
There are no published studies on the diet of Mogollon voles (*Microtus mogollonensis*) although this species occurs throughout the Southwest in montane forestlands. Mogollon voles are believed to be herbivorous, selecting the vegetative portion of grass as their dominant food source. Herbivores frequently select more easily digested C₃ plants over C₄ plants; we thus expected Mogollon voles would feed primarily on C₃ plants. We collected hair samples from Mogollon voles captured in northern Arizona between 1967 and 2003 and plant samples from some capture sites. Then we compared stable carbon (δ¹³C) and nitrogen (δ¹⁵N) isotope ratios to investigate dietary preferences for C₃ or C₄ plants. Mean isotope ratios for C₃ plants we sampled were −26.84‰ (s = 0.17) for δ¹³C and −0.02‰ (s = 0.32) for δ¹⁵N. For C₄ plants, mean isotope ratios for δ¹³C and δ¹⁵N were −15.04 ‰ (s = 0.38) and −0.74‰ (s = 0.55), respectively. Mogollon voles were largely herbivorous based on δ¹⁵N (mean and standard error: 3.77 ± 0.17‰) and used C₃ plants more than C₄ based on δ¹³C (−24.21 ± 0.14‰). Activities that lead to changes in plant species composition or reduction in C₃ plants in montane grasslands and forests (e.g., excessive ungulate grazing) may reduce habitat quality for Mogollon voles.

Key words: Mogollon vole, *Microtus mogollonensis*, carbon stable isotope, nitrogen stable isotope, diet, livestock grazing, Arizona.


There are no published studies on the diet of Mogollon voles (Frey 1995), and available information is limited to analysis of stomach or fecal pellet contents. In general, *Microtus* species are more abundant in areas with higher amounts of graminoid vegetation, because voles use this for both food and cover (Tamarin 1985). The Mogollon vole is believed to be primarily herbivorous. Conley (1976) stated that the vegetative portion of grass is the dominant food source, and a preferred food is Kentucky bluegrass (*Poa pratensis*). Hilton (1976) found grasses and forbs as primary stomach contents from animals captured throughout the year in dry high-elevation meadows in northern Arizona. The Hualapai vole (formerly *M. mexicanus hualpaei sensis*) feeds on green plant material as evidenced from bright green fecal pellets on runways (Spicer et al. 1985).

Stable-isotope analysis can be a useful technique for determining diet, because stable-isotope signatures from assimilated foods are directly incorporated into tissues of the consumer. Carbon and nitrogen stable-isotope ratios (δ¹³C and δ¹⁵N, respectively) are useful in determining source and flow of energy (Kelly 2000). In general, δ¹⁵N is enriched 3–5 per mil (%e) from producer to consumer and thus can indicate an organism’s trophic level (DeNiro and Epstein 1981, Games et al. 1998, Kelly 2000). Diet can also be documented based on the carbon-isotopic distinction between C₃ or C₄ photosynthesis, because the carbon-isotopic composition of the consumer directly reflects its diet (DeNiro and Epstein 1978). The C₃ pathway is common in dicots (e.g., yarrow, *Achillea millefolium*) and cool-season grasses (those that flower in late spring and early summer such as Arizona fescue, *Festuca arizonica*). The C₄ photosynthetic pathway is common in warm-season grasses (those that flower during summer, e.g., blue grama, *Bouteloua gracilis*). Because the difference in δ¹³C values of C₃ (range −35 to −21‰) versus C₄ (range −14 to
plants is large, classifying diet can add information on use of foods (Boutton 1991, Ehleringer 1991, Kelly 2000).

Hair is a biological archive of carbon- and nitrogen-stable-isotope ratios because it is composed of keratin derived in part from exogenous sources such as food and water. Because hair is relatively inert and resistant to degradation, the isotope composition reflects diet at the time hair growth occurred (Macko et al. 1999, West et al. 2004).

