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

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INTRODUCTION

Small mammals provide critical food sources for many carnivores, including the American marten, California spotted owl, and Northern goshawk. As a result, changes in small mammal abundances could have effects on many species throughout the forest. Understanding the demographics, habitat requirements, and natural fluctuations of small mammals is critical to the management of Sierra Nevada forests. Alterations in habitat structure can directly affect small mammals by increasing habitat quality allowing greater small mammal density, higher reproduction, and increased survival. In addition, changes in the spatial distribution of habitat characteristics can lead to differences in small mammal distribution patterns (e.g. more clumping).

Determining which components of the habitat are important in structuring the dynamics of small mammal populations requires close monitoring of several independent populations through multiple years combined with measuring habitat characteristics. In addition, the requirements of key prey species (woodrats and flying squirrels) must be understood in detail. In particular, daily activity and habitat use of key prey species within specific habitat types is necessary to understand the link between small mammal and predator populations.

In addition to understanding small mammal population dynamics and habitat relationships, we will investigate links between physiology and population dynamics in a key diurnal prey species. Golden-mantled ground squirrels represent a primary prey species for diurnal predators, such as the Northern goshawk. Alterations to habitat structure may affect individual fitness of small mammals by altering their ability to build fat layers in anticipation of hibernation. We will quantify fat content of golden-mantled ground squirrels throughout the year and relate that to habitat structure. The results of this aspect of the study would provide a possible link between habitat structure and population dynamics of these important prey species.

Finally, we are establishing separate collaborations with independent researchers to investigate the phylogenetic relationship between the chipmunk species living in the study site. Several of the chipmunk species are virtually identical in appearance and can only be identified by skeletal differences. As a result, we hope to find simple molecular techniques to identify species using a small of ear tissue. This will allow proper identification of the species without killing individuals being studied.

OBJECTIVES

Research objectives for the small mammal unit are to evaluate small mammal responses to different forest management practices, and model these responses in terms of demography, spatial distribution, and habitat associations. Specifically we will investigate:

Demographic profiles of small mammal populations inhabiting a variety of habitat types.

We established nine semi-permanent live-trapping grids for use as experimental plots.

Three sets of three experimental grids were established throughout the treatment area

with each set of three grids established in a cluster. The clustered grids consist of two grids established in known DFPZ treatment zones and will be treated with a light (grid A) or heavy (grid B) thinning treatment, and a third, control, grid (grid C) will not be treated. All grids are located in white fir dominated forest with triplicate grids located in close proximity to each other.

Habitat associations of small mammal populations in the northern Sierra Nevada. This was investigated using multivariate techniques to identify key habitat characteristics used by individual species of small mammals. Nine additional grids were established in various representative habitats throughout the study site. Habitat grids were established in triplicate for each habitat, and did not necessarily need to be located near other grids in the same habitat type.

Dynamics of key spotted owl prey: dusky-footed woodrat and northern flying squirrel. Dusky-footed woodrats (*Neotoma fuscipes*) and northern flying squirrels (*Glaucomys sabrinus*) are of particular concern to forest managers, as they comprise a major portion of California spotted owl diets. We will capture and radio-collar dusky-footed woodrats and perform monthly radio-telemetry throughout the season. Through the use of radio-telemetry we will identify home ranges and nest locations for both sexes and various age classes. In addition, we will capture as many flying squirrels as we can and radio-collar them for use in home range analyses.

Fitness correlates to forest management. Some taxa may not exhibit numerical responses to forest treatments, but the quality of individuals as prey items may be altered, with important implications for spotted owls or northern goshawk. In particular, fat deposition is critical in ground squirrels that live off these stored reserves while hibernating. We will capture and follow 9 females of naturally varying fatness. All individuals will be captured and have their mass, body composition, and overall health measured. Offspring from these natural females will be captured, radio-collared, and followed to determine the effects of maternal body condition on offspring fitness, dispersal, and home range establishment.

Taxonomy and classification of Sierra Nevada chipmunks. Chipmunk species in the Plumas and Lassen National Forests display considerable overlap in habitat requirements, diet, and activity. Additionally, two species (long-eared chipmunk (*Tamias quadrimaculatus*) and Allen's chipmunk (*Tamias senex*)) overlap in appearance to such an extent that they are virtually impossible to identify without using skeletal features. We will collect tissue samples from all chipmunk species to use with molecular markers to determine species identification. In conjunction with molecular identification we will collect data on various aspects of each chipmunk's appearance. We will compare external characteristics with molecular identification to determine what characteristics, if any, are reliable for species identification. While this is not central to the present study, we have begun to establish collaborations with chipmunk taxonomists towards better understanding the nature and distribution of these species using outside funds.

METHODS – 2005 Field Season

Demographic profiles of small mammal populations inhabiting a variety of habitat types:

Small mammal populations were sampled in June and October using established trap grids. We employed a nested grid system. Sherman live traps were established in a 10 x 10 grid with 10m spacing, nested within a larger (6 x 6, with 30 m spacing) grid of Tomahawk live traps (2 traps per station). All traps were opened in the late afternoon and checked the following morning. Both Sherman and Tomahawk traps were checked soon after sunrise (AM1 session). Animals captured during the AM1 session were worked up and released. Tomahawk traps were reset following release of any animals. All Sherman traps were closed following the AM1 session to prevent deaths from heat exposure. All Tomahawk traps were checked again approximately 2 hrs following the AM1 session (AM2). Animals captured during the AM2 session were worked up and released, and all traps were then closed. All traps remained closed from 11:00 – 15:00 to prevent deaths to animals due to heat exhaustion. All traps were baited with a mixture of rolled crimped oats, peanut butter, raisins, and molasses.

All individuals captured were weighed and measured (e.g., ear length, hind foot length), and sex and reproductive condition noted. For males, testes may either be enlarged and scrotal or reduced and abdominal; for females, the vagina may be perforate (thereby receptive) or imperforate (not receptive), the vulva may either be swollen or not, and the nipples may be enlarged and/or reddened (reflecting nursing offspring), or not. All animals were individually marked with numbered ear tags, and released at the site of capture. Total processing time for an experienced technician is generally < 2 minutes.

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. Survival and population densities will be modeled for each species by habitat type using the Cormack-Jolly-Seber data type in program MARK.

Habitat associations of small mammal populations:

We continued to trap the habitat grids during June and October as was described above. However, no macro- or microhabitat characteristics were measured during the 2005 field season. Continued trapping on habitat grids will provide information on the variability found among the different habitats across years. Information from continued trapping will be used to build prey models for spotted owls in the Plumas/Lassen National Forests.

Dynamics of spotted owl prey taxa:

Dusky-footed Woodrat:

This study was conducted within the Sierra Nevada mixed-conifer forest type in Plumas National Forest, Plumas County, California between 1450-1750 m elevation near Meadow Valley, California. Study area boundaries and broad-scale habitat features were derived from

GIS data layers provided by the USDA, Forest Service. Four study areas (hereafter, Black Oak, Gulch, Oasis, and Shrub) were placed in early-seral forest, indicative of the Sierra Nevada mixed-conifer forest type (characterized by California black oak, *Quercus kelloggii*; white fir, *Abies concolor*; sugar pine, *Pinus lambertiana*; yellow pine: ponderosa pine, *P. ponderosa* and Jeffrey pine, *P. jeffreyi*; Douglas fir, *Pseudotsuga menziesii*; and incense cedar, *Calocedrus decurrens*), with a brushy understory component. This habitat type was selected since other studies have indicated that woodrats appear to be most abundant in mixed-conifer forest of this type (Forsman 1984, 1991; Carraway and Verts 1991; Carey et al. 1992; Sakai and Noon 1993, Raphael 1988; Sakai and Noon 1993, 1997).

Study areas differed in macrohabitat characteristics such as overstory and understory composition, canopy closure, and aspect. Oasis, Shrub, and Black Oak had overstories consisting of ponderosa pine and Douglas fir, whereas Gulch had ponderosa pine and white fir. Major understory components consisted of *Ceanothus integerrimus* (Oasis, Shrub, Gulch) and *Arctostaphylos* spp. (Black Oak). Crown diameter (% ground covered by tree canopy) ranged from 4-8 m for Oasis, Shrub, and Black Oak with Gulch having a crown diameter of 3-4 m. Canopy closure was 40-50% in Oasis and Shrub, 30-40% in Black Oak, and 50-60% in Gulch. Oasis and Shrub had moderately sloping topography with E and SW aspects respectively; Gulch and Black Oak had mixed terrain or undulating topography with NE and S aspects.

Historic logging activities (c. 30-40 years prior) and fire suppression practices have contributed to abundant dead wood as well as created dense, shrubby gaps and patches of closed canopy forest throughout each of the study areas. Recent (< 5 yr) management activities (i.e., prescribed burns, cutting) meant to restore pre-fire suppression conditions have created open understory and overstory conditions within intervening habitats allowing for ease of delineation of study area boundaries in the field and reduced house availability for potentially dispersing woodrats in the surrounding landscape (R. Innes, personal observation). No woodrats were observed moving between study areas.

Social Organization:

Animal movement data were collected at Black Oak, Gulch, and Oasis Jul-Oct 2003 and at all study areas May-Oct 2004 and 2005. Radiotelemetry was discontinued at Black Oak and Gulch in 2004. The study areas were systematically searched for woodrat houses in the spring and fall and opportunistically searched during regular monitoring of activities of radiocollared woodrats to ensure that all houses within a study area were discovered. Each house was marked with a flag as its location became known, and numbered sequentially. All woodrat houses were mapped within 1 m accuracy using a Trimble GPS unit. Since woodrat movements and house locations were not contained exclusively within study area boundaries, search efforts extended 100 m beyond study area boundaries to identify the presence of houses, and trap conspecifics that could potentially influence the social organization and habitat utilization of collared woodrats in the core of the study area. Sampling of vegetative characteristics were also not constrained by study area boundaries, but rather were reflective of houses available to resident woodrats. Therefore, within the 4 study areas, research efforts were concentrated within 4 broad-scale habitats, where woodrats and woodrat houses reached their greatest densities, but also included 6 peripheral broad-scale habitat types.

