Status and limiting factors for the Arizona montane vole in New Mexico

Microtus montanus arizonensis captured at Jenkins Creek, Apache National Forest, Catron County, New Mexico, June 2020

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INTRODUCTION

The Arizona montane vole (*Microtus montanus arizonensis*) is listed as endangered in New Mexico based on its small population and restricted habitat. It is also recognized as a New Mexico Species of Greatest Conservation Need, Category I designating it of immediate priority. Based on morphological and genetic data, it is a well-differentiated subspecies with a range primarily limited to the White Mountains of east-central Arizona (Anderson 1959, Frey 2009). In New Mexico, it is only known based on 7 locations in the upper San Francisco River watershed in west-central Catron County (Frey 2005, 2010). It was first discovered in New Mexico at Centerfire Bog, Catron County, in 1978 and 1979 (Hubbard et al. 1983). In 1994 I discovered a second population at Jenkins Creek, Catron County (Frey et al. 1995). NMDGF (2002) reported montane voles at several locations on Jenkins Creek near the original in 1998 and 2000. In 2004 I conducted baseline surveys to establish the distribution and habitats for *M. m. arizonensis* in New Mexico. Of 13 locations surveyed in Catron County, I captured *M. m. arizonensis* at 5 locations (all new), including: a new location on Jenkins Creek, Romero Creek, Flanagan Spring, SA Creek, and San Francisco River (Frey 2005).

Montane voles are usually associated with meadows and grasslands throughout its range in the western USA. However, the habitat associations of *M. m. arizonensis* have not been defined. In Arizona, it was described as associated with wet grassy or marshy areas that provide dense herbaceous cover for its runways (Hoffmeister 1986). During the surveys I conducted in 2004, *M. m. arizonensis* was comparatively rare and appeared restricted to riparian areas (Frey 2005). I compared microhabitat at capture sites for 10 montane voles and 10 Mogollon voles (*M. mogollonensis*), which is the most common vole occurring in the region. Montane voles were captured on saturated soils in herbaceous communities with tall vertical cover averaging at least 9 inches as recorded with a Robel pole. Compared to capture locations for the Mogollon vole, capture locations for montane voles had significantly higher soil moisture and ground cover of graminoid plants, and significantly less bare ground and moss ground cover. Although these data suggest that *M. m. arizonensis* is more specialized on riparian habitat than is *M. mogollonensis*, no study has evaluated the habitat of *M. m. arizonensis* by comparing places where it occurs with comparative sites, which is needed to identify limiting factors for *M. m. arizonensis*. It is necessary to identify its habitat in quantitative terms to facilitate understanding its status in New Mexico and recommend conservation and management actions.

The goal of this study was to determine the current distribution and limiting factors for the Arizona montane vole (*Microtus montanus arizonensis*) in New Mexico. There were four objectives: 1) confirm identification of new specimens of putative *M. montanus* in the Museum of Southwestern Biology collected since the prior review (Frey 2005); 2) survey historical locations; 3) survey other potential locations within the San Francisco River watershed, and 4) evaluate habitat in order to identify limiting factors.

METHODS

Field surveys

Field surveys were primarily aimed at resampling historical locations to determine if the species was still present. Surveys also occurred at new locations with potential habitat as logistics allowed. Sites where *M. m. arizonensis* was previously captured in Catron County were: 1) location on private lands (Hubbard et al 1983); 2) a draw to Jenkins Creek, 1.2 mi W junction Forest Road 385 (Frey et al. 1995); 3) Jenkins Creek below Forest Road 385 (Frey 2005); 4) Flanagan Spring (Frey 2005); 5) Romero Creek above Forest Road 220 (Frey 2005); 6) SA Creek above County Road B012 (Frey 2005); and 7) San Francisco River near junction Stone Creek (Frey 2005). Each of these sites was surveyed except the location on private lands, which was not accessible due to land ownership status.

At each site I set large (7.62 cm x 8.89 cm x 22.86 cm) Sherman live traps (model LFATDG; H.B. Sherman, Tallahassee, FL) baited with commercial horse sweet feed spaced ca 3-5 m apart. Traps were set in informal transects within the riparian zone following the watercourse and, where possible, traps were place on vole runways or in areas with tall herbaceous vegetation on moist soil. The number of traps set at a location typically ranged from 40 to 80, which balances the need for a large effort to capture the species if present but rare but also prevents potential for excessive trap mortalities if abundances are high. This number of traps is also logistically feasible given the effort required to search for vole runways and frequently check traps. Vole runways were located by walking the area and visually searching for runs. Vole runs are typically located in tall dense herbaceous vegetation. To search these areas, I used my hands to part and pull back the vegetation in order to see the ground at frequent intervals. Because vole runs and tall herbaceous habitat usually occurred in patches, the trapping transects also traversed areas with other conditions where traps were also set. Thus, the traps sampled a wide range of streamside environments.

