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Guidelines for Managing Small Mammals in Restored Ponderosa Pine Forests of Northern Arizona

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Ecological Restoration Institute
P.O. Box 15017
Flagstaff, AZ 86011-5017
www.eri.nau.edu

Working Papers in Intermountain West Frequent-fire Forest Restoration

Ecological restoration is a practice that seeks to heal degraded ecosystems by reestablishing native species, structural characteristics, and ecological processes. The Society for Ecological Restoration International defines ecological restoration as “an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability….Restoration attempts to return an ecosystem to its historic trajectory” (Society for Ecological Restoration International Science & Policy Working Group 2004).

Most frequent-fire forests throughout the Intermountain West have been degraded during the last 150 years. Many of these forests are now dominated by unnaturally dense thickets of small trees, and lack their once diverse understory of grasses, sedges, and forbs. Forests in this condition are highly susceptible to damaging, stand-replacing fires and increased insect and disease epidemics. Restoration of these forests centers on reintroducing frequent, low-severity surface fires—often after thinning dense stands—and reestablishing productive understory plant communities.

The Ecological Restoration Institute at Northern Arizona University is a pioneer in researching, implementing, and monitoring ecological restoration of frequent-fire forests of the Intermountain West. By allowing natural processes, such as low-severity fire, to resume self-sustaining patterns, we hope to reestablish healthy forests that provide ecosystem services, wildlife habitat, and recreational opportunities.

The ERI Working Papers series presents findings and management recommendations from research and observations by the ERI and its partner organizations. While the ERI staff recognizes that every restoration project needs to be site specific, we feel that the information provided in the Working Papers may help restoration practitioners elsewhere.

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Cover Photo: The golden-mantled ground squirrel *(Spermophilus lateralis)* pictured here was one of eight small mammals studied by NAU researchers to determine how they would react to ecological restoration thinning treatments. The results indicate that thinning had a generally positive or neutral effect on six of the species, including the golden-mantled ground squirrel.
Photo courtesy of George Andrejko, Arizona Game and Fish Department

Introduction

Restoration thinning and burning treatments in southwestern ponderosa pine (*Pinus ponderosa*) forests are designed to both reduce the risk of wildfire and restore ecosystem functions and structure, including maintaining or reestablishing habitat for wildlife populations. However, we found limited quantitative data regarding wildlife responses to restoration treatments and changes in forest structure because most previous studies were conducted at small temporal and spatial scales, and they generally focused on bird species (Kalies et al. 2010). In addition, although habitat components, such as Gambel oak (*Quercus gambelii*), large-diameter trees, snags and down wood, are thought to be important to wildlife, there is debate about treatment targets on the landscape (Abella et al. 2006, Noss et al. 2006). In this ERI working paper, we present the results of a study that assessed small mammal responses to treatments--responses previously unexamined at the community level or at large temporal and spatial scales in southwestern ponderosa pine forests.

Our study focused on eight species of small mammals: the Mogollon vole (*Microtus mogollonensis* (formerly Mexican vole, *M. mexicanus*; Frey and LaRue 1993, Frey and Yates 1995), Mexican woodrat (*Neotoma mexicana*), deer mouse (*Peromyscus maniculatus*), tassel-eared squirrel (*Sciurus aberti*), golden-mantled ground squirrel (*Spermophilus lateralis*), rock squirrel (*Spermophilus variegates*), gray-collared chipmunk (*Tamias cinereicollis*), and Botta's pocket gopher (*Thomomys bottae*). Small mammals are important in forest ecosystems because they recycle nutrients by processing vegetation, disperse fungal spores and seeds, and aerate and turn soils. Small mammals are also prey for predators including the northern goshawk (*Accipiter gentilis*; a U.S. Forest Service Sensitive Species), Mexican spotted owl (*Strix occidentalis lucida*; federally threatened), and other avian and mammalian species (Reynolds et al. 1992, Block et al. 2005). The dispersion of ectomycorrhizal fungi, which is critical to tree growth and health, is likely heavily reliant on small mammal disturbance and transfer through feces (Johnson 1996). For example, tassel-eared squirrels are known to disperse ectomycorrhizal fungi in ponderosa pine forests (States 1984, Dodd et al. 2003), and ground squirrels and other species may play this role as well (Pyare and Longland 2001).