We conducted 2 trap sessions (May-Jun and July-Sep) of 4 consecutive trap nights each. Trapping sessions coincided with breeding and post-breeding activities. To obtain adequate information regarding the social organization of the species, we began collaring efforts within the center of the study area boundaries and radiated outward until all adults within the study area had been successfully radio-collared. We conducted additional trapping intermittently to document the presence of immigrating adults, and monitor juvenile activities to determine when to initiate post-breeding trapping efforts. Four Sherman live-traps (3 x 3.75 x 12"), baited with raw oats and sunflower seeds lightly covered with peanut butter, were placed within 1 m of the base of each house. Synthetic batting was provided as necessary to provide thermal insulation. Woodrats were highly trappable, as most individuals were captured multiple times. All houses within each study area, even those that appeared vacant, were trapped to ensure that all individuals were caught. Captured woodrats were transferred to a mesh weight bag then marked with numbered aluminum ear tags, weighted, sexed and released at their point of capture. Small snips of ear tissue were collected from all newly captured individuals and stored for future genetic analyses. A 4.0 g collar-type radio transmitter (Model PD-2C) made by Holohil Systems Ltd. was placed on the neck of all adult woodrats captured in the study area. Woodrats were lightly sedated with ketamine hydrochloride (100 mg/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. Radiotelemetry activities of newly collared individuals were initiated after a 24-hour acclimation period succeeding their release.

We documented nocturnal activities and diurnal locations of radio-collared woodrats using radiotelemetry. Diurnal locations were determined once per day, sporadically in 2003 and 3 days per week in 2004 and 2005 using homing techniques. Locations were accurately (≤ 1 m) mapped using a Trimble GPS unit. Nocturnal telemetry sessions using triangulation techniques occurred during 5 nights per month in 2003 and 10 nights per month in 2004 and 2005. 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). Triangulation systems were tested regularly using dummy collars to ensure the accuracy of the triangulation method. Radiolocations were obtained for each woodrat 2-3 times per night, a minimum of 2.5 hours apart to avoid serial correlation. The timing of nightly telemetry was varied from dusk until dawn to ensure that radiolocations were sampled at different times of activity.

Macrohabitat-relations:

Dusky-footed woodrats are considered local dietary specialists (Cameron 1971). Studies of woodrats that examined feeding preferences predominantly showed a preference for oak foliage and acorns where available; although diets may include a variety of fruits, nuts, and foliage from woody plants, as well as fungi, associated with the plant community of study (Cameron 1971, Meserve 1974, Atsatt and Ingram 1983). This suggests that woodrat density may be positively associated with oak density or acorn production. To test the hypothesis that woodrat density was positively correlated with California black oak, we estimated California

black oak density at each of the study areas using 10 x 100 m belt transects placed in a stratified random fashion, such that $\approx 10\%$ of the total area was sampled for California black oak. California black oak trees greater than or equal to 5 cm DBH were recorded. We examined correlations between woodrat density and density of woodrat houses in two size categories of California black oaks to test the hypothesis that woodrat density would show a stronger relationship with the density of mature, larger diameter trees that provide acorns and other wildlife habitat attributes such as cavities, in addition to foliage for forage. California black oaks begin to produce acorns in moderate quantities at about 80 years of age (≈ 33 cm DBH); therefore, the density of California black oak ≥ 33 cm and < 33 cm were chosen (McDonald 1969).

To test the hypothesis that woodrat density was positively correlated with annual acorn crops, acorn production of California black oak was measured on 25 and 28 trees located at Oasis and Shrub, respectively. Black Oak and Gulch 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 1974). 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 visible acorns for the two 15 sec count periods were combined to yield a total count for a 30 sec 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).

Microhabitat-relations:

One of the trials of researchers studying dusky-footed woodrats is that the species may be found in many plant communities that satisfy its food requirements and still be limited in its density by the structural factors and composition of the environment (Willy 1985). Horton and Wright (1944) suggest that higher concentrations of houses are due to greater protection from thick vegetation than from an increased food supply. To look at these potentially limiting factors to the distribution and abundance of woodrats, differences between the structural characteristics and the abundance and composition of plant species adjacent to woodrat houses and the surrounding habitat were measured.

We sampled vegetative and structural characteristics within 4 m radius plots (50.3 m²) centered at 185 randomly selected woodrat houses. Plot size was based upon ocular estimates of patch size at woodrat houses (e.g., the microhabitat changed beyond a 4m radius). Houses less

than 0.2 m in height were not included in vegetative surveys since these houses were considered too small to accommodate a woodrat (Willy 1985). Houses that appeared used based upon green clippings, newly accumulated debris, and fresh feces, and houses that appeared unused or in advanced stages of decay were included in analyses to examine which habitat variables best predicted house site selection and use.

To determine whether habitat variables predicted house placement, we visually estimated percent cover of 4 ground cover variables; in addition, density and frequency of shrubs, trees, snags, stumps, and logs were recorded (Table 1). Only woody plant species were measured in the vegetation sampling, as dusky-footed woodrat diet consists of the leaves, fruits and nuts of woody plants. Woodrats use downed or standing dead woody material and live vegetation to build their houses (English 1923, Vestal 1938, Linsdale and Tevis 1951, Willy 1985). Therefore, a minimum size criterion for downed woody material (e.g., logs) was chosen to quantify debris that a woodrat could not pick up and carry. The volume of each log ($\text{m}^3 \text{ha}^{-1}$) was estimated as a frustrum paraboloid (Husch et al. 1993) using logs length and diameters of both ends. For stumps, snags and trees, the distance from the variable to plot center was recorded. Slope and aspect were measured using a compass and clinometer, respectively, by sighting from the top-most part edge of the plot, viewing downward through the plot center to the bottom-most edge of the plot. The percent of canopy closure was quantified by using a Moosehorn with an 8.5 x 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.

To determine whether habitat variables or house characteristics best predicted house occupancy by a woodrat we measured house-specific characteristics. Woodrat houses are constructed of sticks, bark, and plant cuttings, as well as various other materials. Houses may be conspicuously placed in the crotch of tree limbs, in tree cavities, or on the ground. We measured house-specific characteristics such as house volume, location (i.e. ground, tree), type (i.e. cavity dwelling, stick mound), and supporting structure (e.g., stump, log, tree). Thirteen house volume categories were devised as 0.1 m^3 increments between 0.0 and 2.0 m^3 . We regressed ocular estimates of house volume using these categories against a random subset ($n = 24$) of house volume estimates obtained by measuring height, length, and width of each house and found that volume category determined by ocular estimates was strongly correlated with house volume ($P < 0.001$, $R^2 = 0.71$).

We also sampled, with replacement, the same vegetative and structural characteristics at paired points located a random distance between 10 and 50 m and a random direction between 1 and 360° from the center of each house, resulting in 185 paired random points. Random points were further constrained to lie within the same broad-scale habitat type as the paired house; in addition, woodrat houses could not be built within roadways or drainages, thus random points falling within roadways and drainages were excluded. Adult residents are thought to be the primary creators of new stick houses, and thus these individuals are assumed to be making decisions regarding the placement of houses within their home range area. Current knowledge indicates that the home range in which an adult woodrat satisfies its life history requirements is limited to the vicinity of its house, with the house often lying within the center of the home range (Cranford 1977). In the literature, home range estimates for adult woodrats range from 1942 m^2 to 4459 m^2 (Cranford 1977; Lynch et al. 1994); therefore, the maximum distance to a random

point was set to constrain random plots within the bounds of a surrogate home range area and represent the full range of habitat choices that a resident woodrat could make with regards to house site selection.

We hypothesized that woodrats will place houses with regards to increased structural complexity, vegetative composition and density. Specifically, we hypothesized that woodrats would place houses, 1) with respect to the location of house supporting structures, in the form of increased snag, log, and stump volume, 2) to maximize foraging opportunity in the form of increased density of preferred forage species, such as young and mature oaks trees, and deer brush, 3) to improve access to and mobility within the tree canopy (i.e., increased tree density), 4) to minimize seasonal temperature fluctuations in internal house space through means of increased canopy closure, tree density, and high (> 1m) shrubs, and 5) to enhance protection from predators through an increased density of shrubs (> 1m), greater abundance of logs as travel routes to and from houses, and a decrease in the average distance of trees and snags to house center.

Statistical Analyses:

Program *Locate II* was used to calculate woodrat locations from bearing data obtained during triangulation. Woodrat locations were then entered into an ArcView GIS 3.2 database and plotted. We used the Animal Movements Extension for ArcView GIS to calculate 95% minimum convex polygon (MCP) home range estimates and 50% MCP core area estimates for home range and area overlap analyses. Future analyses will also include fixed kernel (FK) home range and core range estimates. Overlap (shared area) of home ranges and core areas between individuals was calculated. For two animals, A and B, we calculated mean overlap as the geometric mean of the product of the ratios of overlap size to home range size.

$$\text{Overlap} = (\text{Overlap/Home Range A} \times \text{Overlap/Home Range B})^{0.5}$$

Overlap values ranged from 0 - 1, with a mean overlap of 1 equivalent to 100% overlap between two individuals. We compared home range size among sexes using nonparametric tests (e.g., Mann Whitney U).

We used Conditional logistic regression (CLR) to predict the odds for the event of finding a house at a certain location given the explanatory variables. CLR using a 1:1 matched case-control study takes the stratification of the data set into account by basing the maximum likelihood estimation of the model parameters on a conditional likelihood for paired observations. CLR is suitable for studies with few subjects per group as it can fit a model based on conditional probabilities that “condition away” or adjust out the grouped effect. Here, we considered each house-random pair to be a separate stratum or group, conditioned out subject-to-subject (in this case house-to-house) variability and concentrated on within-subject (in this case house-to-random) information. CLR conditions out house-to-house variability due to site or broad-scale habitat differences and concentrates on house-to-random variability due to microhabitat preference. This is conceptually similar to using differences between cases and controls as predictors (Stokes et al 2001). The primary advantage of conditional logistic regression is that it allows one to statistically control for effects that characterize clustered data,

such as woodrat houses (Hosmer and Lemeshow 2000). Quantitative comparisons of habitats 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).

To meet the assumptions of CLR, we used the general guideline that each possible outcome should have a minimum of 5 observations per explanatory variable in the model for valid estimation to proceed (Stokes et al. 2001). We checked all pairs of nominal variables and merged or divided categories as necessary to obtain cells that have expected frequencies greater than 1 and less than 20% of cells with observed frequencies less than 5. Prior to CLR analyses, we examined Spearman's rank correlations between variables and tolerance values for each variable to identify potential collinearity problems. Variables that were highly correlated ($r \geq 0.7$, tolerance < 0.1) and that explained similar biological phenomenon were not included together in multivariate models (Hosmer and Lemeshow 1989). To determine which habitat variables best discriminated between house and random location, we performed CLR using the proportional hazards regression (PHREG) procedure in SAS, initially using univariate analyses to screen for candidate variables. We identified main effects and biologically important interactions and then built multivariate models using forward stepwise selection ($P = 0.05$ to enter and $P = 0.10$ to remove). We examined model residual chi-square and residual diagnostics to further assess model goodness-of-fit (Hosmer and Lemeshow 2002, Stokes et al. 2000).

Logistic regression was used to examine differences between used and unused houses and for differences among age groups (e.g., subadult, adult). Statistical assumptions were validated using the methods described for CLR and simple linear regression was applied using JMP 5.1 (SAS Institute, 2001). Statistical significance was set at $P < 0.05$.

