Chapter 3: Small Mammal Distribution, Abundance, and Habitat Relationships

2007 Annual Report

Submitted February 2008

Project Leader:

Robin J. Innes

University of California Davis Department of Wildlife, Fish, and Conservation Biology One Shields Avenue Davis, CA 95616 rjinnes@ucdavis.edu

Principal Investigators:

Douglas A. Kelt¹, Dirk H. VanVuren¹, and Michael L. Johnson²

¹University of California Davis Department of Wildlife, Fish, and Conservation Biology One Shields Avenue Davis, CA 95616

> ²University of California Davis John Muir Institute of the Environment One Shields Avenue Davis, CA 95616

TABLE OF CONTENTS

EXECUTIVE SUMMARY	4
INTRODUCTION	5
OBJECTIVES	8
METHODS	9
Live-trapping	9
Long-term grids	9
Landbird grids	11
Northern flying squirrels	13
Dusky-footed woodrats	13
Golden-mantled ground squirrels	14
Chipmunks	16
Animal handling	16
Radiotelemetry	17
Radiotransmitter application	17
Homing	18
Triangulation	18
Home range analysis	18
Vegetation	20
Long-term grids	20
Landbird grids	21
Northern flying squirrels	21
Dusky-footed woodrats	22
RESULTS AND DISCUSSION	25
Long-term grids	25
Publications #1 and #4: Habitat associations of small mammals at two spatial scales	
in the northern Sierra Nevada	25
Publication #8: Population dynamics of small mammals in relation to cone	
production in four forest types in the northern Sierra Nevada	26
Publication #9: Trapping rodents in a cautious world: the effects of disinfectants on	
trap success.	26
2007 Field Season	27
Landbird grids	27
2007 Field Season	27
Northern flying squirrels.	28
Publication #/: Home range and activity of northern flying squirrels in the northern	• •
Sterra Nevada	29
Publication #3: Home range and habitat selection of northern flying squirrels in the	• •
northern Sierra Nevada	29
2007 Field Season	29
Dusky-tooted woodrats	30
Publication #2 and #5: Habitat selection by dusky-footed woodrats in managed	• •
mixed-coniter forest of the northern Sierra Nevada	30
Publication #6: Characteristics and use of tree houses by dusky-footed woodrats in	20
managed mixed-coniter forest of the northern Sierra Nevada	30

Publication #11: Spatial organization of dusky-footed woodrats in managed mixed-	
conifer forest of the northern Sierra Nevada.	31
Golden-mantled ground squirrels	36
Publication #8: Effects of maternal body condition on offspring dispersal in golden-	
mantled ground squirrels.	36
Chipmunks	36
Publication #10: A multiple spatial scale perspective of the habitat affinities of	
sympatric long-eared and Allen's chipmunks.	36
2007 Field Season	37
COLLABORATION	37
PUBLICATIONS	38
Theses	38
Peer-reviewed	38
Submitted	38
In Preparation	39
PRESENTATIONS	39
PERSONNEL	40
ACKNOWLEDGEMENTS	40
REFERENCES	41
FIGURES AND TABLES	47

EXECUTIVE SUMMARY

In this document we report on the Mammal Module of the Plumas-Lassen Administrative Study (PLAS). A pilot study was conducted September-November 2002, the study design was incorporated in 2003, and 2007 marked the fifth year of implementation of the study. As of the end of the 2007 field season, all of the proposed treatments have been implemented, thus everything we report in 2007 reflect post-treatment conditions and all data reported prior to 2007 reflect pretreatment conditions.

The information provided in this report is intended to provide background information on the pre-treatment and post-treatment status of small mammals in a variety of forested habitat types, determine habitat associations of many small mammal species, particularly the principle prey of the California spotted owl (i.e., dusky-footed woodrat, *Neotoma fuscipes*; northern flying squirrel, *Glaucomys sabrinus*), and provide resource managers with important habitat attributes to manage for to ensure a sustainable mammalian community.

In 2006, Robin Innes, who has been with the project since 2002, succeeded James Wilson as Project Leader of the Mammal Module of the PLAS. Robin continued as Project Leader in 2007. James Wilson continues to improve manuscripts initiated during his time as a postdoctoral fellow with the PLAS, as a staff member at University of Nebraska, Omaha. To date, we have had two graduate students at the University of California, Davis successfully complete their graduate work with the PLAS. In 2005, Stephanie Coppeto completed her graduate work on the habitat associations of small mammals at multiple spatial scales. In 2006, Robin Innes completed her graduate work on habitat selection by dusky-footed woodrats. In 2006, Jaya Smith joined the Mammal Module and will complete his graduate work in 2007. Jaya is studying the home range and habitat use of the northern flying squirrel.

INTRODUCTION

Small mammals play vital roles in forest ecosystems, serving as important consumers and dispersers of seeds, fruits, and fungi (Carey et al. 1999; Gunther et al. 1983; Maser and Maser 1988; Pyare and Longland 2001), and as prey for mammalian and avian predators, including many species of concern in the Sierra Nevada (e.g., California spotted owl, *Strix occidentalis occidentalis*; northern goshawk, *Accipiter gentilis*; fisher, *Martes pennanti*; and marten, *M. americana*; Carey et al. 1992; Forsman et al. 1984; Zielinski et al. 1983). Given their essential interactions with flora and fauna across multiple trophic levels (e.g., Carey et al. 1992; Forsman et al. 1992; Forsman et al. 1984), changes in the distribution and abundance of small mammals could substantially affect the dynamics of forest communities. This makes small mammals valuable subjects for the integrative research necessary to fully understand the ecological responses of spotted owls and other species to forest management practices.

Here we report on the Mammal Module of the PLAS, one of five integrated study modules intended to evaluate land management strategies within the area covered by the Herger-Feinstein Quincy Library Group Forest Recovery Act (HFQLG) Pilot Project. Understanding how small mammal communities respond to different forest management regimes at macrohabitat (i.e., stand-level, landscape) and microhabitat (trap-level, home range) scales would provide valuable feedback to other PLAS modules. We plan to develop predictive small mammal habitat models to forecast how individual species will respond to forest management treatments and test these models by assessing the impacts of forest management treatments on small mammal abundance and species diversity. We will do this by monitoring several independent populations of small mammals for multiple years before and after forest management treatments are applied, developing demographic profiles (e.g., survival, reproduction) of species, and obtaining detailed measurement of habitat characteristics. To sample and monitor these small mammal populations, we have established permanent (long-term grids) and temporary (landbird grids) live-trapping grids located throughout Plumas National Forest (PNF).

In addition to the valuable feedback that can be gained by determining how the full compliment of small mammals responds to different forest management regimes, we will more closely examine the responses of several key small mammals to forest management practices. Due to differing seasonal energy requirements, hibernating and non-hibernating small mammals are likely to be effected differently by forest management practices. Hibernation may reduce mortality of small mammals during the winter months through conservation of energy and protection from predators (Broadbooks 1970), with mortality rate more heavily influenced by the quantity and quality of food caches (Post et al. 1993) and body condition prior to hibernation (Murie and Boag 1984), parameters which can be related to forest productivity. Non-hibernating small mammals may exhibit elevated mortality during the winter months due to increased levels of thermal stress, limited food resources, and exposure to predators. Thus, our objective was to evaluate the effects of forest management treatments on the ecology of both hibernating and non-hibernating species groups.

Key non-hibernating small mammals in the northern Sierra Nevada include the northern flying squirrel (*Glaucomys sabrinus*) and dusky-footed woodrat (*Neotoma fuscipes*). Northern flying squirrels and dusky-footed woodrats are the principle prey of the California spotted owl (Carey et al. 1992; Rosenberg et al. 2003), a species of concern in California due to its dependence upon late-seral forest ecosystems (United States Department of the Interior 2003), which are among the most highly altered ecosystems in the Sierra Nevada (Beardsley et al. 1999; Franklin and Fites-Kaufman 1996). For example, some populations of northern flying squirrel appear to be depressed by the intensity of spotted owl predation (Carey et al. 1992), and high woodrat biomass may reduce the area requirements of the spotted owl (Carey et al. 1990; Zabel et al. 1995). Thus, northern flying squirrels and dusky-footed woodrats are an important focus of our study module.

Northern flying squirrels are nocturnal, arboreal rodents located throughout the northern latitudes of the United States, and Canada (Wells-Gosling and Heaney 1984), and frequently associated with forests with high densities of large trees (Smith et al. 2004, 2005). Northern flying squirrels act as a major dispersal agent for hypogeous fungal spores, which are important for nutrient and water uptake by host trees (Fogel 1980). Although they are typically associated with mesic northern forests, northern flying squirrels are also found throughout the Sierra Nevada where they experience a much more xeric landscape as compared to the rest of their range; as a result, populations of northern flying squirrel inhabiting the Sierra Nevada may be quite different from those inhabiting the more mesic forests of Oregon, Washington, and Alaska. Specifically, northern flying squirrels may be more sensitive to wetter regions in the Sierra Nevada where truffles, their primary food source, are more abundant. This disjunctive distribution of food resources may drive differences in northern flying squirrel biology, suggesting that northern flying squirrels may exhibit a more clumped distribution, lower overall densities, increased competition for suitable nest trees, and larger individual home ranges; thus, northern flying squirrels in the Sierra Nevada may be affected differently by forest management practices than populations in other parts of their range. We used livetrapping and radiotelemetry techniques to determine the abundance and distribution, habitat use, and home range of northern flying squirrels in the Sierra Nevada, compared this with data from other parts of their distribution, and evaluated the effects of forest management practices on this species within the area covered by the HFQLG Pilot Project.

The dusky-footed woodrat is a nocturnal, semi-arboreal rodent found throughout northern California and Oregon that inhabits a wide variety of densely vegetated habitats, including chaparral, juniper woodland, streamside thickets, and deciduous or mixed forests with well-developed undergrowth (Carraway and Verts 1991). Dusky-footed woodrats play an important role in community dynamics. As mentioned previously, they are prey for many avian and mammalian predators, including the California spotted owl. Additionally, the availability of woodrat houses may influence species richness for small mammals, reptiles, amphibians, and invertebrates (Cranford 1982; M'Closkey et al. 1990; Merritt 1974; Vestal 1938). Thus, promoting quality habitat for the dusky-footed woodrat may provide a variety of ecological values in managed forests, for example in

the form of increased biodiversity, with important consequences for forest conservation (Carey et al. 1999). We used live-trapping and radiotelemetry to determine the abundance and distribution, habitat use, and home range of dusky-footed woodrats in the Sierra Nevada, and evaluate the effects of forest management practices on this species. Specifically, our first objective was to test for an association between woodrat abundance and abundance of California black oak (Quercus kelloggii), an important food source (Atsatt and Ingram 1983; Cameron 1971; Meserve 1974). Our second objective was to evaluate the importance of microhabitat variables to dusky-footed woodrats at 2 levels, placement of houses within mixed-conifer habitat and use of houses. Dusky-footed woodrats construct conspicuous, conical houses on the ground using sticks, bark, and plant cuttings, and sometimes also on limbs or in cavities of trees (Fargo and Laudenslayer 1999). Given the investment involved in building, maintaining, and defending a house, we predicted that houses should be distributed such that they minimize energetic costs in movement, yet maximize individual fitness components (Manley et al. 1993), such as access to food, protection from predators, and a thermally suitable microclimate (Atsatt and Ingram 1983). Thus, we evaluated ground and tree house-site selection of houses by dusky-footed woodrats by comparing house sites with nearby random sites. Since only a subset of available houses is used by woodrats at any one time (Carey et al. 1991; Cranford 1977; Lynch et al. 1994), some houses may be more suitable than others. We evaluated house suitability by comparing characteristics of used and unused ground houses and availability and use of house trees. Because woodrats defend their house against conspecifics, subadults might be forced to settle in lower quality houses (Vestal 1938), thus, we also evaluated whether subadults selected houses differently from those selected by adults. Our third objective was to examine the spatial organization of dusky-footed woodrats. A population's spatial organization has important implications for population dynamics, as well as the genetic structure of a population (e.g., Dunning et al. 1992, Lambin and Krebs 1991; Sugg et al 1996).

Other key small mammals include two diurnal, hibernating rodents, the golden-mantled ground squirrel (Spermophilus lateralis) and chipmunks (Tamias sp.), which are also important prey species of the northern goshawk, a species of increasing concern to resource managers due to the species sensitivity to the effects of forest management. As mentioned previously, the body condition of individual small mammals appears critical to hibernation and over-winter survival (Lenihan & Van Vuren 1996; Murie & Boag 1984). Body condition may also influence reproduction; for example, small mammals that are heavier on emergence form hibernation may produce larger litters (Dobson et al. 1999) that are more likely to be successfully weaned (Neuhaus 2004). Additionally, first-year overwinter survival of juvenile small mammals is positively related to pre-hibernation body mass (Bennett 1999; Lenihan & Van Vuren 1996). Body condition can also affect behavior; for example, juvenile dispersal may be influenced by body condition (Barash 1974) since body fat may be an important cue for dispersal, with lighter individuals dispersing later than heavier individuals (Barash 1974; Nunes et al. 1998). Offspring condition at the time of dispersal may be influenced not only by post-weaning food acquisition by the juvenile, but also by maternal condition (Dobson et al. 1999). Although body condition is important to all animals, it is particularly so for hibernating groundsquirrels, which face a short active season (<5 months) and require large energy reserves.

Thus, our objective was to evaluate the influence of forest management practices at they relate to forest productivity on the body condition of the golden-mantled ground squirrel, a species found commonly at higher elevations (>2000 m) in the Sierra Nevada, where the length of the snow-free growing season could severely limit the animal's ability to acquire enough energy to sustain activity and support reproduction (Armitage 1989). We measured the amount of fat reserves (i.e., body condition) using the total body electrical conductivity (ToBEC) method (Koteja 1996; Walsberg 1988), used radiotelemetry methods to document dispersal and maternal home range, and developed a model which relates offspring natal dispersal to body condition, and incorporates the influence of maternal condition on these factors.

Chipmunks are forest-associated, semi-arboreal rodents that constitute a considerable portion of the small-mammal biomass in an area, making them important prev for a variety of mammalian and avian predators (Vaughan 1974). Additionally, chipmunks are important consumers and dispersers of seeds (Briggs and Vander Wall 2004; Vander Wall 1992,), and may contribute to the natural regeneration of some species of plants by caching seeds (Aldous 1941). Small mammals cache seeds beneath the layer of decaying vegetation on the forest floor (scatter-hoarding), where they stand a better chance of germinating than those remaining on the surface litter (Sumner and Dixon 1953), or deposit seeds in underground burrows where seeds can not establish seedlings (larderhoarding). Chipmunks scatter-hoard seeds more frequently than other small mammals, thus potentially having a greater impact on seedling establishment (Hollander and Vander Wall 2004). If soil-moisture levels have been altered due to fire, logging, or weather patterns, the ability of chipmunks to retrieve cached seeds may be reduced, thus promoting germination of a larger proportion of seeds after disturbance (Briggs and Vander Wall 2004; Vander Wall 2000). However, if chipmunks are very abundant, they can prevent normal regeneration of some plants, particularly pines, by eating their seeds, which may contribute to the generation of dense brushfields that could further hider the return of timber (Smith and Aldous 1947, Tevis 1953). We were particularly interested in two species that occur commonly throughout PNF, the long-eared (*T. quadrimaculatus*) and Allen's (T. senex) chipmunks. These sympatric species are similar in body mass, diet, and general resource utilization, and thus are likely to compete locally. Similar species often coexist by partitioning habitat. However, detecting differences in habitat affinities is influenced by spatial scale. Our objective was to investigate the abundance, distribution, and habitat associations of the long-eared and Allen's chipmunks at three spatial scales in PNF and evaluate the affect of forest management practices on these species.

OBJECTIVES

The primary objective of the Mammal Module is to evaluate small mammal responses to different forest management practices, and to model these responses in terms of demography, spatial distribution, and habitat associations at local and landscape scales. To meet the primary objective, we will address the following:

- 1. Determine small mammal habitat associations at macro- and microhabitat scales.
- 2. Develop demographic profiles of small mammal populations inhabiting a variety of habitat types.

- 3. Develop predictive small mammal habitat models, based on the results of objectives 1-2, to forecast how individual species will respond to forest management treatments.
- 4. Quantitatively assess the impacts of forest management treatments on small mammal abundance and species diversity.
- 5. Determine small mammal population trends, evaluate how populations are changing temporally, and assess the factors responsible for the observed trends.
- 6. Evaluate the spatial distribution (i.e., home range), social organization (i.e., home range overlap), and habitat selection (i.e., den use, house use) of the principle prey of the California spotted owl, the northern flying squirrel and dusky-footed woodrat.
- 7. Determine the fitness correlates of a hibernating small-mammal, the goldenmantled ground squirrel, to forest management.
- 8. Evaluate the taxonomy and habitat affinities of two sympatric chipmunks, the longeared and Allen's chipmunks, at multiple spatial scales.

METHODS

Live-trapping

Capture-recapture data obtained from the live-trapping methods described herein allow us to measure population parameters such as abundance, density, and frequency of occurrence of individual small mammal species and small mammal species richness and diversity, and permit the measurement of habitat use, availability and selection (Lancia et al. 1996, Litvaitis et al. 1996). Live-trapping methods are useful for making comparisons of small mammal communities across time, locations, habitats, and land-use treatments. We established several different live-trapping designs, each appropriate to the small mammal community or species of interest.

Long-term grids

To provide base-line information on small mammal populations inhabiting major forest types, and to quantitatively assess the impacts of forest management treatments on small mammal abundance and species diversity, we established 21 long-term grids using controls and pre- and post-treatment data. In 2007, all of the proposed treatments were implemented. All data collected between 2003 and 2006 were collected prior to any treatments to determine baseline conditions. In 2003, we established 18 semi-permanent, live-trapping grids (Fig. 1a); we established 3 additional long-term grids in 2005. Twenty grids consist of a 10 x 10 array of Sherman traps (Model XLK, 7.6 x 9.5 x 30.5 cm, H. B. Sherman Traps, Inc., Tallahassee, FL, USA) with 10 m spacing, nested within a larger 6 x 6 grid of 72 Tomahawk traps (Model 201, 40.6 x 12.7 x 12.7 cm, Tomahawk Live Trap, Tomahawk, WI, USA; 1 ground, 1 arboreal) with 30 m spacing (Fig. 1b). The remaining long-term grid was constrained by road configuration such that the array of Sherman traps was nested within a 4 x 9 grid of 72 Tomahawk traps (30 m trap spacing; 1 ground, 1 arboreal). Arboreal traps were placed approximately 1.5 to 2 m above the ground on a haphazardly-selected tree located <10 m from the grid point; arboreal traps may or may not be placed on the same tree each trapping session. Ground traps were

placed within 1 m of the grid point under protective cover, such as a shrub or log, at small mammal burrow entrances, and along small-mammal run-ways, when possible.

