, W. C. 2000. **Associations of forest-floor vertebrates with coarse woody debris in managed forests of western Oregon.** Journal of Wildlife Management 64: 95-104.

Chambers, C. L.; McComb, W. C.; Tappeiner, II, J. C. 1999. **Breeding bird responses to three silvicultural treatments in the Oregon Coast Range.** Ecological Applications 9: 171-185.

Cochran, P. H.; Hopkins, W. E. 1991. **Does fire exclusion increase productivity of ponderosa pine?** In: Harvey, A. E.; Neuenschwander, L. F., compilers. Proceedings—management and productivity of western-montane forest soils; 1990 April 10-12; Boise, ID. Gen. Tech. Rep. INT-280. Ogden, UT: Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 224-228.

Conway, C. J.; Martin, T. E. 1993. **Habitat suitability for Williamson's sapsuckers in mixed-conifer forests.** Journal of Wildlife Management 57: 322-328.

Cooper, C. F. 1960. **Changes in vegetation, structure, and growth of southwestern pine forests since white settlement.** Ecological Monographs 30: 129-164.

Covington, W. W.; Sackett, S. S. 1984. **The effect of a prescribed burn in southwestern ponderosa pine on organic matter and nutrients in woody debris and forest floor.** Forest Science 30: 183-192.

Covington, W. W.; Moore, M. M. 1994. **Southwestern ponderosa forest structure: changes since Euro-American settlement.** Journal of Forestry 92: 39-47.

Covington, W. W.; Fulé, P. Z.; Moore, M. M.; Hart, S. C.; Kolb, T. E.; Mast, J. N.; Sackett, S. S.; Wagner, M. R. 1997. **Restoring ecosystem health in ponderosa pine forests of the southwest.** Journal of Forestry 95: 23-29.

Cranford, J. A. 1982. **The effect of woodrat houses on population density of *Peromyscus*.** Journal of Mammalogy 63(4): 663-666.

Crocker-Bedford, C. 1993. **Large snags are important.** Southwest Habitater 6(6): 6 p.

Cunningham, J. B.; Balda, R. P.; Gaud, W. S. 1980. **Selection and use of snags by secondary cavity-nesting birds of the ponderosa pine forest.** Res. Paper RM-222. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, USDA Forest Service; 15 p.

Dahms, C. W.; Geils, B. W. 1997. **An assessment of forest ecosystem health in the southwest.** Gen. Tech. Rep. RM-295. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, USDA Forest Service; 97 p.

Degenhardt, W. G.; Painter, C. W.; Price, A. H. 1996. **Amphibians and reptiles of New Mexico.** Albuquerque, NM: University of New Mexico Press; 431 p.

Dwyer, J. K. 2000. **Response of secondary cavity-nesting birds to wildfire in ponderosa pine forests of northern Arizona.** Flagstaff, AZ: Northern Arizona University; 58 p. M.S. thesis.

Ffolliott, P. F. 1983. **Implications of snag policies on management of southwestern ponderosa pine forests**. Davis, J. W.; Goodwin, G. A.; Ockenfels, R. A., technical coordinators. Snag habitat management: proceedings of the symposium; Flagstaff, AZ. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, USDA Forest Service; 28-32.

Franzreb, K. E. 1978. **Tree species used by birds in logged and unlogged mixed-coniferous forests.** Wilson Bulletin 90: 221-238.

Franzreb, K. E.; Ohmart, R. D. 1978. **The effects of timber harvesting on breeding birds in a mixed-coniferous forest.** Condor 80: 431-441.

Gaines, E. M.; Kallander, H. R.; Wagner J. A. 1958. **Controlled burning in southwestern ponderosa pine: Results from the Blue Mountain Plots, Fort Apache Indian Reservation.** Journal of Forestry 56: 323-327.

Ganey, J. L. 1999. **Snag density and composition of snag populations on two National Forests in northern Arizona.** Forest Ecology and Management 117: 169-178.

Germaine, S. S. 1999. **Short-term effects of ponderosa pine forest restoration on wildlife at Mt. Trumbull, Arizona: 1997 & 1998 data.** Phoenix, AZ: Arizona Game and Fish Department; 43 p.

Goodwin, Jr., J. G.; Hungerford, C. R. 1979. **Rodent population densities and food habits in Arizona ponderosa pine forests.** Res. Pap. RM-214. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, USDA Forest Service; 12 p.

