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

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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 2006 marked the fourth year of implementation of the study. As of the end of the 2006 field season, none of the proposed treatments have been implemented, thus everything we report on reflects pre-treatment conditions.

The information provided in this report is intended to provide background information on the pre-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. James Wilson continues to improve manuscripts initiated during his time as a postdoctoral fellow with the PLAS, as a staff member at California State University, Fresno. 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 2008. He is studying the abundance and distribution, 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., spotted owl, *Strix 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. 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 live-trapping grids (long-term grids) and temporary live-trapping grids (landbird grids) located throughout Plumas National Forest.

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.

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 (*Strix o. occidentalis*; 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, Smith et al. 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 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 live-trapping 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 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 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 typically construct conspicuous, conical houses on the ground using sticks, bark, and plant cuttings, although some houses are built 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 house-site selection 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 houses. 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 will be to examine the home range and space use of dusky-footed woodrats.

Other key small mammals include two diurnal, hibernating rodents, the golden-mantled ground squirrel (*Spermophilus lateralis*) and chipmunks (*Tamias sp.*). 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 2000). Additionally, first-year over-winter 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 ground-squirrels, 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 limits 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 prey 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 (larder-hoarding). 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 the Plumas National Forest, the long-eared (*T. quadrimaculatus*) and shadow (*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 shadow chipmunks at three spatial scales in Plumas National Forest and evaluate the affect of forest management practices on these species.

OBJECTIVES

The primary objective of the small 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 golden-mantled ground squirrel, to forest management.
8. Evaluate the taxonomy and habitat affinities of two sympatric chipmunks, the long-eared and shadow 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. To date, all data have been 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 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 2006. All grids had 120 trap stations and covered 2.25 ha (3.24 ha with a ½ 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. (2006, Publication #1, 2). Forest types were defined by the dominant live tree species representing ≥ 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, *Pinus ponderosa* and *P. jeffreyi*, and incense cedar, *Calocedrus decurrens, n* = 3). In 2003, group selects were established in white fir (n=2) and mixed-conifer (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, the Plumas National Forest 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 whitethorn and deerbrush (*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 buckbrush (*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 (Appendix B). 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 golden-mantled 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. 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, natural cover (e.g., bark, moss) or cover boards and synthetic bedding material (nonabsorbent polyethylene batting) were provided as needed for thermal insulation in all traps. 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, small-mammal trapping grids at a subset of Landbird Module census points in 2006. 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 (Appendix D), and provided the recommended spacing between trap-stations and the suggested minimum number of trap-stations 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. 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). Additionally, long-eared and shadow chipmunks were lumped together; we cannot consider these species separately in these analyses until we have completed taxonomic analyses. Following the completion of data collection in 2007, we plan to begin more detailed analyses of this data in close collaboration with Landbird Module.

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 and 2006 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, 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 deerbrush, buck brush, and mountain whitethorn, with lesser coverage by green- and whiteleaf manzanita, and mountain dogwood (*Cornus nuttallii*). 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 WS-1 and WS-2 had moderately sloping topography; sites WS-3 and WS-4 had mixed terrain or undulating topography. 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.

We documented house use by livetrapping in the spring (May-June) and late summer-early fall (August– September) of 2004-2006. Each trap session consisted of 4 consecutive trap-nights. In 2004 and 2005, 4 Sherman live-traps were used at each house; in 2006, 2 Sherman live-traps were used. All houses within each study site were trapped to ensure that all individuals were captured. Traps were baited with raw oats and sunflower seeds coated with peanut butter. Synthetic batting was provided for thermal insulation. Traps were opened before dusk and checked and closed each morning at dawn. Woodrats were readily captured and frequently recaptured. We assumed that all animals within the population were captured at least once, and we calculated woodrat density as the minimum number known alive divided by study area size. A house was considered used if a woodrat was captured at the house at least once during the 4-day trapping session and unused if no woodrats were captured at that house during that time.

Golden-mantled ground squirrels

We studied golden-mantled ground squirrels at long-term grid located in red-fir habitat at an elevation of 2,100 m from 2003 through 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 ± standard error, and all differences were considered significant at $\alpha = 0.05$.

Chipmunks

Chipmunk species in the Plumas National Forest display considerable overlap in habitat requirements, diet, and activity. Two chipmunk species, the long-eared and shadow 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 Plumas National Forest by salvaging animals from trap mortalities at long-term grids and euthanizing a small portion of animals from landbird grids (≤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; we secured outside funding for these analyses. Finally, we collected data on various aspects of each chipmunk's appearance. In 2005 and 2006, 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. In 2006, we collected tissue samples from all captured animals. Prior to 2006, we collected tissue samples from dusky-footed woodrats and chipmunks.

All specimens, including incidental trap deaths, are thoroughly documented, 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 dusky-footed woodrats. A 4.0 g collar-type radio transmitter (Holohil Systems Ltd., Model PD-2C) was placed on the neck of individuals. Woodrats were lightly sedated with ketamine hydrochloride (100mg/ml) injected into the thigh muscle to facilitate application of radio-collars. Woodrats were allowed to fully recover from anesthesia (4-5 hours) prior to being released at the point of capture. Northern flying squirrels were not anesthetized prior to radiocollaring and were immediately released after application of the radiocollar at their point of capture. Radiotelemetry activities of newly collared individuals were initiated after a 24-hour acclimation period succeeding their release.

Triangulation

Nocturnal telemetry sessions using triangulation techniques occurred during 5 nights per month in 2003 and 8-10 nights per month during 2004-2006. 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 <10 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). 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.

Program Locate II was used to calculate northern flying squirrel and dusky-footed woodrat locations from bearing data obtained during triangulation. We used several criteria to evaluate bearing data and determine animal locations. These included convergence of bearings, presence of outliers, number of bearings (≥ 3), and signal quality. Special attention was paid to signal quality of bearing that had an overwhelming affect in determining the location of the animal. Accepted locations were analyzed in Ranges VI or in Arc GIS 9.1 using the Animal Movements Extension. We estimated home range (95%) and core range (50%) using the minimum convex polygons (MCP) and fixed kernel (FK) methods (Kenward 2001). To provide 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 ± standard error, and all differences were considered significant at $\alpha = 0.05$.

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. 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.

Vegetation

Long-term grids

Coppeto et el. (2006, Publication #1,2) 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 Plumas National Forest during 2003-2004. The Mammal Module staff did not measure the macro- or microhabitat characteristics on the long-term study grids 2005-2006, although the Vegetation Module has continued to monitor habitat and microclimate characteristics on a portion of these plots (Appendix B).

Cone Counts.—To evaluate the effects of conifer seed production on small mammal abundance, we measured cone production during fall of 2003, 2004, and 2006, 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 ≥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 July-October 2006. 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 Coppeto et al. (2006, Publications #1, 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 (Coppeto et al. 2006, 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.

Flying squirrels

Den use.—We documented northern flying squirrel den locations during homing activities. 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 ≥10 cm diameter at the largest end were measured and recorded. Percent slope at each site was estimated using a clinometer.

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 ≈ 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 m^2) 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 (m^{2}ha^{-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 (≥33

cm DBH) oaks separately. We recorded the presence of large (≥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 (≥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 m^2—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 ($r_s ≥ │0.7│$) 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) no-intercept 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 m^3; "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 ± standard error.

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 (≥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 2006, we completed several projects and initiated others. In addition to successfully completing an extensive (17 April-1 November) field season, our study module has produced quality peer-reviewed publications and other products. In 2006, we had 6 manuscripts either in publication or in review and several more in preparatory stages. We have chosen to present the abstracts of our published and submitted manuscripts herein as a representation of the work that we have completed to date.

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 (Publication #1, 2). 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 #5). Following the 2007 field season and the implementation of planned treatments, we will analyze data obtained at long-term grids during 2005-2007 to assess the impacts of forests management treatments on small mammal abundance and species diversity (Objective #4).

Publication #1, 2: 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 year explained 93% of variation in abundance of *Peromyscus maniculatus* (deer mice), whereas 69% was explained by microhabitat and year. Variation in abundance of *Tamias* sp. (long-eared and shadow chipmunk) was slightly better explained by microhabitat and year (70%) than by macrohabitat and year (67%). Red fir forests supported significantly more *Peromyscus* and *Tamias* than mixed conifer and pine-cedar forests, and more *Tamias* than mixed fir forests. Five of 6 uncommon species were significantly associated with macrohabitat type; *Spermophilus lateralis* (golden-mantled ground squirrel)*, Glaucomys sabrinus* (northern flying squirrel)*,* and *Microtus* sp. (long-tailed and mountain voles) were captured almost exclusively in red fir forests, whereas *Neotoma fuscipes* (dusky-footed woodrat) and *Spermophilus beecheyi* (California ground squirrel) were found in pine-cedar, mixed fir, and mixed conifer 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 #5: 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 coniferous 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. 4). Parallel to this, mean maximum densities of *Peromyscus maniculatus* increased in 2004 (from 0.7 - 7.3 ind./ha to 65.7 - 112.7 ind./ha; Fig. 5). Numbers of *Spermophilus lateralis* 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 ± 4.8; Fig. 6). *Tamias quadrimaculatus* reached higher densities in red fir (48.2 ± 13.4 ind./ha) and Douglas fir forests (36.0 ± 13.5 ind./ha) than in white fir forests (7.6 ± 2.7 ind./ha), and all populations peaked in September. *Tamias senex* remained at lower densities than *T. quadrimaculatus* except during September 2004, when populations of the former reached high densities (54.6 ± 26.8 ind./ha; Fig. 7). Survival of *P. maniculatus* was dependant on an interaction between forest type and month with additive effects of winter and 2003 fall mean cone production. *Spermophilus lateralis* survival varied by month whereas survival in both species of *Tamias* varied by an interaction of forest type and month + winter (Table 4). *Neotoma fuscipes* were present at lower elevations and reached greatest densities in ponderosa pine forests. *Glaucomys sabrinus* was uncommonly captured and found predominantly in red fir forests.

2006 Field Season

During the 2006 field season we captured and marked a total of 456 individuals of 11 species. Predominant species in the study area included dusky-footed woodrats, deer and brush mice (*Peromyscus maniculatus, P. boyleii*), long-eared and shadow chipmunks, California and golden-mantled ground squirrels (*Spermophilus beecheyi* and *S. lateralis*), red-backed voles (*Clethrionomys californicus*), Douglas squirrels (*Tamiasciurus douglasii*), montane voles (*Microtus montanus*), and northern flying squirrels. Incidental species captured included shrews (*Sorex* spp.), snowshoe hare (*Lepus americanus*), striped skunks (*Mephitis mephitis*), and birds.

We noticed a marked increase in capture rate of northern flying squirrels at long-term grids in 2006 as compared with previous years. For example, in 2006 we captured 20 northern flying squirrels at 10 long-term grids; whereas in 2005, we captured 8 individuals at 4 grids, representing a 313% increase in abundance of northern flying squirrels across all sites. This marked increase in northern flying squirrel abundance is likely the result of an improved bait mixture and arboreal trap placement, and not due to an actual increase in abundance at these sites, although we would not be able to discern whether an increase in abundance influenced our data. Also notable, northern flying squirrel trap deaths were markedly reduced in 2006 (10% mortality) as compared with

2005 (75% mortality) at long-term grids, which has contributed to a greater success at radiocollaring individuals in 2006. We recaptured 2 individuals and these were recaptured once. Flying squirrels were most commonly captured in arboreal traps (n=15), but also in ground traps (Sherman=3, Tomahawk=4) in 2006; trap type was not recorded in 2005. In addition, we captured 4 dusky-footed woodrats at 3 long-term grids. Notably, this was the first year we documented red-backed voles at long-term grids.

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 2006 field season marks the first year of data collection at landbird grids. We will complete data collection at landbird grids in 2007 at which time we plan to begin more detailed analyses of this data in close collaboration with the Landbird Module.