We trapped all long-term grids (n=21) in 2007. All grids had 120 trap stations and covered 2.25 ha (3.24 ha with a $\frac{1}{2}$ inter-trap distance buffer) of contiguous forest. Arboreal Tomahawk traps were removed from all grids on August 1, 2004 because of consistently poor capture rates; however, arboreal Tomahawk traps were again used in 2005 and thereafter, and capture rates were improved by placing the trap entrance flush against the tree bole, fastening the trap more securely to the tree, and switching to more a desirable bait mixture, in accordance with the recommendations of Carey et al. (1991).

The 18 long-term grids established in 2003 were placed in 5 principal forest types as described by Coppeto et al. (Publications #1 and #2). Forest types were defined by the dominant live tree species representing \geq 70% of total tree composition, and included white fir (Abies concolor, n = 4), red fir (A. magnifica, n = 3), mixed fir (co-dominant mix of white fir and Douglas-fir, *Pseudotsuga menziesii*, n = 5), mixed conifer (n = 3), and pine-cedar (co-dominant mix of yellow pine, ponderosa pine-Pinus ponderosa and Jeffrey pine–P. *jeffreyi*, and incense cedar, *Calocedrus decurrens*, n = 3). In 2005, sampling grids were established in group selects located in white fir (n=2) and mixedconifer (n=1) habitats. In an effort to more fully integrate our module with those of other research modules of the PLAS, Wilson et al. (Publication #5) used alternative forest type classes for these grids, as follows: white fir (n=9), red fir (n=3), Douglas fir (n=3), and ponderosa pine (n=3). According to this classification, the 3 group selects established in 2005 were placed within white fir habitat. Overall, PNF is dominated by white fir and Douglas fir so these forest types had proportionally more trapping grids placed within them. Common shrubs in the region include mountain rose (Rosa woodsii), Sierra gooseberry (Ribes roezlii), serviceberry (Amelanchier utahensis), bush chinquapin (Chrysolepis sempervirens), green- and white-leaf manzanita (Arctostaphylos patula and A. viscida), mountain dogwood (Cornus nuttallii), mountain whitethorn and deer brush (Ceanothus cordulatus and C. intigerrimus), bitter cherry (Prunus emerginata), and huckleberry oak (Quercus vaccinifolium). Pinemat manzanita (Arctostaphylos nevadensis) occurred almost exclusively in red fir forests, and buck brush (Ceanothus *cuneatus*) predominantly in pine-cedar/ponderosa pine forests.

Twelve of the long-term grids were placed within the experimental management plots established by the Vegetation Module of the PLAS. These 12 study plots were placed in 3 groups of 4 study plots, consisting of 1 control plot and 3 experimental plots (1 group select plot, 1 light thin, and 1 heavy thin). The remaining 9 study plots were not established in groups. Minimum distance among long-term grids (n=21) was 1 km with the exception of 4 grids that were 700-900 m apart. In 2006, one individual goldenmantled ground squirrel was documented to move between two grids in red-fir habitat. No small mammals were documented to move between any other long-term grids in any year.

Long-term grids were trapped monthly (May-October) during 2003-2004 and biannually (June, Oct) during 2005-2006. We sampled once in 2007 (July-August) because logging

and prescribed burn activities at treatment grids restricted sampling activities. Trapping sessions consisted of 4 consecutive trap-nights. Sherman and Tomahawk traps were set and baited every evening just before dusk, and checked just after dawn; Sherman traps were then closed until dusk whereas Tomahawk traps were re-baited and checked again at mid-day, a minimum of 2 hours after the first trap check, at which point they were closed until dusk. This resulted in all traps remaining closed from 12:00 - 16:00. This enabled us to sample both diurnal and nocturnal species while reducing deaths that result from heat exposure during the hottest part of the day. Field technicians were thoroughly trained and rotated among grids each trapping session, to reduce the variability in capture success due to differences among technicians.

Prior to August 2005, all traps were baited with crimped oats and black oil sunflower seeds lightly coated in peanut butter; thereafter, traps were baited with a mixture of rolled oats, molasses, raisins, and peanut butter which was formed into a small, sticky ball. We changed the bait because the latter bait is recommended for capturing the difficult-to-capture northern flying squirrel (Carey et al. 1991). Small nest boxes made from waxed-paper milk cartons were placed behind the treadle in Tomahawks to minimize stress and provide thermal and protective cover (Carey et al. 1991); in addition, synthetic bedding material (nonabsorbent polyethylene batting), and natural cover (e.g., bark, moss) or cover boards, were provided as needed for thermal insulation. After the trap session was completed, bait was deposited on the ground at the grid point and all traps were removed.

Demographic profiles.—Population demographics will be modeled by species using program MARK. Species that do not have enough individuals to generate detailed capture history will be modeled using the minimum number known alive (MNKA) parameter. Monthly or seasonal survival and population densities will be modeled for each species by habitat type using the Cormack-Jolly-Seber data type in program MARK. Suitable habitat parameters, such as cone production, will be incorporated into population models and can be used to identify habitat variables that are linked to population parameters using multivariate analyses.

Landbird grids

To complement the data collected at our long-term grids and more fully integrate our live-trapping efforts with that of other modules, we established temporary, smallmammal trapping grids at a subset of Landbird Module census points in 2006 and 2007. Eight to 10 census points within each landbird census transect were randomly selected for small mammal sampling; selection of census transects was stratified to include transects located throughout (former) treatment units 2-5. At each census point, a 2 x 2 array of live-traps with 50 m spacing was established by pacing 35 m from the census point in the four cardinal directions (north, south, east and west; Fig. 2). The live-trapping grids covers 0.25 ha (1 ha with a ½ inter-trap distance buffer). All live-trapping methods were designed to optimize the capture and recapture of the northern flying squirrel, the most difficult to capture small mammal in our study area, and in this way provide the best means of trapping for the full suite of small mammals, including the dusky-footed woodrat (Carey et al. 1991). The live-trap array we used ensured that the 4 trap-stations resided within the 50 m radius vegetation plot that was established by the Landbird Module to access vegetation characteristics around each census point, and provided the recommended spacing between trap-stations and the suggested minimum number of trapstations per home range area recommended for the northern flying squirrel (Carey et al. 1991).

One Sherman and 2 Tomahawk (1 ground, 1 arboreal) traps were placed at each point in the array; thus, each array consisted of 12 live-traps. Arboreal Tomahawks were placed 1.5 to 2 m above the ground on the largest tree within a 10-m radius of the grid point. The largest tree was chosen since large trees provide better support for the trap, thus improving functionality of the trap and improving capture success (Carey et al. 1991). Ground traps were placed within 1 m of the grid point and were placed under protective cover, such as a shrub or log, at small mammal burrow entrances, and along small-mammal run-ways, when possible.

Landbird grids were sampled during May – September 2006 and 2007. Each landbird grid trapping session consisted of 2 sets of 4 consecutive trap-nights each; each set was separated by 3 nights when no trapping was conducted, thus allowing a period of rest for animals from the stress of capture and handling (Carey et al. 1991). This trapping scheme ensured a duration short enough to avoid changes in the sampled population due to births, deaths, immigration, and emigration, and long enough to maximize the number of captures and recaptures of northern flying squirrels and other small mammals (Carey et al. 1991). All traps were set and baited every evening just before dusk; baiting was completed in 3-4 hours. Trap check began just after dawn and completed within 4-6 hours; thus, all traps were closed prior to 12:00 and remained closed until after 15:00 each day.

All traps were baited with a mixture of rolled oats, molasses, raisins, and peanut butter which was formed into a small, sticky ball. Small nest boxes made from waxed-paper milk cartons were placed behind the treadle in Tomahawks to minimize stress and provide thermal and protective cover (Carey et al. 1991); in addition, natural cover (i.e., bark, moss) or cover boards and synthetic bedding material (nonabsorbent polyethylene batting) were provided as needed for thermal insulation for all traps. To encourage capture and recapture of small mammals and to avoid damage to traps by black bear, traps were emptied of bait between trap sets and bait was deposited at the grid point. At the end of the trapping session, traps were again emptied of bait and bait was deposited on the ground at the grid point, and all traps were permanently removed.

Species Richness.— We analyzed species richness indices for each sampled landbird census point. Species richness is defined as the total number of species detected over the course of the trapping session. We utilized a restricted list of species that excluded species that are not accurately surveyed using our live-trapping method (e.g., shrews, skunks, hares). Following the completion of data collection in 2007, we plan to begin more detailed analyses of this data in close collaboration with the Landbird Module.

Northern flying squirrels

We captured and radiocollared northern flying squirrels at long-term grids, landbird grids, and at areas predicted to have moderate and high suitability for northern flying squirrels, hereafter flying squirrel transects. At long-term grids and landbird grids, northern flying squirrels were collared only in areas where triangulation was feasible, which required fairly large areas of habitat with one or two roads bisecting the area. In 2004, animals were captured and radiocollared at 3 long-term study grids located in upper elevation (2,100 m) red-fir habitat. Additional transects bisecting or parallel to original transects were established during 2005-2007 in order to increase the area covered and increase capture success. The 3 long-term grids and intervening habitat are hereafter referred to as study site FS-1. In 2005, we established a second study site, hereafter study site FS-2, in mixed-conifer forest located at 1,500 m elevation; in 2006 and 2007, additional transects bisecting or parallel to original transects were established. Study site FS-2 was selected using a GIS-based northern flying squirrel habitat-relations model developed using available information from the literature, which predicted poor, moderate, and high suitability habitat for northern flying squirrels. Although we established many live-trapping transects (>10) in areas predicted to have high and moderate suitability, study site FS-2 was the only study site to yield successful captures in an area where triangulation was also feasible; study site FS-2 was predicted to have moderate suitability for northern flying squirrels.

We primarily established flying squirrel transects along riparian areas, due to the importance of this habitat type to northern flying squirrels reported by Meyer and North (2005). If habitat, road configuration, and topography were suitable, we used a live-trapping grid (i.e., several parallel transects) to maximize the number of captures. We used a combination of Sherman and Tomahawk traps, typically 1 Sherman and 2 Tomahawk (1 ground, 1 arboreal) traps, spaced 40-50 m apart by pacing. Sherman and Tomahawk traps were set and baited every evening just before dusk, and checked just after dawn; all traps remained closed from 12:00 - 16:00. Prior to August 2005, all traps were baited with crimped oats and black oil sunflower seeds lightly coated in peanut butter; thereafter, traps were baited with a mixture of rolled oats, molasses, raisins, and peanut butter which was formed into a small, sticky ball. Small nest boxes made from waxed-paper milk cartons were placed behind the treadle in Tomahawks to minimize stress and provide thermal and protective cover (Carey et al. 1991); in addition, natural cover (i.e., bark, moss) or cover boards and synthetic bedding material (nonabsorbent polyethylene batting) were provided as needed for thermal insulation for all traps.

Dusky-footed woodrats

Four study sites (1,450–1,750 m elevation; Fig. 3) where established in early-seral forest (30–40 years post-logging), representative of the Sierra Nevada westside mixed-conifer forest type characterized by California black oak, sugar pine (*Pinus lambertiana*), ponderosa pine, Jeffrey pine, white fir, Douglas-fir, and incense cedar. All study sites had a brushy understory consisting primarily of deer brush, buck brush, and mountain whitethorn, with lesser coverage by green- and whiteleaf manzanita, and mountain dogwood. Each study site included 2–4 habitat types, which varied in composition of overstory and understory dominants, canopy closure, and aspect. Habitat type was

defined by GIS data layers provided by the USDA, Forest Service. Study sites WR-1 and WR-2 had moderately sloping topography; sites WR-3 and WR-4 had mixed terrain or undulating topography. Because woodrat activities extended somewhat into adjacent habitats, we trapped woodrats at all houses located within approximately 3 home range diameters (ca. 180 m—Lynch et al. 1994, Cranford 1977, Sakai and Noon 1997) of each study site, to ensure that all woodrats potentially influencing the spatial structure at each study site were identified. Historic logging activities and fire suppression practices contributed to heterogeneity within study sites, with abundant dead wood as well as shrubby gaps interspersed with patches of closed canopy forest. Recent (<5 yr) management activities (e.g., prescribed burns, logging) have created open understory and overstory conditions in areas between study sites. Study sites lay 1.2–2.8 km apart, and no woodrats were recorded moving between study sites.

We systematically searched for woodrat houses in the spring and fall of 2004-2006 by walking overlapping belt transects that covered each study site. In addition, woodrat houses were opportunistically located at all study sites during a concurrent radiotelemetry study of woodrat movements. Each house was marked and its location mapped (≤ 1 m) using a GPS unit (Trimble Navigation, Ltd., Sunnyvale, California; GeoExplorer, GeoXT), and volume was estimated as a cone using measurements of length, width, and height.

Woodrats are active year-round, but our study was limited to the snow-free period (May-October). We documented house use by livetrapping in the spring (May–June) and late summer-early fall (August–September) of 2004-2006 with 4 Sherman live-traps (H.B. Sherman Traps, Inc., Tallahassee, Florida; $7.6 \times 9.5 \times 30.5$ cm) set at the base of each house for 4 consecutive nights; longer trapping efforts (>4 consecutive nights) do not yield higher success (Carey et al. 1999; Laudenslayer and Fargo 1997; Willy 1992). Traps were baited with raw oats and sunflower seeds coated with peanut butter and opened at dusk and checked at dawn. Synthetic batting was provided for thermal insulation. Traps were set at all houses within each study site.

Golden-mantled ground squirrels

We studied golden-mantled ground squirrels at a long-term grid located in red-fir habitat at an elevation of 2,100 m during 2003-2005. Animals were captured with Tomahawk traps baited with rolled oats and sunflower seeds coated with peanut butter, set in the early morning and checked at mid-morning and noon. In 2003 and 2004, we experimentally manipulated maternal diets by supplying supplemental food to a sample of adult females (treatment females, n=6), to assess the effects of maternal condition on offspring growth and fat development as well as exploratory and dispersal distance, and compared treatment and control mothers (n=6) and their offspring. These 12 females were randomly assigned to control (n = 6) or treatment (n = 6) groups, uniquely marked with numbered Monel ear tags, and fitted with radio-collars. We radiotracked treatment squirrels animals to their burrows in late afternoon and dispensed ca. 30 g of black oil sunflower seeds per day of supplementation down the burrow opening. Supplemental feeding began on 1 September 2003 and took place 4 days per week until all individuals entered hibernation in early October. Individuals in the control group were trapped at the same interval as the treatment group, but were not provided supplemental food. We evaluated the effectiveness of food supplementation by comparing the slope of mass gain in female squirrels for control vs. treatment groups during the 2003 field season, with initial mass treated as a covariate. All females survived through the summer and entered hibernation. In spring 2004, we relocated and captured 7 study animals (3 treatment, 4 control), which were fitted with new radiocollars and radiotracked until their offspring (3 females had 2 offspring, while the fourth female had 3) emerged in early July. In 2005, we studied additional unmanipulated females (n=9) and their offspring (9 male, 5 female) to augment our data on control females and their offspring dispersal distances.

We attempted to capture all females and their offspring on a monthly basis to measure mass, body condition, and head+body length. At each capture we returned individuals to our field laboratory; there we chemically immobilized them with ketamine hydrochloride (100 mg/ml KCl), removed their radiocollars, and recorded rectal temperature, total mass to the nearest 0.1 g, and head+body length (measured as tip of nose to anus). We quantified body fat using the ToBEC method (Walsberg 1998, Koteja 1996). Conductivity was measured on anesthetized animals using an EM-SCAN SA-3000 body composition analyzer (EM-SCAN, Springfield, IL, USA). Pulawa & Florant (2000) calibrated the ToBEC machine for golden-mantled ground squirrels, and we used their calibration curve to obtain fat-free mass for our samples. Following analysis, the radio-collar was reattached, and the animal was allowed to recover before release at the site of capture.

Mothers and offspring were radiolocated from July-October 2003-2005. Location of all adult females was determined by triangulation ≥ 3 times daily for ≥ 5 days/mo from July to September 2003. Burrows were located by homing after animals had settled into their burrows for the night and locations were measured using a handheld GPS unit accurate to ca. 3 m. Burrow locations used for hibernation were noted to facilitate relocation of individuals the following spring. For use in calculating offspring exploratory behavior, we calculated 95% kernel home ranges for each mother.

Dispersal was defined as establishing a new home range distinct from the natal home range, and was identified using adaptive kernel home range estimators which produced two home ranges for offspring; one encompassed the natal burrow and one was the final place of residence before hibernation. Dispersal distance was calculated as the linear distance between the point of initial capture (mother's burrow) and the final location for a particular individual (presumed hibernaculum). We defined exploratory movements as round-trip visits to locations that were > 1 radius of the mother's home range from the offspring's initial point of capture.

All statistical analyses were performed using SAS (SAS Institute 2000). Comparisons of monthly maternal and offspring mass and percent fat were analyzed using a repeated measures analysis of variance (rmANOVA) with initial mass or percent fat as a covariate. All measures of percent fat and mass were log transformed prior to analyses. Analyses of offspring exploratory and dispersal distance were analyzed using a 2-way ANOVA with sex and treatment as explanatory factors. Because dispersal parameters usually are not normally distributed and because we had small sample sizes, all data were log

transformed prior to analyses. Comparisons of the rate of mass or fat gain between treatment and control groups was quantified with linear regression (PROC REG) with tests of slope (β) and intercept differences. All data are presented as means \pm standard error, and all differences were considered significant at $\alpha = 0.05$.

