Meadow Jumping Mice (*Zapus hudsonius preblei*) on the U.S. Air Force Academy, El Paso County, Colorado

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Meadow Jumping Mice (*Zapus hudsonius preblei*) on the U.S. Air Force Academy El Paso County, Colorado

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Cover photographs:
1. Subadult meadow jumping mouse from Monument Creek
2. Monument Creek near southeast of Reservoir No. 1

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Introduction

Distribution and Status of *Zapus hudsonius preblei*

The meadow jumping mouse (*Zapus hudsonius*) is the most widely distributed member of the Dipodidae family in North America (Hall 1981). This species ranges from southern Alaska to Newfoundland and south to Georgia, Alabama, Oklahoma, and Kansas. From Kansas, the range of the meadow jumping mouse extends through Nebraska to Wyoming, then north to Saskatchewan and west to British Columbia. There is one arm of the meadow jumping mouse range that extends south through southeastern Wyoming and along the Piedmont physiographic region of Colorado (Figure 1). The subspecies of meadow jumping mouse known from the Piedmont physiographic region of Colorado is *Zapus hudsonius preblei*. Even farther south, an isolated subspecies of meadow jumping mouse (*Z. h. luteus*) occurs along the southern boundary of Colorado (Jones 1999) and in isolated populations near the Sacramento Mountains of New Mexico and the White Mountains of Arizona (Hafner et al. 1981; Figure 2). *Zapus hudsonius* in the southwestern region of North America is a glacial relict (Hafner et al. 1998) and is restricted to the moist wetlands in this arid region.

In May of 1998, the meadow jumping mouse subspecies *Z. h. preblei*, named after the naturalist Edward A. Preble who revised the taxonomy of the genus *Zapus* in 1899, was listed as "threatened" under the Endangered Species Act of 1973 (ESA) by the U.S. Fish and Wildlife Service (USFWS 1998a). The restricted range of the subspecies and increasing difficulty of finding substantial populations spurred the listing of *Z. h. preblei*. Historically in Colorado, this subspecies is known from approximately a dozen locations scattered throughout Larimer, Weld, Boulder, Jefferson, Adams, Arapahoe, Douglas and El Paso counties (Warren 1942, Armstrong 1972, Figure 3). As early as 1991 researchers at Rocky Flats Environmental Technology Site (RFETS) in Jefferson County began surveying for jumping mice within the facility's boundaries (Ryon, pers. comm.). Other than annual surveys at RFETS, only a few jumping mouse-specific surveys were conducted in the early 1990's. Because few presence/absence studies were conducted to identify new jumping mouse populations, the distributional status of *Z. h. preblei* was unknown. In 1993, Compton and Hugie (1993) attempted to verify the presence of historical *Z. h. preblei* populations throughout Colorado. They trapped four locations, but were unable to locate jumping mice. In 1995, Ryon (1996) visited seven historical meadow jumping mouse locations to determine the status of the populations but was unable to capture any jumping mice. These two studies were the first indications that *Z. h. preblei* populations may be declining. Carron Meaney at the University of Colorado also began to search for populations of *Z. h. preblei* by visiting likely, but as yet unsurveyed areas (Meaney and Clippinger 1995, Meaney et al. 1996, Meaney et al. 1997a). Meaney identified new populations during the three-year study, but encountered many unoccupied habitats. As conservation concern for meadow jumping mice was increasing there was a recognized need to better describe the distribution of *Z. h. preblei*. The Colorado Natural Heritage Program (CNHP) collected *Z. h. preblei* survey reports that had been submitted to USFWS and compiled the data into a computerized database. This information has been used to produce the most up-to-date distribution maps of *Z. h. preblei* and to identify key areas for conservation efforts. The range of *Z. h. preblei* is now known to extend north into southeastern Wyoming and as far south as Colorado Springs, Colorado (Warren 1942, p. 241) and east to Peyton, Colorado (Figure 4).

The meadow jumping mouse and the western jumping mouse subspecies *Zapus princeps princeps* display potential sympatry along the eastern foothills of the Rocky Mountains (Armstrong 1972). The western jumping mouse has been documented at elevations of 6000 feet, which is within the range of *Z. h. preblei*. Currently, the dipodid inhabiting elevation below 7400 feet is considered to be *Z. h. preblei*. This hypothesized elevation limit of *Z. h. preblei* was based on captures at the United States Air Force Academy (Academy) in 1995. However, in 1998, possible *Z. h. preblei* specimens were captured in Larimer County and El Paso County near the 7600-foot mark. It is important to note that these elevational limits are artificial and actual distribution limits are ecologically-based. Sympatry has recently been confirmed along Trout Creek, Douglas County, in 1999. Based on dental morphology (Klingenger 1963), three independent identifications determined that both *Z. hudsonius* and *Z. princeps* were found along Trout Creek (Schorr in prep.).

Today *Z. h. preblei* is classified as a “globally-rare” and “state-rare” subspecies by CNHP, as a subspecies of “special concern” by the Colorado Division of Wildlife (CDOW), as a “sensitive” subspecies by the U.S. Forest Service (USFS), and as a federally “threatened” subspecies under the ESA. The International Union for the Conservation of Nature and Natural Resources Species Survival Commission considers *Z. h. preblei* worthy of direct conservation effort because of its “severely restricted and fragmented distribution and the projected decline in both extent and quality of its habitat” (Hafner et al. 1998). As part of the ESA, a recovery plan is being constructed to ensure the long-term persistence of *Z. h. preblei*. More information is available from USFWS representatives Kathleen Linder and Peter Plage.

Ecology and Natural History of *Zapus hudsonius preblei*

Zapus h. preblei has a total length of 187-255 mm (7-10 inches), tail length of 108-155 mm (4-6 inches), and a hindfoot length of 28-35 mm (approx. 1 inch; Fitzgerald et al. 1994). Body weights of reproductive meadow jumping mice range from approximately 15 grams to more than 30 grams. For its body size, *Z. h. preblei* has an extremely long tail, large hind legs, and large hindfeet, which are likely evolutionary adaptations to bipedal, saltatory locomotion. The pelage of *Z. h. preblei* is tawny brown-orange and, as in other meadow jumping mouse subspecies, has a conspicuous dark dorsal band. The tail is sparsely haired and bicolored. Compared to *Z. princeps*, *Z. hudsonius* has smaller molars and a narrower braincase.

Meadow jumping mouse adult (Photograph by Parker Schuerman)

True to its name, the jumping mouse uses its large hind legs to bound through thick, herbaceous vegetation. Meadow jumping mice have been reported to jump distances of 6-8 feet (Preble 1899). It also evades threats by crawling through dense vegetation. When pursued, jumping mice often make a series of long leaps, changing directions erratically, and then crawl under vegetation. Meadow jumping mice swim readily but seem to prefer overland travel. When swimming underwater they may dive under water and kick their hindlimbs for propulsion, but when swimming on the surface, they paddle with their forelimbs. Meadow jumping mice also may conceal themselves within the vegetation and wait for a threat to leave.

Meadow jumping mice are among the smallest mammals that hibernate. The meadow jumping mouse usually begins hibernating in mid-September to mid-October and does not emerge until mid-May. Individuals have been captured as late as early November (Bakeman pers. comm.). Wunder and Harrington (1996) suggested that young *Z. h. preblei* continue to fatten through the later fall months to attain sufficient fat stores for hibernation, whereas adults attain hibernation weight earlier and begin hibernation by early September. *Zapus h. preblei* can accumulate approximately 20 percent of its body weight prior to hibernation (Wunder 1998).

In Colorado, meadow jumping mice are often found in dense, herbaceous riparian vegetation. *Zapus h. preblei* habitat may have an overstory canopy layer, but usually has a well-developed shrub layer and a thick herbaceous layer. Most often the shrub cover consists of willow species (*Salix*), but species composition seems to be secondary to the presence of a mature shrub component. Exotic, invasive plant species do not appear to conflict with *Z. h. preblei* habitat needs (Bakeman 1997). The presence of non-native plants such as Canada thistle (*Cirsium arvense*), toadflax (*Linaria* spp.), and smooth brome (*Bromopsis inermis*), does not preclude *Z. h. preblei*, but invasive, nonnative species such as Russian olive (*Elaeagnus angustifolia*) can displace native vegetation and reduce available wildlife habitat (Knopf 1988). What seems universally true for meadow jumping mouse habitat is that a dense, herbaceous ground cover is present. Most often, *Z. h. preblei* is found in close association with these dense, riparian habitats. Numbers of *Z. h. preblei* captures decrease the further one moves from this characteristic habitat (Corn et al. 1995, Meaney et al. 1996). Getz (1961) believed there is a direct relationship between jumping mice and soil moisture. Based on a study of kidney structure, it its believed that *Z. h. preblei* may be dependent upon open water (Wunder 1998), which may explain its close association to riparian habitats. Jumping mice use upland habitats for hibernacula locations (see "Notes on Natural History of *Zapus hudsonius preblei*" Section) and feeding areas (T. Shenk pers. comm.).

Meadow jumping mice have two, or possibly three, litters per year and have an average of 4-6 young per litter (Quimby 1951, Krutzsch 1954, Whitaker 1963). At RFETS, Jefferson County, Colorado, Ryon (pers. comm.) has found two peaks in juvenile captures.

Systematics and Classification of *Zapus*

The ability to recognize and identify species and subspecies is critical to developing meaningful conservation strategies. Thus, understanding the reasons for current *Zapus* systematics and classification is helpful. Krutzch (1954) first separated *Z. h. preblei* from its most similar relative *Z. h. campestris* because it had paler dorsal pelage, with fewer dark-tipped hairs and a less-distinct dorsal band. *Zapus h. campestris* is the northern cousin of *Z. h. preblei*, found in Montana, Wyoming, and South Dakota. Also, the cranial measurements were slightly smaller with auditory bullae being smaller and less inflated. Compared with *Z. h. pallidus*, the cousin to the east, *Z.h. preblei* is duller and has smaller cranial measurements. Armstrong (1972) separated *Z. h. campetris* and *Z. h. preblei* based on pelage color and morphometrics, but recognized the range of *Z. hudsonius* as being completely within Colorado. The distinction of *Z. h. preblei* as a separate subspecies was later corroborated by Hall (1981). Wunder and Harrington (1996) used nuclear and mitochondrial DNA analysis to distinguish between *Z. h. preblei* and *Z. princeps*. They analyzed 53 specimens from three locations: RFETS, Jefferson County, Colorado (presumed *Z. h. preblei*), Blaine, Amoka County, Minnesota (*Z. h. intermedius*), and Neota Creek, Larimer County, Colorado. The analysis clearly pooled specimens from RFETS with those from Minnesota, thus distinguishing jumping mice from RFETS as *Z. h. preblei.* In 1997, Riggs et al. (1997) conducted mitochondrial DNA (mtDNA) sequencing analysis on 92 specimens of *Zapus*, including both western and meadow jumping mice. *Zapus* specimens from Albany County, Wyoming south to Las Animas County, Colorado were recognized as a coherent genetic group. This is consistent with current knowledge of *Z. hudsonius* in Colorado. Samples from southern Colorado are grouped together and likely are allied with *Z. h. luteus.* Specimens from southeastern Wyoming and Weld County, Colorado were more closely aligned with *Z. princeps*, but Hafner (1997) suggests this is likely due to the "leakage of mtDNA across species boundaries" since samples of *Z. princeps* are immediately adjacent to "historical, persistent, or suspected populations of *Z. hudsonius*." He contends that the population identified as *Z. h. preblei* is a relatively homogenous group based on Riggs et al. (1997) analyses.

The U. S. Air Force Academy and Meadow Jumping Mice

The U.S. Air Force Academy

In 1958, the United States Air Force established the premiere aerospace officer academy northwest of Colorado Springs. The Academy encompasses 7,285 ha (approx. 18,000 ac) at the base of the Rampart Range in central Colorado. The Academy ranges in elevation from 6,360 feet within Monument Creek valley to approximately 8,600 feet along the slopes of Stanley Creek canyon. Annual rainfall from 1951 to 1980 averaged 43.2 cm (17 inches; Doesken and McKee 1988). On the Academy, snowfall peaks in March with an average of 32 cm (12 inches; Academy Airfield data).

Within the Academy boundaries there are five recognized landforms: 1) the slopes of Rampart Range; 2) the ridges of sedimentary rock that run parallel to Rampart Range; 3) the mesas and ridges, and the associated valleys, that extend eastward perpendicular to the Rampart Range; 4) the Monument Creek valley; and 5) the rolling slopes east of Monument Creek (Varnes and Scott 1967). Soils on the Academy consist of nineteen separate soil series (Larsen 1981). The parent material for many of these soils is arkose, a feldspar-rich sandstone from Pike's Peak granite (Ripley 1994).

Riparian habitat along Monument Creek

A great variety of vegetation communities are represented within the Academy boundaries. Five major plant communities are present: Douglas-fir/white fir woodlands, Ponderosa pine woodlands, chaparral scrubland, grasslands, and riparian communities. There are nearly 650 plant species or subspecies, roughly 20 percent of the Colorado flora, on the Academy (Ripley 1994). On the Academy, the Douglas-fir/White fir woodland is charcterized by Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), common juniper (*Juniperus communis*), aspen (*Populus tremuloides*), waxflower (*Jamesia americana*), and kinnikinnik (*Arctostaphylos adenotricha*). The Ponderosa pine woodlands are represented by Ponderosa pine (*Pinus ponderosa*), currant (*Ribes cereum*), gooseberry (*Ribes aureum*), ninebark (*Physocarpus monogynus*), and mountain maple (*Acer glabrum*) in riparian areas. Chaparral scrublands are dominated by Gambel oak (*Quercus gambelii*). Other common floral species are one-seeded juniper (*Sabina monosperma*), Spanish bayonet (*Yucca glauca*), prickly pear cactus (*Opuntia macrorhiza*), and mountain mahogany (*Cercocarpus montanus*). Grasslands consist of a great variety of grass species, including big bluestem (*Andropogon gerardii*), needle-and-thread (*Stipa comata*), and little blue stem (*Shizachyrium scoparium*). Other species found in the grassland community are fringed sage (*Artemesia frigida*), mullein (*Verbascum thapsus*), and scattered Ponderosa pine and Gambel oak. The riparian zones are dominated by willow species such as sandbar willow (*Salix exigua*), peachleaf willow (*Salix amygdaloides*), and crack willow (*Salix fragilis*). Also found in these mesic habitats are narrowleaf cottonwood (*Populus angustifolia*), snowberry (*Symphoricarpos occidentalis*), wild plum (*Prunus americana*), and Russian olive (*Elaeagnus angustifolia*).

Wildlife on the Academy is as diverse as the vegetation. Mule deer (*Odocoileus hemionus*), white-tailed deer (*Odocoileus virginianus*), elk (*Cervus elaphus*), coyote (*Canis latrans*), black bear (*Ursus americanus*), red-tailed hawks (*Buteo jamaicensis*), great horned owls (*Bubo virginiana*), great blue herons (*Ardea herodias*), Steller's jays (*Cyanocitta stelleri*), wild turkeys (*Meleagris galapavo*), western terrestrial garter snakes (*Thamnophis elegans*), northern leopard frogs (*Rana pipiens*), and black-billed magpies (*Pica pica*) routinely are seen on the Academy. Many other species occur at the Academy, but are more elusive. For a complete account of mammals see Langlois and Munson (1991), and for birds see DeFusco and Cassel (1988).

History of Meadow Jumping Mice on the Academy

Since the meadow jumping mouse first became of conservation interest in the early 1990's the need for information on the mouse's distribution has been critical. There have been few complete inventories for *Z. h. preblei*. Early survey efforts were interspersed thoughout the Front Range and Wyoming during the mid-1990's (Compton and Hugie 1993, Corn et al. 1995, Meaney and Clippinger 1995, Armstrong et al. 1996, Ellingson et al. 1996, Meaney et al. 1996, Ryon 1996, Pague and Schuerman 1997). The RFETS has had on-going inventories since 1992 (EG&G 1993), yet populations within RFETS are considerably smaller than those found in other areas (Ryon pers. comm.). Inventory efforts in 1997 and 1998 began to clarify the extent of meadow jumping mouse range in Colorado (Meaney et al. 1997a, Ensight Technical Services 1998, Pague and Schuerman 1998, Shenk and Eussen 1998). Since 1980, meadow jumping mice have been captured in Larimer, Weld, Boulder, Jefferson, Douglas, Elbert, and El Paso counties (Figure 4).