Northern flying squirrel:

We captured northern flying squirrels in the Plumas National Forest, northern California. Animals were collected from red fir and mixed conifer forests at an elevation of approximately 2,100 and 1,500 m, respectively. Red fir forests were dominated by red fir (*Abies magnifica*), interspersed with western white pine (*Pinus monticola*), lodgepole pine (*Pinus contorta*), and sugar pine (*Pinus lambertiana*). Prostrate manzanita (*Arctostaphylos prostrata*) and snowplant (*Ceanothus* spp.) composed much of the understory. Mixed conifer consisted of Douglas fir (*Pseudotsuga menziesii*), ponderosa pine (*P. ponderosa*), white fir (*A. concolor*), and sugar pine with a complex understory of manzanita (*A. spp.*), *Ceanothus*, and other shrubs.

We trapped for northern flying squirrels using a combination of Sherman (Model XLK; Tallahassee, FL) and Tomahawk (Model 201 Tomahawk, WI) live traps placed on the ground or strapped to trees at a height of approximately 1.5 m. Traps were baited in late afternoon with a mixture of rolled oats, peanut butter, molasses, and raisins (modified from Carey et al. 1991), and checked for captures in the morning. Polyfill fluff and a cardboard box were provided for warmth during cold nights. All work was performed under the auspices of an approved animal care and use protocol (ACUC 10394) and followed guidelines established by the American Society of Mammalogists.

All captured individuals were weighed using spring scales, and both sex and reproductive condition were noted. For males, testes were recorded as either scrotal or non-scrotal; for females, the vagina may be perforate (thereby receptive) or imperforate (not receptive), the vulva was either swollen or not, and nipples may be enlarged and/or reddened (reflecting nursing offspring), or not. All animals were individually marked with numbered ear tags and fitted with a radiocollar (Model PD-2C; Holohill, Carp, Canada). Following radiocollar attachment, individuals were released at the site of capture and monitored until they entered a nest or cavity. The animal was allowed to rest for 24 - 48 hrs before radiotelemetry began.

We radiotracked individuals during the day to locate nest trees. We marked each nest tree and determined the location with hand-held GPS units, in UTM coordinates. We recorded diameter at breast height (DBH), species, condition (live, dead snag), and nest type (cavity or external nest) of each nest tree.

Squirrels were located with hand-held radiotelemetry receivers (Communications Specialist R-1000, Tustin, CA) 5-8 times per month from May to October, 2004 and August to October, 2005. Within each session we located animals at least 3 times, with each "fix" separated by at least 1 hour following Swihart and Slade (1988) and Taulman and Smith (2004). The latter authors found that this interval was sufficient to achieve independence of locations and that the occasional lack of independence was due to nonrandom use of home ranges. Animal locations were determined in UTM coordinates from triangulation using program LOCATE II, and entered into an ArcView GIS database. The animal movement extension in ArcView was used to generate monthly home range estimates using the 95% minimum convex polygon for interspecific comparison with published data. Additionally, we evaluated 50% and 95% adaptive kernel home ranges to identify core usage for individuals (50%) and because this method is not subject to some of the constraints of MCP.

Technician accuracy was quantified at each study site. We placed a radiocollar in a hidden location to determine location error using these "dummy collars." Technicians did not know where collars were located and collars were moved periodically. To assess bearing error rates technicians recorded bearings to dummy collars as if they were performing telemetry on individual squirrels. Bearings to dummy collars were recorded in conjunction with normal telemetry sessions; giving a potential dummy location for each night of telemetry. Dummy collar locations were determined and compared to their actual location. The dummy collar was located an average of 253.3 ± 47.2 m from any given station. Results of this procedure indicated that we had a mean angular error of 15.9 ± 1.4 degrees, resulting in a mean error of location of 34.9 ± 4.0 m for our flying squirrels.

To provide an index of activity throughout the night we measured the distance between each location and the nearest known nest tree. We tracked squirrels periodically during daylight hours to find nest trees. Although we did not find evidence of additional, unknown nest trees it is possible that we missed some. These distances were used to generate a time series of distances each individual was found from its nearest nest 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).

We performed a T-test to determine if non-adult male home ranges differed from adult males. Analysis of adult home range size and nocturnal activity was performed using a 2 x 2 factorial design, with habitat (red fir, mixed conifer) and time of night (4 3-hr 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 2006). If there were no significant interactions, differences in the main effects were compared using the PDIFF option in the LSMEANS statement. Differences in terms with significant interactions were compared using the SLICE option in the LSMEANS. All data are presented as means $\pm$ standard error, and all differences were considered significant at $\alpha = 0.05$.

Fitness correlates to forest management:

Nine female golden-mantled ground squirrels were captured for use as experimental subjects in June of 2005 and fitted with radio-collars. Individuals represented a range of naturally occurring body conditions. All females were anesthetized (using ketamine hydrochloride, 100 mg/ml), had total mass measured to the nearest 0.1g using a portable electronic balance, had head+body length recorded, and had total body electrical conductivity (ToBEC) was measured using an EM-SCAN body composition analyzer. Following body composition analysis the radio-collar was reattached.

Once offspring become available aboveground (mid July 2005) the remaining mothers were located early in the morning before they became active and traps were placed around the burrow. Traps were checked around 11:00 for the presence of the female squirrel and her offspring. Typically the female was captured along with a number of offspring within 2 hours of trap placement. A total of 14 offspring from 6 females were captured and used for the remainder of the study. Offspring were fitted with radio-collars and subjected to the same measurements: overall mass, body condition, head+body length, and home range. Each offspring was marked as described above and tissue samples will be collected for possible maternity analyses. All subjects (i.e., offspring and mothers) were followed throughout the remainder of the 2005 field season (July-October) to determine home ranges and dispersal locations. 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 (hibernation burrow).

Taxonomy and classification of Sierra Nevada chipmunks:

We continued to collect small sections (< 1 cm) of ear pinna from all chipmunks trapped in this study to identify the distribution of closely related chipmunk species. Ear tissue was placed in cryovials containing 95% ethanol and stored in a refrigerator. Tissues from both reference and live chipmunks will be sent to the University of Idaho for molecular analysis to determine what molecular markers exist to identify chipmunk species. In addition, we will investigate whether hybridization is occurring between certain species, most notably *Neotamias senex* and *N. quadrimaculatus*.

In addition, external features were characterized for every chipmunk captured. Features included the length of the face stripe (if it extended to the base of the ear or not), the color of the face stripe (black or brown), rump color (grey or red), size (large or small) and brightness (white or dull) of the earpatch, shape of the ears (narrow and pointed or rounded), and hind foot and ear

notch measurements (mm). Features were characterized every time a chipmunk was captured, regardless as to whether a particular individual had been previously captured. This will enable us to identify differences in the variation within and among technicians on how well these external characteristics can be used to identify sympatric chipmunk species. External characteristics will be matched to molecular identification to determine which characteristics, if any, is a reliable indicator for separating the two species of chipmunk inhabiting our study site.

2005 FIELD SEASON PROGRESS AND RESULTS

The 2005 season began in April with the hiring of 8 technicians. Work began at the study site on 23 May and continued through 31 October. Due to heavy snow, we were limited in the amount of area we could access at the beginning of the season. As a result, we began the field season by training the technicians on trapping and telemetry methods. We continued pretreatment trapping of the nine experimental grids and continued a third season of trapping for the nine habitat grids. However, rather than trap the grids every month we switched to only trapping them in June and October. This allowed us to have more time to focus on finding and marking flying squirrels. The nine experimental grids (Grids 1-9) were located in white fir dominated forests in the Snake Lake, Dean's Valley, and Waters districts. During each trap session, we trapped 5 consecutive days (4 nights), opening traps for an AM2 check on the first day and closing the traps after the AM1 check on the last day of trapping. Each night's effort comprised 100 Sherman trap-nights and 72 Tomahawk trap-nights ($n = 172$ trap-nights total), and each grid experienced 688 trapnights during each month of trapping. Similarly, the habitat grids were trapped on the same schedule.

Demographic profiles of small mammal populations inhabiting a variety of habitat types:

During the 2005 field season we captured and marked a total of 566 individuals across all species of small mammal and all sites (Table 2). A total of 10,368 trapnights were evenly distributed across all sites during June and October 2005. Predominant species in the study area include dusky-footed woodrat (*Neotoma fuscipes*), deer mice (*Peromyscus maniculatus*), long-eared and Allen's chipmunks (*Tamias quadrimaculatus* and *T. senex*), California and golden-mantled ground squirrels (*Spermophilus beecheyi* and *S. lateralis*), montane vole (*Microtus montanus*), Douglas squirrel (*Tamiasciurus douglasii*), and the northern flying squirrel (*Glaucomys sabrinus*). Incidental species captured during our trapping included shrews (*Sorex* spp.), brush mice (*Peromyscus boylii*), snowshoe hare (*Lepus americanus*), striped skunk (*Mephitis mephitis*), and pocket gopher (*Thomomys bottae*).

To allow for more research time with flying squirrels we have reduced grid trapping to June and October. This will give us an index of the relative abundance of small mammals, particularly *Peromyscus*, across years. Results from the previous three years of trapping indicate high interannual variance within *Peromyscus* (Figure 1). *Peromyscus* levels were very low in 2003, increased dramatically in 2004, and were intermediate in 2005 across all habitats. The similarity in pattern between all forest types suggests that *Peromyscus* populations are being driven by a large-scale environmental factor. Fewer *Peromyscus* were captured in Fall compared

to Summer (Figure 1). October abundances were at least half that of June across all forest types. Changes in *Peromyscus* populations represent an important factor in determining whether spotted owls have a good reproductive year.

Dynamics of spotted owl prey taxa:

Dusky-footed woodrats:

Adult woodrat densities were variable between sites and among years, with adult woodrat densities consistently lower at all sites in 2005 as compared with 2004 (Table 3). In 2005 we radio-collared 18 adult woodrats (6 Oasis, 12 Shrub). In 2004 we fitted 31 adult woodrats (14 Oasis, 17 Shrub) with radio-collars. In 2003 we radio-collared 20 adult and juvenile woodrats (12 Oasis, 4 Black Oak, 2 Gulch, 1 Between, and 1 Nogo.). We captured 17 woodrats in 2005 that were also captured in 2004 (10 Shrub, 5 Oasis, 1 Black Oak and 1 Gulch). In 2004 we captured 9 woodrats that were also trapped in 2003 (6 Oasis, 3 Gulch). Notably, 1 adult male woodrat was trapped at Gulch in 2003, 2004 and 2005.