Chipmunks

Chipmunk species in PNF display considerable overlap in habitat requirements, diet, and activity. Two chipmunk species, the long-eared and Allen's chipmunk, are frequently captured during our live-trapping efforts. These species overlap greatly in external characteristics and are thus difficult to identify in the field (Clawson et al. 1994; Gannon and Forbes 1995). To date, the only sure means to identify these species is by using skeletal features obtained by sacrificing animals. To evaluate the habitat affinities and distribution of these chipmunks, we first needed a non-lethal means of identifying them in the field. First, we collected representative samples of chipmunks to identify species through the use of pubic bones, and collected tissue samples from these known species to develop molecular markers for non-lethal identification of chipmunk species in the future. We collected a sample of reference chipmunks throughout PNF by salvaging animals from trap mortalities at long-term grids and euthanizing a small portion of animals from landbird grids (\leq 3 chipmunks per census transect). So as to avoid affecting capture-recapture data, animals were only collected on the last day of the trapping session. All specimens were frozen and submitted to the University of California, Davis Natural History Field Museum. Individuals collected were prepared as standard museum specimens (full skeleton plus skin) and tissues (e.g., liver, heart, muscle, and kidney) were collected for use in molecular analyses. Next, we collected tissue samples (small sections (< 1 mm) of ear pinna stored in cryovials containing 95% ethanol and stored in a freezer) from all chipmunks captured at long-term grids, landbird grids, and flying squirrel transects. Then, tissue samples and specimens were sent to the University of Idaho for molecular analysis to determine species identification; outside funding was secured for these analyses. Finally, we collected data on various aspects of each chipmunk's appearance. During 2005-2007, we recorded the presence of six external characteristics that have been suggested to visually distinguish between the two species. These are ear patch size and color, face stripe color and curvature, length and shape of the ear, and body color. We will use these data to compare external characteristics with molecular identification and skeletal features to determine what characteristics, if any, are reliable for species identification. Once we have identified individuals to species, it is then possible to examine habitat use and management implications for these species.

Animal handling

Similar animal handling protocols were used regardless of live-trapping sampling design. Captured animals were transferred to a mesh handling bag, identified to species, marked with numbered Monel ear tags (National Band & Tag Co., Newport, Kentucky), weighed, aged, measured (e.g., ear length, hind foot length), examined for reproductive status, and released at the point of capture. Total processing time for an experienced technician was generally <2 minutes. Reproductive condition for males was noted as either scrotal (enlarged and scrotal testes) or non-scrotal (reduced and abdominal testes); for females, the vagina was noted as either perforate (thereby receptive) or imperforate (not

receptive), the vulva as either swollen or not, and the animal as lactating (nipples were enlarged and/or reddened, reflecting nursing offspring), or not. Animals were aged based upon a combination of weight, pelage (juvenile: gray, subadult: intermediate, and adult: brown), and reproductive condition (juvenile/subadult: nonreproductive, adult female: pregnant/lactating, and adult male: scrotal).

At initial capture, a tissue sample was collected from each animal. Tissue samples were collected by snipping the terminal 1 mm of ear tissue using sterile surgical scissors and placing the tissue in a Nunc cryovial with 95% Ethanol. Tissue samples were placed in a freezer for long-term storage to preserve genetic material for current and future studies. Prior to 2006, we collected tissue samples from dusky-footed woodrats and chipmunks. In 2006, we collected tissue samples from all captured animals. In 2007, we collected tissue samples from all captured animals.

Any trap mortality, including incidental trap deaths, is thoroughly documented, and specimens are frozen and submitted to the University of California, Davis Field Museum of Natural History, in accordance with the permitting requirements of the California Department of Fish and Game and used for the educational and research purposes of the PLAS, and other interests. All field work and handling procedures are approved by the University of California, Davis Animal Use and Care Administrative Advisory Committee protocol (#10394), and meet guidelines recommended by the American Society of Mammalogists (Animal Care and Use Committee 1998).

Radiotelemetry

Movement data obtained from the radiotelemetry methods described herein allow us to measure home range, movement patterns, and social organization of individuals, permit the detailed measurement of habitat use and selection, and document the location and frequency of use of denning, nesting, and resting sites (Lancia et al. 1996, Litvaitis et al. 1996). Radiotelemetry methods are useful for making comparisons of small mammal movements and space use across time, locations, habitats, and land-use treatments. We applied radiocollars to a subset of dusky-footed woodrats and northern flying squirrels and radiolocated them during the day during resting activities and at night during foraging activities.

Radiotransmitter application

During 2003-2006, we applied radio transmitters to northern flying squirrels and duskyfooted woodrats. In 2007, we applied radio transmitters to northern flying squirrels only. A 4.0 g collar-type radio transmitter (Holohil Systems Ltd., Model PD-2C) was placed on the neck of individuals. Woodrats and northern flying squirrels were lightly sedated with ketamine hydrochloride (100mg/ml), or a combination of ketamine, xylazine, and saline solution, injected into the thigh muscle to facilitate application of radio-collars. Animals were allowed to fully recover from anesthesia prior to being released at the point of capture. Radiotelemetry activities of newly collared individuals were initiated after a 24hour acclimation period succeeding their release.

Homing

To document the location and frequency of use of denning, nesting, and resting sites we used homing techniques. For northern flying squirrels, diurnal locations were determined once per day, sporadically in 2003-2005 and 1-2 days per week in 2006 and 2007. For dusky-footed woodrats, diurnal locations were determined once per day, sporadically in 2003 and 3 days per week in 2004 and 2005 and 1-2 days per week in 2006. Locations were marked and accurately (≤ 1 m) mapped using a Trimble GPS unit.

Triangulation

Nocturnal telemetry sessions using triangulation techniques occurred during 5 nights per month in 2003 and 8-10 nights per month during 2004-2007. We used a Yagi antenna and a hand-held radiotelemetry receiver (Model R-1000, Communications Specialists, Orange, CA, USA) to obtain the location of radiocollared animals. Compass bearings for the radio-collared animal were obtained by using a hand-held compass and bisecting the signal drop-offs. Fixed telemetry stations, mapped to within 1 m accuracy using a Trimble GPS unit were located remotely from the transmitter's position to avoid disturbance of the radio-tagged animal. Technicians worked in synchronized teams to achieve 3 (or more) directional bearings within as short a time interval as possible (typically <15 minutes). Radiolocations were obtained for each animal 2-3 times per night, a minimum of 2.5 hours and 1 hour apart for dusky-footed woodrats and northern flying squirrels, respectively, to avoid serial correlation (Swihart and Slade 1988, Taulman and Smith 2004). Observers subjectively ranked their confidence in the accuracy of a signal based on signal flux due to animal movement, topography, vegetation, and distance, using a scale from 1-10, where 1 represents no confidence (signal faint and fluxing, signal drop-offs indistinct) and 10 represents high confidence (signal strong and steady, signal drop-offs distinct); these rankings were then divided into 3 categories: low (1-3), medium (4-6), and high (7-10) confidence. Haskell and Ballard (2007) determined that a similar ranking was correlated with absolute bearing error and could be used to increase the accuracy of location estimates. The timing of nightly telemetry was varied from dusk until dawn to ensure that radiolocations were sampled at different times of activity. Field technicians were thoroughly trained and rotated among stations and study sites each radiotelemetry session, to reduce the error due to differences among technicians. To ensure the accuracy of the triangulation method, triangulation systems were tested each night during regular radiotelemetry activities using 1-2 "dummy" collars placed within each study area; technicians did not know dummy collar locations, and the dummy collars were moved about once per week. To assess bearing error rates, dummy collar locations were determined and compared to their actual location.

Home range analysis

Northern flying squirrels.—We combined locations determined via homing and triangulation to estimate each animal's home range using 2 methods, the minimum convex polygon method (MCP, Fig. 4), and the kernel method (Fig. 5; Fuller et al. 2005). For MCP, a home range is defined by drawing lines that connect the outermost points to form a contained area. This area can be sub-sampled for habitat quality or compared with home ranges of different individuals by looking at area and overlap of home ranges. The

kernel method uses utilization distributions to estimate focal points of activity within the home range. This method weighs areas with a high density of points more heavily than areas with fewer points to generate "core areas" (Silverman 1986, Worton 1989). Examining core areas can be informative; for example, by examining differences between animal focal areas and other less used areas within or outside the home range. We used the maximum-likelihood estimator method (Lenth 1981) in the software program Locate III (Nams 2006) to estimate locations and error ellipses for triangulations. We used several criteria to evaluate bearing data and determine animal locations. These included convergence of bearings, presence of outliers, number of bearings (\geq 3), and signal rank. All bearings with low confidence were excluded from analysis. Bounce was an issue that contributed to large error at our study sites. To address this issue, we removed the two most divergent bearings until no fewer than 4 bearings were used for triangulation. This was possible because in 2007 we typically took 6 simultaneous bearings for each animal. Accepted locations were analyzed in Ranges6 (Kenward et el. 2003). We estimated home range (95%) and core range (50%) using the minimum convex polygons (MCP) and fixed kernel (FK) methods (Kenward 2001).

During 2004 and 2005, we calculated an index of activity for northern flying squirrel throughout the night. We measured the distance between each location and the nearest known den tree. These distances were used to generate a time series of distances each individual was found from its nearest den tree. We constrained this analysis to the period between 18:00 and 06:00 as that represented the active time for flying squirrels (Weigl and Osgood 1974). Analysis of home range size and nocturnal activity was performed for northern flying squirrels using a 2 x 2 factorial design, with habitat (FS-1: red fir, FS-2: mixed conifer) and time of night (4 categories) as primary factors, and sex (male, female) as the secondary factor. PROC MIXED was used to calculate F-test values, and Satterthwaith's approximation was used to calculate the degrees of freedom for the error term (SAS Institute 2000). If there were no significant interactions, differences in the main effects were compared using the PDIFF option in the LSMEANS statement. Differences in terms with significant interactions were compared using the SLICE option in the LSMEANS. All data are presented as means \pm standard error, and all differences were considered significant at $\alpha = 0.05$.

Dusky-footed woodrats.— We used radiotelemetry to determine space use of woodrats during 2004 to 2006 at study sites WR-1 and WR-2 (Fig. 3). We used the maximum-likelihood estimator method (Lenth 1981) in the software program Locate III (Nams 2006) to estimate locations and error ellipses for triangulations. We excluded all triangulations for which >50% of bearings received a rank of low confidence. Locations ≥ 1 km from the station to the transmitter also were excluded (Schmutz and White 1990). We used Ranges6 (Kenward et el. 2003) to calculate incremental area analysis, home range, core area, and overlap among individuals. All analyses used a combination of nocturnal movement locations and diurnal locations obtained from trapping and homing. Because a given woodrat was often found multiple times at 1 house, we used only 1 diurnal location per house to avoid biasing core area estimates towards house locations, resulting in about 80% of locations being nocturnal.

Minimum convex polygon (MCP—Mohr 1947) and fixed kernel (FK—Worton 1989)

methods were used to calculate home range and core area. MCP home range (95%) and core area (50%) were calculated using the arithmetic mean (Nams 2006). Incremental plots of home range size versus number of locations were inspected for each individual using Ranges6 to check that the range area reached an asymptote; if an asymptote was not observed, then that individual was excluded from further analysis (Kenward 2001). We found that a minimum of 16 (mean= 24.5 ± 1.3) locations was required to reach an asymptote in home range area using MCP. In addition, woodrats that were radiocollared for <30 days were also excluded because of the short duration. Application of these criteria resulted in the exclusion of 12 collared woodrats (2 in 2004; 7 in 2005; 2 in 2006), all of which appeared to have been killed by predators shortly after collaring. In addition, 5 collared woodrats (2 in 2004; 3 in 2005; 0 in 2006) were excluded from analyses because they were transient or resided outside of the study areas. Fixed kernel volume contours (95% home range, 50% core area) were calculated utilizing the leastsquares cross-validation method in Ranges6 for those animals with \geq 30 locations (Seaman et al. 1999, Millspaugh et al. 2006); application of this criteria resulted in the exclusion of 17 additional individuals for FK analyses.

We calculated an index of overlap (OI; Minta 1992), with possible values ranging from 0 (no overlap) to 1 (100% overlap). For each study site and year, we calculated OI for home ranges and core areas for each male-male, male-female, and female-female pair. We only included woodrats whose home ranges overlapped with ≥ 1 other home range. All overlap calculations were based on MCP home ranges and core areas, because we did not want to exclude any potentially interacting individuals from overlap calculations, and to facilitate comparison with previous studies (e.g., McEachern 2005).

We assessed synchronous and asynchronous sharing and successive occupancy of houses by all radiocollared woodrats based on diurnal locations, when woodrats are inactive within their houses. Duration of house sharing was determined by assuming sharing occurred between successive radiolocations. We examined placement of houses within core areas using FK because it relies on probability distributions, which indicate areas of intense use (Seaman and Powell 1996).

All statistical tests were performed using JMP IN 5.1.2 (SAS Institute 2004) and significance was set at α =0.05 and Bonferroni-corrected for multiple comparisons, when appropriate. Only 10% of woodrats were radiocollared for two consecutive years, thus we considered data from different years to be different samples. Differences among groups were analyzed using analysis of variance (ANOVA) after transformation to meet assumptions of normality (Kutner et al. 2005). The Wilcoxon rank scores test was used to test for differences between groups when data could not be transformed to meet assumptions of normality.

Vegetation

Long-term grids

Coppeto et el. (Publications #1 and #2) provides a detailed analysis of the macro- and microhabitat associations of the full compliment of small mammal communities within 18 long-term grids established within 5 habitat types in PNF during 2003-2004. The

Mammal Module staff did not measure the macro- or microhabitat characteristics on the long-term study grids 2005-2007, although the Vegetation Module has continued to monitor habitat and microclimate characteristics on a portion of these plots.

Cone Counts.—To evaluate the effects of conifer seed production on small mammal abundance, we measured cone production during fall of 2003, 2004, 2006, and 2007 using 10 randomly selected individual trees of each species on each long-term grid. For this we selected mature dominant or codominant trees with pointed crowns, as tall as or taller than the surrounding canopy, sufficiently far apart that their crowns did not touch. For grids with <10 individual trees of a given species, additional trees were found as close to the grid as possible (<500 m). The same trees were counted in each year within the same 2-wk period to prevent confounding temporal factors. Counting was performed by standing at a distance of $\geq 1.5x$ the tree height and visually counting cones using binoculars. For each tree we recorded tree height, diameter at breast height (DBH), species, and crown class. Temporal differences in cone production were determined using repeated measures analysis of variance (rmANOVA) with year, habitat type, and species as treatments, and individually counted trees as the repeated measure.

Landbird grids

Microhabitat characteristics were sampled at landbird grids May-October, 2006 and 2007. All measurements were recorded within a 1-m radius circular plot (3.14 m^2) centered at each grid point. We followed the protocols and definitions established by Stephanie Coppeto (Publications #1 and #2); however, we measured canopy closure using a Moosehorn with an 8.5×8.5 cm grid viewed at eye-level (1.7 m) from the center of the plot, and recorded the number of squares obscured by vegetation, as opposed to using hemispherical photographs, due to logistical constraints. We visually estimated percent cover of the same 12 ground cover and recorded 3 species richness variables (Publication #2, Table 1). We used the following ground cover classes: 0, rare, 1, 5, 10, 15, ..., 90, 95, 99, and 100%, since these cover classes approximate a normal distribution. In addition, we tallied the number of trees of each species at each point using a Panama gauge. All ocular estimates were performed by trained observers.

Northern flying squirrels

Den use.— We documented northern flying squirrel den locations during homing activities, and a number of measurements were taken at these dens to determine the habitat preferences of squirrels. These data will be used to test for tree use versus availability. We recorded the DBH, species, condition (live tree, snag), den height, and type (cavity or external) of each den tree. We measured habitat characteristics at den locations and paired random points. Den plots were centered on the den tree, and paired with a plot whose outer edge intersected the outer edge of the den plot. All trees ≥ 10 cm DBH within an 18 m radius (0.1 ha) were measured and species recorded. Additionally, decay characteristics (fungi present, cavities) were noted and epiphyte loads estimated according to the methods of Bakker and Hastings (2002) to see if northern flying squirrels showed any preferential selection of den trees within sites. All trees <10 cm DBH were tallied. Estimates were taken of ground cover to the nearest percent. Dominant over- and understory trees were recorded as well. Spherical densiometers were

used to take canopy measurements in a randomly selected direction at the edge of the plot, with 3 successive measurements at 90° from the first. Canopy readings were also taken at the plot center. Two randomly chosen transects were used to estimate coarse woody debris. Degree of decay, length, diameter and both ends, and species were recorded. All woody debris \geq 10-cm diameter at the largest end were measured and recorded. Percent slope at each site was estimated using a clinometer. We measured habitat characteristics at 78 northern flying squirrel dens and 78 paired comparison plots during 2006–2007.

Dusky-footed woodrats

Macrohabitat selection.—To determine if woodrat density was positively related to California black oak abundance, we estimated California black oak density (ha^{-1}) at each study site by counting trees ≥ 5 cm DBH during September 2005 in 10 x 100 m belt transects placed in a stratified random fashion, such that $\approx 10\%$ of the total area was sampled. We regressed mean adult woodrat density (2004 and 2005 combined) on oak density. Because California black oaks begin to produce acorns in substantial quantities (≥ 9 kg) at about 80 years of age (≈ 33 cm DBH—McDonald 1969), we ran separate analyses on small (<33 cm DBH) and large (≥ 33 cm DBH) oaks. We assessed the relationship between mean adult woodrat density and California black oak density among the 4 study sites with simple linear regression using JMP IN 5.1.2 (SAS Institute 2004). Because we predicted a positive association, we used a 1-tailed test. We ran residual diagnostics to confirm that the model was appropriate for the data set (Neter et al. 1996).

Microhabitat selection.—We measured microhabitat variables within a 4-m radius circle (50.3 m²) centered on 144 houses and 144 paired random sites during September–November 2003, May–October 2004, and May–September 2005. Plot size was based upon ocular estimates of patch size at woodrat houses (i.e., the microhabitat changed beyond a 4-m radius). We randomly selected 66% and 87% of houses at sites WR-1 and WR-2, respectively, where houses were more abundant, and sampled 100% of houses at sites WR-3 and WR-4.

At each woodrat house, we visually estimated percent cover of 3 ground cover variables and measured density and cover of shrubs, trees, snags, stumps, and logs (Table 2). We determined density of short and tall shrubs by counting individual stems. To determine if woodrats were selecting for greater density and basal area of smaller trees, we measured density (ha⁻¹) and basal area (m²ha⁻¹) of tree species in 4 DBH classes modified from Bell and Dilworth (1993): sapling, poletimber, small sawtimber, and large sawtimber. California black oak may be important at the microhabitat level as well as the macrohabitat level; hence, we excluded California black oak trees from tree density and basal area calculations and examined the presence of small (<33 cm DBH) and large (\geq 33 cm DBH) oaks separately. We recorded the presence of large (\geq 30 cm DBH) snags because we observed that woodrats frequently accumulate debris in the cavities of large snags. We measured tree and snag diameters using a diameter tape. We measured the diameter at root collar (DRC) of stumps using a measuring tape, and recorded the presence of large (\geq 30 cm DRC) stumps because these were big enough to provide a platform for debris. We measured the diameter and length of logs using calipers and a measuring tape, and the volume of each log (m^3ha^{-1}) was estimated as a frustrum paraboloid using log length and diameters at both ends (Bell and Dilworth 1993). The percent of canopy closure was quantified using a Moosehorn with an 8.5×8.5 cm grid viewed at eye-level (1.7 m) from the center of the plot, and the number of squares obscured by vegetation was recorded. Slope was measured using a clinometer. All ocular estimates were performed by one observer (RJI).