Inventories for meadow jumping mice on the Academy have been conducted since 1994. The Academy houses one of the largest concentrations of meadow jumping mice along the Front Range, rivaled only by the densities found along East and West Plum Creek and their tributaries in Douglas County (Pague and Schuerman 1998).

I. Academy Jumping Mouse Inventories: 1994 and 1995

In 1994, CNHP conducted a rapid ecological assessment of the Academy specifically looking for less-common species. During this biological inventory meadow jumping mice were captured on the Academy for the first time (Ellingson et al. 1996). The extent of jumping mouse distribution within the Academy was then unknown.

In 1995, the distribution of meadow jumping mice in Monument Creek was better clarified and preliminary population estimates were made (Corn et al. 1995). Also, jumping mice were documented along West Monument Creek, Kettle Creek, Deadmans Creek, Smith Creek, Black Squirrel Creek, Stanley Creek, and Monument Branch.

II. Academy Jumping Mouse Inventories: 1997-1999

To understand the natural history of meadow jumping mice within the Academy, studies to determine movement patterns, population parameters, and distribution were initiated. In 1997, stretches of Monument Creek were trapped (Table 1; Figure 5) to confirm jumping mouse locations and to begin a radio-telemetry study. Also, Lehman Run near Academy Drive and Stadium Drive, and the unnamed creek which drains from Douglass Valley were trapped.

In 1998, efforts to delineate the upper-elevational limit of meadow jumping mouse on the Academy included extensive trapping of Stanley Creek, Goat Camp Creek west of Academy Drive, Lehman Run west of Academy Drive, and Deadmans Lake. Trapping was also conducted along West Monument Creek near the Pine Valley community, at Tesla Hydrologic Plant, and along Black Squirrel Creek. Monument Creek was trapped at five locations three times per year. The five locations are the established population sampling grids A through E near Non-potable Reservoir 1. In 1999, the population grids were again trapped in June, July and September. Other trapping was conducted along the unnamed drainage through the Douglass Valley community.

Meadow jumping mouse research on the U.S. Air Force Academy (1997-1999)

Home Range and Movement of *Z. h. preblei*

Introduction

To develop relevant conservation strategies it is essential to understand their movement patterns and how much area is required by individuals. Because *Z. h. preblei* are relatively inconspicuous and inhabit dense habitats their movement patterns have been difficult to assess. In 1995, Dr. Bruce Wunder of Colorado State University attached radio transmitters to meadow jumping mice. He located one hibernaculum, but was unable to assess movements of jumping mice long enough to adequately assess movement patterns (Wunder pers. comm.). From 1994-1995, researchers at RFETS began using chemo-illuminescent dyes to follow mice, but the dyes were not persistent enough to permit evaluation of long-term movements (Ryon pers. comm., Bakeman pers. comm.). Estimates produced for *Z. h. preblei* home range were 9625 m^2 (0.9625 ha; Harrington et al. 1996) from a study conducted at RFETS. This study determined the movement patterns of meadow jumping mice to better understand how much area individual mice use. Important to conservation planning is the incorporation of all areas utilized by the species of interest. Understanding subspecies movement patterns allows biologists and planners to better identify the habitats that are likely utilized on a regular basis. We wanted to ensure that conservation boundaries included the areas that this subspecies was utilizing. In particular, we knew very little about overwinter habitat requirements and wanted to identify hibernacula. Also, we wanted to determine whether or not the common assumption that the riparian zone was the most frequently utilized habitat was correct.

Methods

Jumping mice were captured using Sherman live traps (8 x 8 x 25 cm) and anesthetized with Metofane (methoxyflurane) for 2-5 minutes. Once anesthetized, mice were fitted with collars and allowed to recover in a transparent plastic box with food and water. Mice were released only when they moved freely with the collar in place. Transmitters were 1.0-gram Holohil Systems, Ltd. MD-2C collars that transmit for approximately 30 days.

Mice were tracked from approximately sunset to early morning (approximately 1900 - 0200 hours) for half of the life of the transmitter battery, and from early morning to sunrise (approximately 0300 – 0800 hours) for the other half of the battery life. Timing of tracking was alternated every 5 days in 1997 and every 10 days in 1998 and 1999. Locations of *Z. h. preblei* were determined using triangulation from two known geographic locations. Periodically, researchers located and observed collared mice to ensure collars were not visibly jeopardizing their health. Known geographic locations were chosen by their proximity to mouse activity centers and vantage to gain clear signals from the transmitters. The latter criterion was most often based on the ability of the researcher to get clear signals from multiple angles without signal bounce from nearby geographic features.

In September of 1997, 5 *Z. h. preblei* were fitted with radio transmitters and released along Monument Creek. In June of 1998, eleven PMJM were fit with radio collars along Monument Creek and Deadmans Creek. In September of 1998, four mice were collared along Deadmans Creek. In early summer of 1999, three mice were tracked along Deadmans Creek and eight were tracked along Monument Creek. In fall of 1999, eight mice were tracked along Monument Creek (Table 2). Thirty-nine *Z. h. preblei* were tracked during the 3-year period.

To determine locations of collared mice, triangulation techniques were used (White and Garrott 1990). Two bearings from different locations were used to pinpoint the location of an animal.

Following a mouse's exact movements throughout the collaring period is the best method of assessing home range. However, movement patterns may be altered by frequent contact with the researchers (Turchin 1998) and home range estimates may be biased because of this contact.

Prior to calculating movement patterns and home range the data were reviewed and edited to remove improbable triangulation points (White and Garrott 1990). For example, a location that depicted extremely long movements over a very short time period was eliminated. It is unlikely, based on the interval of time between some triangulation efforts, that mice moved such large distances. Also, locations that placed mice in unlikely terrain, such as very steep slopes, were removed. If locations were commonly documented from such terrain the locations were included in analysis. In the field, researchers frequently approached and observed radio-collared animals when the animal's location was in question. To further prevent exaggeration of movement patterns due to false locations, home range estimates were computed using 95% fixed kernel estimates, which only incorporate 95% of home range use (Seaman and Powell 1996).


Radio tracking jumping mice along Monument Creek

Farthest distance traveled over the life of the collar was determined using a geographic information system (GIS). Telemetry locations of collared individuals were displayed on a GIS and measurements of distances between points were calculated using distance measurement tools.

Home ranges were calculated using minimum convex polygon, Jennrich-Turner estimator, a kernel-based estimator, and a bootstrap estimate of kernel-based estimators (Seaman and Powell 1991, Hovey 1998, Hooge 1999). Minimum convex polygon (MCP) connects all the outer locations of the individual and forms a convex polygon. The problem with MCP is that it does not take into account area within the polygon that was never visited by the individual. Thus its home range estimates are usually inflated. The Jennrich-Turner estimator assumes the spatial model for home ranges is a bivariate normal probability distribution. The estimator assumes there is a like central mode for both the x- and y-axes of the home range, then associates an ellipse with the x- and y-axes centered at the mode with bivariate normally-distributed axes (White and Garrott 1990). This estimator allows one to include a particular percentage of the observation in an effort to limit outliers. For the jumping mice tracked at the Academy, a Jennrich-Turner estimator which incorporated 95% of the observations was used. Although this model avoided the pitfalls experienced with MCP, it also can inflate estimates because it assumes animal movement is bivariate normally distributed. The final method of estimating home range used was the kernel-based home range estimator. The kernel density estimator is advantageous because it is nonparametric and attributes density probabilities using known locations (Seaman and Powell 1996). In short, the kernel estimator is not plagued by some of the biases mentioned previously (Worton 1995). All kernel home ranges were calculated using fixed-kernel estimators with a least squares cross validation (LSCV) smoothing parameter (Silverman 1986). The LSCV is a jackknife method that selects the amount of smoothing to minimize the estimated error for a sample (Seaman and Powell 1991). Additionally, kernel home range estimates were bootstrapped using 1000 simulations

(Hovey 1998). Bootstrapping is a method of resampling in which a value from the data set is randomly selected for removal and then another randomly-selected value from the data set is used as its replacement (Efron 1982). This technique is valuable because it allows non-normally distributed data to be analyzed and the computation of variance feasible (Krebs 1989). These home range estimates are intended to give biologists and managers an understanding of meadow jumping mouse resource utilization within the Monument Creek watershed. These estimates allow a manager to visualize home range and, ideally, ecological requirements with different management objectives in mind. Since home range calculations have not been standardized, several estimators are provided to allow the biologist or manager to compare home range estimates of meadow jumping mice from the Academy with other meadow jumping mice.

Results

In 1997, four mice were tracked for the lives of the transmitter batteries, but one was undetectable after 3 weeks. The outcome of this individual was undetermined. In 1998, three mice were tracked for the lives of the transmitter batteries, three mice were predated, seven mice were untrackable because the signals were lost and never recovered, one was parasitized, and one perished due to unknown causes. In 1999, one individual was likely predated, one died of unknown causes, three were untrackable because the signals were lost, one slipped its collar, one signal did not move for the duration of the collar, but could not be retrieved, and eleven were tracked for the lives of the collars. Individuals were tracked for periods from 1 – 34 days. Home range and farthest distance traveled were calculated only for individuals with 30 or more locations (range = 38-180, mean = 77.3 ± 38.0, Table 4). When calculating home range estimates using kernel estimators obtaining greater than 20 representative telemetry locations is recommended and obtaining greater than 50 representative telemetry locations is preferred (Seaman et al. 1999).

Mean farthest distance traveled during the battery lives of the collars for 12 mice was 232 ± 113 m (Table 3). Mean 95% volume kernel home range estimates for 12 individuals was 0.53 ± 0.39 ha (Table 4). Mean bootstrapped 95% kernel home range estimator, using 1000 iterations, was 0.831 ± 0.681 ha (Hovey 1999; Table 4). For minimum convex polygon and Jennrich-Turner estimators see Table 4.

Mean distance from a creek for radio-collared jumping mouse telemetry locations was 35.0 ± 27.3 m (Table 5). Mean distance from a creek for jumping mouse locations in 1997 was 39.5 ± 28.6 m . Mean distance from a creek for jumping mouse locations in 1998 was 11.5 ± 7.9 m. Mean distance from a creek for jumping mouse locations in 1999 was 50.5 ± 29.7 m (Table 5). Maximum distance moved away from a creek was 144.0 m.

Expectations for the three-year period were to determine the home ranges of 50 individuals, but due to difficulties in capturing jumping mice only 39 individuals were collared. Of these, only 12 were relocated enough times to produce reliable estimates of home range. There were difficulties in trapping meadow jumping mice in early September in all years. It is possible that many of the adults began to hibernate at this time, leaving only juveniles available to be trapped. This is consistent with fat analysis of meadow jumping mice from RFETS (Wunder and Harrington 1996). In 1999, efforts to capture mice in mid-August were met with the same difficulties experienced in mid-September trapping in previous years.

Discussion

Estimates of home range are, by nature, subject to high degrees of bias because of the logistics of tracking times, number of location points, and accuracy of locations (White and Garrott 1990). Also, home range estimates are plagued with inestimable variance estimates. Thus, accuracy of home range calculations is difficult to assess. Despite these problems, home range information can help biologists identify area usage within the frame of tracked periods. Specifically, for conservation purposes, home range allows planners to visualize what areas may be required to persist. Furthermore, home range estimates, in conjunction with other life history parameters, allow planners and wildlife managers to determine how changes to the organism's habitat may or may not affect individuals. For example, an understanding of home range estimates prior to habitat modifications provides a metric by which home ranges can be compared after manipulations are conducted.

Technology in the realm of radio telemetry has progressed substantially in the last 40 years (Kenward 1987). Since many of the home range estimates for meadow jumping mice were calculated using capture data on predefined trapping areas there was a high degree of bias (Blair 1940, Quimby 1951). The use of radio-telemetry equipment now allows researchers to assess movement remotely, without having to constrain encounters.

Early estimates of jumping mouse home range ranged from 0.08 – 0.64 ha (Blair 1940, Quimby 1951). Home range estimates from the U.S. Air Force Academy are considerably larger. It is likely that these differences are simply due to the improvements in our ability to determine movement patterns. Some averages of home range for jumping mice from the Academy fall within the range of previous estimates.

Reliable movement information on meadow jumping mice is lacking (Quimby 1951, Whitaker 1963, Whitaker 1972, Tester et al. 1993). Not until recently have telemetry studies begun to better depict the movement patterns of small mammals in general. In 1995, Corn et al. used mark-recapture methods to document movements as great as 450 m. With the listing of *Z. h. preblei* came several studies that addressed the movement patterns of this subspecies. Bakeman (Ensight 1999) used mark-recapture-trapping studies in and around an interstate overpass to determine what physical features limit meadow jumping mouse movement. Most movement distances were less than 100 m, but the farthest distance recorded was 1050 m. This distance is much larger than any recorded for radio tracking at the Academy. Bakeman was also able to document movements through man-made structures, including metal and cement culverts. Movement under the nearly 100-m long, cement overpass may have been facilitated by the presence of artificial cover. Artificial willow-shrub mimics built of perforated plastic boxes and willow sprigs were placed at regular intervals within the culvert. Similar to field studies at the Academy, Bakeman documented frequent creek crossings. Meadow jumping mouse swimming ability has long been documented (Hamilton 1935, Preble 1944, Quimby 1951, Sutton 1955) and creeks should not be considered a barrier to dispersal.

Ryon (1999) documented similar long-distance movements at the RFETS. Using radio telemetry, Ryon found one individual that moved greater than 1600 m within a 30-day period. Over two consecutive nights one individual moved greater than 1000 m. As Ryon pointed out, many of these longer forays were restricted to seep wetland and riparian corridors within the research area. The maximum distance from a stream channel for a collared jumping mouse was 245 m.

Shenk and Sivert (1998) used radio telemetry to determine meadow jumping mouse movement patterns. Like Ryon, they documented movement of greater than 1600 m. They also found long-distance movements along intermittent and perennial waterways and they documented seasonal movements of jumping mice. Shenk and Sivert described multiple movements of jumping mice greater than 100 meters away from waterways, extending well into the uplands. They also documented some of the most extensive use of upland communities to date.

The extent of jumping mouse movement away from waterways has been a critical information need in developing conservation boundaries. The maximum detected distance that a radio-collared jumping mouse moved from Monument Creek or a tributary was 144 m. Conservation strategies should provide for such movements outside of the riparian areas, however, this distance is based on only a few individuals over several weeks. Meadow jumping mice may be moving greater distances from riparian systems at the Academy, but we have not been able to document such movements with the sample size of this study. To ensure that the conservation of the subspecies is met at the Academy and other locations it is important to develop boundaries in the context of the surrounding habitat.

There appears to be a significant difference in the mean distance moved from a waterway between year 1998 and years 1997 and 1999 (ANOVA, $P < 0.0001$). In 1998, all radio collaring was conducted along Deadmans Creek whereas in 1997 and 1999 all collaring was conducted along Monument Creek. The riparian systems are much narrower along Deadmans Creek than they are along Monument Creek. Researchers initially predicted that jumping mouse movements along Deadmans Creek would be substantially greater than those of individuals from Monument Creek. This prediction was based on the generalization that larger riparian systems provide more resources and, thus, jumping mice would not have to travel as far to access these resources. As the data show, however, the original prediction was incorrect. Likely, the idea that the riparian community provides all of the necessary resources for jumping mouse is erred. Resources available in upland communities may be more important to jumping mouse persistence than was previously thought.

