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University of Nevada, Las Vegas

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ECOLOGY AND GROWTH OF TAMIAS PALMERI AND TESTING OF A
PROTOCOL TO MONITOR HABITAT RELATIONSHIPS

by

Christopher Lowrey
Bachelor of Science
Humboldt University
Arcata, California
1997

A thesis submitted in partial fulfillmen
t of the requirements for the

Master of Science Degree
Department of Biology
College of Sciences

Graduate College
University of Nevada, Las Vegas
August 2002
The Thesis prepared by

Christopher Lowrey

Entitled

ECOLOGY AND GROWTH OF TAMIAS PALMERI AND TESTING OF A PROTOCOL TO MONITOR HABITAT RELATIONSHIPS

is approved in partial fulfillment of the requirements for the degree of

Master of Science

Examination Committee Member

Dean of the Graduate College
ABSTRACT

Ecology and Growth of *Tamias palmeri* and Testing of a Protocol to Monitor Habitat Relationships

By

Christopher Lowrey

Dr. Brett Riddle, Examination Committee Chair
Professor of Mammalogy
University of Nevada, Las Vegas

The ecology of *Tamias palmeri* is investigated. Presence-absence and relative abundance of *T. palmeri* are related to principle component scores of habitat variables using logistic regression and multiple linear regression, respectively. Relative abundance of *Tamias palmeri* estimated with live capture-recapture was positively correlated with shrub cover and negatively correlated with slope. Timing of emergence from dens by juveniles was earlier and weights of juveniles were greater in ravine areas as compared to upslope areas. Track plates were not correlated with trap captures. Track plate success was not correlated with habitat variables. The results of this study were used to build a GIS model to predict potential habitat for *T. palmeri*. Shrub cover, lower slopes, and access to water are believed to be important habitat variables for *T. palmeri*.
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ACKNOWLEDGEMENTS

I humbly give a heart-felt thank you to Mom and Dad, brothers Craig, Darren, and sister-in-law Angie for their generous support throughout my college years. I would also like to sincerely thank Dr. Brett Riddle, Dr. Diane Wagner, Dr. Daniel Thompson, and Dr. Richard Orndorff for their essential guidance, generosity, and contributions to this manuscript. I further extend my most sincere appreciation to Chiaki Brown and Nicola Ventolini for their dedication to the field data collection.
CHAPTER 1

BACKGROUND, HYPOTHESES, AND OBJECTIVES

Species living in heterogeneous environments are confronted with a range of habitat choices that may lead to uneven distributions of individuals (Adler 1986, Morris 1987). Which habitat variables animals respond to may depend on spatial or temporal scale (Bowers and Matter 1997). Early attempts at understanding distribution patterns focused on microhabitat use over short periods of time and paid little attention to the surrounding habitat matrix (Hatfield 1940, Hirth 1959). More recent species distribution work has focused on landscape level metapopulation models where patches of suitable habitat are surrounded by areas of unsuitable habitat (Bowers and Matter 1997, Moilanen and Hanski 1998). Both approaches have inherent limitations. Focusing on microhabitat use disregards the effects that surrounding habitat may have on species distribution and behavior. Focusing on landscape level habitat patches disregards that areas often occur as a continuum of greater to lesser suitability, and may not occur as discrete entities as many metapopulation models assume (Hanski et al. 2000). How animals respond to the same habitat variables at different scales remains an important question in ecology (Bowers and Matter 1997). The first step in answering this question is addressing to what degree subpopulations vary in ecologically relevant variables across a heterogeneous landscape.
Animal distributions and densities may change significantly across habitat types (Terborgh 1971, Patterson et al. 1989). That species richness declines with increasing elevation has been demonstrated for many taxa and is proposed as a general pattern (Rahbek 1997, Hofer et al. 1999). However this decline is not necessarily continuous with increasing elevation, and non-linear patterns have been found in small mammals, birds, and reptiles (Terborgh 1985, Patterson et al. 1989, Rahbek 1997, Hofer et al. 1999). Plant species composition, vegetation structure, and topography appear to explain a great deal of variation in population densities of many small mammals (Armstrong 1979, Bonvicino et al. 1997, Sureda and Morrison 1999). Sharples (1983) recognized that distribution of the genus *Tamias* is correlated with major vegetation zones that corresponded to elevation and aspect differences. Life-history strategies (Bronson 1979), ambient temperatures, and precipitation are also known to affect distributions of small mammals (Zammuto and Millar 1985).

Animal distributions may also be associated with microhabitat variables (Adler 1987, Doyle 1990, Sureda and Morrison 1999). Microhabitat heterogeneity has been shown to be particularly important for small mammals (Levins 1962, Bowers 1995). Selection or avoidance of particular microhabitats by small mammals has been associated with cover, predation risk, inter and intra-specific interactions, and resource availability (Mares et al. 1982, Kotler and Brown 1988, Bowers 1995, Devenport et al. 1998). Specific microhabitat variables are difficult to generalize across broad geographic areas.
however, and must often be established independently for species within unique or isolated habitats (Doyle 1990, Carey 1995).

**Population estimates / Monitoring**

The monitoring of wildlife populations is an essential aspect of any wildlife conservation effort, and monitoring methods must dependably estimate wildlife population trends over time and space (Lancia et al. 1994). Assessing changes in local populations is key to evaluating the efficacy of management practices and documenting compliance with regulatory requirements (Gibbs et al. 1998).

The goals of managing natural populations are frequently expressed in terms of population density, and managers interested in conservation often use abundance estimates as a means for assessing the health of animal populations (Sinclair 1991). An estimate of population size at one point in space and time is often of little value, however, and provides less information about the status of a species than is commonly thought (Nichols and Pollock 1983). Repeated estimates of relative population size, across different areas simultaneously or across time in the same place, are essential to estimate abundance variability. Such information allows comparison of abundance estimates among habitats and across multiple years, and may allow identification of correlated environmental variables (Skalski and Robson 1992).

Monitoring changes in population size provides valuable information on the viability of natural populations. A population maintains viability through recruitment of new individuals via reproduction and immigration. However the high cost of directly measuring long-term reproductive success and dispersal dynamics is not financially reasonable for most wildlife managers. The most cost effective way for managers to
estimate trends in the viability of natural populations therefore is the monitoring of changes in abundance across space and time. Detection of precipitous decreases in abundance may indicate declining population viability, thus triggering an appropriate management prescription.

Monitoring of natural populations further has strong legal merits. For species that are endangered, threatened, or otherwise of concern, the legal basis for monitoring is especially acute. The requirements upon federal agencies from acts such as the National Environmental Policy Act (NEPA) or the Endangered Species Act (ESA) are significant in terms of cost, personnel, and resources. Failing to properly comply with these requirements inflates these costs beyond any reasonable budget, and delays the implementation of needed management practices necessary for conservation (C. Tomlinson, Z. Marshall, pers. comm.).

Monitoring of natural populations can be performed via census, visual observation, or some other form of indirect estimation. Taking a census, or complete count of all animals, is an unrealistic goal for most wild populations. For mammals, visual observations are difficult since mammals are often nocturnal, and rarely occur in sufficient numbers to make this technique feasible. Therefore, correlatives of actual densities, or index techniques, are used almost exclusively in mammal population monitoring (Caughley 1977, Gibbs et al. 1998). Indices of relative population size are appropriate for addressing most questions regarding differences in density over time or across landscapes (Foresman and Pearson 1998, Kurki et al. 1998). These indices are based on the assumption that a fixed amount of searching effort will always locate a fixed
proportion of the population. This implies that the index is proportional to the density, and the rate of proportionality is constant (Schwarz and Seber 1999).

Trapping data have been used to answer questions about wildlife populations for many decades (Le Cren 1965). Trapping is a direct counting method and is therefore preferred to other indices when a census is not possible. Mark-recapture trapping techniques are the most common, and are classified into those suitable for closed or open populations. In mark-recapture studies, each animal is uniquely marked and released back into the population creating a complete capture history by the end of the study. Batch marks, where animals are not uniquely marked, do not provide unique capture histories and should be avoided, except perhaps for use in simple Lincoln-Peterson techniques (Otis et al. 1978). Enumeration methods, otherwise known as ‘minimum number known alive’ counting methods, are biased towards underestimation of population sizes and therefore are also not recommended (Nichols and Pollock 1983).

The closed population model is commonly used to estimate small mammal population sizes (Greenwood et al. 1985, Menkens and Anderson 1988). Because closed population models do not allow for fluctuation in population size during a sampling session, they are normally conducted over short periods of time (4-8 days). The most common of these is the Schnabel method (Schnabel 1938). This method is based on the assumption that each individual has an equal probability of capture, but that these probabilities can vary at each sampling time (time heterogeneity). Closed population models are thought to be robust against random movement into or out of the trapping area (Kendall 1999). Closed population models are biased, however, if capture probabilities of
individuals are heterogeneous (e.g. high frequency of trap-happy or trap-shy animals in the population) (Huggins 2001).

An open population model assumes population size is fluctuating naturally and is therefore more realistic than closed models. The most important open population model is the Jolly-Seber estimator (Jolly 1965, Seber 1965). This model can be used to estimate population size and, unlike the closed models, survival and number joining the population (births or immigration). The additional ability of the open population model to estimate survival rates is important. Comparisons of survival rates in addition to abundance may lead to more direct inference about the importance of a particular habitat, and both researchers and managers have begun to emphasize this approach (Lebreton et al. 1992).

Traditional capture-recapture methods present researchers with inherent problems, however (Sharples 1983, Belk et al. 1988, Dobson 1995). The effectiveness of mark-recapture techniques to determine actual population sizes is not well understood (Lefebvre et al. 1982). Violations to the underlying assumptions, such as equal probability of capture, are a common occurrence and can lead to serious error in abundance estimates (Nichols and Hines 1984). The effects of learned trap response, in which animals become more or less likely to be trapped, or use of different trap configurations or types of traps among studies, may also result in a high degree of experimental variability (Zarnoch 1979, Schroder 1981, O'Farrell 1994). Mark-recapture techniques require significant training and resources, and subject investigators to injury or exposure to diseases. Trapped animals are subject to stress, injury, or death from the marking and repetitive handling required of these techniques (Krebs et al. 1995, Mills
1995). This problem is especially acute in studies of endangered, threatened, or species otherwise of concern.

**Track Plates**

As an alternative to trapping, track plate techniques developed to circumvent these problems, are used as an index to estimate population abundance (Marten 1972, Becker et al. 1998, Drennan et al. 1998, Foresman and Pearson 1998, Hubbs et al. 2000). Track plates (also known as track boards or smoke plates) are an index-based to measure population attributes based on identification of species by their footprints. Track plates were found to be nearly as powerful as mark-recapture techniques in detecting differences in abundance among plots, but were considerably less powerful in detecting differences between seasons (Drennan et al. 1998). Compared to mark-recapture efforts, track plates were less expensive, less labor intensive, required less training of the investigator, and were easier to deploy in the field than traps (Drennan et al. 1998, Foresman and Pearson 1998, but see Carey 1991). The use of track plates allows observation of natural daily foraging and movement behavior, which is useful for understanding small mammal ecology. The use of track plates eliminates risks to the investigator associated with handling animals infected with disease, and eliminates risk of injury or death to the animal (Krebs et al. 1995, Mills et al. 1995).

