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Preliminary Results: Second Year Study of the Impact of Trails on Small Mammals and Population Estimates for Preble's Meadow Jumping Mice on City of Boulder Open Space

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SUMMARY

This report summarizes the results from the first two years of a three year study of the impact of trails on small mammals. We studied the impact of trails on small mammal relative abundance, species richness, and species diversity at six paired sites with and without trails along South Boulder Creek. There is some indication that trails have a negative effect on relative abundance, species richness, and species diversity of small mammals. However, sample sizes are insufficient to provide conclusive evidence of this relationship. The third year's data will likely clarify this relationship.

We also used mark-recapture techniques with Preble's meadow jumping mice (*Zapus hudsonius preblei*) to determine linear population density estimates. The average density estimate per km estimated from the six sites was 32.7 animals per km in June, prior to the birth pulse. Extrapolating to the 3.7 km of the study area, we calculated a population density of 121 jumping mice. This does not account for the added mice along the numerous irrigation ditches that extend out from South Boulder Creek. An extrapolation to a longer section of South Boulder Creek with the linear distances of suitable ditches would provide an estimate of the entire South Boulder Creek population. Survival rates were estimated at 61 percent during summer (two months) and 22 percent over winter (ten months). We found a slight, but nonsignificant effect of trails on population densities of Preble's meadow jumping mice

Introduction

Many people who live in Colorado do so because they love the outdoors. Open spaces are seen as vistas of natural beauty with plenty of room for both wildlife and human enjoyment. In recent times, however, human populations have increased dramatically. At the same time, there has been an increase in outdoor recreational activities (Flather and Cordell 1995) and a decrease in available open landscapes as development proceeds. As human populations increase and open lands become more scarce, wildlife is squeezed into increasingly smaller areas. Consequently, there is a strong motivation to optimize use of existing open spaces for both recreation and wildlife.

This problem is of particular interest in riparian habitats that have trails. Such riparian corridors provide important habitat to a diverse array of wildlife species, and are also a preferred recreational corridor, enjoyed by humans for a number of different recreational uses such as hiking, cycling, bird-watching, jogging, and dog-exercising (Bekoff and Meaney 1997). We do not know what the impact of this use may be on small mammals.

A motivating factor for the present study was the known presence of Preble's meadow jumping mouse (*Zapus hudsonius preblei*) on City of Boulder Open Space where a bike trail was completed in the spring of 1997. This small mammal occurs only in Colorado and Wyoming, and was listed as threatened under the Endangered Species Act on May 13, 1998 (63 FR 26517). Probably a Pleistocene relict, Preble's meadow jumping mouse previously enjoyed a wider distribution in tallgrass prairie across the eastern plains of these two states (Fitzgerald et al. 1994). Probably, development along riparian areas, predation by both wild and domestic predators, destruction of wetland areas, grazing, and gravel-mining probably have all had a detrimental effect on local populations. As a consequence, this small mammal has become rare. Elsewhere in North America, other subspecies of meadow jumping mice are broadly distributed (Hall 1981) and populations are not known to be threatened.

The preferred habitat of this mouse is moist lowlands with dense vegetation, such as grassy fields, thick vegetation along ponds, streams, and marshes, and the rank herbaceous vegetation of wooded areas. In Colorado, *Z. h. preblei* shows an affinity for complex riparian communities with shrub (both tall and short), tree, grass, and forb species (Bakeman 1997, Ryon 1996).

Willows (*Salix* sp.) seem to be particularly, but not exclusively, favored, and other vegetation communities are also used.

The impact of recreational trails on wildlife is a new and growing field with a relative paucity of knowledge. A little over a decade ago, recreational activities other than hunting were not considered harmful to wildlife because they are nonconsumptive, however, it has become increasingly apparent that there are impacts on wildlife from human recreational activities (Boyle and Samson 1985, Knight and Gutzwiller 1995). Disturbance by recreationists can affect habitat, populations (abundance), or community interactions and composition (e.g. species richness) (Anderson 1995, Gutzwiller 1995). Trails create edges to habitats, increasing the so-called "edge effect." Traditionally, edges were created to enhance habitat for game and other species that used two or more habitat types, such as forest and meadow. This provided heterogeneity to the habitat in terms of food and cover resources. Unfortunately, many native, nongame species require contiguous, undisturbed habitat (Cole and Landres 1995), and rare, endemic species may suffer from creation of unnaturally high amounts of edge (Robinson 1988).

Edges can cause changes in wildlife species diversity and composition (Harris and Silva-Lopez 1992). Some bird species, such as blue jays (*Cyonocitta cristata*) and brown-headed cowbirds (*Molothrus ater*), are attracted to trails and can have a detrimental effect on other, more vulnerable species (Hickman 1990). Cowbirds are nest parasites and jays feed on nestlings of other species that require uninterrupted forest (Brittingham and Temple 1983, Wilcove 1985). In a study on City of Boulder Open Space and Boulder Mountain Parks, generalists species such as robins (*Turdus migratorius*) were more abundant near trails (Knight and Miller 1997), and rates of nest predation were greatest near trails. Nest success improved and predation and parasitism were reduced at a distance of 45-50 m from trail edges (Johnson and Temple 1986, Paton 1994). A second study on City of Boulder Open Space found that fewer birds used riparian areas associated with heavily-used trails than riparian areas that had no trails (Miller et al. 1997 and J. Miller, personal communication). Interestingly, the same study found reduced predation in the vicinity of trails, possibly due to human activity displacing certain predators. The impact zone of the trail/edge effect is dynamic and depends on a number of factors including vegetation buffering, wildlife species present, time of year, topography, surrounding land use, and amount of trail use (Miller 1994).

Most studies of wildlife and recreational trails have focused on birds. Very little is known about the effects of trails on small mammal communities. One study on small mammals found that species richness was higher near trails, but this was typically a result of increasing numbers of very common species such as deer mice (*Peromyscus maniculatus*) (Weber 1995). Computer simulations of the effect of habitat fragmentation on small mammals found that the edge effect was disproportionately greater in small than large fragments, and had a greater effect on species with large home ranges (Bowers et al. 1996). Habitat fragmentation also can have very different effects on different species. For example, some species such as deer mice may benefit from fragmentation because of the reduction of competitors (Diffendorfer et al. 1995). For other species, such as dormice (*Muscardinus avellanarius*), continuous hedgerows without gaps are necessary for dispersal corridors (Bright 1998)

There have been a few studies of the effect of roads on animal crossings. An extensive study concluded that the width of the inhospitable habitat presented by a road was the most critical factor in determining road crossing by mammals (Oxley et al. 1974). In some cases, even a 10 m grassy strip inhibited movements of prairie voles (*Microtus ochrogaster*) (Cole 1978). Dirt or gravel roads of 3 to 3.6 m wide present a formidable barrier to prairie voles (Meserve 1971, Swihart and Slade 1984). Such barriers cause fragmentation of vegetation and/or habitats, which negatively affects populations.

There are solutions to the problems caused by recreationists to wildlife. A study of the effectiveness of barrier fences and culverts found suggestive evidence that desert tortoises and various mammals do make use of the corridors provided by the culverts for safe passage across a highway (Boarman and Sazaki 1996). Bald eagles are flushed from nests by human activity; however, appropriate viewing distances can be determined at which the eagles do not leave the nest (Fraser et al. 1985). Although the details of optimal human/wildlife sharing of open spaces may not always be immediately apparent, the success of managing wildlife in these areas will be dependent on an understanding of the specific wildlife species and populations being managed (Knight and Temple 1995).

Purpose

The purpose of this project is to address the question of whether trails have an impact on small mammals by comparing small mammal relative abundance (captures per 100 trap nights), species richness (number of species), and diversity (number and evenness of species), on the trail and non-trail sides of South Boulder Creek. The null hypothesis is that there will be no effect due to trails on small mammal relative abundance, species richness, and diversity.

We are also interested in population estimates for meadow jumping mice, both in terms of trail impacts and in terms of population estimates along the reach of creek encompassed by the study sites. The null hypothesis is that trails have no effect on jumping mouse population estimates; the alternative hypothesis is that the presence of trails will reduce the population estimates of jumping mice.

Study Site

South Boulder Creek heads in the mountains west of Boulder; in the foothills it has been dammed to form Gross Reservoir from which it also emerges. Once in Boulder it forms a broad floodplain. The entire study area is generally characterized by a broad floodplain with well-developed grasses adjacent to the cottonwood riparian corridor, though there is much variation in the vegetation communities. The vegetation is well-developed with shrubs and some cottonwoods along the creek, and diverse forbs and lush grasslands further out from the creekbed. Additionally there are numerous wetlands throughout. A number of ditches conduct water away from the creek for irrigation. A large headgate is located by South Boulder Road; it draws water off South Boulder Creek into the Baseline Land Reservoir intake, the Enterprise Ditch, and the new Dry Creek Carrier. A smaller ditch, East Boulder Ditch, draws water from the creek at the north end of the study area. Numerous other ditches draw water out through the wide lowland meadow adjacent to the creek. The state is in the process of designating South Boulder Creek a State Natural Area (M. Gershman, personal communication).

The City of Boulder Open Space along South Boulder Creek provides an ideal site to study the impact of trails on small mammals: A long stretch of the creek is under Open Space management and there is a recreational trail on one side of the creek and no trail on the other. The trail(s) starts on the east side of the creek at Baseline Road, heads south and crosses over to the west side at South Boulder road. This is also an excellent location for the study of Preble's meadow jumping mice due to their occupation of this stream, and the suitable habitat and protected status of the creek. The study sites are located on both sides of the creek between Baseline Road and the westward extension of the South Boulder Creek Trail (Figure 1).

Methods

Field Methods

Six study sites were randomly selected from all possible 100 meter sections of South Boulder Creek between Baseline Road and the gravel ponds at the westward extension of the trail. Each site contained two trapping grids, one on the trail side of the creek and the other, immediately opposite, on the non-trail side of the creek. The three grids used in 1997 (called sites, and composed of three parallel transects of 25 traps each) either superimposed or overlapped with the 1998 grids, and thus were easily incorporated into the new design. Grid locations were marked on aerial photographs and were recorded with a GPS (Geographic Positioning System) unit. Each grid contains 72 traps, laid out as eight trap stations along the creek and nine trap stations out perpendicular to the creek. Traps were placed 9 meters apart on both axes, thus forming a grid 63 meters along the creek by 72 meters out from the creek.

In order to continue our evaluation of the use of East Boulder Ditch by jumping mice, a transect of 50 traps was placed along the ditch with a brief interruption at the bridge where the two trails converge and cross the ditch. This was identical to the trap layout in August 1997.

Vegetation data were collected at each grid. Nine randomly selected vegetation plots were sampled on each of the twelve trapping grids and along East Boulder Ditch, with plots placed over the center of a trap. Data collection focused on percent plant canopy cover and plant species richness. Plots were 5 m in radius with the trap at the center. Percent canopy cover of trees, shrubs, grasses, and forbs was noted to the nearest 10 (i.e. 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, or 100 percent cover). Cover values do not tally to 100 because they are estimated for each plant group separately regardless of multiple canopy layers. Species richness, or the number of species, was tabulated in one of three categories: 0-1, 2-3, and 4-5 species for trees and grasses; 0-2, 3-5, and 6-8 species for shrubs, and 1-3, 4-7, and greater than 7 species for forbs.

We followed standard mammalogical procedures, using Sherman live traps for small mammal trapping and following guidelines approved by the Animal Care and Use Committee of the American Society of Mammalogists (1998). Traps were baited with a sweet feed combination (molasses in rolled oats, corn, and filler grains) and a ball of polyester was placed inside each trap for insulation and bedding. We placed traps in a covered location under vegetation as much as possible, to prevent over-cooling and over-heating of animals during the trapping period.