Home range estimates have been calculated for 2003 and 2004 and core range estimates have been calculated for 2004. Core area calculations are from the Shrub study site only. Male woodrats consistently had larger home range and core area estimates compared to that of females. In 2003 mean home range size for males (1.9 ha) and females (0.9 ha) were larger than in 2004 (1.1 males, 0.7 females). Core areas calculated from 2004 data were 0.4 and 0.1 ha for males and females respectively.

Overlap indices, ranging from 0.0 (no overlap) to 1.0 (total overlap), for female-female, male-male and female-male dyads at Shrub in 2004 indicated overlap among individual's home ranges. Male-male overlap was greatest (0.42) followed by female-male (0.36), and female-female (0.22). Core area overlap also showed overlap among female-male (0.29) and female-female (0.59). Occurrences of home range overlap among male-female and female-female dyads were higher than that between males. An individual female overlapped with an average of 3.4 other females and 1.9 males. A given male overlapped with an average of 1.2 other males and 4.6 females. Male-male dyads overlapped more than female-female and male-female dyads; however this relationship was not significant, perhaps due to the high amount of variation evident in overlap among male-male dyads (range: 0.03 - 0.75) and the small number of adult males present in the study area. Core range overlap analyses revealed greater segregation between same sex pairs than was evident in home range overlap analyses (Figure 2). Female core ranges overlapped with 0-1 male core ranges, whereas male core ranges overlapped with 1-3 female core ranges.

Home ranges were larger in comparison to other studied populations. A high degree of home range overlap and a low degree of core area overlap between same sex pairs suggest that woodrats are semi-territorial and share foraging areas, but defend the area around houses, a result supported by studies elsewhere. Male home ranges were larger than females, and male core ranges typically overlapped with several females while females overlapped with only one male, suggesting a polygynous mating system. Conversely, some males overlapped with only one female; these pairs exhibited a high degree of core area overlap and readily shared the use of houses, suggesting that some woodrats may be monogamous. In addition, the incidence of

female-female overlap was low, but did occur on one occasion. This, combined with evidence elsewhere that suggests that female woodrats may be philopatric to natal home range area, suggests that relatedness between individuals may influence territorial behavior and ultimately population density. Our preliminary results suggest that the sex-ratio and age structure of a population appear to play an important role in the social organization and movement patterns of the species. In addition, mating system and genetic relatedness may play a role in population density.

House Use:

Most woodrat houses were located on the ground, but many were also located in tree and snag cavities or on the limbs of live trees. The proportion of available ground/tree woodrat houses was 75/25% in Oasis and 66/34% in Shrub. Use of these houses reflected their availability in the habitat with occupancy at Oasis being 70/30% and 63/37% in Shrub.

There was no apparent difference between sexes with regards to type of house used (ground: $P = 0.28$, tree: $P = 0.53$); therefore all house types were combined. Woodrats had more houses available within their home range than were used. Males used ($P = 0.18$) more houses (7.4 houses/home range) and had more houses available (22.2 houses available; $P = 0.19$) than females (5.3 houses used/home range; 16.3 houses available).

Woodrats used multiple houses within their home range; however, not all houses available within a home range were used, suggesting that woodrats may be selecting some houses preferentially. Stick houses in trees and those located on the ground were used in accordance with availability, a somewhat surprising result since houses on the ground were more vulnerable to destruction by black bears (see below). Males had more houses available within their home range than females, a pattern consistent with the larger home range areas of males; males also used more houses than females, likely as a result of the polygynous mating system.

Macrohabitat features:

California black oak densities varied among sites and between small (< 33 cm DBH) and large (> 33 cm DBH) oaks. Shrub, Oasis, Gulch, and Black Oak had oak densities of 1.0, 0.7, 0.3, and 0.6 ba/ha for small DBH oaks, and 5.1, 3.1, 1.9, and 0.0 ba/ha for large DBH oaks. There was no statistical correlation between woodrat house density and density of California black oak < 33 cm DBH ($P = 0.19$) or density of California black oak < 33 cm DBH and adult woodrat density in 2004 ($P = 0.25$) or 2005 ($P = 0.19$). In addition, there was no statistical correlation between woodrat house density and density of California black oak ≥ 33 cm DBH ($P = 0.11$). The lack of a statistical correlation between woodrat house density and California black oak density was not surprising given the lack of correlation between woodrat house density and adult woodrat density in 2004 ($P = 0.10$) and 2005 ($P = 0.11$). However, there was a strong statistical correlation between density of California black oak ≥ 33 cm DBH and adult woodrat density in 2004 ($P = 0.0001$, $R^2 = 0.99$; Figure 3) and 2005 ($P = 0.0215$, $R^2 = 0.96$; Figure 3).

Although our sample only included 4 sites, our results suggest that woodrat density consistently responds in a linear fashion to the density of mature, California black oak trees. These data should be accepted with caution until further study to determine whether this pattern is consistent across the landscape. California black oaks begin to produce acorns in moderate quantities at about 80 years of age (33 cm DBH), therefore, the density of California black oak $\geq$ 33 cm DBH represents the potential of the site to produce acorns (McDonald 1969). We quantified acorn production at Oasis and Shrub in 2005. Average acorn production indices in 2005 were greater at Shrub (mean: 13.1; range: 0 - 65) compared with Oasis (mean: 9.4; range: 0 - 29). We will continue to monitor acorn production in the coming field season to look for long term trends and further examine the relationship between woodrat density and acorn production.

Microhabitat features:

Our data suggest that the abundance and distribution of woodrats is affected by habitat composition and structure at the microhabitat scale, which plays an important role in predicting the presence and use of woodrat houses. Results of these analyses will be completed shortly.

Destruction of houses by black bear:

In addition to dusky-footed woodrats, many mammals, including the black-tailed deer, black bear, and several bird species rely upon acorn production. Black bears heavily use mixed-conifer forest in California during the fall during acorn production and in the winter-spring when other food resources are minimal. Dusky-footed woodrats cache large quantities of acorns in their houses. In future reports we intend to examine patterns of destruction of woodrat houses by black bears at Shrub in 2004 and 2005 and to examine the relationship between black bears and dusky-footed woodrats.

Northern flying squirrels:

We captured 20 (6 in 2004, 14 in 2005) northern flying squirrels over both years, consisting of 14 males and 6 females (Table 4). Sixteen individuals were adult, based on size and coloration (Villa et al. 1999), with M2, F2, and M10 being subadults and M9 a juvenile. In 2004 only 3 individuals (M1, M3, and F3) survived long enough to calculate home ranges. The remains of 2 squirrels were found within a week of release (M2) or within 24 hr of release (F2). Radiotracking of M1 stopped after 7 July 2004 because the collar never moved from the top of a tree indicating the squirrel had lost its collar or had been predated. The final two squirrels (M3 and F3) were tracked until October when snowfall precluded access to our study site.

In 2005, we applied radiocollars to 11 individuals. Three of these (M4, M5, F4) were captured in mixed conifer forest; the remainder (M6 – M13, F5 – F7) were captured in the same red fir forest as the individuals from 2004. Three individuals (M6, M7, M12) died either during handling or shortly after release. One squirrel (F6) was successfully collared and released, but the radiosignal disappeared after a week. The fate of F6 is unknown and no home range was generated for her. We were able to calculate home ranges for all 3 individuals in the mixed conifer forest and for 10 of the 17 individuals from the red fir forest.

Adaptive kernel home ranges were calculated for all individuals with >20 locations (Figure 4). Considerable overlap existed in the distribution of home ranges and showed both inter- and intra-sexual overlap. Home range size (95% adaptive kernel) was significantly smaller for non-adult males (6.3 ± 1.6 ha) compared to adult males (25.5 ± 4.0 ha; $T_7 = 2.45$, $P = 0.04$). As a result, juveniles and subadults were not included in further analyses. Within adults, we did not find a significant difference between male and female (35.8 ± 10.4 ha) home range size ($F_{1,7} = 0.96$, $P = 0.4$; Figure 5). We also did not find a difference in the home range size between adults inhabiting mixed conifer, and those from red fir forests ($F_{1,7} = 0.08$, $P = 0.8$). The use of minimum convex polygon home ranges produced similar results as the adaptive kernel method; however, MCP home ranges are susceptible to outlier locations (White and Garrot 1990) and in one individual (M3) produced a wildly exaggerated home range size (Table 4).

Nest trees were located for 13 individuals. Only 2 external nests were used by flying squirrels in this study area, with the remainder of nests consisting of cavities drilled by woodpeckers, or natural cervices. Both external nests were found in live trees: one in a red fir (*Abies magnifica*) and one in a sugar pine (*Pinus lambertiana*). Of the cavity nests, most were in live trees of various species, four in solid, well formed snags, and one in a decayed snag. All snags, but one consisted of the trunk of a dead red fir with a diameter at breast height (DBH) of 44.0 - 121.3 cm. The decayed snag was a small red fir 4.9 m in height with a DBH of 22.3 cm and was in an advanced stage of decay.

In both males and females the mean distance to the nearest nest tree was similar throughout the night; however, females moved significantly greater distances compared to males ($F_{1,607} = 22.53$, $P < 0.0001$; Figure 6). Movement patterns did not show a time effect ($F_{3,607} = 1.60$, $P = 0.2$) and were similar through the four time periods: evening (18:00 – 21:00), night (21:00-24:00), late-night (24:00 – 03:00), and morning (03:00 – 06:00).

Fitness correlates to forest management:

Nine females representing a continuum of naturally occurring body conditions were captured and fit with radio-collars during 2005. These females were followed throughout 2005, as described above, until their offspring emerged from the natal burrow. Their offspring ($n = 14$) were captured and fitted with radio-collars as described above. Offspring were then followed through the remainder of the year to determine their dispersal locations and exploratory behavior.

Offspring from both experimental females (2003 mothers) and natural females (2005 mothers) were used to determine the relationship between maternal body condition and offspring dispersal (Figure 7). Male offspring dispersed ~120m farther than female offspring at any given maternal body condition (Figure 7). Both male (slope = 7.76) and female (slope = 8.35) offspring increased dispersal distance with increasing maternal body condition ($F_{1,19} = 0.1$, $P = 0.7$). Although dispersal distance in relation to maternal body condition did not differ by offspring sex, exploratory behavior showed a sex bias (Figure 8). Mean (slope = 7.6) and maximum (slope = 11.1) male exploratory distances increased with increasing maternal body condition (Figure 8). Female exploratory distance, however, did not vary with maternal body condition (slopes = 0.1 mean; 1.9 maximum; Figure 8). Dispersal distance in male and female

offspring was directly proportional to the mean exploratory distance (slope = 0.97, $r^2 = 0.80$; Figure 9).

Taxonomy and classification of Sierra Nevada chipmunks:

All tissue samples collected during the 2005 field season will be stored in refrigeration until funds are appropriated to run molecular analyses. Data pertaining to the external characteristics of individual chipmunks handled during 2005 will also be stored until molecular analyses have taken place.