Although small mammal species may serve similar functional roles in the ecosystem, their habitats differ. For example, chipmunks and deer mice are generalists, found in a variety of forest types and age classes. Meanwhile, research suggests that tassel-eared squirrels are specialists and may respond negatively to a reduction in ponderosa pine trees, which they depend on for nesting (Patton 1977, Dodd et al. 2006). However, Wightman and Rosenstock (unpublished data) found that up to 75% of the landscape can be treated while still providing adequate habitat for tassel-eared squirrels. Other small mammals, including the Mogollon vole, golden-mantled ground squirrel, and pocket gopher, occupy more open forest structure and may benefit from openings and the increased understory vegetation cover (Converse et al. 2006, Bagne and Finch 2009). Woodrats and rock squirrels are associated with more specific habitat features, such as shrub cover and rocky outcrops, respectively (Hoffmeister 1986, Block et al. 2005). Thus, land managers need to consider both forest structural differences and fine-scale habitat features when considering small mammal-habitat relationships in treated ponderosa pine forests.

Small Mammal-Habitat Relationships

During 2006-2009, we trapped eight species of small mammals at 294 sites in northern Arizona, on the Coconino National Forest near Flagstaff and the Kaibab National Forest near Jacob Lake. Historically, these areas experienced a variety of forest management practices, including high grading (early 1900s), commercial logging (1970-1990s) and fuels reduction and restoration treatments (late 1990s-present). This land use history created a range of stand structures in terms of tree basal area and density from which we randomly selected sites. We used occupancy modeling (MacKenzie et al. 2006) and model selection to determine wildlife responses to thinning treatments and habitat features (see Kalies 2010 for further details on the study). We evaluated small mammal occupancy, or the probability (from 0 to 1) of a species being present at a site, rather than small mammal density because occupancy is less susceptible to year-to-year environmental changes. We analyzed 14 habitat variables to determine which were most important in predicting small mammal species and community occupancy (Table 1). These variables are presented below along with an explanation of how they affected small mammal occupancy.

Pine basal area/tree density

Tree density and basal area are critical habitat variables because they 1) can be directly manipulated through management and 2) affect most of the small mammal community. Tree density (which ranged from 16 trees/acre to 1,943 trees/acre; average 286 trees/acre) was highly correlated with pine basal area in our study. Six of the eight small mammal species decreased in occupancy on sites with higher pine basal area, whereas tassel-eared squirrels and woodrats increased in those areas (Figure 1). Tassel-eared squirrels use the tree canopy for cover, food and nesting (Patton 1977), while woodrats are usually found in sites with high tree and shrub density and down wood for cover (Block et al. 2005). Of the variables we analyzed, this one had the greatest effect on the overall small mammal community (7 of the 8 species; Table 1).

Time since treatment

Time since treatment (thinning or logging) represents a range from current restoration or fuels reduction treatments (0 years) to stands that have not been treated since the late 1800s (109 years); most sites in this study were treated less than 20 years ago. Time since treatment was an important variable for four species--Mexican woodrat (+), Mogollon vole (-), rock squirrel (-), and gray-collared chipmunk (-) (Table 1). The only species that increased in occupancy in untreated sites were woodrats, tassel-eared squirrels, and pocket gophers (Figure 2). Woodrats and tassel-eared squirrels benefit from the cover of increased tree density and basal area associated with greater time since treatment or no treatment. Pocket gophers may be associated with untreated sites (although they also occupy sites with lower pine basal area, see above) because they require areas where they can create burrow systems free of the disturbance (i.e., compaction) caused by the heavy machinery used during thinning treatments.

Presence of Slash/Duration of Slash Piles
After thinning treatments, slash was piled and then burned immediately or within three years. Either the presence or duration of slash piles left on the ground was important for woodrats, golden-mantled ground squirrels, and rock squirrels (Table 1). Duration of slash was the only variable to produce positive occupancy responses from all but one small mammal species--the pocket gopher (Figure 3), which lives underground and derives no benefits from slash. Moreover, pocket gophers may have been adversely affected by machinery as explained above.

Understory vegetation
A structurally and compositionally diverse understory provides food and cover for many small mammal species. We found a positive relationship between understory vegetation cover, richness, and height. We excluded understory vegetation height from further analysis because it was not well represented across the sites sampled. Understory vegetation species richness was important for two species--gray-collared chipmunk (+) and Botta's pocket gopher (+) (Table 1). Meanwhile, understory vegetation cover was an important variable for five species--Mogollon vole (+), gray-collared chipmunk (+), Botta's pocket gopher (+), Mexican woodrat (-), and rock squirrel (-) (Table 1). Woodrat, tassel-eared squirrel, and rock squirrel occupancy was negatively associated with increased understory vegetation cover (Figure 4). This may be because these three species rely on fungi, pine trees, and nuts more heavily than understory vegetation for food (Hoffmeister 1986).