The relationship between the index and the estimated population size is often assumed to be linear. However validation studies to address this assumption are rare. Lacking such information, an index validation study should be conducted in areas where abundance can be estimated. Such a validation study should be replicated across multiple sites, and repeated in areas with different population sizes.
Study Area

The alpine mountain ranges are significant contributors to the biodiversity of the arid southwest of North America. Due to their isolation from other like environments, these areas are refugia for fauna and flora that occur nowhere else in the world. The Spring Mountain Range in southern Nevada is one such geographically isolated boreal and montane refugium. The Spring Mountain Range is located in the northern Mojave Desert in southern Nevada northwest of Las Vegas (Fig. 1). The range is approximately 110km long by 45km wide and has a northwest orientation. Steep, rocky slopes and high limestone cliffs characterize this range. There are over 10 peaks above 3,300m, the highest being Mt. Charleston at 3,632m. The Spring Mountains are completely isolated by the surrounding desert floor that is just above 700m in elevation. This range has an arid to semi-arid climate influenced by a rain shadow created by the Sierra Nevada to the west. Annual precipitation is typically less than 13cm in the lower areas and as high as 71cm in the higher elevations with the east side of the range receiving the majority of rain and snow. The upper slopes are further subject to extreme seasonality with heavy snow cover 5-7 months of the year. Mean temperature is 10°C at 2000m.

The boreal/montane biota of the Spring Mountains was isolated by lowland deserts and woodlands near the late Pleistocene/early Holocene, about 11,000-8,000 years ago (Grayson 1993). The climate during the early part of the latest (Wisconsinan) glacial episode was significantly cooler and wetter than it is today, supporting perennial streams and marshes in the valleys, and providing ecological continuity with the surrounding ranges.
Figure 1: Map of Nevada showing the Spring Mountain Range. Color coding indicates elevation. Hotter colors are lower and cooler colors are higher in elevation.
These conditions persisted until about 8,000 years ago, when the cool, moist regime disappeared, the water table dropped 25m, and something close to present conditions arrived. Vegetation communities in the Spring Mountains were further reorganized as plants responded to the unique conditions of the range (Grayson 1993, Brown and Lomolino 2000).

There are four distinct vegetation types distributed along an elevation gradient from 2200m to timberline, ca. 3400m (Nachlinger and Reese 1996). These habitat types are dominated by communities of Pinion pine-juniper (*Pinus monophylla – Juniperis osteosperma*), occurring from 1800m to 2500m, ponderosa pine (*Pinus ponderosa*), occurring from 2400m to 2700m, white fir (*Abies concolor*), occurring from 2700m to 2900m, and bristlecone pine (*Pinus longaeva*), occurring above 2800m (Nachlinger and Reese 1996) (Fig 2). Limber pine (*Pinus flexilus*) occurs in the ecotone between fir and bristlecone, though rarely as pure stands. Thirteen species of plants comprise 95% of the vegetation abundance above 2500m (Table 1). Vegetation is significantly heavier on the northern facing aspects of the range where they are relatively protected from the drying effects of direct sunlight.

There are over 150 springs within the Spring Mountain range. Most of these are ephemeral and exist largely as wet ground though a few discharge running water all year. The water to these springs is supplied largely by rainwater and melting snow (Hershey 1989). These springs provide the only sources of water in an otherwise dry landscape and are therefore important biological resources (Sada and Nachlinger 1996).
Figure 2: Vegetation zones within the Spring Mountains, NV. 2000. Vegetation contours adapted from Nachlinger and Reese (1996).
Table 1. Common plant species occurring above 2500m within the Spring Mountains, NV. 2001.

<table>
<thead>
<tr>
<th>Common name</th>
<th>Scientific name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ponderosa pine</td>
<td><em>Pinus ponderosa</em></td>
</tr>
<tr>
<td>White fir</td>
<td><em>Abies concolor</em></td>
</tr>
<tr>
<td>Bristlecone pine</td>
<td><em>Pinus longaeva</em></td>
</tr>
<tr>
<td>Limber pine</td>
<td><em>Pinus flexilus</em></td>
</tr>
<tr>
<td>Rocky mountain juniper</td>
<td><em>Juniperis scopularum</em></td>
</tr>
<tr>
<td>Mountain mahogany</td>
<td><em>Cercocarpus ledifolius</em></td>
</tr>
<tr>
<td>Quaking aspen</td>
<td><em>Populus tremuloides</em></td>
</tr>
<tr>
<td>Currant</td>
<td><em>Ribes cereum</em></td>
</tr>
<tr>
<td>Elderberry</td>
<td><em>Sambucus</em></td>
</tr>
<tr>
<td>Mountain maple</td>
<td><em>Acer glabrum</em></td>
</tr>
<tr>
<td>Yellow rabbit brush</td>
<td><em>Chrysothamnus viscidiiflourus</em></td>
</tr>
<tr>
<td>Dwarf juniper</td>
<td><em>Juniperis communis</em></td>
</tr>
<tr>
<td>Wood wild rose</td>
<td><em>Rosa woodsii</em></td>
</tr>
</tbody>
</table>

Presently there are approximately 22 mammalian species (Hall 1995) and 30 commonly found species of birds (Austin 1967) within the Spring Mountains above 2000m. There are 26 known endemic species on the Spring Mountains (15 plants, seven butterflies, one mammal, one ant, and two snails).

The Federal government manages most of the Spring Mountains as part of the Toiyabe National Forest. The U.S. Forest Service manages elevations above 1200 – 1500m and the Bureau of Land Management manages lower elevations. Most areas above 2500m around Mount Charleston are designated wilderness areas. All Forest Service lands in the Spring Mountains were designated as a National Recreation Area in 1993.

Human activity is concentrated on the east side of the range. Tourism reaches over 200,000 visitors a year, mainly in the two largest canyons (Kyle and Lee). There are seven campgrounds, 16 picnic areas, and one ski resort. Elk, black-tailed deer, grouse and quail are hunted within their respective seasons.
There are approximately 24 species and 69 subspecies in the genus *Tamias*. The subgenus *Neotamias*, in North America (Bergstrom and Hoffman 1991). Of these, 22 occur west of the Rocky Mountains, and range from sea level to above the timberline. Species of *Tamias* are morphologically very similar to each other, making field identification difficult. Historically, the shape of the baculum has provided the most reliable characters for identification of species within *Tamias*. Baculum shape separated *Tamias* into 5 (Howell 1929) or 3 (White 1953) general taxonomic groups. Levenson et al. (1985) split *Neotamias* into 5 taxonomic groups based on electrophoretic data. These divisions have recently been revised by molecular analyses to create 7 general groups of more closely related species (Piaggio and Spicer 2000). Piaggio and Spicer (2000) regard *T. palmeri* as a subspecies of *T. umbrinus*.

Parapatric distributions are the most common pattern among chipmunks, with sympatry usually occurring only in narrow overlap zones (Bergstrom and Hoffman 1991). Most mechanisms maintaining parapatric distributions are thought to be behavioral or physiological. Heller (1971) found that *T. amoenus* aggressively excludes *T. minimus* from more heavily forested habitats. Bergstrom (1992) concluded that parapatry between *T. umbrinus* and *T. minimus* is maintained by both aggressive behavior and susceptibility of *T. umbrinus* to botfly parasitism. Physiological constraints, specifically lack of adaptations to heat, prevent *T. amoenus* from colonizing the dryer areas occupied by *T. minimus* (Heller and Poulson 1972). Brown (1971) concluded that interspecific aggression and the ability of the subordinate *T. umbrinus* to utilize features of the habitat to escape from the dominant *T. dorsalis* explained the observed narrow
overlap between these two species. Among sympatric species, Chappell (1978) concluded from his research in the Sierra Nevada that *T. speciosis* aggressively excludes *T. amoenus* and *T. minimus* from more heavily forested areas where *T. speciosis* is physiologically restricted. Meredith (1972) found differences in habitat choice, but not interspecific aggression, explained sympatric distributions of *T. amoenus* and *T. townsendii*.

Tamias dispersal patterns are believed to be similar to other ground squirrels. In most *Tamias* species, the dispersing population is strongly male-biased and there is a tendency for dispersers to immigrate into similar habitats, suggesting affinity for the natal habitat (Olson and Van Horne 1998). Permanent dispersal away from the natal area generally occurs within a few days and dispersers generally establish territories close to the natal range (Sun 1997). Loew (1999) found proximal causes of dispersal in *T. striatus* to be the behavioral exclusion of juvenile males by adult females. Holekamp (1986), however, found dispersal in *Spermophilus beldingii* to be correlated with the attainment of a particular body mass or body composition.

Chipmunk species cache seeds of several plant species which represents an important mechanism of seed dispersal (West 1968, Abbott 1970, Vander Wall 1994.) Vander Wall (1994) found that yellow-pine chipmunks (*T. amoenus*) cached or scatter-hoarded up to 88% of antelope bitterbrush (*Purshia tridentata*) seeds, an important food plant for wild browsers (Nord 1965). The burial of seeds, and subsequent neglect of some caches, resulted in a higher probability of seedling establishment than seeds that were not cached. West (1968) found that 90% of bitterbrush seedlings and 15% of ponderosa pine seedlings were established after caching by yellow-pine and Townsend's chipmunks.
Dispersal by abiotic agents were insufficient to account for significant recruitment of seedlings in fir-pine forests (Vander Wall 1994).

*Tamias palmeri*

*Tamias palmeri* is a high elevation species endemic to the Spring Mountain range of southern Nevada. *T. palmeri* occurs across at least 3 habitat types from near 2300m to the timberline (ca. 3400m). *T. palmeri* is the most abundant diurnal mammal above 2500m in the Spring Mountains (Deacon 1964, Ambos and Tomlinson 1996). *T. palmeri* is thought to be most abundant along the eastern side of the range at elevations of 2400m to 2700m within the ponderosa pine-white fir community. This species is thought to generally occur on the floor and lower slopes of deep, mesic canyons where fallen logs, large rocks, and cliffs provide shelter (Deacon et al. 1964, Best 1993, Ambos and Tomlinson 1996). Population densities of 2 to 6 animals per hectare have been reported. Home range is reported as 0.5 hectare with significant overlap (Ambos and Tomlinson 1996). The center of activity is the burrow. Burrows are often located under fallen logs, under the base of living trees, or under large rocks (Deacon 1964, WESTEC 1980). Burrows serve as a retreat from weather, conspecifics, and predators as well as a nursery and hibernaculum (Svendsen and Yahner 1979).