We also sampled, with replacement, the same vegetation and structural characteristics at paired points located a random distance (10-50 m) and a random direction from the center of each house. Random sites were constrained to lie within the same habitat type as the paired house. The distance requirement ensured that the random sites fell outside of the sampled house site, but within the estimated home range of a dusky-footed woodrat (1,942–4,459 m²—Cranford 1977; Lynch et al. 1994).

House-site selection.—We used conditional logistic regression (CLR) to predict the odds of finding a house at a certain location given the explanatory variables. CLR can fit a model based on conditional probabilities that "condition away" or adjust out the grouped effect (Stokes et al. 2001). We considered each house-random pair to be separate strata, adjusted out subject-to-subject (i.e., house-to-house) variability and concentrated on within-subject (i.e., house-to-random) information. In this way, CLR conditions out variability due to macrohabitat differences and concentrates on variability due to microhabitat preference. Quantitative comparisons of microhabitats are possible by examining odds ratios, which indicate the increased likelihood of the outcome with each unit increase in the predictor given the covariate pattern (Keating and Cherry 2004).

Prior to CLR analyses, we examined Spearman's rank correlations between variables to identify collinearity. Variables that were highly correlated ($r_s \ge |0.7|$) and those that explained similar biological phenomena were not included together in multivariate models (e.g., sapling density and sapling basal area, $r_s = 0.98$; Hosmer and Lemeshow 1989). In addition, we performed univariate CLR using PROC PHREG in SAS 8.02 (SAS Institute 2001) to reduce the number of candidate variables for model building. We compared microhabitat variables between house and random sites and included habitat type (n = 10) as an interaction term in each single-variable model because we hypothesized that some variables might respond differently among habitats. We retained those variables with P-values ≤ 0.25 from log-likelihood ratio tests or variables that had significant habitat type interactions (Hosmer and Lemeshow 1989).

We then performed multivariate CLR to determine which combination of microhabitat variables best discriminated between house and random sites. We built CLR models using forward stepwise selection using the screening criteria recommended by Hosmer and Lemeshow (1989—P = 0.15 to enter and P = 0.20 to remove), so as not to exclude potentially important variables from the model. At each step, we selected the model with the lowest Akaike's Information Criterion (AIC) value, and combined this model with all other variables (Table 3); the best model was that with the lowest AIC value, and any model within 2 AIC points of the best model was considered to be a competing model (Burnham and Anderson 1998). The final model(s) were those for which all coefficients

were significant. We examined model residual chi-square and residual diagnostics to further assess model goodness-of-fit (Hosmer and Lemeshow 1989; Stokes et al. 2000).

House use.—We used a reverse stepwise multiple logistic regression (MLR) nointercept model to determine if there were combinations of microhabitat variables that best distinguished houses used and unused by adult woodrats, and to compare houses used by adults and subadults. All 21 variables were included in MLR models; in addition, we included house volume (above versus below the median of 0.3 m³; "large" versus "small," hereafter) to determine if house size influenced use (Vestal 1938). MLR was applied using JMP IN 5.1.2 (SAS Institute 2004). Only houses used exclusively by an adult or a subadult were included in analyses; houses at which an adult and a subadult were captured at least once during the 4-day trapping session were omitted from analyses comparing adult and subadult house use, resulting in the omission of 6 houses in 2004 (4.2%) and 4 houses in 2005 (2.8%). Juvenile woodrats were excluded from all analyses. Significance level for all tests was set at $\alpha = 0.05$. All means are presented as \pm standard error.

Tree house characteristics and use.— We examined tree house characteristics and use during 2004 to 2006 at 2 study sites WR-1 and WR-2 (Fig. 3). Ground houses were those located on the soil surface or on downed wood. Tree houses were characterized as either built within a tree cavity or externally on limbs. For all tree houses, we recorded whether the tree was alive or a snag and the species of live trees. We measured diameter at breast height (dbh; cm) of a random sample of the trees in which houses were found (88% and 83% of house trees at study sites 1 and 2, respectively). We determined tree availability by counting all trees and snags (≥ 5 cm dbh) in randomly located, 4-m radius circular plots (72 at site 1, 77 at site 2), and recorded tree and snag characteristics for each plot. We based house use analyses on radiotelemetry locations during the daytime period of inactivity determined using homing. For each woodrat, we calculated the proportion of radio locations occurring at each house type (ground or tree), then averaged across individuals and years by sex. We tested for differences in tree house use between sexes each month using the Wilcoxon rank scores test. Because we found no difference in proportional availability and use of houses between sites, results from the 2 study sites were combined for all analyses.

Acorn Counts.—We hypothesized that there would be a positive relationship between adult dusky-footed woodrat density and annual acorn crop; therefore acorn production of California black oak was measured on 25 and 28 trees located at woodrat study sites WR-1 and WR-2, respectively. Dusky-footed woodrat study sites WR-3 and WR-4 had insufficient densities of mature oaks to estimate mast crops at these locations. Mature (\geq 33 cm DBH), dominant or co-dominant California black oak trees with visible crowns in a variety of conditions (e.g., mistletoe, bole cavities, broken tops) were arbitrarily selected as sample trees without a priori knowledge of the acorn production potential of the trees and somewhat stratified to include a range of sizes (range: 33.7-75.2 cm DBH). Sample trees were permanently marked with aluminum tags for future surveys. We recorded DBH, height, crown width and condition since these factors are known to influence acorn yield (Macdonald 1969). We visually estimated acorn production in early September, just prior to acorn drop when acorns are most readily visible, using the methods developed by Garrison et al. (1998) for California black oak in Placer County, California. One observer made counts in two randomly selected parts of the tree by visually dividing the tree's live crown into a lower and upper half and further dividing each half into thirds. A random numbers table was used to select a subdivision in the lower and upper halves for counting. Binoculars were used to scan the crown and the observer counted as many apparently viable acorns as possible within 15 seconds. Visual counts of acorns for the two 15 second count periods were combined to yield a total count for a 30 second period. Visual counts of California black oak acorns using this method have been shown to be an adequate index of overall acorn production as well as the amount of acorns available as food for wildlife (Garrison et al. 1998).

RESULTS AND DISCUSSION

We have been making steady progress towards our objectives. In 2007, we completed several projects. In addition to successfully completing an extensive (1 May-1 November) field season, our study module has produced quality peer-reviewed publications and other products. In 2007, we had 3 manuscripts in publication, 2 manuscripts in review, and several more in preparatory stages. We have chosen to present the abstracts of our published, submitted, or in preparation manuscripts herein as a representation of the work that we have completed to date. Publications #3, #6, #9, and #11 are new to this year's annual report

Long-term grids

One of our objectives for the long-term grid data is to determine small mammal habitat associations at macro- and microhabitat scales (Objective #1). We have examined this at our long-term grids and include this summary herein (Publications #1 and #4). Another objective for our long-term grid data was to determine small mammal population trends, evaluate how populations are changing temporally, and assess the factors responsible for the observed trends (Objective #5). We have documented the dynamics of small mammal abundance at long-term grids since 2003, and we have currently evaluated trends using data from 2003-2004, and include this summary herein (Publication #8). In 2007, the planned treatments were implemented and data on small mammals were collected immediately after the treatments were completed. This coming field season we will collect the first full year of post-treatment data. We will analyze data obtained at long-term grids pre-treatment (2005-2006) and post-treatment (2007-2008) to assess the impacts of forests management treatments on small mammal abundance and species diversity (Objective #4).

Publications #1 and #4: Habitat associations of small mammals at two spatial scales in the northern Sierra Nevada

Effective management strategies require an understanding of the spatial scale at which fauna use their habitat. Towards this end, small mammals were sampled in the northern Sierra Nevada, California, over 2 years (2003-2004) at 18 live-trapping grids among 5 forest types (Fig. 1a). Macrohabitats were defined by overstory tree composition, and 19 microhabitat variables were measured at all trap stations (Table 1). Macrohabitat and

vear explained 93% of variation in abundance of deer mice (*Peromyscus maniculatus*). whereas 69% was explained by microhabitat and year. Variation in abundance of Tamias sp. (long-eared and Allen's chipmunk) was slightly better explained by microhabitat and year (70%) than by macrohabitat and year (67%). Red fir forests supported significantly more mice and chipmunks than mixed conifer and pine-cedar forests, and more chipmunks than mixed fir forests. Five of 6 uncommon species were significantly associated with macrohabitat type; golden-mantled ground squirrels, northern flying squirrels, and *Microtus* sp. (long-tailed vole–*M. longicaudus*; Mountain vole–*M.* montanus) were captured almost exclusively in red fir forests, whereas dusky-footed woodrats and California ground squirrels were found in pine-cedar, mixed fir, and mixedconifer forests. The first 2 axes of a canonical correspondence analysis on microhabitat variables explained 71% of variation in combined small mammal abundance. Microhabitat associations varied among species but were driven primarily by canopy openness, shrub cover, and shrub richness. Although much of the small mammal fauna appeared to select habitat at both spatial scales studied, CCA using macrohabitat as a covariate revealed that microhabitat explained much less of the variation in small mammal abundance than did macrohabitat. Still, the strongest scale of association may be species-dependent and hierarchical in nature.

Publication #8: Population dynamics of small mammals in relation to cone production in four forest types in the northern Sierra Nevada

We studied the small mammal assemblage in 4 forest types (white fir, red fir, Douglas fir, and ponderosa pine) in the Sierra Nevada of California for 2 consecutive field seasons (2003-2004). We also assessed cone production by dominant conifer species in both years. Cone production was greater overall in fall 2003, but varied within forest type and between conifer species (Fig. 6). Parallel to this, mean maximum densities of deer mice increased in 2004 (from 0.7 - 7.3 ind./ha to 65.7 - 112.7 ind./ha; Fig. 7). Numbers of golden-mantled ground squirrels were similar in both years, and displayed the typical pattern of a hibernating species, with low densities in May (6.6 ± 0.2), peak densities in September (24.5 - 32.5 ind./ha), and declines in October $(9.2 \pm 4.8; \text{Fig. 8})$. Long-eared chipmunks reached higher densities in red fir (48.2 ± 13.4 ind./ha) and Douglas-fir forests $(36.0 \pm 13.5 \text{ ind./ha})$ than in white fir forests $(7.6 \pm 2.7 \text{ ind./ha})$, and all populations peaked in September. Allen's chipmunk remained at lower densities than long-eared chipmunks except during September 2004, when populations of the former reached high densities $(54.6 \pm 26.8 \text{ ind./ha}; \text{Fig. 9})$. Survival of deer mice was dependent on an interaction between forest type and month with additive effects of winter and 2003 fall mean cone production. Golden-mantled ground squirrel survival varied by month whereas survival in both species of chipmunk varied by an interaction of forest type and month + winter (Table 4). Dusky-footed woodrats were present at lower elevations and reached greatest densities in ponderosa pine forests. Northern flying squirrels were uncommonly captured and found predominantly in red fir forests.

Publication #9: Trapping rodents in a cautious world: the effects of disinfectants on trap success.

Recommendations for hantavirus prevention include disinfecting traps that have captured small mammals. However, the potential effects of disinfection on small mammal

trappability have not been thoroughly investigated. We conducted an experiment to compare the effects of 2 disinfectants (Lysol and household bleach) on trappability of 3 small mammal species (deer mice, chipmunks, and golden-mantled ground squirrels). We established triplicate trap grids in 2 forest types (red fir and mixed conifer), each consisting of a 6 x 6 array of Sherman live traps placed at 10 m intervals. Traps were given 1 of 3 treatments: control (water), Lysol, or bleach; and were placed such that the 3 treatments alternated in a regular pattern. Traps were run for 4 consecutive nights with application of each treatment daily. We found a difference in the trappability of deer mice between years; however we did not detect a statistically significant difference in trappability due to disinfection for any of the 3 study species. Within deer mice, disinfectant effects on capture probability were not supported by model selection in Program MARK. These results indicate that although populations may fluctuate temporally and spatially, trap disinfection does not have a significant effect on small mammal trappability.

2007 Field Season

During the 2007 field season we captured and marked a total of 732 individuals of 10 species. Predominant species in the study area included deer mice, brush mice (*Peromyscus boylii*), long-eared and Allen's chipmunks, California ground squirrels (*Spermophilus beecheyi*), golden-mantled ground squirrels, dusky-footed woodrats, Douglas squirrels (*Tamiasciurus douglasii*), long-tailed voles, and northern flying squirrels. Incidental mammals captured included shrews (*Sorex* sp.) and western gray squirrels (*Sciurus griseus*).

In 2007, abundance of mice and chipmunks reached levels not observed since 2004 (Fig. 10-11). We noticed a marked increase in capture rate of northern flying squirrels at long-term grids in 2005, 2006, and 2007 as compared with 2003 and 2004 (Fig. 13). This marked increase in northern flying squirrel abundance is likely the result of an improved bait mixture and arboreal trap placement, protocols implemented in the fall of 2005; however data since 2005 indicate that northern flying squirrel abundance has steadily increased over the past 3 years, particularly within mixed-conifer forest, a trend which cannot be explained by differences in sampling protocols. Interestingly, during this time woodrat abundance at long-term grids steadily declined, and presence of woodrats in 2007 remained only within mixed-fir habitat (Fig. 12), the only habitat within which northern flying squirrel abundance declined over the past 3 years.

Landbird grids

Landbird grids were established to compliment the data collected at our long-term study grids and more fully integrate our live-trapping efforts with that of other modules. The 2007 field season marks the second and final year of data collection at landbird grids. In the near future we plan to begin more detailed analyses of this data in close collaboration with the Landbird Module.

2007 Field Season

We sampled small mammals at 192 points within 24 transects located in 4 (former) treatment units in 2007. During the 2007 field season we captured and marked a total of

1,528 individuals of 12 species. Species captured included dusky-footed woodrats, deer and brush mice, long-eared and Allen's chipmunks, California and golden-mantled ground squirrels, mountain, long-tailed, and California red-backed (Clethrionomys occidentalis) voles, Douglas squirrels, and northern flying squirrels. Incidental mammals captured included shrews, snowshoe hare (*Lepus americanus*), striped skunks (*Mephitis mephitis*), spotted skunks (*Spilogale putorius*), short-tailed weasel (*Mustela erminea*), and ringtail (*Bassariscus astutus*).

In total, we sampled small mammals at 367 points within 44 landbird transects across 4 (former) treatment units at a total of 1,468 trap locations for 11,396 trap nights, and captured 2,513 individual small mammals during 2006 and 2007. Deer mice (n=1,041) were captured at 75% of points and were the most commonly captured species followed by chipmunks (47% Allen's chipmunk, n=781; 28% long-eared chipmunk, n=261), brush mice (23%, n=188), golden-mantled ground squirrels (11%, n=93), northern flying squirrels (10%, n=58), California ground squirrels (10%, n=65), dusky-footed woodrats (8%, n=54), and Douglas squirrels (4%, n=17). Other species were captured at $\leq 2\%$ of plots. We measured habitat characteristics in 3.14 m² plots centered about trap locations at all trap locations in 2006 and 2007 (n=1,468).

In 2007, we captured 36 northern flying squirrels (24 males, 12 females) at 15 landbird transects and 14 of these were recaptured. A majority (82%) of northern flying squirrels were captured in tree traps, emphasizing the importance of this trapping method. Two individuals captured at 2 landbird transects were radiocollared. In addition, we captured 12 dusky-footed woodrats (6 males, 6 females) at 5 landbird transects; 7 of these were recaptured.

In total, we captured 58 flying squirrels at landbird transects during 2006-2007. Most notably, nearly 30% of all flying squirrel captures occurred at a single transect (transect 223 in TU 2). Also, over 50% of dusky-footed woodrat captures occurred at 2 transects (BLH2 and HAL2 in TU3). We determined small mammal species richness at all sites sampled in 2006 and 2007 (Fig. 14-17). Species richness ranged from 0-5. Mean species richness was greatest at TU-2 (2.59, n=82), and TU-5 (2.46, n=80), followed by TU-4 (1.95, n=113) and TU-3 (1.88, n=92). In the future we hope to examine how landbird species richness compares to small mammal species richness at a site (i.e., are areas of high landbird species richness also areas of high small mammal species richness?).

Northern flying squirrels

We have captured and radiotracked northern flying squirrels since 2004 in an effort to evaluate the abundance and distribution, habitat use, and home range of this important species (Objective #6). We have examined data from 2004-2005 and include this summary herein (Publication #7). We continued these efforts during 2006 and 2007 to increase our sample size and improve our statistical power; 2007 marks the final year of northern flying squirrel radiotracking. Data from 2006 and 2007 will be included in an additional publication (Publication #3).

Publication #7: Home range and activity of northern flying squirrels in the northern Sierra Nevada

We studied the northern flying squirrel in PNF using radiotelemetry. Fourteen northern flying squirrels from 2 forest types (mixed conifer and red fir; Fig. 18) were fitted with radiocollars and provided sufficient locations for home range analysis. We used 95% adaptive kernel and 95% minimum convex polygon (MCP) analysis to determine home ranges (Table 5). No sex differences and no differences in forest type were observed for home range size (Fig. 18). Mean kernel home range size was 25.7 ha for all squirrels. Mean distance to the nearest nest tree did not vary throughout the night; however, females tended to travel greater distances from nest trees (Fig. 20).

Publication #3: Home range and habitat selection of northern flying squirrels in the northern Sierra Nevada

Average home range size for female northern flying squirrels during 2006 using 95% MCP was 12.55 ha \pm 2..58 and using 95% FK was 17.56 ha \pm 5.67. Home range was only calculated for females, because of low numbers of successful male captures during this year. In 2007, average home range size for northern flying squirrels using 95% Minimum Convex Polygon was 8.27 ha \pm 4.64 and using 95% Fixed Kernel was 6.97 ha \pm 4.25. Each year, females were larger than males (2006: fem = 122.2 g, male = 102.0 g; *P* <0.0001; 2007: fem = 129.7 g, male = 103.6 g; *P* = 0.0039); however, home ranges of females and males were similar (*P* = 0.41).