We investigated diet of Mogollon voles using stable-isotope analysis of hair. Because many herbivores select C3 over C4 plants for grazing (e.g., Gannes et al. 1998), we hypothesized that the diet of voles would reflect the C3 photosynthetic pathway. We hypothesized that the δ15N would indicate that voles are herbivorous, with a 3–5‰ increase in their nitrogen stable-isotope ratios over plant (producer) stable-isotope ratios in areas where Mogollon voles were captured. We also suspected that hair might serve as a sensitive indicator of climatic conditions (amount of precipitation) as reflected by carbon-stable-isotope enrichment in plants (e.g., enrichment during drier years because during dry conditions plants open stomata less during photosynthetic uptake of carbon dioxide [CO2] to avoid desiccation. Plants take in less external CO2, the internal CO2 concentration inside the plant cell decreases, and the plant must use relatively more 13CO2 than under moister conditions; Elheringer et al. 1993, Adams and Kolb 2004). We captured Mogollon voles or sampled them from the Northern Arizona University museum collection and collected representative plants at some capture sites to test our hypotheses.

Study Sites

We captured Mogollon voles by live-trapping in 3 riparian and 4 dry meadows from 2001 to 2003. Meadows were located within 100 km of Flagstaff on the Coconino and Kaibab National Forests. Riparian meadows were dominated by grasses and sedges including Kentucky bluegrass, clustered field sedge (Carex praegracilis), western wheatgrass (Pascopyrum smithii), deer muhly (Muhlenbergia rigens), and spike muhly (M. terightii; C. Chambers unpublished data, Steed 2001); dry meadows were dominated by Arizona fescue and blue grama (Yarborough 2006). Ponderosa pine forest surrounded meadows. In northern Arizona, annual precipitation averages 55 cm. The average high and low temperatures are 17.3°C and –0.9°C, respectively. During our trapping years, the study sites received 45, 33, and 45 cm of precipitation for 2001, 2002, and 2003, respectively (Western Regional Climate Center 2006).

METHODS

Vole Hair Samples

We placed 60–180 traps in each meadow for 2–5 days. We checked traps daily and identified captured animals to species, gender, and reproductive status. Using Winstead et al. (1999), we weighed and categorized Mogollon voles as juveniles, subadults, or adults with weight categories of <17 g, 17.1–25 g, or >25 g, respectively. We removed approximately 1 mg of hair from the dorsal surface of 68 voles captured in riparian meadows in June 2001 (n = 8), October 2001 (n = 6), June 2002 (n = 23), June 2003 (n = 6), and in dry meadows in July–August 2002 (n = 18) and 2003 (n = 7). Hair was stored frozen in individual vials prior to analysis. Animals were captured and handled under guidelines of the American Society of Mammalogists and with approval of the Northern Arizona University (NAU) Institutional Animal Care and Use Committee (Protocols 00-011 and 02-072).

Voles typically undergo synchronous molting (al-Khateeb and Johnson 1971, Lidicker 1973, Kuhlmann et al. 2003), and adults generally molt twice a year (late spring–early summer and fall; Lidicker 1973, Cherry and Verner 1975). We assumed that isotope signatures of adult Mogollon voles captured during summer and early fall indicated summer diet and that signatures of those captured during winter and spring indicated winter diet. Subadult-to-adult molt can occur within 2–3 months of age (Martin 1956). Subadult and juvenile voles that we captured were dispersing individuals, and we assumed they had lost any weaning signature after 3 weeks of age (M.D. Dearing, University of Utah, personal communication).

We obtained hair from 23 Mogollon voles in the NAU mammals collection to increase our sample size and scope of inference temporally and spatially (Appendix). These animals, collected between 1967 and 1979, represented captures from spring (Mar–May, n = 4), summer (Jun–Aug, n = 11), fall (Sep–Nov, n = 6), and winter (Dec, Feb, n = 2) at 12
Diet of Mogollon Voles

Table 1. Precipitation measurements (cm) and mean and standard error for δ13C and δ15N from hair samples from Mogollon voles (Microtus mogollonensis) that were captured in riparian and dry meadows in northern Arizona, 2001–2003, and from Mogollon voles that were collected in northern Arizona between 1967 and 1979 and curated in the Northern Arizona University Mammals Collection. Means for δ13C with the same letter and means for δ15N with the same letter were not significantly different (P > 0.05).