To prevent mortalities, traps were protected from the sun and checked as frequently as possible. Captured animals were identified and released at their capture locations. For all voles (*Microtus*) captured, I measured hindfoot length, tail length, mass, and gender. One *M. m. arizonensis* from each new location was preserved as a voucher specimen, as were unintended trap mortalities. For these specimens, I also collected total length and ear length. Specimens will be deposited at the Museum of Southwestern Biology. Capture rate was calculated as the number of captures of a species at a site per 100 trap-nights (a trap-night is a measure of survey effort wherein 1 trap-night is equivalent to one trap set for one night; Wilson et al. 1996).

Habitat data collection

Quantitative habitat data were collected at two scales, landscape (i.e., along an up to ca 1 km reach of stream) and microhabitat (i.e., on a 4 m radius plot). Both methods were previously described and used in studies on the distribution and habitat of the New Mexico meadow jumping mouse (*Zapus hudsonius luteus*; Frey 2017a) and water shrew (*Sorex palustris*; Frey and Calkins 2020) in adjacent areas of Arizona, during which *M. m. arizonensis* was the most common species captured (Frey 2011). In addition, the microhabitat methods were used in the prior survey for *M. m. arizonensis* (Frey 2005). Use of these consistent methodologies allowed for combining data among studies to have more robust sample sizes for statistical analysis.

For the landscape scale, at each survey site I established paired transects paralleling the stream and located 0.5 m (i.e., “stream-edge transect”) and 4.5 m (i.e., “inland transect”) from the edge of the green-line (i.e., vegetation closest to the water). I located the paired transects on the same side of the stream that trapping occurred, or I randomly determined the side if trapping occurred on both sides of the stream. I established sample stations each 20 m along transects. The goal for transect length was 1 km, but site characteristics or lack of access reduced the length at most sites. Vertical cover was measured with a Robel pole (Robel et al. 1970). At each station a Robel pole was read from the opposing transect (i.e., 4 m away) at 1 m eye level and the lowest 1 inch (25.4 mm) segment that was not obstructed by cover was recorded. In addition, the dominant plant or other structure that covered the pole was recorded: conifer, rush Juncaceae, sedge (*Carex* spp.), grass Poaceae, forb, willow (*Salix* spp.), alder (*Alnus* spp.), shrub cinquefoil (*Dasiphora fruticosa*), Wood’s rose (*Rosa woodsii*), other shrub, other plant, dead standing plant, coarse woody debris, rock, and bank.

I collected microhabitat data at traps where *M. m. arizonensis* was captured. If no *M. m. arizonensis* was captured, I collected microhabitat data at a representative location where *M. mogollonensis* was captured since the two species occur in the best available vole habitat at a site. If no voles were captured, the microhabitat plot was established at a representative location. Because the sample unit was the trap location, at some sites more than one microhabitat plot was measured. I only collected microhabitat at one trap if animals were caught in close proximity so that plots would overlap. At the trap, slope and aspect were visually estimated. Canopy cover was measured with a densiometer in the four cardinal directions. An index of soil moisture ranging from 1(dry) to 10 (saturated) was obtained using a soil moisture probe (Lincoln Irrigation, Lincoln, NE) inserted into the ground approximately 4 cm. Vertical cover was assessed with a Robel pole (read in inches) from a 4 m distance at a 1 m eye level. The Robel pole was read at the trap site from three random azimuths as well as away from the trap along three random azimuths. Four 4-m perpendicular transects were established at a random azimuth from the trap. At each 1 m interval along a transect, a Daubenmire frame was used to assess the percent cover of sedges, rushes Juncaceae, field horsetail (*Equisetum arvense*), forbs, grass, willow, alder, redosier dogwood (*Cornus sericea*), shrub cinquefoil, Wood's rose, moss, other plants, coarse woody debris, litter, rocks, gravel, bare ground, and open water. Cover classes were 1 for 0-5% cover, 2 for 5-25% cover, 3 for 25-50% cover, 4 for 50-75% cover, 5 for 75-95% cover, and 6 for 95-100% cover. In addition, soil moisture, litter depth, and stubble height were recorded in each frame. Stubble height was measured with a ruler and was recorded as both the laid-over stubble height and vertical stubble height (in mm). Laid-over stubble height was measured as the representative height of the vegetation as it naturally lay. Vertical stubble height was obtained by measuring the height of a representative blade of the dominant herbaceous vegetation that was fully extended vertically from the ground. Finally, the number and identity of each tree and shrub within 1 m of the transect were recorded. For each trap location, measurements of canopy cover, soil moisture, litter depth, vertical cover, stubble height, and ground cover class estimates were averaged.

Statistical analyses

At the landscape scale, I compared habitat attributes at the site level, which is the comparison of sites where *M. m. arizonensis* was captured versus sites where it was not captured. Because this was a mensurative study design that did not control for confounding variables, use replication, or manipulate the system, the scope of inference is limited to the study sites (Morrison et al. 2008). To increase sample sizes, I included stream reach data collected during prior surveys aimed at the New Mexico meadow jumping mouse (*Zapus hudsonius luteus*) and conducted in the White Mountains, Arizona (Frey 2011). *M. m. arizonensis* is a close associate of *Z. h. luteus* in the White Mountains ecosystem, and *M. m. arizonensis* was the most frequently captured mammal in those surveys (Frey 2011).