Most dens (n=53) were located in cavities (49%), but some were external stick nests located on the limbs of trees (12%); 39% could not be identified because they were not visible to the observer. Preliminary results obtained using 53 dens and 53 paired random plots indicate that dens were distributed amongst various tree species and size classes. Most den trees were located in white fir (28%) and California black oak (26%; Table 6). However, comparison of use and availability indicate that California black oak may be used preferentially for den sites (Fig. 21). Many den trees were located in large sawtimber (\geq 53.4 cm dbh, 44%), but poletimber (10-27.9 cm dbh, 35%) and small sawtimber (28-53.3 cm dbh, 21%) were also used. Comparison of use and availability indicate that northern flying squirrels are using larger trees than those available (Table 6).

2007 Field Season

In 2006, we captured 55 northern flying squirrels (long-term grids, n=20; landbird grids, n=20; flying squirrel transects, n=15). We radiocollared 19 northern flying squirrels at 6 study sites. Of these, sufficient data to estimate home range was obtained for 7 northern flying squirrels. In 2007, we captured 77 northern flying squirrels (long-term grids, n=21; landbird grids, n=36; flying squirrel transects, n=20). We radiocollared 20 northern flying squirrels at 7 study sites. Of these, sufficient data to estimate home ranges was obtained for 17 northern flying squirrels.

To evaluate den use by northern flying squirrels, we measured habitat characteristics at 39 and 40 den trees in 2006 and 2007, respectively. We also measured the same characteristics at paired random points (n=79). During 2007, we conducted preliminary analyses of den-tree selection by northern flying squirrels.

Dusky-footed woodrats

We have captured and radiotracked dusky-footed woodrats since 2003 in an effort to evaluate the abundance and distribution, habitat use, and home range of this important species (Objective #6). To date, we have examined vegetation data obtained during 2004-2005 and include this summary herein (Publications #2, #5, and #6). In 2007, we prepared a manuscript on the spatial organization of dusky-footed woodrats (Publication #11). The 2006 field season marked the final year of data collection, so that we might focus our efforts on northern flying squirrel ecology during 2007 and analyze data obtained on woodrats from previous years.

Publication #2 and #5: Habitat selection by dusky-footed woodrats in managed mixed-conifer forest of the northern Sierra Nevada

Dusky-footed woodrats are important components of forest communities, including serving as a primary prey of the California spotted owl, a species of concern in California. We examined the macro- and microhabitat associations of the dusky-footed woodrat at 4 study sites within mixed-conifer forest of the northern Sierra Nevada, California, during 2003–2005. We investigated the importance of California black oak as a macrohabitat component for woodrats, and we examined microhabitat selection at 2 levels, house location and house use, by comparing house-site (n = 144) characteristics to random sites (n = 144) and characteristics of used and unused houses, respectively. We found a strong trend towards a positive relationship between woodrat density and large (≥33 cm diameter at breast height) oak density (Fig. 22), suggesting that large oaks are an important macrohabitat component for woodrats, probably because of their value as a food resource. At the microhabitat scale, house location was strongly influenced by the presence of large (\geq 30 cm diameter at root collar) stumps, but also by abundance of logs, steeper slopes, and lack of bare ground and mat-forming shrub cover (Table 7). Houses used by adults were not distinguishable from unused houses on the basis of microhabitat variables, suggesting that woodrats make decisions about microhabitat conditions at the time a house is built. Adult and subadult woodrats selected houses with different microhabitat characteristics, but this pattern was not consistent between years. In 2005, adults chose larger houses that were characterized by more logs and less poletimber, but we detected no such differences in 2004. Dusky-footed woodrats in the northern Sierra Nevada would benefit from management techniques that promote the growth and retention of large California black oaks and create abundant dead wood within a stand.

Publication #6: Characteristics and use of tree houses by dusky-footed woodrats in managed mixed-conifer forest of the northern Sierra Nevada

Dusky-footed woodrats are important components of forest communities, including serving as a primary prey of the California spotted owl, a species of concern in California. Because previous studies have focused on the more "typical" ground houses, little is known about tree houses, perhaps because their inconspicuous nature makes them difficult to locate (Fargo and Laudenslayer 1999). Our objective was to describe locations of tree houses and determine if dusky-footed woodrats used these houses preferentially.

Most houses (n=252) were located on the ground (58%), but many were also located in cavities of trees or snags (27%) or on the limbs of live trees (15%). Three houses were

located aerially in shrubs (hence neither ground nor tree), and were excluded from analyses. Tree houses were located primarily in white fir, Douglas-fir, California black oak, and snags (Table 8). Comparison of use and availability suggests that white fir were preferred as locations for houses constructed on limbs. White fir were mostly smaller, understory trees with splayed branches suitable for supporting the woody debris used in house construction. Large California black oaks and snags were strongly preferred as sites for cavity houses, probably because their size and tendency to decay resulted in formation of cavities of sufficient size for constructing houses.

Individual woodrats used as many as 3 tree houses and 8 ground houses, and use of tree houses was common, with 70% of males and 73% of females using at least 1 tree house. We expected that tree houses might provide increased protection from predation, because houses on the ground were vulnerable to destruction by black bears, or provide better access to arboreal food sources. However, woodrats did not spend more time at tree houses than expected on the basis of availability (Table 9). Among tree houses, cavity locations seemed preferred to limb locations when compared with availability, perhaps because cavity locations more frequently than did males (Table 9). Use of tree houses increased during the late summer with a peak in October (Fig. 23), possibly because mast availability in the fall increased arboreal foraging opportunities. Females used tree houses more frequently than did males during June (Z = -2.13, P = 0.032) and July (Z = -0.2.22, P = 0.026), coincident with the time of reproduction, perhaps because tree houses offer enhanced protection for unweaned offspring.

Our results suggest that tree houses are a prevalent and frequently used resource for dusky-footed woodrats in mixed-conifer forest of the northern Sierra Nevada. Tree house use is most prevalent during late summer and fall, and large California black oaks and snags are the most important forest elements for tree house location because of the protected sites provided by their cavities.

Publication #11: Spatial organization of dusky-footed woodrats in managed mixedconifer forest of the northern Sierra Nevada

The spatial organization of dusky-footed woodrats is poorly understood, especially in mixed-conifer forest, which is one of the most prevalent and intensively managed forest types in the Sierra Nevada (Franklin and Fites-Kaufman 1996). Woodrats in this region are a primary prey of the California spotted owl (Verner et al. 1992), a species of concern in California (United States Department of the Interior 2003); as a result, it has been suggested that resource managers increase the availability of woodrats to spotted owls (Sakai and Noon 1993, 1997). A population's spatial structure has important implications for population dynamics, as well as the genetic structure of a population (e.g., Dunning et al. 1992, Lambin and Krebs 1991; Sugg et al 1996). The goals of this study were to document the spatial organization of woodrats in mixed-conifer forest of the northern Sierra Nevada at 2 study sites across multiple years to compare patterns of space use by males and females, to examine variation is home range size and overlap across sites and years, and to compare the distribution of same-sex and opposite-sex neighbors to characterize the social mating system of this species (e.g., Ostfeld 1986,

Topping and Millar 1996, Cooper and Randall 2007). Because critical resources are different for the sexes (Ostfeld 1990), we predicted that woodrats would exhibit reduced intersexual overlap of home ranges as compared with intrasexual overlap. Because woodrats are solitary and territorial, we expected to find territoriality of houses and placement of occupied houses within defended core areas.

Home range and core area.— We radiotracked 37 woodrats (13 males, 24 females) at study site 1, and 26 woodrats (11 males, 15 females) at study site 2 (Fig. 3) for a mean of 99 days (range 34-144), obtaining a mean of 43 locations (range 16-75). The home range estimators used in this study provided similar estimates, with MCP sizes of 0.17-7.38 ha and FK sizes of 0.24-7.96 ha for home range and MCP sizes of 0.06-2.99 ha and FK sizes of 0.09-3.06 ha for core area (Table 10). Each year, woodrats at site 2 had larger home ranges and core areas than woodrats at site 1 (all P<0.0001). At site 2, home range and core area estimates were larger in 2005 than 2004 and 2006 (all P<0.01); home range and core areas were similar among years at site 1. Mean sizes of male home range and core areas were similar to that of females at both sites each year, although males frequently had larger home ranges and core areas than females (Table 10).

Home range of woodrats at our study sites were similar to those reported elsewhere (0.2– 5.8 ha—Lynch et al. 1994, Cranford 1977, Sakai and Noon 1997, McEachern 2005), and our estimates show similar variability in sizes of home ranges in rodents of similar body size (ca. 0.23 kg; e.g., Steele 1998, Verts and Carraway 2002, Whisson et al. 2007). In general, dusky-footed woodrats at our study sites (mean=1.2 ha, n=37 at site 1; mean=3.8 ha, n=26 at site 2) in mixed-coniferous forest and those reported for woodrats in coniferous forest (mean=4.7 ha—McEachern 2005) and juniper woodland (mean=1.4 ha—McEachern 2005) habitats appear to have much lower population density (range: 1-2 woodrats/ha) and much larger home ranges than those reported in riparian woodland (mean=0.2 ha, density range: 14-20 woodrats/ha—Cranford 1977), oak woodland (mean=0.4 ha, density 22 woodrats/ha—Lynch et al. 1994) and shrub field (mean=0.4, density: 80 woodrats/ha—Sakai and Noon 1993, 1997) habitats. Previous studies have suggested that habitat and food resource availability and distribution influences density of dusky-footed woodrats (Carey et al. 1992, 1999; Forsman et al. 1984; Sakai and Noon 1993, Publication #2 and #5), and thus the spatial organization of the species.

Home range boundaries are expected to change with response to resource-limiting factors that fluctuate across seasons and years (Cranford 1977, Anderson 1982, Slobodchikoff and Schulz 1988). Our study is the first to document variability of woodrat home ranges across multiple years. Woodrats in our study exhibited stable patterns in home range within sites across years; although in 2005, home ranges were larger at site 2 than any other year. This may be partially due to the exceptionally large home range of 1 male at this site in 2005. This male occupied the largest number of houses of any woodrat in the study (n=11), which spanned a distance >500 m and encompassed an area (2.3 ha) larger than nearly 60% of the home range estimates in this study. He overlapped with all females at the site, and shared houses with 50% of these. Woodrats at site 2 had consistently larger home range areas than woodrats at site 1, which may be partially

attributed to differences in the availability and distribution of a preferred forage species, California black oak (Publication #2 and #5).

We found that males tended to have larger home range and core area sizes than females, a finding supported by studies of the spatial organization of dusky-footed woodrats in other habitats (Cranford 1977, Sakai and Noon 1997, McEachern 2005). A number of factors may account for the larger home ranges and greater mobility of male woodrats. One explanation for this pattern in our study is the larger body size (g) of males (245.0 ± 6.1) as compared with females $(211.3\pm4.2;$ McNab 1963); however we found that body size was not correlated with home range or core area size at our study sites. An alternative explanation is that the larger home ranges of males in our study may be due to reproductive behavior, with males searching larger areas to gain access to multiple females or females reducing home ranges to meet energy requirements of reproduction (Cooper and Randall 2007, Whisson et al. 2007).

Overlap.— Mean overlaps of home ranges and core areas did not differ between study sites and years, and we found no interactions between site, year, and overlap category (male-male, male-female, or female-female); therefore, we combined data among sites and years and tested for differences among overlap categories. Home range overlaps of same-sex (n=97, mean OI=0.35, range 0–0.84) and opposite-sex (male-male: n=29, mean OI=0.31, range 0-0.82; female-female: n=50, mean OI=0.26, range 0-0.77) pairs were similar (P=0.159). However, core area overlaps for male-female pairs (n=47, mean OI=0.34, range 0-78), we larger than either of the same-sex pairs (P=0.037); malemale pairs (n=12, mean OI=0.18, range 0-45) and female-female pairs (mean OI=0.18, range 0-60) exhibited similarly low overlap of core areas. Woodrats tolerated a high degree of home range overlap with opposite-sex and same-sex neighbors (Fig. 24b). Male home ranges overlapped with an average of 2.4 ± 0.4 neighboring males and 4.0 ± 0.2 neighboring females, and female home ranges overlapped with an average of 2.5 ± 0.2 neighboring males and 2.6 ± 0.2 neighboring females. All males and females overlapped home ranges with ≥ 1 individual of the opposite sex, and nearly all overlapped home ranges with ≥ 1 individual of the same sex; for example, 96% of male home ranges overlapped with that of ≥ 1 neighboring male and 97% of female home ranges overlapped with that of ≥ 1 neighboring female.

Woodrats were less likely to share core areas than home ranges with other woodrats. Male core areas overlapped with an average of 1.0 ± 0.3 neighboring male and 2.0 ± 0.2 neighboring females, and female core areas overlapped with an average of 1.2 ± 0.2 neighboring males and 0.8 ± 0.1 neighboring females. Although woodrats tolerated a high degree of core area overlap with opposite-sex neighbors, woodrats tended to avoid core area overlap with same-sex neighbors (Fig. 24a); for example, 88% of males (n=21) and 79% of females (n=31) shared their core area with ≥ 1 neighbor of the opposite sex, whereas only 50% of males (n=12) and 59% of females (n=23) shared their core area with ≥ 1 neighbor of the same sex. Interestingly, a majority of females shared their core areas with a single neighboring male (65%, n=20), whereas a majority of males shared their core areas with multiple females (81%, n=17). Because critical resources are different for the sexes (Ostfeld 1990), we expected that adult woodrat would exhibit reduced intersexual overlap of home range as compared with intrasexual overlap. Instead, we found that same-sex and opposite-sex pairs exhibited mean overlaps of home ranges that were similar (range: 0.25-0.37) and overlapped a mean of 2.8±0.13 (n=126) neighboring woodrats, indicating that individual woodrats were not defending large portions of their home range from conspecifics. Although woodrats tolerate a high degree of home range overlap with conspecifics, woodrats appeared to largely display intrasexual avoidance behavior of core areas. Core area overlap indicated that opposite-sex pairs shared substantially more core area (0.36) than same-sex pairs, and overlap of male-male pairs and that of female-female pairs was relatively low (0.18), as expected. Home range overlap would be expected to be highest when densities are highest; however, a high degree of home range overlap has been reported at varying woodrat population densities (e.g., Cranford 1977), which suggests the system of overlapping home ranges we report is likely not the result of woodrat density, but rather may be a reflection of dispersal patterns and associated mating system (Greenwood 1980, Pusey 1987).

House placement and sharing.— We located 252 woodrat houses (150 at site 1, 102 at site 2). We found no year or site differences in placement of occupied houses within core areas; therefore, we combined data across sites and years and tested for differences between sexes. Placement of houses appeared to occur predominantly within an individual's core area, and females were more likely to occupy houses placed within their core area than males (Z=-1.99, P=0.047); 82% of houses occupied by females occurred within female core areas, whereas 67% of houses occupied by males were placed within male core areas. Woodrats occupied between 2-11 houses, and frequently shifted occupancy among them. Duration of occupancy at a given house ranged 1–107 days.

Across all years and sites, 52% of males (n=33) and 49% of females (n=47) synchronously or asynchronously shared a house on ≥ 1 occasion. Synchronous sharing mostly involved opposite-sex pairs (94%, n=49), but synchronous sharing by femalefemale (4%, n=2) and male-male (2%, n=1) pairs also occurred. Most pairs (64%, n=25 pairs), including all same-sex pairs, were observed synchronously sharing a house only once. However, it was common for a given opposite-sex pair to synchronously share a house multiple times (41%, n=22 pairs), and for periods lasting 2-38 days. Although it was common for individuals to shift occupancy among multiple houses, a given oppositesex pair found synchronously sharing a house multiple times usually shared the same house (89%, n=9 pairs). Only 1 opposite-sex pair was recorded synchronously sharing 2 houses about 90 m apart; 1 house was occupied by the male, and the other, by the female. Typically, a given female synchronously shared a house with only 1 male in a give year (90%, n=21 females), but males frequently shared a house with more than 1 female (57%, n=14 males). Males typically were found at the house occupied by the female (67%, n=14), although females were also found at the house occupied by the male (14%, n=3), and occasionally a house was occupied frequently by both individuals of a given pair such that occupancy by a certain individual was not possible to assign (19%, n=4). Synchronous house sharing between male-female pairs usually occurred in June (38%,

n=19), July (34%, n=18), and August (25%, n=10), but also occurred in September (2%, n=2; Fig. 25). Males were observed synchronously at houses with females during periods when females were accompanied by unweaned young.

Many of the same pairs that shared houses synchronously also shared houses asynchronously (47%, n=30), and as many as 4 individuals were found to asynchronously share a single house. Asynchronous sharing of houses also occurred predominantly between male-female pairs (77%), but also occurred between female-female (10%) and male-male (13%) pairs. A majority of asynchronously sharing pairs shared a single house together (83%), but a given pair asynchronously shared as many as 2 (13%) or 3 (3%) different houses. Successive occupancy of houses occurred both within and between years. Males succeeded males (17%, n=18) and female succeeded females (17%) less frequently than opposite-sex pairs succeeded one another (67%). It was common for a house to have successive occupants across years (39%, n=173), and many were used by successive occupants every year of the study (13%).

Houses are a critical resource for woodrats. We found that woodrats frequently shifted occupancy among 2-11 houses, a majority of which were located within a woodrat's core area. However a substantial portion, particularly those of males, were scattered throughout a woodrat's entire home range. Other studies have found that an individual woodrat may use a single house (Linsdale and Tevis 1951, Wallen 1982) or multiple houses (Cranford 1977, Lynch et al. 1994) within their home range. Although house sites remain fixed, house occupancy may change according to the distribution of food resources, and maintenance of multiple houses throughout their range may be a strategy woodrats have adopted to more efficiently use a habitat where food resources vary spatially and temporally (Whisson et al. 2007). This is supported by evidence that woodrats at our study sites shifted occupancy from ground houses in the spring and summer to houses located in California black oak trees in the fall, when mast becomes available (Publication #6).

We found that house sharing was more common than previously reported. House sharing occurred frequently and repeatedly among same-sex pairs, with >50% of individuals sharing a house on at least one occasion. Captures of juveniles indicated that woodrats at our study sites likely have 1 litter in May or June per year, and occasionally have a second litter in August or September. We found that house sharing occurred primarily during June, July, and August and lasted for periods up to 38 days. This period was coincident with a peak in apparent breeding activity, and suggests that house sharing may be indicative of mated pairs.

The high degree of home range overlap and frequency of house sharing among duskyfooted woodrats we observed may be a consequence of a polygynous mating system and female natal philopatry, a common pattern in mammals; although, it is likely that a combination of interrelated factors, such as low population density and the pattern of food distribution and availability, contributed to the observed spatial organization. Our results provide important information for resource managers attempting to enhance woodrat populations for the benefit of its predators. The large home-range sizes of males and females, territorial behavior of core areas, placement of houses outside of core areas, and potential influence of spatially and temporally variable food resources should be considered in developing management strategy.