*Tamias palmeri* eats seeds, fruits, fleshy fungi, green vegetation, flowers, and insects although most of the diet consists of fruits of conifers (WESTEC 1980, Best 1993.) Males are active by March, while females are usually not active until April, with peak activity for both sexes in mid-summer (Hirshfeld 1975, Best 1993.) Adult males molt from winter to summer pelage in May-June and from summer to winter pelage in Sept-Oct. Breeding probably occurs between April and early May and parturition in May.
and June. Average size of litters in captivity is 3-6. Growth of young occurs rapidly with young venturing from the natal burrow within 30-33 days. Average lifespan of *T. palmeri* is between 3-4 years (Hirshfeld 1975).

The physiology of *T. palmeri* has been studied mainly with regard to its growth and development and in response to temperature. Whether *T. palmeri* hibernates (Hirshfeld and Bradley 1977) or not (O’Farrell 1980), activity almost ceases during cold winter months, although this species may be active on snow covered ground when temperatures are well above normal. Torpor and/or hibernation are believed to be triggered by low ambient temperatures through the mechanism of increased plasma thyroid levels affecting basal metabolism (Scott et al. 1976). *T. palmeri* has a relatively narrow thermo-neutral zone for a hibernator of 32°C - 34°C (Bradley and Yousef 1974). Adult *T. palmeri* are not believed to accumulate fat in the active season except during pregnancy (Scott et al. 1976).

*Tamias palmeri* was formerly classified as a federal species of concern, and is currently a species of concern in the Conservation Agreement for the Spring Mountains National Recreation Area (CASMNRA, 1998). *T. palmeri* is in the vulnerable (VU): A2c category on the IUCN Red List based on the restricted range of the species and the immediate threat of urban expansion and development (O’Farrell 1998). *T. palmeri* is ranked G2/S2 by the Nevada Natural Heritage program and is a covered species in the Clark County Multiple Species Habitat Conservation Plan. Population monitoring of *T. palmeri* is listed as a conservation action in the CASMNRA (U.S.F.S. 1998, O’Farrell 1980). *T. palmeri* carries no state or federal protection outside the designated wilderness area.
Other species may compete with *T. palmeri* for resources. The golden-mantled ground squirrel (*Spermophilus lateralis*) is the only other sympatric sciurid abundant enough to compete significantly with *T. palmeri*. *S. lateralis* eats primarily leaves of herbs and fungi, although it may also eat pine seeds after they have fallen to the ground (McKeever 1964). *S. lateralis* is significantly larger and more aggressive than *T. palmeri*, and therefore may be expected to be behaviorally dominant to *T. palmeri*. Burrow occupation by *S. lateralis* at the expense of *T. palmeri*, especially at lower elevations where the two species are more commonly sympatric, certainly may occur (McKeever 1964).

The Clarks nutcracker (*Nucifraga columbiana*) is another species sympatric with *T. palmeri*. Clarks nutcracker eats primarily the seeds of limber and pinyon pine (*Pinus monophylla*) (VanderWall 1988) and has been shown to aggregate in areas of high conifer seed production (Tomback and Kramer 1980). This species’ food preference, aggressive flocking behavior, and large size may put this species in direct competition for resources with *T. palmeri* (pers. obs).

The panamint chipmunk (*T. panamintinus*) inhabits pinyon pine-juniper forests along the lower elevation edge of *T. palmeri* habitat. This species is largely parapatric to *T. palmeri* probably due to physiological constraints rather than food preference (Best et al. 1986). Effects of competition for resources between *T. panamintinus* and *T. palmeri* are unknown.

Predation is a constant threat to *T. palmeri*, although it is unknown what impact predation has on the population as a whole. The long-tailed weasel (*Mustela frenata*) is predominately nocturnal though is also diurnal in the summer months (Kavanau and
Ramos 1975). The small, thin body shape of *M. frenata* allows it to access small mammal burrows. *M. frenata* can tolerate the low prey density typical of high altitudes, and sustain itself through the harsh winters (King 1989). *M. frenata* is therefore likely an important predator to the ground dwelling *T. palmeri*.

Birds of prey are another important predator of *T. palmeri*. The relatively open forest canopy of the Spring Range is hunting habitat for aerial predators (Johnsgard 1990). Although there are at least seven bird of prey species in the Spring Mountains, the red-tailed hawk (*Buteo jamaicensis*) is the most abundant (Austin 1967). This species has been observed by the author to capture *T. palmeri*, and attempting to capture *T. palmeri* on several occasions. Due to the high abundance of *T. palmeri* relative to other small mammal species above 2500m, it is likely a frequent prey choice of *B. jamaicensis*.

Feral cats occur in relatively high abundance in the developed valley areas of the Spring Mountains (Tomlinson, pers. comm.). The spread of feral cats into the wilderness areas of the forest, and therefore the potential threat to *T. palmeri*, is undocumented except for 1 set of cat tracks taken by the author from a track plate at 2600m. Other important predators of *T. palmeri* include gray fox (*Urocyon cinereoargenteus*), spotted skunk (*Spilogale gracilis*), badger (*Taxidea taxus*), and coyote (*Canis latrans*) (Hall 1995).

The effects of human activities on *T. palmeri* population sizes are unknown. A relative abundance study has documented densities of *T. palmeri* at between two and seven per hectare within camping and picnicking areas (Tomlinson 2001). Housing development is restricted mainly to Kyle and Lee canyons where existing private lands are located. The vast majority of *T. palmeri* habitat is above developed areas; therefore
the impacts of housing development likely do not threaten *T. palmeri* populations in the outlying wilderness areas (pers. obs.). The ski resort is located in Lee canyon and covers about 1 km$^2$ from 2650m to 2900m. The ski resort is not thought to have a negative impact on local populations of *T. palmeri* due to the small size of this resort and the fact that it is occupied primarily during the winter months (pers. obs.).

**Objectives and Predictions**

This study utilizes closed and open population models to measure relative abundance of *Tamias palmeri* along an elevation gradient in the Spring Mountains of southern Nevada and quantifies habitat variables that may be associated with *T. palmeri* abundance and distribution. Additionally, relative abundance estimates derived from track plates are contrasted with trapping estimates to test the validity of the track plate methodology as an index to population abundance and as a correlative to habitat use.

The scale of measurement of habitat variables is dependent upon the species of interest. In this study, *Tamias palmeri* is measured at the micro and macrohabitat scales. Measurement of similar habitat variables at both scales allows researchers to differentiate between habitat variables that are important at the population level and habitat variables that are important at the individual level. In this study, three hectares is considered the macrohabitat scale. Three hectares encompasses several home ranges of most *Tamias* species (Bergstrom 1988). Consistent response of abundance estimates to similar habitat variables at the three-hectare scale may suggest habitat variables that can be used to predict species abundance. *Tamias* abundance has been positively associated with overstory tree density (Sullivan et al. 2000) and/or shrub cover (Sullivan and Klenner 2000, Sharples 1983). If *T. palmeri* density is dependent upon conifer seed and/or shrub
seed abundance there will be a positive correlation between *T. palmeri* abundance and these two variables.

Microhabitat can also be important to small mammals (Morrison 1999). In this study, 200m$^2$ is considered the microhabitat scale. This scale is within the home range of individual *Tamias palmeri* (Tomlinson 1998), and allows correlation of presence of *T. palmeri* to microhabitat variables. *T. palmeri* presence has been positively correlated with the presence of large logs and/or large rocky outcroppings (Tomlinson 1998, Deacon 1964). If *T. palmeri* presence is dependent on abundance of large logs and/or large rocky outcroppings, there will be a positive correlation between presence of *T. palmeri* and these variables.

Track plates have been used as an index to population size (Drennan et al. 1998), but not as a correlative to habitat use. Track plates have many advantages to trapping, and may provide an alternative to trapping if correlatives to habitat use can be found. This study determines the reliability of estimating *Tamias palmeri* abundance and habitat use with track plate methodology.

In testing the effect of habitat variables, *T. palmeri* abundance may also correlate with other ecological variables across and within elevations. Other factors that may be responsible for differences in chipmunk density include changing weather conditions during and between trapping periods. Patch size, patch juxtaposition or quality of interspersion areas can affect density estimates. Distances to cliff areas, water sources, trails, campgrounds or otherwise disturbed areas may also influence habitat quality. Over-winter survival, physiological constraints, inter- and intraspecific competition.
demographics, predation, or dispersal rates may also be different within habitats, thus affecting density estimates.

**Structure of Document**

Chapter one documents the distribution of *T. palmeri* across elevation in the Spring Range. Abundance of the species is assessed by mark-recapture methods, and abundances are then correlated with habitat variables at the macrohabitat scale. Presence-absence of *T. palmeri* is correlated at the microhabitat scale with the use of track plate and trapping methods. In chapter two, habitat use across time is addressed by comparing home range, weights, and timing of emergence from burrows in two different habitat types. Chapter three utilizes findings of the previous chapters and the literature to create spatially broad scale models of habitat use within a geographic information system framework.
CHAPTER 2
ESTIMATING DISTRIBUTION AND ABUNDANCE OF TAMIAS PALMERI

Few studies have documented the distribution, abundance, and correlations of habitat and abundance of sub-alpine small mammals. Ecological studies of mammals within the Spring Mountain Range are especially rare, and consist of two studies of limited scope (Tomlinson 1996, Deacon 1964). This chapter documents the distribution and abundance of *T. palmeri* across habitat types in the Spring Mountain Range, and correlates *T. palmeri* abundance with habitat variables at both the macro- and microhabitat scale. This chapter further addresses the efficacy of using track plates as an index of abundance estimates and habitat use.

**Methods**

*T. palmeri* abundance surveys were conducted from 6/1/00 to 9/1/00. Two sites were selected in each of the 3 major habitat types of ponderosa, fir, and bristlecone for a total of six sites (Fig. 3). To determine the order in which sites were trapped, sites were chosen randomly by placing a numbered grid across the area and choosing from a random number table. If locations chosen from this method were logistically impossible to survey, the nearest logistically feasible location was chosen.
Figure 3: Survey grids. Spring Mountains, NV. 2000. Numbers refer to table 3. Not all grids are shown for clarity. Vegetation contours adapted from Nachlinger and Reese (1996).
Trapping methods

There were 2 trapping grids per site. On sites 1-3, 1 grid was between 2500m and 2700m, and the other grid was between 2700m and 3000m. On sites 4-6, 1 grid was between 2700m and 3000m, and the other grid was between 3000m and 3300m. Grid one was sampled twice for a total of 14 grids sampled. One site was trapped every 8 days, weather permitting. Both grids within each site were trapped simultaneously. The trapping grids consisted of 6 parallel lines of 10 traps each. Each line was 25m apart. Traps were spaced 25m apart to create a rectangular grid 225m x 125m. Trap locations were recorded with a global positioning system (GPS). Animals were trapped for 4 days at each site using 25cm x 9cm x 8cm aluminum Sherman live traps with 1 gram of peanut butter and oatmeal used as bait. Traps were checked twice per day, just after sunrise and just before sunset. Chipmunks were weighed, aged (juvenile or adult), sexed, uniquely marked with ear tags (type 1 monel), and released. An ear clipping was taken from one ear of each animal for genetic analysis within a related study.