At the microhabitat scale, I increased sample sizes by supplementing with data collected during the prior *M. m. arizonensis* survey (Frey 2005) and prior surveys aimed at the New Mexico meadow jumping mouse (*Zapus hudsonius luteus*; Frey 2011). Even with the increased sample size, it was not possible to conduct a meaningful, site level comparison due to sample size limitations. For instance, although *M. m. arizonensis* was frequently captured during the surveys of Frey (2011), I rarely collected microhabitat data on the vole, but always collected the landscape level stream-reach data at the site. Therefore, it was possible to conduct a site level analysis, between sites with and without *M. m. arizonensis* captures, on the stream-reach data, but not the microhabitat data. In order to still provide useful information, I instead compared microhabitat conditions at specific trap locations where *M. m. arizonensis* was captured to microhabitat conditions at trap locations representative of the best developed riparian vegetation from throughout the range of *M. m. arizonensis* (Apache and Greenlee counties, Arizona, and Catron County, New Mexico. The representative locations were at traps that captured animals in the best developed riparian habitats at a site. The prior surveys targeting *Z. l. luteus* (Frey 2011) were focused on its foraging habitat, which is similar to habitat for *M. m. arizonensis*: near water; saturated soil; vegetation composed of tall, dense herbaceous vegetation; and lacking trees, rocks, coarse woody debris, or bare ground (Frey 2017). Because those conditions are patchy, transects also included a wide range of conditions where traps were also set. Thus, the traps sampled a wide range of streamside environments. Representative locations represented the best available riparian conditions at the site and were at traps that captured *Z. h. luteus* (n=39), *M. mogollonensis* (n=25), *Sorex navigator* (n=16), *Myodes gapperi* (n=5), and *Mustela frenata arizonensis* (n=5), and representative locations where no species was captured (n=10). This was an unbalanced sampling strategy, as well as a mensurative study design that did not control for confounding variables, use replication, or manipulate the system, thus the scope of inference is limited to the microhabitat plots (Morrison et al. 2008).

I calculated statistics using GNU PSPP version 1.4.1. I tested variables for normality using one-sample Kolmogorov-Smirnov tests and used Pearson and Spearman correlations to assess relationships among variables for normal and non-normal variables, respectively. For the stream reach variables, I tested for differences between survey sites where *M. m. arizonensis* was captured or not captured using two-tailed t-tests (equality of variances not assumed) and two-sample Kolmogorov-Smirnov tests for parametric and non-parametric data, respectively. For the microhabitat variables, I tested for differences between traps where *M. m. arizonensis* was captured versus representative traps using two-tailed t-tests (equality of variances not assumed) and two-sample Kolmogorov-Smirnov tests for parametric and non-parametric data, respectively. Sample size issues prevented use of multivariate analyses.

RESULTS

Putative new locations

I found 9 new putative records of *M. m. arizonensis* in the catalog of the Museum of Southwestern Biology. This was a series of specimens collected by the University of New Mexico Mammalogy class between 30 August and 1 September 2008 from three locations in the San Francisco River drainage near Luna, Catron Co. (Table 1). I was unable to confirm the identity of the specimens based on examination of skull characters due to the COVID-19 pandemic. For purposes of the surveys, I assumed the identifications were correct. I resurveyed two of these locations (San Francisco River, "Unnamed Creek") during this study. I did not resurvey the Stone Creek location due to access issues and logistics.

2 km N 5 km W of Luna.—Six specimens were collected from "2 km N 5 km W of Luna". The specific locality indicates that the specimens were collected on the Apache National Forest, but the coordinates map to private land along an unnamed intermittent tributary to the San Francisco River (named "Unnamed Creek" herein). Based on the ratio of tail length to total length (Frey 2005), two of the adult specimens from this location might be referable to *M. montanus*, while two specimens were more consistent with *M. longicaudus*.

8 km West of Luna.—A juvenile and an embryo were collected from "8 km West of Luna". The coordinates map to near the San Francisco River ca 0.9 km above the confluence with Stone Creek. However, identification based on external measurements of these specimens was not possible.

Stone Creek, 1.9 km N 7.8 km W Luna.—An adult male specimen was collected from "Stone Creek, 1.9 km N 7.8 km W Luna". Based on external measurements it was not possible to distinguish its identification as *M. montanus* or *M. longicaudus*. The coordinates map to Stone Creek, ca 1.1 km above the confluence with the San Francisco River.

Table 1. Specimens of putative Arizona montane vole (*Microtus montanus arizonensis*) in the Museum of Southwestern Biology captured since Frey (2005).