2006 Field Season

We sampled small mammals at 176 points within 24 transects located in 12 watersheds across 4 (former) treatment units. During the 2006 field season we captured and marked a total of 909 individuals of 11 species. Species captured included dusky-footed woodrats, deer and brush mice, long-eared and shadow chipmunks, California and golden-mantled ground squirrels, red-backed voles, Douglas squirrels, northern flying squirrels, and western jumping mice (*Zapus princeps*). Incidental species captured included shrews, snowshoe hare, western gray squirrels (*Sciurus griseus*), striped skunks, spotted skunks (*Spilogale gracilis*), and birds. We determined small mammal species richness at all sites sampled in 2006 (Fig. 8-11). Species richness ranged from 0-4. Mean species richness was greatest at TU-5 (2.34), followed by TU-4 (1.97), TU-3 (1.71), and TU-2 (1.66). 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?).

We captured 18 northern flying squirrels (3 males, 15 females) at 10 landbird transects; two of these were recaptured. A majority (79%) of northern flying squirrels were captured in tree traps, emphasizing the importance of this trapping method. Six individuals captured at 3 landbird transects were radiocollared. In addition, we captured 39 dusky-footed woodrats (22 females, 16 males, 1 unknown) at 7 landbird transects; sixteen of these were recaptured. We measured habitat characteristics in 3.14 m^2 plots centered about trap locations at all trap locations (n=176).

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 this data for 2004-2005 and include this summary herein (Publication #7). We continued these efforts in 2006 to increase our sample size and improve our statistical power.

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

We studied the northern flying squirrel in Plumas National Forest using radiotelemetry. Fourteen squirrels from two forest types (mixed conifer and red fir) were fitted with radiocollars and were able to provide enough locations for home range calculations (Table 5). We used 95% adaptive kernel and 95% minimum convex polygon (MCP) analysis to determine home ranges. No sex differences and no differences in forest type were observed for home range size (Fig. 12-13). Mean kernel home range size was 25.7 ha for all squirrels. MCP home ranges were biased towards overestimation and did not provide reliable calculations. Mean distance to the nearest nest tree did not vary throughout the night; however, females tended to travel greater distances from nest trees (Fig. 14).

2006 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 ($\geq$ 50 locations) was obtained for 7 northern flying squirrels to estimate home range during 2006. Females weighed more than males ($\bar{x}_{fem}$ = 129.7 g, $\bar{x}_{male}$ = 103.6 g; P = 0.0039). Home range was only calculated for females, because of low numbers of successful male captures. Average home range size for female northern flying squirrels using 95% MCP was 12.55 ha $\pm$ 2..58 and using 95% FK was 17.56 ha $\pm$ 5.67. To evaluate den use by northern flying squirrels, we measured habitat characteristics at 39 den trees and 39 paired random points. This data will be analyzed in the near future.

<p align="center">Dusky-footed woodrats</p>

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 (Publication #3, 4). In future analyses, we will present home range estimates for these animals for 2003-2006. The 2006 field season marks the final year of data collection, so that we might focus our efforts on northern flying squirrel ecology.

Publication 3, 4: Habitat selection by dusky-footed woodrats (*Neotoma fuscipes*) in managed mixed-conifer forest of the northern Sierra Nevada

Dusky-footed woodrats (*Neotoma fuscipes*) are important components of forest communities, including serving as a primary prey of the California spotted owl (*Strix occidentalis occidentalis*), 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 (*Quercus kelloggii*) 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 ($\geq$33 cm

diameter at breast height) oak density (Fig. 15), 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 6). 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.

2006 Field Season

In 2006, we captured 70 dusky-footed woodrats and applied radiocollars to 20 adults (male, n=7; females, n=13) and 19 subadults (male, n=7; female, n=12). Adult woodrat density was lower in 2006 than 2005 or 2004 (Table 7). Acorn productivity indices for 2005 and 2006 indicated no apparent trend or pattern; however, there is not enough data to date to truly evaluate this.

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 no additional data was collected at this time. The following summary (Publication #6) represents the culmination of this work and satisfies Objective #7.

Publication #6: Effects of maternal body condition on offspring dispersal in golden-mantled ground squirrels (*Spermophilus lateralis*).

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. 16). We measured the effect of maternal body condition on offspring natal dispersal in golden-mantled ground squirrels (*Spermophilus lateralis*) 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. 17). 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 18). Dispersal distance was positively related to exploratory distance for both males and females (Fig. 19). In spite of low sample

sizes, our data indicate that maternal body condition affects offspring growth, fat development, and dispersal, supporting our trans-generational model of offspring dispersal.

Chipmunks

We have live-trapped chipmunks coincident with long-term grid, landbird grid, and flying squirrel transect trapping activities since 2003. One of our objectives was to evaluate the habitat affinities of two species found commonly in the Plumas National Forests, the long-eared and shadow chipmunk, using data obtained from long-term grids during 2003-2004 (Objective #8). The following (Publication #8) is a summary of these results.

Publication #8: A multiple spatial scale perspective of the habitat affinities of sympatric *Tamias quadrimaculatus* and *T. senex.*

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 (*Tamias quadrimaculatus*) and the shadow chipmunks (*Tamias senex*) – 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. 20). At the macrohabitat scale, both the species reached their highest mean abundance in red fir (*Abies magnifica*) forests but showed divergent secondary affinities (Fig. 21). At the microhabitat scale, however, habitat affinities differed significantly. Logistic regression models indicate that microhabitat presence of *T. quadrimaculatus* was associated positively with open canopies, cover by rocks, and multiple sapling species, and negatively with east and south facing, steep slopes (Table 8, Fig. 22). *T. senex* 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., *Ceanothus prostratus*). Affinities at micro- and macrohabitat scales varied between sampling years, indicating that these species retain a certain flexibility in habitat associations while maintaining segregation and minimizing the potential for competition (Table 9, Fig. 23).

2006 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 chipmunks 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 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 our 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 spotted owl using pellets collected from nests throughout the year.

In 2006, 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 flying squirrels and western gray squirrels for a study on disease ecology. We collaborated with Mary Brooke McEachern, a post doctoral fellow at the University of California, Davis, by providing data regarding territorial bequeathal by dusky-footed woodrats, which complimented our examination of the dispersal ecology of the dusky-footed woodrat. We collaborated with Winston Smith, a Research Wildlife Biologists with the U.S.D.A. Forest Service (Region 6), by providing data on the abundance and density of flying squirrel in different habitat types for a presentation to the American Society of Mammalogist at the 2006 annual meeting in Amherst, Massachusetts. 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

Peer-reviewed

1. Copetto, 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.

2. 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.

3. Innes, R.J. 2006. Habitat selection by dusky-footed woodrats in managed, mixed-conifer forest of the northern Sierra Nevada. M.S. Thesis, University of California, Davis, 31 pp.

Submitted

4. Innes, R. J., D. H. Van Vuren, D. A. Kelt, M. L. Johnson, J. A. Wilson, P. A. Stine. Submitted. Habitat selection by dusky-footed woodrats in managed, mixed-conifer forest of the northern Sierra Nevada. Journal of Mammalogy

5. 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.

6. Wilson, J. A., D. A. Kelt, and D. H. Van Vuren. Submitted. Effects of maternal body condition on offspring dispersal in golden-mantled ground squirrels (*Spermophilus lateralis*). Oikos.

7. Wilson, J. A., D. A. Kelt, and D. H. Van Vuren. Submitted. Home range and activity of northern flying squirrels (*Glaucomys sabrinus*) in the Sierra Nevada. Southwestern Naturalist.

In Preparation

8. Coppeto, S. A., D. A. Kelt, and others. A multiple spatial scale perspective of the habitat affinities of sympatric *Neotamias quadrimaculatus* and *N. senex*. Winter 2007.

9. Innes, R. J., D. H. Van Vuren, M. B. McEachern, J. M. Eadie, D. A. Kelt, M. L. Johnson, and J. A. Wilson. In Prep. Genetic relatedness and social organization of the dusky-footed woodrat (*Neotoma fuscipes*) in mixed-conifer forests of the northern Sierra Nevada. Journal of Mammalogy. Winter 2007.

10. Mabry, K.E., and Wilson, J. A. In Prep. Trapping rodents in a cautious world: the effects of disinfectants on trap success. Journal of Wildlife Management.

PRESENTATIONS

Data from the mammal module of the Plumas-Lassen Administrative Study were used in the development of 2 posters presented at the 2006 annual meeting of the American Society of Mammalogists in Amherst, Massachusetts. James Wilson presented a poster on the home range and activity of the northern flying squirrel in the northern Sierra Nevada. Robin Innes presented a poster on the habitat relations of the dusky-footed woodrat in mixed-conifer forests of the northern Sierra Nevada. We anticipate that data from 2006 will be used in the development of 2 or more posters or oral presentations at the 2007 annual meeting of the American Society of Mammalogists in Albuquerque, New Mexico. Topics may include 1.) den use by northern flying squirrels to be presented

by Jaya Smith, and 2) home range and social organization of the dusky-footed woodrat to be presented by Robin Innes. To date, the following presentations have been given.

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.

2. 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.

3. 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.

4. 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.

5. 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.

8. 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.

9. 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, a University of California Davis graduate student. Sean Connelly was the field crew supervisor. Field work in 2006 was conducted by Robin Innes, Sean Connelly, Lishka Arata, Alicia Brommer, Daniel Auerbach, Sean Bogle, Scott Cohen, John Diener, Carina Port, Tiffany Russell, Jaya Smith, and Kelly Weintraub. 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.