Track plates methods

For two days randomly alternating immediately before or immediately after trapping, traps were replaced by 25cm x 7.5 cm x 0.31cm plastic track plates with carpenters chalk covering 8cm of each end. A 10cm piece of contact paper was centered on each plate. One gram of peanut butter-oatmeal bait was placed at the center of each plate. By placing the Sherman trap on its side and sliding the track plate through the trap, the trap doors were held open and the traps became inoperative, forming a covered tube for the track plate.
Habitat survey methods

I characterized three habitat types based on the dominant tree species of *P. ponderosa*, *A. concolor*, and *P. longeava*. In all grids, the topography and vegetation surrounding traps that successfully captured animals was measured. Vegetation and topography surrounding a corresponding number of randomly selected traps was measured for comparison. I measured 24 habitat variables within 420 eight-meter radius plots centered on the traps (Table 2). I defined downed logs as >0.5m in diameter and >2m in length. I defined large rocks as any rock or rocky outcropping > 1m$^3$. I defined shrubs as species > 0.25m and < 2.0m. Water sources were defined as either wet ground or open water. Trails or other structures within the plots were recorded. Height and length of cliffs and large rocky outcroppings occurring within plots were measured.

Data analysis

Densities were calculated from trapping data using the Schnabel capture-recapture method for closed populations. The closed-population Schnabel method was considered most appropriate given the short trapping period (Krebs 1998).

All habitat variables were standardized. Only those variables meeting the assumption of normality were included in the analyses. Dimensionality of habitat variables was reduced through principle component (PC) analyses. Varimax-rotated PC analyses were then performed on the respective variables.

To determine if *T. palmeri* population estimates were correlated with habitat types at the macro-habitat scale, grids were classified into habitat types by their respective dominant tree species. *T. palmeri* abundance means within the grids were then compared across habitat types with an ANOVA. To determine if *T. palmeri* abundance estimates
were correlated with habitat variables at the macro-habitat scale, two stepwise multiple linear regression approaches were used. In separate tests, of *T. palmeri* and *S. lateralis* abundances were conducted on rotated principle component scores of habitat variables and on standardized habitat variable means to determine if abundance is correlated with the measured habitat variables in Table 2.

Table 2. List of habitat variables used to predict relative densities of *Tamias palmeri* in the Spring Mountains of southern NV, summer 2000.

<table>
<thead>
<tr>
<th>Shrub (% cover)</th>
<th>Snags (# / hA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density of overstory trees (# / hA)</td>
<td>Overstory tree height (m)</td>
</tr>
<tr>
<td>Density of understory trees (# / hA)</td>
<td>Understory tree height (m)</td>
</tr>
<tr>
<td>Density of logs (# / hA)</td>
<td>Slope (degrees)</td>
</tr>
<tr>
<td>Canopy cover (% cover)</td>
<td>Elevation (m)</td>
</tr>
<tr>
<td>DBH (cm)</td>
<td></td>
</tr>
</tbody>
</table>

To determine if *T. palmeri* trap success was correlated with habitat variables at the micro-habitat scale, two logistic regression approaches were used. Traps (dependent variables) successfully capturing chipmunks were classified as 1’s, and randomly selected traps were classified as 0’s (Menard 1995). In two separate tests, these binary dependent variables were regressed on standardized habitat variables and principle component scores of habitat variables occurring within the 8m plots.

A correlation analysis was conducted to determine if *Tamias* abundance estimates were correlated with *S. lateralis* population densities.

I calculated densities from track plate data by counting the number of track plates with tracks per day. I assumed that only one chipmunk visited each track station found.
with tracks, and that an individual chipmunk only visits 1 track station per day. As *T. palmeri* is the only chipmunk found at this elevation, tracks are easily identifiable. I regressed trap density estimates accrued over 4 days trapping on track station density estimates averaged over 2 days tracking (modified from Drennan et al. 1998).

**Results**

**Abundance**

A total of 3360 trap-days were conducted across 14 three-hectare grids in the 3 different types of forest. A total of 186 (114 adults and 72 juveniles) unique *T. palmeri* and 61 unique *S. lateralis* were captured across the 14 grids. Abundances of both species were estimated for the 10 grids that captured enough *T. palmeri* to calculate an abundance estimate (Table 3). There was a significant effect of time on abundance of *T. palmeri* ($R^2 = 0.47, F_{1,12} = 10.487, P = 0.007$) and *S. lateralis* ($R^2 = 0.594, F_{1,10} = 14.62, P = 0.003$). Both species were more active in July than in May or June (Fig. 4). To control for seasonal differences in population size, data from early season trapping periods were removed from the analysis in chronological order until there was no significant effect of estimates on population size. A total of eight grids were then left available for correlations of habitat and population abundance.

**Habitat**

The diversity of vegetation in the Spring Mountains is relatively low. There are four predominant species of trees and two predominant shrub species above 2500m. Tree cones mature on a two-year cycle, supplying a relatively steady supply throughout the season. The berries of *Ribes cereum*, the dominant shrub, ripen late in the season in late
Table 3. Abundance estimates in #’s / hA’s of adult *Tamias palmeri* and adult *Spermophilus lateralis*. Spring Mountains, NV. Summer 2000.

<table>
<thead>
<tr>
<th>Grid number</th>
<th>Site type</th>
<th><em>T. palmeri</em></th>
<th>90% CI</th>
<th><em>S. lateralis</em></th>
<th>90% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ponderosa</td>
<td>2.7</td>
<td>1.3 - 5.3</td>
<td>5.0</td>
<td>3.3 - 8.3</td>
</tr>
<tr>
<td>2</td>
<td>Fir</td>
<td>4.3</td>
<td>2.7 - 6.7</td>
<td>4.3</td>
<td>2.7 - 6.7</td>
</tr>
<tr>
<td>5</td>
<td>Ponderosa</td>
<td>1.3</td>
<td>0.7 - 3.7</td>
<td>3.7</td>
<td>2.0 - 5.0</td>
</tr>
<tr>
<td>6</td>
<td>Ponderosa</td>
<td>1.7</td>
<td>1.0 - 3.7</td>
<td>4.0</td>
<td>3.3 - 5.3</td>
</tr>
<tr>
<td>7</td>
<td>Fir</td>
<td>5.7</td>
<td>4.7 - 7.3</td>
<td>4.0</td>
<td>3.3 - 5.3</td>
</tr>
<tr>
<td>8</td>
<td>Bristlecone</td>
<td>4.7</td>
<td>3.0 - 12.0</td>
<td>2.7</td>
<td>1.3 - 5.3</td>
</tr>
<tr>
<td>9</td>
<td>Ponderosa</td>
<td>4.3</td>
<td>4.0 - 5.3</td>
<td>5.0</td>
<td>3.3 - 8.3</td>
</tr>
<tr>
<td>10</td>
<td>Bristlecone</td>
<td>3.3</td>
<td>2.0 - 5.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>11</td>
<td>Fir</td>
<td>5.7</td>
<td>3.7 - 7.7</td>
<td>3.0</td>
<td>1.3 - 5.3</td>
</tr>
<tr>
<td>12</td>
<td>Bristlecone</td>
<td>1.7</td>
<td>0.7 - 3.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

July-early August (Pers. obs., L. Walker pers. comm., F. Landau pers. comm.). Habitat parameters are shown in Table 4.

Three principle components combined to explain 79% of the variation in habitat variables. Steeper slopes (+0.927), lower shrub cover (-0.881), and relatively shorter overstory trees (-0.645) characterized PC 1. Relatively tall understory trees (+0.964), relatively larger diameter trees (+0.749), and relatively taller trees (+0.552) characterized PC 2. Greater density of overstory trees (+0.953), greater canopy cover (+0.948), and greater density of understory trees (+0.665) characterized PC 3.

**Correlation of Abundance with Macrohabitat Variables**

Both *T. palmeri* and *S. lateralis* were found in ponderosa, fir, and bristlecone forest (see Fig. 2). There was no difference in *T. palmeri* abundance between the habitat types (*F* = 1.36, df = 2, *P* = 0.336). *Tamias palmeri* abundance estimates were negatively correlated.
Figure 4: *Tamias palmeri* and *Spermophilus lateralis* abundance estimates / hectare over time. Spring Mountains, NV. 2000.

with PC 1 ($R^2 = 0.871$, $\text{df} = 1,6$, $F = 18.821$, $P = 0.005$). *S. lateralis* abundance estimates were uncorrelated with PC's ($F_{4,3} = 2.43$, $P = 0.243$).

There was no correlation between *T. palmeri* population sizes and *S. lateralis* population sizes ($R^2 = 0.198$, $F_{1,6} = 1.483$, $P = 0.269$).

**Correlation of Presence with Microhabitat Variables**

The habitat variables in Table 2 were used to attempt to predict trap success at the microhabitat level. Logistic regression of habitat variables did not reliably predict trap success of *T. palmeri* across all eight sites ($\chi^2 = 1.30$, $\text{df} = 3$, $P = 0.722$, 67.5% correctly predicted).
Table 4: Habitat parameters of the Spring Mountain Range above 2500m.