Catalog number	Locality	Latitude	Longitude	Date	Sex	Reproductive	Total	Tail	Hind foot	Ear	Mass
198735	Apache National Forest, 2 km N 5 km W of Luna			30-Aug-08	female	Embryos (3R, 3L)	171 mm	47 mm	19 mm	19 mm	69.5 g
198421	Apache National Forest, 2 km N 5 km W Luna			31-Aug-08	male	A T = 22 x 4	168 mm	47 mm	21 mm	19 mm	52 g
198425	Apache National Forest, 2 km N 5 km W Luna			31-Aug-08	male	T = 3 x 5	115 mm	35 mm	19 mm	14 mm	19 g
198747	Apache National Forest, 2 km N 5 km W of Luna			31-Aug-08	female	Adult, no embs	140 mm	50 mm	20 mm	15 mm	40 g
198418	Apache National Forest, 2 km N 5 km West Luna			1-Sep-08	female	non - perf	139 mm	45 mm	21.5 mm	15 mm	25 g
196261	Apache National Forest, 2 km N, 5 km W Luna			30-Aug-08		embryo					
196636	Apache National Forest, 8 km West of Luna	33.82554	-109.0355	30-Aug-08		embryo					
198414	Apache National Forest, 8 km West of Luna	33.82554	-109.03558	1-Sep-08	male	juvenile	111 mm	28 mm	18 mm	10 mm	15 g
195586	Apache National Forest, Stone Creek, 1.9 km N 7.8 km W Luna	33.50071	-109.02069	31-Aug-08	male		152 mm	44 mm	18 mm	12 mm	29 g

Field Surveys

I surveyed 14 sites, of which 13 were trapped using a total of 1,466 trap-nights (Table 2, Figure 1). The 14 sites included 6 of the 7 known historical sites (excluded location on private lands), 1 putative historical site based on unverified museum specimen (”Unnamed Creek”; survey conducted on public lands), and 7 other sites. I captured 14 *M. m. arizonensis* at 4 of the 14 sites (29%). This included only 1 of 5 (20%) historical sites, Romero Creek, where they were known to occur in 2004 (Frey et al. 2005). The three new sites were Trap Spring, Flanagan Cienega, and Jenkins Creek below FR 3050. Relative abundance of *M. m arizonensis* was very low (<3%) at the three new sites, but moderate at the historical site Romero Creek (11.3%; Table 2). No other areas of potential habitat were observed in the study area. Site descriptions and photographs are in Table 5 and Appendix 1.

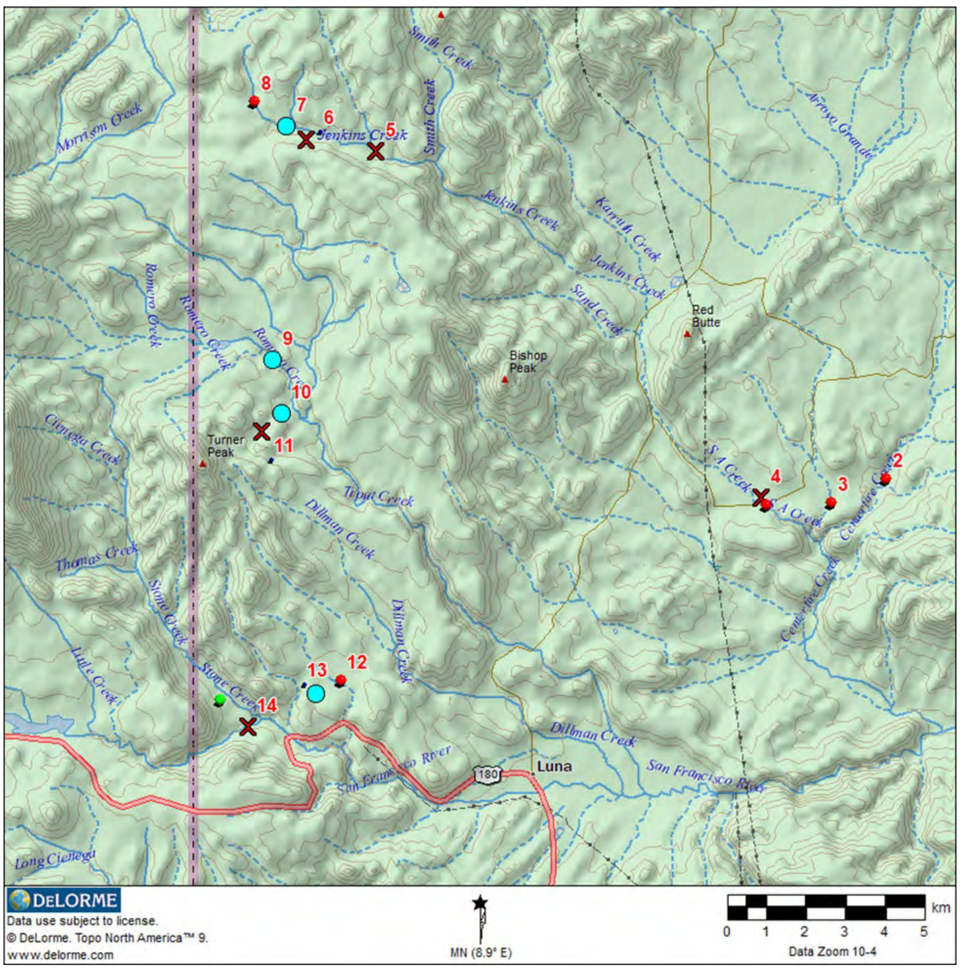

Figure 1. Map of sites surveyed for the Arizona montane vole (*Microtus montanus arizonensis*) in Catron County, New Mexico, June 2020. Blue circles indicate extant populations (2020) and red X indicates potentially extirpated populations. Red dots indicate other sites surveyed where the species was not detected. The green dot indicates a putative record in the Museum of Southwestern Biology that was not surveyed. Site numbers are in Table 5.