We trapped these grids twice during the field season, for three weeks in June (June 1 through June 19) and again in August (August 3 through August 21). We set traps out on Monday afternoons, checked them and closed them early each morning, reopened them late each afternoon, and picked them up the Friday morning of the same week. Traps were washed each Friday in a 10 percent bleach solution. Each grid contained 72 traps, and each site contained two grids. We ran 2 sites (288 traps) per week the first two weeks. The third week in each month we added East Boulder Ditch with an additional 50 traps. This represents a 7,312 trap night effort for the summer season.

We noted the sex and age of small mammals and marked them with permanent marker for recognition of recaptures. Jumping mice were marked individually with Passive Integrated Transponder (PIT) tags. PIT tags are electromagnetic, glass-encased tags that are inserted under the skin on the back. These tags emit a passive signal that is decoded by a hand-held reader similar to those that read bar codes in supermarkets. We purchased Destron-Fearing PIT tags and a mini portable reader from Biomark of Boise, Idaho. We used tags with a scanner exciter frequency of 125 kHz.

Indices of Abundance and Diversity

Relative abundance was calculated as the number of individuals captured per 100 trap nights. Species richness is a simple count of the number of different species captured on a particular trapping grid. Species diversity can be thought of as species evenness. Diversity was calculated by the Shannon-Wiener diversity index as described in Zar (1996):

$$H' = -\sum p_i \log p_i$$

where p_i is the proportion of the total number of individuals represented by species *i*. Unidentified voles were assigned as either meadow (*Microtus pennsylvanicus*) or prairie (*M. ochrogaster*) vole in proportion to the occurrence of those two species on the particular grid.

Population Size Estimation

Estimation of jumping mouse population size was done using the Robust Design model (Kendall et al. 1997, Kendall and Nichols 1995, Kendall et al. 1995) for capture-recapture studies (Pollock et al. 1990; Seber 1982, 1986, 1992) in program MARK (Cooch and White 1998, White and Anderson 1998). See Appendix for further details.

A random immigration/emigration model was assumed in which these rates were set equal to each other. As in all closed population studies, permanent migration out of the study areas can not be distinguished from mortality, only temporary migrations can be measured. Sex, time (week and session), and site were tested for effects on capture probabilities. Because of the large number of trapping occasions, and the small population sizes, estimation of separate probabilities for each trapping occasion was not possible. Instead, we estimated separate capture probabilities by week and session. The possibility that recapture probability differs from capture probability was also examined.

These alternative models were compared and population size was then estimated using model averaging over the best models (Burhnam and Anderson 1998). The support for a non-zero temporary migration rate, and for sex, time, and site effects was tested using a likelihood ratio test of models with and without these parameters.

Population Adjustments and Extrapolations

Researchers from the Colorado Division of Wildlife (CDOW), the Colorado Natural Heritage Program, and the Colorado Department of Transportation, and I are working with Gary White at Colorado State University to develop linear population estimates along different streams that can be compared across sites statewide. Dr. White is a specialist in population dynamics who developed the MARK program being employed for the population estimations. This group, called the Preble's Meadow Jumping Mouse Research Group, has met as the need arises to deal with research design and analysis issues.

The group recognized two factors that we wished to standardize: which month to use for population estimation, and development of a correction factor for trap grid boundary effects. We elected to use capture data from June to mid-July in order to focus on population numbers prior to the birth pulse, i.e., the post-hibernation adults available for breeding. Because there is no natural or artificial boundary to ensure geographic closure of populations on each trap grid (an important assumption of the analytical techniques used), the linear population estimates include individuals drawn from outside the boundaries of the grid. To adjust for this, an estimate of the boundary strip on either side (upstream and downstream) of a trap grid was estimated independently based on telemetry studies conducted by Tanya Shenk (CDOW, personal communication). The calculated correction factor, or percent residency, represents the proportion of animals captured on the grid or transect that are true residents (defined has having more than 50 percent of their telemetry observations on the transect). See Appendix for details of this calculation.

Population size estimates for each site were converted to linear population density estimates of the number of animals per km of stream reach. It was assumed that trap grids on one side of South Boulder Creek measured the population size along that side of the creek only. This assumption is justified by the width and swiftness of the creek and the low estimates of trapping probability for individuals from the other side of the creek. Conversely, estimates from trapping along one side of East Boulder Ditch were assumed to measure the entire population on both sides. This assumption is supported by several observations of individuals swimming in the narrow and slow moving ditch, and the fact that telemetry observations in El Paso and Douglas counties showed small creeks did not present a barrier (Rob Schorr and Tanya Shenk, personal communication).

ANOVA of Indices and Population Density Estimates

Analyses of variance were calculated on richness, abundance, and diversity indices, and on the density estimates using PROC GLM in SAS (SAS Institute 1989). Alternative models for each response variable were examined which include independent effects of trapping session, site, trail use, and stream segment (north/south). Two-way interactions were also examined. Best models were selected based on Akaiki's Information Criteria (AIC) (Burnham and Anderson 1998). Model averaging was not used in computing estimates from the ANOVA results. Least squares means and other linear estimates of response variables were computed with the LSMEANS and ESTIMATE options in PROC GLM of SAS and used in the interpretations.

Results

Some differences emerge between the northern segment (Sites 1, 2, 3) and southern segment (Sites 4, 5, 6) of the study area in terms of gross-scale riparian habitat and management practices. Riparian habitat mapping was conducted by the Colorado Division of Wildlife (CDOW) for much of the Front Range. This mapping is from color IR (infra-red) aerial photographs, flown at an altitude of 20,000 ft., at a scale of 1:24,000, and using photo-interpretive techniques (Dave Lovell, CDOW, personal communication). Adjacent to the cottonwood corridor, the northern segment is characterized as "Riparian Herbaceous - Sedges/Rushes/Mesic Grasses (Waterlogged or Moist Soils)", whereas the southern segment is predominantly "Riparian Herbaceous - General" (See Figure 2). The differences can be characterized by the fact that there are more bottom-land tallgrass irrigated meadows in the northern segment, and more upland benches in the southern segment, especially on the east side.

Management at present includes some differences in grazing patterns and recreational use on the two segments. In the northern segment, fencing protects the riparian corridor from grazing, whereas the cows are not fenced out in the southern segment. Both areas are grazed at the rate of 1-2 Animal Unit Months per acre, which occurs from December to February in the northern segment and from December to mid-May in the southern segment. The amount of forage removed is the same in both areas but the southern segment has more spring grazing, is grazed longer, and the grazing occurs in the riparian corridor. The northern segment experiences a higher trail usage (Brent Wheeler, personal communication), and dogs are allowed on the northern segment but not on the southern segment. Development is closer in the northern segment, whereas the southern segment has a greater extent of agricultural use on adjacent lands.

Vegetation

As a consequence of these differences we elected to separate the vegetation comparisons into a northern and southern segment for comparison of trail and non-trail sides of the creek. The percent tree canopy cover, shrub cover, grass, and forb cover is very similar between the trail and non-trail sides of the creek within both the northern and southern segments of the study area (Figures 3, 4, 5, and 6). Species richness also is very similar between the trail and non-trail sides in both the northern and southern segments of the study site, except for a higher forb species richness on the non-trail side in the southern segment (Figures 7, 8, 9, and 10). On the trail side, the northern and southern segments are similar in tree, grass, and forb cover, but shrub cover is much lower in the southern segment. On the non-trail side, tree canopy and grass cover are similar, but shrub cover is again lower in the south, and forb cover is higher. East Boulder Ditch had virtually no tree cover, low shrub cover, and high grass and forb cover (Figure 11). Although not directly on the transect, dense patches of willows and other shrubs do occur in the vicinity of the ditch. Species richness followed this pattern, with low tree and shrub species richness but higher grass and forb species richness.

Small Mammals

One hundred and sixty individual small mammals were captured in June on the 12 grids: 1 hispid pocket mouse (*Chaetodipus hispidus*), 13 prairie voles (*Microtus ochrogaster*), 10 meadow voles (*M. pennsylvanicus*), 1 Mexican woodrat (*Neotoma mexicana*), 87 deer mice (*Peromyscus maniculatus*), 1 western harvest mouse (*Reithrodontomys megalotis*) and 47 meadow jumping mice (Table 1). In August, animal abundances were higher than in June, with a total of 265 individuals captured: 17 prairie voles, 65 meadow voles, 15 unidentified voles, 4 house mice (*Mus musculus*), 1 Mexican woodrat, 133 deer mice, 5 western harvest mouse, 1 thirteen-lined ground squirrel, and 29 meadow jumping mice (Table 2). The Mexican woodrat and hispid pocket mouse were captured only on the non-trail side, whereas the thirteen-lined ground squirrel was only captured on the trail side. Otherwise, all species were found on both trail and non-trail sides of the creek. More individuals were captured on the non-trail side in both months (136 versus 129 in June and 92 versus 68 in August). Jumping mice comprised 29 percent and 11 percent of the individuals captured in June and August, respectively.

On East Boulder Ditch in June, there were 24 individuals captured: 1 meadow vole, 2 deer mice, and 21 meadow jumping mice (Table 3). In August, 40 individuals were captured: 3 prairie voles, 15 meadow voles, 2 unidentified voles, 2 house mice, 7 deer mice, and 11 meadow jumping mice. Jumping mice comprised 87 percent and 27 percent of the individuals captured in June and August, respectively.

Trail Effect on Small Mammals

Species richness, relative abundance (the number of individual small mammals captured per 100 trap nights), and diversity measures are shown in Tables 4-6. A multi-factor ANOVA with these variables, trapping session, site, and presence or absence of trails found a significant effect of time (session) on all three indices (p=0.0023; p=0.0001; p=0.0015 for richness, abundance, and diversity, respectively). Richness is best modeled as a function of session only. Abundance is best modeled as a function of session and segment (north/south). Diversity is best modeled as a function of session and individual site. Overall, the means were slightly higher on the non-trail side than on the trail side. The effect of trails on richness is -0.34 and is non-significant (p=0.383); on abundance it is -2.48, and is non-significant (p=0.108); and on diversity is -0.048, and is non-significant (p=0.263). Effects of stream segment (north/south) are non-significant for richness (p=0.334) and diversity (p=0.413), but highly significant for abundance (p=0.002), with 7.4 greater abundance on the south segment. See also "Trails effect on jumping mice", below.

Preble's Meadow Jumping Mice

A total of 89 individual Preble's meadow jumping mice were captured, and 85 PIT-tagged during June and August; 57 along South Boulder Creek (30 males, 25 females, and two of undetermined sex) and 32 on East Boulder Ditch (17 males, 15 females). Seven males and two females were recaptured from 1997.

All of the between-site movement occurred between East Boulder Ditch, Site 1, and Site 2 (25 animals), and between Sites 5 and 6 (two animals). Three animals recaptured at Site 1NT (no trail) had been marked at Site 2, and another three had been marked at EBD. Eight animals at Site 2T (trail) and 2NT had been marked at EBD (East Boulder Ditch). Eleven individuals recaptured at EBD had been marked at Site 1NT, Site 2T, or 2NT. One animal was marked at 5NT, moved across South Boulder Creek to 5T, and then returned to 5NT. Of the nine animals marked in 1997 and recaptured in 1998, six were marked at EBD. Three of these moved between East Boulder Ditch, 2T, and 2NT. One was marked and recaptured at 3T; one was marked at 2T and crossed the creek to 2NT; three were marked and recaptured at EBD; and one was marked at EBD and recaptured at 2NT then at 1NT.

Linear Population Density Estimates

Capture probabilities on jumping mice were high, 37.6 percent for both captures and recaptures. Linear population estimates were based on averaging the four best models. The best model is the one with capture and recapture probabilities set equal; the second has emigration and immigration set at zero; the third includes the effect of sex; and in the fourth, capture and recapture rates are unequal. For details on the best model and model averaging, please see Appendix.