<table>
<thead>
<tr>
<th>Type of variable</th>
<th>Mean</th>
<th>Std Dev</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canopy cover %</td>
<td>37.2</td>
<td>8.2</td>
<td>23.4 - 48.0</td>
</tr>
<tr>
<td>Shrub cover %</td>
<td>10.6</td>
<td>3.2</td>
<td>5.3 - 15.5</td>
</tr>
<tr>
<td>Density of overstory trees/hA</td>
<td>173.0</td>
<td>55.8</td>
<td>99.5 - 227.5</td>
</tr>
<tr>
<td>Density of overstory pine/hA</td>
<td>25.2</td>
<td>34.3</td>
<td>0.0 - 83.3</td>
</tr>
<tr>
<td>Density of overstory fir/hA</td>
<td>50.1</td>
<td>52.9</td>
<td>6.7 - 173.5</td>
</tr>
<tr>
<td>Density of overstory bristlecone/hA</td>
<td>78.9</td>
<td>73.8</td>
<td>7.5 - 187.2</td>
</tr>
<tr>
<td>Density of mountain mahagony/hA</td>
<td>18.9</td>
<td>44.6</td>
<td>0.0 - 127.4</td>
</tr>
<tr>
<td>Density of understory trees/hA</td>
<td>303.7</td>
<td>147.1</td>
<td>118.0 - 580.0</td>
</tr>
<tr>
<td>Density of understory pine/hA</td>
<td>19.9</td>
<td>32.0</td>
<td>0.0 - 83.7</td>
</tr>
<tr>
<td>Density of understory fir/hA</td>
<td>161.3</td>
<td>147.0</td>
<td>4.98 - 425.0</td>
</tr>
<tr>
<td>Density of understory bristlecone/hA</td>
<td>121.9</td>
<td>108.7</td>
<td>14.56 - 360.5</td>
</tr>
<tr>
<td>Density of <em>Ribes cereum</em>/hA</td>
<td>159.8</td>
<td>65.9</td>
<td>23.62 - 223.9</td>
</tr>
<tr>
<td>Water sources</td>
<td>0.7</td>
<td>1.0</td>
<td>0.0 - 2.0</td>
</tr>
<tr>
<td>Forest litter cover %</td>
<td>48.7</td>
<td>12.6</td>
<td>36.14 - 71.2</td>
</tr>
<tr>
<td>Surface rock cover %</td>
<td>46.5</td>
<td>13.5</td>
<td>24.8 - 63.5</td>
</tr>
<tr>
<td>DBH (cm)</td>
<td>174.6</td>
<td>37.9</td>
<td>127.0 - 250.0</td>
</tr>
<tr>
<td>Overstory tree height (m)</td>
<td>17.1</td>
<td>1.6</td>
<td>15.1 - 19.3</td>
</tr>
<tr>
<td>Understory tree height (m)</td>
<td>6.2</td>
<td>0.6</td>
<td>5.23 - 6.90</td>
</tr>
<tr>
<td>Density of snags/hA</td>
<td>38.2</td>
<td>16.2</td>
<td>16.27 - 60.7</td>
</tr>
<tr>
<td>Density of large rocks/hA</td>
<td>18.9</td>
<td>16.0</td>
<td>0.0 - 49.7</td>
</tr>
<tr>
<td>Density of logs/hA</td>
<td>76.2</td>
<td>23.5</td>
<td>35.2 - 109.6</td>
</tr>
<tr>
<td>Aspect (bearing downhill)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Elevation (m)</td>
<td>2802.0</td>
<td>143.1</td>
<td>2600.0 - 3200.0</td>
</tr>
<tr>
<td>S lone (degrees)</td>
<td>15.8</td>
<td>7.9</td>
<td>4.0 - 35.0</td>
</tr>
</tbody>
</table>

Habitat-Trap Success Results for Single Grids

Logistic regression of trap success on principle component scores was used within each grid to determine if microhabitat variables were related to trap success on a finer spatial scale. Multiple logistic regression successfully predicted trap success in 1 fir grid. Trap success was positively correlated with greater density of logs and greater density of...
ribes and negatively correlated with canopy cover and litter cover ($R^2 = -0.270, \chi^2 = 7.959, df = 1, p = 0.0048$). In the remaining seven grids there were no relationships between trap captures and habitat variables ($R^2 = 0.022, \chi^2 = 0.210, df = 3, p = 0.976$).

Track plates

Track plates are considered successful if an animal crosses the track plate. Traps are considered successful if an animal enters the trap. In comparing equal numbers of traps and track plates at the same locations, track plates were 40% more successful in the detection of *T. palmeri* occurrence than were traps. Average numbers of track plates with tracks were uncorrelated with population sizes as determined by capture-recapture methods ($r = 0.60, df = 6, P > 0.05$). The habitat variables in Table 2 were used to attempt to predict track plate success at the microhabitat level. There was no significant logistic regression of habitat variables with track plate success of *T. palmeri* across all sites ($R^2 = 0.074, \chi^2 = 16.69, P = 0.214, 58.5\%$ correctly predicted).

Habitat-Track Success Results for Single Grids:

Multiple logistic regression of track plate success on PC scores found no correlation between track plate success and habitat variables ($R^2 = -0.028, \chi^2 = 6.246, df = 3, P = 0.102, 56.7\%$ correctly predicted).

Discussion

Very few studies have documented the distribution and habitat associations of *T. palmeri*. Therefore I will discuss my findings in the context of other Tamias species that inhabit similar habitats.

Abundance estimates of *T. palmeri* were relatively lower (see Table 3) than estimates of other *Tamias* species (Sharples 1983, Bergstrom and Hoffman 1991). The
Spring Range has relatively low vegetation density relative to other conifer forests likely due to low rainfall (Landau pers. comm.). This low vegetation density and the harsh climate of sub-alpine environment may contribute to the observed low density of *T. palmeri*.

The results suggest that differences in environment due to elevation do not significantly affect abundances of *T. palmeri* within the species elevation range. The three dominant tree species of ponderosa pine, white fir, and bristlecone pine follow elevation very closely in the Spring Range (Nachlinger and Reese 1996). Therefore the data suggest that *T. palmeri* has no preference for any of these primary habitat types. *Pinus* seeds are the major food source for *T. palmeri* (Hirshfeld 1975), and it may be that neither tree species provides a significant nutritive advantage to the species. *T. palmeri* further has the ability to conserve energy by entering torpor within a few hours after exposure to temperatures < 8°C (Pers. observation, Hirshfeld 1977). This ability may be an important defense mechanism against prolonged exposure to sudden cold-weather storms more common at the highest elevations.

My findings suggest a preference of *T. palmeri* for habitats with relatively lower slopes and greater shrub cover. *T. palmeri* must burrow to escape predators and the harsh winters of the Spring Mountain Range, and lower slopes may provide relatively deeper soil for burrowing. Shrub species may provide an important supplemental seed source for *T. palmeri*, and also may provide greater protection from aerial predators. A greater density of shrub cover may therefore support greater *T. palmeri* abundances. These results compare to Sullivan et al. (2000) and Sullivan and Klenner (2000) who found mean abundance of *T. amoenus* to be greater in open areas with higher relative shrub
cover. *T. speciosus* has also been shown to have a preference for shrub cover (Sharples 1983). It should be noted that PC 1 explains only 38% of the variance in vegetation across the sampled sites. However, given the heavy loading of the slope (0.927) and shrub (-0.881) variable on PC 1, the strong correlation of abundance on PC 1 (P = 0.005), and the inherent ability of *T. palmeri* to make choices about its location in the environment, the data suggests that areas with lower slopes and relatively greater shrub cover are important to *T. palmeri*.

My findings of a negative correlation between *S. lateralis* abundance and elevation suggest habitat variables necessary for *S. lateralis* are less likely to occur at higher elevations. Herbaceous plants are one of the primary food sources for *S. lateralis* (McKeever 1964, Bihr and Smith 1998), and density of herbaceous plants are also negatively correlated with elevation in the Spring Range (Nachlinger and Reese 1996).

Using trap/track success as an indicator of microhabitat preference, *T. palmeri* did not demonstrate a preference for any measured habitat variable across all eight sites. Several factors may have contributed to these results. *T. palmeri* may not depend upon any specific habitat variable at the microhabitat level besides the burrow itself. *T. palmeri* is naturally low in density, has a relatively large home range, and is highly mobile (pers. obs., Tomlinson, pers. comm.). It is therefore unlikely that the local *T. palmeri* population would utilize most of the area within a grid during the short 4-day trapping period. Due to the relatively homogeneous habitat within grids, microhabitat areas that may be suitable *T. palmeri* habitat would be perceived as unsuitable by the logistic regression model, resulting in a type 2 error.
Further analyses of microhabitat use on a grid-by-grid basis indicate that *T. palmeri* uses different habitats in different ways. Studies by Sureda and Morrison (1999) support this generalist inference in western chipmunks. Large downed logs were the only habitat variable associated with presence of *T. palmeri*. It has been inferred from two previous studies that *T. palmeri* population densities are correlated with large downed logs (Deacon et al. 1964, Tomlinson 2001). Although my findings suggest downed logs are an important habitat component for *T. palmeri* on one grid, density of downed logs were unable to predict consistently presence/absence of the species across all eight sites. Furthermore, large logs were present near as many successful traps/track plates as unsuccessful traps/track plates, suggesting that downed logs are not a limiting resource for *T. palmeri*.

The numbers of track plates with tracks were consistently greater than the numbers of successful traps. The ability of *T. palmeri* to cover large areas quickly and its excellent eyesight and sense of smell may have allowed individual animals to visit more than one track station. *Tamias palmeri* may also be more likely to enter the open-ended track plates than the traps that are closed on one end. My findings of no correlation between track plate numbers and capture data compare with Carey and Witt (1991) who found no correlation between track plate counts and abundance estimates from either live trapping or point counts of calls. These results are however in contrast with Drennan (1998), who found track plates to correlate strongly (*r = 0.924-0.983*) with population estimation of sciurids as measured against mark-recapture methods.

The use of track plates allowed observation of natural daily foraging and movement behavior of local populations. Track plates are useful for understanding small
mammal ecology because effects of previous trapping on the behavior of the individual animals likely introduce an unknown bias into habitat use results. The lack of correlation between track plate success and habitat variables across all eight sites support the generalist hypothesis of *T. palmeri* habitat use, as *T. palmeri* was able to travel freely across the landscape. In contrast, the traps held animals for what may be all day and this lowers the probability of making meaningful correlations between trap success and natural habitat use. The use of track plates eliminated risk of disease transmission to the investigator, and eliminated stress, injury, and death to the animal. Until track plate methodology is tested on a natural animal population of known size, track plates may best be utilized for the observation of natural foraging behavior and validation of occurrence than for population estimation.

Relevant literature and evidence from this study suggest that valley areas may be more important than upslope areas for *T. palmeri*. Relatively greater abundance estimates of *T. palmeri* were found in two valley areas (grids 9 and 11) when compared simultaneously to 2 upslope areas (grids 10 and 12, respectively. See Table 3). Due to their shallower slope, valley areas have deeper soil than upslope areas. Since *T. palmeri* must dig relatively deep burrows to escape predation and the harsh winter environment, soil depth may be an important factor. Logs were also found to be an important habitat variable on at least one site, and *T. palmeri* will utilize log cover if it is available (pers. observation). Valley areas also have greater forest litter and log accumulation, and therefore greater overall plant fertility and structural complexity than upslope areas.

*Tamias palmeri* populations appear to respond to relatively higher shrub cover and relatively shallower slopes. Dominant tree species composition does not appear to
affect *T. palmeri* population sizes. However the species does appear to take advantage of downed logs when they occur adjacent to areas with greater shrub cover and lower slope. Population densities of *S. lateralis* do not appear to affect *T. palmeri*, and the two species likely utilize different resources in their areas of overlap. Track plates are believed superior to trapping for observing habitat use, however track plates must still be tested against a known population for abundance estimation.
CHAPTER 3

HABITAT USE OF *TAMIAST PALMERI* IN RAVINE AND UPSLOPE AREAS

Introduction

How small mammals use different areas within their habitats is an important question in ecology (Bergstrom and Hoffman 1991, Bowers 1995). Identification of areas of greater suitability within animal habitats can lead to a greater understanding of habitat needs. Management objectives that are pertinent to the conservation of the species can then be applied. Habitat suitability may be measured indirectly by individual body mass, time of birth or emergence (Phillips 1984), and home range size (Mares 1979). Mares et al. (1979) found social spacing of *S. columbianus* decreased with increasing food availability. Phillips (1984) found *S. lateralis* productivity was higher in heavier individuals. Neuhaus (2000) found in *S. columbianus* that more juveniles surviving to yearling age came from litters that were born earlier.