Gordon, J. V. 1996. **Effects of prescribed fire on snags and logs in northern Arizona ponderosa pine forests.** Flagstaff, AZ: Northern Arizona University; 59 p. M.S. thesis.

Graham, R. T.; Harvey, A. E.; Jurgensen, M. F.; Jain, T. B.; Tonn, J. R; Page-Dumroese, D. S. 1994. **Managing coarse woody debris in forests of the Rocky Mountains.** Ogden, UT: Intermountain Research Station, USDA Forest Service; 12 p.

Grissino-Mayer, H. D.; Swetnam, T. W. 2000. **Century-scale climate forcing of fire regimes in the American Southwest.** The Holocene 10(2): 213-220.

Hall, L. S.; Morrison, M. L. 1997. **Den and relocation site characteristics and home ranges of *Peromyscus truei* in the White Mountains of California.** Great Basin Naturalist 57: 124-130.

Hay, D. B.; Guntert, M. 1983. **Seasonal selection of tree cavities by pygmy nuthatches based on cavity characteristics.** Davis, J. W.; Goodwin, G. A.; Ockenfels, R. A., technical coordinators. Snag habitat management: proceedings of the symposium; Flagstaff, AZ. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, USDA Forest Service; 117-120.

Horton, S. P.; Mannan, R. W. 1988. **Effects of prescribed fire on snags and cavity-nesting birds in southeastern Arizona pine forests.** Wildlife Society Bulletin 16: 37-44.

Keller, R. 1992. **Effect of ponderosa pine overstory and snags on the songbird community, northern Arizona**. Stafford, AZ; 19 p.

Klemmedson, J. O.; Smith, E. L. 1979. **Vegetation-soil relations of forests, woodlands, and grasslands of Arizona and New Mexico.** In: Forest soils and land use. Fort Collins, CO: Department of Forest and Wood Sciences, Colorado State University; 42-67.

Kyle, S. C. 2000. **Abundance and habitat correlates of small mammals following varied-severity wildfire in ponderosa pine-bunchgrass forests.** Flagstaff, AZ: Northern Arizona University; 125 p. M.S. thesis.

Li, P.; Martin, T. E. 1991. **Nest-site selection and nesting success of cavity-nesting birds in high elevation forest drainages.** Auk 108: 405-418.

Maser, C.; Mate, B. R.; Franklin, J. F.; Dyrness, C. T. 1981. **Natural history of Oregon coast mammals.** Gen. Tech. Rep. PNW-133. Portland, OR: Pacific Northwest Research Station: USDA Forest Service.

Maser, C.; Maser, Z.; Molina, R. 1988. **Small mammal mycophagy in rangelands of central and southeastern Oregon.** Journal of Range Management 41: 309-312.

Mast, J. N.; Fulé, P. Z.; Moore, M. M.; Covington, W. W.; Waltz, A. E. M. 1999. **Restoration of presettlement age structure of an Arizona ponderosa pine forest.** Ecological Applications 9(1): 228-239.

Meyer, W. H. 1961. **Yield of even-aged stands of ponderosa pine.** Technical Bulletin No. 630, revised. Washington, DC: USDA; 59 p.

Miller, R.; Benedict, C. 1994. **Arizona Game and Fish Department snag recruitment model, snag recruitment and longevity modeling.** Feb 4-5, 1994; 16 p.

Mollohan, C.; Brady, W. W.; LeCount, A. L. 1989. **Habitat use of an Arizona ponderosa pine-mixed conifer forest by female black bears.** Western Journal of Applied Forestry 41: 6-10.

Morrison, M. L.; Hall, L. S. 1998. **Responses of mice to fluctuating habitat quality I. Patterns from a long-term observational study.** Southwestern Naturalist 43(2): 123-136.

Neitro, W. A.; Binkley, V. W.; Cline, S. P.; Mannan, R. W.; Marcot, B. G.; Taylor, D.; Wagner, F. F. 1985. **Snags.** In: Brown, E. R., technical editor. Management of wildlife and fish habitats in forests of western Oregon and Washington. Pub. R6-F&WL-192-1985. Portland, OR: Pacific Northwest Region, U.S. Department of Agriculture; 129-169.

Pearson, G. A. 1937. **Mortality in cutover stands of ponderosa pine.** Journal of Forestry 35: 383-387.