Even with this study and the aforementioned research projects addressing movement of meadow jumping mice in Colorado, it is clear that more information is needed. Shenk and Sivert were able to clearly rule out the use of a 300-foot-from creek edge universal conservation boundary as recommended by the USFWS Draft 4D Ruling (USFWS 1998b), but an understanding of why certain habitats consistently have jumping mouse movements greater than other areas is needed. With the use of global positioning systems (GPS) and GIS, researchers can categorize jumping mouse locations into particular habitat types. The ongoing project at the Academy is attempting to map out certain dominant plant communities to determine the relative amount of time jumping mice spend in willow riparian versus upland grass. Projects that manipulate the vegetation will also better illustrate how jumping mice respond to particular disturbances and help identify limiting factors. With the past several years of successful jumping mouse movement research, biologists and planners have a clearer understanding of how and where to draw conservation boundaries. As Shenk and Sivert demonstrated, use of a single distance measurement for drawing conservation boundaries will not ensure adequate conservation at all sites. The Preble's Meadow Jumping Mouse Science Team has identified this problem and is using floodplain maps to delineate potential conservation boundaries. Upland grass and shrub habitats must be accounted for in any conservation strategy.

Meadow jumping mouse populations on the U. S. Air Force Academy

"A fundamental difficulty with all models of population estimation is that we need to know the area to which a given population estimate is applicable." Kenneth Watt, *Ecology and Resource Management* (1968)

Introduction

Very little is known about meadow jumping mouse populations in Colorado. In 1995, when CNHP began a mark-recapture study of meadow jumping mice along Monument Creek it was the first attempt to assess population size at one of the known population centers (Corn et al. 1995). A more rigorous attempt to determine densities, abundance, and survival was begun in 1998. Population-level information is valuable in designing conservation strategies for meadow jumping mice in Colorado for several reasons. Understanding the size of the population that inhabits the Academy would allow wildlife managers and planners to develop strategies for maintaining the meadow jumping mouse population while allowing the Academy's daily operations to continue. Also, it provides a better understanding of how this population contributes to the overall conservation of the subspecies. Determining population parameters, such as size, density, and survival, provides baseline information for later assessment of how these parameters change over time. This becomes particularly relevant to conservation of the subspecies when determining where to focus conservation efforts.

Methods

To determine densities, abundance, and survival of meadow jumping mice on the Academy, mark-recapture methodology was implemented. For a summary of techniques and methods for assessing closed populations see White et al. (1982). Five randomly-selected trapping grids were established along Monument Creek. To reduce conflicts between trapping and the activities of Academy personnel and visitors, trapping grids were selected between the Northgate Boulevard overpass and the Southgate Boulevard overpass. Sampling was limited to Monument Creek and not the associated tributaries because optimization of capture rates was necessary to produce useful population models. Grids were trapped for 7 consecutive days unless interrupted by extreme weather. Grids consisted of 70 Sherman live traps spaced 7 meters apart in 7 rows of ten. Each grid occupied 0.26 ha (0.63 ac). Trapping occurred in early June, late July, and early September. Traps were baited with whole oats, and a ball of polyfil batting was provided for insulation. If weather precluded trapping, effort was resumed when weather allowed. For this methodology to be valid, individuals must be marked and marks must be detectable in the future. Due to financial constraints, individuals were marked with ear tags in June of 1998. Unfortunately, many individuals lost their tags before the next trapping effort in late July 1998. During all subsequent trapping sessions (July 1998 – September 1999), individuals were marked using passive integrated transponder (PIT) tags. These tags can be inserted subcutaneously and later detected by an electronic reader that identifies the specific code for that tag. Animals marked with PIT tags were detected in later trapping effort with no evidence of harm to the animals.

Program MARK (Gary White, Colorado State University) was used to analyze the mark-recapture data collected on the Academy (White and Burnham 1999). The robust design model was chosen because it combines features of the closed-population models and open-population models. Pollock (1982) developed a model that incorporates the assumptions of the closed-population model with the Jolly-Seber model (Jolly 1965, Seber 1965), which is commonly used to model open populations. This is appropriate for meadow jumping mouse trapping since during a trapping effort the population is assumed to be closed (no deaths, births, immigration, or emigration). Between sampling periods there are certainly births, deaths, immigration, and emigration. Pollock's robust design (Kendall and Pollock 1992, Kendall et al. 1995) models this scenario and is the most appropriate model for depicting meadow jumping mouse population dynamics at the Academy (Menkens and Anderson 1988).

To ensure abundance estimates are applied to an appropriate area or distance, some assessment of effective trapping area must be conducted. To determine this area we need some knowledge of how far mice are immigrating from outside the grid. Radio-telemetry data can help determine the effective trapping size of sampling grids (Kenward 1987). White and Shenk (2000a, in review) approached this problem by determining the fraction of telemetry observations within the stream-length distance of the trapping transects executed by Shenk in Douglas County and Tom Ryon in Jefferson County. Fitting more than fifteen trapping transects and telemetry efforts to a curve White and Shenk modeled the probability of catching all radio-collared individuals using different trapline lengths. Based on White and Shenk's study 43% of the mice caught on a trapline length of 63 m, like the ones at the Academy, are resident to the area of capture. Thus, over the course of trapping one would expect 43% of the captures to be found from within the length of the trapline.

Since radio collars affect collared mice it is likely that they will act differently than uncollared mice (Koehler et al. 1987, Mikesic and Drickamer 1992). Thus at the Academy, radio telemetry and mark-recapture efforts were not conducted in the same areas. Yet it would be helpful to assess how far Academy jumping mice immigrate into trapping areas to be captured. To estimate this, the farthest-distance-traveled-along-a-waterway was calculated for each collared individual with more than 30 observations. These distances then were overlapped at 1-m intervals with the 63-m length of trap grid to determine the amount of intersection. This exercise provided an estimate of how frequently one would expect to encounter each individual on a trapping grid 63 m long. For example, a mouse that moved 215 m along the creek would only expect to intersect the 63-m grid about 29% of the time if its center of activity was near the grid. This is also the maximum amount of overlap one would expect. However, if the center of this mouse's activity was 200 m away, one would expect it to be on the grid only 7% (15 m/215 m) of the time. Each mouse maximum movement distance was brought 1 m closer until it passed the center of the grid and then the distance was moved 1 m beyond the center until there was no overlap. After all iterations were complete, the mean amount of overlap for all individuals was 0.25. Thus, the probability the average collared jumping mouse on the Academy would have of moving onto a grid of length 63 m would be 25%. This analysis is based on collared mice that were not captured on the population grids. This probability is an assessment of the likelihood of capturing all mice that would be found near the grid.

Results

There were 514 captures of 187 jumping mice during two years. One hundred twenty-five meadow jumping mice were captured on the population grids in 1998 and 62 were captured on the grids in 1999 (Table 6). Total trapnights during the two-year period were 14,700. Mean weight of 187 individuals was 19.2 $\pm$ 3.3 grams (Table 6). The sex ratio (m:f) among trapped jumping mice was nearly 4:3 (105:79; Table 6). Removing the June 1998 captures and mortalities from the data set, there were 97 mark-recapture histories that could be used for survival analysis.

i. Abundances

Estimates of abundance are provided using the two methodologies described in the above "Methods" section. They are provided to allow planners and biologists to evaluate the assumptions and methods independently and use the estimates that best fit the biology and conservation of the subspecies on the Academy. In the "Discussion" section the merits of both methods are compared.

Using White and Shenk's (2000a, in review) residency estimates, there were approximately 67 $\pm$ 12 jumping mice per km in June of 1998 and 57 $\pm$ 6 jumping mice per km in July/Sept of 1998 (Table 7). In June of 1999, there were 29 ± 8 jumping mice per km and 40 ± 7 jumping mice per km in July/Sept. 1999. Using residency factors based on telemetry and capture data from the Academy, there were approximately 39 ± 7 jumping mice per km in June of 1998 and 33 ± 4 in July/Sept. 1998. In June of 1999, there were 17 ± 4 jumping mice per km and 23 ± 4 jumping mice per km in July/Sept. 1999 (Table 7).

The sampling frame from which the sampling grids were chosen included 7.4 km of Monument Creek from the North Entrance overpass to the Stadium Drive overpass. The population estimates are only applicable to this sampled area. Extrapolating abundances per km using White and Shenk residency factor, there were approximately 490 individuals in June of 1998, 420 in July and September of 1998, 210 individuals in June of 1999, and 290 individuals in July and September of 1999. Using the residency factor based on information from the Academy, there were approximately 280 individuals in June of 1998, 240 in July and September of 1998, 210 in June of 1999, and 170 in July and September of 1999.

To better illustrate the size of the population within the 7.4 km of Monument Creek sampled it is best to report them as population ranges. More adequate portrayals of jumping mouse abundances are acquired using the 95% confidence intervals for these estimates. Using White and Shenk's technique, 95% confidence intervals for the population in June of 1998 and July/September of 1998 are 349-697 and 341-524, respectively. In 1999, 95% confidence intervals for the population were 127-352 in June and 57-411 in July/September. Using residency calculations from the Academy, 95% confidence intervals for June and July/September of 1998 are 201-401 and 196-301, respectively. In 1999, June 95% confidence intervals for the population were 73-202 and in July/September intervals were 119-411 individuals.

Extrapolating abundance estimates for all of Monument Creek within the Academy (14.1 km) 95% confidence intervals for the mean population sizes are 670-1338 for June of 1998, 654-1007 for July/September of 1998, 243-676 for June of 1999, and 110-789 for July/September of 1999. These estimates give a better idea of the total number of mice likely to be found along Monument Creek. Although much of Monument Creek appears to be suitable jumping mouse habitat, extrapolations beyond the sampling frame are not recommended because the variation outside of the sampling frame is not incorporated. Habitat outside of the sampling frame is not always similar to that found within the sampling frame.

ii. Survival

Overwinter survival rate estimates for meadow jumping mice between July 1998 and September 1999 were 0.972 ± 0.023. Active-season survival rate estimates were 0.385 ± 0.075.

Discussion

The techniques of population analysis have become more prominent tools in wildlife management and conservation (White et al. 1982, Thompson et al. 1998). Small mammals have been studied extensively to determine important parameters such as survival and population fluctuations (Batzli 1992). The Family Dipodidae has not been addressed as intensively as other small mammal taxa, but several studies have attempted to clarify jumping mouse population parameters (Blair 1940, Brown 1970, Nichols and Conley 1982, Adler et al. 1984, Muchlinski 1988). Prior to federal listing by USFWS, little was known about *Z. h. preblei* populations.

Corn et al. (1995) used Lincoln-Peterson estimators to analyze mark-recapture data from *Z. h. preblei* studies at the Academy. They estimated 2 mice per acre. Extrapolating estimates to the amount of suitable riparian habitat within the Academy, they determined there were approximately 450 individuals within the Academy boundaries. Even compared to the lowest pre-breeding estimates along Monument Creek in 1999, this estimate seems low. Corn et al.'s estimate encompasses the entire Academy, yet is only slightly above the lowest estimates for the Monument Creek pre-breeding population in 1999. It is likely that Corn et al. did not accurately assess effective trapping area or they did not accurately assess the amount of jumping mouse habitat (Corn et al. 1995).

Ensight Technical Services (1999) conducted mark-recapture studies of *Z. h. preblei* near Monument, Colorado. They assessed populations along Dirty Woman Creek and Monument Creek using similar assessments of effective trapping area as developed by White and Shenk (2000a) and information from day nest site locations on the Academy. After establishing stream-length abundance estimates, they extrapolated to the amount of appropriate habitat using Colorado Division of Wildlife riparian mapping (Dave Lovell, CDOW). Pre-breeding population estimates ranged from 60-120 mice in the approximately 5.6-km stretch of study area. Ensight estimated the number of mice per km to range between 16 and 26.

Meaney (1999) conducted mark-recapture studies to assess the effects of recreational trail use on meadow jumping mouse abundance in Boulder County. Similar to Ensight, Meaney used effective trapping area assessments developed by White and Shenk. Based on the June 1998 linear abundance estimate of 33 individuals per km, Meaney estimated there were 121 jumping mice in the 3.7-km stretch of South Boulder Creek. In the East Boulder Ditch, the estimate of jumping mouse abundance was 55 mice per km, producing a population estimate of 14 mice through the 0.25-km stretch.

The aforementioned estimates during the same time frame (1998-1999) fall within the range of abundance estimates from the Academy. Estimates of abundance from the Academy during June 1998 are comparable to East Boulder Ditch estimates. Yet, even with the estimated abundance documented in 1998, the number of mice present in 1999 was substantially lower. The cause of this decrease is unknown, but likely the flood of April 1999 (details in "Meadow Jumping Mouse Habitat Characterization and Correlations " section) affected food and cover resources for meadow jumping mice. The habitat along Monument Creek was substantially altered. In some areas complete stream banks were washed downstream, leaving less soil substrate for shrub or herbaceous components, while providing new sandbars in other areas. Banks that were not removed were scoured to the point of removing nearly all herbaceous vegetation and shrub foliage to differing heights. These habitat modifications may have diminished necessary resources or caused direct mortality to meadow jumping mice. Accounts of similar flooding effects on small mammal populations have been reported (Yeager and Anderson 1944, Brown and Arnold 1984).

Documenting significant declines or increases in population numbers can be difficult because of the temporal and spatial variation inherent to the population, and because of sampling variation (Thompson et al. 1998). Sampling variation can affect estimates of population. In this study, this variation could manifest itself in the assessment of the movement patterns of radio-collared jumping mice (see " Home Range and Movement of *Z. h. preblei* " section), in the assessment of modeled abundance estimates (variation from field sampling and computer modeling techniques), and assessments of occupied jumping mouse stream stretches. Understanding how the first form of variation affected the assessment of relevant area of trapping (effective trapping area) became a critical component to determining population estimates. Effective trapping area, or effective survey area, is an assessment of how the mean probability of being captured in a trap attenuates with distance from the trap effort (Turchin 1998). Accurately assessing effective trapping area can be a complicated task (Wilson and Anderson 1985, White and Shenk 2000a, in review). Two alternative methods for assessing effective trapping area were attempted in the study and each may contain considerable bias. White and Shenk based their assessments of effective trapping area on data from telemetry projects in Jefferson and Douglas County. These projects determined mouse locations by walking in on collared mice. In the field, this technique has caused individuals to move extensively (personal observation, pers. comm. J. Zahratka). This may cause assessments of jumping mouse locations to be biased by the activity of the researchers. Alternately, the Academy study used triangulation to assess radio-collared mouse locations. This technique avoids bias due to researcher activity, but can produce errant locations since there is more opportunity for experimental error (White and Garrott 1990).

The population estimates conducted using the radio-telemetry data from the Academy appear to underestimate the number of individuals actually inhabiting the 7.3 km stretch of Monument Creek that was sampled. Based on trapping success during this study and reports of trapping success from earlier studies it is difficult to believe that these population estimates are accurately assessing the total number of individuals. Part of this may be due to the use of the farthest distance moved by individuals as the assessment of immigration into the trapping areas. It is possible that these long distance movements are not common or that using triangulation to assess these movements may not have accurately portrayed actual movements. Also, this assessment of immigration into the area failed to incorporate the likelihood that individuals that normally have their home range overlapping the trapping grids were no longer in the trapping area (emigration). For now, the estimates developed using White and Shenk (2000a, in review) likely depict the populations found in this area more accurately than those developed using the information from the Academy.

Survival estimates from the Academy resemble those of other studies. Meaney (1999) found over-winter monthly survival rates for meadow jumping mice to be 0.86 ± 0.03 and active-season (June-Aug.) monthly survival rates to be 0.78 ± 0.28. Active-season survival was less near Monument, Colorado, where Ensight (1999) found monthly survival rates of 0.44. Academy meadow jumping mouse survival during the active season more closely resembles the rates estimated by Ensight. Contrary to original speculation, winter may not be the key time of hardship for meadow jumping mice.