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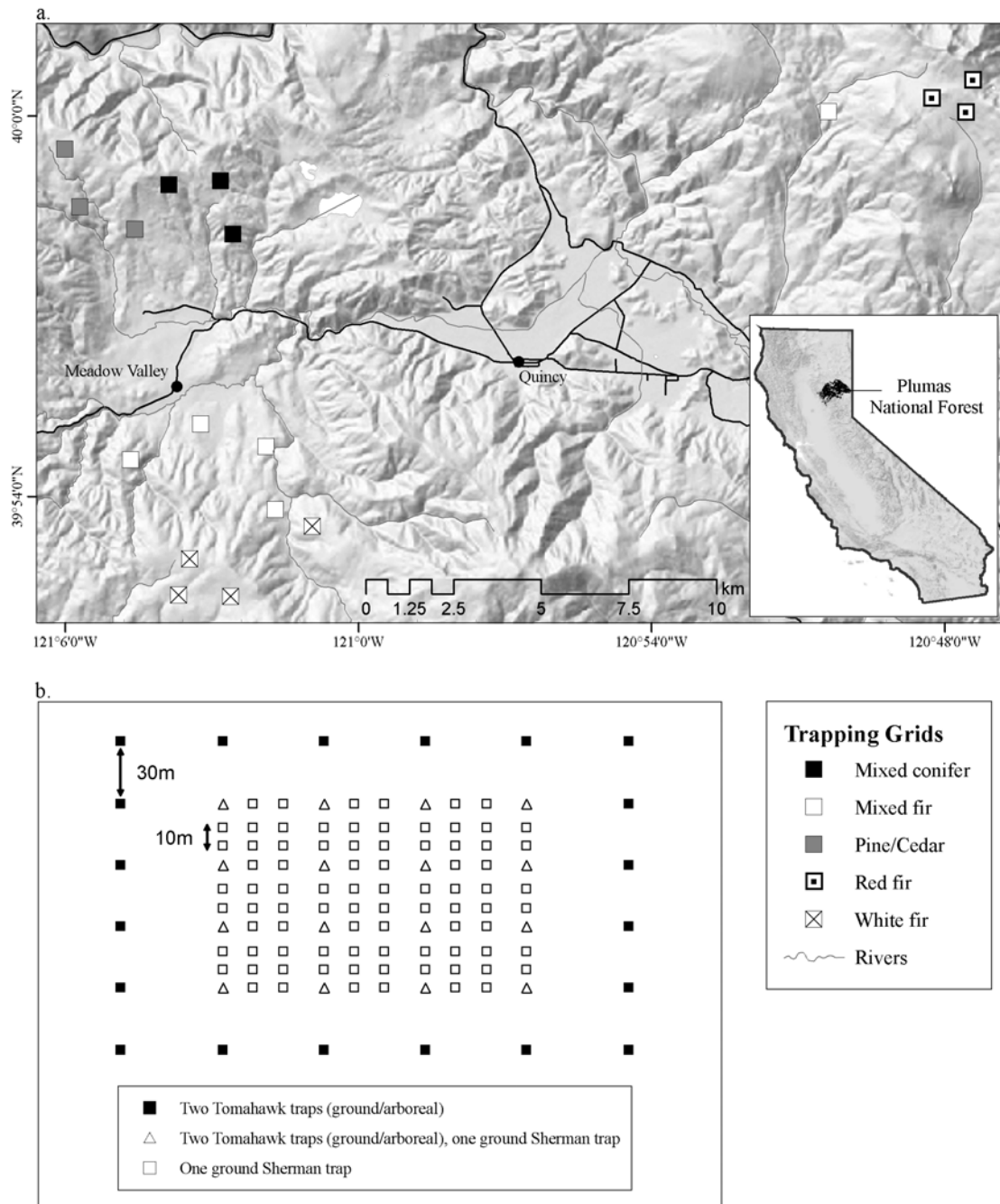
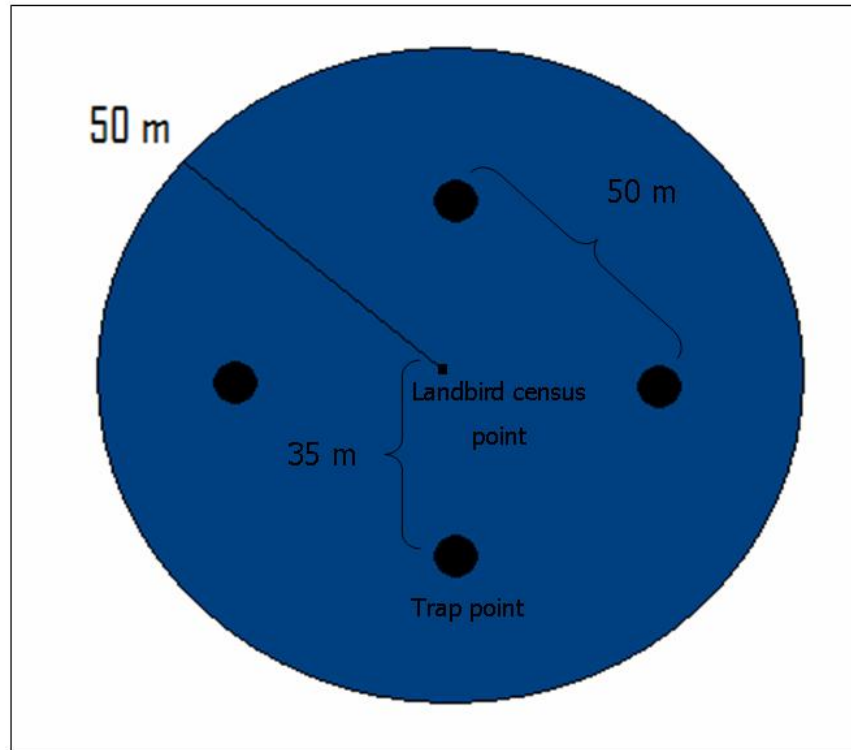**Fig. 2**. — Schematic of trap configuration within a landbird grid.

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.
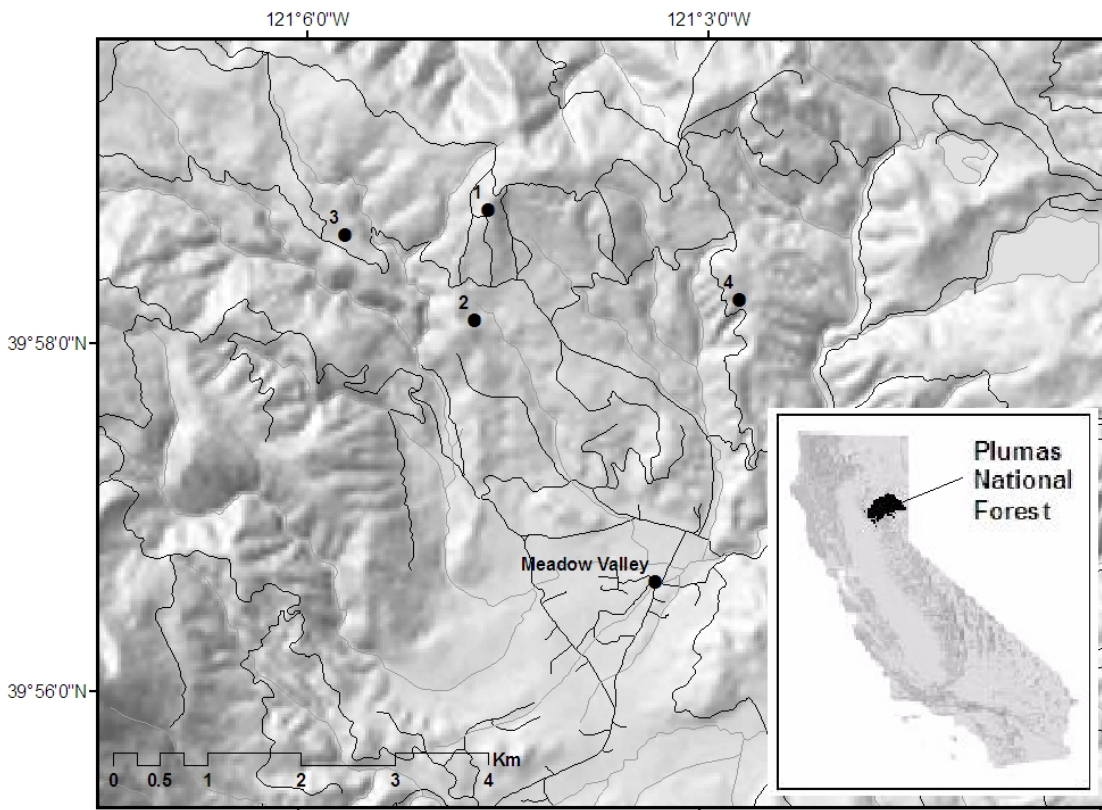
Table 1.—Description of microhabitat variables measured in 1m radius ($3.14m^2$) plots at all long-term grid and landbird grid trap stations. Table from Coppeto et al. (2006).

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 ≤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 ≤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