<table>
<thead>
<tr>
<th>Locationa</th>
<th>Year</th>
<th>n</th>
<th>δ13C</th>
<th>δ15N</th>
<th>Precipitationb (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collection</td>
<td>1967–1979</td>
<td>23</td>
<td>–23.2</td>
<td>0.3</td>
<td>c</td>
</tr>
<tr>
<td>Riparian</td>
<td>Oct 2001</td>
<td>6</td>
<td>–25.7</td>
<td>0.1</td>
<td>a</td>
</tr>
<tr>
<td>Riparian</td>
<td>Jun 2001</td>
<td>8</td>
<td>–25.6</td>
<td>0.1</td>
<td>a</td>
</tr>
<tr>
<td>Riparian</td>
<td>Jun 2003</td>
<td>6</td>
<td>–25.3</td>
<td>0.2</td>
<td>a</td>
</tr>
<tr>
<td>Dry</td>
<td>Jun 2003</td>
<td>7</td>
<td>–24.9</td>
<td>0.4</td>
<td>ab</td>
</tr>
<tr>
<td>Dry</td>
<td>Jul 2002</td>
<td>18</td>
<td>–23.4</td>
<td>0.2</td>
<td>c</td>
</tr>
</tbody>
</table>

aLocations of 3 riparian (35°27′N, 111°34′25″W, 2140 m elevation; 35°3′57″N, 111°19′32″W, 2100 m elevation; 34°32′39″N, 111°10′53″W, 2125 m elevation) and 4 dry meadows (35°3′57″N, 111°39′36″W, 2004 m elevation; 35°5′50″N, 112°17′19″W, 2173 m elevation; 35°9′41″N, 112°10′19″W, 2187 m elevation; 35°27′1″N, 111°53′10″W, 2439 m elevation).
bTotal precipitation from previous year to capture month (e.g., if capture month was October, precipitation was from November previous year to October capture month); not calculated for specimens from the Northern Arizona University Mammals Collection.

Sites. Because we did not have weights for these individuals, we could not categorize them as adults, subadults, or juveniles; they were excluded from analyses testing for age class differences.

Vegetation Samples

We collected representative samples from understory plants in areas we trapped, categorizing the species as high (dominant), moderate, or low density, and noted plants that covered Mogollon vole runways or showed signs of herbivory by voles.

Stable-Isotope Analysis

Prior to analysis, all hair samples were cleaned using a mild liquid detergent to remove dirt and then washed in a solvent mixture (chloroform:methanol, 2:1, v/v) to remove oils. Hair samples were then rinsed thoroughly with DI water and dried for 24–48 hours at 60°C. Plant samples were dried at 60°C for 48 hours and then ground to a fine powder using a ball-mill grinder. Samples were weighed (about 1 mg for hair and 4 mg for plant material) in tin capsules on a micro-analytical balance and analyzed on a Carlo Erba NC 2100 elemental analyzer interfaced to a Thermo Electron Delta Plus XL isotope-ratio mass spectrometer. Carbon- and nitrogen-stable-isotope ratios were analyzed simultaneously from the same sample. Replicate analyses of an internationally recognized standard (National Institute of Standards & Technology 1547, peach leaves) were precise to ±0.2‰ for both δ13C and δ15N. δ13C values were normalized on the VPDB scale using 2 standards available from the International Atomic Energy Association (IAEA): IAEA-CH6 (δ13C = –10.4‰) and IAEA-CH7 (δ13C = –31.8‰). δ15N values were normalized on the AIR scale using IAEA-N1 (δ15N = 0.4‰) and IAEA-N2 (δ15N = 20.3‰). Isotope ratios were expressed in ‰ as

$$\delta^N = 1000(R_{\text{sample}}/R_{\text{standard}} - 1),$$

where N is the mass of the heavy isotope of element E, and R is the ratio of the heavy isotope to the light isotope (13C/12C and 15N/14N). The δ values were reported relative to the international standards of Vienna-PeeDee Belemnite marine limestone (VPDB) and atmospheric N2 (AIR), for δ13C and δ15N, respectively. We used a linear mixing model (ISOERROR 1.04) to determine the proportion of C3 and C4 plants in the diet of Mogollon voles (Phillips and Gregg 2001).