Linear Density Estimates
Linear density estimates for jumping mice along South Boulder Creek are shown in Table 7. These estimates incorporate the correction factor for percent residency (see Appendix), which was 0.31 for the 63 m grids used in 1998, 0.47 for the 125 m transects used in 1997, and 0.64 for the 250 m transect along East Boulder Ditch. Thus the raw linear density estimates were reduced to these proportions of their original value. After this correction, the values were extrapolated to 1 km. Linear density estimates vary greatly from a high value of 91.6 animals per km for Site 2 in August 1997 (24 animals had been captured at that site) to 0.0 for July 1997 (no jumping mice captured). Focusing on the post-hibernation population of potentially reproducing adults (June and first half of July), the linear densities vary between 19.5 and 55.1 animals per km, with a mean of 32.7 animals per km. East Boulder Ditch had consistently high values, ranging from 26.4 to 65.8 animals per km.

To estimate the total population of mice on the 3.7 km (2.3 miles) stretch of South Boulder Creek that encompassed the six study sites, we used the June 1998 mean linear density of 32.7 animals/km. This results in an estimation of 121 jumping mice.

East Boulder Ditch has June and July linear densities of 44.2 and 65.8; the mean of these two values is 55.0 mice/km. We trapped along 250 m, which represents one quarter of a km, or 13.75 mice. We do not at this time have a determination of how many of the irrigation ditches contain suitable habitat in order to extrapolate the added numbers of mice along these drainages.

Survival Rates
The temporary immigration and emigration rates were estimated to be 0.585 ± 0.376 (se). Survival rates, shown below, are higher per month in winter than in summer. These monthly rates can be extrapolated to develop an over-winter rate, summer rate, and annual rate.

Survival Rates

	S (per month)	se(S)
Winter (Aug 1997-June 1998)	0.86	0.03
Summer (June 1998-Aug 1998)	0.78	0.28

Assuming ten months at the winter rate (August to June), and two months at the summer rate (June to August), we calculate a winter survival rate of 22 percent (calculated as 0.86^{10}=0.22), a summer survival rate of 60 percent (calculated as 0.78^2=0.61), and an annual survival rate of 13.5 percent (0.86^{10} X 0.78^2 = 0.135).

Trails effect on jumping mice
Population densities for jumping mice vary significantly across site (p=0.006) and session ($p<0.0022$). The best model of the population data includes both of these effects but not their interaction (p = 0.0001, R^2=0.458). The effect of trails is negative, reducing population density (least squares mean) from 33.4 ± 7.2 (SE) on the non-trail side to 24.8 ± 6.4 on the trail side; however this effect is not statistically significant (p=0.264). Sex is not a useful factor in modeling population density (p=0.916), nor is segment (with the attendant difference in intensity of human use) (p=0.339).

Riparian habitat densities of jumping mice
The riparian habitat mapping conducted by the Colorado Division of Wildlife allowed us to compare three different habitat types present on the sites (Figure 2). The northern half of the study areas is characterized as "Riparian Deciduous Tree - Cottonwood" (Category rt2) right along the creek, and "Riparian Herbaceous - Sedges/Rushes/Mesic Grasses (Waterlogged or Moist Soils" (Category rh2) immediately adjacent (Sites 1, 2, 3); the southern half of the study area is also rt2 along the creek and "Riparian Herbaceous - General" (Category rh) adjacent (Sites 4, 5, 6); East Boulder Ditch is rh2 only. The results, estimated as number of jumping mice per km, suggest that the northern segment has the lowest density of mice along South Boulder Creek; however, two of these sites had 0 values. Higher densities were found in the southern segment, and the highest densities were found along East Boulder Ditch where the tree canopy was lacking (Table 8).

Discussion

Small Mammals

The patterns of the vegetation between the trail and non-trail side of the creek are similar, such that differences in small mammal indices do not appear to be confounded by the vegetation. Although not statistically significant, a negative trail effect is suggested by the lower richness, abundance, and diversity on the trail versus non-trail sides of the creek. The third year of this study will provide a conclusive answer to this question. The importance of session in the ANOVA is probably due to the well-documented fluctuations in small mammal populations over time. The significantly greater abundance in the southern segment (Sites 4, 5, and 6) is attributable to a greater abundance of deer mice in the south, where they represented more than 50 percent of the captures: Total small mammals captured followed by the number of deer mice in parentheses is 109 (76) and 166 (98) in the southern segment and 52 (11) and 101 (35) in the northern segment in June and August, respectively (Tables 1 and 2). Habitat disturbances that affect specialists negatively benefit this quintessential generalist (Armstrong 1977). Although the vegetation data, collected in August, suggested only that shrub cover was lower in the southern segment, the grazing regime (longer grazing period and into the riparian) reduces cover earlier in the season which may enhance deer mouse habitat. Adapted to exploit disturbances, deer mice are tolerant of the reduction in vegetation associated with grazing, and studies have found that the deer mouse is more abundant under grazed conditions (Lusby et al. 1971; Moulton et al. 1981a, b; Schulz and Leininger 1991).

The data suggest that some factor may dampen small mammal richness, abundance, and diversity in the vicinity of trails. This may be due to the trails themselves with their lack of cover and habitat fragmentation effect; the activity or disturbance caused by the recreationists and/or their dogs; the edge effect; or to some indirect effect such as use of the same trails by predators. Coyotes (*Canis latrans*) were seen during the study, and red foxes (*Vulpes vulpes*) and striped skunks (*Mephitis mephitis*) are undoubtedly present as well; raptors may benefit from trails due to lack of interfering cover for their prey. The presence of domestic cats can have a notably deleterious effect on small mammal populations, but their occurrence at the site is not known. Studies have found that dirt roads impede free movement of voles (Cole 1978, Meserve 1971, Swihart and Slade 1984). Lack of cover and fragmentation of the habitat, recreationists, and the edge effect may function in combination to create disturbances that small mammals avoid.

We captured a Mexican woodrat last year on Site 3T, and again this year on Site 3NT. A thirteen-lined ground squirrel was captured last year on 2NT, and one was captured across the creek at 2T this year. A hispid pocket mouse was captured for the first time this year in June only on Site 4NT. No Norway rats were found this year, although one was captured last year on East Boulder Ditch.

Preble's Meadow Jumping Mice

There were some movements of jumping mice between transects. The movements between Sites 1 and 2 and East Boulder Ditch (25 animals) represented a maximum of 200 m, whereas those between Sites 5 and 6 (2 animals) were roughly 630 m. Thus travel distances of 200 m appear to be undertaken regularly and those in the 600 m range are undertaken occasionally. Travel distances determined from of tracking jumping mice with fluorescent pigment were 18.2 m for the average straight line distance and 32.2 m for total distance (Tester et al. 1993). However, travel distances of a few hundred meters to 1.6 km have been found locally at Rocky Flats Environmental Technology Site from tagged animals and radio-telemetry (Tom Ryon, personal communication).

The mean linear density estimate for meadow jumping mice in June, prior to the birth pulse, was 32.7 mice per km along South Boulder Creek, and resulted in an extrapolated estimate of 121 mice along the entire 3.7 km (2.3 mile) stretch of the study site. These estimates are substantially affected by the residency correction factor. This factor is 0.31 for the 63 m grids. Without the correction factor, the estimate would be 105 animals per km, or 390 animals for the entire stretch. Although the problem of capturing animals that do not reside on the grid is real, there are no standard solutions for dealing with this problem. The next year's data will allow us to learn more and perhaps fine-tune this correction factor.

These linear density estimates are at the low end of what have been reported but are within the range of other studies, which were computed as number of animals per ha or acre, rather than our linear density per km of stream reach. With the assumption that grids going out 72 m from the creek are a sufficient approximation to one hectare, we can use 3.2 animals/ha for South Boulder Creek for comparison. Adler et al. (1984) found peak densities of 3.1 - 7.5 animals/ha in Massachusetts, Nichols and Conley (1982) found densities of 17 - 93 animals/ha in Michigan in what they considered to be a dense population, and Blair (1940) found 2.8 to 5.0 animals per acre in the vicinity of a pond and ditch in Michigan.

Along East Boulder Ditch we estimated 55 mice/km (averaging from the first sessions from 1997 and 1998) and 13.75 mice total along the 250 m transect. These estimations could be extrapolated along other ditches of suitable habitat in the broad floodplain of South Boulder Creek to develop an estimate of jumping mouse populations along the creek and its ditch tributaries.

While monthly survival rates are lower in summer than in winter, the survival rate over the two months of summer is higher than the survival rate over the ten months of winter (22 percent for winter and 60 percent for summer). This reflects the fact that there are only two months in which to die during summer compared with ten months for winter. In a study in New York (Whitaker 1963), meadow jumping mice had an over-winter mortality rate of 67 percent, and thus a higher over-winter survival rate in that population than along South Boulder Creek. Survival rates from a study in Michigan were in the same range as those reported here, although calculated very differently (Muchlinski 1988); and in that population, young of the year born in early litters had higher overwintering survival values than those born in late litters.

Our modeling showed the immigration and emigration rate to be 58 percent, indicating that more than half the animals will leave temporarily and may come back. Adler et al. (1984) also found that individual jumping mice were transitory in their residence on a trapping grid. This finding, in combination with our high emigration and immigration rate, does support the need for substantial residency correction factor, as we have incorporated in our calculation. Our calculated survival rates assume permanent emigration as equivalent to mortality and unfortunately, at this point we do not have the ability to separate these two.

Densities of jumping mice varied significantly across site and session. A number of factors may contribute to this: patchiness of food resources in space and time, social behavior, degree of territoriality, and size of home range. It is difficult at this point to understand to what extent each of these factors plays a role. As with the small mammals in general, there is a negative, but non-significant effect of trails. Very possibly, the width of woody vegetation (Miller et al. 1997), the diverse plant structure, and the overall lushness of vegetation at the site contribute a degree of tolerance to trails because food resources and cover are still available.

The very limited grazing (December through February) on the study site appears not to have a detectable negative impact on the abundance of jumping mice, but does allow for an increase in deer mice. Habitat requirements of jumping mice may be more similar to those of meadow voles than deer mice, as suggested by evidence that meadow voles can exclude jumping mice (Boonstra and Hoyle 1986). The ecological relationships between deer mice and jumping mice are not known, although deer mice (and meadow voles) are common on small mammal trapping grids where jumping mice are found.

The present grazing regime started around 1990. Prior to that, grazing was heavy and occurred year round, resulting in denuded pasture (Mark Grundy, personal communication). The intervening years have clearly seen a resurgence in vegetation, and probably also in jumping mice. The limited grazing regime used at this site seems compatible with conservation and management of jumping mice, with the exception of grazing in the riparian corridor in the southern segment, where shrub canopy cover was lower. Although there was no difference in jumping mouse densities between the northern and southern segments, this could be due to other factors, and the plans to remove cows from the riparian corridor in the southern segment will likely allow for an increase in the shrubs and is likely to benefit jumping mice.

References

Adler, G.H., L.M. Reich, and R.H. Tamarin. 1984. Demography of the meadow jumping mouse (Zapus hudsonius) in eastern Massachusetts. American Midland Naturalist, 112:387-391.

Anderson, S.H. 1995. Recreational disturbance and wildlife populations. Pp. 157-168 *in* Wildlife and recreationists: coexistence through management and research. R.L. Knight and K.J. Gutzwiller, eds. Island Press, Washington, D.C. 372 pp.

Animal Care and Use Committee. 1998. Guidelines for the capture, handling, and care of mammals as approved by the American Society of Mammalogists Journal of Mammalogy, 79(4):1416-1431.