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

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 ≥53.4 cm dbh
Small oak	*Quercus kelloggii* stems 5.0 – 32.9 cm dbh
Large oak	*Quercus kelloggii* 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 ≥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 3. — Frequency, mean values and standard errors (SE) for microhabitat variables in 4-m radius plots centered at dusky-footed woodrat (Neotoma fuscipes) 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)	*P*	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. 4.—Mean fall cone production by the major conifers at long-term grids. 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 (A) 2003 and (B) 2004. Statistically significant differences are represented by different letters within each species and in each year.
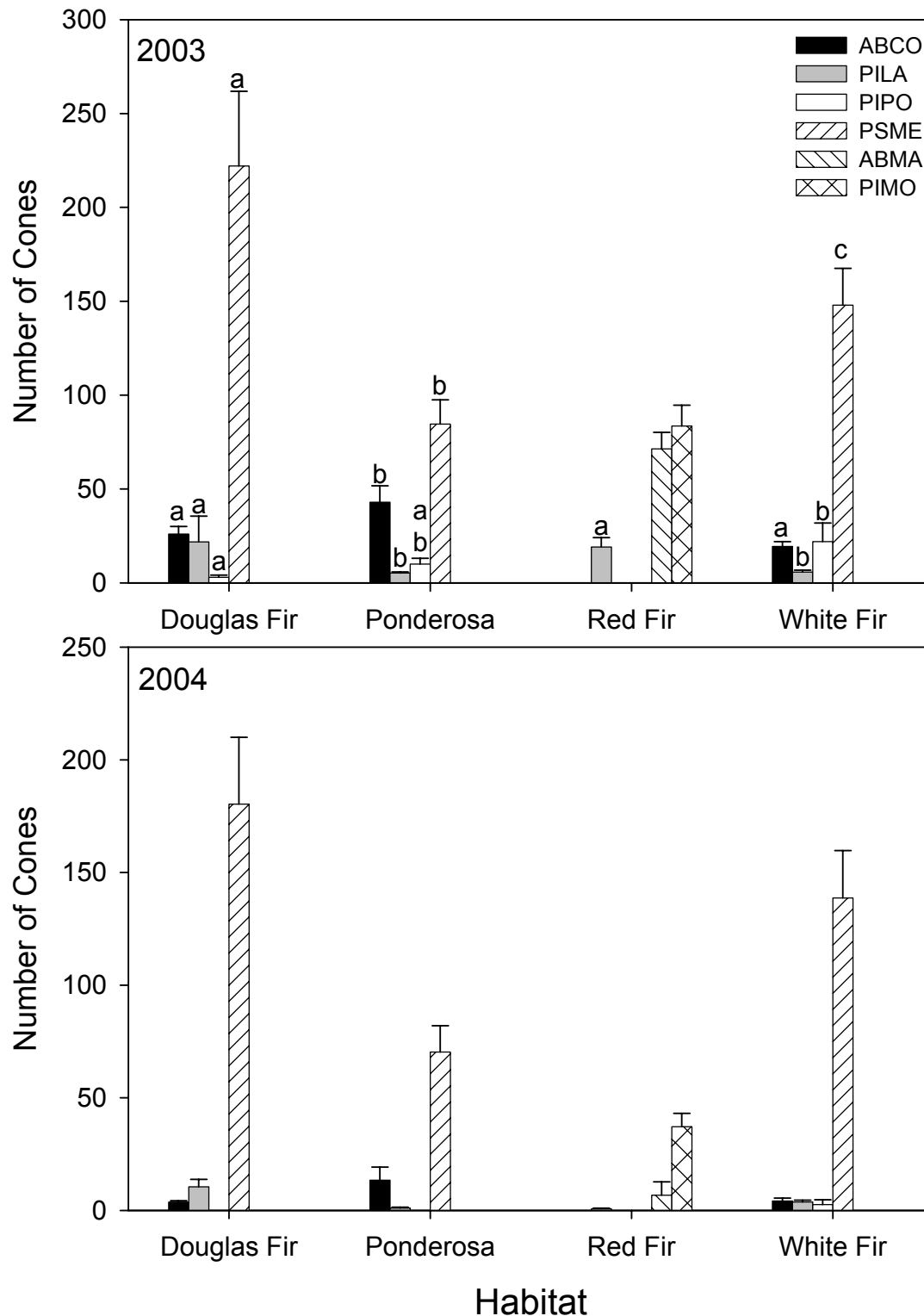
Fig. 5. — Mean monthly density (A) and survival (B) of deer mouse (*Peromyscus maniculatus*) populations inhabiting four forest types in the northern Sierra Nevada: white fir, Douglas fir, red fir, and Ponderosa pine. Population estimates were obtained using long-term grid data and program MARK. Populations were monitored from June 2003 to October 2004.
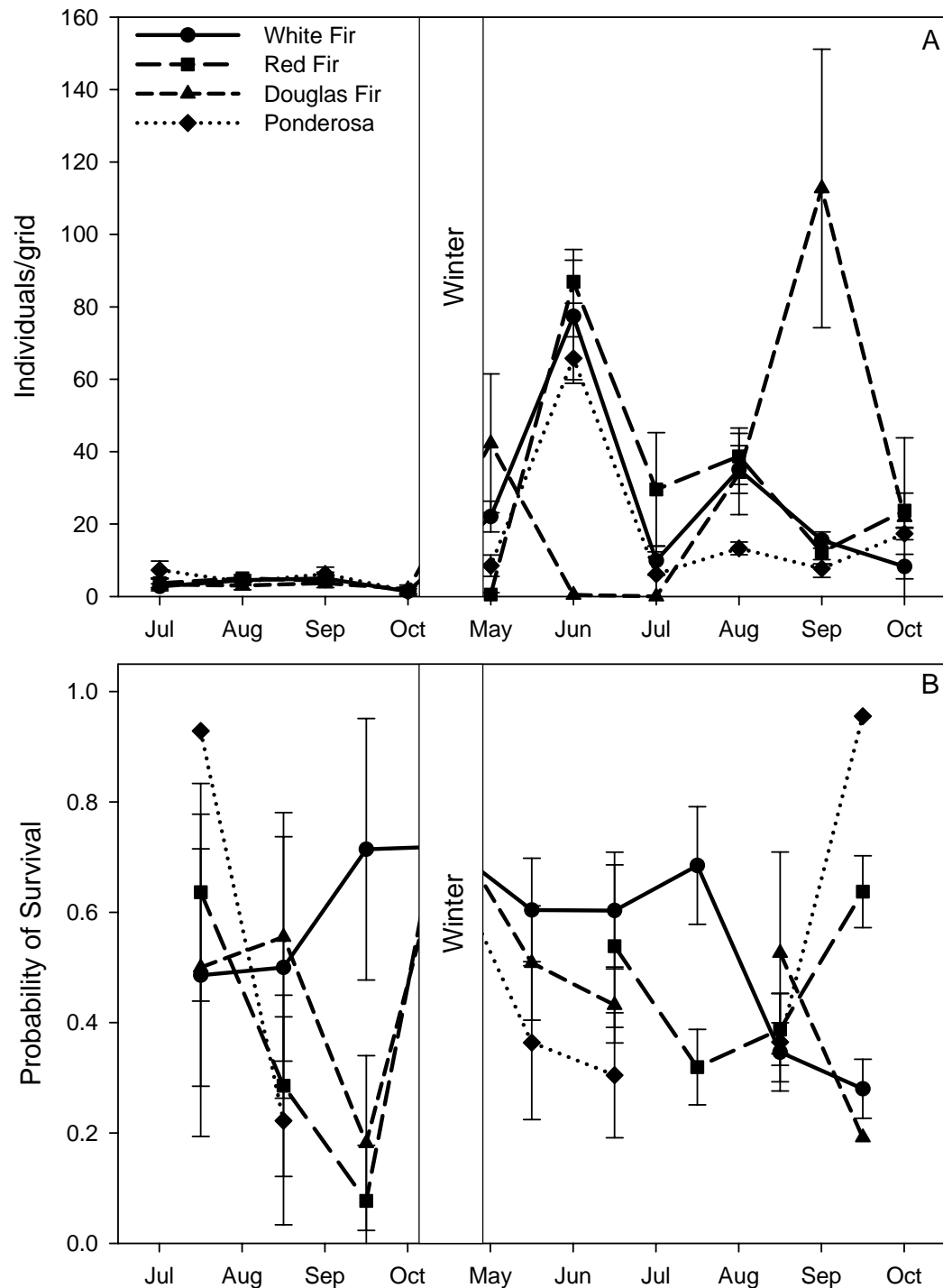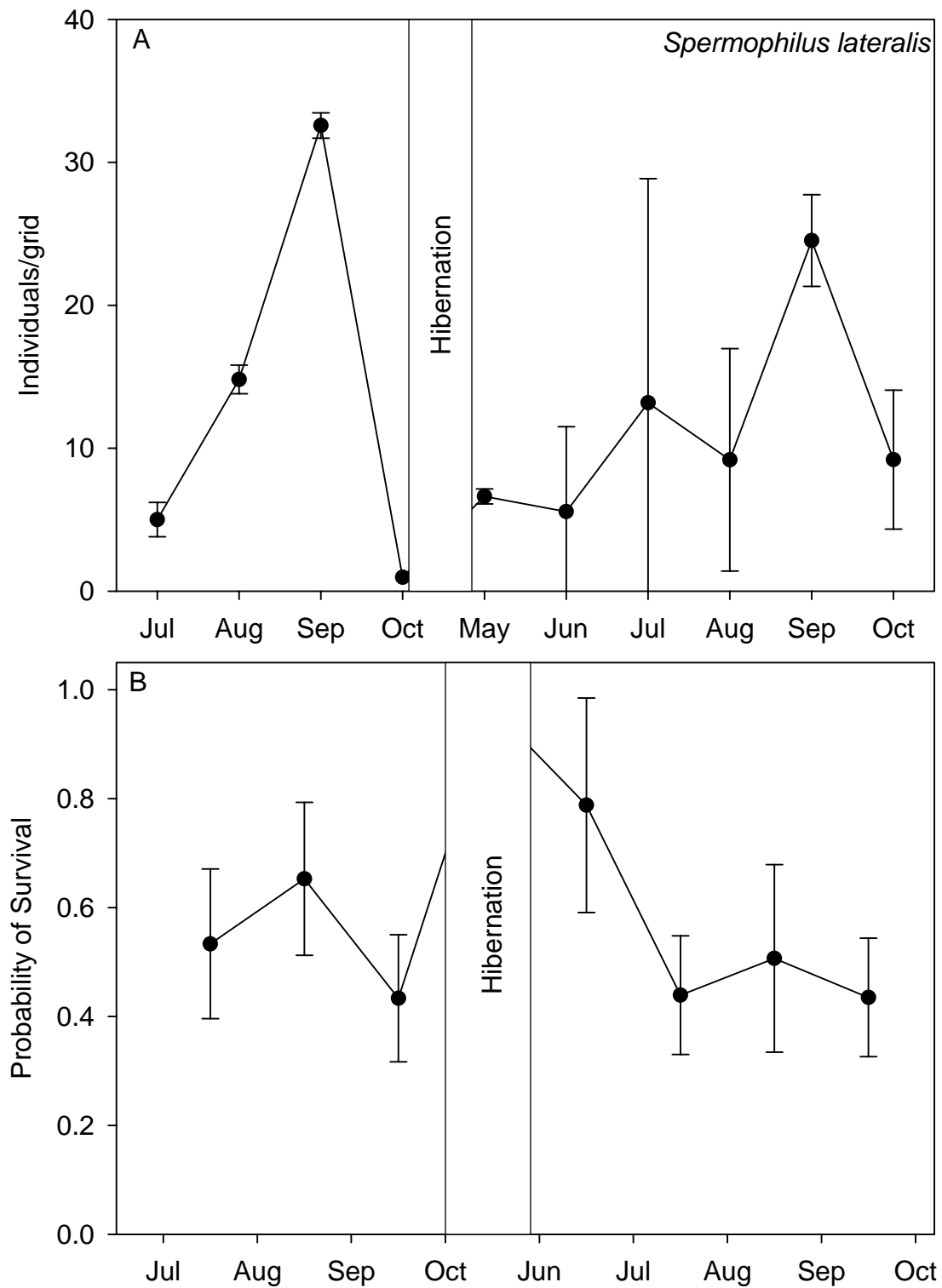
**Fig. 6**. — Mean monthly density (A) and survival (B) of golden-mantled ground squirrel (*Spermophilus lateralis*) populations inhabiting red fir forests in the northern Sierra. Population estimates were obtained using long-term grid data and program MARK. Populations were monitored from June 2003 to October 2004.