Clumpiness
We attempted to assess the "clumpiness" of trees, which we defined as the percent understory vegetation cover divided by the total overstory basal area per acre. The rationale behind this ratio is that in two stands of equal basal area, a more clumpy arrangement of trees would result in higher understory percent cover than evenly spaced trees. In our metric, high values indicate a clumpy arrangement and low values indicate an even distribution of trees. Clumpiness was an important variable for three species--Mogollon vole (+), Botta's pocket gopher (+), and Mexican woodrat (-) (Table 1). Woodrats probably responded negatively because they prefer dense cover. Vole and pocket gopher occupancy increased in "clumpy" areas because they eat herbaceous vegetation and require open areas to build their elaborate tunnel and burrow systems.

This variable identified species that are particularly sensitive to openings, although all species' responses to clumpiness followed the same trends we observed for understory vegetation cover (Figure 4).

Gambel oak basal area
Gambel oak basal area was an important variable for rock squirrels (+), Mogollon voles (-), and golden-mantled ground squirrels (-) (Table 1). Rock squirrels are highly associated with oak clumps in rocky areas for burrowing and cover. The other three species whose occupancy increased (Mexican woodrat, deer mouse, tassel-eared squirrel) may take advantage of oaks for cover or acorns as a food source (Figure 5).

Large trees
We defined densities of large trees using three thresholds: trees greater than 16 inches, greater than 20 inches, and greater than 24 inches in diameter at breast height (DBH) per acre. Density of trees greater than 20 inches DBH was an important variable for the greatest number of species (three species; Table 1). Nearly all species increased in occupancy, except for voles and golden-mantled ground squirrels (Figure 6). Large trees are important for nesting and cover, particularly for tassel-eared squirrels (Patton and Green 1970). They also provide food, such as truffles, that is associated with mature tree clumps in open, forest stands (Korb et al. 2003).

Snags
We excluded two variables--densities of snags greater than 20 inches and 24 inches DBH per acre--from the analysis because the variables were not well represented across the sites we sampled. We found most small mammal species (six of eight) decreased in occupancy in response to total (all sizes) snag density, but five of the eight species (all, except golden-mantled ground squirrel, rock squirrel, Botta's pocket gopher) increased in occupancy in response to density of snags greater than 16 inches DBH (Figure 7). While small mammals may not be as closely associated with snags as other wildlife species, such as cavity-nesting birds, larger snags provide habitat for small mammals in the form of nesting habitat and cover from predators.

Down wood
In response to down wood, half the community (Mogollon vole, Mexican woodrat, golden-mantled ground squirrel, gray-collared chipmunk) increased in occupancy and the other half (deer mouse, tassel-eared squirrel, rock squirrel, and Botta's pocket gopher) decreased. However, down wood was important to only two species--deer mouse (-) and Botta's pocket gopher (-) (Table 1). Thus, this was not one of the more important variables to the overall small mammal community in this study. However, these results should be interpreted with caution because our study sites had low volumes of down wood, and occupancy rates may have been highly influenced by a few outliers (Table 1). Previous research shows that down wood is an important habitat feature for small mammals because it is used for cover, nesting, and food (Chambers 2002, Converse et al. 2006).

Management Implications and Recommendations

In this section we discuss the management implications of these results and make recommendations based on our findings in respect to eight species of small mammals in northern Arizona ponderosa pine forests. While our recommendations will likely increase occupancy of small mammals, we understand that land managers will determine the desired rates of small animal occupancy in a particular landscape according to the goals and objectives of a given project.