Golden-mantled ground squirrels

We captured and radiotracked golden-mantled ground squirrels during 2003-2005. Data analysis and manuscript preparation took place in 2006 and 2007; no additional data has been collected since 2005. The following summary (Publication #8) represents the culmination of this work and satisfies Objective #7.

Publication #8: Effects of maternal body condition on offspring dispersal in goldenmantled ground squirrels.

Maternal body condition may play an important role in determining natal dispersal distance. We developed a trans-generational model relating maternal body condition to natal dispersal distance in male and female offspring in ground squirrels (Fig. 26). We measured the effect of maternal body condition on offspring natal dispersal in goldenmantled ground squirrels in the Sierra Nevada of California. Mothers were allowed to forage normally (control, n = 6) or were provided with supplemental food (treatment, n = 6) prior to hibernation, and offspring dispersal distance was measured the following year. Not surprisingly, treatment mothers gained mass more rapidly than control mothers, although the proportion of fat in mothers did not differ between treatments (Fig. 27). Additionally, offspring from treatment mothers grew at a significantly faster rate, increased fat stores, and had greater mass than control offspring. Male offspring of treatment mothers dispersed 3x farther than those of control mothers (770 m vs. 213 m), whereas female offspring of control mothers dispersed 4.8x farther than those of treatment mothers (496 m vs. 102 m; Fig. 28). Dispersal distance was positively related to exploratory distance for both males and females (Fig. 29). In spite of low sample sizes, our data indicate that maternal body condition affects offspring growth, fat development, and dispersal, supporting our transgenerational model of offspring dispersal.

Chipmunks

We have live-trapped chipmunks at long-term grids, landbird grids, and flying squirrel transects since 2003. One of our objectives was to evaluate the habitat affinities of 2 species found commonly in PNF, long-eared and Allen's chipmunks, using data obtained from long-term grids during 2003-2004 (Objective #8). The following (Publication #10) is a summary of these results.

Publication #10: A multiple spatial scale perspective of the habitat affinities of sympatric long-eared and Allen's chipmunks.

Sympatric species that are similar in body mass, diet, and general resource utilization are likely to compete locally. Similar species often coexist by partitioning habitat. However, detecting differences in habitat affinities is influenced by spatial scale. We investigated the habitat associations of two ecologically similar chipmunk species – the long-eared chipmunk and the Allen's chipmunks – at three spatial scales in the northern Sierra Nevada, California. Locally, we censused these species over two years at 18 trapping grids, and recorded 19 microhabitat metrics at all trap stations. At a macrohabitat scale,
we assessed relative abundances at different study sites as a function of forest type. Finally, at a landscape (e.g., geographic range) scale we examined digital vegetation information and calculated extent of range overlap. At this largest spatial scale, both species showed similar habitat affinities, with extensive overlap in distribution within the Sierra Nevada (Fig. 30). At the macrohabitat scale, both the species reached their highest mean abundance in red fir forests but showed divergent secondary affinities (Fig. 31). At the microhabitat scale, however, habitat affinities differed significantly. Logistic regression models indicate that microhabitat presence of long-eared chipmunks was associated positively with open canopies, cover by rocks, and multiple sapling species, and negatively with east and south facing, steep slopes (Table 11, Fig. 32). Allen's chipmunks shared the affinity for open canopies but differed in exhibiting a preference for traps on south facing slopes with multiple shrub species, and aversion to traps on hard substrates covered by litter and vegetation mats (e.g., Mahala mat-Ceanothus prostratus). Affinities at micro- and macrohabitat scales varied between sampling years, indicating that these species retain a degree of flexibility in habitat associations while maintaining segregation and minimizing the potential for competition (Table 12, Fig. 33).

2007 Field Season

We will continue to capture and collect chipmunks while performing live-trapping duties at long-term grids, landbird grids, and flying squirrel transects. In future analyses we hope to evaluate our technique of determining chipmunk species using external characteristics.

COLLABORATION

We have continued to maintain and improve collaborative efforts with all PLAS Modules. Most notably, we improved collaboration with the Landbird Module in 2006 and 2007 by establishing temporary trapping grids at songbird census stations. Vegetation and Fuels Modules have collected and continue to collect vegetation, fire and fuels, and microclimate data within some portion of our long-term and landbird trapping grids. We are currently coordinating an effort in which the Mammal Module will provide valuable feedback to the remote sensing analyses and resultant models developed by the Fire and Fuels Module. In the near future, we hope to initiate collaborative efforts with the Spotted Owl Module by working with them to examine the diet of the California spotted owl.

In 2007, we increased collaborative efforts with agencies and institutions outside of the PLAS. We collaborated with Janet Foley, a Professor with the University of California, Davis School of Veterinary Medicine, and her graduate student Nathan Nieto, providing them with blood and tissue from northern flying squirrels and western gray squirrels for a study on disease ecology. We collaborated closely with the directors of the University of California Davis McLaughlin Reserve, Cathy Koehler and Paul Aigner, who provided space to train our field crew prior to our housing becoming available at the University of California, Berkeley Forestry Camp. In exchange for housing and training facilities, we provided information on the abundance and distribution of small mammal species within a long-term study grid established on the reserve. We collaborate with the University of Idaho for molecular analyses to determine chipmunk species identification and worked

together with them to secure outside funding for these analyses. Lastly, we work closely with the University of California Davis Natural History Field Museum to preserve specimens for research and educational purposes.

PUBLICATIONS

Theses

- Coppeto, S. A. 2005. Habitat associations of small mammals at two spatial scales in the northern Sierra Nevada, California. M.S. Thesis, University of California, Davis, 39 pp.
- Innes, R.J. 2006. Habitat selection by dusky-footed woodrats in managed, mixedconifer forest of the northern Sierra Nevada. M.S. Thesis, University of California, Davis, 31 pp.
- 3. Smith, J.R. *In Prep*. Home range and habitat selection of the northern flying squirrel (*Glaucomys sabrinus*) in northeastern California. M.S. Thesis, University of California, Davis. Winter 2009.

Peer-reviewed

- Coppeto, S. A., D. A. Kelt, D. H. Van Vuren, J. A. Wilson, S. Bigelow, and M. L. Johnson. 2006. Habitat associations of small mammals at two spatial scales in the northern Sierra Nevada. Journal of Mammalogy 87:402-416.
- Innes, R. J., D. H. Van Vuren, D. A. Kelt, M. L. Johnson, J. A. Wilson, P. A. Stine. 2007. Habitat selection by dusky-footed woodrats in managed, mixed-conifer forest of the northern Sierra Nevada. Journal of Mammalogy 88(6): 1523-1531.
- 6. Innes, R. J., D. H. Van Vuren, D. A. Kelt. 2008. Characteristics and use of tree houses by dusky-footed woodrats in the northern Sierra Nevada. Northwestern Naturalist 89(2).
- 7. Wilson, J. A., D. A. Kelt, and D. H. Van Vuren. 2008. Home range and activity of northern flying squirrels (*Glaucomys sabrinus*) in the Sierra Nevada. Southwestern Naturalist.

Submitted

- 8. Wilson, J. A., D. A. Kelt, D, H, Van Vuren, and M. Johnson. *Submitted*. Population dynamics of small mammals in relation to cone production in four forest types in the northern Sierra Nevada. Western North American Naturalist.
- 9. Mabry, K.E., and Wilson, J. A. *Submitted*. Trapping rodents in a cautious world: the effects of disinfectants on trap success. American Midland Naturalist.

In Preparation

- Coppeto, S. A., D. A. Kelt, D. H. Van Vuren, J. Sullivan, J. A. Wilson, and N. Reid. *In Prep.* Different scales tell different tales: niche conservatism vs. niche differentiation in chipmunks in the northern Sierra Nevada. To be determined. Spring 2008.
- 11. Innes, R. J., D. H. Van Vuren, D. A. Kelt, M. L. Johnson, and J. A. Wilson. *In Prep.* Spatial organization of the dusky-footed woodrat (*Neotoma fuscipes*) in mixedconifer forests of the northern Sierra Nevada. To be determined. Winter 2008.
- 12. Wilson, J. A., D. A. Kelt, and D. H. Van Vuren. *In Prep*. Effects of maternal body condition on offspring dispersal in golden-mantled ground squirrels (*Spermophilus lateralis*). To be determined. Spring 2008.

PRESENTATIONS

- 1. Coppeto, S. A., D. A. Kelt, J. A. Wilson, D. H. Van Vuren, and M. L. Johnson. 2004. Habitat selection by small mammals in the northern Sierra Nevada, California. Poster to the American Society of Mammalogists, Annual Meeting, Arcata, CA.
- Coppeto, S. A., D. A. Kelt, D. H. Van Vuren, J. A. Wilson, S. Bigelow, and M. L. Johnson. 2005. Spatial scale and habitat use of small mammals in the northern Sierra Nevada, California. Poster to the American Society of Mammalogists, Annual Meeting, Springfield, MO.
- Innes, R. J., D. H. Van Vuren, J. A. Wilson, D. A. Kelt, and M. B. Johnson. 2004. Factors affecting the distribution and use of dusky-footed woodrat (*Neotoma fuscipes*) houses. Poster to the American Society of Mammalogists, Annual Meeting, Arcata, CA.
- Innes, R. J., D. H. Van Vuren, J. A. Wilson, D. A. Kelt, and M. B. Johnson. 2005. Space use and social organization of dusky-footed woodrats (*Neotoma fuscipes*) in mixed-conifer forests of the northern Sierra Nevada. Poster to the American Society of Mammalogists, Annual Meeting, Springfield, MO.
- Innes, R. J., D. H. Van Vuren, D. A. Kelt, M. B. Johnson, J.A. Wilson. 2006. Habitat relations of dusky-footed woodrats (*Neotoma fuscipes*) in mixed-conifer forests of the northern Sierra Nevada. Poster to the American Society of Mammalogists, Annual Meeting, Amherst, MA.
- 6. Smith, W. 2006. Ecology of *Glaucomys sabrinus*: habitat, demography, and community relations. Presentation to the American Society of Mammalogists, Annual Meeting, Springfield, MO.
- 7. Wilson, J.A., and K.E. Mabry. 2005. Trap disinfection to reduce Hantavirus risk: does it also reduce small mammal trapability? Presentation to the American Society of Mammalogists, Annual Meeting, Springfield, MO.

- Wilson, J. A., D. A. Kelt, and D. H. VanVuren. 2005. Effects of maternal body condition on offspring dispersal in golden-mantled ground squirrels (*Spermophilus lateralis*). Presentation to the American Society of Mammalogists, Annual Meeting, Springfield, MO.
- Wilson, J. A., D. A. Kelt, and D. H. VanVuren. 2005. Effects of maternal body condition on offspring dispersal in golden-mantled ground squirrels (*Spermophilus lateralis*). Presentation to the IX International Mammalogical Conference, Sapporo, Japan.
- 10. Wilson, J. A., D. A. Kelt, and D. H. Van Vuren. 2006. Home range and activity of the northern flying squirrel (Glaucomys sabrinus) in the northern Sierra Nevada. Poster to the American Society of Mammalogists, Annual Meeting, Amherst, MA.

PERSONNEL

This project is coordinated and supervised by Robin Innes. Paul Smotherman was the field crew supervisor. Field work in 2007 was conducted by Robin Innes, Chelsea Beebe, Denise Everhart, Brett Jesmer, Heidi Schott, Jaya Smith, and Paul Smotherman. This study was carried out under the guidance of Dr. Douglas Kelt, Dr. Dirk Van Vuren, and Dr. Michael Johnson, professors at the University of California Davis.

ACKNOWLEDGEMENTS

We thank the dedicated field crews of 2003–2007, particularly our 2006 crew leader S. Connelly and our 2007 crew leader, P. Smotherman, We would like to extend our appreciation to the contributions and collaborative efforts of PLAS module project leaders and principal investigators, S. Bigelow, J. Keane, and M. North of the U.S.D.A Forest Service, Pacific Southwest Research Station, Sierra Nevada Research Center, R. Burnett of the Point Reyes Bird Observatory, and S. Stevens and K. Manning of the University of California Berkeley. We would also like to thank G. Rotta, S. Cosmaker, and K. Felker of the Mt. Hough Ranger District. We thank J. Schaber of the University of California Berkeley Forestry Camp for providing housing for our field crew. We would also like to thank the Quincy Library Group and the communities of the Plumas National Forest, particularly that of Quincy, California. This work was supported by the Joint Fire Sciences Program and the United States Department of Agriculture, Forest Service (Region 5).

REFERENCES

ALDOUS, S.E. 1941. Food habits of chipmunks. Journal of Mammalogy 22:18-24.

- ANDERSON D.J. 1982. The home range: a new nonparametric estimation technique. Ecology 63: 103-112.
- ANIMAL CARE AND USE COMMITTEE. 1998. Guidelines for the capture, handling, and care of mammals as approved by the American Society of Mammalogists. Journal of Mammalogy 79:1416-1431.
- ARMITAGE, K. B. 1989. Sociality as a life-history tactic in ground squirrels. Oecologia 48:36-49.
- ATSATT, P. R., AND T. INGRAM. 1983. Adaptation to oak and other fibrous, phenolic-rich foliage by a small mammal, *Neotoma fuscipes*. Oecologia 60:135-142.
- BAKKER V.J., AND K. HASTINGS. 2002. Den trees used by northern flying squirrels (*Glaucomys sabrinus*) in southeastern Alaska. Canadian Journal of Zoology 80: 1623-1633.
- BARASH, D. P. 1974. The evolution of marmot societies: a general theory. Science 185:415-420.
- BELL, J. F., AND J. R. DILWORTH. 1993. Log scaling and timber cruising. OSU Book Stores, Inc., Corvallis, Oregon.
- BENNETT, R. P. 1999. Effects of food quality on growth and survival of juvenile Columbian ground squirrels (*Spermophilus columbianus*). Canadian Journal of Zoology 77:1555-1561.
- BRIGGS, J.S., AND S.B. VANDER WALL. 2004. Substrate type affects caching and pilferage of pine seeds by chipmunks. Behavioral Ecology 15:666-672.
- BROADBOOKS, H.E. 1970. Populations of the yellow-pine chipmunk, Eutamias amoenus. American Midland Naturalist 83:472-488.
- BURNHAM, K. P., AND D. R. ANDERSON. 1998. Model selection and inference: a practical information-theoretic approach. Springer, New York, NY.
- CAMERON, G. N. 1971. Niche overlap and competition in woodrats. Journal of Mammalogy 52:288-296.
- CAREY, A. B., B. L. BISWELL, AND J. W. WITT. 1991. Methods for measuring populations of arboreal rodents. United States Department of Agriculture, Forest Service, General Technical Report PNW-GTR-273.
- CAREY, A. B., S. P. HORTON, AND B. L. BISWELL. 1992. Northern spotted owls: influence of prey base and landscape character. Ecological Monographs 62:223-250.
- CAREY, A. B., J. KERSHNER, B. BISWELL, AND L. DOMINGUEZ DE TOLEDO. 1999. Ecological scale and forest development: squirrels, dietary fungi, and vascular plants in managed and unmanaged forests. Wildlife Monographs 142:1-71.
- CAREY, A. B., J. A. REID, AND S. P. HORTON. 1990. Spotted owl home range and habitat use in southern Oregon Coast Ranges. Journal of Wildlife Management 54:11-17.
- CARRAWAY, L. N., AND B. J. VERTS. 1991. Neotoma fuscipes. Mammalian Species 386:1-10.
- CLAWSON, R.G., J.A. CLAWSON, AND T.L. BEST. 1994. *Tamias quadrimaculatus*. Mammalian species 469:1-6.
- COOPER, L.D., AND J.A. RANDALL. 2007. Seasonal changes in home ranges of the giant kangaroo

rat (*Dipodomys ingens*): A study of flexible social structure. Journal of Mammalogy 88:1000-1008.

- CRANFORD, J. A. 1977. Home range and habitat utilization by *Neotoma fuscipes* as determined by radiotelemetry. Journal of Mammalogy 58:165-172.
- CRANFORD, J. A. 1982. The effect of woodrat houses on population density of *Peromyscus*. Journal of Mammalogy 63:663-666.
- DOBSON, F. S., T. S. RISCH, & J. O. MURIE. 1999. Increasing returns in the life history of Columbian ground squirrels. Journal of Animal Ecology 68:73-86.
- DUNNING, J.B., B.J. DANIELSON, AND H.R. PULLIAM. 1992. Ecological processes that affect populations in complex landscapes. Oikos 65: 169-175.
- FARGO, R., AND W. F. LAUDENSLAYER. 1999. Are house counts reliable estimators of duskyfooted woodrat population size? Transactions of the Western Section of the Wildlife Society 35:71-75.
- FOGEL, R. 1976. Ecological studies of hypogeous fungi. II. Sporocarp phenology in Oregon Douglas-fir stand. Canadian Journal of Botany 54:1152-1162.
- FORSMAN, E. D., E. C. MESLOW, AND H. M. WIGHT. 1984. Distribution and biology of the spotted owl in Oregon. Wildlife Monographs 87:1-64.
- FRANKLIN, J. F., AND J. FITES-KAUFMAN. 1996. Assessment of late-successional forests of the Sierra Nevada. Pp. 627-662 in Sierra Nevada Ecosystem Project. Final report to Congress. Volume II. Assessments and scientific basis for management options. University of California, Centers for Water and Wildland Resources, Davis, California.
- FULLER, M.R., J.J. MILLSPAUGH, K.E. CHURCH, AND R.E. KENWARD. 2005. Wildlife radiotelemetry. Pages 377-414 in C.E. Braun, editor. Techniques for wildlife investigations and management. Sixth edition. The Wildlife Society, Bethesda, Maryland, USA.
- GANNON, W.L., AND R.B. FORBES. 1995. Tamias senex. Mammalian species 502:1-6
- GARRISON, B.A., R.L. WACHS, J.S. JONES, AND M.L. TRIGGS. 1998. Visual counts of acorns of California black oak (*Quercus kelloggii*) as an indicator of mast production. Western Journal of America Forestry 13(1): 27-31.
- GUNTHER, P. M., B. S. HORN, AND G. D. BABB. 1983. Small mammal populations and food selection in relation to timber harvest practices in the western Cascade Mountains, Washington, USA. Northwest Science 57:32-44.
- GREENWOOD, P.J. 1980 Mating system, philopatry, and dispersal in birds and mammals. Animal Behavior 28:1140-1162.
- HASKELL, S.P., AND W.B. BALLARD. 2007. Accounting for radiotelemetry signal flux in triangulation point estimation. European Journal of Wildlife Research 53:204-211.