Fig. 7.—Mean monthly density of two species of chipmunk, (A) long-eared (*Tamias quadrimaculatus*) and (B) Allen's (*T. senex*) 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.
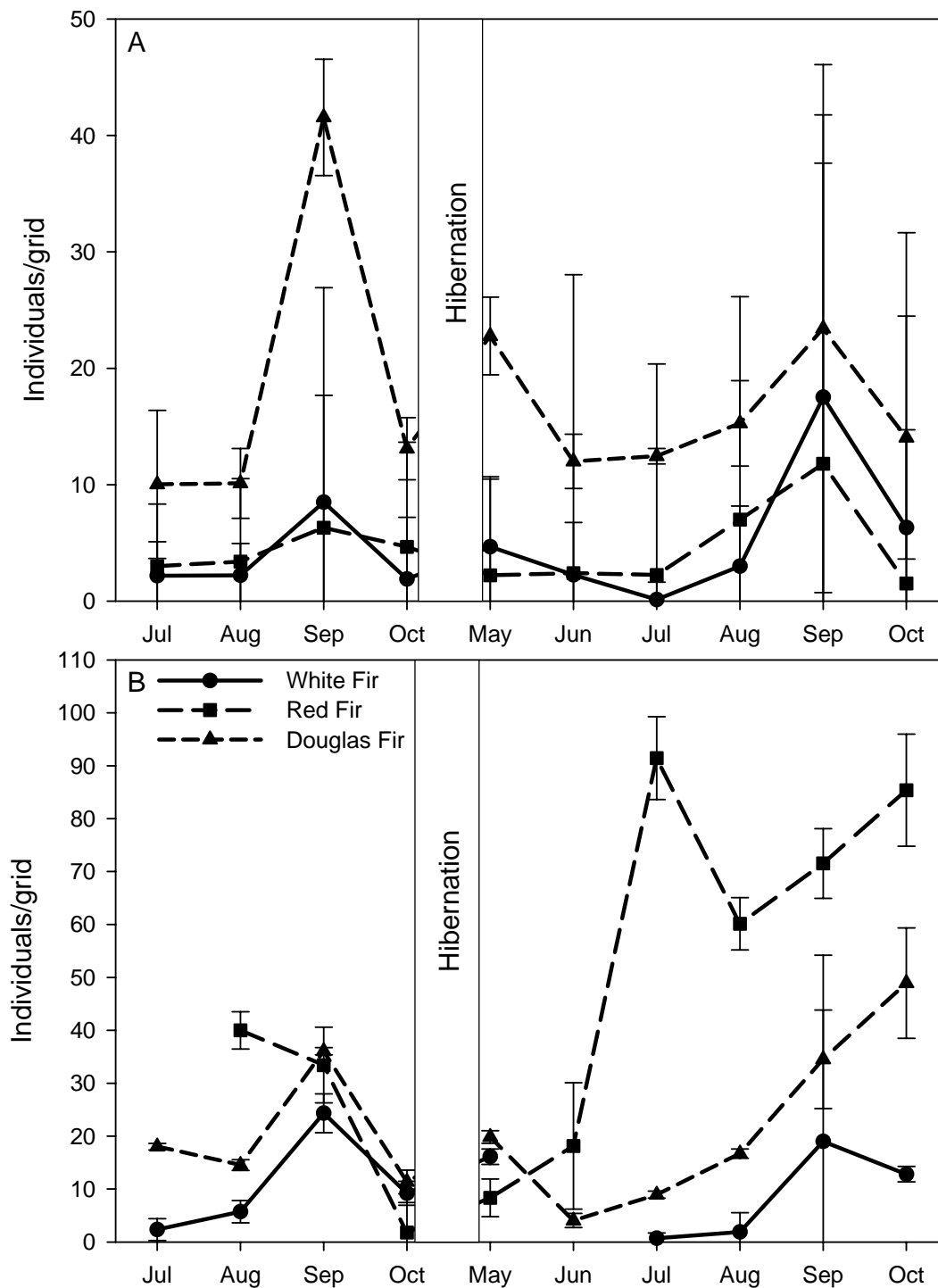
Table 4. — Results of the Program MARK analyses for 4 species of rodent in the northern Sierra Nevada. All species were analyzed individually using the Cormack-Jolly Seber data type. Best-fit models are shown for each species. Akaike's corrected information coefficient (AICc), adjusted for overdispersion, 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	Φ(t)p(t)	358.2	0.96	1.14
Neotamias quadrimaculatus	Φ(habitat*t+overwinter+mean cones)p(habitat*t)	923.5	1.00	1.22
Neotamias 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. 8.—Small mammal species richness in (former) treatment unit 2 of the PLAS study area in 2006.
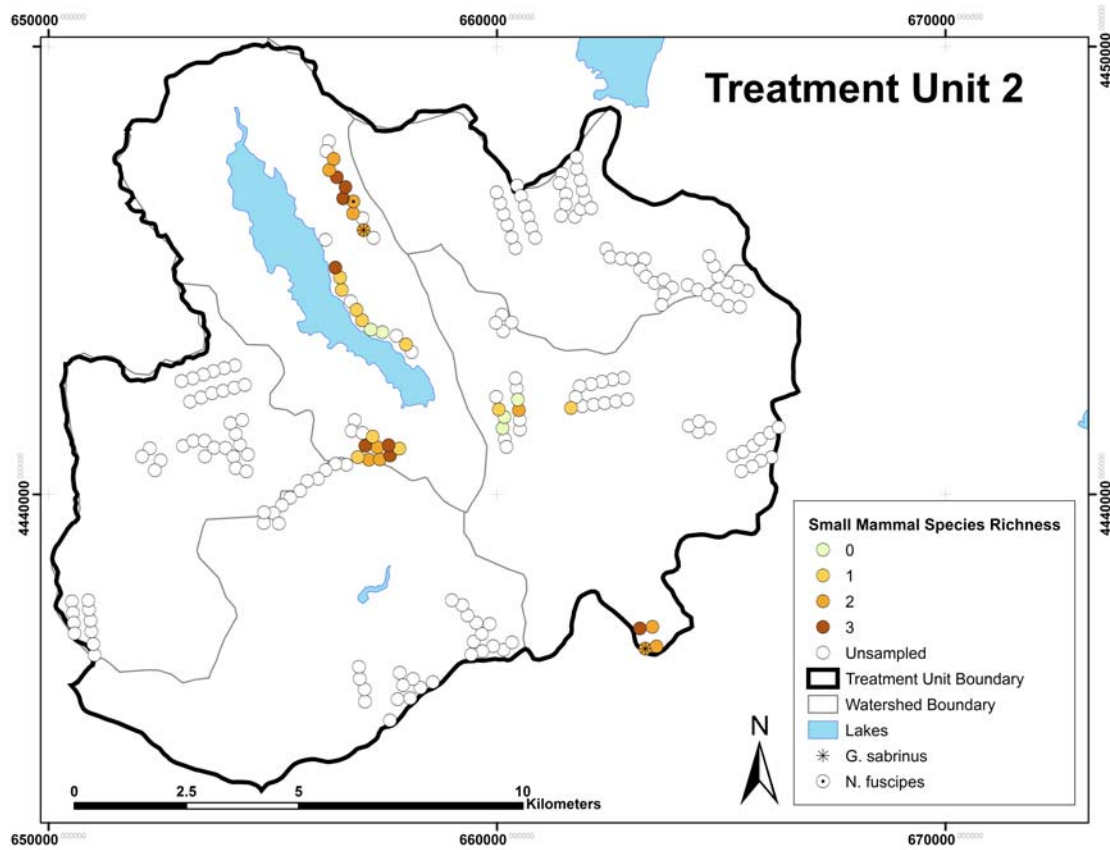
Fig. 9.—Small mammal species richness in (former) treatment unit 3 of the PLAS study area in 2006.
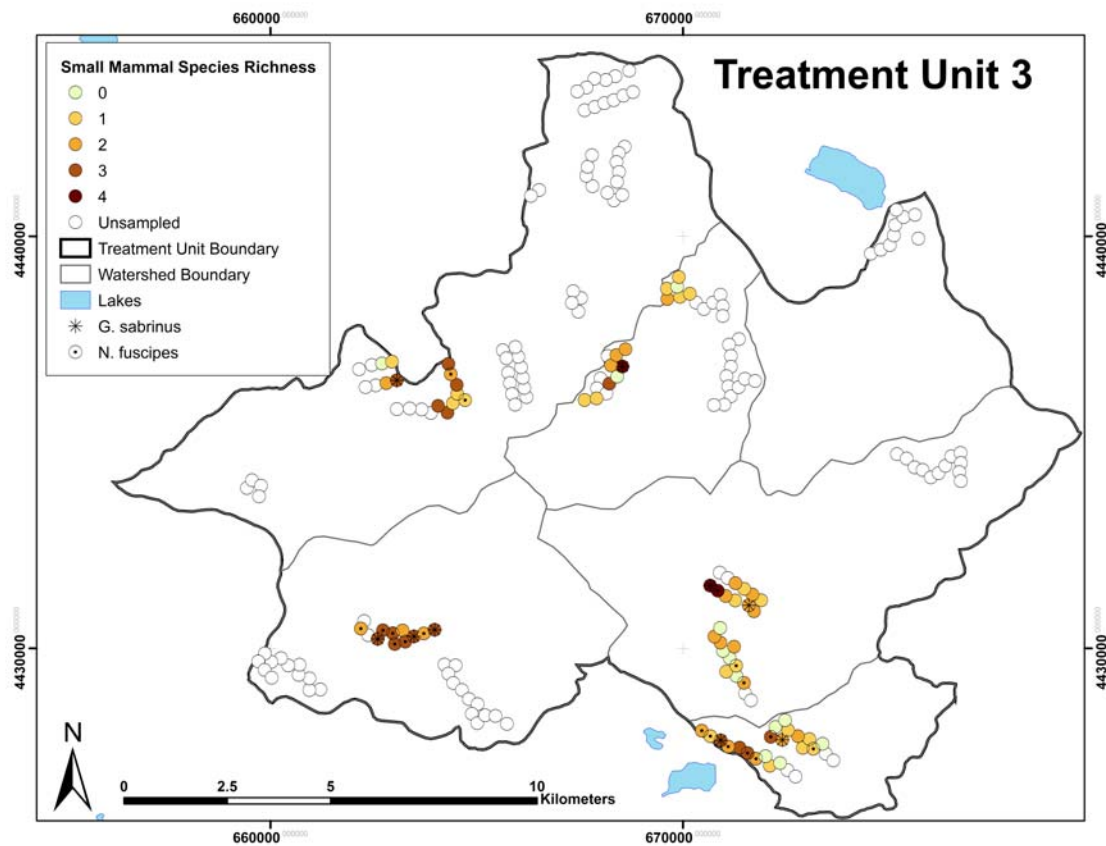
Fig. 10.—Small mammal species richness in (former) treatment unit 4 of the PLAS study area in 2006.
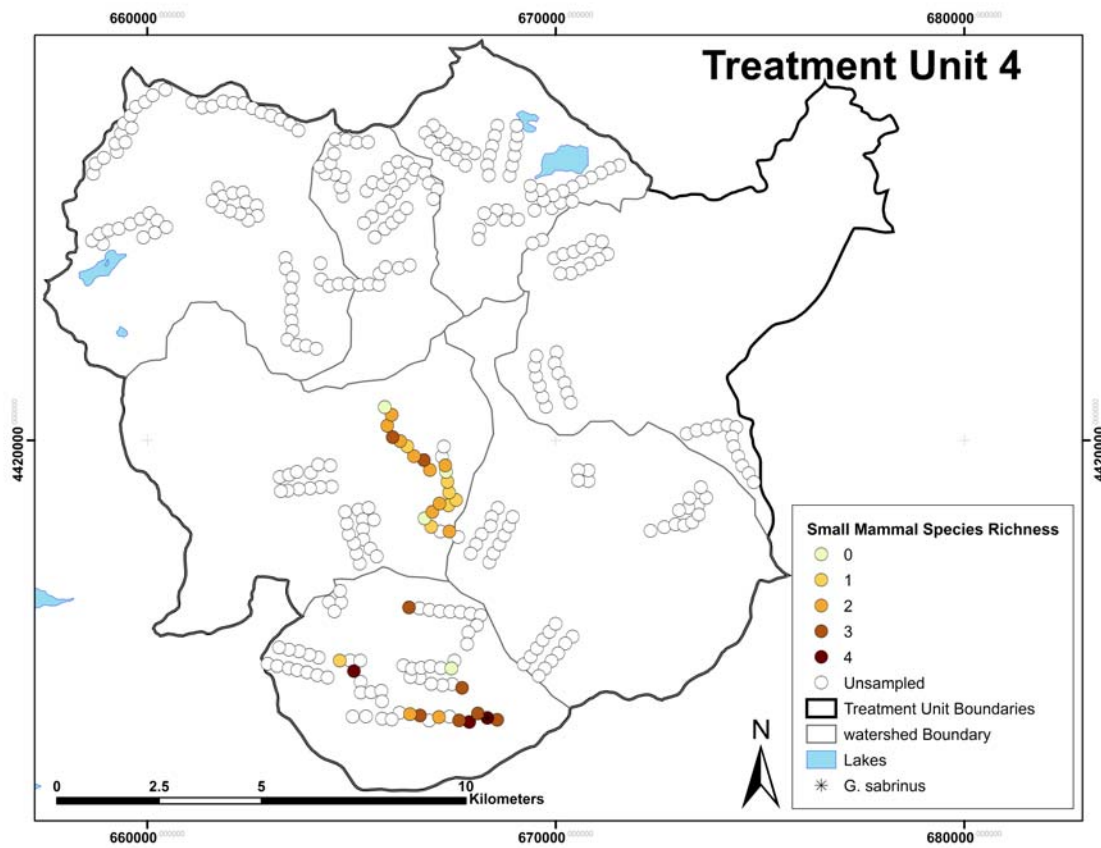
Fig. 11.—Small mammal species richness in (former) treatment unit 5 of the PLAS study area in 2006.
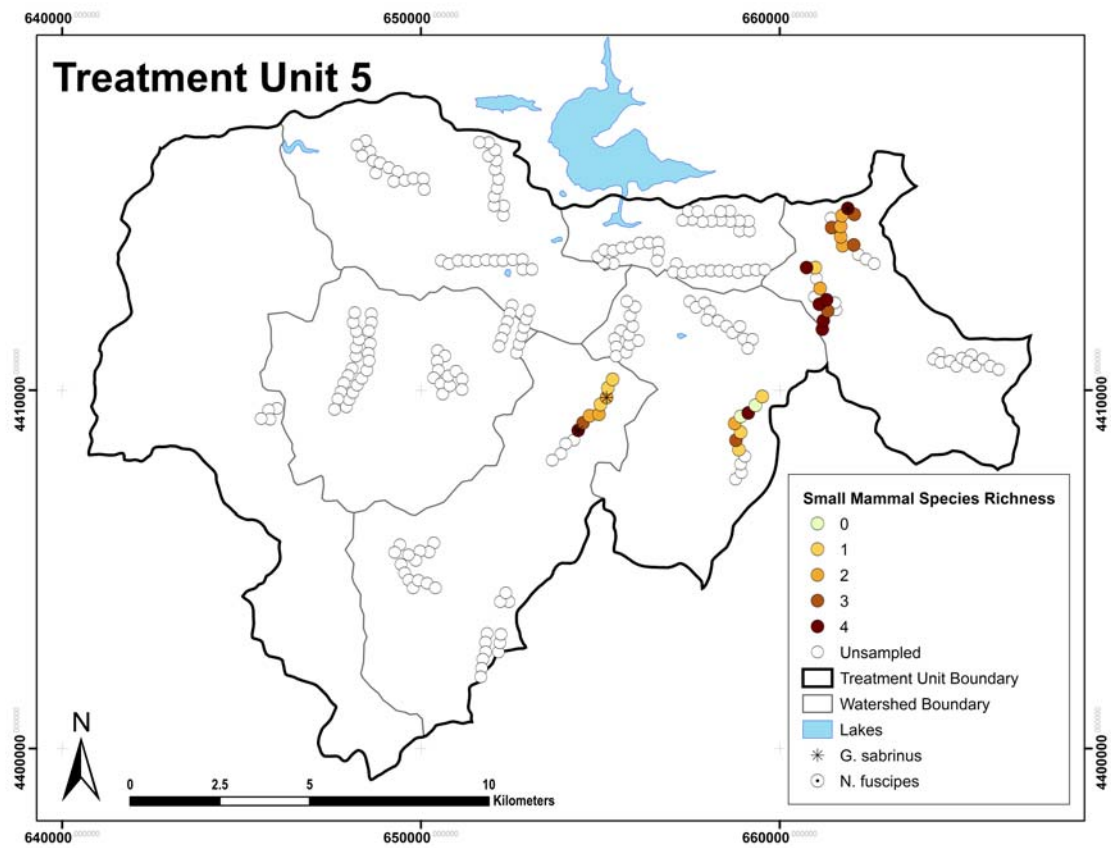
Table 5. — Home range of individual flying squirrels trapped during 2004-2005. Sex (male or female), Age (subadult or adult), mass (g), number of nests (nests), and home range size (ha) calculated with minimum convex polygon (MCP) or adaptive kernel (kernel) analyses. Unknown values are indicated by NA.