- Restoration treatments will likely increase occupancy for most species of small mammals. Retaining dense clumps and stands of trees on the landscape will ensure habitat for tassel-eared squirrels and Mexican woodrats.
- Higher understory vegetation cover, height, and species richness will benefit most small mammal species. In particular, increased clumpiness and openings will help increase the occupancy of Mogollon voles and pocket gophers.
- Retaining slash piles on the landscape for several years, rather than immediate burning, will increase small mammal occupancy.
- While only one species responded positively to trees greater than 16 inches DBH, three species responded to trees greater than 20 or 24 inches DBH. This may be relevant in determining diameter caps.
- Retaining larger snags (greater than 16 inches) during restoration treatments will increase small mammal occupancy.
- Managers typically retain Gambel oak when implementing thinning treatments, which has resulted in an increase in oak density during the past several decades (Abella and Fulé 2008). Our results showed that increasing oak basal area is not a strong driver of occupancy for the small mammal community, although it is likely important to other wildlife species, especially birds and bats (Rosenstock 1998, Bernardos et al. 2004).
- Down wood is an important habitat feature for some members of the small mammal community, but less important than overstory and understory vegetation composition and structure, according to the results of this study. Slash may be serving as surrogate habitat in the absence of down wood or other types of cover at treated sites.
- Although tassel-eared squirrels remain an indicator of the negative effects of restorative thinning treatments, we suggest the golden-mantled ground squirrel as an indicator of the positive effects because the species had a strong positive response to treatment, slash, and reduced pine basal area. Furthermore, Mogollon voles showed a dramatic response to understory vegetation cover and, thus, may be a good indicator of a restored site.
- The occupancy modeling approach was highly effective in evaluating the response of the small mammal community to treatment and other habitat attributes.

Conclusions

These results support the inference that the small mammal community in southwestern ponderosa pine forests is adapted to an open forest structure with low tree density and a well-developed herbaceous ground cover. However, both open stand and dense stands occurred naturally prior to Euro-American settlement (Noss et al. 2006). Creating and maintaining both stand types across the landscape will lead to higher overall small mammal species diversity. Current forest management in the Southwest tends to promote retention of Gambel oak trees, large ponderosa pine trees, snags, and down wood. Our results showed that these attributes are good for some species, but there is no “one-size-fits-all” solution for the small mammal community at the fine scale. A diversity of these features across the landscape will yield the greatest diversity of small mammal species, and will ensure that associated ecosystem functions (e.g., prey for predators, dispersal of fungi) will be maintained as well.

Acknowledgments

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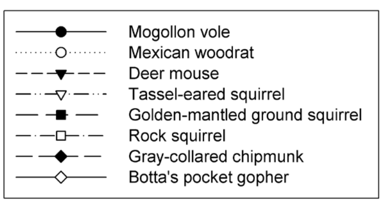
Table 1. Habitat variables analyzed, average and range of each variable, species' responses (positive or negative), and total number of responses across the community. Responses are shown only for variables that are considered to be strong drivers of occupancy for each species.

	Ponderosa pine basal area (ft^2/acre)	Time since treatment (years)	Presence of slash piles	Time slash piles left intact (years)	Understory vegetation (% cover)	Understory species richness	Clumpiness[a]	Gambel oak basal area (ft^2/acre)	Trees >16in (#/acre)	Trees >20in (#/acre)	Trees >24in (#/acre)	All snags (#/acre)	Snags >16in (#/acre)	Down wood volume (ft^3/ft^2)
Average (range) of habitat variable	145 (0-475)	24 (1-109)	0.2 (0-1)	0.4 (0-3)	21 (0-65)	8 (1-19)	0.3 (0-6)	8 (0-183)	28 (0-97)	10 (0-97)	4.4 (0-65)	22 (0-453)	1.0 (0-16)	155 (0-6267)
Mogollon vole	-	-			+		+	-	-	-		-	+	
Mexican woodrat	+	+	+		-		-							
Deer mouse										+	+		+	-
Tassel-eared squirrel	+									+				
Golden-mantled ground squirrel	-		+	+				-				-	-	
Rock squirrel	-	-		+	-			+						
Gray-collared chipmunk	-	-			+	+			+			-	+	
Botta's pocket gopher	-				+	+	+				+	-		-
Total # species	**7**	**4**	**2**	**2**	**5**	**2**	**3**	**3**	**2**	**3**	**2**	**4**	**4**	**2**

a Clumpiness was calculated as: percent understory vegetation cover/total overstory basal area per acre.



Figures 1-7 display the occupancy rates of eight small mammals in seven different habitat settings.