Like all ground dwelling species in alpine environments, *T. palmeri* must dig relatively deep burrows to survive over-winter, suggesting soil depth is an important habitat variable for *T. palmeri*. Over-winter survival for *T. quadrivittatus, T. umbrinus,* and *T. minimus* has been shown to be less than one-third of the respective population estimates (Bergstrom and Hoffman 1991). Kawamichi (1996) demonstrated in *T. sibricus*
that juveniles selected hibernation burrows only after adults, suggesting burrows may be a limiting factor to over-winter survival. *T. palmeri* were more abundant on two grids of lower slope (mean = 17°) when compared to two grids of higher slope (mean = 24°) (present study, Chapter 2). Soil depth is determined largely by slope, and therefore areas with lower slope may allow *T. palmeri* to more easily find or establish burrow sites.

The presence of water may limit the distribution and reproductive success of *Tamias* species (Heller and Poulson 1972, Hirshfeld 1975). Some *Tamias* species are physiologically constrained to particular elevations due to the inability of the species to dissipate heat through rolling and squatting behaviors (Heller and Poulson 1972). *T. palmeri* has been observed drinking, rolling in, and defending wet areas from conspecifics (pers. obs.). The presence of water may therefore allow longer foraging times during the summer. Hirshfeld found lactating females and juveniles consumed more water than other *T. palmeri*, indicating the importance of water for reproduction. In addition, VanderWall (1995, 1998) found that *T. amoenus* was better able to detect seeds under wet vs. dry conditions. *T. palmeri* may therefore prefer the more mesic conditions found in ravine areas.

**Hypothesis and Predictions**

To further address hypotheses concerning the suitability and use of habitat by *T. palmeri*, a survey was conducted to address how *T. palmeri* uses habitats within the fir forests by measuring both relative abundance and home range sizes throughout the active season. Individual vigor was measured by comparing weights of individuals and timing of juvenile emergence across ravine and upslope habitats.
I hypothesize that soil depth and water sources are important habitat variables for *T. palmeri* burrowing and foraging success, and hence affect *T. palmeri* population biology. If vital resources of food, water, cover, and burrow sites are abundant in ravines, home ranges of adult *T. palmeri* are predicted to be smaller, individuals will have greater weights, and juveniles will emerge from burrows earlier in ravine areas compared to upslope areas.

**Methods**

*T. palmeri* population surveys were conducted from 6/07/01 to 8/30/01 in Mummy Spring Canyon in the Spring Mountains, NV. Grids were chosen in regards to similar vegetation composition and to their position on a northwest-facing slope. There were four trapping grids. Grids were within the fir forests between 2750m and 2950m in elevation (Fig. 5). Two grids were placed 250m apart in the ravine bottom and two were placed 250m directly upslope from each lower grid. Each grid used an eight by six trap configuration with traps placed 15m apart giving one hectare of trapping area. 25cm x 9cm x 8cm aluminum Sherman live traps were used (Sherman Trap Co., Tallahassee, FL.). All four grids were trapped for seven five-day periods. There was approximately one week between each trapping period when traps were closed. One gram of peanut butter and oatmeal was used as bait. Traps were checked twice per day, at sunrise and just before sunset. Trap locations were recorded with a global positioning system (GPS) unit. Chipmunks were weighed, aged (juvenile or adult), sexed, uniquely marked with type one (monel) ear tags, and released. Due to the relatively long trapping period of three months, population estimates and survival were determined using the Jolly-Seber open population estimator.
Figure 5: Survey grid locations. Spring Mountains, NV. 2001. Vegetation contours adapted from Nachlinger and Reese (1996).
Habitat Survey Methods

Habitat grids were chosen to maintain similarity across grids except for the relative position of ravine and upslope grids. Thirteen habitat variables were measured (see Table 5) within three twenty-meter radius circular plots randomly placed within each grid. All tree and shrub species, snags, rocks, and logs were counted within each plot, and means were taken from the three plots to get estimates for each grid. Canopy and shrub cover were estimated by standing at 20 systematically placed points within each plot and looking straight up (canopy) and down (shrub) through a 20cm long by 3cm diameter tube. Counting the number of times the canopy (or shrubs) covered the line of sight (hits) and dividing that number by 20 (total) gave percent cover. Diameter at breast height (DBH) was measured with a tape. Tree heights were measured with a Haga height estimator. Forest litter and surface rock cover were estimated. Aspect was taken with a compass, elevation with a GPS unit, and slope was derived with a geographic information system from digital maps supplied by the U.S.G.S.

All habitat variables were standardized. Dimensionality of habitat variables were reduced through principle component (PC) analyses. An un-rotated PC analysis was performed on 13 habitat variables (Table 5). The non-significant habitat variables were then removed from the model, and a varimax-rotated PC analysis was performed on the remaining seven variables (Table 6). Principle component scores of the rotated PC analysis were compared between grids with an ANOVA.
Table 5. List of habitat variables used in un-rotated principle component analysis in Mummy Springs, Spring Mountains NV, summer 2001.

<table>
<thead>
<tr>
<th>Habitat Variable</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logs (#/hA)</td>
<td>1.4</td>
<td>1.4</td>
<td>3.0 - 6.0</td>
</tr>
<tr>
<td>Canopy (% cover)</td>
<td>15.0</td>
<td>15.0</td>
<td>32.0 - 51.0</td>
</tr>
<tr>
<td>Shrub (% cover)</td>
<td>15.0</td>
<td>15.0</td>
<td>10.0 - 43.0</td>
</tr>
<tr>
<td>Density Ribes (#/hA)</td>
<td>207.0</td>
<td>102.0</td>
<td>151.0 - 310.0</td>
</tr>
<tr>
<td>Density overstory fir (#/hA)</td>
<td>55.7</td>
<td>15.9</td>
<td>39.6 - 71.7</td>
</tr>
<tr>
<td>Density overstory bristlecone (#/hA)</td>
<td>15.9</td>
<td>10.3</td>
<td>0.0 - 39.6</td>
</tr>
<tr>
<td>Density overstory limberpine (#/hA)</td>
<td>23.9</td>
<td>8.0</td>
<td>15.9 - 39.6</td>
</tr>
<tr>
<td>Density overstory trees (#/hA)</td>
<td>91.6</td>
<td>29.8</td>
<td>55.7 - 151.0</td>
</tr>
<tr>
<td>Density understory trees (#/hA)</td>
<td>278.6</td>
<td>95.5</td>
<td>214.0 - 421.0</td>
</tr>
<tr>
<td>Diameter at Breast Height (cm)</td>
<td>150.0</td>
<td>15.0</td>
<td>130.0 - 170.0</td>
</tr>
<tr>
<td>Overstory tree height (m)</td>
<td>18.1</td>
<td>2.6</td>
<td>16.2 - 22.0</td>
</tr>
<tr>
<td>Large rocks (#/hA)</td>
<td>7.9</td>
<td>4.3</td>
<td>2.0 - 12.0</td>
</tr>
<tr>
<td>Snags (#/hA)</td>
<td>15.2</td>
<td>6.7</td>
<td>8.0 - 24.6</td>
</tr>
</tbody>
</table>

Table 6: habitat variables used in a varimax-rotated principle component analysis.


<table>
<thead>
<tr>
<th>Habitat Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density of logs (#/hA)</td>
</tr>
<tr>
<td>Shrub (% cover)</td>
</tr>
<tr>
<td>Density of overstory trees (#/hA)</td>
</tr>
<tr>
<td>Density of understory trees (#/hA)</td>
</tr>
<tr>
<td>Tree height (m)</td>
</tr>
<tr>
<td>Snags (#/hA)</td>
</tr>
<tr>
<td>Density of large rocks (#/hA)</td>
</tr>
</tbody>
</table>

Home Range and Weight Comparison Methods

Due to the low number of recaptures, the convex-polygon technique was used to estimate *T. palmeri* home ranges. This technique incorporates all known area used by the species, but may overestimate home range size due to this methods’ sensitivity to extreme data points (Boitani and Fuller 2000, Seaman et al. 1999). Home range size was estimated for every adult *T. palmeri* captured ≥ seven times. Individual home ranges of *T.*
*palmeri* of were nested within grids and compared with an ANOVA. Weights of individuals were compared with an ANOVA.

**Results**

**Abundance**

Sampling effort consisted of 6300 trap days with trapping grids covering more than 4 hectares. A total of 161 (82 adults and 79 juveniles) unique *T. palmeri* were captured across all grids. Sixty percent of adults were male. Juveniles were evenly split among the sexes. *T. palmeri* abundance was estimated in all grids. Mean abundance estimates are shown in table 7. Abundance estimates for each grid throughout the season are shown in figure 6. Juveniles were first captured the first week of July in the ravine habitat and the third week of July in the upslope habitat.

<table>
<thead>
<tr>
<th>Grid</th>
<th>Habitat type</th>
<th>Mean <em>T. palmeri</em></th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ravine</td>
<td>11</td>
<td>9 - 20</td>
</tr>
<tr>
<td>3</td>
<td>Ravine</td>
<td>29</td>
<td>24 - 47</td>
</tr>
<tr>
<td>2</td>
<td>Upslope</td>
<td>17</td>
<td>12 - 34</td>
</tr>
<tr>
<td>4</td>
<td>Upslope</td>
<td>12</td>
<td>11 - 19</td>
</tr>
</tbody>
</table>

**Habitat Analyses**

Water was the only habitat variable present in ravine areas that was not present in upslope areas. The first three PC's explained 76% of the variance in habitat variables. Density of overstory trees (+0.864), canopy cover (+0.831), and density of understory
trees (+0.667) significantly contributed to the first PC. Density of logs (+0.951), and shrub cover (+0.869) contributed significantly to the second PC. DBH (+0.914) contributed significantly to the third PC. A comparison of PC scores revealed no significant differences of vegetation between grids (F_{3,8} = 2.03, P = 0.187).

Figure 6: *Tamias palmeri* abundance estimates and standard errors for each grid across time. Mummy Springs, Spring Mountains, NV. 2001.

**Weight**

Seventy-nine adults and 48 juveniles were weighed. There was no difference in mean weights of adult *T. palmeri* between habitat types (F_{1,79} = 0.014, P = 0.905) or among grids (F_{3,79} = 0.68, P = 0.567). Adult females were significantly heavier than adult males (F_{1,79} = 38.09, P < 0.001). Adult females reached their maximum weight in mid-July due to pregnancy. Adult female weights peaked about two weeks earlier in ravine areas than in upslope areas (Fig. 7).

The mean weight of juveniles are significantly heavier in ravine areas than in upslope areas (F_{1,48} = 6.750, P = 0.012, ravine mean = 44.0 g, S.E. = 1.35. Upslope mean
= 37.7g, S.E. = 2.17) (see Fig. 8). There was no difference in weight between male and females juveniles (F_{1.48} = 0.721, P = 0.40).

Figure 7: Adult female Tamias palmeri weights in grams and standard deviations over time. Spring Mountains, NV. 2001.