COLLABORATION WITH OTHER MODULES

We have initiated collaborative efforts with the vegetation module as well as the fire and fuels module, and will establish collaborative efforts with the spotted owl module over the next year. We have completed rigorous vegetation sampling on all trap grids for use with small mammal habitat associations. Vegetation data were collected in conjunction with the vegetation and fire and fuels modules. The vegetation module has also established a number of weather stations within the mammal trap grids to coordinate specific climate data with our grids. In addition, we will benefit from the remote sensing analyses of the fire and fuels team. Finally, we will initiate a study of California spotted owl diet by working with the spotted owl crew to collect and analyze pellets collected from spotted owl nests throughout the year. Results of our woodrat study will directly benefit the spotted owl module in their development of prey models within the Sierra Nevada. The results of the small mammal study will be available for any of the other modules to use, and will be of particular benefit to the spotted owl team.

CONCLUSIONS

The 2005 calendar year marked the third full year of data collection. We continued to trap all 18 grids that were trapped in 2003 and 2004. We have now completed three years of pretreatment data on the nine experimental grids. We have also added a third year of trapping on the nine habitat grids. We anticipate that the thinning treatments will occur sometime in 2006 and allow us to trap for 2-5 years (2007-2011) of post treatment seasons.

With the budget forecast for 2006, we plan to continue trapping on the nine experimental grids to obtain a third year of pretreatment data for June and October, or if the thinning treatments occur then we will begin post treatment data collection. Thinning on the treatment grids will begin as early as spring 2006. In an effort to increase our flying squirrel sample size we will change our methodology to include stratified habitat sampling for northern flying squirrels throughout the Plumas and Lassen NF. We will also try to bring in a new Master's student to take control of the flying squirrel habitat associations study. We will continue to trap and follow flying squirrels in various habitats throughout the Plumas National Forest.

We will return to the woodrat site and capture new and recapture woodrats from last field season to continue to monitor their activities and habitat use through a second year. We have enough tissue samples from chipmunks and will not continue collecting these from wild chipmunks. Additional studies may be added as opportunities present themselves and may include a descriptive study of the chipmunk species in the study area and the rate of fat development in chipmunks from different forest types.

Forest managers will benefit from these data in being able to more accurately predict the responses of small mammals to forest treatments, and to relate these to the population dynamics of important predator species such as northern goshawk, California spotted owl, and American marten. We have begun to publish the data obtained and expect to continue publishing through the next year. Articles have been submitted for publication to the following journals: Western North American Naturalist, Journal of Mammalogy, and Ecology (see below).

PUBLICATIONS

Wilson, J. A., and Mabry, K. E. Submitted. Trapping rodents in a dangerous world: effects of disinfectants on trap success. *Journal of Mammalogy*

Wilson, J. A., D. A. Kelt, D. H. Van Vuren, and M. Johnson. Submitted. Effects of maternal body condition on offspring dispersal in Golden-Mantled Ground Squirrels (*Spermophilus lateralis*). *Ecology*.

Wilson, J. A., D. A. Kelt, D. H. Van Vuren, and M. Johnson. Submitted. Population dynamics of small mammals inhabiting four forest types in the northern Sierra Nevada. *Western North American Naturalist*.

Copetto, S., D. A. Kelt, D. H. VanVuren, J. A. Wilson, and S. Bigelow. In Press. Habitat associations of small mammals at two spatial scales in the northern Sierra Nevada. *Journal of Mammalogy*.

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.

PRESENTATIONS

Data from the 2003 – 2005 field seasons will be used in the development of 2-3 presentations to the 2006 annual meeting of the American Society of Mammalogists in Amherst, Massachusetts or the Ecological Society of America meetings in Memphis, TN. We anticipate giving presentations on 1. Northern flying squirrel home ranges, and 2. Woodrat home range structure and nest use. To date, the following presentations have been given.

Wilson, J. A., D. A. Kelt, and D. H. Van Vuren. 2005. The effects of maternal body condition on offspring fitness. Presentation to the 2005 American Society of Mammalogis, Springfield, MO.

Mabry, K. E., and J. A. Wilson. 2005. Trap disinfection to reduce hantavirus risk: does it also reduce small mammal trapability? Presentation to the 2005 American Society of Mammalogists, Springfield, MO.

Wilson, J. A., D. A. Kelt, and D. H. Van Vuren. 2005. Effects of maternal body condition on offspring dispersal in golden-mantled ground squirrels (*Spermophilus lateralis*). Presentation to the Ninth International Mammalogical Society, Sapporo, Japan.

PERSONNEL

Fieldwork was coordinated by James A. Wilson, postdoctoral fellow at the University of California, Davis. Principal investigators for the small mammal module are Doug Kelt and Dirk VanVuren, Dept. of Wildlife, Fish, & Conservation Biology, University of California, Davis, and Mike Johnson, John Muir Institute of the Environment, University of California, Davis. Fieldwork in 2005 was conducted by James A. Wilson, Robin Jenkins, Sean Connelly, Holly Robertson, Dan Haggerty, Valerie Godfrey, Stephanie Bergh, Laura Cheney, Kelly Weintraub, Rachael Carson, Deborah Hill, Meghan Edgar, and Amber Gates.

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REFERENCES

- Atsatt, P.R., and T. Ingram. 1983. Adaptation to oak and other fibrous, phenolic-rich foliage by a small mammal, *Neotoma fuscipes*. *Oecologia* 60: 135-142.
- Cameron, G.N. 1971. Niche overlap and competition in woodrats. *Journal of Mammalogy* 52:288-296.
- Carey A.B., S.P. Horton, and B.L. Biswell. 1992. Northern spotted owls: influence of prey base and landscape character. *Ecological Monographs* 62(2):223-250.

- Carraway, L.N., and B.J. Verts 1991. *Neotoma fuscipes*. Mammalian Species 386: 1-10.
- Cranford J.A. 1977. Home range and habitat utilization by *Neotoma fuscipes* as determined by radiotelemetry. Journal of Mammalogy 58(2):165-172.
- English, P.F. 1923. The dusky-footed woodrat (*Neotoma fuscipes*). Journal of Mammalogy 4:1-9.
- Forsman E.D., E.C. Meslow, and H.M. Wight. 1984. Distribution and biology of the spotted owl in Oregon. Wildlife Monographs, 87:1-64.
- Forsman E.D., I. Otto, and A.B. Carey. 1991. Diets of spotted owls on the Olympic Peninsula, Washington and the Roseburg District, Bureau of Land Management. 527p. In: L.R. Ruggiero, A.B. Aubrey, A.B. Carey, and M.H. Huff, technical coordinators. Wildlife and vegetation of unmanaged Douglas-fir forests. United States Forest Service General Technical Report PNW-285.
- Garrison, B.A., R.L. Wachs, J.S. Jones, and M.L. Triggs. 1998. Visual counts of acorns of California black oak (*Quercus kelloggii*) as an indicator of mast production. Western Journal of America Forestry 13(1): 27-31.
- Horton, J.S., and J.T. Wright. 1944. The woodrat as an ecological factor in southern California watersheds. Ecology 25: 341-351.
- Hosmer, D.W., and S. Lemeshow. 2000. Applied logistic regression analysis. Second Edition. John Wiley & Sons, New York, NY, USA.
- Husch, B., C.I. Miller, and T.W. Beers. 1993. Forest mensuration. Krieger publishing, Florida 402 pp.
- Keating, K.A., and S. Cherry. 2004. Use and interpretation of logistic regression in habitat-selection studies. Journal of Wildlife Management 68(4):774-789.
- Linsdale J.M., and L.P. Tevis. 1951. The dusky-footed wood rat; a record of observations made on the Hastings Natural History Reservation. Berkeley, California: University of California Press. 664pp.
- Lynch M.F., A.L. Fesnock, and D.H. Van Vuren. 1994. Home range and social structure of the dusky-footed woodrat (*Neotoma fuscipes*). Northwestern Naturalist 75:73-75.
- McDonald, P.M. 1969. Silvicultural characteristics of California black oak (*Quercus kelloggii* Newb.). U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, CA. Research Paper PSW-53.

- Meserve, P.L. 1974. Ecological relationships of two sympatric woodrats in California coastal sage scrub community. *Journal of Mammalogy* 55:442-447.
- Meyers, M. D., D. A. Kelt, and M. P. North. 2005. Nest trees of northern flying squirrels in the Sierra Nevada. *Journal of Mammalogy* 86:275-280.
- Raphael, M.G. 1988. Long-term trends in abundance of amphibians, reptiles, and mammals in Douglas-fir forests of northwestern California. 23-31pp. In R.C. Szare, K.E. Severson, and D.R. Patton, editors. Proceedings of the symposium of the management of amphibians, reptiles, and small mammals in North America. Forest Service General Technical Report RM-166.
- Sakai H.F., and B.R. Noon. 1993. Dusky-footed woodrat abundance in different-aged forests in northwestern California. *Journal of Wildlife Management* 57(2):373-382.
- Sakai H.F., and B.R. Noon. 1997. Between-habitat movement of dusky-footed woodrats and vulnerability to predation. *Journal of Wildlife Management* 61(2):343-350.
- SAS Institute, Inc. 2006. Statistical analysis system (SAS) user's guide: statistics, version 8 SAS Institute Inc. Clay, North Carolina 1686pp.
- Stokes, M.A., C.S. Davis, and G.G. Koch. 2001. Categorical data analysis using the SAS system. Second Edition. John Wiley & Sons, New York, NY, USA.
- Vestal, E.H. 1938. Biotic relations of the woodrat (*Neotoma fuscipes*) in the Berkeley Hills. *Journal of Mammalogy* 19: 1-36.
- Weigl, P. D., and D. W. Osgood. 1974. Study of the northern flying squirrel, *Glaucomys sabrinus*, by temperature telemetry. *American Midland Naturalist* 92:482-486.
- Willy, A.G. 1985. The habitat associations of the dusky-footed woodrat (*Neotoma fuscipes*) in Marin County, CA. M.S. Thesis, University of California Berkeley, CA.