Statistical Analysis

We used multiresponse permutation procedures (MRPP for single-factor designs; Zimmerman et al. 1985) to detect differences in diet as indicated by δ13C and δ15N between sexes, age classes, and locations by year. If sex or age class was not identified for a sample, it was excluded from analyses. We also compared diet by season (winter, spring, summer, fall) for specimens from the NAU mammals collection. These tests detect concentration within a priori groups. For these analyses we
assumed that a representative sample of the population was taken and that there was an equal probability of occurrence among groups. We used pairwise multiple comparisons among groups (Peritz closure method; Petridas and Gabriel 1983) to test the null hypothesis that for each subset of groups, observations were similar among groups within the subset. We

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**Table 2.** $\delta^{13}C$ and $\delta^{15}N$ values from plants sampled in riparian and dry meadows where Mogollon voles (*Microtus mogollonensis*) were captured in northern Arizona, 2001–2003.

<table>
<thead>
<tr>
<th>Plant species</th>
<th>Common name</th>
<th>$\delta^{13}C$</th>
<th>$\delta^{15}N$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RIPARIAN MEADOWS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C3 plants</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Elymus trachycaulis</em></td>
<td>slender wheatgrass</td>
<td>-28.2</td>
<td>-1.5</td>
</tr>
<tr>
<td><em>Pascopyrum smithii</em></td>
<td>western wheatgrass</td>
<td>-28.1</td>
<td>-0.5</td>
</tr>
<tr>
<td><em>Carex praegracilis</em></td>
<td>clustered field sedge</td>
<td>-27.4</td>
<td>-0.1</td>
</tr>
<tr>
<td><em>Eleocharis palustris</em></td>
<td>common spikerush</td>
<td>-27.4</td>
<td>0.2</td>
</tr>
<tr>
<td><em>Juncus arcticus var. mexicanus</em></td>
<td>Mexican rush</td>
<td>-26.7</td>
<td>1.9</td>
</tr>
<tr>
<td><em>Festuca ovina</em></td>
<td>sheep fescue</td>
<td>-25.9</td>
<td>-0.6</td>
</tr>
<tr>
<td><em>Poa pratensis</em></td>
<td>Kentucky bluegrass</td>
<td>-25.4</td>
<td>-1.1</td>
</tr>
<tr>
<td>C4 plants</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Bouteloua gracilis</em></td>
<td>blue grama</td>
<td>-15.3</td>
<td>0.9</td>
</tr>
<tr>
<td><em>Muhlenbergia wrightii</em></td>
<td>spike muhly</td>
<td>-14.1</td>
<td>-0.0</td>
</tr>
<tr>
<td><em>Muhlenbergia rigens</em></td>
<td>deer muhly</td>
<td>-13.4</td>
<td>-1.1</td>
</tr>
<tr>
<td><strong>DRY MEADOWS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C3 plants</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Festuca arizonica</em></td>
<td>Arizona fescue</td>
<td>-26.2</td>
<td>-1.8</td>
</tr>
<tr>
<td><em>Verbascum thapsus</em></td>
<td>woolly mullein</td>
<td>-26.1</td>
<td>1.6</td>
</tr>
<tr>
<td><em>Carex sp.</em></td>
<td>sedge</td>
<td>-25.9</td>
<td>-0.1</td>
</tr>
<tr>
<td>C4 plants</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Muhlenbergia rigens</em></td>
<td>deer muhly</td>
<td>-15.2</td>
<td>-0.4</td>
</tr>
<tr>
<td><em>Bouteloua gracilis</em></td>
<td>blue grama</td>
<td>-14.9</td>
<td>-1.3</td>
</tr>
<tr>
<td><em>Blepharoneuron tricholepis</em></td>
<td>pine drop seed</td>
<td>-14.6</td>
<td>0.2</td>
</tr>
<tr>
<td><em>Muhlenbergia montana</em></td>
<td>mountain muhly</td>
<td>-14.5</td>
<td>-5.9</td>
</tr>
</tbody>
</table>