Armstrong, D.M. 1977. Ecological distribution of small mammals in the upper Williams Fork Basin, Grand County, Colorado. Southwestern Naturalist, 22:289-304.

Bakeman, M. E., editor. 1997. Report on habitat findings of the Preble's meadow jumping mouse. Processed report to U. S. Fish and Wildlife Service and Colorado Division of Wildlife, iv + 91 pp.

Bekoff, M., and C.A. Meaney. 1997. Interactions among dogs, people, and the environment in Boulder, Colorado: a case study. Anthrozoös, 10(1):23-31.

Blair, W.F. 1940. Home ranges and populations of the jumping mouse. American Midland Naturalist, 23:244-250.

Boarman, W.J., and M. Sazaki. 1996. Highway mortality in desert tortoises and small vertebrates: success of barrier fences and culverts. Pp. 1-5 *in* Highways and movement of wildlife: improving habitat connections and wildlife passageways across highway corridors. G. Evink, D. Ziegler, P. Garrett, and J. Berry, eds. Proceedings of the Florida Department of Transportation/Federal Highway Administration, Transportation-Related Wildlife Mortality Seminar, Orlando, Florida, April 30-May 2, 1996.

Boonstra, R., and J.A. Hoyle. 1986. Rarity and coexistence of a small hibernator, *Zapus hudsonius*, with fluctuating populations of *Microtus pennsylvanicus* in the grasslands of southern Ontario. Journal of Animal Ecology, 55:773-784.

Bowers, M.A., S.F. Matter, J.L. Dooley, Jr., J.L. Dauten, and J.A. Simkins. 1996. Controlled experiments of habitat fragmentation: a simple computer simulation and a test using small mammals. Oecologia, 108:182-191.

Boyle, S.A., and F. B. Samson. 1985. Effects of non-consumptive recreation on wildlife: a review. Wildl. Soc. Bull., 13:110-116.

Bright, P.W. 1998. Behaviour of specialist species in habitat corridors: arboreal dormice avoid corridor gaps. Animal Behaviour, 56:1485-1490.

Brittingham, M.C. and S.A. Temple. 1983. Have cowbirds caused forest birds to decline? BioScience 33:31-35.

Burhnam, K. P. and D. R. Anderson. 1998. Model selection and inference – a practical information theoretic approach. Springer, New York. 353 pp.

Cole, D.N., and P.B. Landres. 1995. Indirect effects of recreation on wildlife. Pp. 183-202 *in*: Wildlife and recreationists: coexistence through management and research. R.L. Knight and K.J. Gutzwiller, eds. Island Press, Washington, D.C.

Cole, F.R. 1978. A movement barrier useful in population studies of small mammals. American Midland Naturalist, 100:480-482.

Cooch, E., and G. White. "MARK – An Introductory Guide."August 29, 1998. http://www.biol.sfu.ca/cmr/mark/page2.html (4 Feb. 1999).

Diffendorfer, J.E., N.A. Slade, M.S. Gaines, and R.D. Holt. 1995. Population dynamics of small mammals in fragmented and continuous old-field habitat. Pp. 175-199 *in* Landscape approaches in mammalian ecology and conservation. W.Z. Lidicker, Jr., ed. University of Minnesota Press, Minneapolis. 215 pp.

Fitzgerald, J.P., C.A. Meaney, and D.M. Armstrong. 1994. Mammals of Colorado. University Press of Colorado, Boulder, and Denver Museum of Natural History, Denver. 467 pp.

Flather, C.H., and H.K. Cordell. 1995. Outdoor recreation: historical and anticipated trends. Pp. 3-16 *in*: Wildlife and recreationists: coexistence through management and research. R.L. Knight and K.J. Gutzwiller, eds. Island Press, Washington, D.C.

Fraser, J.D., L.D. Franzel, and J.E. Mathisen. 1985. The impact of human activities on breeding bald eagles in north-central Minnesota. Journal of Wildlife Management, 49:385-392.

Gutzwiller, K.J. 1995. Recreational disturbance and wildlife communities. Pp. 169-181 *in* Wildlife and recreationists: coexistence through management and research. R.L. Knight and K.J. Gutzwiller, eds. Island Press, Washington, D.C. 372 pp.

Hall, E.R. 1981. The mammals of North America, Volume II. John Wiley and Sons, New York. Pp. 601-1181 + 90.

Harris, L.S. and G. Silva-Lopez. 1992. Forest fragmentation and the conservation of biological diversity. Pp. 198-237 *in*: Conversation biology: the theory and practice of nature conservation, preservation, and management. P.L. Fiedler and S.K. Jain, eds. Chapman and Hall, New York, New York.

Hickman, S. 1990. Evidence of edge species attraction to nature trails within deciduous forest. Natural Areas Journal, 10(1):3-5.

Johnson, R.G., and S.A. Temple. 1986. Assessing habitat quality for birds nesting in fragmented tallgrass prairies. Pp. 245-249 *in*: Wildlife 2000, modeling habitat relationships of terrestrial vertebrates. J. Verner, M.L. Morrison, and C.J. Ralph, eds. University of Wisconsin Press, Madison, Wisconsin.

Kendall, W. L., and J. D. Nichols. 1995. On the use of secondary capture-recapture samples to estimate temporary emigration and breeding proportions. J. Applied Statistics 22:751-762.

Kendall, W. L., J. D. Nichols, and J. E. Hines. 1997. Estimating temporary emigration using capture-recapture data with Pollock's robust design. Ecology 78:563-578.

Kendall, W. L., K. H. Pollock, and C. Brownie. 1995. A likelihood-based approach to capture-recapture estimation of demographic parameters under the robust design. Biometrics 51:293-308.

Knight, R.L., and Gutzwiller, K.J. (editors). 1995. Wildlife and Recreation: Coexistence Through Management and Research. Island Press, Washington, D.C. 372 pp.

Knight, R.L., and S.G. Miller. 1997. Influence of recreational trails on breeding bird communities. Research Abstracts of the City of Boulder Open Space and Mountain Parks Research Symposium, March 15, 1997.

Knight, R.L., and S.A. Temple. 1995. Wildlife and recreationists: coexistence through management. Pp. 327-333 *in* Wildlife and recreationists: coexistence through management and research. R.L. Knight and K.J. Gutzwiller, eds. Island Press, Washington, D.C. 372 pp.

Lusby, G.C., V.H. Reid, and O.D. Knipe. 1971. Effects of grazing on the hydrology and biology of the Badger Wash Basin in western Colorado, 1953-1966. Water Supply Papers, U.S. Geological Survey, 1532-D:1-90.

Meserve, P.L. 1971. Population ecology of the prairie vole, *Microtus ochrogaster*, in the western mixed prairie of Nebraska. American Midland Naturalist, 86:417-433.

Miller, C.K. 1994. Environmental impacts of passive recreational trails in riparian areas. Proceedings of the 6th Annual Colorado Riparian Association Conference. 12 pp.

Miller, J.R., N.T. Hobbs, and J.A. Wiens. 1997. Avian diversity and predator assemblages in lowland riparian areas across a gradient of urbanization. A final report to the City of Boulder Open Space Department.

Moulton, M.P. 1981. Small mammals on revegetated agricultural land in eastern Colorado. Prairie Naturalist, 13:99-104.

Moulton, M.P., J.R. Choate, S.J. Bissell, and R.A. Nicholson. 1981. Associations of small mammals on the central High Plains of eastern Colorado. Southwestern Naturalist, 26:53-57.

Muchlinski, A.E. 1988. Population attributes related to the life-history strategy of hibernating *Zapus hudsonius*. Journal of Mammalogy, 69:860-865.

Nichols, J.D., and W. Conley. 1982. Active-season dynamics of a population of *Zapus hudsonius* in Michigan. Journal of Mammalogy, 63:422-430.

Oxley, D.J., M.B. Fenton, and G.R. Carmody. 1974. The effects of roads on populations of small mammals. Journal Applied Ecology, 11:51-59.

Paton, P.W.C. 1994. The effect of edge on avian nests success: how strong is the evidence? Conservation Biology, 8:17-26.

Pollock, K. H., J. D. Nichols, C. Brownie, and J. E. Hines. 1990. Statistical inference for capture-recapture experiments. Wildlife Monographs 107. 97pp.

Robinson, S.K. 1988. Reappraisal of the costs and benefits of habitat heterogeneity for nongame wildlife. Transactions of the North American Wildlife and Natural Resources Conference, 53:145-155.

Ryon, T.R. 1996. Evaluation of historical capture sites of the Preble's meadow jumping mouse in Colorado. M.S.E.S. Thesis, University of Colorado, Denver.

SAS Institute, Inc. 1989. SAS/STAT User's Guide, Version 6, Fourth Edition, Volume 2, Cary NC. 846 pp.

Schultz, T.T., and W.C. Leininger. 1991. Nongame wildlife communities in grazed and ungrazed montane riparian sites. Great Basin Naturalist, 51:286-292.

Seber, G. A. F. 1982. The estimation of animal abundance and related parameters. 2nd ed. Macmillan, New York, USA. 654 pp.

Seber, G. A. F. 1986. A review of estimating animal abundance. Biometrics 42:267-292.

Seber, G. A. F. 1992. A review of estimating animal abundance II. Reviews of the International Statistics Institute 60:129-166.

Swihart, R.K., and N.A. Slade. 1984. Road crossing in *Sigmodon hispidus* and *Microtus ochrogaster*. Journal of Mammalogy, 65 (2):357-360.

Tester, J.R., S. Malchow, C. Mclain, and J.B. Lehrer. 1993. Movements and habitat use by meadow jumping mice in northwestern Minnesota. Prairie Naturalist, 25:33-37.

Van Horne, B. 1983. Density as a misleading indicator of habitat quality. Journal of Wildlife Management, 47 (4):893-901.

Weber, S.E. 1995. Life on the edge: small mammal and vegetation community response to trail-induced ecotones in southern California chaparral. Abstract, 9th Annual meeting of the Society for Conservation Biology, Colorado State University, June 7-11, 1995.

Whitaker, J.O., Jr. 1963. A study of the meadow jumping mouse, *Zapus hudsonius* (Zimmermann), in central New York. Ecological Monographs, 33:215-254.

White, G. C. and D. R. Anderson. "Analysis of Marked Animal Encounter Data." January 21, 1998. http://neota.cnr.colostate.edu/fw663/Mark.html (4 Feb. 1999).

Wilcove, D. 1985. Nest predation in forest tracts and the decline of migratory songbirds. Ecology 66:1211-1214.

Zar, J.H. 1996. Biostatistical Analysis. Prentice Hall, New Jersey.