Other population or habitat parameters, more so than density or abundance estimates, may be more helpful in addressing conservation or management of a species or subspecies (Van Horne 1983). In developing meaningful and effective conservation strategies for wildlife, the focus should be on the critical times of survival simply because these times may be most relevant in deferring stresses to the population or populations. This study was designed to illuminate those population parameters that will be most helpful to addressing conservation in the future. Based on the survival estimates from the Academy, winter hardship seems to be negligible compared to summer stresses. Since this subspecies tends to be at the lower end of most food chains it is not surprising to find substantial predation of radio-collared individuals (see "Notes on the Natural History of *Zapus hudsonius preblei* " Section). Although there are few non-native predators present at the Academy, attempts to alleviate non-native predation pressures may be helpful to the conservation of this subspecies rangewide.

At the Academy sex ratios were noticeably skewed temporally. After hibernation, captures of male meadow jumping mice outnumbered captures of females more than 3:1. In July, female captures outnumbered male captures approximately 4:3. Males may emerge from hibernation earlier than females (Quimby 1951, Whitaker 1963, Nichols and Conley 1982, Hoyle and Boonstra 1986, Muchlinski 1988). This difference in emergence times also has been noted in the western jumping mouse (Cranford 1978). Differences in emergence times were not seen in *Zapus princeps* except above 2200 m elevation in Utah (Cranford 1983). Hoyle and Boonstra (1986) noticed a more prominent disparity in sex ratios prior to hibernation that was not seen at the Academy. In September, jumping mouse sex ratios at the Academy were nearly 1:1.

Meadow Jumping Mouse Habitat Characterization and Correlations

Introduction

The habitat associations of *Z. h. preblei* are similar to the habitat associations of many of the eastern subspecies of meadow jumping mouse. Over much of their range meadow jumping mice prefer dense, wet grasslands near ponds, streams, or other bodies of water (Whitaker 1972). In Colorado, meadow jumping mice are usually found in areas with dense herbaceous cover with a dense shrub component (Armstrong et al. 1997, Bakeman and Deans 1997, Meaney et al. 1997b). As with other subspecies, *Z. h. preblei* do not seem to prefer a particular vegetation-species composition (Bakeman and Deans 1997, Meaney et al. 1997b). However, they do seem to be found more frequently in areas with high plant species diversity (Meaney et al. 1997b). In 1996, the Preble's Meadow Jumping Mouse Advisory Group initiated a comparative habitat study throughout the range of *Z. h. preblei*. The primary objectives of this project were to determine habitat associations and to classify capture and no-capture areas based on habitat parameters. The product from this cooperation is probably the most complete summary of *Z. h. preblei* habitat characteristics to date. Unfortunately, a host of vegetation characterization protocols were used and standardized comparisons of vegetation characteristics were not conducted. Establishing habitat-characteristic differences between capture and no-capture areas is problematic. Comparing successful and unsuccessful trapping efforts in a particular area is difficult because mice, though present, may not be captured during the trapping effort (Ask and Schorr 1997, Stoecker 1997, Meaney et al. 1998). To better clarify habitat-mouse associations, habitat characteristics were collected at the Academy and correlations with jumping mouse abundances were attempted. Also, in an attempt to get broader-scale habitat comparisons, microsite habitat characteristics from the Academy and RFETS were compared.

Methods

Habitat monitoring protocol for the Academy study is an adaptation of several habitat-sampling techniques: James and Shugart (1970) sampling protocol that was first adapted for Breeding Bird Survey routes and some of Daubenmire (1959). The union of the two was intended to capture both ground cover characteristics and mid-story cover characteristics. These two features were deemed essential because they address the characteristics that are believed to be important to meadow jumping mouse: vertical vegetation density and amount of ground cover.

Sampling was conducted on 0.04 ha (0.10 ac.) circular plots centered at either a trap location within the population trapping grids or at the center of another jumping mouse natural history feature like a hibernaculum. Measurements of canopy cover, vertical vegetation density, canopy-cover species and diameter-at-breast-height (dbh) class, shrub density, ground cover, and downed-woody debris are taken. This was conducted at six plots for each grid (at trap locations 23, 26, 29, 53, 56, 59). These sites were not chosen randomly, but were chosen to cover as much of the trapping area as possible.

Habitat characterization measurements were taken in the following manner:

Canopy cover species and dbh classes: Tree species were identified to species and classified into appropriate dbh classes using a Biltmore stick or dbh tape measure.

Shrub density: Shrubs (stems) were tallied as every stem greater than 1 m tall that was within 1 m of the cardinal directions of the 0.04 ha plot. This measurement is an index of shrub density and not a tally of actual shrubs found in the area. With the difficulty in distinguishing between willow individuals it was decided to assess relative shrub density based on number of stems.

Canopy cover: Canopy cover was determined using a spherical densiometer 3 m from the center of the plot along each cardinal direction.

Vegetation Profile (Vertical vegetation density): This was assessed using a density profile board and estimating the percentage of vegetation covering each 0.5 m section 3 m tall. The profile board was raised at the terminus of each cardinal direction transect.

Ground Cover: A Daubenmire frame was placed on the ground and estimates were made of the percentage of forb/fern (non-grass/sedge herbaceous vegetation), grass/sedge (members of Poaceae and *Carex* spp.), rock/soil (bare ground, soil, rock), woody debris (branches, root masses, etc.), litter (leaves, pine needles, bark, etc.), moss/lichen , and "other". The Daubenmire frame was placed on the ground at the center of the plot and at every 3-m increment along each cardinal direction tape measure.

Downed Woody Debris: Along each cardinal direction any downed woody material more than 3 cm in diameter that crossed the transect was recorded and placed into diameter classes.

Results

In 1998, meadow jumping mouse habitat was characterized by dense vertical vegetation cover and high shrub density (Table 8). Jumping mouse densities were correlated to some height classes of vertical vegetation density: 0.0 – 0.5 m (R = 0.76, P = 0.13), 1.0 – 1.5 m (R = 0.69, P = 0.20), 1.5 – 2.0 m (R = 0.69, P = 0.20), 2.0 – 2.5 m (R = 0.76, P = 0.14), total grass ground cover (R = 0.78, P = 0.12), and total number of downed woody debris between 20 and 30 cm in diameter (R = 0.77, P = 0.13). However, none of these are significantly correlated. In 1999, shrub density and vertical vegetation density where high (Table 8). Jumping mouse densities in 1999 were significantly negatively correlated to total number of canopy trees with dbh greater than 46 cm (R = -0.80, P = 0.10) and negatively correlated to total number of canopy trees (R = -0.79, P = 0.11).

Discussion

Zapus h. preblei are often found in dense habitats dominated by heavy shrub cover and dense ground cover (Armstrong et al. 1997). However, there are little data correlating jumping mouse densities to any particular habitat characteristic. The 1998 habitat and jumping mouse capture data from the Academy indicate that jumping mouse densities are correlated with quantity of shrub cover and amount of ground cover. These correlations are not significant, but they do show a tendency for jumping mouse abundances to be associated with herbaceous cover. This is consistent with other habitat information concerning the species and genus (Whitaker 1972, Schulz and Leininger 1991). The 1999 habitat data show that jumping mouse densities are negatively correlated with the number of large canopy trees in the area. It is likely that the shade created by the canopy cover of large trees precludes the growth of mid-level shrubs. The habitat and jumping mouse correlations from 1999 may be confounded by two factors: (1) jumping mouse captures were very low during this year; and (2) the flood of April 1999 modified the vegetation along Monument Creek significantly. On 30 April, 1999, the Academy received 4.87 inches of rain in 24 hours (Academy Airfield Data). Monument Creek normally flows at 24.4 cubic feet per second, but was elevated to an estimated 3000 cubic feet per second during the flood event. Flow rates were estimated because most gaging stations were lost (D. Green pers. comm.). Since jumping mouse captures were less common in 1999 it was difficult to see a difference between capture numbers at each population grid. Also, since the flood of 1999 removed much of the ground cover and shrub vegetation the correlations observed in 1998 may not be as apparent.

In 1996, several researchers collaborated on rangewide habitat assessments and comparisons (Bakeman 1997). Armstrong et al. (1997) looked at trap-site specific vegetation structure and diversity in Boulder County. In comparing successful trapping locations with unsuccessful locations in similar areas, they found no significant differences. In the same compendium, Bakeman and Deans (1997) described and compared a host of habitat parameters from successful and unsuccessful trapping locations on RFETS. Using multivariate analysis they were unable to differentiate between successful and unsuccessful capture locations. Similarly, Meaney et al. (1997b) compared successful and unsuccessful trapping sites in Boulder, Jefferson, Douglas, and El Paso counties. They measured microsite and macrosite habitat characteristics at multiple locations. At the microsite level, there were no significant differences. Larger-scale comparisons showed that successful trapping sites had greater species richness and lower maximum vegetation height. Ryon (1997) compared habitat parameters at historic *Z. h. preblei* capture locations. His comparison of recent and historic trapping locations determined that recent capture locations had more complete vertical vegetation density in the shrub layer and greater shrub density. Shenk and Eussen (1998) attempted to delineate certain habitat characteristics between successful and unsuccessful trapping attempts in Larimer and Weld counties. Unfortunately, no clear differences were apparent between successful and unsuccessful sites. White and Shenk (2000b, in review) modeled jumping mouse presence using cover catergories from infrared aerial photograph interpretation. Based on availability of riparian shrub and tree cover, habitat quality for meadow jumping mice can be predicted. They determined that 78% of the variation in meadow jumping mouse abundance per km could be explained by the presence of riparian shrub and tree cover.

Meadow jumping mouse habitat along Monument Creek

Perhaps the best way to determine what vegetation characteristics control jumping mouse densities would be to conduct manipulative experiments. Modifying the habitat parameters that possibly control jumping mouse densities will provide more concrete evidence regarding these assumed associations. Identifying limiting factors will be an important information need for the conservation of this subspecies of meadow jumping mouse. Without a clear understanding of what habitat parameters are important for jumping mouse persistence it will be difficult to mitigate habitat losses or modifications. Also, it is important to fully understand how, or if, habitat quality controls meadow jumping mouse populations. It is important to define successful conservation in terms of persistent populations and not just large population numbers. Quite frequently, that success is dictated by habitat quality and habitat availability.

Comparison of Positive Trapping Locations between the Academy and RFETS (Microsite Comparisons)

Introduction
Since field studies began in the early 1990's there has been little progress in comparing aspects of *Z. h. preblei* habitat throughout its range. Habitat studies of *Z. h. preblei* have described successful capture locations and often compared them to unsuccessful capture locations (Armstrong et al. 1997, Bakeman and Deans 1997, Meaney et al. 1997b). Comparisons of successful versus unsuccessful trapping sites are usually conducted within the same drainage or trapping area. This is problematic since successful trapping locations may not be determined by habitat cues, but rather behavior of the jumping mice inhabiting that area. For several years, the RFETS has documented microsite habitat characteristics at successful capture locations (Ryon pers. comm.). In an effort to compare habitats from multiple locations throughout *Z. h. preblei* range, similar measurements of habitat characteristics were adopted for describing successful capture locations at the Academy. These measurements allow comparison of site-specific characteristics, which are useful for identifying possible reasons for different mouse abundances in different habitats throughout its range.

Methods
Microsite monitoring protocol is identical to the sampling protocol used by Exponent, Inc on RFETS in 1997 and earlier. Exponent, Inc. is a consulting organization with scientists, physicians, engineers, and business consultants that is currently conducting environmental monitoring on RFETS. Working with Tom Ryon of Exponent, Inc., who has more than 5 years of experience with *Z. h. preblei*, the vegetation sampling protocol was simplified and standardized.

Sampling was conducted on a 3-m radius circle centered at a successful trap location. Measurements of canopy cover, vertical vegetation density, canopy-cover species diversity, trap-location descriptions, foliar cover estimate, and plant species richness were taken. These data were collected at six randomly-chosen successful trap locations for each of five population grids, yielding 30 samples.

Microsite habitat characterization measurements were taken in the following manner:

Canopy species: Tree species were identified and recorded.

Plant species richness: All plant species were identified using Ripley (1994) and Weber (1976) and recorded.

Trap position in relation to canopy: Trap position in relation to canopy was categorized into 3 possible positions: 1= in; 2=out; and 3=edge.

Aspect: Aspect of the trap location was on a scale from 0-360 degrees.

Slope: Slope of the trap location was on a scale from 0-90 degrees. Slope was determined using a clinometer.

Moisture gradient: Moisture gradient at trap location was one of four categorical variables: 1=hydric (inundated); 2=humic (moist); 3=mesic; and 4=xeric (dry).

Slope position: Slope position at trap location was one of six categorical variables: 1=hilltop; 2=top slope; 3=upper slope; 4=mid-slope; 5=bottom of slope; and 6=level floodplain.

Soil texture: Soil texture at trap location was one of six categorical variables: 1=cobbly; 2=gravelly; 3=sandy; 4=loamy; 5=silty, and 6=clayey.

Distance to stream or waterway: Distance to waterway was the distance to the nearest body of water measured in meters.

Distance to nearest continuous woody riparian canopy: Distance to nearest continuous woody canopy is the distance to the nearest canopy cover consisting of more than one tree canopy.

Canopy cover: Canopy cover is measured using a densiometer, in a fashion similar to the one used in 0.04-ha habitat measurements (see "Meadow Jumping Mouse Habitat Characterization and Correlations" Section). Measurements were taken in each of the four cardinal directions.

Vertical vegetation density: Vertical vegetation density was measured using a 1 m x 1 m cover board centered at the trap location. Estimates were made 3 m from the center in each cardinal direction and estimating the amount of vegetation obscuring the density board.

Foliar cover estimates: Foliar cover estimates were estimates of the amount of cover for each of five vegetation categories: trees, shrubs, subshrubs, forbs, and grasses. Estimates were taken immediately above or within the 3-m radius circle centered at the trap locations. The subshrub category was added to address the substantial component of snowberry that is often found in *Z. h. preblei* habitat. The shrub category was reserved for taller shrubs such as willow or currant.

Results

Comparisons using 1998 Academy data and 1997 RFETS data were conducted. Although there is the likelihood of temporal changes between the two sites, it provided a comparison between trapsite characteristics at different population centers. There were only four microsite habitat characteristics that differed significantly between RFETS successful capture locations and the Academy successful capture locations (Table 9). The Academy successful capture locations had significantly less plant species richness ($P < 0.05$), less slope at the trap location ($P < 0.01$), greater graminoid cover ($P < 0.05$), and greater shrub cover ($P < 0.05$).

Discussion

Based on telemetry data (Ryon pers. comm.) and riparian vegetation mapping (Dave Lovell, Colorado Division of Wildlife), the utilized habitat is much narrower at RFETS than the habitat at the Academy. It is likely that this difference in available habitat is the reason population densities of meadow jumping mice at the Academy are much greater than those at RFETS. It is possible that the differences in vegetative cover between RFETS and the Academy positive capture locations indicates that the Academy may provide more habitat structure for larger populations. Similar to the correlative habitat structure studies conducted at the Academy, this comparison of microsite characteristics indicates a jumping mouse preference for areas with dense herbaceous and shrub cover.

A host of vegetation and microsite habitat comparisons have been conducted (see "Meadow Jumping Mouse Habitat Characterization and Correlations" Section), but no clear indicators for jumping mouse habitat preference have been identified. Most of these studies were unable to detect differences between successful and unsuccessful capture locations. Meaney et al. (1997b) compared successful and unsuccessful trapping sites in Boulder, Jefferson, Douglas, and El Paso counties. They measured microsite and macrosite habitat characteristics at multiple locations. At the microsite level, capture locations had more cover, lower shrub height, close proximity to overstory trees, and higher species richness. Larger-scale comparisons showed that successful trapping sites had greater vegetative species richness.   Their findings on cover density indicate a similar reliance of meadow jumping mice on the dense cover components identified in the comparisons between the Academy and RFETS.

The area of habitat description and comparison will need more attention in the future. As attempts to mitigate meadow jumping mouse habitat loss increase, our ability to create areas with healthy meadow jumping mouse populations will become critical. Conducting habitat manipulation studies may help to determine the factor or factors critical to jumping mouse persistence.