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Fig. 1. Values of $\delta^{15}N$ vs. $\delta^{13}C$ from hair samples taken from Mogollon voles that were live-trapped in northern Arizona or were from the Mammals Collection at Northern Arizona University collected between 1967 and 1979. Figure symbols: June 2001 riparian meadows (open squares), October 2001 riparian meadows (open diamonds), June 2002 riparian meadow (dashes), summer 2002 dry meadow (open triangles), June 2003 riparian meadow (plus signs), June 2003 dry meadow (open circles), mammals collection (filled circles).
used Spearman rank correlations (Zar 1999) to determine whether a relationship existed between δ13C signatures for Mogollon voles we captured (2001–2003) and cumulative precipitation values (precipitation from the 12-month period preceding capture; Table 1). We set α = 0.05 for all analyses.

RESULTS

We detected no difference (P ≥ 0.5) between diets of male (n = 47, δ13C = −24.2 ± 0.2, δ15N = 3.6 ± 0.2) and female (n = 34, δ13C = −24.0 ± 0.2, δ15N = 4.0 ± 0.3) voles as indicated by δ13C or δ15N. Nor did we detect differences for δ13C among voles of different age classes (P = 0.09; juvenile: δ13C = −24.0 ± 0.4, n = 5; subadult: δ13C = −23.7 ± 0.3, n = 12; adult: δ13C = −24.5 ± 0.2, n = 31). However, δ15N differed among age classes (P = 0.02). Adult and juvenile voles were similar in diet (P = 0.3; adult: δ15N = 4.1 ± 0.2; juvenile: δ15N = 3.7 ± 0.2) but differed from subadults (δ15N = 3.2 ± 0.1; juvenile: subadult P = 0.05; adult: subadult P = 0.01). Diet of subadults may reflect their adjustment to procuring food after weaning and during dispersal.

We did not detect differences in δ13C or δ15N among season of capture for specimens collected between 1967 and 1979 (P = 0.06) (winter: n = 2, δ13C = −24.0 ± 0.1, δ15N = 4.7 ± 1.3; spring: n = 4, δ13C = −21.7 ± 1.5, δ15N = 6.1 ± 2.2; summer: n = 11, δ13C = −23.3 ± 0.2, δ15N = 2.4 ± 0.5; fall: n = 6, δ13C = −23.9 ± 0.5, δ15N = 4.9 ± 1.0, Fig. 1). However, we noted a trend for more enriched δ13C in spring diet compared with summer diet of voles (P = 0.09), suggesting that diet between late winter and spring could differ from summer diet. Small samples sizes likely limited our ability to detect significant differences.

We found few differences for voles among locations and years for δ15N, but δ13C varied among both (Table 1, Fig. 1). During years with higher precipitation, δ13C was more depleted (n = 6, R = −0.81, P = 0.05; Table 1). The δ13C values that we sampled in meadows ranged from −28.2 to −25.4 for C3 plants and from −15.3 to −13.4 for C4 plants (Table 2). The δ15N values for vegetation varied between −5.86 and 1.85. Stable-isotope signatures indicated that voles were primarily herbivorous (mean ± standard error for δ15N = 3.8 ± 0.2 ‰) and, according to the mixing model, used C3 plants (70% ± 3%), although a smaller percentage (30% ± 3%) of their diet included C4 plants.