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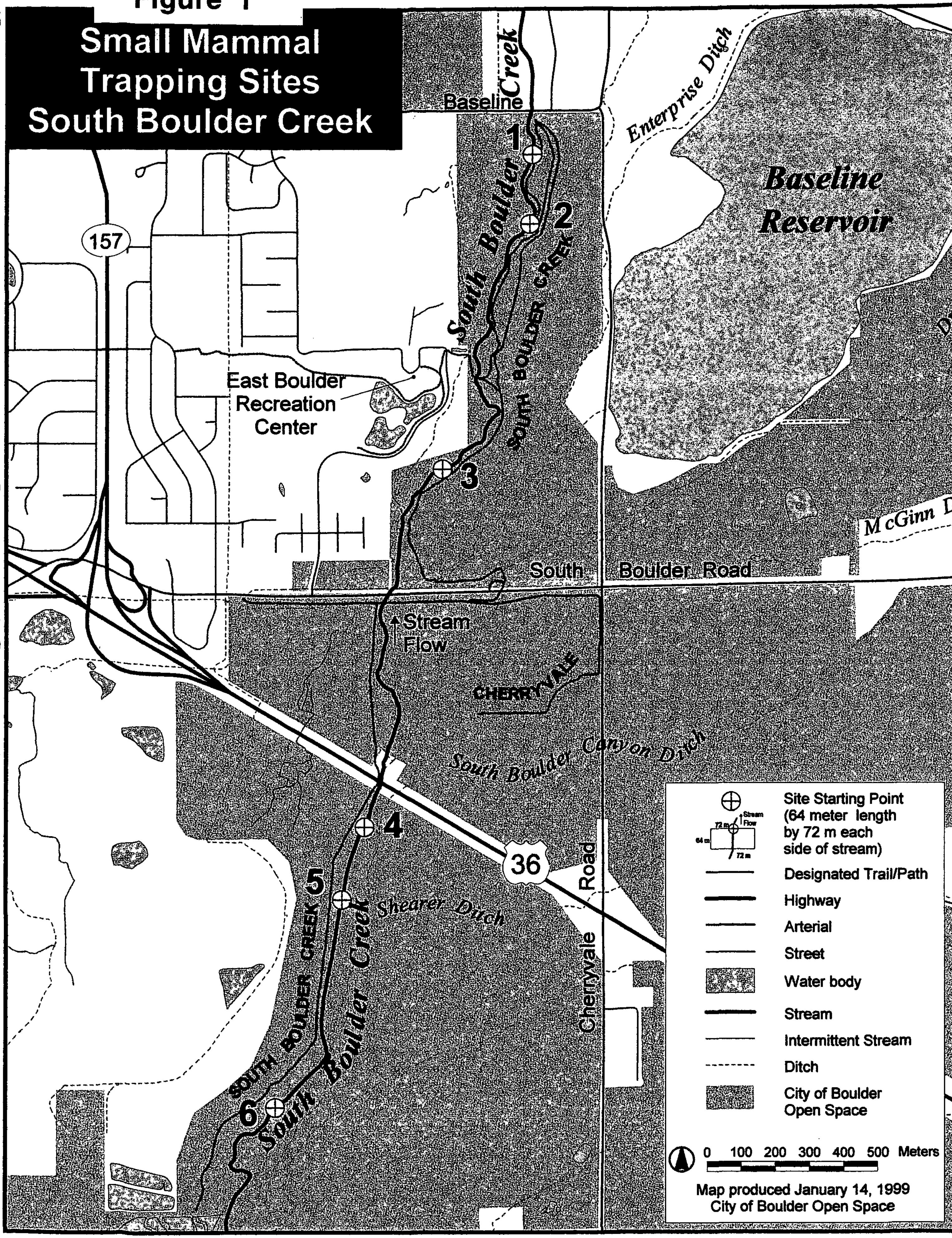
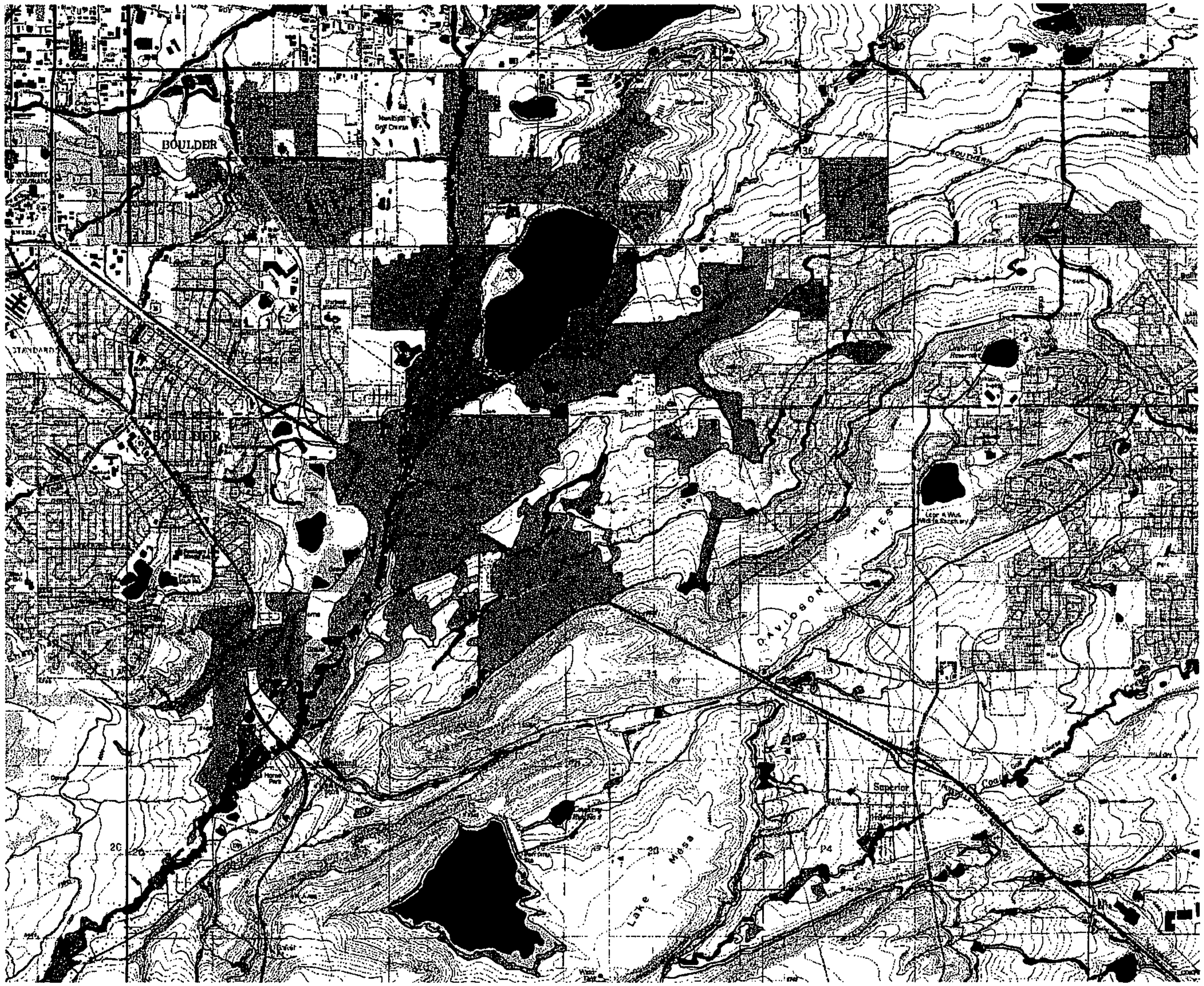
Figure 1



Small Mammal Trapping Sites South Boulder Creek
Baseline
South Boulder Creek
Enterprise Ditch
Baseline Reservoir
157
SOUTH BOULDER CREEK
East Boulder Recreation Center
1
2
3
4
5
6
McGinn D
South Boulder Road
Stream Flow
CHERRYVALE
South Boulder Canyon Ditch
36
Cherryvale Road
Shearer Ditch
Site Starting Point (64 meter length by 72 m each side of stream)
Designated Trail/Path
Highway
Arterial
Street
Water body
Stream
Intermittent Stream
Ditch
City of Boulder Open Space
0 100 200 300 400 500 Meters
Map produced January 14, 1999
City of Boulder Open Space

Figure 2 - Riparian Habitat Map
South Boulder Creek, Colorado



Riparian Legend

- General Tree
- Aspen
- Cottonwood
- Russian Olive
- Riparian Evergreen
- Riparian Shrub (general)
- Willow
- Tamarisk
- Alpine Willow
- Gambel's Oak
- Riparian Herbaceous (general)
- Riparian Herbaceous (Standing Water)
- Riparian Herbaceous (Waterlogged Soils)
- Open Water - Lentic
- Open Water - Riverine
- Open Water - Canal
- Non-Vegetated
- Sandbar
- Upland Tree
- Upland Shrub
- Upland Grass
- Urban

0 1 2 3 4 5 Miles

N W E S

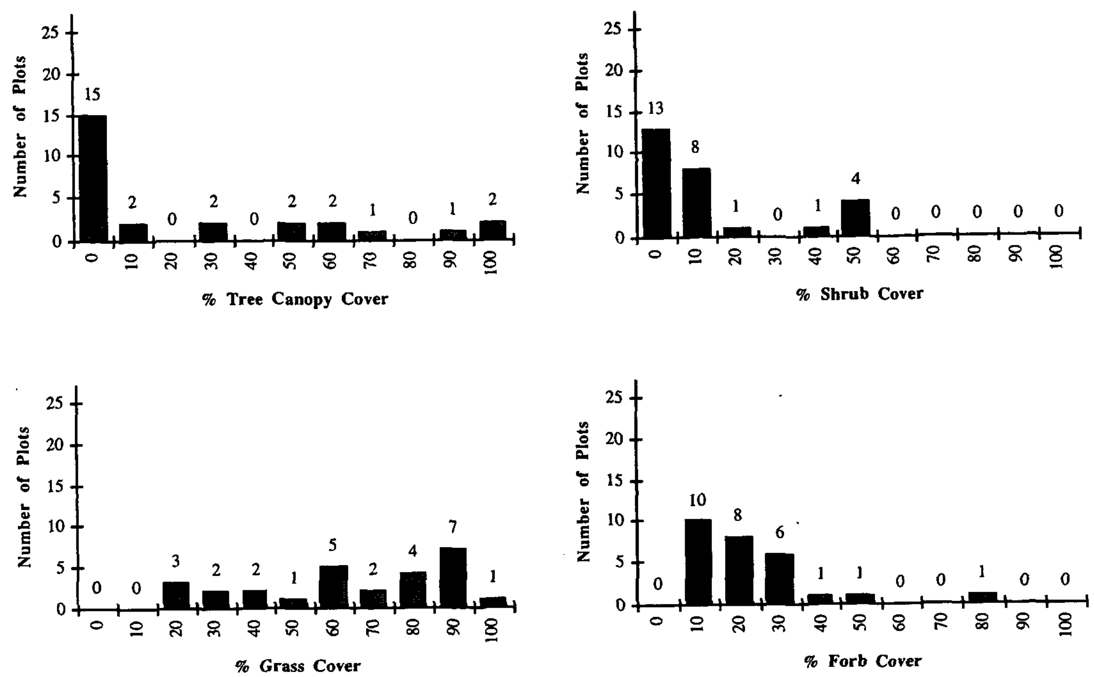


Figure 3. Percent cover of trees, shrubs, grasses and forbs at South Boulder Creek Sites 1, 2, 3, trail side. Data collected from 10-meter diameter circles at 27 randomly selected traps.