Notes on the Natural History of *Zapus hudsonius preblei*

Hibernacula

In three years of telemetry research at the Academy, six hibernacula were located. Expectations were to locate 30 hibernacula over three years, but because of the low capture success and the inability to confirm hibernation only six sites were considered hibernacula. Hibernation was assumed after an individual was stationary for more than 7 days and the individual was observed alive several times after collaring. To confirm an animal was alive after collaring, mice were tracked and visually identified prior to hibernating.

Four hibernacula were located at the bases of willow shrubs (*Salix exigua* and *S. fragilis*) and two were located at the bases of scrub oaks (*Quercus gambeli*). As is evident by the large variance estimates associated with the vegetation and site characteristics there was little consistency among hibernacula (Table 10). Hibernacula averaged 22.6 m ($\pm$ 14.6 m) from the associated waterway (either Monument Creek or Deadmans Creek). Most often, hibernacula were directed north (aspect mean of 293 degrees $\pm$ 77 degrees). Having a hibernaculum facing north may prevent soil temperatures from rising substantially during brief periods of spring warming, thus preventing the hibernator from emerging early (Muchlinski 1988). North-facing slopes may provide more stable soil temperatures during hibernation. Four of the six hibernacula were located in the slope of a floodplain ridge. A floodplain ridge is a bench that rises away from the riparian system. It is possible that jumping mice select hibernacula in areas that are outside of the regularly flooded floodplain.

Most previous records of hibernacula resulted from chance encounters (Dilger 1948). Often they were underground or under debris, lined with leaves or other forest litter, and they may or may not have had an obvious entrance (Whitaker 1972). In the mid-1990's, Bruce Wunder of Colorado State University radio tracked meadow jumping mice at the RFETS and found one hibernaculum that was lined with leaves and was located roughly 0.30 meters under ground (Wunder pers. comm.).

Day nests

One day nest was located in 1998 and 19 were located in 1999. Many of these nests matched historic descriptions of nests (Whitaker 1972), usually lined with leaves or grass in a softball-sized mass. At the Academy, nests were found under debris within the riparian shrub communities and in open grassland communities with little protection from weather or sun. Nests were located under mountain-mahogany (*Cercocarpus montanus*), scrub oak, locust (*Robinia pseudoaccacia*), assorted grasses, and snowberry. Several mice were found using multiple day nests (Table 11). In one instance, a mouse spent nearly all of its time in and around a day nest in upland grass community, moved into the riparian willow community and used another day nest for two days, and then returned to the upland community. Such movements may be more common than originally suspected (Bain and Shenk 2000, in review). Becker and Christian (1979) noted similar multiple nest utilization in the woodland jumping mouse (*Napaeozapus insignis*). In a movement study of the woodland jumping mouse they found male nests were not associated with extensive burrow systems, but nests of females usually were. Shenk and Sivert (1999) documented extensive upland use and a multitude of day nests in Douglas Co., Colorado. Day nests found at the Academy are similar to those found in Jefferson Co., Colorado (Ryon 2000, in press). Ryon found day nests lined with *Poa compressa* , *Poa pratensis*, *Juncus balticus*, and *Carex* spp., but indicated that nest construction material is likely determined by what is available. Day nests were found near shrubs and in dense herbaceous cover.

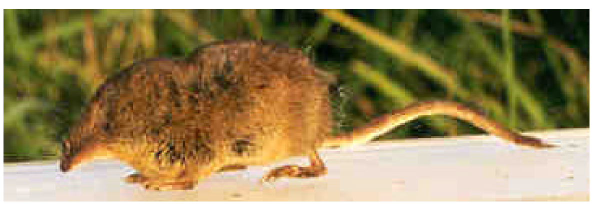
Parasites

Ectoparasites were taken opportunistically as meadow jumping mice were handled during anesthesia for attachment of radio collars or while attaching PIT tags. Four fleas, *Megabothris abantis*, were taken from jumping mice at the Academy and later identified by Ken Gage of the Center for Disease Control, Fort Collins, Colorado. One nymphal *Ixodes* sp. was taken from a meadow jumping mouse and is currently being curated and identified at the U.S. National Tick Collection at Georgia Southern University. Preliminary identification was made by Bill Black of Colorado State University, Fort Collins, Colorado.

One occurrence of myiasis was documented during the three-year study. Myiasis is infestation by maggots. Four grey flesh fly (*Wohlfahrtia vigil*) larva were extracted from a wound in the hind quarters of one radio-collared meadow jumping mouse. Flesh fly specimens were identified and deposited in the C. P. Gillette Museum of Arthropod Diversity, Colorado State University, Fort Collins by Boris Kondratieff. Percentage of meadow jumping mice infected at the Academy was less than 1%. This is the first documentation of grey flesh fly myiasis in the Dipodidae family (Schorr and Davies, in prep). It is also a documented range extension for this flesh fly. Although myiasis has been reported in Colorado (Kondratieff pers. comm.), there are no published records.

Associated Mammal Species

Over the 14,700 trapnights for the population study there were six other small mammal species that were captured (Table 12). The most prevalent species found along Monument Creek was the deer mouse (*Peromyscus maniculatus*) comprising 59.7% (2298/3852) of all captures. Meadow voles (*Microtus pennsylvanicus*) were the next most abundant, comprising 34.3% (1320/3852) of all captures. Meadow jumping mice comprised 4.9% (187/1320) of all captures. Four other species were trapped sporadically throughout the study: montane shrew (*Sorex monticolus/*sp.; n = 36); western harvest mouse (*Reithrodontomys megalotis*; n = 5); least chipmunk (*Tamias minimus*; n = 5); and long-tailed weasel (*Mustela frenata*; n = 1).



Sorex monticolus captured along tributary of Monument Creek

Predators and mortality factors

Although documenting predation can be difficult, the radio-telemetry study provided opportunities to document direct predation and to speculate on likely predation. One western terrestrial garter snake (*Thamnophis elegans*) was seen predating a meadow jumping mouse (picture below). Several meadow jumping mice were found beheaded, which may indicate predation by raptors or weasels (King 1989 p. 82, Sealander and Heidt 1990 p. 220). One dead radio-collared meadow jumping mouse was found approximately 15 feet high in the limbs of a ponderosa pine. This mouse was likely the cache of an adult red-tailed hawk that was nesting approximately 60 m away. Other mortality factors were drowning and predation by an unknown predator (Table 2).

Meadow jumping mouse being consumed by a western terrestrial garter snake (Photograph by Jose Maldonado)

Recommendations

"When a stream is in its natural state, fed by a stabilized watershed, and supporting the kind and quantity of life that is adapted to it - there will be little need for improvement."
Durwood Allen, *Our Wildlife Legacy* (1952)

The meadow jumping mouse population at the Academy is one of the healthiest within the subspecies' range. This is due probably to the condition of the habitat along the riparian systems. This is especially true of Monument Creek, which contains the broadest riparian-shrub zones on the Academy. Much of Monument Creek is a model for riparian systems along the Front Range, and, as the above quote suggests, the health of Monument Creek is probably a result of the absence of attempts to modify it.

The Academy restricts access to Monument Creek, allowing only authorized Academy personnel to use the dirt roads that parallel the creek. Except for a water treatment plant and the Santa Fe Trail, there is very little modern development along Monument Creek. Restricted access and the lack of modern facilities near the creek are the key reasons why the riparian habitat is some of the healthiest along the Front Range of Colorado. Some riparian areas within the Academy boundaries, however, are closer to Academy facilities. These riparian systems may be more difficult to maintain, since necessary Academy operations may conflict with the management of riparian habitat for meadow jumping mice.

Perhaps the best method for mediating conflicts between jumping mouse habitat management and infrastructure maintenance demands would be to follow the recommendations and guidelines set forth in the Conservation and Management Plan for Preble's meadow jumping mouse on the U.S. Air Force Academy (Grunau et al. 1999). Proactive approaches to determining what projects would likely affect jumping mouse habitat would afford natural resource planners and biologists the opportunities to minimize impacts. Furthermore, designing projects that avoid jumping mouse habitat would decrease impacts to the existing habitat at the Academy.

Ensuring the persistence of meadow jumping mice along Monument Creek can be accomplished by maintaining existing management practices. Limiting access and keeping development outside the floodplain and the associated upland habitats would protect the resources needed by meadow jumping mice. Efforts to ensure that riparian systems are minimally impacted by off-site operations should be continued. Since the Academy is near ongoing industrial and residential development, it is important to coordinate with off-site project managers to prevent inadvertent, deleterious modification of the hydrology and vegetation within Academy riparian systems.

In other areas of the Academy where infrastructure maintenance may conflict with jumping mouse habitat management, reduction of impacts to the riparian vegetation and the surrounding upland communities would benefit meadow jumping mice. Successful mitigation of jumping mouse habitat loss has not been documented, but there is evidence that if riparian and upland habitats are allowed to recover after disturbance jumping mice will re-inhabit these areas. The most dramatic demonstration of such recolonization exists along Monument Creek. Before Northgate overpass was installed north of the confluence of Monument and Deadmans Creeks, there was a bridge that traversed Monument Creek near the train stop called Husted. The supports for this bridge still stand. Construction of the bridge and these supports likely altered the riparian and upland habitat considerably, yet meadow jumping mice are commonly found along Monument Creek between the two supports. Meadow jumping mice probably recolonized after the vegetation began to resemble its historic condition.

Attempts to mitigate losses of jumping mouse habitat are underway along Lehman Run at the Academy. After the soil surrounding a storm-runoff structure began to erode, engineers and natural resource planners installed detention ponds. Riparian vegetation along Lehman Run near the Academy campus was sparse at the time and did not support jumping mice. One jumping mouse was captured approximately 200 m west of the ponds in over 10,000 trapnights of trapping (T. Unangst, pers. comm.). The newly-constructed detention ponds should retain water along Lehman Run and create a more accessible groundwater supply, permitting the establishment a riparian-shrub community. Native willows and grasses were planted near the ponds to facilitate the establishment of suitable habitat for jumping mice. Since this effort began in 1999, jumping mice have been trapped within 200 m upstream and downstream of the ponds.

Modifications to the vegetation in jumping mouse habitat may be easier to mitigate than less overt problems such as alterations to hydrology and soils. For this reason, Academy natural resource planners, biologists, and engineers should attempt to address on-site and off-site operations that would likely jeopardize jumping mouse habitat and persistence within the Academy boundaries. Working cooperatively with surrounding landowners to minimize impacts to Academy habitats is advised. Furthermore, expansion of the Academy's existing population of meadow jumping mice would decrease the likelihood that stochastic events would damage the population. The Academy houses the largest population of a threatened subspecies of meadow jumping mouse in the Arkansas River drainage. The stability of this population is crucial to the range-wide conservation of the *Zapus hudsonius preblei.*

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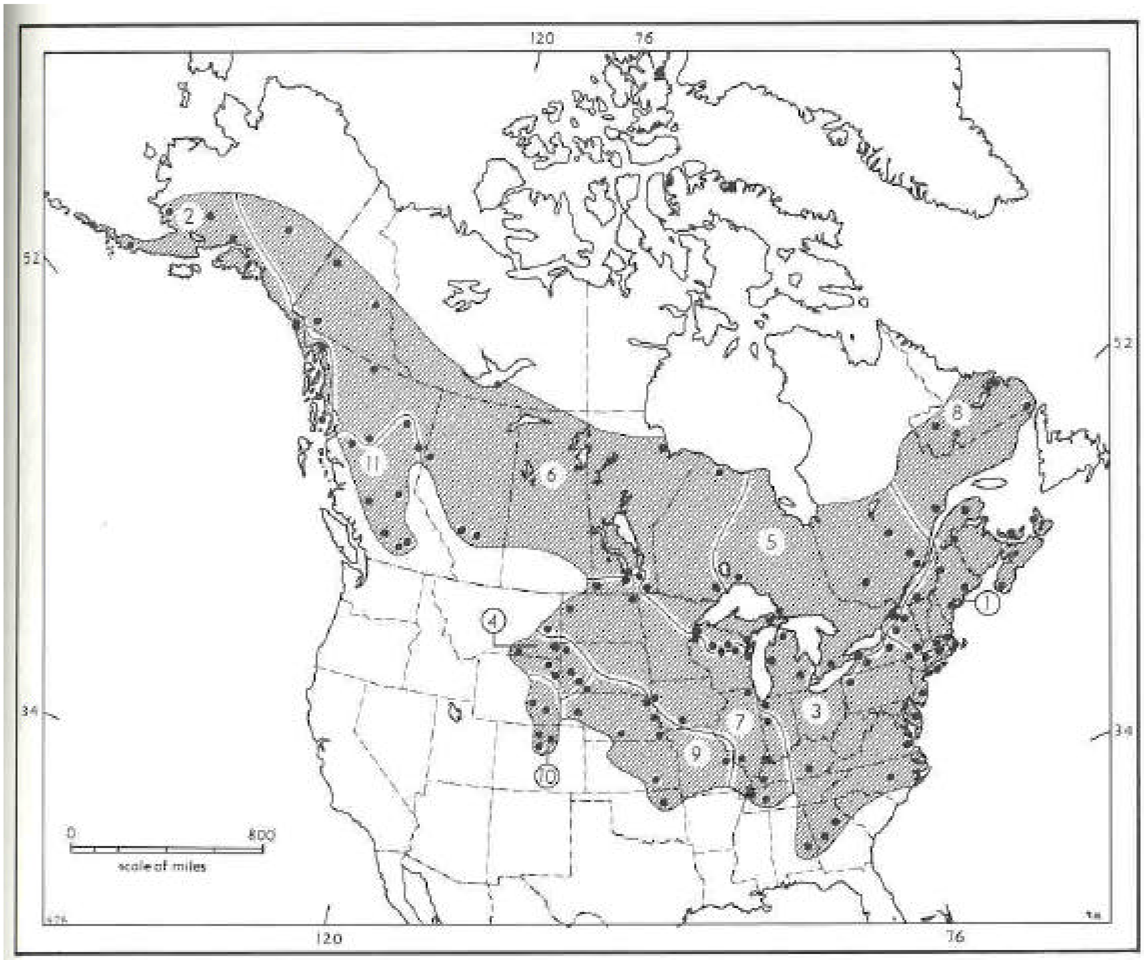
Figures and Tables

Figure 1. Distribution of *Zapus hudsonius* from E. Raymond Hall. 1981. Mammals of North America. John Wiley and Sons Publishing. New York. 1187 pp.



Map 474. *Zapus hudsonius.*

Guide to subspecies
1. Z. *h. acadicus*
2. Z. *h. alascensis*
3. Z. *h. americanus*
4. Z. *h. campestris*
5. Z. *h. canadensis*
6. Z. *h. hudsonius*
7. Z. *h. intermedius*
8. Z. *h. ladas*
9. Z. *h. pallidus*
10. Z. *h. preblei*
11. Z. *h. tenellus*

Figure 2. Distribution of *Zapus hudsonius* in the southwestern part of its range. Taken from D. J. Hafner, K. E. Petersen, and T. L. Yates. 1981. Evolutionary relationship of jumping mice (Genus *Zapus*) of the southwestern United States. *Journal of Mammalogy* 62:501-512.