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

Fig. 12. — Home range extent of northern flying squirrels (*Glaucomys sabrinus*) at 2 study 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%).
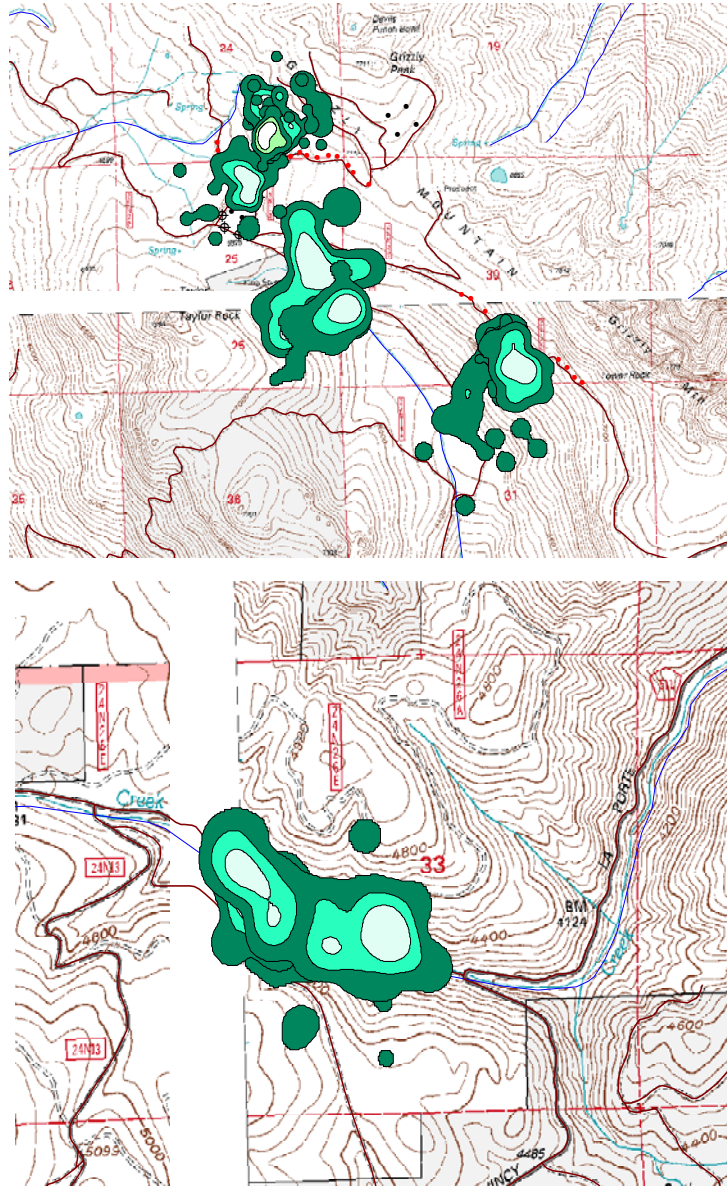
Fig. 13.— Mean home range size (ha) of male and female northern flying squirrels 2004-2005 in the northern Sierra Nevada. Mean home range size represents the 95% adaptive kernel estimates.
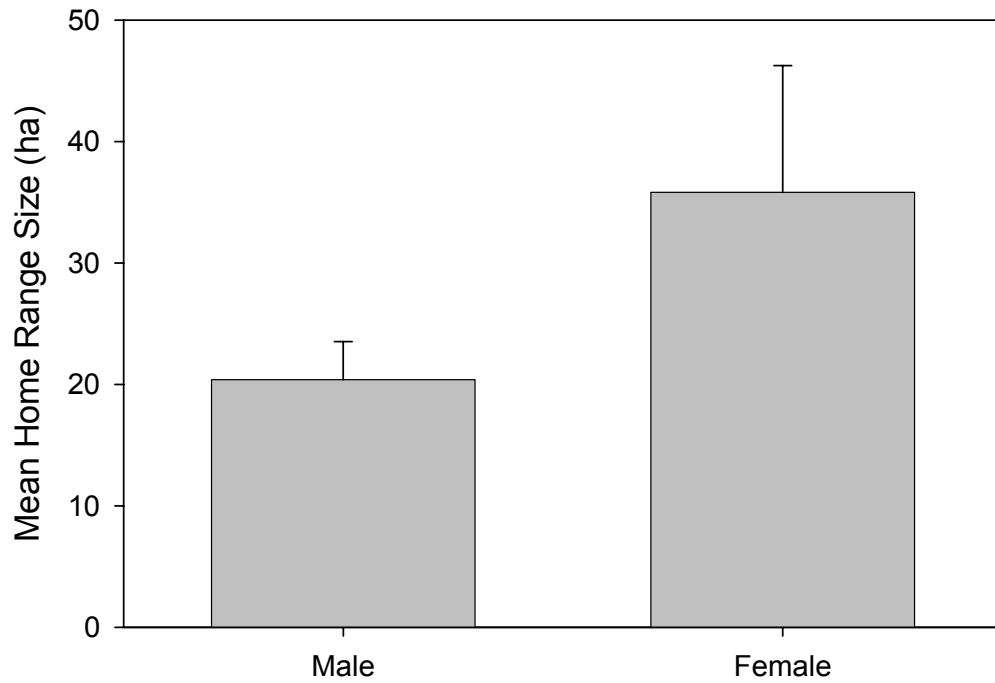
Fig. 14. — Nocturnal movement patterns of northern flying squirrels during 2004-2005. Movement patterns are represented as distance to the nearest known nest tree. Only locations between 18:00 and 06:00 were used.
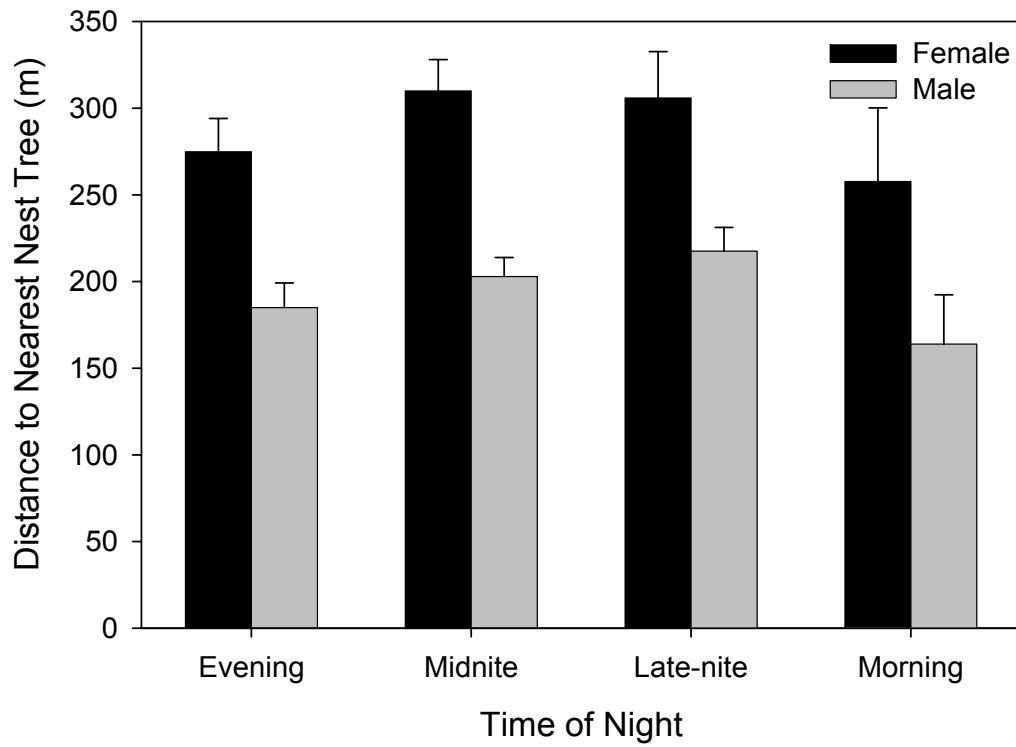
Fig. 15. — Regression of mean adult dusky-footed woodrat (*Neotoma fuscipes*) density (ha−1) on large (≥33 cm dbh) California black oak density (ha−1) in Plumas National Forest, California, 2004 – 2005.
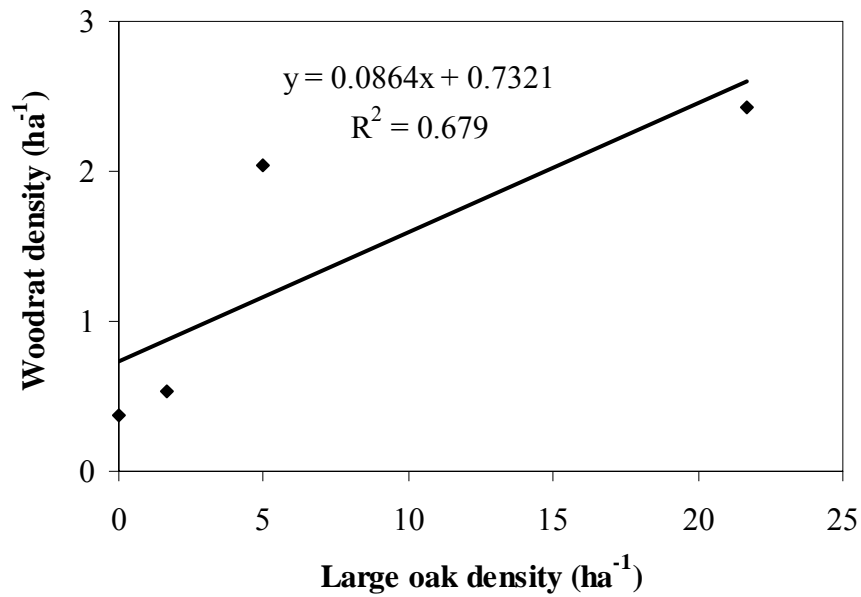

$y = 0.0864x + 0.7321$

$R^2 = 0.679$

Table 6.— The best habitat model based upon the lowest Akaike Information Criterion used to explain the difference between dusky-footed woodrat (*Neotoma fuscipes*) 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.

Variable	Parameter estimate (SE)	*P*-value	Odds ratio	95% Odds ratio confidence 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^3ha^{-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 7.— Density (ha-1) of adult dusky-footed woodrats (*Neotoma fuscipes*), ground houses mean density (ha^{-1}), and density (ha^{-1}) and basal area (baha[-1]) of small (< 33 cm dbh) and large (≥ 33 cm dbh) California black oak (*Quercus kelloggii*) trees, and acorn production indices at 4 study sites in the northern Sierra Nevada, California, 2004 - 2006.