Peterson, S. R. 1980. **The role of birds in western communities.** In: DeGraff, R. M.; Tilghman, N. G., compilers. Management of western forests and grasslands for non-game birds: proceedings of the workshop; 1980 February 11-14; Salt Lake City, UT. Gen. Tech. Rep. INT-86. Ogden, UT: Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 6-12.

Rabe, M. J.; Morrell, T. E.; Green, H.; deVos, Jr., J. C.; Miller, C. R. 1998. **Characteristics of ponderosa pine snag roosts used by reproductive bats in northern Arizona.** Journal of Wildlife Management 62: 612-621.

Randall-Parker, T.; Miller, R. 2002. **Effects of prescribed fire in ponderosa pine on key wildlife habitat components: preliminary results and a method for monitoring.** In: Laudenslayer, William F., Jr.; Shea, Patrick J.; Valentine, Bradley E.; Weatherspoon, C. Phillip; Lisle, Thomas E., technical coordinators. Proceedings of the symposium on the ecology and management of dead wood in western forests. 1999 November 2-4; Reno, NV. Gen. Tech. Rep. PSW-GTR-181. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; [this volume].

Reynolds, R. T.; Graham, R. T.; Reiser, M. H.; Bassett, R. L.; Kennedy, P. L.; Boyce, Jr. D. A.; Goodwin, G.; Smith, R.; Fisher, E. L. 1992. **Management recommendations for the northern goshawk in the southwestern United States.** Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, USDA Forest Service.

Sabin, T. E.; Stafford, S. G. 1990. **Assessing the need for transformation of response variables.** Special Publications 20, Forest Research Lab, Oregon State University, Oregon; 31 p.

SAS Institute, Inc. 1985. **SAS user's guide: statistics 5th ed.** Cary, North Carolina.

SAS Institute, Inc. 1990. **SAS/STAT user's guide, version 6, 4th edition, Volume 2.** Cary, NC: SAS Institute Inc., 1989; 1072-1126.

Scott, V. E. 1978. **Characteristics of ponderosa pine snags used by cavity-nesting birds in Arizona.** Journal of Forestry 76: 26-28.

Scott, V. E. 1979. **Bird response to snag removal in ponderosa pine.** Journal of Forestry 77: 26-28.

Scott, V. E.; Oldemeyer J. L. 1983. **Cavity-nesting bird requirements and response to snag cutting in ponderosa pine.** In: Davis, J. W.; Goodwin, G. A.; Ockenfels, R. A., technical coordinators. Snag habitat management: proceedings of the symposium. Gen. Tech. Rep. RM-99. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 19-23.

Scott, V. E.; Patton, D. R. 1989. **Cavity-nesting birds of Arizona and New Mexico forests.** Gen. Tech. Rep. RM-10. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 71 p.

Smith, G. R. 1996. **Habitat use and fidelity in the striped plateau lizard *Sceloporus virgatus*.** American Midland Naturalist 135: 68-80.

Smith, A. A.; Mannan, R. W. 1994**. Distinguishing characteristics of Mount Graham red squirrel midden sites.** Journal of Wildlife Management 58: 437-445.

Sokal, R. R.; Rohlf, F. J. 1981. **Biometry.** 2nd ed. New York: W. H. Freeman and Company; 663-671.

Szaro, R. C.; Balda, R. P. 1986. **Relationships among weather, habitat structure, and ponderosa pine forest birds.** Journal of Wildlife Management 50(2): 253-260.

Touchan, R.; Allen, C. D.; Swetnam, T. W. 1996. **Fire history and climatic patterns in ponderosa pine and mixed-conifer forests of the Jemez Mountains, northern New Mexico.** In: Allen, C. D., technical editor. Fire effects in southwestern forests: Proceedings of the second La Mesa fire symposium; 1994 March 29-31; Los Alamos, NM. Gen. Tech. Rep. RM-GTR-286 Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 33-46.

Vahle, J. R.; Patton, D. R. 1983. **Red squirrel cover requirements in Arizona mixed conifer forests.** Journal of Forestry 81: 14-15, 22.

Wadsworth. 1943. **Lightning damage in ponderosa pine stands of northern Arizona.** Journal of Forestry 41: 684-685.

Ward, J. P.; Block, W. M. 1995. **Mexican spotted owl prey ecology.** In: Mexican spotted owl recovery plan. Volume II. Albuquerque, NM: USDI Fish and Wildlife Service; 1-48.