Home Range

Twenty-six (11 male, 15 female) adult T. palmeri were used for determining home range. Mean home range was 0.27 / hectare. Upslope Tamias had significantly larger home ranges than ravine Tamias (F_{1.24} = 4.16, P = 0.017). There was no difference in home range between the sexes (F_{1.26} = 0.926, P = 0.345). Home ranges overlapped considerably, no sex-specific patterns of overlap were discernable.
Figure 8: Mean weights in grams and standard errors of juvenile *T. palmeri* in ravine and upslope habitats across time. Spring Mountains, NV. 2001

Discussion

My results suggest that quality of habitat may be higher in the ravine areas than in upslope areas for *T. palmeri*. Smaller home ranges of *T. palmeri* suggest that resources may be more abundant in ravine areas (Boutin 1990). This finding is similar to that of Hubbs and Boonstra (1997), who found that home range size of *S. parryii* declined 2-7 times when supplemental food was available. Home range size estimates were similar to those of Bergstrom (1988), who found home ranges of *T. quadrivittattus* and *T. umbrinus* to be about 0.49 / hectare. However my estimates are less than half those reported in most studies reporting home range (Martinsen 1968, Broadbooks 1970, Mares et al. 1979, Mares et al. 1980, Slade and Russell 1998). Different techniques to calculate home ranges produce different results, so comparisons must proceed with caution (Bergstrom 1988).
My findings suggest that male and female home ranges are relatively equal in size. This is in contrast to Broadbooks (1970), who found male *T. amoenus* home ranges to be almost twice the size of females. Home range size is likely a function of time of year. Martinsen (1968) demonstrated that home range size of males changed with time. Males searching for female mates early in the season necessarily use a larger area than they would require for normal foraging activities. After mating, which occurs from April – May, it would not be adaptive for the male to continue to expose itself to higher predation rates resulting from larger home ranges. Therefore studies carried out over the entire active season should normally demonstrate approximately equal home range sizes.

Juveniles in ravine areas were active outside the burrow two weeks earlier than in upslope areas. Furthermore, adult females reached maximum weight, presumably immediately prior to giving birth, earlier in ravine areas (see Fig. 7). This suggests earlier mating times in ravine areas as compared to upslope areas. If habitat quality is greater in ravine areas, females may come into estrous earlier than females in upslope areas. Given the smaller home ranges of *Tamias* in the ravine areas, and the relatively widespread distribution of *T. palmeri* across the landscape, earlier mating times may result from a greater concentration of females, allowing males to locate females more easily. Earlier emergence from den sites would allow juveniles more foraging days, and greater weight gain, during the short active season. Greater juvenile weights in ravine vs. upslope areas may lead to an increase ability of larger juvenile *T. palmeri* from ravine areas to establish or take over existing burrows before hibernation at the expense of smaller upslope juvenile *T. palmeri*. This may therefore allow greater ravine *T. palmeri* juvenile over-winter survival. (Rieger 1996, Neuhaus 2000).
Differences in juvenile weights earlier in the season may also be explained by faster growth rates or adaptive behavior of the mother. The mother may be able to provide a greater abundance of food stores for the juveniles earlier in the ravine areas compared to mothers in the upslope areas, resulting in disparate growth rates. The data suggest that juveniles are emerging from the den within a two-week period regardless of the weight of the juveniles (Fig. 8). It may be that juveniles are born at nearly the same time in ravine vs. upslope areas, have different growth rates, and the mothers force juveniles out of the dens regardless of juvenile weight. Forcing the juveniles out of the den regardless of their size may be adaptive to the mother, in order to preserve food stores for her own over-winter survival. Whatever the cause of initial differences in emergence time and body size, after emergence juveniles in upslope areas had a faster rate of growth compared to ravine areas such that juvenile weigh in mid-August was only slightly higher in the ravines.

Water was the most apparent habitat variable occurring only in the ravine areas. Although *T. palmeri* has been captured in areas remote from water (present study, chapter 2), Hirshfeld (1975) found in a laboratory study that pregnant *T. palmeri* females consumed more water than either non-breeding females or males. Access to water may therefore be a benefit for nursing females, and presence of open water may lead to greater nesting success.

Habitat use in terms of home range size and individual vigor in terms of juvenile weights at emergence indicate that ravine areas provide a higher quality habitat than upslope areas. Upland habitat juveniles, however, appear to have faster growth rates after
emergence from the burrow. Water is believed important due to its occurrence in ravine areas, demonstrated importance in a laboratory environment, and personal observations.
CHAPTER 4

IDENTIFYING POTENTIALLY IMPORTANT *TAMIAS PALMERI* HABITAT
WITH GEOGRAPHIC INFORMATION SYSTEMS

Introduction

In order to develop broad-scale hypotheses concerning animal distributions, there is a need to spatially extrapolate empirical data to identify potentially important habitats that lie outside the sample area (Schamberger and O’Neil 1986, Pereira and Itami 1994). The prediction of habitat quality can be accomplished by utilizing a geographic information system (GIS; Knick and Dyer 1997, Wethington et al. 1997, Ostro et al. 1999). A GIS is a computer system capable of storing, retrieving, organizing, quantifying, and analyzing spatial data. There is a paucity of small mammal studies in sub-alpine regions, due in part to the cost and logistical difficulties of these projects (Blumstein and Arnold 1998). The spatially large scale, high relief, and low accessibility of the Spring Mountain Range create serious logistical problems for wildlife population monitoring. Regardless of these difficulties, wildlife managers need to identify areas across the entire range that may be important to species of concern in order to establish management practices that are feasible and comprehensive (Storns and Estes 1993).

Given adequate field data, a GIS can create digital spatial maps outlining potentially important habitats to species of interest. Lancia (1986) developed habitat
models for three bird species using geo-referenced data to create habitat suitability maps. Using thematic mapping, from which specific vegetation species can be determined. Ormsby and Lunetta (1987) mapped white-tailed deer (*Odocoileus virginianus*) food availability. Pereira and Itami (1994) modeled probability of occurrence of the endangered Mt. Graham red squirrel (*Tamiasciurus hudsonicus grahamensis*) across areas of its range in southern Arizona.

**Building a Predictive Habitat Model for *Tamias palmeri***

Temperature can have a significant effect on high elevation sciurids. Cade (1963) observed that *T. amoenus* and *T. quadriraculatus* became progressively less active with the onset of lower temperatures, and became torpid when exposed to temperatures \( \leq 4^\circ C \). Heller and Poulson (1970) found that *T. alpinus* and *T. speciosus* began hibernation at \(< 6^\circ C \). French (1982) found that time of periodic arousal from hibernation in *S. lateralis* increased as temperature increased above \( 5^\circ C \). Personal observations from this study further indicate that *T. palmeri* is rarely active at temperatures \( \leq 7^\circ C \). *T. palmeri* have been observed sunning themselves in the early morning, and population size was greatest on the site exposed to sun earlier in the morning (Pers. obs., present study 2001). Areas that receive sun earlier in the morning relative to other areas may allow *T. palmeri* longer foraging times, and therefore indicate greater quality of habitat.

Aspect relative to sunlight is one environmental variable dictating the moisture gradient available to plants. Like many ranges in the northern hemisphere, vegetation in the Spring Range is significantly heavier on northern facing slopes than on southern facing slopes (Tomlinson, pers. comm., pers. observation). Tomlinson (1999) found greater population sizes of *T. palmeri* in mesic canyons as compared to dryer, upslope
areas. The lowest population size of the present study (2000) was also found on the only site with a dryer, southwestern-facing aspect. Pereira and Itami (1994) found that the montane *Tamiasciurus hudsonicus* preferred the cooler east-facing sites. Southern facing aspects in the Spring Mountains create conditions that are too dry for consistent conifer tree establishment (pers. obs.). As conifer trees are the primary food source for *T. palmeri* (Hirshfeld 1975), northern aspects may provide greater habitat quality relative to southern aspects in the Spring Range.

Soil depth is often dictated by slope, and ground dwelling mammals like *T. palmeri* require sufficient soil depth to escape predation and winter temperatures. A slope of $< 24^\circ$ was found to positively affect population sizes of *T. palmeri*. Grids with relatively greater population sizes had a mean slope of $17^\circ$ while grids with relatively lower population sizes had a mean slope of $24^\circ$ (present study, chapter 1). Pereira and Itami (1994) found the slope of inactive sites to be significantly steeper (mean $= 44^\circ$) than active sites (mean $= 25^\circ$) in their study of the tree squirrel *Tamiasciurus hudsonicus*. Ravine areas and plateaus with shallower slopes may indicate greater habitat quality for *T. palmeri*.

Open water is rare in the Spring Range. Species that need to drink are therefore dependent on the few areas that provide open water year round. *T. palmeri* has been found in several areas remote from water (Present study, chapter 1), and is not believed to require open water on a daily, year-round basis. *T. palmeri* breeding females, however, may need greater quantities of water to cope with the added physiological stresses of young-bearing. Hirshfeld (1975) found that both *T. palmeri* and *T. panamintinus* breeding females exhibited higher water intake than non-breeding females. Pregnant females also
consumed more water than non-breeding females. Furthermore, juveniles (adjusted for
weight) consumed higher quantities of water than adults (Hirshfeld, 1975). Smaller home
range sizes, earlier birth, and greater weights of *T. palmeri* juveniles occurred in areas
with open water (Present study, chapter 2). Areas with open water may therefore indicate
greater habitat quality for *T. palmeri*.

**Building the GIS Model**

An important element of GIS is that it allows mathematical data to represent
geographical features of interest. Although there is more than one way to accomplish this
for map data, one of the most useful is the raster model. Raster data models uses a grid,
such as the grid created by a map coordinate system, as its model to hold the map data.
Each grid cell (or pixel) in the map is one map unit. When a map is captured into a raster
data model, each grid cell must be assigned a value. The value may be an actual value
such as in a digital elevation model (DEM), or as an index value that represents an
attribute that is stored separately in the attribute database. The grid cell size determines
the resolution of the map. A 30m resolution, for example, means the grid cell is 30m x
30m in size on the ground. The raster format has several advantages: easy to understand,
easy to portray, and capable of rapid retrieval and analyses (Clark 2001).

Based on the goal of this study to develop a baseline model for predicting habitat
use of *T. palmeri*, a raster data model was chosen due the ease of attaching specific
attributes to the grid cells, the ability to add, subtract, and/or multiply attributes in order
to delineate areas of potential importance, and the ability to understand and modify the
finished model.
The ability to extrapolate empirical data across the landscape is a powerful tool for wildlife researchers and managers (Reading and Matchett 1997). Maps created from this extrapolation can indicate areas where probabilities of occurrence differ. It is from these possible differences in occurrence that testable hypotheses can be formulated. In order to develop spatially broad-scale hypotheses, a GIS was utilized to delineate potentially important habitats of *Tamias palmeri* in the Spring Mountains. The following hypotheses underlie the creation of the GIS model.