Figure 1

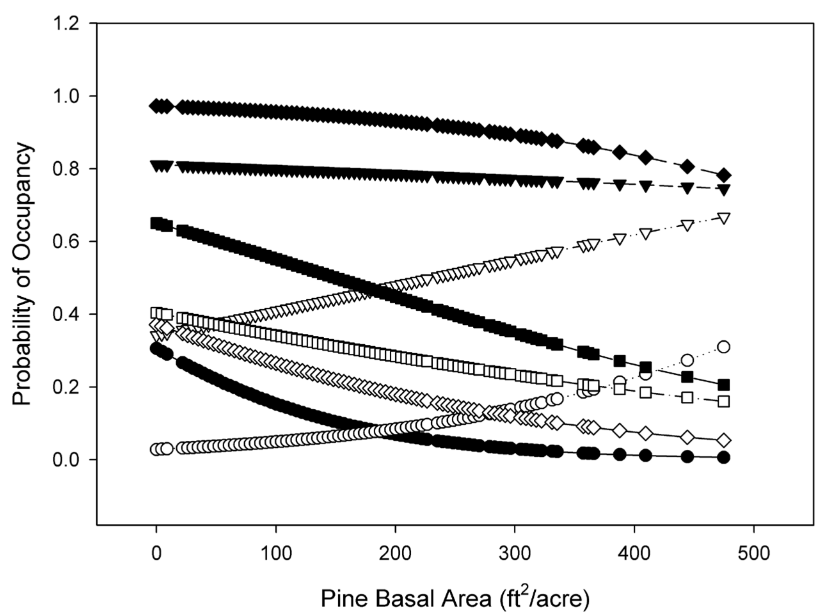


Figure 2

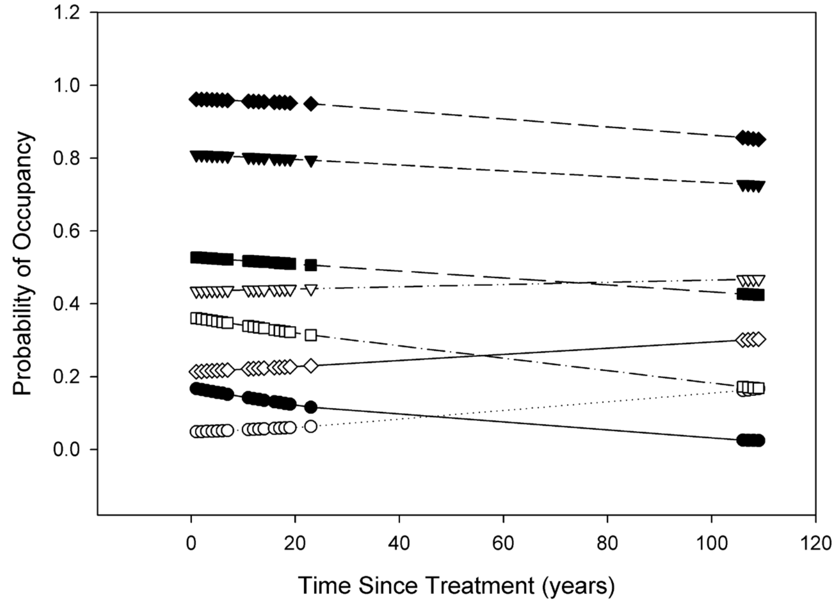


Figure 3

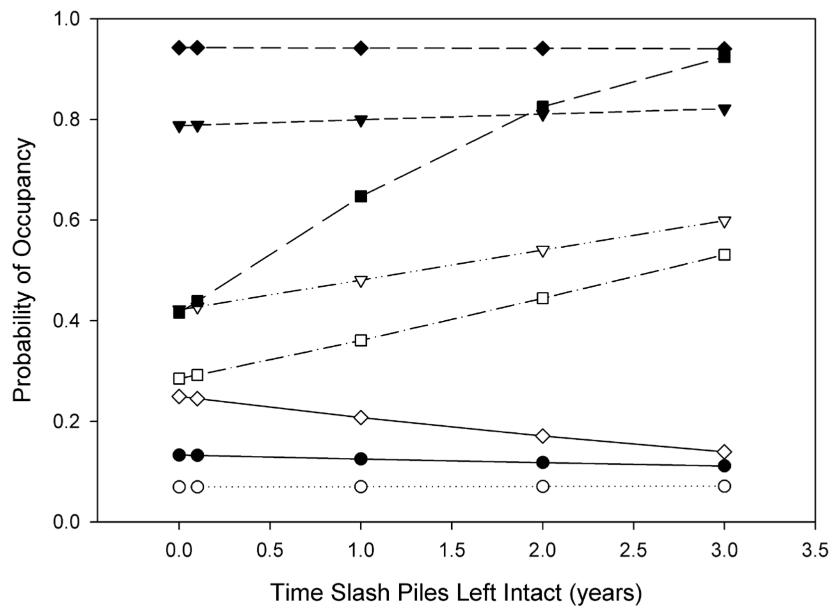