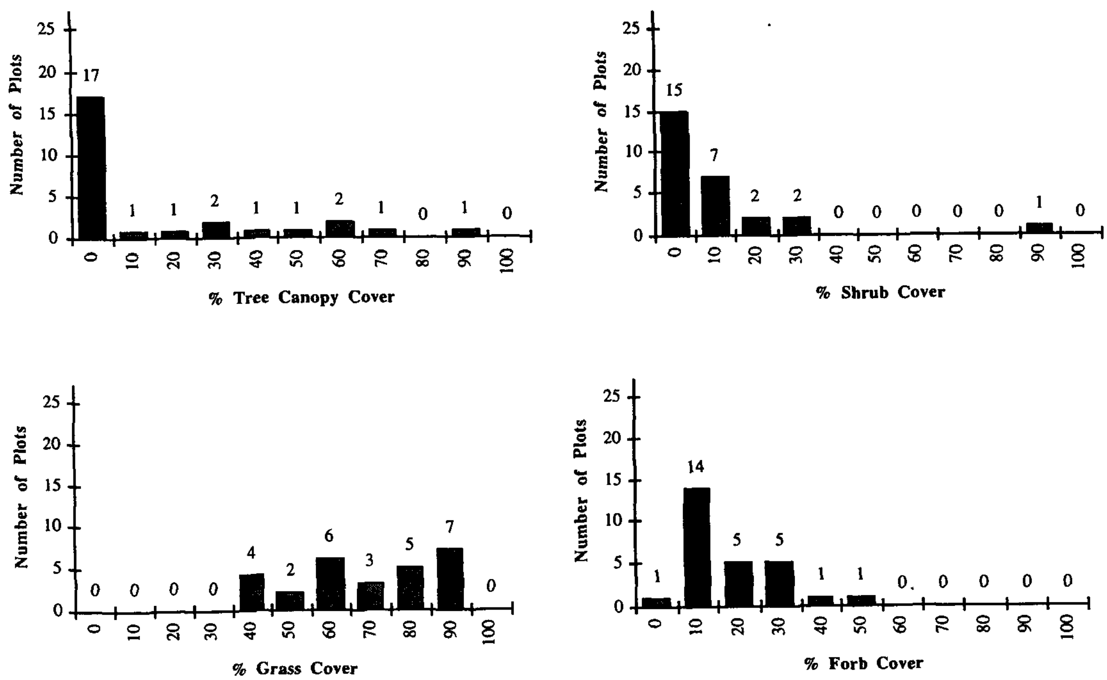


Figure 4. Percent cover of trees, shrubs, grasses and forbs at South Boulder Creek, Sites 1, 2, 3 non-trail side. Data collected from 10-meter diameter circles at 27 randomly selected traps.

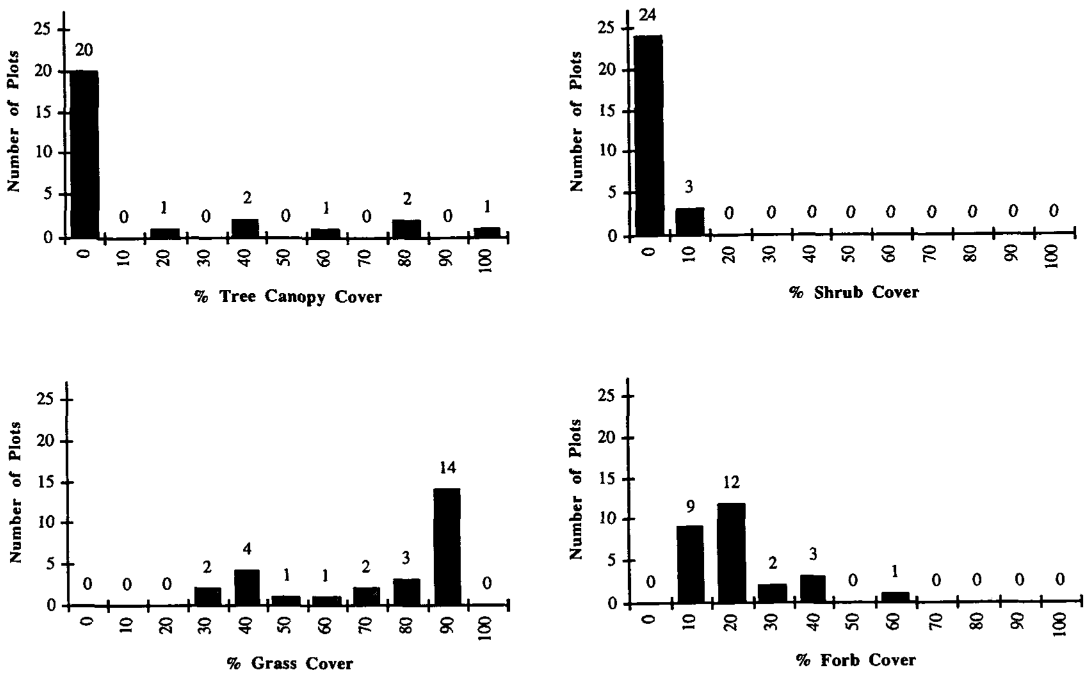


Figure 5. Percent cover of trees, shrubs, grasses and forbs at South Boulder Creek, Sites 4, 5, 6 trail side. Data collected from 10-meter diameter circles at 27 randomly selected traps.

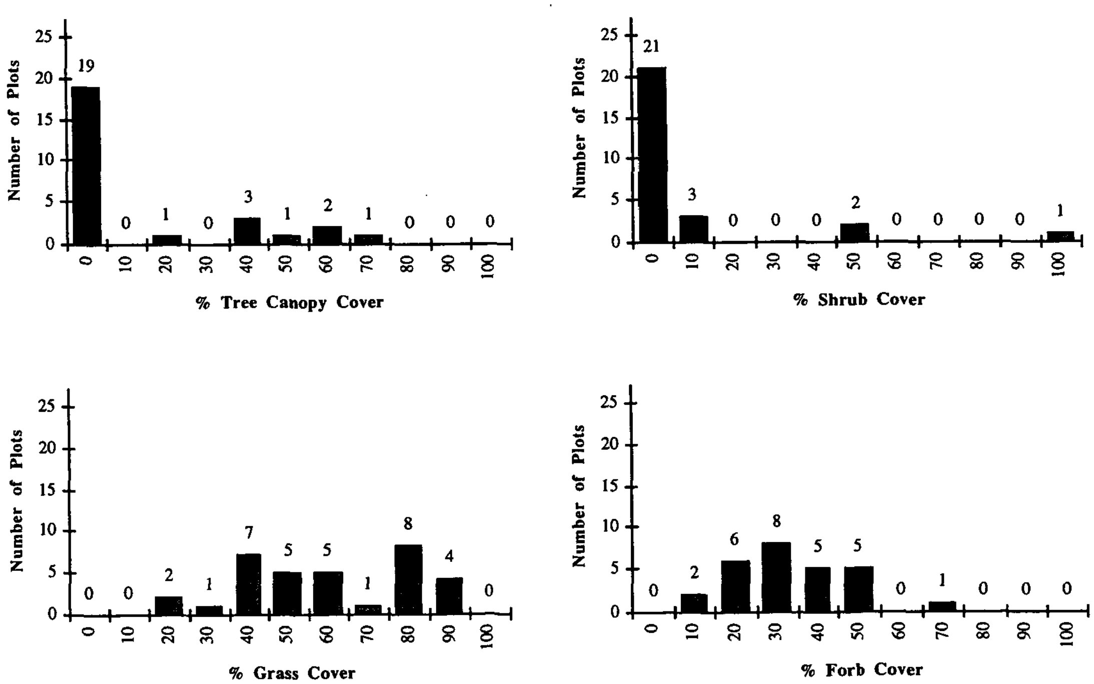


Figure 6. Percent cover of trees, shrubs, grasses and forbs at South Boulder Creek, Sites 4, 5, 6 non-trail side. Data collected from 10-meter diameter circles at 27 randomly selected traps.

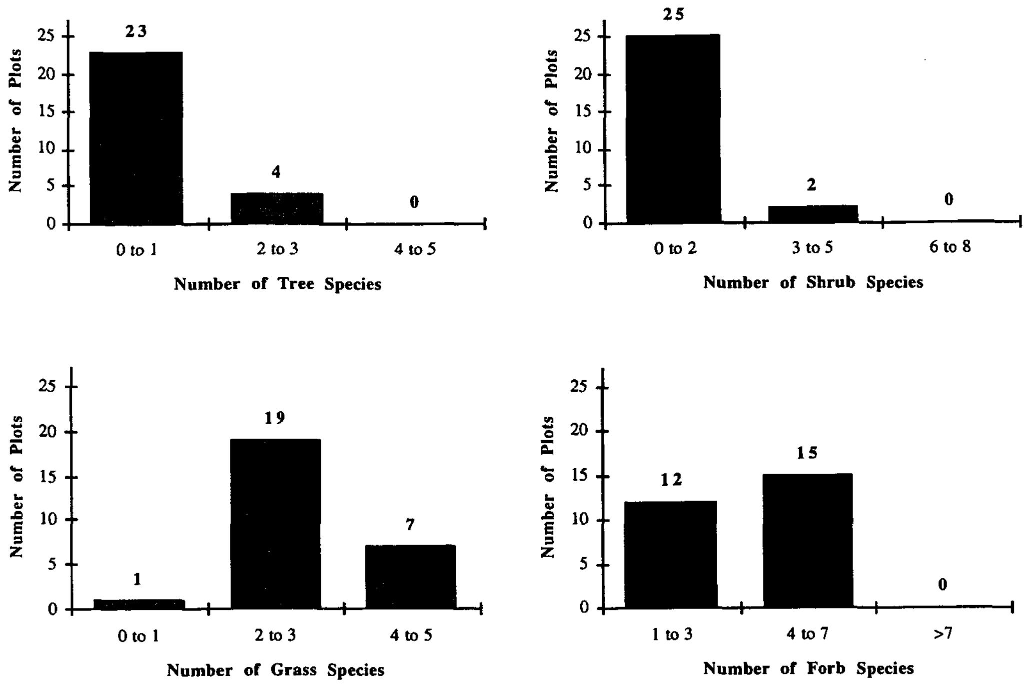


Figure 7. Tree, shrub, grass and forb species richness at South Boulder Creek, Sites 1, 2, 3 trail side. Data collected from 10-meter diameter circles at 27 randomly selected sites.

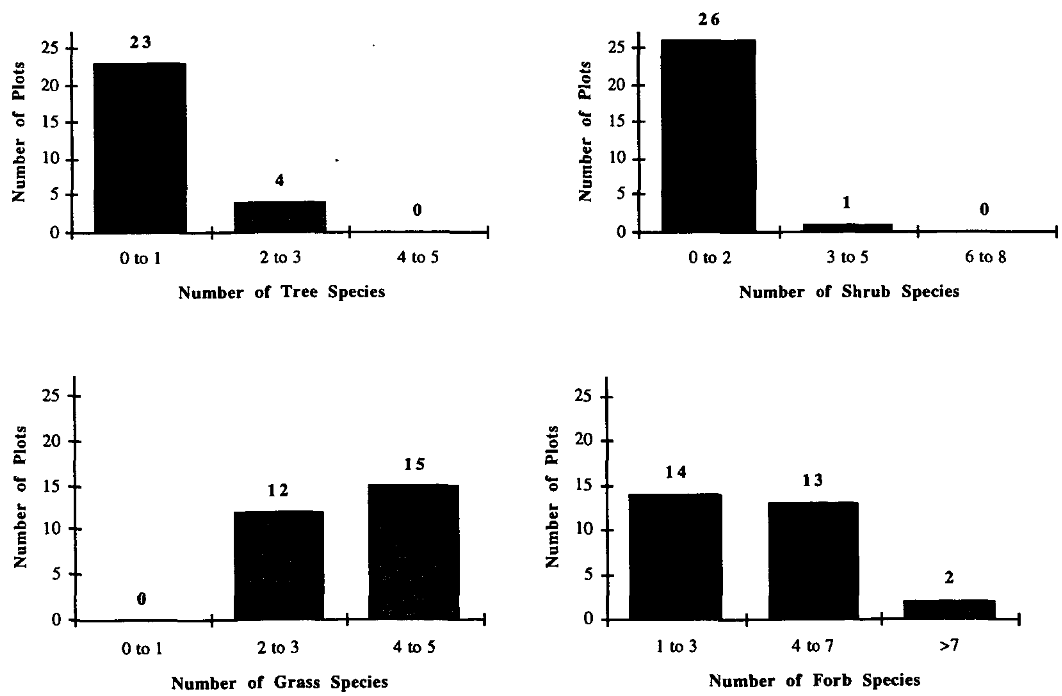


Figure 8. Tree, shrub, grass and forb species richness at South Boulder Creek, Sites 1, 2, 3, non-trail side. Data collected from 10-meter diameter circles at 27 randomly selected sites.