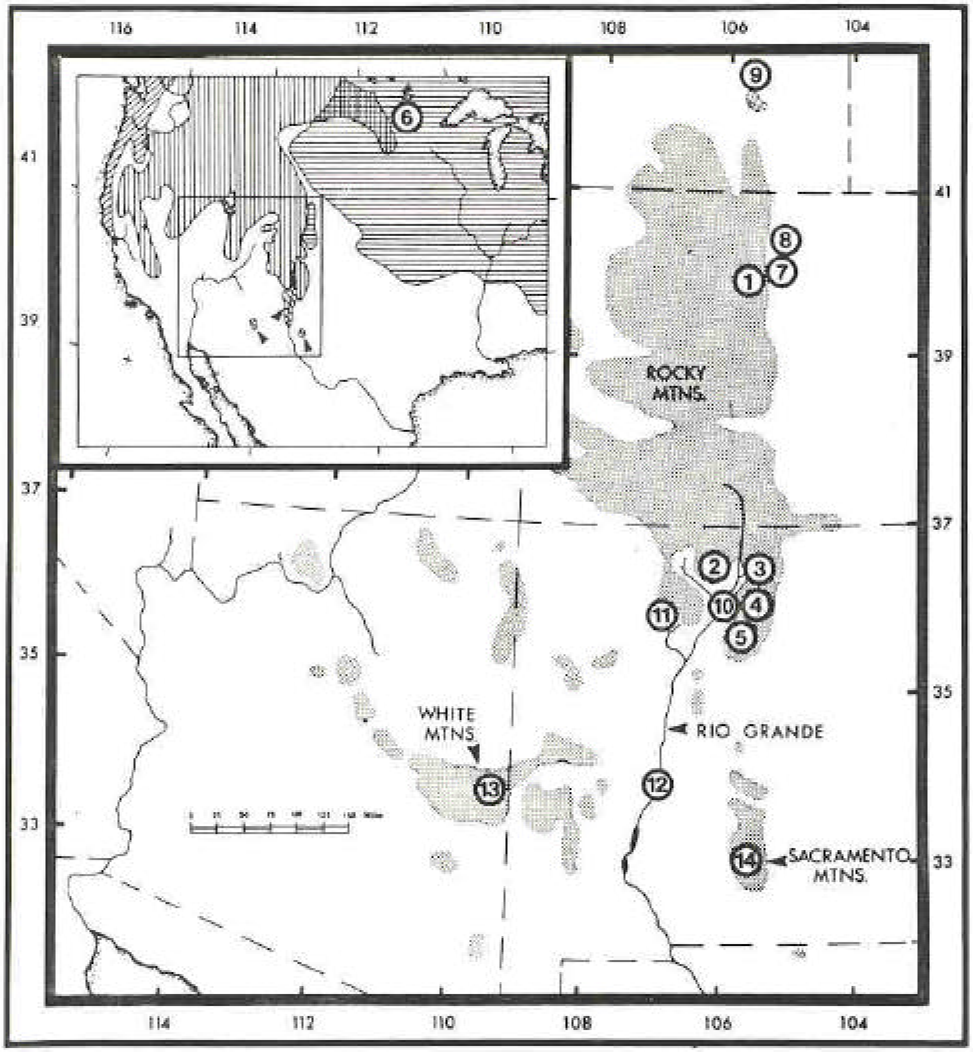


FIG. 1.—Distribution of jumping mice in the southwestern United States. (Inset: distribution of the genus *Zapus* in central North America. *Z. trinotatus*—right-oblique hatching; *Z. princeps*—vertical hatching; *Z. hudsonius*—horizontal hatching; peripheral forms previously referred to *Z. p. luteus*—left-oblique hatching.) Numbered localities are identified in Appendix I. Shading indicates areas above 250 m.

Figure 3. Distribution of *Zapus hudsonius preblei* in Colorado. Taken from Armstrong, D. M. 1972. *Distribution of Mammals in Colorado*. Museum of Natural History, University of Kansas, Lawrence, KS. 415 pp.

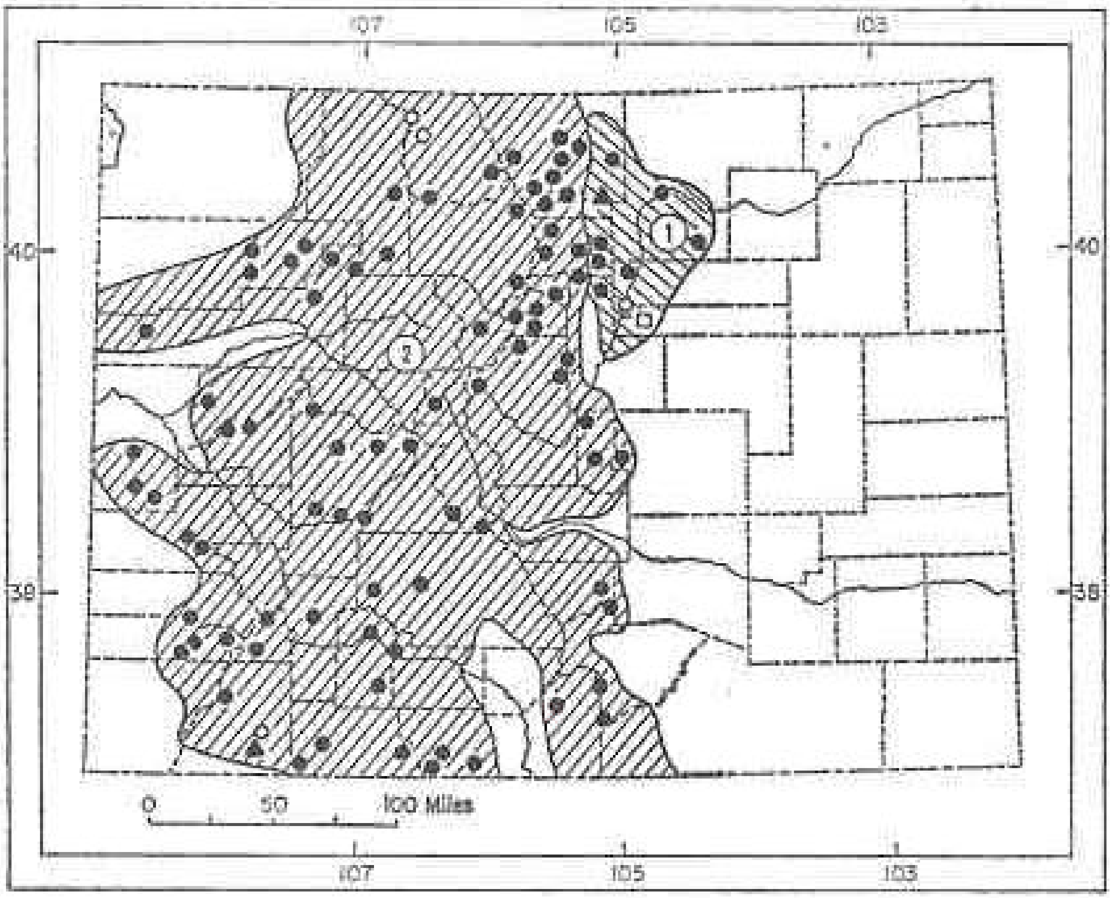


FIG. 87. Distribution of two species of jumping mice in Colorado. 1, *Zapus hudsonius preblei*. 2. *Zapus princeps princeps*. For explanation of symbols, see p. 9.

Figure 4. Distribution of *Zapus hudsonius preblei* in Colorado

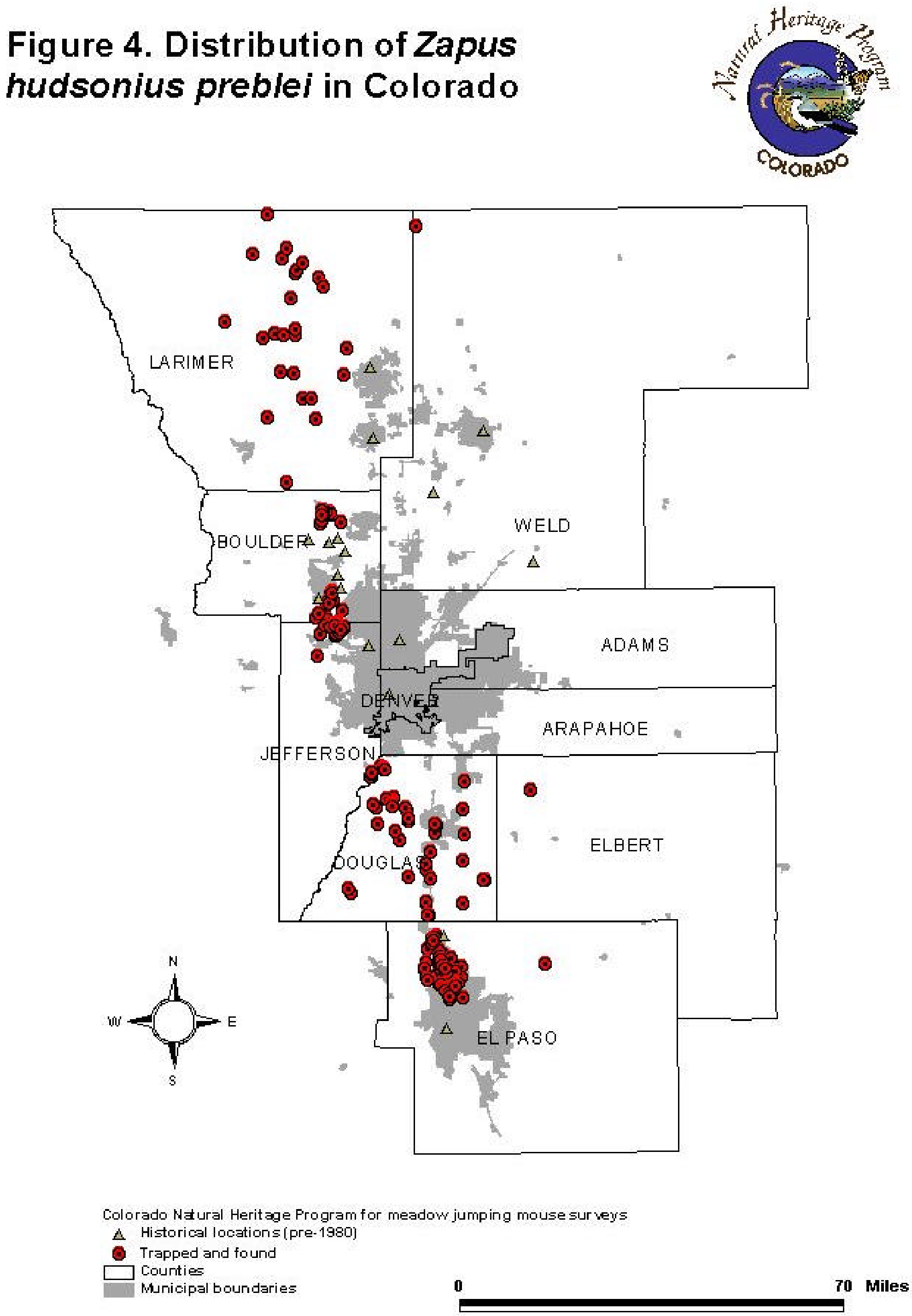


Figure 5. Distribution of *Zapus hudsonius preblei* on the U. S. Air Force Academy

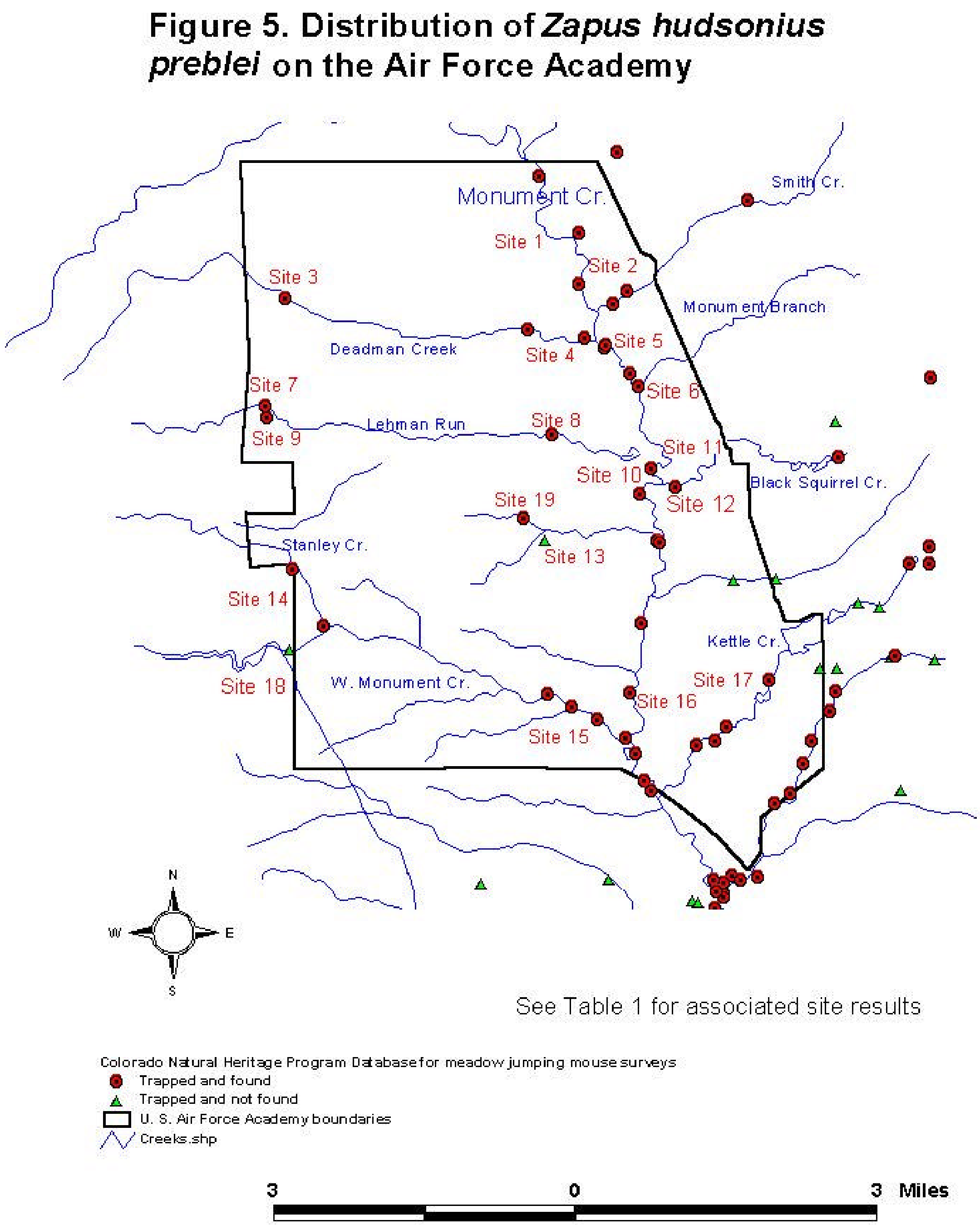


Table 1. Trapping effort on the U.S. Air Force Academy (1997-1999)

Table 1. Trapping effort on the U.S. Air Force Academy (1997-1999)

Site # *	Site Name	Legal Description	Trapnights	Dates trapped	*Zapus?*
1	Monument Creek (Jack's Valley confluence)	T12S, R67W, S2 NE1/4 of NE1/4	300	21-25 Aug 1998	no
2	Tributary near emergency air field	T12S, R67W, S1 NE1/4 of SW1/4	200	10-13 Sept 1997	no
3	Deadmans Lake	T12S, R67W, S9 NE1/4 of NW1/4	150	6-11 Aug 1998	yes
4	Deadmans Creek	T12S, R67W, S12 N1/2 of SW1/4	1200	30 May - 6 June (300 tn), 3-15 Sept 1998 (900 tn)	yes
5	Monument Creek near Husted	T12S, R67W, S12 SW1/4 of SE1/4	650	10-13 Sept 1997	yes
6	Monument Branch	T12S, R67W, S13 NE1/4 of NE1/4	200	10-13 Sept 1997	yes
7	Goat Camp Creek	T12S, R67W, S16 SE1/4 of NW1/4	360	27 June - 17 July 1998	yes
8	Lehman Run at Academy Drive	T12S, R67W, S13 SW1/4 of SW1/4	565	13-19 Aug 1997	yes
9	West Lehman Run	T12S, R67W, S16 SE1/4 of NW1/4	540	9 July - 13 Aug 1998	yes
10	Lehman Run at Stadium Blvd. Overpass	T12S, R67W, S13 SW1/4 of SE1/4	750	13-19 Aug 1997	no
11	Monument Creek, Population Sampling Grid A	T12S, R66W, S19 NW1/4 of NW1/4	2940	*Each population sampling grid*	yes
11	Monument Creek, Population Sampling Grid B	T12S, R66W, S19 NW1/4 of NW1/4	2940	*was trapped for the following days*	yes
11	Monument Creek, Population Sampling Grid C	T12S, R66W, S19 NW1/4 of NW1/4	2940	*in 1998 and 1999:*	yes
11	Monument Creek, Population Sampling Grid D	T12S, R67W, S24 SE1/4 of NE1/4	2940	*June 11-17, July 23-29, Sept 3-9 1998*	yes
11	Monument Creek, Population Sampling Grid E	T12S, R66W, S19 NW1/4 of NW1/4	2940	*June 5-15, July 7-16, Sept 2-10 1999*	yes
12	Black Squirrel Creek	T12S, R66W, S19 N1/2	200	6-11 Aug 1998	yes
13	unnamed drainage from Douglass Valley	T12S, R67W, S24 NE1/4 of SE1/4	750	20-22, 26-28 Aug 1997	no
14	Stanley Creek	T12S, R67W, S21 SE1/4 of SW1/4, S28 W1/2	466	26 June - 17 July 1998	yes
15	West Monument Creek	T12S, R67W, S35 SW1/4 of NE1/4	500	16-21 Sept 1998	yes
16**	Monument Creek, Southgate Overpass	T12S, R67W, S25 NE1/4 of SE1/4	200	10-13 Sept 1997	no
17	Kettle Lakes	T12S, R66W, S32 NW1/4 of NW1/4	500	16-21 Sept 1998	yes
18	Tesla Hydrologic Plant	T12S, R67W, S28 NE 1/4 of SW1/4	505	3-8 Aug 1998	no
19	unnamed drainage from Douglass Valley	T12S, R67W, S23 NE1/4 of SE1/4	300	10-13 Aug 1999	yes
		Total trapnights over two-year study	23186		