Habitat

Stream reach

At the stream reach scale, sites where *M. m. arizonensis* was captured were dominated by grasses (28.0%), sedges (20.6%), and forbs (19.4%; Table 3). Capture sites had significantly more cover from alders (*Alnus*), other shrubs, and conifers, and less cover of "other" compared to noncapture sites. Capture sites had significantly higher vertical cover than noncapture sites, at both the stream-edge and inland transects. On the stream-edge transects, which best represent conditions of the riparian zone, the mean vertical cover at capture sites was 19.6 inches (confidence interval 16.1 – 23.1; Figure 2), but at noncapture sites the mean vertical cover was 11.8 inches (confidence intervals 6.0 – 17.7). Based on the confidence intervals, the threshold separating capture sites from noncapture sites was a mean vertical cover of ca 17 inches (capture sites had > ca 17 inches vertical cover; noncapture sites had < ca 17 inches vertical cover). All sites surveyed in New Mexico in 2020 had vertical cover less than the lower 95% confidence interval for the stream-edge transect at capture sites, indicating degraded or highly degraded riparian conditions (Figure 2). Capture sites were at significantly higher elevation (mean = 8,268 ft) than noncapture sites (mean = 7,835 ft), although this measure is likely biased due to distribution and management of sites sampled.

Microhabitat

Microhabitat at capture locations was typified by saturated soil (mean = 9.9 on scale 0-10), low canopy cover (mean = 8.4%), uniformly high vertical cover (mean = 15.9 inches at the trap), and cover dominated by sedges, but also including relatively high cover from grasses, forbs, rushes, and litter (Table 4). Vertical cover and soil moisture at the trap was higher than on the surrounding 4-m radius plot, indicating fine scale habitat selection for the wettest spots with highest cover of herbaceous vegetation. In comparison with representative riparian locations (see methods for context), capture locations of *M. m. arizonensis* had significantly greater litter depth, litter cover, and rush cover, but significantly less canopy cover, vertical cover, open water, coarse woody debris, bare ground, alder, rock, and shrub and tree stems.

The mean vertical cover at the traps where *M. m. arizonensis* was captured (n=24) was 15.9 inches, with a lower 95% confidence interval of 10.9 inches (Figure 3). Vertical cover at three precise capture locations where *M. m. arizonensis* has become extirpated since 2004 (Flanagan Spring, Jenkins Creek draw, and Jenkins Creek below FR 220) were the lowest recorded throughout its range (Figure 3). Vertical cover at the only site on Jenkins Creek where the species is known to persist (below FR 3050) was below the 95% confidence interval (Figure 3). In addition, the predominant cover at those two capture locations on Jenkins Creek was bank rather than vegetation, indicating exceptionaly poor riparian conditions. Vertical cover at capture locations at Flanagan Cienega, Romero Creek, and Trap Spring were above the lower 95% confidence interval for all capture locations. Howevever, the high vertical cover measurement (23.7 inches) at the capture location at Trap Spring was not typical of the overall site, which had a mean vertical cover along the reach at 5.1 inches (Figure 2 and 3). This indicates that Trap Spring currently has limited and marginal habitat for *M. m. arizonensis* and likely does not support a permanent source population.

Table 2. Relative abundance (captures per 100 trap-nights) of small mammals captured during surveys for the Arizona montane vole (*Microtus montanus arizonensis*) in the San Francisco River watershed, Catron County, New Mexico, June 2020. Site numbers refer to Figure 1 and Table 5.

	Trap-nights	**Riparian habitat condition**	***Microtus montanus***	***Microtus mogollonensis***	***Microtus longicaudus***	***Peromyscus manicualuts***	***Peromyscus gratus***	***Reithrodontomys megalotis***	***Neotoma mexicana***	***Callospermophilus lateralis***	***Neotamias cincereicollis***
Historical sites											
6 Jenkins Creek, draw	80	absent	0	0	0	0	0	0	0	0	0
5 Jenkins Creek below FR 385	160	very poor	0	1.3	0	0.6	0	0	0	0.6	0
11 Flanagan Spring	0	very poor									
9 Romero Creek	80	well-developed	11.3	0	0	1.3	0	0	0	0	0
4a SA Creek above CR B012	100	well-developed	0	6.0	0	0	0	1.0	0	0	0
14 San Francisco River	280	patchy, poor	0	7.9	0.4	3.6	0	0	0.4	0	0
New sites where captured											
7 Jenkins Creek below FR 3050	80	poor	2.5	0	0	0	0	0	0	0	0
10 Flanagan Cienega	70	well-developed	2.9	0	0	0	0	0	0	0	0
13 Trap Spring	160	small; developed	0.6	10.0	0	0	0.6	0	0	0	0
Other sites where not captured											
8 Jenkins Creek, upper	160	very poor	0	0	0	0	0	0	0	0	0.6
4b SA Creek below CR B012	100	well-developed	0	3.0	0	2.0	0	0	0	0	0
2 Centerfire Creek	36	well-developed	0	22.2	0	5.6	0	0	0	0	0
3 Funderburg Spring	80	well-developed	0	5.0	0	0	0	0	0	0	0
12 "Unnamed Creek"	80	very poor	0	10.0	0	0	0	0	0	0	0