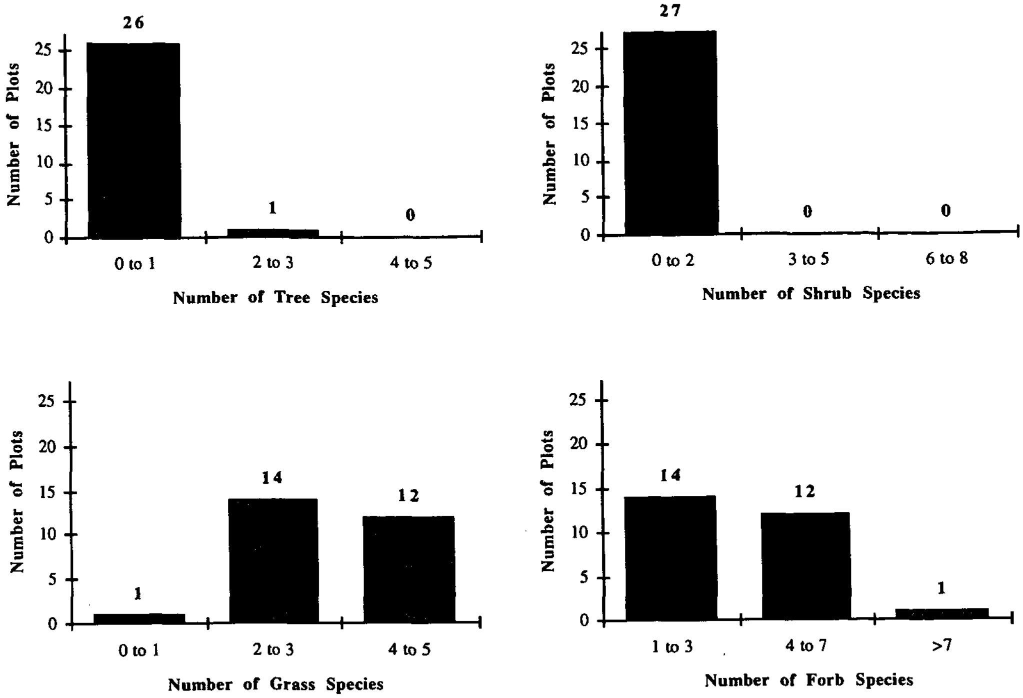


Figure 9. Tree, shrub, grass and forb species richness at South Boulder Creek, Sites 4, 5, 6, trail side. Data collected from 10-meter diameter circles at 27 randomly selected sites.

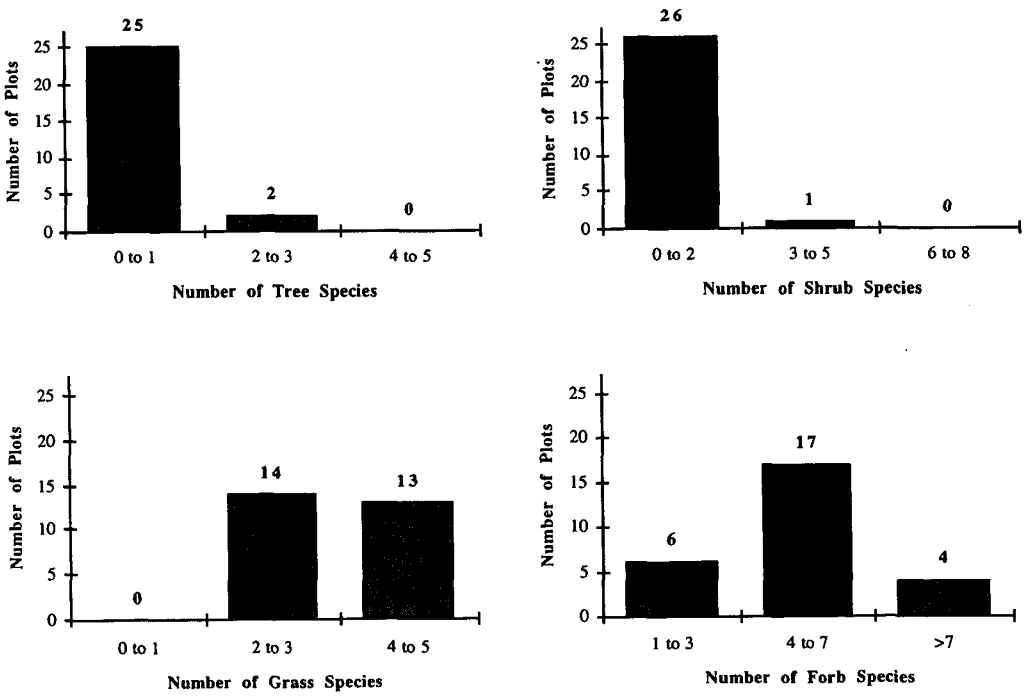


Figure 10. Tree, shrub, grass and forb species richness at South Boulder Creek, Sites 4, 5, 6 non-trail side. Data collected from 10-meter diameter circles at 27 randomly selected sites.

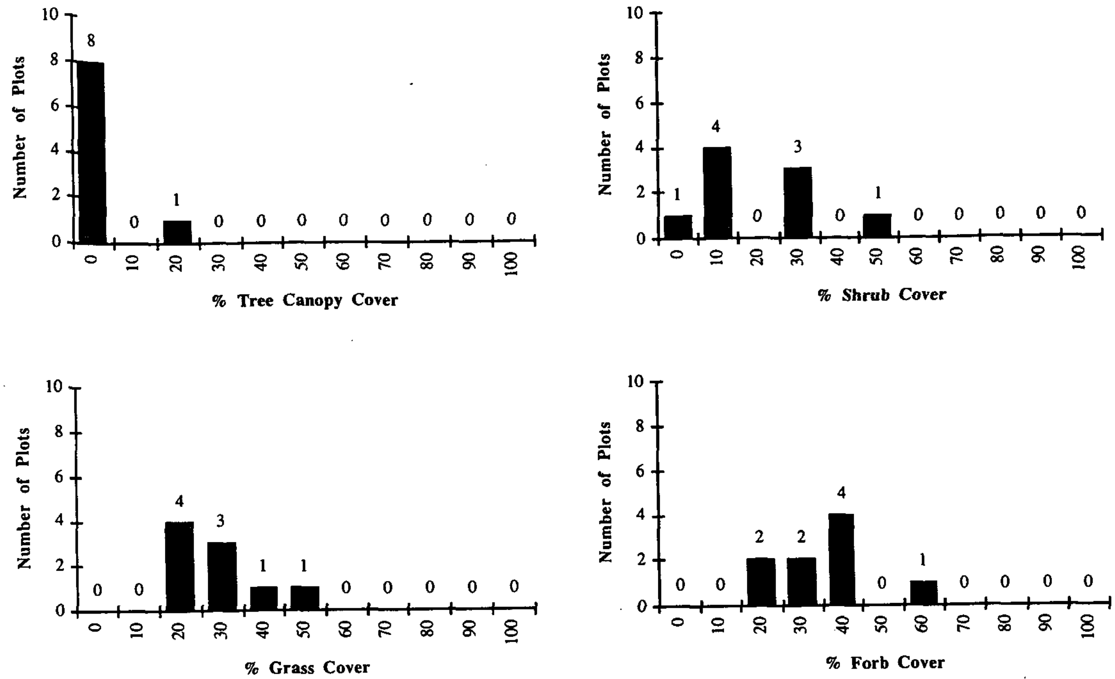


Figure 11. Percent cover of trees, shrubs, grasses and forbs at East Boulder Ditch. Data collected from 10-meter diameter circles at 9 randomly selected traps.

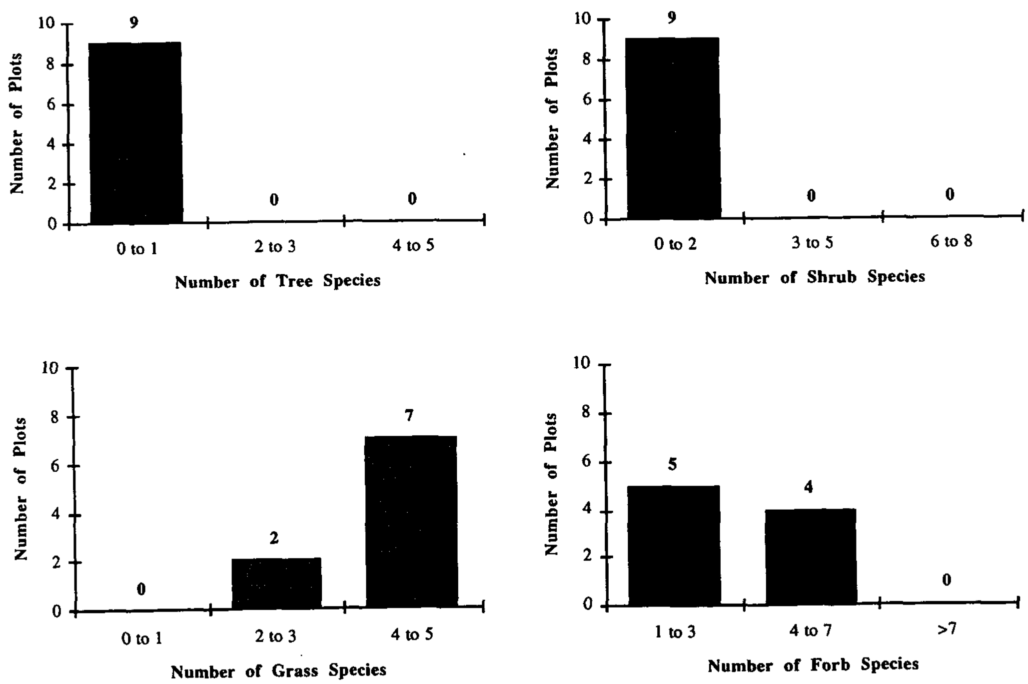


Figure 12. Tree, shrub, grass and forb species richness at East Boulder Ditch. Data collected from 10-meter diameter circles at 9 randomly selected traps.

Table 1. South Boulder Creek individual small mammal captures by site, on trail and non-trail side of creek, June 1998.

Species	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6		TOTAL	
	T	NT	T	NT	T	NT	T	NT	T	NT	T	NT	T	NT
Chaetodipus hispidus Hispid Pocket Mouse	0	0	0	0	0	0	0	1 (1)	0	0	0	0	0	1 (1)
Microtus ochrogaster Prairie Vole	0	1	0	5	1	0	1	1	1	3	0	0	3	10
Microtus pennsylvanicus Meadow Vole	0	0	0	4 (1)	0	1	1	0	0	3	0	1	1	9 (1)
Neotoma mexicana Mexican Wood Rat	0	0	0	0	0	1 (1)	0	0	0	0	0	0	0	1 (1)
Peromyscus maniculatus Deer Mouse	4 (2)	0	1 (3)	3 (1)	3 (2)	0	12 (13)	7 (9)	8 (9)	18 (30)	16 (3)	15 (9)	44 (32)	43 (49)
Reithrodontomys megalotis Western Harvest Mouse	0	0	1	0	0	0	0	0	0	0	0	0	1	0
Zapus hudsonius preblei Preble's Meadow Jumping Mouse	0	9 (6)	5 (1)	7 (6)	3	1	1	3 (1)	2	4 (3)	8	4 (3)	19 (1)	28 (19)
Total	4 (2)	10 (6)	7 (4)	19 (8)	7 (2)	3 (1)	15 (13)	12 (11)	11(9)	28 (33)	24 (3)	20 (12)	68 (33)	92 (71)

Notes:
T - Trail side
NT - Non-trail side
Values in parentheses indicate recaptures

Table 2. South Boulder Creek individual small mammal captures by site, on trail and non-trail side of creek, August 1998.