* See Figure 5. Distribution of *Zapus hudsonius preblei* on the Air Force Academy

** In 1995, Corn et al. (1995) documented jumping mice from this location

Table 2. *Zapus h. preblei* radiocollared and tracked on the U.S. Air Force Academy, 1997-1999

Table 2. *Zapus h. preblei* collared and tracked on the U.S. Air Force Academy, 1997-1999

Collar Frequency	Sex	Repro.	Weight (g)	Dates tracked	Total days*	Total days tracked**	Outcome	Location	PIT tag number
6.127	M	NA	17.5	18 Sept - 21 October, 1997	32	19	Tracked to hibernation	Husted	NA
6.749	M	NA	20.5	18 Sept - 21 October, 1997	32	19	Tracked to hibernation	Husted	NA
6.367	M	NA	19.5	19 Sept - 10 October, 1997	21	18	Lost signal	Husted	NA
6.587	M	NA	16.0	19 Sept - 21 October, 1997	32	16	Tracked to hibernation	Husted	NA
6.647	M	NA	18.0	19 Sept - 21 October, 1997	32	16	Tracked to hibernation	Husted	NA
7.167	F	NA	17.0	28 May - 29 May, 1998	2	2	Predated by *Thamnophis elegans*	Deadmans Cr.	NA
7.167***	F	NA	20.0	30 May - 5 June, 1998	7	4	Likely predated by *Buteo jamaicensis*	Husted	NA
7.409	M	NA	16.5	30 May - 31 May, 1998	2	2	Lost signal	Deadmans Cr.	NA
7.768	M	NA	18.5	31 May - 4 June, 1998	5	3	Parasitized by *Wohlfahrtia vigil*	Deadmans Cr.	NA
7.61	M	NA	21.5	30 May - 4 June, 1998	6	5	Found collar	Deadmans Cr.	NA
7.668	F	NA	19.0	30 May - 15 June, 1998	17	11	Lost signal	Deadmans Cr.	NA
7.428	M	NA	19.0	31 May - 5 June, 1998	6	3	Found beheaded/predated	Husted	NA
7.629	M	NA	20.0	31 May - 5 June, 1998	6	3	Lost signal	Husted	NA
7.688	M	NA	19.0	31 May - 11 June, 1998	12	4	Drowned	Husted	NA
7.788	F	NA	19.0	30 May - 13 June, 1998	15	8	Slipped collar	Husted	NA
7.729	M	NA	26.0	30 May - 3 June, 1998	5	5	Lost signal	Deadmans Cr.	NA
7.848	F	NA	19.5	3 Sept - 7 October, 1998	34	25	Tracked to hibernation	Deadmans Cr.	4064751804
7.984	F	NA	22.0	17 Sept - 20 September, 1998	4	2	Found collar	Deadmans Cr.	NA
7.917	M	NA	21.0	19 Sept - 7 October, 1998	18	14	Tracked to hibernation	Deadmans Cr.	4140762120
7.878	F	NA	19.5	20 Sept - 5 October, 1998	16	11	Tracked to hibernation	Deadmans Cr.	41414A3F72
6.147	F	NA	18.5	21 June - 19 July, 1999	28	8	Tracked	Grid A	NA
6.167	M	NA	17g	30 June - 19 July, 1999	20	5	Tracked	Deadmans Cr.	NA
6.187	M	NA	24.5g	20 June - 12 July, 1999	22	8	Tracked	Grid E	41353C397D
6.428	M	NA	19g	20 June - 12 July, 1999	22	8	Tracked	Grid E	407A36175A
6.609	F	lact.	21g	21 June - 13 July, 1999	22	8	Tracked	Grid A	NA
6.688	M	NA	22g	20 June - 12 July, 1999	22	8	Predated	Grid E	413A403711
6.708	M	NA	18.5g	20 June - 1 July, 1999	11	6	Lost signal	Grid E	40653A7A67

* Total days = total number of days animal was collared

** Total days tracked = total number of days researchers collected telemetry information for that animal

*** In 1998, collar frequency 217167 MHz was attached to another animal after the first animal was predated

Table 2. *Zapus h. preblei* radiocollared and tracked on the U.S. Air Force Academy, 1997-1999 (cont.)

Table 2. *Zapus h. preblei* collared and tracked on the U.S. Air Force Academy, 1997-1999 (cont.)

Collar Frequency	Sex	Repro.	Weight (g)	Dates tracked	Total days*	Total days tracked**	Outcome	Location	PIT tag number
216.768 MHz	M	scrotal	15.5g	1 July - 15 July, 1999	15	3	Found collar	Deadmans Cr.	NA
217.871 MHz	M	NA	15.5g	21 June - 30 June, 1999	9	5	Signal did not move	Grid A	NA
217.901 MHz	F	NA	17.5g	1 June - 15 June, 1999	15	3	Lost signal	Deadmans Cr.	NA
217.935 MHz	M	NA	18.5g	21 June - 30 June, 1999	9	6	Lost signal	Grid A	NA
216.304 MHz	F	lact.	19g	25 August - 22 September, 1999	28	11	Tracked	Grid A	NA
216.264 MHz	M	NA	17g	27 August - 26 September, 1999	30	7	Tracked	Grid E	4133621F4A
216.390 MHz	M	NA	17.5g	28 -29 August, 1999	2	1	Died	Grid E	406509785B
216.225 MHz	F	NA	24g	28 August - 8 September, 1999	12	4	Tracked	Grid A	40654E041D
217.949 MHz	M	NA	21g	30 August - 22 September, 1999	23	5	Tracked	Grid E	NA
216.247 MHz	F	lact.	22g	9 - 26 September, 1999	17	3	Tracked	Grid B	4141203F34
217.971 MHz	F	NA	20g	14 - 26 September, 1999	12	4	Tracked	Grid A	4141253370
216.351 MHz	M	NA	22g	10 - 22 September, 1999	12	1	Tracked	Grid E	40653A7A67

* Total days = total number of days animal was collared

** Total days tracked = total number of days researchers collected telemetry information for that animal

*** In 1998, collar frequency 7.167 was attached to another animal after the first animal was predated

Table 3. Farthest distance traveled by collared meadow jumping mice over the life of the collar
Table 4. Home ranges for *Zapus hudsonius preblei* on the U.S. Air Force Academy
Table 5. Radiocollared meadow jumping mouse distance from the associated waterway

Table 3. Farthest distance traveled by collared meadow jumping mice over life of collar

Collar Frequency	Farthest distance traveled (m) rounded to nearest 5 m
6.127	195
6.367	230
6.587	190
6.647	280
6.749	205
6.917	110
6.848	145
6.878	90
6.225	165
6.264	315
6.304	470
7.949	385
Mean	**232**
Std. Dev.	**113**

Table 5. Radiocollared meadow jumping mouse distance from the associated waterway

Species	Number of telemetry locations	Mean distance to creek (m)	Standard error of mean (m)	Maximum distance from creek (m)
Zapus hudsonius	1024	35.0	27.3	144.0

Year	Number of telemetry locations	Mean distance to creek (m)	Standard error of mean (m)	Maximum distance from creek (m)
1997	325	39.5	28.6	131.0
1998	316	11.5	7.9	42.5
1999	383	50.5	29.7	144.0

Table 4. Home ranges for *Zapus hudsonius preblei* on the U.S. Air Force Academy

Collar frequency	Total number of locations	95 % Kernel home range (ha)*	Minimum convex polygon (ha)**	95% Jennrich-Turner Estimator**	Bootstrap 95% Kernel home range estimator (ha)		
					Mean	Standard error	Bias
6.647	71	0.703	3.065	4.650	1.836	0.078	-0.191
6.749	71	0.169	0.956	0.647	0.141	0.004	-0.004
6.367	50	0.968	3.636	3.730	0.898	0.036	-0.068
6.587	58	0.641	1.572	1.433	0.749	0.035	-0.068
6.127	75	1.307	1.843	1.826	1.265	0.059	-0.123
7.848	180	0.347	0.573	0.800	0.365	0.008	-0.023
7.917	74	0.118	0.338	0.456	0.117	0.004	-0.007
7.878	38	0.277	0.598	0.766	0.389	0.022	-0.032
7.949	69	0.692	6.093	3.495	0.629	0.084	0.019
6.225	40	0.054	0.823	1.158	0.055	0.004	0.001
6.264	100	0.843	2.816	3.566	1.540	0.062	-0.168
6.304	101	0.191	4.423	3.195	1.990	0.060	-0.093
Mean	**77.3**	**0.526**	**2.228**	**2.144**	**0.831**		
Std. Dev.	**38.0**	**0.393**	**1.807**	**1.481**	**0.681**		

* Using Kernel HR v.4.27 Estimation Program by E. Seaman and R. Powell. 1991.
** Using Animal Movement v.1.1 ArcView Extension by P. Hooge. 1998.
*** 1000 bootstrap samples using HomeRanger v.1.5 by F. Hovey. 1999.

Table 6. Total meadow jumping mouse captures, sex ratios, and average weights on population grids

Table 6. Total meadow jumping mouse captures, sex ratios, and average weights on population grids

	Total captured	Sex ratio (m/f)	Average weight (g) [N]	Stnd. Dev.(g)
Jun-98				
Grid A	11	7/4	17.0 [11]	2.1
Grid B	8	7/1	18.9 [8]	1.5
Grid C	4	3/1	16.7 [4]	2.0
Grid D	13	9/4	18.1 [13]	1.8
Grid E	11	8/3	18.3 [11]	2.4
Total	47	34/13	17.9 [47]	2.1
Jul-98				
Grid A	7	4/3	18.9 [7]	3.7
Grid B	8	1/7	21.5 [8]	3.1
Grid C	7	3/4	19.2 [7]	1.8
Grid D	14	9/5	18.2 [14]	4.8
Grid E	9	3/6	20.2 [8]	3.6
Total	45	19/26	19.7 [44]	3.1
Sep-98				
Grid A	7	6/1	18.8 [5]	4.9
Grid B	8	2/6	18.1 [7]	4.3
Grid C	8	4/4	16.2 [5]	2.2
Grid D	6	4/2	20.6 [6]	6.3
Grid E	4	2/2	18.3 [4]	1.7
Total	33	18/15	18.5 [27]	4.3
1998 Totals	125	71/54	18.8 [120]	3.2
Jun-99				
Grid A	2	2/0	18.5 [2]	3.5
Grid B	5	5/0	20.0 [5]	3.5
Grid C	3	2/1	17.3 [3]	3.1
Grid D	4	3/0	18.9 [4]	3.4
Grid E	7	6/1	17.6 [7]	2.3
Total	21	18/2	18.5 [21]	2.9
Jul-99				
Grid A	4	1/3	21.3 [4]	4.2
Grid B	3	1/2	19.3 [3]	2.4
Grid C	6	1/5	19.0 [6]	1.2
Grid D	8	4/4	20.9 [8]	3.6
Grid E	8	5/3	21.2 [8]	2.9
Total	29	12/15	20.5 [29]	3.0
Sep-99				
Grid A	6	3/3	18.0 [4]	1.5
Grid B	4	0/4	22.9 [4]	1.5
Grid C	0	0	0	0.0
Grid D	1	0/1	22.0 [1]	NA
Grid E	1	1/0	32.0 [1]	NA
Total	12	4/8	21.8 [10]	4.5
1999 Totals	62	34/21	20.0 [60]	3.4
Total	187	105/79	19.7 [133]	3.5

Note: Individuals were only counted once if they were caught on multiple grids within the same trap session. Their weights and sex were only contributed to the grid they were first captured on during that session.

Table 7. Abundance and population estimation for meadow jumping mouse at the U.S. Air Force Academy

Table 7. Abundance and population estimation for meadow jumping mice at the Air Force Academy*

Calculations using White and Shenk (2000)

												Density (D)			
Month	**Year**	**Study Area**	**Grid**	**Grid Length (m)**	**N-hat**	**Var (N-hat)**	**p**	**N-hat(adj)**	**Var BSW**	**Var P**	**Var (N-hat, adj)**	**mice/km**	**Var (D)**	**Lower CI**	**Upper CI**
June	1998	Monument Creek	A	63	11	0.0000	0.4312	5	84.04	0.00293	0.35	75	89.3	58.9	96.2
June	1998	Monument Creek	B	63	8	0.0007	0.4312	3	84.04	0.00293	0.19	55	47.3	42.9	70.0
June	1998	Monument Creek	C	63	4	0.0000	0.4312	2	84.04	0.00293	0.05	27	11.8	21.4	35.0
June	1998	Monument Creek	D	63	14	0.0000	0.4312	6	84.04	0.00293	0.57	96	144.7	75.0	122.4
June	1998	Monument Creek	E	63	12	0.0000	0.4312	5	84.04	0.00293	0.42	82	106.3	64.3	104.9
											Mean	**67**			
											SE(Mean)	**12**			
June	1999	Monument Creek	A	63	2	0.0000	0.4312	1	84.04	0.00293	0.01	14	3.0	10.7	17.5
June	1999	Monument Creek	B	63	5	0.0000	0.4312	2	84.04	0.00293	0.07	34	18.5	26.8	43.7
June	1999	Monument Creek	C	63	2	0.0000	0.4312	1	84.04	0.00293	0.01	14	3.0	10.7	17.5
June	1999	Monument Creek	D	63	4	0.0000	0.4312	2	84.04	0.00293	0.05	27	11.8	21.4	35.0
June	1999	Monument Creek	E	63	8	0.0000	0.4312	3	84.04	0.00293	0.19	55	47.2	42.9	70.0
											Mean	**29**			
											SE(Mean)	**7.6**			

Calculations using information from collared mice at the Air Force Academy (R. Schorr and Bruce Lubow, Colorado State University)

											Density (D)			
Month	**Year**	**Study Area**	**Grid**	**Grid Length (m)**	**N-hat**	**Var (N-hat)**	**Res. Factor**	**N-hat(adj)**	**Var Res. Factor**	**Var (N-hat, adj)**	**mice/km**	**Var (D)**	**Lower CI**	**Upper CI**
June	1998	Monument Creek	A	63	11	0.0000	0.2479	3	0.0071	0.86	43	216.5	22.6	82.8
June	1998	Monument Creek	B	63	8	0.0007	0.2479	2	0.0071	0.45	31	114.5	16.5	60.2
June	1998	Monument Creek	C	63	4	0.0000	0.2479	1	0.0071	0.11	16	28.6	8.2	30.1
June	1998	Monument Creek	D	63	14	0.0000	0.2479	3	0.0071	1.39	55	350.8	28.8	105.3
June	1998	Monument Creek	E	63	12	0.0000	0.2479	3	0.0071	1.02	47	257.7	24.7	90.3
										Mean	**39**		**20.2**	**73.7**
										SE(Mean)	**6.9**			
June	1999	Monument Creek	A	63	2	0.0000	0.2479	0	0.0071	0.03	8	7.2	4.1	15.0
June	1999	Monument Creek	B	63	5	0.0000	0.2479	1	0.0071	0.18	20	44.7	10.3	37.6
June	1999	Monument Creek	C	63	2	0.0000	0.2479	0	0.0071	0.03	8	7.2	4.1	15.0
June	1999	Monument Creek	D	63	4	0.0000	0.2479	1	0.0071	0.11	16	28.6	8.2	30.1
June	1999	Monument Creek	E	63	8	0.0000	0.2479	2	0.0071	0.45	31	114.5	16.5	60.2
										Mean	**17**		**8.6**	**31.6**
										SE(Mean)	**4.4**			

* Glossary of abbreviations in table

N-hat = estimated population

Var = variance of the identified estimator

P = residency factor calculated in White and Shenk 2000a

Res. Factor = residency factor calculated using movement data from AFA

N-hat adj. = the population estimate adjusted using P or Res. Factor

Var BSW = variance of basal strip width (White and Shenk 2000a)

Lower CI/Upper CI = the 95% confidence interval for that estimator

SE = standard error

This table was compiled and analyzed with the assistance and guidance of Bruce Lubow, Colorado State University

Table 7. Abundance and population estimation for meadow jumping mouse at the U.S. Air Force Academy (cont.)