Table 3. Means, standard errors, and test statistics for comparisons of stream reach cover variables at sites where the Arizona montane vole (*Microtus montanus arizonensis*) was captured (n = 29) or not captured (n = 10) in Arizona (Apache and Greenlee counties; 2008-2009) and New Mexico (Catron County; 2020).

Variable	Capture		Noncapture		Test statistic	*P*
	x	SE	x	SE		
Elevation (m)[a]	2519.9	32.05	2387.6	57.68	t = -2.01	0.052
Vertical cover (inch)						
Stream-edge mean	19.6	1.69	11.8	2.58	t = -2.52	0.022
Stream-edge variance	144.1	22.68	160.4	75.26	t = 0.21	ns
Inland mean	16.3	1.60	9.2	2.85	t = -2.19	0.045
Inland variance	151.5	25.61	79.3	34.75	t = -1.67	ns
Cover type (% of stations obscured by cover type)						
Grass (Poaceae)	28.0	2.73	29.6	5.09	t = 0.26	ns
Sedge (*Carex*)	20.6	3.58	11.8	6.12	t = -1.24	ns
Forb	19.4	2.81	14.1	4.48	t = -1.00	ns
Rush (Juncaceae)	7.5	2.5	14.6	4.24	z = 2.57	ns
Alder (*Alnus*)	4.6	1.42	0.3	0.3	z = 3.46	0.063
Willow (*Salix*)	4.6	1.64	2.7	1.45	z = 0.19	ns
Bank	3.2	0.63	5.6	1.65	t = 1.39	ns
Other	2.9	1.54	17.0	4.24	z = 13.91	<0.001
Dead standing limbs	2.4	0.68	1.2	0.54	z = 0.26	ns
Other shrub	1.8	0.98	0.0	0	z = 2.83	0.092
Conifer	1.6	0.7	0.0	0	z = 0.050	0.050
Wood's rose (*Rosa woodsii*)	1.4	0.61	0.8	0.45	z = 0	ns
Rock	0.8	0.32	1.6	0.74	z = 0.89	ns
Log	0.8	0.39	0.6	0.43	z = 0.02	ns
Shrub cinquefoil (*Dasiphora fruticosa*)	0.5	0.26	0.0	0	z = 1.49	ns

[a]Sample size was N=35 for capture sites and N=24 for non-capture sites.