Site	Area	Woodrat density (ha^{-1})			Ground House Density (ha^{-1})	Tree House Density (ha^{-1})	California black oak (ha^{-1})		California black oak (baha[-1])		Acorn Production Index	
		2004	2005	2006			Small	Large	Small	Large	2005	2006
1	6.18	2.91	1.94	1.46	8.90	5.83	291.67	21.67	7.78	2.71	13.11	14.82
2	3.68	2.18	1.90	1.09	11.15	3.26	142.50	5.00	2.36	0.78	9.44	3.28
3	5.60	0.54	0.54	0.36	1.96	0.36	28.33	1.67	0.49	0.48	-	-
4	6.72	0.30	0.45	0.15	1.04	0.30	207.50	0.00	2.80	0.00	-	-

Fig. 16. — Hypothesized model for offspring dispersal in ground dwelling sciurids (*Spermophilus*). 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.
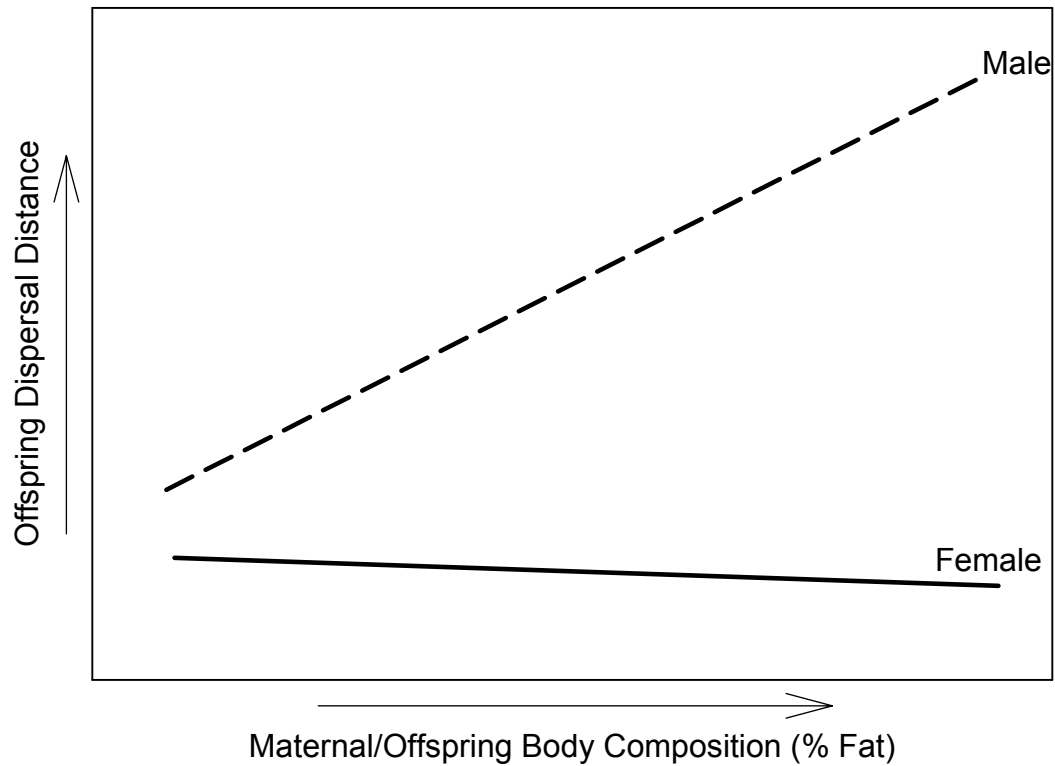
Fig. 17. — Mass of female (mother) golden-mantled ground squirrels and their offspring during 2003 – 2004. All squirrels enter hibernation during early October and emerge following snowmelt in mid May. Significance is indicated by (*).
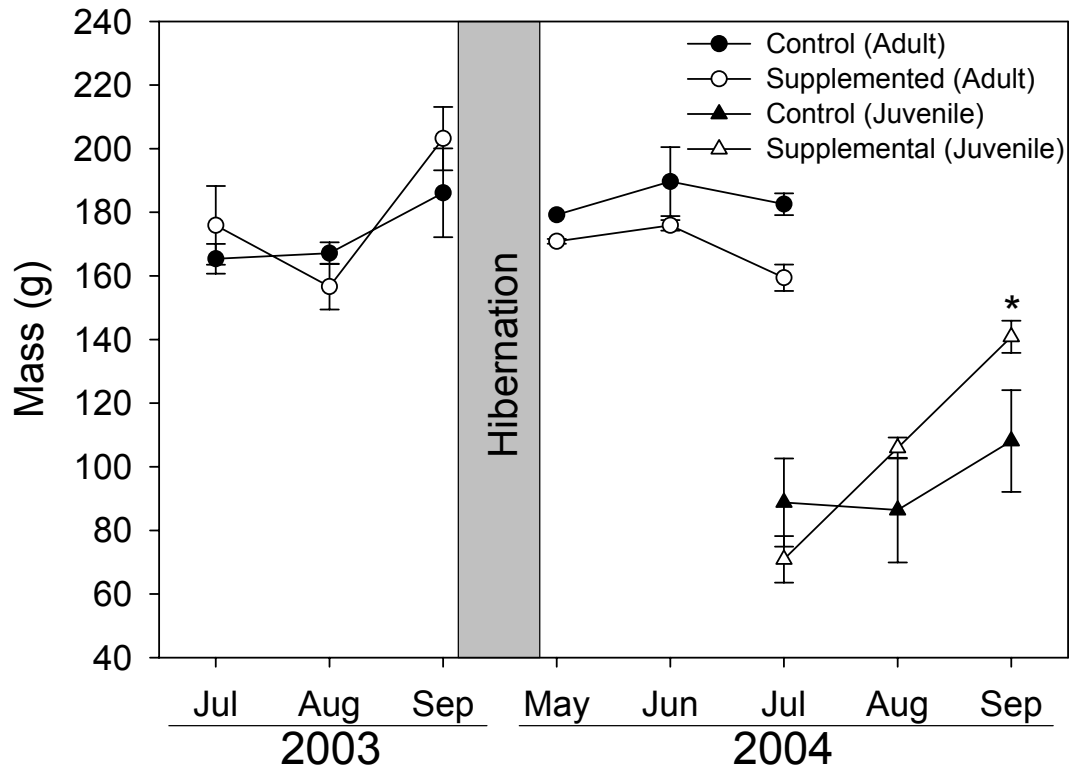
Fig. 18.— Mean exploratory distance (A) and post-natal dispersal (B) distance (m), measured as the distance between location of first capture and location of hibernation, of male (n = 13) and female (n = 10) offspring golden-mantled ground squirrels from each treatment group.
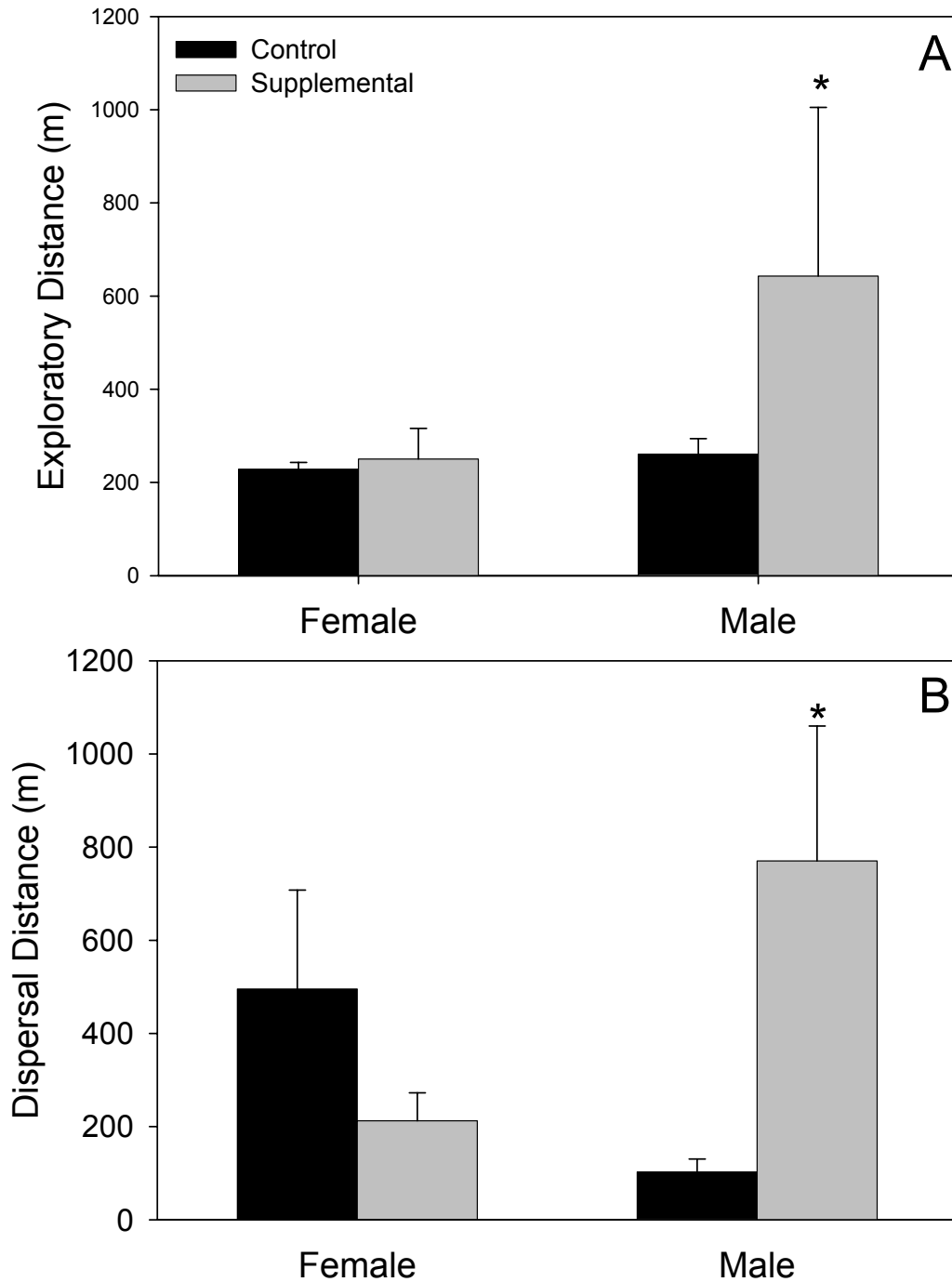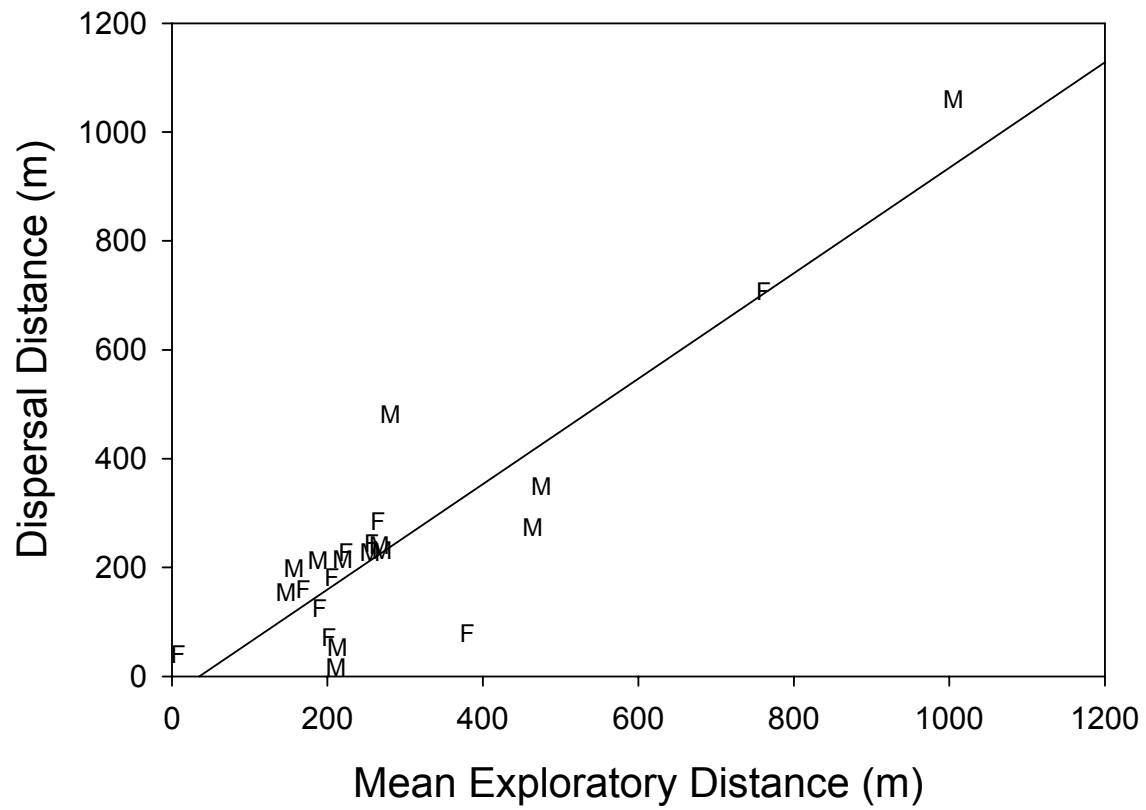
Fig. 19. — Relationship between mean exploratory distance and post-natal dispersal in male (M) and female (F) golden-mantled ground squirrel offspring.
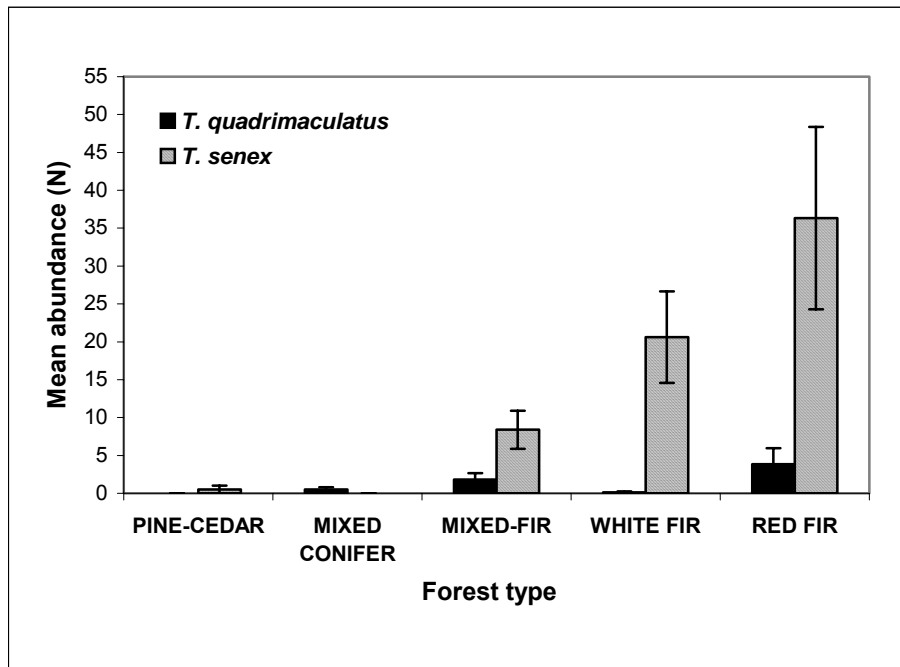
Habitat Associations and Partitioning at the Landscape Spatial Scale