HOLLANDER, J.L., AND S.B. VANDER WALL. 2004. Effectiveness of six species of rodents as dispersers of singleleaf pinon pine (*Pinus monophylla*). Oecologia 138:57-65.

- HOSMER, D. W., AND S. LEMESHOW. 1989. Applied logistic regression. 2nd ed. John Wiley & Sons, Inc., New York, NY.
- KEATING, K. A., AND S. CHERRY. 2004. Use and interpretation of logistic regression in habitatselection studies. Journal of Wildlife Management 68:774-789.
- KENWARD, R.E. 2001. A manual for wildlife radio tagging. Academic Press, San Francisco, U.S.A.

- Kenward, R.E., A.B. South, and S.S. Walls. 2003. Ranges6 v1.215: For the analyses of tracking and location data. Online manual. Anatrack Ltd. Warehame, UK.
- KOTEJA, P. 1996. The usefulness of a new TOBEC instrument (ACAN) for investigating body composition in small mammals. Acta Theriol. 41:107-112.
- KUTNER, M.H., C.J. NACHTSHEIM, J.NETER, AND W. LI. 2005. Applied linear statistical models. 5th ed. McGraw-Hill/Irwin, New York, NY. 1396 pp.
- LAMBIN, X., AND C.J. KREBS. 1991. Spatial organization and mating system of *Microtus townsendii*. Behavioral Ecology and Sociobiology 28:353-363.
- LANCIA, R.A., J.D. NICHOLS, AND K.H. POLLOCK. 1996. Estimating the number of animals in wildlife populations. Pp 215-254, *In* T.A. Bookhout, (Ed.). Research and Management Techniques for Wildlife and Habitats. The Wildlife Society, Bethesda, MD. 740 pp.
- LAUDENSLAYER, W. F., AND R. J. FARGO. 1997. Small nocturnal mammals in oak woodlands: some considerations for assessing presence and abundance. U.S. Forest Service General Technical Report PSW-GTR-160.
- LENIHAN, C., & D. VAN VUREN. 1996. Growth and survival of juvenile yellow-bellied marmots (*Marmota flaviventris*). Canadian Journal of Zoology 74:297-302.
- LENTH, R.V. 1981. On finding the source of a signal. Technometrics 23(2):149-154.
- LINSDALE J.M., L.P. TEVIS. 1951. The dusky-footed wood rat; a record of observations made on the Hastings Natural History Reservation. Berkeley, California: University of California Press. 664pp.
- LITVAITIS, J.A., K. TITUS, AND E.M. ANDERSON. 1996. Measuring vertebrate use of terrestrial habitats and foods. Pp 254-274, *In* T.A. Bookhout, (Ed.). Research and Management Techniques for Wildlife and Habitats. The Wildlife Society, Bethesda, MD. 740 pp.
- LYNCH, M. F., A. L. FESNOCK, AND D. H. VAN VUREN. 1994. Home range and social structure of the dusky-footed woodrat (*Neotoma fuscipes*). Northwestern Naturalist 75:73-75.
- MANLEY, B.F.J., L.L. MCDONALD, AND D.L. THOMAS. 1993. Resource selection by animals: statistical design and analysis for field studies. Chapman & Hall, Ney York, USA.
- MASER, C., AND Z. MASER. 1988. Interactions among squirrels, mycorrhizal fungi, and coniferous forests in Oregon USA. Great Basin Naturalist 48:358-369.
- MCDONALD, P. M. 1969. Silvicultural characteristics of California black oak (*Quercus kelloggii* Newb.). United States Department of Agriculture, Forest Service, General Technical Report PSW-53.
- MCEACHERN, M.B. 2005. Behavioral variation and genetic structure in dusky-footed woodrats, Neotoma fuscipes. PhD Dissertation. University of California, Davis.
- M'CLOSKEY, R. T., R. J. DESLIPPE, C. P. SZPAK, AND K. A. BAIA. 1990. Tree lizard distribution and mating system: the influence of habitat and food resources. Canadian Journal of Zoology 68:2083-2089.
- MERRITT, J. F. 1974. Factors influencing the local distribution of *Peromyscus californicus* in northern California. Journal of Mammalogy 55:102-114.
- MESERVE, P. L. 1974. Ecological relationships of two sympatric woodrats in California coastal sage scrub community. Journal of Mammalogy 55:442-447.

- MEYER, M. D., AND M. P. NORTH. 2005. Truffle abundance in riparian and upland mixedconifer forest of California's southern Sierra Nevada. Canadian Journal of Botany 83:1015-1020.
- MILLSPAUGH, J.J., R.M. NIELSON, L. MCDONALD, J.M. MARZLUFF, R.A. GITZEN, C.D. RITTENHOUSE, M.W. HUBBARD, AND S.L. SHERIFF. 2006. Analysis of resource selection using utilization distributions. Journal of Wildlife Management 70:386-395.
- MINTA, S.C. 1992. Tests of spatial and temporal interaction among animals. Ecological applications 2(2):178-188.
- MOHR, C.O. 1947. Table of equivalent populations of North American small mammals. American Midland Naturalist 37: 223-249.
- MURIE, J. O., & D. A. BOAG. 1984. The relationship of body weight to overwinter survival in Columbian ground squirrels. Journal of Mammalogy 65:688-690.
- NAMS, V.O. 2006. Locate III user's guide. Pacer Computer Software, Tatamagouche, Nova Scotia, Canada.
- NETER, J., M. H. KUTNER, C. J. NACHTSHEIM, AND W. WASSWEMAN. 1996. Applied linear statistical models. Fourth edition. WCB McGraw-Hill Co., Inc., New York, NY.
- NUNES, S., P. A. ZUGGER, A. L. ENGH, K. O. REINHART, AND K. E. HOLEKAMP. 1998. Body fat and time of year interact to mediate dispersal behaviour in ground squirrels. Animal Behavior 55:605-614.
- NEUHAUS, P., D. R. BROUSSARD, J. O. MURIE, & F. S. DOBSON. 2004. Age of primiparity and implications of early reproduction on life history in female Columbian ground squirrels. J. Animal Ecology 73:36-43.
- OSTFELD, R.S. 1986. Territoriality and mating system of California voles. Journal of Animal Ecology 55:691-706.
- OSTFELD, R.S., 1990. The ecology and territoriality in small mammals. Trends in Ecology and Evolution 5:411-415.
- POST, D.M., O.J. REICHMAN, AND D.E. WOOSTER. 1993. Characteristics and significance of the caches of eastern woodrats (*Neotoma floridana*). Journal of Mammalogy 74(3):688-692.
- PULAWA, L. K., & G. L. FLORANT. 2000. The effects of caloric restriction on the body composition and hibernation of the golden-mantled ground squirrel (*Spermophilus lateralis*). Physiol. Bio. Zool. 73:538-546.
- PUSEY, A.E. 1987. Sex-biased dispersal and inbreeding avoidance in birds and mammals. Trends in Ecology Evolution 2:295-299.
- 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.
- ROSENBERG, D. K., K. A. SWINDLE, AND R. G. ANTHONY. 2003. Influence of prey abundance on northern spotted owl reproductive success in western Oregon. Canadian Journal of Zoology 81:1715-1725.
- SAKAI, H. F., AND B. R. NOON. 1993. Dusky-footed woodrat abundance in different-aged forests in northwestern California. Journal of Wildlife Management 57:373-382.
- SAKAI, H. F., AND B. R. NOON. 1997. Between-habitat movement of dusky-footed woodrats and vulnerability to predation. Journal of Wildlife Management 61:343-350.
- SAS INSTITUTE. 2000. Statistical analysis system (SAS) user's guide: statistics, version 8 SAS Institute Inc. Clay, North Carolina 1686pp.

SAS INSTITUTE. 2001. SAS version 8.02. SAS Institute, Cary, North Carolina.

SAS INSTITUTE. 2004. JMP version 5.1.2. SAS Institute, Cary, North Carolina.

- SCHMUTZ, J.A., AND G.C. WHITE. 1990. Error in telemetry studies: effects of animal movements on triangulation. Journal of Wildlife Management 54:506-510.
- SEAMAN, D.E., J.J. MILLSPAUGH, B.J. KERNOHAN, G.C. BRUNDIGE, K.J. RAEDEKE, AND R.A. GITZEN. 1999. Effects of sample size on kernel home range estimates. Journal of Wildlife Management 63:739-747.
- SEAMAN, D.E., AND R.A.POWELL. 1996. An evaluation of the accuracy of kernel density estimators fro home range analysis. Ecology 77(7):2075-2085.
- SILVERMAN, B.W. 1986. Density estimation for statistics and data analysis. Chapman and Hall, London, England.

SLOBODCHIKOFF, C.N., AND W.C. SCHULZ. 1988. Cooperation, aggression, and the evolution of social behavior (C.N. Slobodchikoff, ed.) Academic Press, Inc., San Diego, California.

SMITH, C.F., AND S.E. ALDOUS. 1947. The influence of mammals and birds in retarding artificial and natural reseeding of coniferous forests in the United States. Journal of Forestry 45:361-369.

SMITH, W. P., S. M. GENDE, AND J. V. NICHOLS. 2004. Ecological correlates of flying squirrel microhabitat use and density in temperate rainforests of southeastern Alaska. Journal of Mammalogy 85:663-674.

- SMITH, W. P., S. M. GENDE, AND J. V. NICHOLS. 2005. The northern flying squirrel as an indicator species of temperate rain forests: test of a hypothesis. Ecological Applications 689-700.
- STEELE, M.A. 1998. Tamiasciurus hudsonicus. Mammalian Species 586:1-9.
- STOKES, M. E., C. S. DAVIS, AND G. G. KOCH. 2001. Categorical data analysis using the SAS system. SAS Institute, Cary, North Carolina.
- SUGG, D.W., R.K., CHESSER, F.S. DOBSON, AND J.L. HOOGLAN. 1996. Population genetics meets behavioral ecology. Trends in Ecology and Evolution 11:338-342.
- SUMNER, L., AND J.S. DIXON. 1953. Birds and mammals of the Sierra Nevada with records from Sequoia and Kings Canyon National Parks. University of California Press, Berkeley, CA, 484 pp.
- SWIHART, R. K., AND N. A. SLADE. 1988. Relating body size to the rate of home range use in mammals. Ecology 69:393-399.
- TAULMAN, J. F., AND K. G. SMITH. 2004. Home range and habitat selection of southern flying squirrels in fragmented forests. Mammalian Biology 69:11-27.
- TEVIS, L., JR. 1953. Stomach contents of chipmunks and mantled squirrels in northeastern California. Journal of Mammalogy 34:316-324.
- TOPPING, M.G. AND J.S. MILLAR. 1996. Spatial distribution in the bushy-tailed woodrat (*Neotoma cinerea*) and its implications for the mating system. Canadian Journal of Zoology 74:565-569.
- UNITED STATES DEPARTMENT OF THE INTERIOR. 2003. Endangered and threatened wildlife and plants: determination of threatened status for the California spotted owl. Federal Register 68:7580-7608.
- VANDER WALL, S.B. 1992. The role of animals in dispersing a "wind-dispersed" pine. Ecology 73:614-621.

- VANDER WALL, S.B. 2000. The influence of environmental conditions on cache recovery and cache pilferage by yellow-pine chipmunks (*Tamias amoenus*) and deer mice (*Peromyscus maniculatus*). Behavioral ecology 11:544-549.
- VAUGHAN, T.A. 1974. Resource allocation in some sympatric, alpine rodents. Journal of Mammalogy 55:764-795.
- Verner, J., K.S. McKelvey, B.R. Noon, R.J. Gutierrez, G.I. Gould, Jr., T.W. Beck, (technical coordinators). 1992. California spotted owl: A technical assessment of its current status. U.S. Forest Service General Technical Report PSW-GTR-133. 286p.
- VERTS, B.J., AND L.N. CARRAWAY. 2002. Neotoma lepida. Mammalian Species 669:1-12
- VESTAL, E. H. 1938. Biotic relations of the woodrat (*Neotoma fuscipes*) in the Berkeley Hills. Journal of Mammalogy 19:1-36.
- WALLEN, K. 1982. Social organization in the dusky-footed woodrat (*Neotoma fuscipes*): a field and laboratory study. Animal Behavior 30: 1171-1182.
- WALSBERG, G. E. 1988. Evaluation of a nondestructive method for determining fat stores in small birds and mammals. Physiological Zoology 61:153-159.
- WEIGL, P. D., AND D. W. OSGOOD. 1974. Study of the northern flying squirrel, *Glaucomys* sabrinus, by temperature telemetry. American Midland Naturalist 92:482-486.
- WELLS-GOSLING, N., AND L. R. HEANEY. 1984. *Glaucomys sabrinus*. Mammalian Species No. 229:1-8.
- WHISSON, D.A., J.H. QUINN, AND K.C. COLLINS. 2007. Home range and movements of roof rats (*Rattus rattus*) in old-growth riparian forest, California. Journal of Mammalogy 88(3):589-594.
- WILLY, A. G. 1992. The habitat associations of the dusky-footed woodrat (*Neotoma fuscipes*) in Marin County, California. Thesis, University of California, Berkeley, California, USA.
- WORTON, B.J. 1989. Kernel methods for estimating the utilization distribution in homerange studies. Ecology 70:164-168.
- ZABEL, C. J., K. S. MCKELVEY, AND J. P. WARD. 1995. Influence of primary prey on home range size and habitat use patterns of spotted owls (*Strix occidentalis*). Canadian Journal of Zoology 73:433-439.
- ZIELINSKI, W. J., W. D. SPENCER, AND R. H. BARRETT. 1983. Relationship between food habits and activity patterns of pine martens. Journal of Mammalogy 64:387-396.

FIGURES AND TABLES

Fig. 1. — Map of long-term grids in Plumas National Forest with a) locations of 18 long-term grids in 5 forest types and b) trap configuration within a long-term grid. Inset shows the location of the Forest in California. Map extracted from Coppeto et al. (2006).



Fig. 2.— Schematic of trap configuration within a landbird grid.



Fig. 3.— Map of 4 dusky-footed woodrat study areas in Plumas National Forest (PNF), California. Numbers indicate study site location. Inset shows the location of PNF in California.

1



Table 1.—Description of microhabitat variables measured in 1-m radius (3.14m²) plots at all long-term and landbird grid trap stations. Table from Coppeto et al. (2006).

Microhabitat Variable	Description
Ground Cover (%):	
Rocks	Exposed large rocks and stones
Bare ground	Exposed soil
Forbs and grasses	Herbaceous and flowering vegetation and grasses
Litter	Dead leaves, pine needles, wood chips, sawdust-like debris
Branches	Twigs with diameter <10cm
Small logs	Logs and stumps with diameter (within plot) of 10-50cm
Large logs	Logs and stumps with diameter (within plot) of >50cm
Live shrubs	Woody vegetation not considered sapling; height $\leq 2m^a$
Dead shrubs	Same description as for live shrub but with no living/no foliage
Vegetation mats	Near ground surface shrub cover (Ceanothus prostratus)
Saplings	Small trees with height $\leq 2m$
Non-woody perennials ^b	Shrub- and forb-like vegetation lacking woody stems
Canopy openness (%)	Percent open sky above breast height (1.4m)
Shrub species richness	Number of distinct, live shrub species
Sapling species richness	Number of distinct, live sapling species
Substrate hardness	Ground hardness averaged across 4 randomly sampled points
Slope	Degree of ground surface decline/incline
Aspect	Probable direction of water flow from center of trap station

Fig. 4. — Minimum convex polygon home range estimate for an adult female northern flying squirrel (F14) at FS-2 in 2007. Numbers correspond to UTM coordinates.



Fig. 5. — Fixed kernel home range estimate for an adult female northern flying squirrel (F14) at FS-2 in 2007. Like contours on a contour map, each line represents the degree of usage of the home range by the animal. As you go from the exterior to the interior, the animal uses the area more frequently. Numbers correspond to UTM coordinates.



Variable	Description
Stems of woody plants	
Low shrub	Woody stems <1 m tall, excluding mat-forming shrubs
High shrub	Woody stems ≥ 1 m tall and < 5 cm dbh
Sapling	Woody stems $5.0 - 9.9$ cm dbh
Poletimber	Woody stems $10.0 - 27.9$ cm dbh
Small sawtimber	Woody stems $28.0 - 53.3$ cm dbh
Large sawtimber	Woody stems \geq 53.4 cm dbh
Small oak	<i>Quercus kelloggii</i> stems 5.0 – 32.9 cm dbh
Large oak	<i>Quercus kelloggii</i> stems ≥33.0 cm dbh
Dead wood	
Log	Downed, dead wood ≥ 1 m long and ≥ 5 cm at the narrowest end
Large snag	Standing dead wood \geq 30 cm dbh and $>$ 1.3 m tall
Large stump	Standing dead wood ≥ 30 cm drc and $0.1 - 1.3$ m tall
Ground cover (%)	
Bare ground	Exposed soil
Rock	Exposed boulders, cobble and gravel
Mat-forming shrub	Trailing, near ground surface (<0.3 m tall) woody stem cover (e.g.,
-	Symphoricarpos rotundifolius)
Other	
Canopy closure	Percent closed sky at eye-level (1.7 m)
Degree slope	Degree of ground surface decline/incline

Table 2.— Description of habitat variables measured in 4-m radius plots at 144 dusky-footed woodrat houses and 144 random sites in the northern Sierra Nevada, California, 2003 – 2005.

Table 3.— Frequency, mean values and standard errors (SE) for microhabitat variables in 4-m radius plots centered at dusky-footed woodrat ground houses (n = 144) and paired random sites (n = 144) in Plumas National Forest, California, 2003 – 2005. Parameter estimates, *P*-values for the Wald chi-squared statistic, and Akaike Information Criteria (AIC) are presented from a univariate conditional logistic regression.