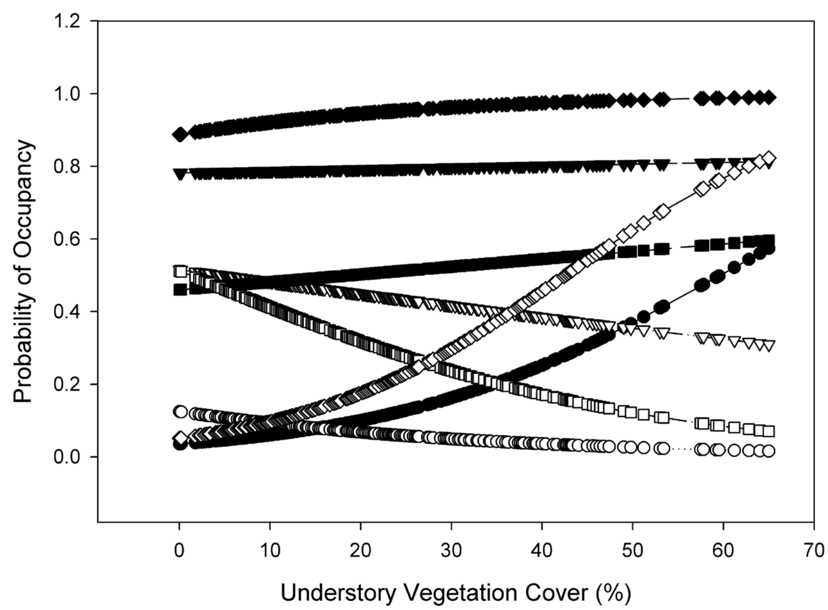


Figure 4



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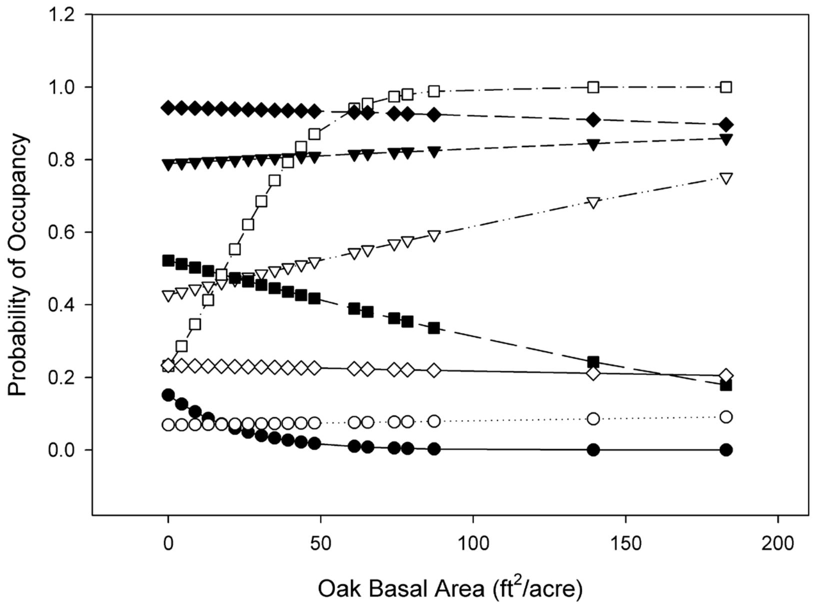