Species	**Site 1**		**Site 2**		**Site 3**		**Site 4**		**Site 5**		**Site 6**		**TOTAL**	
	T	**NT**	**T**	**NT**	**T**	**NT**	**T**	**NT**	**T**	**NT**	**T**	**NT**	**T**	**NT**
Microtus ochrogaster Prairie Vole	1	0	5 (1)	0	1	3	0	2 (1)	0	4	1	0	8 (1)	9 (1)
Microtus pennsylvanicus Meadow Vole	0	1	6 (2)	6 (3)	9	8	10	6 (1)	9 (3)	4	5	1	39 (5)	26 (4)
Microtus spp. vole species	2	0	8	0	2	0	1	0	1	1	0	0	14	1
Mus musculus House Mouse	0	0	1	1	0	0	0	1	0	0	0	1	1	3
Neotoma mexicana Mexican woodrat	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Peromyscus maniculatus Deer Mouse	4 (1)	4 (7)	8 (3)	5 (2)	7 (4)	7 (2)	15 (15)	27 (14)	9 (4)	24 (22)	11 (9)	12 (17)	54 (36)	79 (64)
Reithrodontomys megalotis Western Harvest Mouse	0	0	0	0	0	3	0	0	0	0	0	2	0	5
Spermophilus tridecemlineatus 13-lined ground squirrel	0	0	1	0	0	0	0	0	0	0	0	0	1	0
Zapus hudsonius preblei Preble's Meadow Jumping Mouse	1	0	5(1)[1]	[1]	0	0	1	0	0	4	5(4)[2]	8(6)[1]	12(5)[3]	12(6)[2]
Total	8 (1)	5 (7)	34(7)[1]	12(5)[1]	19(4)	21(2)	27 (15)	37 (16)	19(7)	37 (22)	22(13)[2]	24(23)[1]	129(47)[3]	136(75)[2]

Notes:
T - Trail side
NT - Non-trail side
Values in () parentheses indicate recaptures
Values in [ ] parentheses indicate recaptures of animals marked in June

Table 3. East Boulder Ditch individual small mammal captures, June and August 1998.

Species	June	August
Microtus ochrogaster Prairie Vole	0	3 (1)
Microtus pennsylvanicus Meadow Vole	1	15 (11)
Microtus spp. Vole species	0	2
Mus musculus House Mouse	0	2
Neotoma mexicana Mexican Wood Rat	0	0
Peromyscus maniculatus Deer Mouse	2 (3)	7 (5)
Zapus hudsonius preblei Preble's Meadow Jumping Mouse	21 (15)	11 (7) [3]
Total	24 (18)	40 (24) [3]

Notes:
Values in ( ) parentheses indicate recaptures
Values in [ ] parentheses indicate recaptures of animals marked in June

Table 4. Species richness estimates for small mammals modeled on session, segment (north vs. south), and use (trail vs. non-trail) along South Boulder Creek.

Area	Factor		Richness	se(Richness)
SBC	Session[1]	1	4.33	0.598
		2	5.67	0.598
		2	2.92	0.299
		4	3.83	0.299
	Segment[2]	N	4.08	0.259
		S	4.50	0.400
	Use[3]	N	4.39	0.327
		T	4.05	0.286
	Segment + use [4]	N N	4.28	0.344
		N T	3.94	0.306
		S N	4.70	0.457
		S T	4.36	0.429
	All[1]		4.19	0.236
EBD	Session	1	4.00	
		2	4.00	
		3	3.00	
		4	5.00	
	All		4.00	0.410

Notes:
[1] Model: Richness = session
[2] Model: Richness = session + den
[3] Model: Richness = session + use
[4] Model: Richness = session + den + use

Table 5. Abundance estimates for small mammals modeled on session, segment (north vs. South), and use (trail vs. non-trail) along South Boulder Creek.

Area	Factor		Abundance	se (Abundance)
SBC	Session[1]	1	9.0	2.55
		2	31.5	2.55
		3	7.6	1.20
		4	11.5	1.20
	Segment[1]	N	11.2	1.04
		S	18.6	1.59
	Use[2]	N	16.3	1.33
		T	13.9	1.18
	Segment + use[2]	N N	12.6	1.33
		N T	10.1	1.18
		S N	20.1	1.76
		S T	17.6	1.65
	All[1]		14.9	1.04
EBD	Session	1	26.0	
		2	30.0	
		3	21.5	
		4	33.0	
		All	27.6	2.49

Notes:
[1] Model: abundance = session + segment
[2] Model: abundance = session + segment + use

Table 6. Diversity estimates for small mammals modeled on session, segment (north vs. South), and use (trail vs. non-trail) along South Boulder Creek.

Area	Factor		Diversity	se(Diversity)
SBC	Session[1]	1	0.41	0.07
		2	0.55	0.07
		3	0.28	0.03
		4	0.39	0.03
	Use[2]	N	0.44	0.04
		T	0.39	0.03
	Segment[3]	N	0.46	0.04
		S	0.41	0.06
	Segment + use[4]	N N	0.47	0.05
		N T	0.45	0.04
		S N	0.42	0.07
		S T	0.40	0.06
	All[1]		0.41	0.03
EBD	Session	1	0.44	
		2	0.36	
		3	0.20	
		4	0.56	
	All		0.39	0.08

Notes:
[1] Model: diversity = session + site
[2] Model: diversity = session + site + use
[3] Model: diversity = session + segment
[4] Model: diversity = session + segment + use

Table 7. Population density estimates (per km) for Preble's meadow jumping mice on South boulder Creek and East Boulder Ditch (EBD), ± SE. Estimates incorporate residency correction factor; trail and non-trail grids combined. LSMeans for overall densities by session and site are based on a site+session model (ANOVA).

	Date				
Site	July 1997	August 1997	June 1998	August 1998	LSMean (All sessions)
1			39.0 ± 14.1	0.0 ± 0.0	21.1 ± 11.7
2	0.0 ± 0.0	91.6 ± 29.5	43.9 ± 15.9	29.2 ± 10.6	41.2 ± 7.2
3	0.0 ± 0.0	7.5 ± 2.1	19.5 ± 7.1	0.0 ± 0.0	8.3 ± 8.6
4			19.5 ± 7.1	4.9 ± 1.8	13.8 ± 11.7
5			19.5 ± 7.1	14.6 ± 5.3	18.6 ± 11.7
6			55.1 ± 21.3	74.8 ± 28.5	66.5 ± 11.7
Sites 1-6 LSMean	0.0[1] ± 13.3	61.6 ± 13.3	32.7 ± 5.9	20.6 ± 5.9	28.2 ± 5.6
EBD	65.8 ± 22.8	54.7 ±12.9	44.2 ± 10.4	26.4 ± 6.0	47.8 ± 3.4

Note:
[1]Value truncated to 0.0

Table 8. Preliminary evaluation of jumping mouse densities on three different riparian habitat types.

Habitat Classification	Site	Date	Adjusted Density (per km)	LSMeans
rh2, rt2	1	June 98	39.0	
	2	July 97	0.0	
	2	June 98	43.9	
	3	July 97	0.0	
	3	June 98	19.5	23.5±5.6
rh, rt2	4	June 98	19.5	
	5	June 98	19.5	
	6	June 98	56.1	33.0±8.1
rh2	EBD	July 97	65.7	
	EBD	June 98	44.0	47.8±3.4

Notes:
rt2 - Riparian Deciduous Tree - Cottonwood
rh2 - Riparian Herbaceous - Sedges/Rushes/Mesic Grasses (Waterlogged or Moist Soils)
rh - Riparian Herbaceous - General

Sites 1, 2, 3, and East Boulder Ditch are in the northern segment of the study area, and Sites 4, 5, and 6 are in the southern segment of the study area.

APPENDIX

METHODS

Population Size Estimation

The Robust Design model accommodates multiple trapping sessions separated by long intervals (months in this study) where each session consists of multiple trapping occasions separated by short intervals (days in this study). Both population size during each session and survival and immigration/emigration rates during the intervening intervals are estimated.

The 1998 trapping sessions present a complex analytical situation, because not all sites were trapped simultaneously and it was possible for individuals to be captured at multiple sites. Consequently, the sites cannot be analyzed separately as entirely independent populations. We chose to model the entire 12 days of trapping during each of the two sessions in 1998 (June and August) as a single trapping session Individuals were assigned to a home site (one of the six study sites), based on the largest number of captures, or if tied, then based on the location of first capture. Probability of capturing individuals during a week in which traps were placed on its home grid was modeled separately from the probability of capturing individuals during a week when traps were placed on adjacent grids, but not the home grid. Probability of capturing individuals during a week when traps were not placed either on the home or adjacent grids was assumed to be negligible. Because the entire study was analyzed as a single data set, there were 26 groups (13 sites x 2 sexes) and 31 capture occasions (3 nights in July 1997 + 4 nights in August 1997 + 12 nights in June 1998 + 12 nights in August 1998).

Population Adjustments and Extrapolations

Percent residency, p_0, represents the proportion of animals captured on her grids or transects of length, L_0, that are true residents (defined has having more than 50 percent of their observations on the transect). This parameter was converted to an effective boundary strip width, w_0, as follows:

$$w_0 = \frac{L_0}{2}\left(\frac{1}{p_0} - 1\right) \qquad se(w_0) = \sqrt{\frac{L_0^2}{p_0^4}\frac{[se(p_0)]^2}{4}}$$

Based on her analysis, adjustment for a boundary strip of $w_0 = 70.585 \pm 37.22$ m (se) is required. This effective strip width, w_0, was then used to estimate the residency proportion, p, for grids in this study according to the following:

$$p = \frac{L}{L + 2w_0} \qquad se(p) = \sqrt{\frac{4L^2}{(2w_0 + L)^4}[se(w_0)]^2}$$

where L is the length of a particular grid.

Density is computed as

$$\hat{D} = \frac{1000f\hat{N}\hat{p}}{L} \qquad \hat{se}(\hat{D}) = \left(\frac{1000f}{L}\right)\sqrt{\left(\hat{N}\hat{se}(\hat{p})\right)^2 + \left(\hat{p}\hat{se}(\hat{N})\right)^2}$$

where f, is an adjustment to convert data taken from one side of a stream to represent the entire population on both sides of the stream. A factor of $f = 2$ was used for sites along South Boulder Creek and $f = 1$ was assumed for the East Boulder Ditch site.

RESULTS

Linear Population Density Estimates

Best Model

The best model is the one in which capture and recapture probabilities are all equal for animals caught on their "home" grid (p = c = 0.376 ± 0.023). For animals caught off of their home grid, capture probabilities differ between pairs of grids but are the same for both directions (A to B or B to A), as shown below:

Pair	p	se
Site 1 and 1997 traps	0.08	247
Site 1 – Site 2	0.12	0.03
Site 5 – Site 6	0.02	0.02
EBD – Site 2	0.04	0.02

The best model includes separate values for trapping probabilities of animals caught in a grid adjacent to its home grid. All other capture and recapture probabilities are the same for both sexes at all times. Immigration and emigration are set equal (random migration model) and the value is estimated.

Model averaging

Population estimates are based on model averaging among the four models with significant AIC weights. The models, shown below, reveal that the best model (AIC weight = 0.44) is the one with capture and recapture probabilities set equal; the second is set with emigration and immigration set at zero; the third accounts for the effect of sex; and the fourth sets capture and recapture rates unequal.

Model	Delta AIC	AIC Weight	Number of Parameters
S(t) G'=G"(.) p=c(.) q=r(pair)	0.00	0.44	49
S(t) G'=G"(0) p=c(.) q=r(pair)	0.68	0.31	48
S(t) G'=G"(.) p=c(sex) q=r(pair)	2.19	0.15	50
S(t) G'=G"(.) p(.), c(.) q=r(pair)	3.05	0.10	50