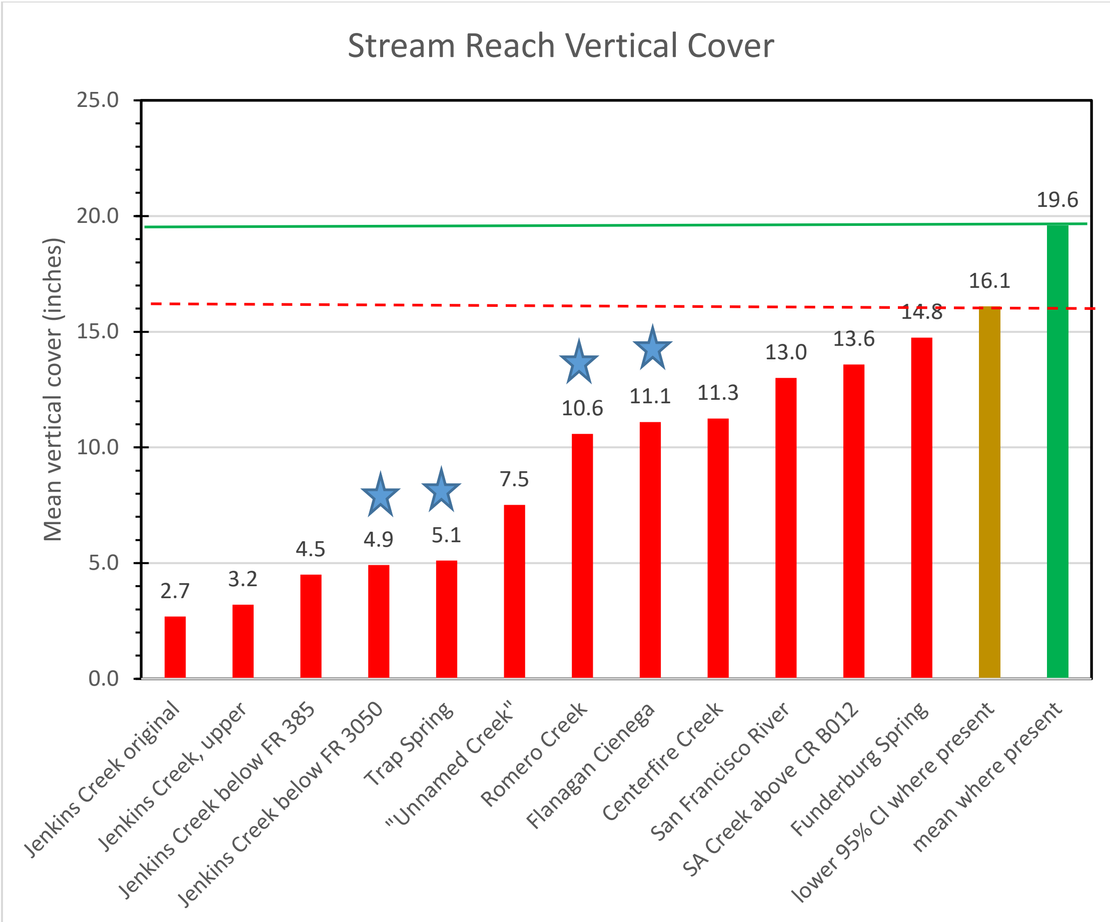

Figure 2. Mean vertical cover as measured by a Robel pole (inches) 0.5 m from the stream edge along reaches surveyed for the Arizona montane vole (*Microtus montanus arizonensis*) in June 2020. These are compared with the lower 95% confidence interval (horizontal red dashed line) and mean (horizontal green line) for reaches where it was captured throughout its range (n = 29). All stream reaches in New Mexico had riparian cover conditions below the 95% confidence interval for occupied reaches (often substantially so), indicating degraded or highly degraded riparian conditions. The stars indicate sites where *M. m. arizonensis* was captured in 2020.

Table 4. Means, standard errors, and test statistics for comparisons of microhabitat characteristics at capture locations for the Arizona montane vole (*Microtus montanus arizonensis*; *n* = 24) and representative riparian locations (*n* = 100) in the Apache and Greenlee counties, Arizona (2008-2009) and Catron County, New Mexico (2004, 2020).

Variable	*M. montanus*		Representative locations		Test statistic	*P*
	x	SE	*x*	SE		
Elevation (m)	2465.73	39.93	2453.39	22.58	*t* = -0.27	ns
Soil moisture (1[dry] - 10 [saturated])						
At trap	9.95	0.05	9.65	0.14	*z* = 0.90	ns
Mean on plot	9.12	0.28	8.86	0.22	*z* = 0.09	ns
Variance	3.73	1.22	15.21	12.48	*z* = 0.10	ns
Canopy cover (%)	8.4	2.93	31.23	3.19	*z* = 9.76	0.002
Vertical cover (inch)						
At trap	15.94	2.43	21.32	1.35	*t* = 1.94	0.060
4 m from trap	12.26	2.63	18.22	1.35	*z* = 6.53	0.011
Mean	13.59	2.54	19.72	1.31	*t* = 2.14	0.039
Variance	23.83	6.8	126.26	17.97	*z* = 14.50	<0.001
Height of stubble (cm)						
Vertical	428.33	48.83	493.32	25.72	*t* = 1.18	ns
Laid-over	230.79	46.11	289.21	15.67	*t* = 1.20	ns
Depth of litter (cm)	39.14	8.38	23.12	2.34	*z* = 4.82	0.028
Ground-cover class (1-6)						
Forb	1.76	0.13	1.99	0.07	*t* = 1.53	ns
Sedge (*Carex*)	2.26	0.35	2.01	0.11	*z* = 0.35	ns
Open water	1.26	0.06	1.63	0.06	*z* = 7.05	0.008
Grass (Poaceae)	1.8	0.27	1.71	0.07	*z* = 0.15	ns
Alder (*Alnus*)	1	0	1.19	0.03	*z* = 11.17	0.001
Coarse woody debris	1.04	0.02	1.27	0.04	*z* = 9.63	0.002

Litter	1.75	0.14	1.48	0.05	*z* = 3.47	0.062
Rush (Juncaceae)	1.67	0.18	1.3	0.06	*z* = 4.69	0.030
Willow (*Salix*)	1.1	0.09	1.09	0.03	*z* = 0.52	ns
Redosier dogwood (*Cornus sericea*)	1	0	1.01	0.01	*z* = 0.70	ns
Other plant	1.05	0.02	1.06	0.02	*z* = 0.01	ns
Bare ground	1.13	0.05	1.26	0.05	*z* = 5.24	0.022
Rock	1.02	0.01	1.13	0.03	*z* = 7.19	0.007
Field horsetail (*Equisetum arvense)*	1.01	0.01	1.01	0	*z* = 0.69	ns
Wood's rose (*Rosa woodsii*)	1.07	0.05	1.02	0.01	*z* = 0.01	ns
Shrub cinquefoil (*Petaphylloides floribunda*)	1	0	1.01	0	*z* = 0.70	ns
Moss	1.02	0.02	1.04	0.01	*z* = 1.73	ns
Gravel	1.01	0.01	1.04	0.03	*z* = 0.36	ns
Cattail (*Typha*)	1.03	0.03	1	0	*z* = 1.33	ns
Shrub stem count	4.11	3.59	10	2.85	*z* = 8.68	0.003
Trees stem count	0	0	0.19	0.13	*z* = 3.02	0.082