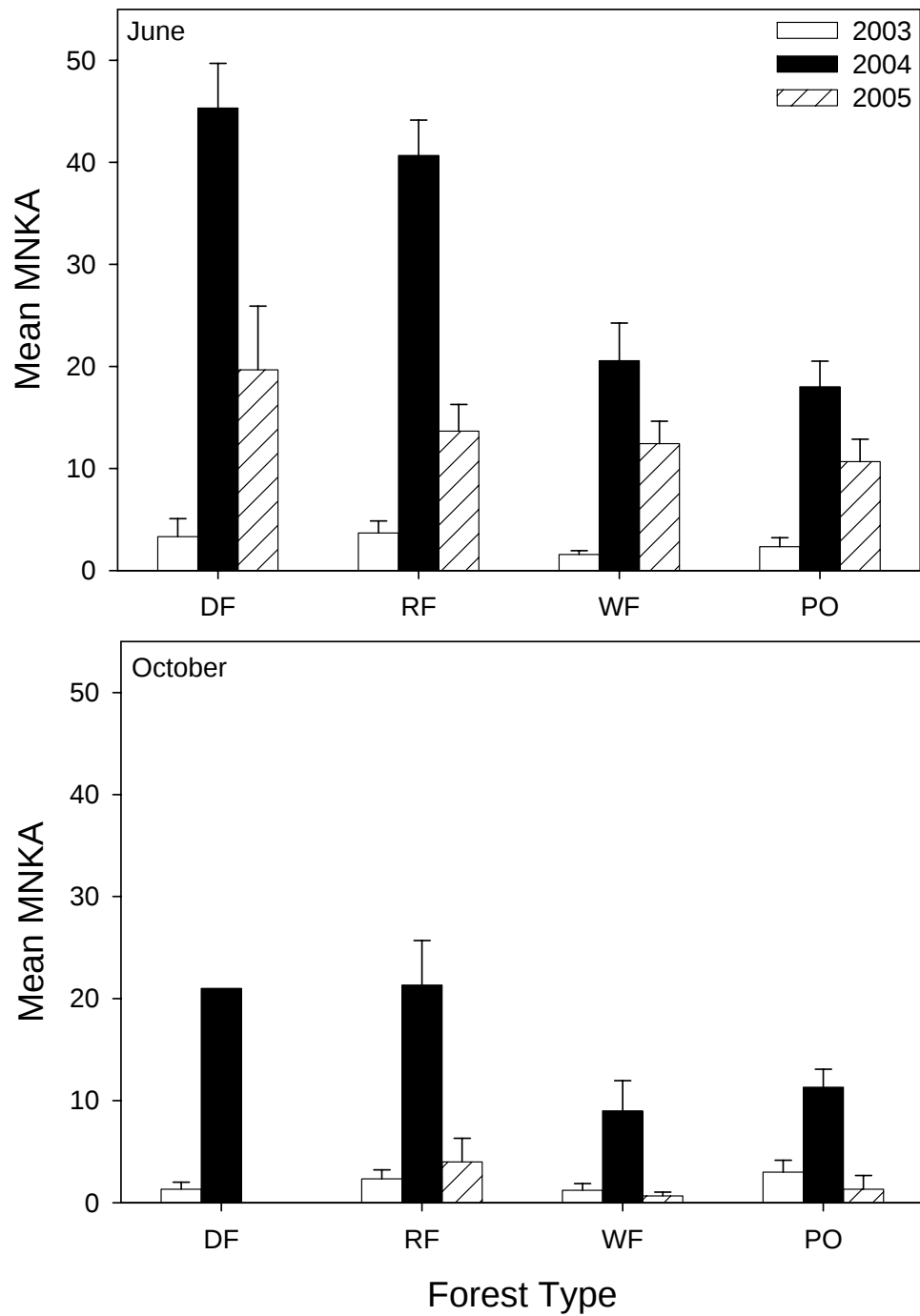


Figure 1. Mean minimum number known alive (MNKA) of *Peromyscus maniculatus* in June and October. Forest type is Douglas fir (DF), red fir (RF), white fir (WF), and ponderosa pine (PO).

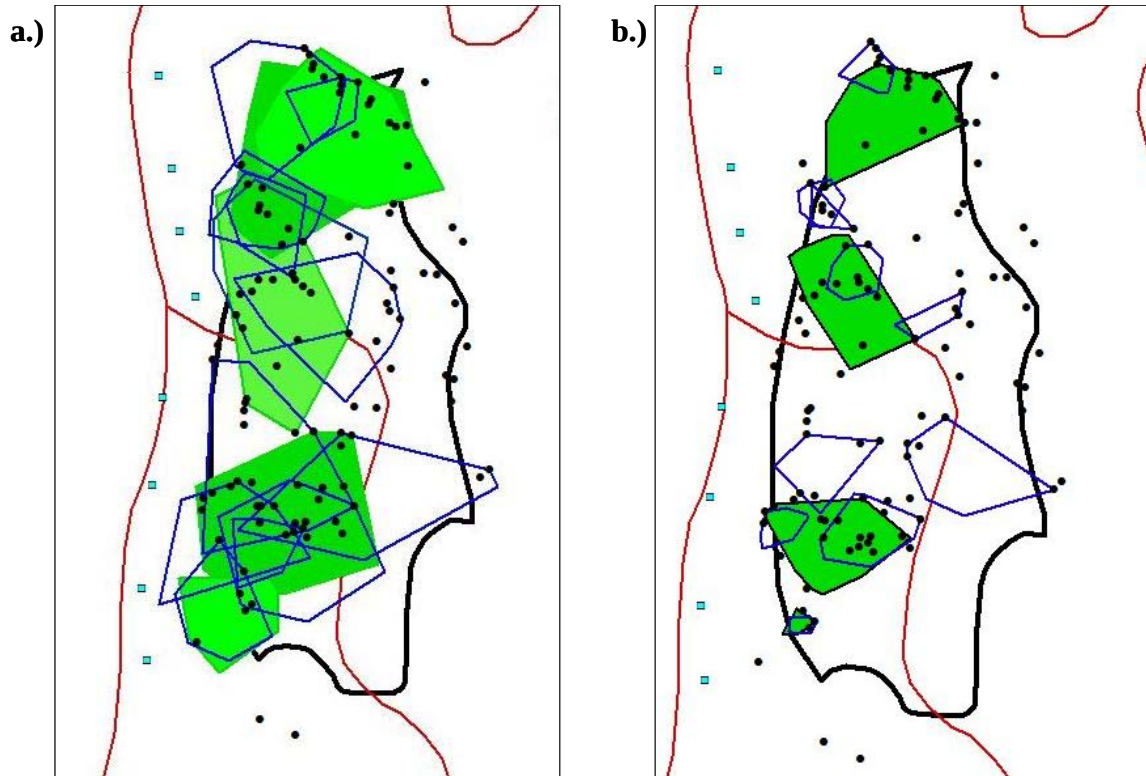


Figure 2. Examples of a) home range overlap of 12 female and 5 male woodrats and b) core area overlap of 10 female and 4 male woodrats at Shrub in 2005.

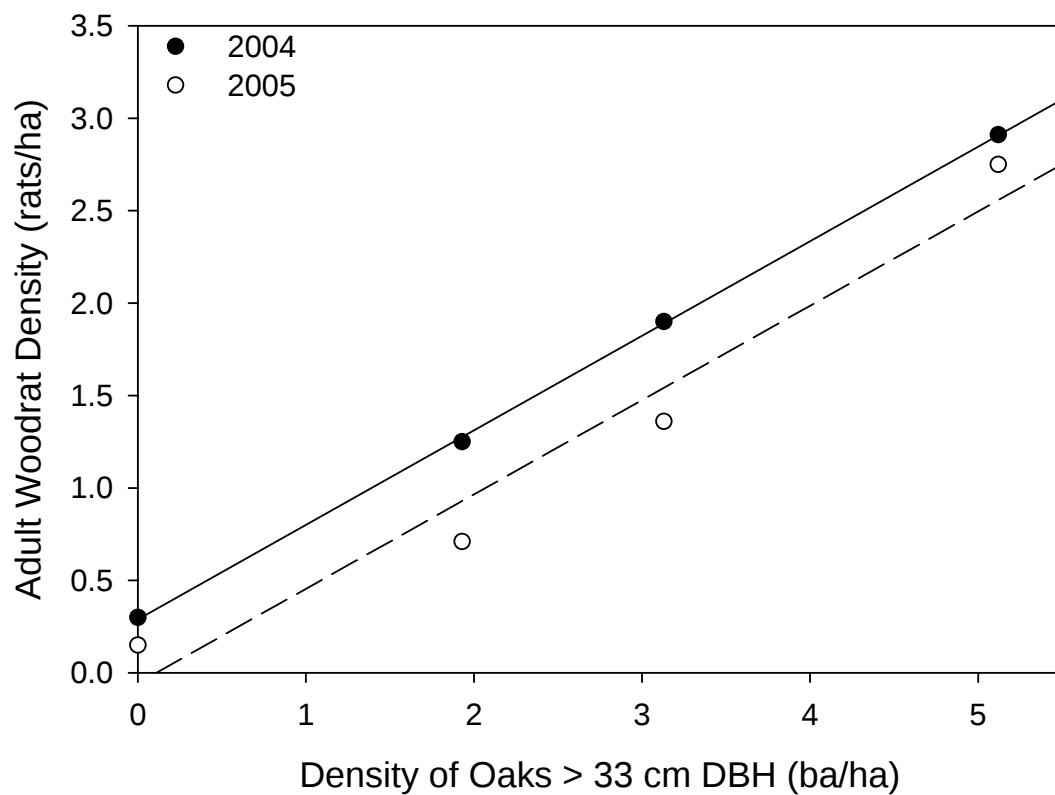


Figure 3. Abundance of adult woodrats in relation to Black Oak (*Quercus kelloggii*) basal area. Only oaks > 33 cm diameter at breast height (DBH) were counted.

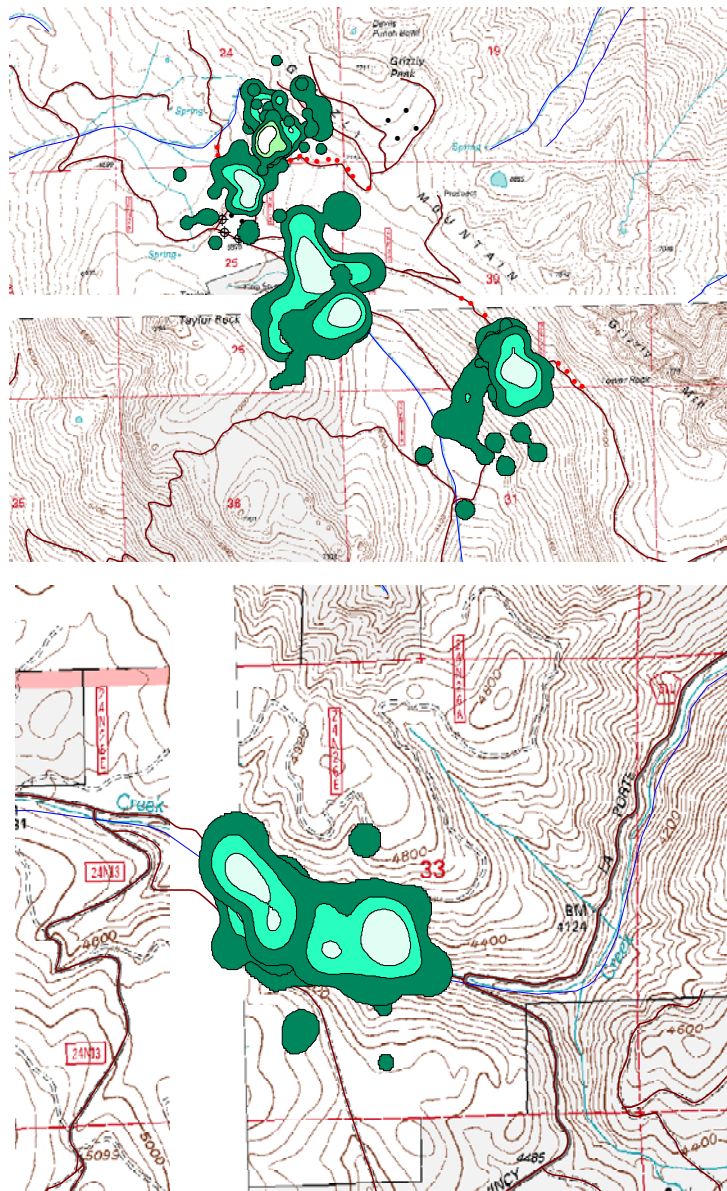


Figure 4. Location and distribution of 14 flying squirrel home ranges inhabiting red fir (top) and mixed conifer (bottom) forests. Home ranges represent 95% (dark green), 75% (med green), and 50% (light green) kernel core use. Considerable overlap exists among the home ranges.