Dominant C3 plants in meadows were clustered field sedge, western wheatgrass, Arizona fescue, and Kentucky bluegrass; C4 dominants were deer and spike muly. We found signs of herbivory by Mogollon voles, indicating they fed on clustered field sedge. They built runways under common spikerush (Eleocharis palustris), sheep fescue (Festuca ovina), Arizona fescue, and deer muly.

DISCUSSION

Many herbivores select C3 over C4 plants as food sources because C3 plants have higher nutritional content and digestibility (Gannes et al. 1998). Our data indicated that Mogollon voles fed primarily on C3 plants, despite the availability and dominance of C4 plants. Frey et al. (2002) found that ground cover of forbs and grasses during capture periods for Mogollon voles included Idaho fescue (Festuca idahoensis), western wheatgrass, and timothy (Phleum pratense), all C3 plant species (Williams 1974, Brown 2004). Yarborough (2006) surveyed 13 meadows in northern Arizona in 2002 and failed to detect sign (runways) of Mogollon voles in 6 of these. These meadows lacked the dense understory vegetation typical of meadows that had runways and in some cases were dominated by C4 plants such as blue grama. Blue grama did not appear to provide structure for adequate cover for Mogollon voles and also may be inadequate as a food source. Dominant plants (Arizona fescue, deer muly, spike muly, western wheatgrass, Kentucky bluegrass, clustered field sedge) where we captured more voles formed dense, tall (e.g., ≥35 cm) clumps in dry meadows or continuous cover in riparian meadows (C.L. Chambers unpublished data). Plants often leaned or collapsed so that grasses formed mats over runways, and runways thus functioned as tunnels. Both C3 and C4 plants were used as cover for runways, so C4 plants may in part have been ingested by Mogollon voles as they constructed new runways or cleared old runways.

Average fractionation of carbon isotopes between diet and hair in mammalian herbivores was +2‰ to +3‰ (Sponheimer et al. 2003, Dearing unpublished data), suggesting that the amount of C3 in the diet of Mogollon voles...
might be underrepresented by carbon-stable-isotope analysis. Based on Sponheimer et al. (2003), the amount of C3 plant species in the diet of Mogollon voles actually might be >70%. C3 plants appeared to be the dominant food source, although C4 plants did contribute in lower quantities to the diet of Mogollon voles.

Although we did not compare availability of C3 and C4 plants to their use by Mogollon voles, we did not find runways in areas without dense grasses, and these areas were usually dominated by a mix of C3 and C4 plants. Despite availability of both, voles appeared to feed primarily on C3 plants. Additional work can clarify whether Mogollon voles can use dense grasslands where C4 plants are dominant or whether this species is limited to areas dominated by C3 plants because of diet selection. At least 1 vole species, the montane vole (Microtus montanus), can live in habitat dominated by C4 plants. Montane voles fed almost exclusively on C4 salt grasses year-round in salt marshes bordering the Great Salt Lake, Utah (Dearing personal communication).

We suspect that the diet of Mogollon voles might vary seasonally. Mogollon voles captured in spring had δ13C that appeared more enriched (δ13C = –21.7) than captures during other seasons (δ13C ≤ –23.3). Although not statistically significant, this trend suggests a difference in food selection or availability following winter. During seasons when foods are limiting, voles might be less selective or forced to use other foods (e.g., Cherry and Verner 1975) such as C4 plants, resulting in more enriched δ13C values in hair samples. Batzli and Pitelka (1971) found changes in diet of the California vole (Microtus californicus) between seasons. High vole populations reduced preferred foods and forced animals to select others. For Mogollon voles, high densities or limited foods during late winter and spring could change diet.

We also may have found evidence that Mogollon voles feed on insects, thus affecting both δ13C and δ15N signatures. Prairie voles (Microtus ochrogaster) supplement their diet with seeds and insects in poorer quality habitat (Cole and Batzli 1979). Brower et al. (1982) found that Mexican voles feed on overwintering monarch butterflies (Danaus plexippus) in Mexico. If plant foods become limiting, insects might become an alternative source for Mogollon voles. From our data, this did not appear to be a common occurrence. Most voles we sampled had δ15N <8‰, with the average (3.8‰) indicating Mogollon voles were primary consumers feeding directly on plants (Fig. 1). However, we did sample a single individual with high δ15N (12.6‰), which might indicate this animal was a secondary consumer (fed on insects; e.g., Gannes et al. 1998). Alternately, it might indicate that the animal was starving (Gannes et al. 1997). This pregnant female was captured during late spring (1 May 1972, NAU 2210), at a time when food might have been limiting.