Figure 6

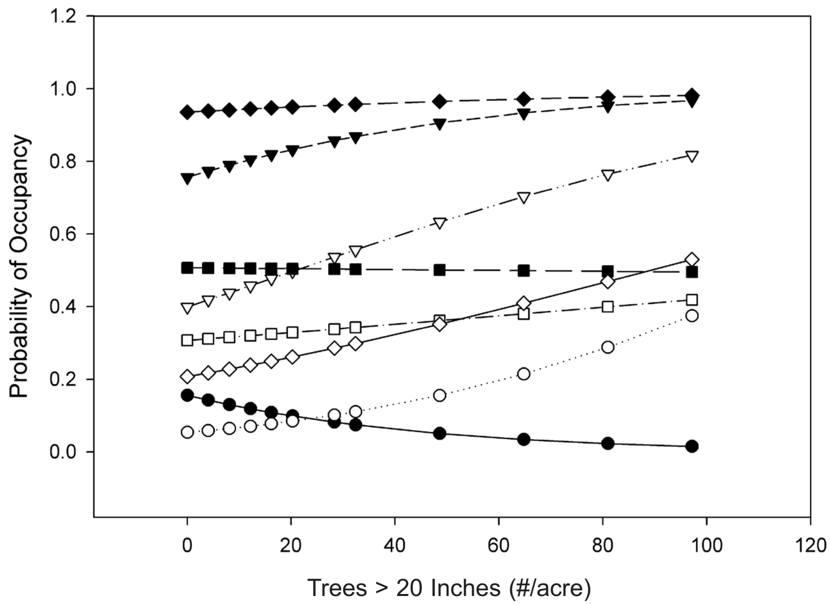
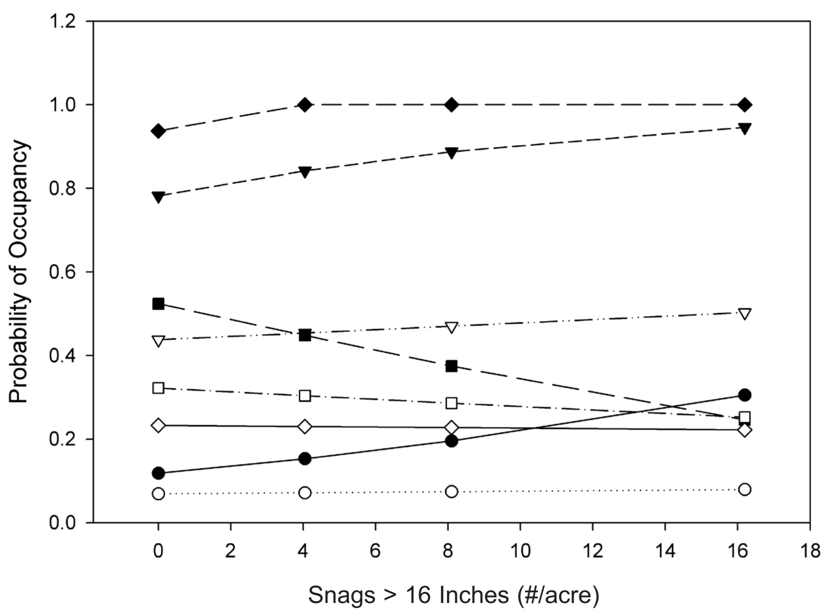


Figure 7



References

Abella, S.R. and P.Z. Fulé. 2008. Changes in Gambel oak densities in southwestern ponderosa pine forests since Euro-American settlement. Report Research Note RMRS-RN-36. Fort Collins, CO: U.S. Dept. of Agriculture Forest Service Rocky Mountain Research Station.

Abella, S.R., P.Z. Fulé, and W.W. Covington. 2006. Diameter caps for thinning southwestern ponderosa pine forests: viewpoints, effects, and tradeoffs. *Journal of Forestry* 104:407-414.

Bagne, K.E. and D.M. Finch. 2009. Response of small mammal populations to fuel treatment and precipitation in a ponderosa pine forest, New Mexico. *Restoration Ecology.* Available online at http://www3.interscience.wiley.com/cgi-bin/fulltext/122648890/PDFSTART.

Bernardos, D.A., C.L. Chambers, and M.J. Rabe. 2004. Selection of Gambel oak roosts by southwestern Myotis in ponderosa pine-dominated forests, northern Arizona. *Journal of Wildlife Management* 68:595-601.

Block, W.M., J.L. Ganey, P.E. Scott, and R. King. 2005. Prey ecology of Mexican spotted owls in pine-oak forests of northern Arizona. *Journal of Wildlife Management* 69:618-629.

Chambers, C.L. 2002. Forest management and the dead wood resource in ponderosa pine forests: effects on small mammals. Pages 679-693 in Proceedings of Proceedings of the Symposium on the Ecology and Management of Dead Wood in Western Forests. General Technical Report PSW-GTR-181:679-693.

Converse, S.J., W.M. Block, and G.C. White. 2006. Small mammal population and habitat responses to forest thinning and prescribed fire. *Forest Ecology and Management* 228:263-273.