	Mean (SE)		Parameter			
Variable	House site	Random site	estimate (SE)	Р	AIC	
Density (ha ⁻¹)						
Low shrub	19,054.2 (1,656.5)	24,552.4 (1,945.9)	-0.00003 (0.00001)	0.003	186.24	*
High shrub	9,950.0 (641.8)	6,761.1 (561.7)	0.0001 (0.00002)	< 0.001	189.39	*
Sapling	494.4 (51.0)	418.1 (42.9)	0.0003 (0.0002)	0.241	200.20	*
Poletimber	395.8 (41.6)	381.9 (34.2)	0.0001 (0.0003)	0.774	201.54	
Small sawtimber	123.6 (15.3)	143.1 (16.7)	-0.0005 (0.0006)	0.385	200.86	
Large sawtimber	12.5 (4.0)	16.7 (4.6)	-0.0014 (0.0022)	0.514	201.20	
Log	845.7 (77.8)	717.1 (64.2)	0.0002 (0.0002)	0.218	188.95	*
Basal area (m ² ha ⁻¹)						
Sapling	2.0 (0.2)	1.6 (0.2)	0.0778 (0.0549)	0.157	199.47	*
Poletimber	8.2 (0.9)	9.0 (0.8)	-0.0087 (0.0126)	0.490	201.15	
Small sawtimber	13.3 (1.7)	16.3 (2.0)	-0.0059 (0.0053)	0.266	200.36	
Large sawtimber	4.1 (1.4)	4.9 (1.4)	-0.0027 (0.0068)	0.689	201.47	
Volume (m ³ ha ⁻¹)						
Log	124.7 (18.2)	38.5 (7.5)	0.0048 (0.0015)	0.001	171.54	*
Ground cover (%)						
Bare ground	3.5 (0.5)	5.1 (1.0)	-0.1282 (0.0543)	0.018	192.71	*
Rock	1.3 (0.2)	2.8 (0.8)	-0.0216 (0.0148)	0.144	193.65	*
Mat-forming shrub	13.9 (1.2)	19.8 (1.7)	-0.0273 (0.0091)	0.003	189.43	*
Other						
Canopy closure (%)	67.8 (2.8)	64.2 (2.8)	0.0035 (0.0036)	0.331	199.29	
Degree slope	19.3 (0.7)	16.4 (0.6)	0.1257 (0.0311)	< 0.001	199.29	*
Presence (no. plots)						
Small oak	40%	30%	0.5390 (0.2746)	0.050	197.63	*
Large oak	10%	3%	1.7912 (0.7636)	0.019	193.70	*
Large snag	4%	4%	0.0000 (0.5774)	1.000	201.63	
Large stump	49%	17%	1.4191 (0.2877)	< 0.001	169.44	*

*Variables with *P*-values ≤ 0.25 from log-likelihood ratio tests were included in multivariate models predicting house sites from random sites

Fig. 6.—Mean fall cone production by the major conifers at long-term grids (n=18). Means were derived by counting cone production on 10 individual trees/species on each grid and averaging across forest types. Cones were counted visually during the fall of 2003 and 2004. Statistically significant differences are represented by different letters within each species and in each year.



Fig. 7.— Mean monthly density (A) and survival (B) of deer mouse populations inhabiting four forest types in the northern Sierra Nevada: white fir, Douglas-fir, red fir, and ponderosa pine. Population estimates were obtained using long-term grid data and program MARK. Populations were monitored from June 2003 to October 2004.



Fig. 8. — Mean monthly density (A) and survival (B) of golden-mantled ground squirrel populations inhabiting red fir forests in the northern Sierra. Population estimates were obtained using long-term grid data and program MARK. Populations were monitored from June 2003 to October 2004.



Fig. 9.—Mean monthly density of (A) long-eared chipmunk and (B) Allen's chipmunk, inhabiting three forest types (white fir, red fir, Douglas-fir) in the northern Sierra. Density estimates were obtained using long-term grid data and program MARK. Populations were monitored from June 2003 to October 2004.



Fig. 10.— Mean abundance of mice (*Peromyscus sp.*) within 5 forest types within the Plumas National Forest, California, during 2003-2007.



Fig. 11.— Mean abundance of chipmunks (*Tamias sp.*) within 5 forest types within the Plumas National Forest, California, during 2003-2007.



Fig. 12.— Mean abundance of dusky-footed woodrats within 5 forest types within the Plumas National Forest, California, during 2003-2007.



Fig. 13.— Mean abundance of northern flying squirrels within 5 forest types within the Plumas National Forest, California, during 2003-2007.



Table 4. — Results of the Program MARK analyses for 4 species of rodent in the northern Sierra Nevada. All species were analyzed individually using the Cormack-Jolly Seber data type. Best-fit models are shown for each species. Akaike's corrected information coefficient (AICc), adjusted for overdispersion, and the model weight relative to other less fit models is given. Data for other species were too sparse for analysis with Program MARK.

Species	Model	AICc	Weight	C-hat
Peromyscus maniculatus	Φ (habitat*t+overwinter+mean cones)p(habitat*t)	1740.6	0.99	1.85
Spermophilus lateralis	$\Phi(t)p(t)$	358.2	0.96	1.14
Tamias quadrimaculatus	Φ (habitat*t+overwinter+mean cones)p(habitat*t)	923.5	1.00	1.22
Tamias senex	Φ(habitat*t)p(habitat*t)	683.2	0.60	1.23
	Φ (habitat*t+overwinter)p(habitat*t)	684.1	0.39	



Fig. 14.—Small mammal species richness in (former) treatment unit 2 of the PLAS study area during 2006-2007.

Fig. 15.—Small mammal species richness in (former) treatment unit 3 of the PLAS study area during 2006-2007.



Fig. 16.—Small mammal species richness in (former) treatment unit 4 of the PLAS study area during 2006-2007.



Fig. 17.—Small mammal species richness in (former) treatment unit 5 of the PLAS study area during 2006-2007.



Table 5.—Home range of individual flying squirrels trapped during 2004-2005. Sex (male or female), Age (subadult or adult), mass (g), number of nests (nests), and home range size (ha) calculated with minimum convex polygon (MCP) or adaptive kernel (kernel) analyses. Unknown values are indicated by NA.

					Home Range Size (ha)		
ID	Sex	Age	Mass	Nests	95% MCP	95% Kernel	
F1	F	А	125	NA	NA	NA	
M1	Μ	А	127	3	26.1	23.0	
M2	Μ	S	92	2	NA	NA	
M3	Μ	А	104	2	83.4	39.8	
F2	Μ	S	103	NA	NA	NA	
F3	F	А	117	1	35.5	63.4	
Archie	Μ	А	75	3	18.8	17.2	
Brooser	Μ	А	75	3	19.5	24.8	
Captain	Μ	А	91	NA	NA	NA	
Delia	F	А	93	2	26.7	35.5	
Emilio	Μ	А	96	NA	NA	NA	
Feliz	Μ	А	104	2	24.8	39.4	
Gulliver	Μ	J	78	3	4.5	4.7	
Horatio	Μ	S	96	2	6.9	7.8	
Isabella	F	А	99	1	25.1	31.4	
Jelly	Μ	А	100	3	15.2	22.8	
Kayto	Μ	А	73	NA	NA	NA	
Layla	F	А	141	NA	NA	NA	
Madeline	F	А	NA	1	8	13.0	
Ninja	Μ	Α	139	1	12.7	11.7	

Fig. 18.—Home range extent of northern flying squirrels at 2 studies sites: FS-1 (red fir habitat, upper image) and FS-2 (mixed-conifer habitat, lower image). Home ranges represent the results of adaptive kernel analyses and show frequency of use with lighter shades representing areas of higher use (95, 75 and 50%).



Fig. 19.—Mean home range size (ha) of male and female northern flying squirrels 2004-2005 in the northern Sierra Nevada. Mean home range size represents the 95% adaptive kernel estimates.



Fig. 20.—Nocturnal movement patterns of northern flying squirrels during 2004-2005. Movement patterns are represented as distance to the nearest known nest tree. Only locations between 18:00 and 06:00 were used.



Table 6.—Mean size (cm; dbh) of trees by species available and used by northern flying squirrels at den sites (n = 53) and paired random sites (n = 53) in the northern Sierra Nevada, California, 2006 – 2007. Presence of an asterisk indicates significant differences. Yellow pine includes ponderosa pine (*Pinus ponderosa*) and Jeffrey pine (*P. jeffreyi*).

	Mean available tree	Mean den tree	
Tree Type	size	size	Ν
Abies concolor	26.76	61.07*	15
Abies magnifica	32.42	58.25	4
Calocedrus decurrens	26.38	73.60*	5
Yellow Pine	36.17	121.33*	3
Pseudotsuga menziesii	30.45	89.25*	8
Quercus kelloggii	17.59	29.61*	14
Acer macrophyllum	18.96	19.00	4

Fig. 21.— Total number and percentage (n, %) of trees available (A) and used (B) by northern flying squirrels at den sites (n = 53) and paired random sites (n = 53) in the northern Sierra Nevada, California, 2006 – 2007.





Fig. 22.—Regression of mean adult dusky-footed woodrat density (ha^{-1}) on large (\geq 33 cm dbh) California black oak density (ha^{-1}) in Plumas National Forest, California, 2004 – 2005.



Table 7.— The best habitat model based upon the lowest Akaike Information Criterion used to explain the difference between dusky-footed woodrat house sites (n = 144) and paired random sites (n = 144) in the northern Sierra Nevada, California, 2003 – 2005. Parameter estimates, standard errors (SE), *P*-values for the Wald chi-square statistic, odds ratios, and 95% odds ratio confidence limits are presented from a conditional logistic regression. Odds ratios indicate the increased likelihood of the outcome with each unit increase in the predictor given the covariate pattern.

	95% Odds ratio				
Variable	estimate (SE)	<i>P</i> -value	Odds ratio	confide	nce limits
Large stump presence	1.6051 (0.3779)	< 0.001	4.978	2.373	10.442
Degree slope	0.1515 (0.0433)	0.0030	1.164	1.069	1.267
Log volume (m ³ ha ⁻¹)	0.0048 (0.0016)	0.0010	1.005	1.002	1.008
Mat-forming shrub (%)	-0.0433 (0.0141)	0.0020	0.958	0.932	0.984
Bare ground (%)	-0.0527 (0.0251)	0.0360	0.949	0.903	0.997

Table 8.— Availability and use of trees for tree house locations by dusky-footed woodrats, by species (%) and by mean size (cm), in the northern Sierra Nevada, 2004 to 2006. Other trees include mountain dogwood (*Cornus nuttallii*), green and white-leaf manzanita (*Arctostaphylos sp.*), and willow (*Salix sp.*). Availability was calculated as the mean proportion of trees and snags.

		Tree h	ree houses	
Species	Availability (%)	Cavity (%)	Limb (%)	
White fir	30	3	56	
Incense cedar	20	0	10	
Ponderosa pine	7	0	0	
Sugar pine	4	1	0	
Douglas-fir	16	3	15	
California black oak	13	72	15	
Snag	7	21	0	
Other trees	4	0	3	
Size group	Availability (cm)	Cavity (cm)	Limb (cm)	
Tree size	16.7	49.6	18.4	
Snag size	10.5	58.2	-	

	Ground houses	Ground houses Tree ho	
		Cavity	Limb
Female (%)	61 (4.7)	37 (4.6)	2 (0.7)
Male (%)	71 (5.2)	24 (5.3)	5 (1.7)
Availability (%)	58	27	15

Table 9.— Proportional (%) availability and use of ground and tree houses by dusky-footed woodrats in the northern Sierra Nevada, 2004 to 2006. Numbers in parentheses indicate standard error.

Fig. 23.—Proportional use of tree houses by dusky-footed woodrats, by month, in the northern Sierra Nevada, 2004 to 2006.



				MCP			FK			
Site	Year	Sex	N	Home range	Core area	Ν	Home range	Core area		
1	2004	Male	5	1.2 ± 0.2	0.3±0.1	3	1.1±0.4	0.4±0.2		
		Female	9	0.8±0.1	0.2±0.04	6	1.1±0.3	0.4±0.1		
	2005	Male	5	1.9±0.6	0.6±0.2	5	1.7±0.7	0.6±0.2		
		Female	8	1.2±0.2	0.3±0.1	7	1.4±0.3	0.6±0.1		
	2006	Male	3	1.8±0.5	0.4±0.1	1	3.0	0.9		
		Female	7	1.2±0.3	0.4±0.1	5	1.2±0.3	0.5±0.1		
2	2004	Male	7	3.7±0.3	0.9±0.1	4	3.5±0.4	1.0±0.2		
		Female	6	2.8±0.3	0.7±0.1	4	2.9±0.7	1.0±0.3		
	2005	Male	2	7.0±0.4	2.6±0.3	2	7.7±0.2	2.8±0.3		
		Female	4	5.0±0.5	1.5±0.2	4	6.3±0.7	2.4±0.2		
	2006	Male	2	4.6±0.4	1.2±0.6	2	3.6±1.6	1.5±0.9		
		Female	5	2.9±0.6	0.7±0.1	3	4.0±1.2	1.3±0.2		

Table 10.— Mean home range (95%) and core area (50%) estimates and associated standard errors (\pm SE) of dusky-footed woodrats using minimum convex polygon (MCP) and fixed kernel (FK) methods at 2 study sites in the northern Sierra Nevada, California.

Fig. 24.—Core areas (a) and home ranges (b) of dusky-footed woodrats at study site 1 in the northern Sierra Nevada, California, during May-October 2004. The minimum convex polygons for core area (50% MCP) and home range (95% MCP) are shown for graphical simplicity. Solid lines indicate adult females and dashed lined indicate adult males.



Fig. 25.— Frequency of house sharing (%) by dusky-footed woodrats, by month, in the northern Sierra Nevada, 2004 to 2006.


Fig. 26.—Hypothesized model for offspring dispersal in ground dwelling Sciurids (*Spermophilus sp.*). Predicted offspring dispersal distance varies by offspring sex and both offspring and maternal body condition (% fat). Offspring born to mothers in better body condition (i.e., more fat) would begin life higher on the x-axis.



Maternal/Offspring Body Composition (% Fat)

Fig. 27.—Mass of female (mother) golden-mantled ground squirrels and their offspring during 2003 - 2004. All squirrels enter hibernation during early October and emerge following snowmelt in mid May. Significance is indicated by (*).



Fig. 28.—Mean exploratory distance (A) and post-natal dispersal (B) distance (m), measured as the distance between location of first capture and location of hibernation, of male (n = 13) and female (n = 10) offspring golden-mantled ground squirrels from each treatment group.



Fig. 29.—Relationship between mean exploratory distance and post-natal dispersal in male (M) and female (F) golden-mantled ground squirrel offspring.



Fig. 30.—Landscape-scale map showing the geographic ranges of long-eared (*T. quadrimaculatus*) and Allen's (*T. senex*) chipmunk, and associated habitat, throughout the Sierra Nevada.



Fig. 31.—Mean abundance (N) of long-eared (*T. quadrimaculatus*) and Allen's (*T. senex*) chipmunk among 5 macrohabitat types of Plumas National Forest, CA (2003-2004).



Model	Variables	Estimate	SE	Wald x ²	Р	Odds ratio	Goodness of Fit
T. quadrimaculatus							
-	Canopy Openness	0.030	0.006	22.12	<0.0001	1.030 (1.018-1.043)	P = 0.89
	Cover by rocks	0.024	0.009	7.03	0.0080	1.025 (1.006-1.043)	
	Sapling species richness	0.018	0.007	6.00	0.0143	1.018 (1.004-1.033)	
	Slope	-0.045	0.020	4.91	0.0268	0.956 (0.918-0.995)	
	South aspect	-0.013	0.003	25.41	<0.0001	0.987 (0.982-0.992)	
	East aspect	-0.008	0.003	6.85	0.0089	0.992 (0.986-0.998)	
T. senex	·					,	
	Shrub species richness	0.623	0.086	52.94	<0.0001	1.865 (1.577-2.206)	<i>P</i> = 0.24
	Canopy Openness	0.019	0.004	26.59	<0.0001	1.019 (1.012-1.026)	
	South aspect	0.007	0.001	38.21	<0.0001	1.007 (1.004-1.009)	
	Substrate hardness	-0.460	0.121	14.30	0.0002	0.633 (0.499-0.802)	
	Cover by mats	-0.029	0.010	9.18	0.0025	0.971 (0.953-0.990)	
	Cover by litter	-0.009	0.002	14.47	0.0001	0.991 (0.987-0.996)	

Table 11.—Stepwise logistic regression models of long-eared (*T. quadrimaculatus*) and Allen's (*T. senex*) chipmunk microhabitat (trap-scale) associations in Plumas National Forest, CA (2003 and 2004 pooled); variables are ordered by positive parameter estimate.

Fig. 32.—Biplot of axes 1 and 2 from canonical correspondence analysis of small mammal trap-scale abundances and microhabitat variables in the Plumas National Forest, California (2003-2004). Vector length indicates the strength of correlation between variables and the canonical axes. *T. quadrimaculatus* is represented by the acronym Taqu and *T. senex* is Tase. The symbol *a* is dead shrubs, *b* is branches, *c* is non-woody vegetation, *d* is small logs, and *e* is large logs. All other species acronyms are as follows: Glsa = *Glaucomys sabrinus*, Misp = *Microtus* species, Nefu = *Neotoma fuscipes*, Pema = *Peromyscus maniculatus*, Spbe = *Spermophilus beecheyi*, Spla = *Spermophilus lateralis*, Tado = *Tamiasciurus douglasi*.



Fig. 33.—Mean abundance (N) of long-eared (*T. quadrimaculatus*) and Allen's (*T. senex*) chipmunk, for 2003 and 2004 data separately, among 5 macrohabitat types of Plumas National Forest, CA.



Table 12.—Stepwise logistic regression models of long-eared (*T. quadrimaculatus*) and Allen's (*T. senex*) chipmunk microhabitat (trap-scale) associations in Plumas National Forest, CA (2003 and 2004 data separately); variables are ordered by positive parameter estimate. Hosmer Lemeshow goodness of fit values for each of the models include: *T. quadrimaculatus* P > 0.33 (2003), P > 0.09 (2004); *T. senex* P > 0.08 (2003), P > 0.1 (2004).

	2003			2004		
Model	Variables	Estimate	Р	Variables	Estimate	Р
T. quadrimaculatus	Cover by rocks	0.04	<0.0001	Shrub species richness	-1.72	0.0012
-	South aspect	-0.02	<0.0001	Cover by live shrubs	0.02	0.0180
	Canopy Openness	0.03	<u>0.0009</u>	Canopy Openness	0.04	<0.0001
	Cover by large logs	0.02	0.0061	Cover by saplings	0.03	0.0002
	East aspect	-0.01	0.0412	Slope	-0.07	0.0101
T. senex	South aspect	0.01	<0.0001	South aspect	0.01	<0.0001
	Cover by large logs	0.02	0.0002	Canopy Openness	0.02	<0.0001
	Shrub species richness	0.48	<0.0001	Shrub species richness	0.62	<0.0001
	Cover by small logs	0.01	0.0213	Cover by Mats	-0.03	0.0060
	Cover by dead shrubs	0.03	0.0066	Cover by litter	-0.01	0.0001
	Sapling species richness	0.27	0.0427	Substrate hardness	-0.39	0.0029
	Cover by non-woody perennials	0.02	0.0085			