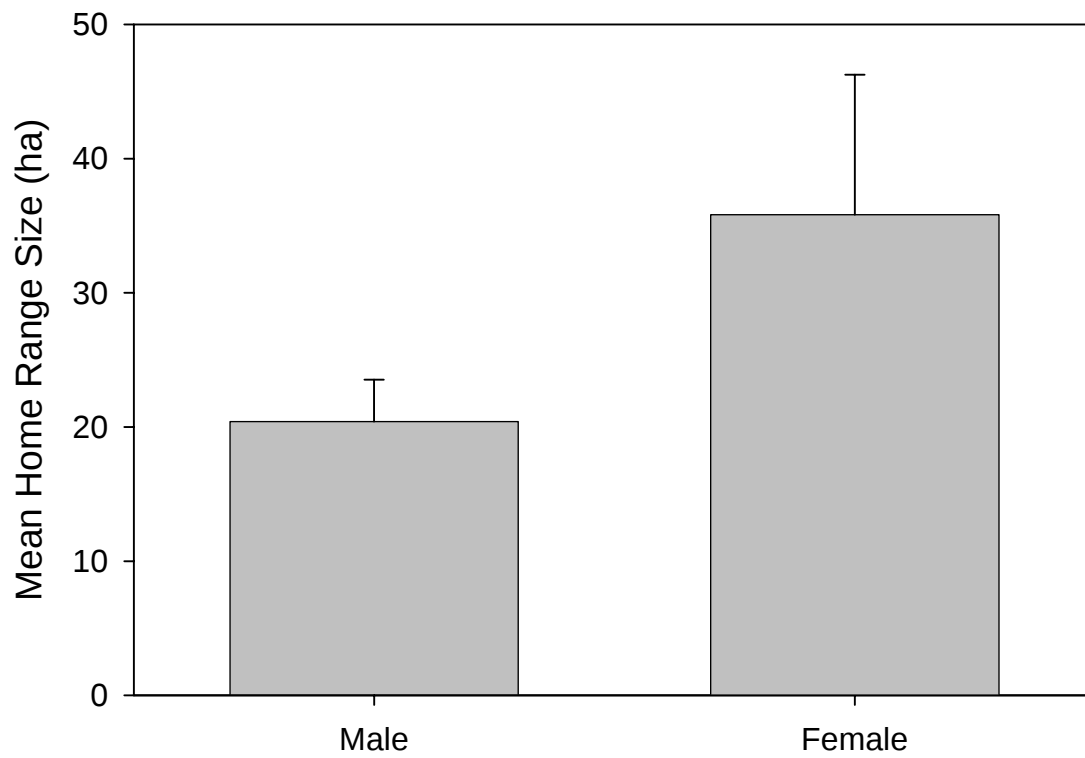


Figure 5. Mean home range size (ha) of male and female northern flying squirrels in the northern Sierra Nevada. Mean home range size represents the 95% adaptive kernel estimates.

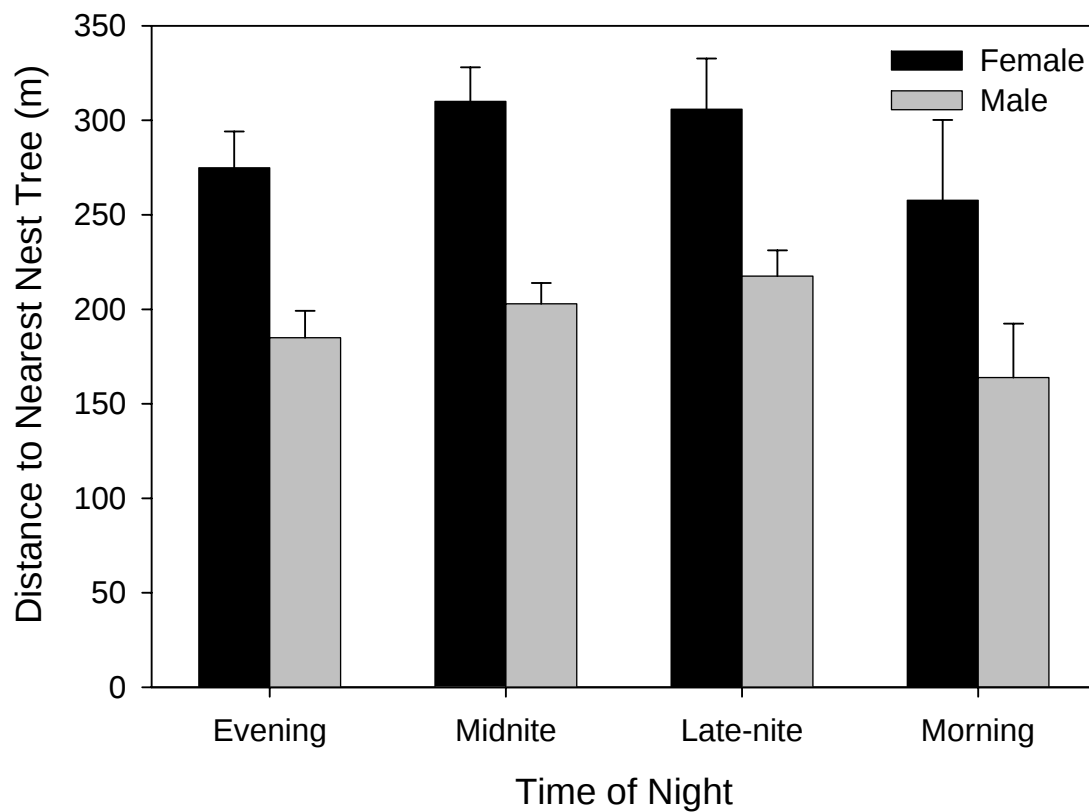


Figure 6. Nocturnal movement patterns of northern flying squirrels represented as distance to the nearest known nest tree. Only locations between 18:00 and 06:00 were used.

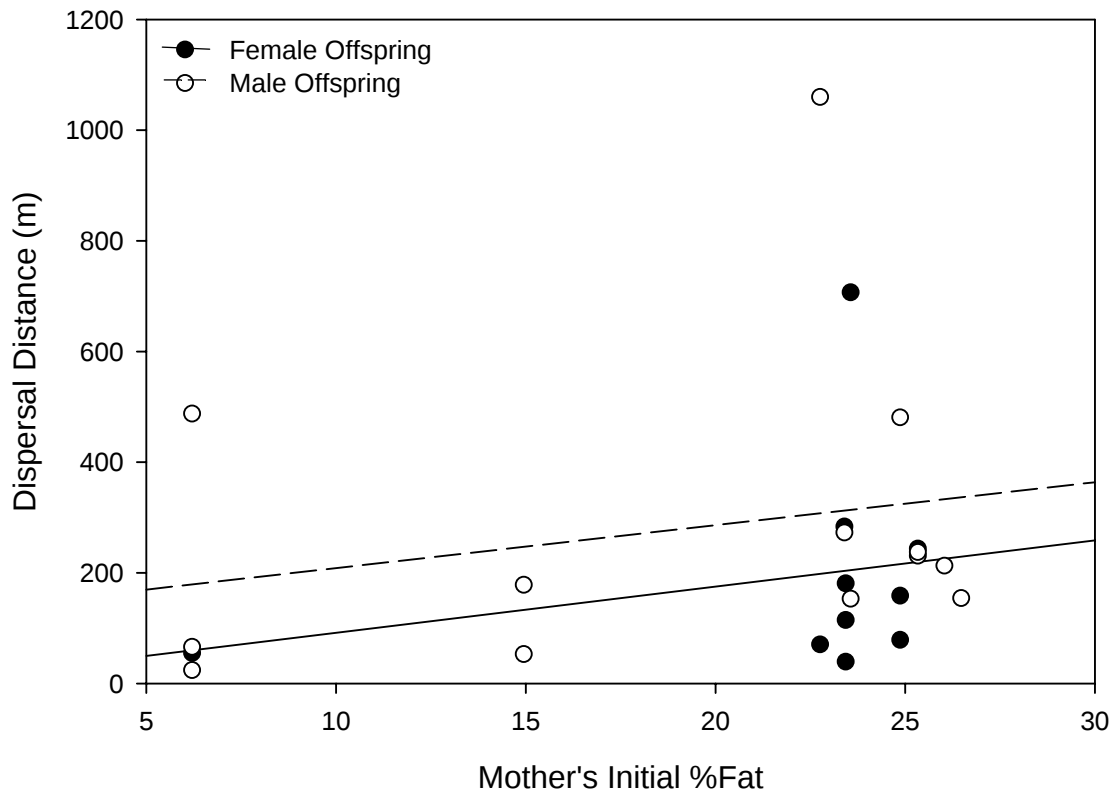


Figure 7. Dispersal distance (m) in relation to standardized maternal body condition as measured by total body electrical conductivity (ToBEC). Mother's initial % fat was standardized to % fat on June 11, the earliest capture date.