Dodd, N.L., R.E. Schweinsburg, and S. Boe. 2006. Landscape-scale forest habitat relationships to tassel-eared squirrel populations: implications for ponderosa pine forest restoration. *Restoration Ecology* 14:537-547.

Dodd, N.L., J.S. States, and S.S. Rosenstock. 2003. Tassel-eared squirrel population, habitat condition, and dietary relationships in north-central Arizona. *Journal of Wildlife Management* 67:622-633.

Frey, J.K. and C.T. LaRue. 1993. Notes on the distribution of the Mogollon vole (*Microtus mogollonensis*) in New Mexico and Arizona. *Southwestern Naturalist* 38:176-178.

Frey, J.K. and T.L. Yates. 1995. Hualapai vole (*Microtus mogollonensis hualpaiensis*) genetic analysis. Unpublished report to the Arizona Game and Fish Department, Phoenix, Arizona.

Hoffmeister, D.F. 1986. *Mammals of Arizona.* Tucson: University of Arizona Press.

Johnson, C. N. 1996. Interactions between mammals and ectomycorrhizal fungi. *Trends in Ecology & Evolution* 11(12):503-507.

Kalies, E.L. 2010. The effects of forest management on small mammal community dynamics in ponderosa pine ecosystems. Doctoral dissertation. School of Forestry, Northern Arizona University.

Kalies, E.L., C.L. Chambers, and W.W. Covington. 2010. Wildlife responses to thinning and burning treatments in southwestern conifer forests: a meta-analysis. *Forest Ecology and Management* 259:333-342.

Korb, J.E., N.C. Johnson, and W.W. Covington. 2003. Arbuscular mycorrhizal propagule densities respond rapidly to ponderosa pine restoration treatments. *Journal of Applied Ecology* 40:101-110.

MacKenzie, D.I., J.D. Nichols, J.A. Royle, K.H. Pollock, L.L. Bailey, and J.E. Hines. 2006. *Occupancy estimation and modeling.* Amsterdam: Elsevier.

Noss, R.F., P. Beier, W.W. Covington, R.E. Grumbine, D.B. Lindenmayer, J.W. Prather, F. Schmiegelow, T.D. Sisk, and D.J. Vosik. 2006. Recommendations for integrating restoration ecology and conservation biology in ponderosa pine forests of the southwestern United States. *Restoration Ecology* 14:4-10.

Patton, D.R. 1977. Managing southwestern ponderosa pine for the Abert squirrel. *Journal of Forestry* 75:264-267.

Patton, D.R. and W. Green. 1970. Abert's squirrels prefer mature ponderosa pine. Report Research Note RM-169. Fort Collins, CO: U.S. Dept. of Agriculture Forest Service Rocky Mountain Forest and Range Experiment Station.

Pyare, S. and W.S. Longland. 2001. Patterns of ectomycorrhizal-fungi consumption by small mammals in remnant old-growth forests of the Sierra Nevada. *Journal of Mammalogy* 82:681-689.

Reynolds, R.T., R.T. Graham, M.H. Reiser, R.L. Basset, P.L. Kennedy, D.A. Boyce, Jr., G. Goodwin, R. Smith, and E.L. Fisher. 1992. Management recommendations for the northern goshawk in the southwestern United States. General Technical Report RM-217. Fort Collins, CO: U.S. Dept. of Agriculture, Forest Service, Rocky Mountain Forest and Research Station.

Rosenstock, S.S. 1998. Influence of Gambel oak on breeding birds in ponderosa pine forests of northern Arizona. Condor 100:485-492.

States, J.S. 1984. Hypogeous, mycorrhizal fungi associated with ponderosa pine: sporocarp phenology. Page 271 in R. Molina, ed., Proceedings of 6th North American Conference on Mycorrhizae. Covallis, OR: Oregon State University, Forest Research Laboratory.

Wightman, C.S. and S.S. Rosenstock. Unpublished data. Tassel-eared squirrel responses to fuel reduction and forest restoration treatments: Mosaics matter.

Resources

Arizona Game and Fish Wildlife Restoration Research
http://www.azgfd.gov/w_c/research_forest_restoration.shtml

Occupancy modeling tools and information
http://www.uvm.edu/envnr/vtcfwru/spreadsheets/occupancy/occupancy.htm

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Written by Dr. Elizabeth L. Kalies and Dr. Carol L. Chambers
Reviewed by Shaula Hedwall, Dr. David Patton, and Steven Rosenstock
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