In Mogollon vole hair, δ13C was negatively correlated with precipitation from the 12-month period preceding capture, indicating that vole hair was capable of recording environmental conditions. Plant δ13C can reflect past changes in climate (e.g., Ehleringer and Cerling 1995). Mammalian hair might therefore be a useful indicator of past environmental conditions since, in our case, hair reflected annual moisture regimes. However, the correlation we found could be coincidental or due to subtle changes in the relative proportion of C3 and C4 plants in Mogollon vole diet.

Grazing could alter availability of both food and cover for Mogollon voles. Livestock and wild ungulates (e.g., elk, Cervus elaphus) use meadows where we captured voles. In some areas, grazing had reduced plant biomass by one-half to three-quarters (e.g., from an average of 3000 kg ha–1 in ungrazed areas to 1150 kg ha–1 in grazed areas) and reduced cover from an average of 31 to 12 cm height (C.L. Chambers unpublished data). Grazing can also affect plant composition (Chambers and Holthusen 2000). Since grazers often select C3 over C4 plants (Gannes et al. 1998), overgrazing could reduce cover and eliminate plants that are of higher nutritive value to Mogollon voles. The Mogollon vole’s selection of C3 plants as food sources makes it a useful indicator species for land-management agencies in the Southwest. Monitoring Mogollon voles through live-trapping or the use of a rapid assessment technique (runway density and fecal pellet sampling; Yarborough and Chambers 2007) could be used to indicate grazing levels that are sustainable for this species.

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LITERATURE CITED


San Francisco Peaks, Schultz Pass ($n = 3$): collected 6 October 1967, 1 male (NAU 262, $\delta^{13}$C only), 2 females (1 pregnant, 1 recent parturition) (NAU 264, 265).

Hart Prairie ($n = 1$): collected 16 December 1968 in ponderosa pine forest, Festuca and blue grama understory, Coconino National Forest, sex unknown (NAU 730).

North of Walnut Canyon ($n = 1$): collected 24 March 1968 in pinyon-juniper woodland, 4.8 km north of Walnut Canyon, sex unknown (NAU 731).

Inner Basin, San Francisco Peaks, Coconino County ($n = 6$): collected 29 June to 11 August 1969, 3 males, 3 females (1 pregnant, 1 lactating, 1 unknown condition) (NAU 1775, 1782, 1786, 1793, 1796, 1797).

Unknown location ($n = 1$): male collected 1 June 1971 (NAU 2211).

Inner Basin, San Francisco Peaks, Fremont Saddle, Coconino County ($n = 1$): male collected 20 August 1971 (NAU 2355).

Beaver Creek Watershed Unit 12, 64 km southeast of Flagstaff ($n = 3$): collected 11 November 1971 and 7–8 Apr 1972, 2 females (pregnant), 1 male (NAU 2553, 2554, 2555).

Ashurst Lake, west shore, Coconino County ($n = 1$): pregnant female collected 1 May 1972 (NAU 2210).

Hart Prairie, Coconino National Forest ($n = 3$): 1 male, 2 pregnant females collected 23 June 1972 and 9 July 1972 (NAU 2425, 2426, 2427).

Coconino County, Route 180, 4 km west of Flagstaff ($n = 1$): nonreproductive female captured 12 September 1976 (NAU 3611).

Coconino County, N. Paradise Road, Flagstaff ($n = 1$): male captured 30 November 1976 (NAU 4169).

Coconino County, Lindberg Springs, 8 km south of Flagstaff ($n = 1$): male captured 17 February 1979 (NAU 3704).