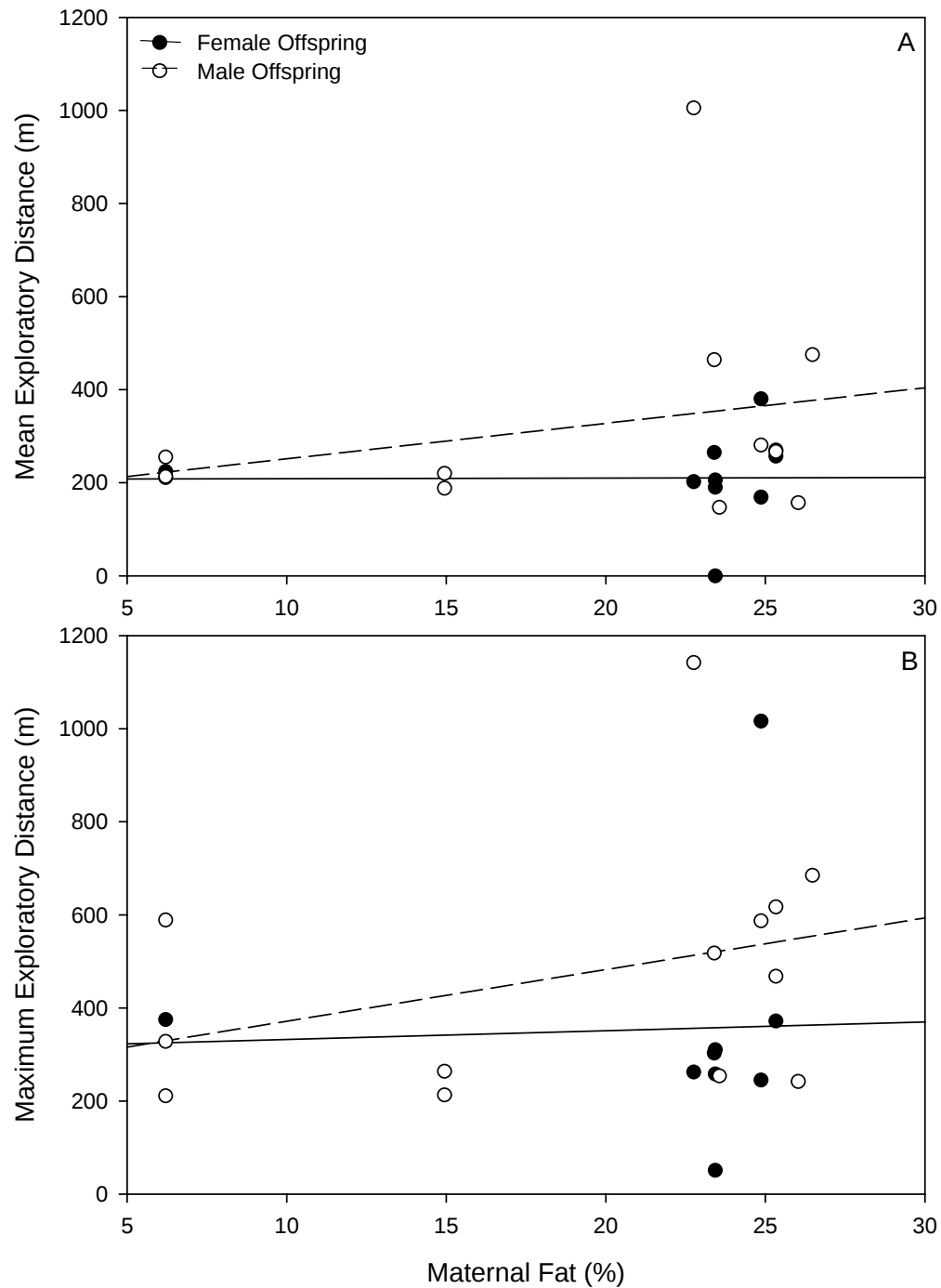


Figure 8. Mean (A) and Maximum (B) exploratory distances for male (open circle, dashed line) and female (solid circle and line) offspring in relation to standardized maternal body condition. Offspring locations more than 1 maternal home range radius were considered as exploratory.

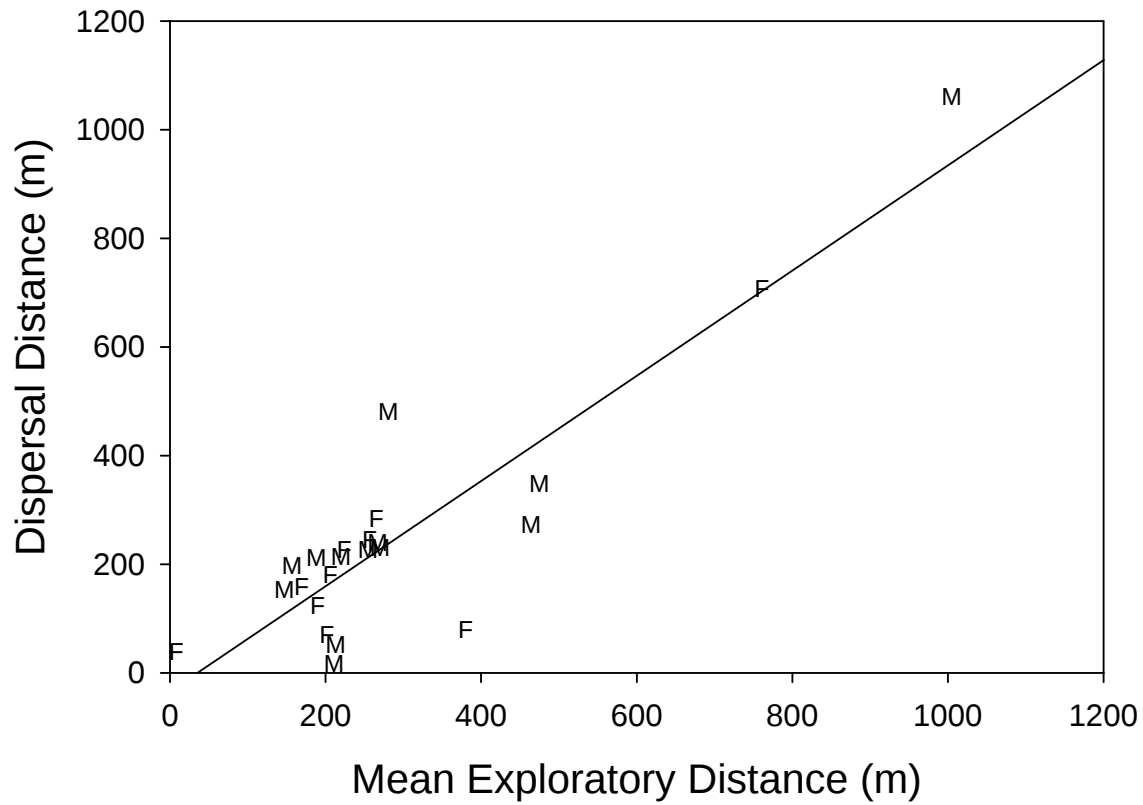


Figure 9. Relationship between mean exploratory distance and post-natal dispersal in male (M) and female (F) golden-mantled ground squirrel offspring.

Table 1. Description of habitat variables measured in 4 m radius plots at all woodrat house and random points. Values for variable categories are in the form of counts (stem density and dead woody material), percent (ground cover and canopy closure), and degrees (slope).

Variable	Description
Stem Density	
High Shrub	Woody stems > 1 m tall and $\leq$ 5 cm DBH
Low Shrub	Woody stems < 1 m tall, excluding mat vegetation
Tree	Woody stems > 5 cm DBH
Dead Woody Material	
Log	Downed dead wood > 1 m long and > 5 cm diameter
Snag	Standing dead wood > 5 cm DBH and 1.3 m tall
Stump	Standing dead wood ? 10 cm diameter and 0.1 - 1.3 m tall
Ground Cover	
Mat Shrub	Trailing, near ground surface (< 0.3 m tall), woody stem cover
Rock	Exposed rocks and stones
Bare Ground	Exposed soil
Litter	Dead leaves, pine needles, and wood chips
Canopy Closure	Percent closed at eye-level (1.7 m)
Slope	Degree of surface decline/incline

Table 2. Number of individuals captured on each site during the 2005 field season. Sites 1-9 were established for use in the thinning experiment. Habitat types are white fir (WF), red fir (RF), Douglas fir (DF), and ponderosa pine (PO). Incidental species were captured on a single occasion and not recaptured. All sites were only trapped in June and October during 2005.

Code	Site	Habitat	<i>Peromyscus</i>		<i>Neotoma</i> <i>fuscipes</i>	<i>Tamias</i>		<i>Microtus</i> <i>longicaudus</i>	<i>Spermophilus</i>		<i>Tamiasciurus</i> <i>douglasii</i>	<i>Glaucomys</i> <i>sabrinus</i>	Incidental
			<i>boylii</i>	<i>maniculatus</i>		<i>quadrimaculatus</i>	<i>senex</i>		<i>beecheyi</i>	<i>lateralis</i>			
1	Triangle	WF		18			11						b
2	Cabin	WF		11			12						a, b
3	Ripper	WF		9			2						b
4	Gimp	WF		6					1			1	b
5	No Name	WF	2	26	1		1				1	1	b, d
6	TeePee	WF		4		2	3	1			2		b
7	Black Oak	WF	2	12		3							
8	Nogo	WF	2	12		2	1					1	
9	View	WF	3	18	1	1	3						
10	Greenbottom	RF	1	24		15	26	1		43			
11	Gulch	PO		15	3				2				b
12	Dogwood	DF		31		1	12		1				b
13	Boa	DF		12			9		2				
14	Mono	RF	3	13		14	27			22		1	
15	Swarm	PO	1	9									
16	Steep	DF	4	15	3	4	10		2	3			a, b, c
17	Ralph	RF	3	12		13	43			12			b
18	Oasis	PO		12									
Total			21	259		55	160	2	8	80	3	4	

Incidental captures: Snowshoe hare (a), Shrew (b), Striped Skunk (c), gopher (d)

Table 3. Density of adult woodrats (rats/ha) at each of the study sites in 2004 and 2005. House density did not change between years.

Site	House Density	Woodrat Density	
		2004	2005
Shrub	15.8	2.9	2.8
Oasis	14.6	1.9	1.4
Gulch	2.3	1.3	0.7
Black Oak	1.2	0.3	0.1

Table 4. 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.

Squirrel	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	A	103	NA	NA	NA
F3	F	A	117	1	35.5	63.4
M4	M	A	75	3	18.8	17.2
M4	M	A	75	3	19.5	24.8
M6	M	A	91	NA	NA	NA
F4	F	A	93	2	26.7	35.5
M7	M	A	96	NA	NA	NA
M8	M	A	104	2	24.8	39.4
M9	M	J	78	3	4.5	4.7
M10	M	A	96	2	6.9	7.8
F5	F	A	99	1	25.1	31.4
M11	M	A	100	3	15.2	22.8
M12	M	A	73	NA	NA	NA
F6	F	A	141	NA	NA	NA
F7	F	A	NA	1	8	13.0
M13	M	A	139	1	12.7	11.7