1) Because cold temperatures restrict *T. palmeri*’s food gathering activity, areas that are in direct sunlight earlier in the day provide higher quality habitats.

2) Because northern facing aspects provide greater densities of food resources, northern aspects provide higher quality habitats compared to southern aspects.

3) Because slopes >24° do not provide the soil depth necessary for den sites, areas with < 24° slope provide higher quality habitats.

4) Because laboratory experiments have found water is important to pregnant females and juveniles, areas near open water provide higher quality habitats.

**GIS Methods**

All computer-based analyses were performed using on ArcView 3.2. Seven and one-half minute digital elevation models of terrain (DEM’s), digital orthophoto quadrangles (DOQ’s), and digital raster graphics (DRG’s) of the Spring Mountain Range of southern Nevada were obtained from the U.S. Geological Survey and brought into ArcView as independent themes. Grid cell sizes are 30m x 30m.
In order to approximate temperatures across the Spring Range, exposure to sunlight was calculated with the hillshade function in ArcView. As temperatures on 1 July at 7am at 2700m (this date, time, and elevation were used as a standard) were found to reach > 8°C only after exposure to direct sunlight, areas exposed to sunlight at 8am were regarded as superior habitat relative to areas not yet exposed to sunlight at 8am. A theme was created that mathematically represented grid cells in areas exposed to sunlight at 8am as 1’s, and those areas not exposed to sunlight at 8am were represented as 0’s.

The average slope of all sites were calculated using the “summarize zones” function in ArcView. As grids with slopes averaging 17° were found to have greater population densities than grids with slopes averaging 24°, areas in the Spring Range with slopes < 20° were regarded as superior habitat relative to areas with slopes > 20°. A theme was created that mathematically represented areas with slopes < 20° as a 1’s and areas with slopes > 20° represented as a 0’s.

Aspect of the Spring Range was calculated using the “find aspect” function of ArcView. As northerly facing aspects are believed to be superior to southerly facing aspects, a theme was created with areas of aspects > 270° and < 90° bearing mathematically represented as 1’s and areas with aspects > 90° and < 270° bearing represented as 0’s.

Areas closer to water sources are believed to be superior habitat relative to areas distant from water. All water sources (springs, seeps, open water, streams) were georeferenced and brought into the DEM as a theme. Given T. palmeris’ home range size, a distance of 150m from the water sources was considered the maximum distance
that *T. palmeri* would benefit from the presence of water. A theme was created that represented areas within 100m of a water source as 1’s and areas outside 100m as 0’s.

Due what are believed to be physiological constraints, *T. palmeri* has a lower elevation range of approximately 2500m. As the species relies on *Pinus* seed as its main food source, the upper limit is determined by the timberline. A theme was created that represented areas in the Spring Range between 2500m and 3200m as 1’s and areas outside this range as 0’s.

To address logistical considerations of working in mountainous terrain, potential areas of study may have to be limited to areas accessible from trailheads. A maximum distance of 1.5km from trailheads was chosen to allow personnel access to study sites within 2 hours of arriving at the trailhead. To delineate areas that are accessible from trailheads, trailheads were georeferenced and brought into the DEM as a theme. Grid cells in areas within 1.5km of a trailhead were represented as 1’s, and areas outside 1.5km were represented as 0’s.

Three models were developed. Model 1: the individual elevation, aspect, slope, and sunlight themes were added together and then multiplied by the elevation theme with the map calculator to create a single theme of potentially important habitat areas for *T. palmeri*. Model 2: the individual water, elevation, aspect, slope, and sunlight themes were added together and then multiplied by the elevation theme with the map calculator to create a single theme of potentially important habitat areas for *T. palmeri* if water sources are important. Model 3: the elevation, aspect, slope, and sunlight themes were added together and then multiplied by both the elevation theme and the trailhead theme with the map calculator to create a single theme of potentially important habitat areas for *T.
*palmeri* that are within 1.5km of any trailhead in order to accommodate logistical constraints of wildlife management personnel.

**GIS Results**

Using the given variables, model 1 predicted that areas northwest of Lee canyon between 2700m and 2900m had the greatest concentration of potentially important areas for *T. palmeri*. Areas west of Deer creek campground were also found to be potentially important. Many areas within Lee canyon were also determined to be important. Model 1 also delineated some areas on the western and extreme southern part of the range not previously thought to have potentially significant populations of *T. palmeri* (Fig. 9). The addition of water as a variable in model 2 did not appreciably change the amount of area considered important (not shown). Constraining the model to only allow those areas within 1.5km of any trailheads (model 3) seriously restricted alternatives for management personnel to monitor potentially important areas and especially to test hypotheses. Model 3 delineated the areas west of deer creek campground and within the upper Macks canyon as potentially important areas (Fig. 9).
Figure 9: Model 1. Potentially important areas for *Tamias Palmeri*. Spring Mountains, NV. 2001.
Figure 10: Model 3. Potentially important *Tamias palmeri* Habitat within 1.5 kilometers of trailheads. Spring Mountains, NV. 2001.
Conclusion

This study suggests that *T. palmeri* is a generalist species within the sub-alpine forests of the Spring Mountain Range. The species occurs across a wide elevation range without correlation with tree species type across three macro-habitats. *T. palmeri* appears to prefer relatively shrubby, open areas of relatively lower slope but is not restricted by these habitat characteristics. *Pinus* cones, the species primary food source, grow closer to the ground in open areas, requiring much less effort to harvest than in heavier forests, where cones occur at the tops of trees. Preference for open areas may also be an adaptation to predation in a species whose eyesight and alarm calls are its' primary defenses. Preference for more open areas suggests that *T. palmeri* loses its advantages against predators in the heavier forests, and the rewards of shrub seeds are greater than the risks of aerial predation, which is more likely in open areas.

Slopes < 24° allow for greater soil deposition and *T. palmeri* may therefore establish burrows at a greater density in ravine areas than on steeper slopes. *Tamias* dispersal is male-biased, and unless juvenile males are able to establish burrows at a depth necessary for over-winter survival, existing burrows may be a limiting factor to *T. palmeri* abundance. For males, success at finding females in estrous to breed with may depend on density of burrows in a given area. Early mating is likely an important attribute in the short active season of the Spring Mountains.

Although access to water is not essential for *T. palmeri* survival, water is believed important since the greatest relative abundance of both adult and juvenile *T. palmeri* occurred in areas with open water during both seasons. Greater juvenile weights, earlier
births, and smaller home range sizes of *T. palmeri* in areas with water also indirectly support this hypothesis. Water occurs in ravine areas where springs and seeps are present. Since these locations are documented, hypotheses concerning the importance of water on *T. palmeri* populations are easily tested.

Three potential mechanisms of habitat separation between the *T. palmeri* and *S. lateralis* are implied by both the lack of correlation between *T. palmeri* and *S. lateralis* population sizes and the fact that *S. lateralis* was captured only in areas below 2850m. The simplest explanation is that *S. lateralis*’s primary foods, herbaceous plants, are not abundant enough at higher elevations to support them. Constraints on digestion of *pinus* and shrub spp. seeds found at higher elevations may also restrict *S. lateralis* distribution (Frank 1998). Secondly, both *T. palmeri* and *S. lateralis* were occasionally captured after traps were checked in the afternoon, thus staying in the traps all night. Without exception, *T. palmeri* would be in torpor, and thus saving energy, at the morning trap check. Also without exception, *S. lateralis* would not be in torpor, and therefore using valuable energy. The ability of *T. palmeri* to quickly adapt to changing conditions may increase survival, enabling it to live and reproduce more successfully at higher elevations. This suggestion is consistent with Bronson (1979), who found lower fecundity at higher elevations in *S. lateralis*. The third potential mechanism is morphological. Unless there was a large log very nearby, all *T. palmeri* (over 800 animals handled) escaped up the nearest tree upon release. However not a single *S. lateralis* (over 500 animals handled) escaped up a tree upon release. This inability or strong disinclination to climb trees is a serious disadvantage to any species in this habitat where, especially at higher elevations, the vast majority of available food is conifer seed. Chipmunks and bird species often
harvest conifer seeds while the cones are still in the tree, and *S. lateralis* is excluded from this activity.

Although *S. lateralis* is larger and more aggressive than *T. palmeri*, these observations further suggest the mechanism behind habitat separation is not behavioral. *T. palmeri* can easily escape *S. lateralis* by climbing trees. Therefore attempts at competitive exclusion by *S. lateralis* would be ineffective (Brown 1971). Furthermore, *S. lateralis* and *T. palmeri* were often observed feeding in very close proximity (within 1m) to each other, suggesting behavioral antagonism between the two species is not inherent.

The differences in *Tamias* abundance estimates between years demonstrate how population model used, trap spacing, and trapping continuity affect abundance estimates. Although taken in different years, abundance estimates (adjusted for trap spacing to reflect larger trapping area and wider trap spacing in 2000) across the same area during the same time of year (July 5-10) revealed six *Tamias* / hA in 2000 and eight / hA in 2001 under the closed population model. Utilizing the open population model, estimates in this same geographic area over a longer time period, from 6/0/01 to 7/20/01, gave estimates (unadjusted) of up to 39 *Tamias* / hA. Therefore density estimates are likely a function of trapping intensity, model used, and especially length of trapping period. These results highlight the importance of using consistent time periods and trap configurations when making direct comparisons of abundance. Studies of relative abundance, those comparing > 1 area simultaneously or ≥ 1 area across time are best suited to interpret differences in animal abundance. Conclusions about actual population size are inappropriate using either trapping or track plate methods as implemented in this study.
The data suggest a source-sink population dynamic for *T. palmeri*. Source-sink populations consist of areas of positive population growth (source) and areas of negative population growth (sink) (Murphy 2001). The species is more abundant in areas where shrub seeds provide supplemental food late in the active season. Lowers slopes provide areas where a greater density of burrows can be established for predator avoidance and over-winter survival. Access to water may provide greater nesting success, and open water is more common in ravine areas. Large downed logs, though not limiting to *T. palmeri* abundance, are consistently utilized as cover from predation when occurring in areas with these other attributes. It is this combination of shrub cover, lower slopes, open water, and large downed logs that provide important habitat attributes for *T. palmeri*. 

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VITA

Graduate College
University of Nevada, Las Vegas

Christopher Lowrey

Local Address:
8455 West Sahara #266
Las Vegas, Nevada 89117

Home Address:
10446 Oleander Avenue
Fontana, California 92337

Degrees:
Bachelor of Science, Wildlife Management
Humboldt State University
Arcata, California

Special Honors and Awards:
Presidential Scholar 1997

Thesis Title: Ecology and Growth Rates of *Tamias palmeri* and Testing of a Protocol to Monitor Habitat Relationships

Thesis examination Committee:
Chairman, Dr. Brett Riddle, Ph. D.
Committee Member, Dr. Diane Wagner, Ph. D.
Committee Member, Dr. Daniel Thompson, Ph. D.
Graduate Faculty Representative, Dr. Richard Ormdorff, Ph. D.