Table 7. Abundance and population estimation for meadow jumping mice at the Air Force Academy (cont.)

Calculations using White and Shenk (2000)

												Density			
Month	**Year**	**Study Area**	**Grid**	**Grid Length (m)**	**N-hat**	**Var (N-hat)**	**p**	**N-hat(adj)**	**Var BSW**	**Var P**	**Var (N-hat, adj)**	**Est. (mice/km)**	**Var (D)**	**Lower CI**	**Upper CI**
JulySept	1998	Monument Creek	A	63	7	0.0000	0.4312	3	84.04	0.00293	0.14	48	36.2	37.5	61.2
JulySept	1998	Monument Creek	B	63	8	0.0000	0.4312	3	84.04	0.00293	0.19	55	47.2	42.9	70.0
JulySept	1998	Monument Creek	C	63	8	0.0000	0.4312	3	84.04	0.00293	0.19	55	47.2	42.9	70.0
JulySept	1998	Monument Creek	D	63	12	0.0000	0.4312	5	84.04	0.00293	0.42	82	106.3	64.3	104.9
JulySept	1998	Monument Creek	E	63	7	0.0000	0.4312	3	84.04	0.00293	0.14	48	36.2	37.5	61.2
											Mean	**57**			
											SE(Mean)	**6**			
JulySept	1999	Monument Creek	A	63	4	0.0003	0.4312	2	84.04	0.00293	0.05	27	11.8	21.4	35.0
JulySept	1999	Monument Creek	B	63	3	0.0000	0.4312	1	84.04	0.00293	0.03	21	6.6	16.1	26.2
JulySept	1999	Monument Creek	C	63	6	0.0001	0.4312	3	84.04	0.00293	0.11	41	26.6	32.1	52.5
JulySept	1999	Monument Creek	D	63	8	0.0005	0.4312	3	84.04	0.00293	0.19	55	47.3	42.9	70.0
JulySept	1999	Monument Creek	E	63	8	0.0005	0.4312	3	84.04	0.00293	0.19	55	47.3	42.9	70.0
											Mean	**40**			
											SE(Mean)	**7.0**			

Calculations using information from collared mice at the Air Force Academy (R. Schorr and Bruce Lubow, Colorado State University)

											Density			
Month	**Year**	**Study Area**	**Grid**	**Grid Length (m)**	**N-hat**	**Var (N-hat)**	**Res. Factor**	**N-hat(adj)**	**Var Res. Factor**	**Var (N-hat, adj)**	**Est. (mice/km)**	**Var (D)**	**Lower CI**	**Upper CI**
JulySept	1998	Monument Creek	A	63	7	0.0000	0.2479	2	0.0071	0.35	28	87.7	14.4	52.7
JulySept	1998	Monument Creek	B	63	8	0.0000	0.2479	2	0.0071	0.45	31	114.5	16.5	60.2
JulySept	1998	Monument Creek	C	63	8	0.0000	0.2479	2	0.0071	0.45	31	114.5	16.5	60.2
JulySept	1998	Monument Creek	D	63	12	0.0000	0.2479	3	0.0071	1.02	47	257.7	24.7	90.3
JulySept	1998	Monument Creek	E	63	7	0.0000	0.2479	2	0.0071	0.35	28	87.7	14.4	52.7
										Mean	**33**		**17.3**	**63.2**
										SE(Mean)	**3.6**			
JulySept	1999	Monument Creek	A	63	4	0.0003	0.2479	1	0.0071	0.11	16	28.6	8.2	30.1
JulySept	1999	Monument Creek	B	63	3	0.0000	0.2479	1	0.0071	0.06	12	16.1	6.2	22.6
JulySept	1999	Monument Creek	C	63	6	0.0001	0.2479	1	0.0071	0.26	24	64.4	12.4	45.1
JulySept	1999	Monument Creek	D	63	8	0.0005	0.2479	2	0.0071	0.45	31	114.5	16.5	60.2
JulySept	1999	Monument Creek	E	63	8	0.0005	0.2479	2	0.0071	0.45	31	114.5	16.5	60.2
										Mean	**23**		**11.9**	**43.6**
										SE(Mean)	**4.0**			

* Glossary of abbreviations in table

N-hat = estimated population

Var = variance of the identified estimator

P = residency factor calculated in White and Shenk 2000a

Res. Factor = residency factor calculated using movement data from AFA

N-hat adj. = the population estimate adjusted using P or Res. Factor

Var BSW = variance of basal strip width (White and Shenk 2000a)

Lower CI/Upper CI = the 95% confidence interval for that estimator

SE = standard error

This table was compiled and analyzed with the assistance and guidance of Bruce Lubow, Colorado State University

Table 8. Summary of habitat measurements from meadow jumping mouse population grids (1998-1999)

Table 8. Summary of habitat measurements from meadow jumping mouse population grids (1998-1999)

	1998			1999		
Variable	N	Mean	Std dev.	N	Mean	Std dev.
Number of canopy trees with DBH <15cm	30	4.23	5.96	30	1.90	2.78
Number of canopy trees with DBH 15-25 cm	30	1.20	1.92	30	1.00	1.82
Number of canopy trees with DBH 26-35 cm	30	0.60	1.75	30	0.47	0.90
Number of canopy trees with DBH 36-45 cm	30	0.53	1.70	30	0.13	0.43
Number of canopy trees with DBH >46 cm	30	0.70	1.42	30	0.70	1.06
Number of stems (north)	30	13.57	9.13	30	106.87	69.81
Number of stems (south)	30	12.70	11.99	30	93.73	65.61
Number of stems (east)	30	13.93	9.58	30	100.30	78.94
Number of stems (west)	30	10.06	7.67	30	103.40	78.60
Average number of woody stems	30	12.56	7.09	30	101.08	59.56
Percent canopy cover (north)	30	32.53	40.07	30	62.47	36.17
Percent canopy cover (south)	30	24.83	36.21	30	33.80	35.28
Percent canopy cover (east)	30	27.40	35.69	30	33.87	34.77
Percent canopy cover (west)	30	31.87	39.49	30	32.53	36.78
Average percent canopy cover	30	21.53	23.95	30	33.17	27.40
Percent vertical vegetation density (0.0-0.5 m)	30	74.29	19.20	30	81.70	20.79
Percent vertical vegetation density (0.5-1.0 m)	30	56.00	27.68	30	67.30	26.14
Percent vertical vegetation density (1.0-1.5 m)	30	47.50	30.54	30	56.25	28.68
Percent vertical vegetation density (1.5-2.0 m)	30	41.17	30.85	30	44.34	27.60
Percent vertical vegetation density (2.0-2.5 m)	30	35.17	30.27	30	38.98	26.93
Percent vertical vegetation density (2.5-3.0 m)	30	29.25	28.36	30	31.28	23.89
Percent ground cover of forbs	30	37.42	16.59	30	15.90	8.99
Percent ground cover of grasses	30	16.71	10.63	30	15.77	11.36
Percent ground cover of rock	30	3.19	9.24	30	14.36	18.97
Percent ground cover of bare soil	30	8.72	10.70	30	*	*
Percent ground cover of woody debris	30	12.95	8.91	30	10.95	11.53
Percent ground cover of litter	30	22.32	15.71	30	11.57	14.20
Percent ground cover of lichen and moss	30	1.36	2.72	30	3.14	6.50
Amount of downed woody debris 3-7 cm diam.	30	2.30	12.60	30	13.33	47.52
Amount of downed woody debris 8-10 cm in diam.	30	2.81	1.06	30	5.10	16.46
Amount of downed woody debris 11-20 cm in diam.	30	1.08	4.53	30	0.20	0.48
Amount of downed woody debris 21-30 cm in diam.	30	0.24	0.37	30	0.20	0.61
Amount of downed woody debris >31 cm diam.	30	0.08	0.15	30	0.27	0.58

* Ground cover of bare soil was combined with ground cover of rock in 1999

Table 9. Meadow jumping mouse micro-habitat characterization comparison between Rocky Flats Environmental Technology Site (RFETS) and the U.S. Air Force Academy

Table 9. Meadow jumping mouse micro-habitat characterization comparison between Rocky Flats Environmental Technology Site (RFETS) an the U. S. Air Force Academy

From Ryon, Nelson, and Schorr (in prep.)

Variable	RFETS	Air Force Academy
Slope ***	12[a]	6.4[b]
Number of Plant Species/Trap Station *	30.5[a]	19.1[b]
Distance to Stream (m)	1.7	16.8
Percent Herbaceous Density	77.3[a]	83.3[a]
Percent Tree/Shrub Canopy	25.5	25.0
Percent Tree Cover **	17.7[a]	1.2[a]
Percent Shrub Cover **	38.3[a]	56.5[b]
Percent SubShrub Cover **	10.1[a]	23.2[a]
Percent Forb Cover **	28[a]	42[a]
Percent Graminoid Cover ***	32.8[a]	56.7[b]
Woody Index	66.1	80.9
Herbaceous Index	60.8	98.7

All values are means (n = 25).
Different letters between sites for individual variables indicate significant differences.

* t test (P = 0.05)

** Mann-Whitney U test (P = 0.05)

*** Mann-Whitney U test (P = 0.01)

Table 10. Characteristics of meadow jumping mouse hibernacula on the U.S. Air Force Academy

Table 10. Characteristics of meadow jumping mouse hibernacula

	Collar Frequency							
	6.647	**6.127**	**6.749**	**6.587**	**7.878**	**7.917**	**Mean**	**SE**
Distance from water	7	28.5	31	12	12	45	22.58	14.66
Slope	40-45	0-5	0-5	0	20-25	20-25		
Aspect	280	165	340	NA	320	360	293.00	77.43
Number of overstory trees								
DBH Class								
5-15 cm	0	0	19	0	17	1	6.00	9.20
16-25 cm	0	0	1	0	0	4	1.00	1.60
26-35 cm	0	0	0	0	2	6	1.00	2.40
36-45 cm	0	0	0	0	1	1	0.00	0.50
46+ cm	0	0	0	0	1	0	0.00	0.40
Soils	Kg	TC	TC	TC	Kr	Kr		
Shrub Density	13.25	22.75	14.50	23.00	62.00	17.00	25.42	18.38
Canopy Cover	0.00	0.00	97.50	24.75	77.00	81.00	46.71	43.63
Mean Vertical Vegetation Density								
0.0 - 0.5 m	70.00	87.50	83.75	100.00	32.50	40.00	68.96	27.18
0.5 - 1.0 m	53.75	88.75	63.75	100.00	32.50	41.50	63.38	26.49
1.0 - 1.5 m	52.50	76.25	48.75	97.50	26.75	36.50	56.38	26.20
1.5 - 2.0 m	43.75	55.00	41.25	70.00	29.50	37.50	46.17	14.35
2.0 - 2.5 m	31.25	32.50	36.25	61.25	36.25	23.75	36.88	12.79
2.5 - 3.0 m	22.50	5.00	27.50	40.00	28.75	6.00	21.63	13.74
Mean Percent Ground Cover								
Forb/Fern	30.00	55.38	42.69	40.00	15.77	10.77	32.43	16.98
Grass/Sedge	17.69	12.69	23.08	17.69	27.92	11.69	18.46	6.18
Rock/Soil	2.69	11.15	2.69	1.15	12.69	15.46	7.64	6.17
Woody Debris	11.15	4.62	22.31	11.92	8.31	7.00	10.88	6.21
Litter	30.00	16.15	9.23	27.69	18.23	53.62	25.82	15.62
Moss/Lichen	0.77	0.00	0.00	1.54	6.15	0.69	1.53	2.34
Downed woody debris								
Diameter class								
3-7 cm	1	0	43	2	1	4	8.50	16.96
7.1-10 cm	0	0	1	0	2	2	0.83	0.98
10.1-20 cm	0	0	2	0	4	0	1.00	1.67
20.1-30 cm	0	0	0	0	0	0	0.00	0.00
30.1+ cm	0	0	0	0	0	0	0.00	0.00

Soil types are:
TC- Tomah-Crowfoot loamy sand, 8-15% slopes (USGS Soil Survey, El Paso County)
Kg- Kettle gravelly loamy sand, 8-40% slopes (USGS Soil Survey, El Paso County)
Kr-Kettle-Rock outcrop complex

Table 11. Day nests for radio-collared meadow jumping mice at the U.S. Air Force Academy (1999)

Table 11. Day nests for radio-collared meadow jumping mice at the Academy (1999)

Frequency	Sex	Weight (g)	Nest searches	Nests found
6.147	F	18.5	3	1
6.187	M	24.5	3	1
6.304	F	19.0	20	2
6.264	M	17.0	14	4
6.390	M	17.5	2	0
6.225	F	24.0	11	2
7.949	M	21.0	15	6
6.247	F	22.0	5	0
7.971	F	20.0	7	2
6.351	F	22.0	4	1
		Total	84	19

Table 12. Mammals captured in Grids A-E along Monument Creek, U.S. Air Force Academy (1998-1999)

Table 12. Mammals captured in Grids A - E along Monument Creek, Air Force Academy (1998-1999)

	June 1998		July 1998		Sept 1998		June 1999		July 1999		Sept 1999	
Species	captures	captures/tn*	captures	captures/tn	captures	captures/tn	captures	captures/tn	captures	captures/tn	captures	captures/tn
Microtus pennsylvanicus	111	0.04	192	0.07	129	0.04	98	0.03	357	0.12	433	0.15
Peromyscus maniculatus	246	0.08	306	0.10	284	0.10	554	0.19	458	0.16	450	0.15
Sorex monticolus/ sp.**	3	0.00	12	0.00	8	0.00	4	0.00	6	0.00	3	0.00
Tamias minimus	0	0.00	0	0.00	1	0.00	1	0.00	2	0.00	1	0.00
Mustela frenata	0	0.00	0	0.00	1	0.00	0	0.00	0	0.00	0	0.00
Reithrodontomys megalotis	0	0.00	0	0.00	0	0.00	5	0.00	0	0.00	0	0.00
Zapus hudsonius preblei	47	0.02	45	0.02	33	0.01	21	0.01	29	0.01	12	0.00
Total captures	407	0.14	555	0.19	456	0.16	683	0.23	852	0.29	899	0.31

*tn = trapnights; There were 2940 trapnights per session of trapping

** Several shrews collected from Monument Creek were identified as Sorex monticolus, but not all shrews were positively identified using dentition and cranial characteristics