Fig. 20. — Landscape scale map showing the geographic ranges of *T. quadrimaculatus* and *T. senex*, and associated habitat, throughout the Sierra Nevada.
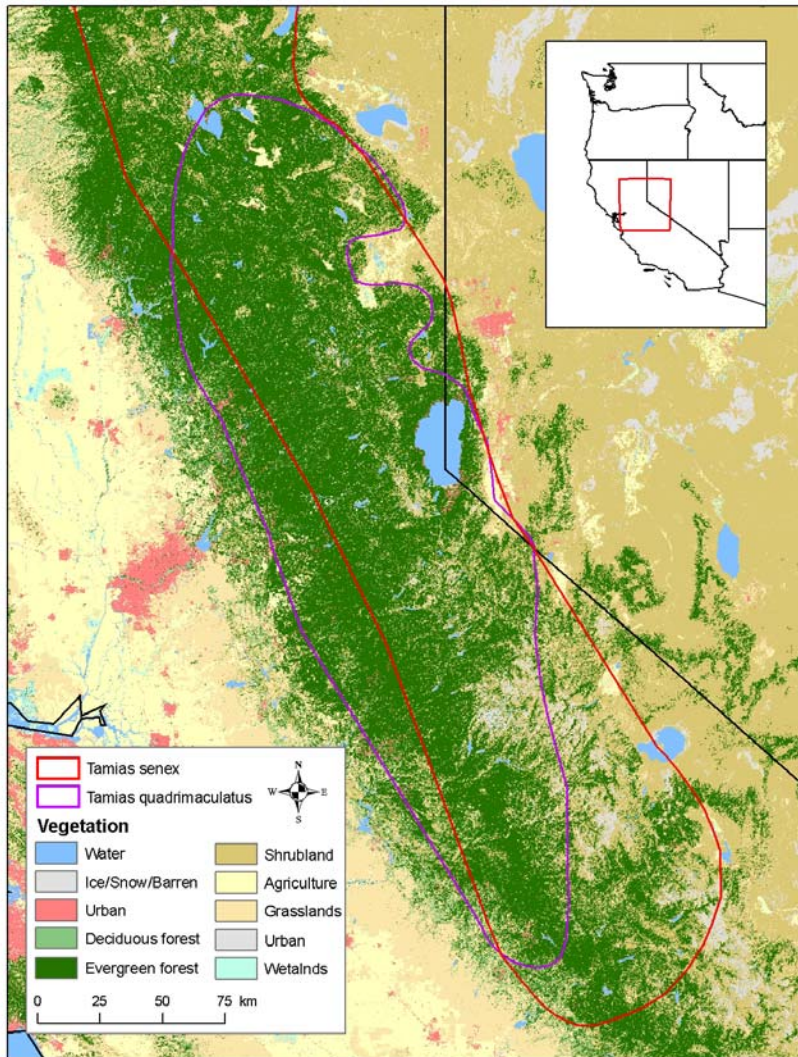
Habitat Associations and Partitioning at the Macrohabitat Spatial Scale

Fig. 21. — Mean abundance (N) of *T. quadrimaculatus* and *T. senex* among five macrohabitat types of Plumas National Forest, CA (2003-2004).
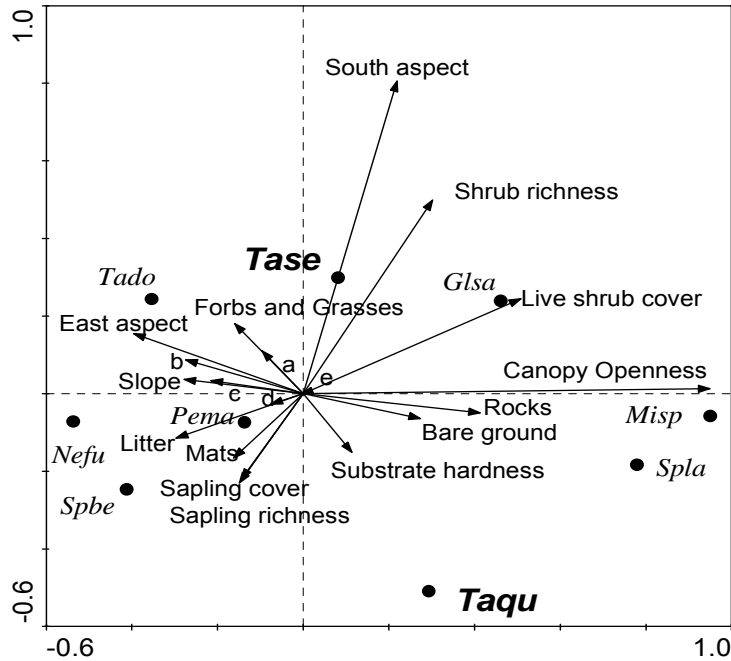
Habitat Associations and Partitioning at the Microhabitat Spatial Scale

Table 8. — Stepwise logistic regression models of Tamias quadrimaculatus and T. senex microhabitat (trap-scale) associations in Plumas National Forest, CA (2003 and 2004 pooled); variables are ordered by positive parameter estimate.

Model	Variables	Estimate	SE	Wald χ^2	P	Odds ratio	Goodness of Fit
N. 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)	
N. senex							
	Shrub species richness	0.623	0.086	52.94	<0.0001	1.865 (1.577-2.206)	$P = 0.24$
	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)	

Fig. 22. — 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*.

Year-to-year shifts in Habitat Preferences at the Macrohabitat Spatial Scale

Fig. 23.—Mean abundance (N) of *T. quadrimaculatus* and *T. senex*, for 2003 and 2004 data separately, among five macrohabitat types of Plumas National Forest, CA.
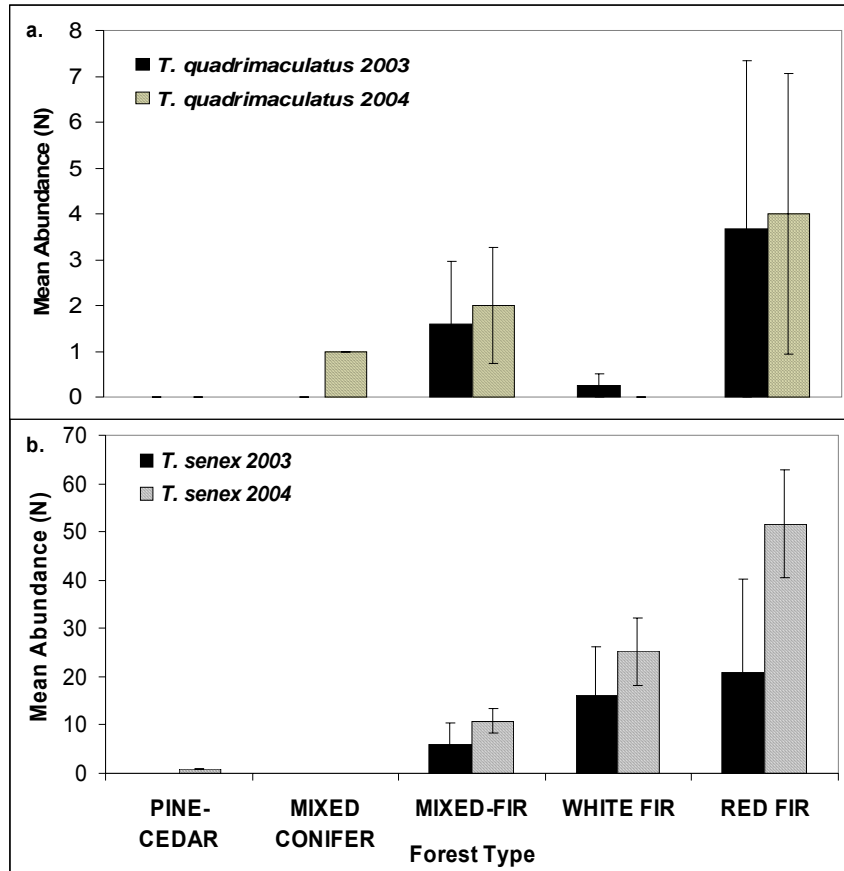
Year-to-year shifts in Habitat Preferences at the Microhabitat Spatial Scale

Table 9. — Stepwise logistic regression models of T. quadrimaculatus and T. senex 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**	**P**	**Variables**	**Estimate**	**P**
N. 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	**0.0009**	***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
N. 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			