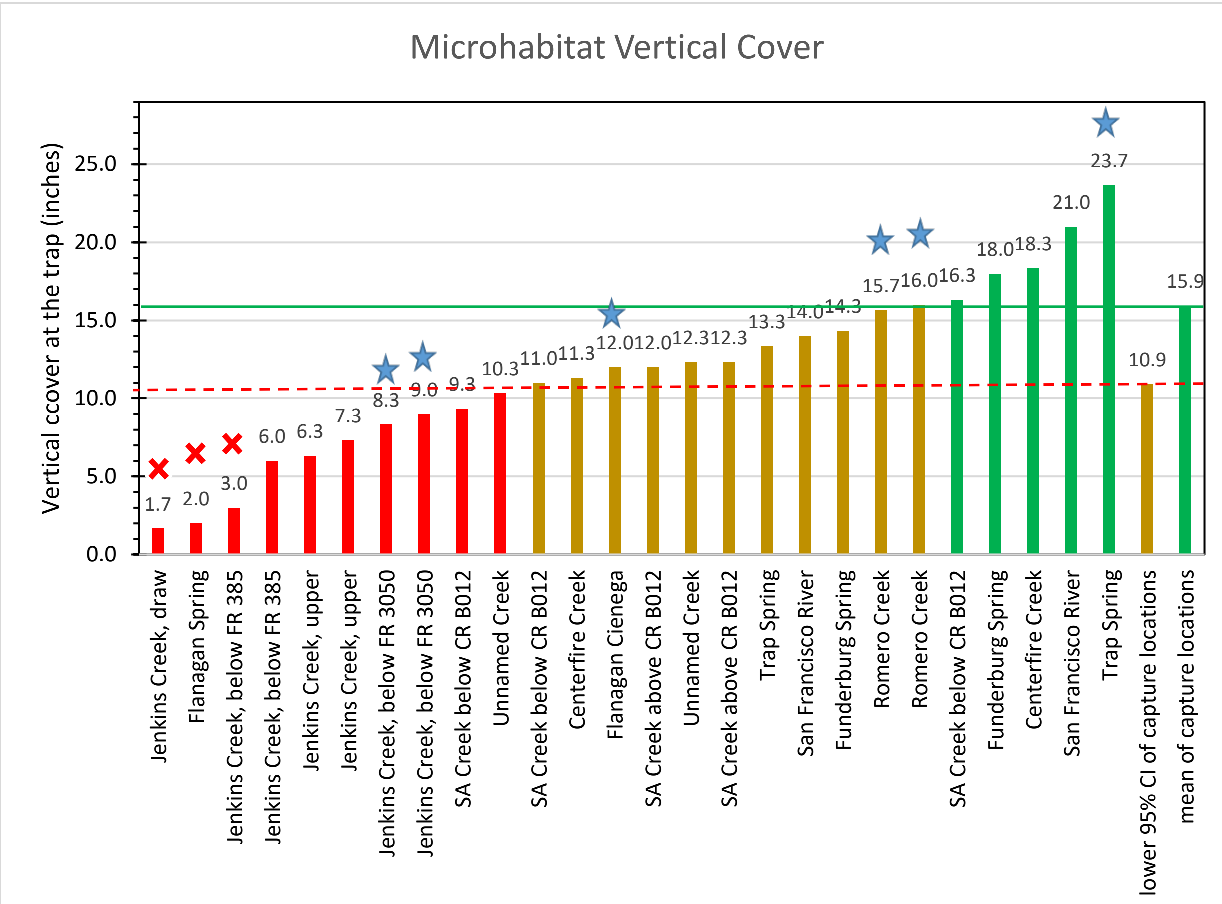

Figure 3. Mean vertical cover as measured by a Robel pole (inches) on microhabitat plots at trap locations during surveys for the Arizona montane vole (*Microtus montanus arizonensis*) in June 2020. Stars indicate traps that caught the species. The green line indicates the mean and the red dashed line indicates the lower 95% confidence interval of capture locations throughout its range (n=24). Red “X” indicates precise locations where the species has been extirpated since 2004.

Livestock grazing

There was a significant relationship between capture or noncapture locations of *M. m. arizonensis* with livestock grazing policy ($z = 4.93$, $p = 0.026$), but not with presence or absence of livestock sign ($p > 0.05$). *M. m. arizonensis* was significantly more likely to occur when livestock grazing was not authorized (Figure 4) and the relative abundance of *M. m. arizonensis* was significantly higher in areas where grazing was not authorized (z=3.42, p = 0.064).

On the stream reach scale, livestock grazing policy was a highly significant (p < 0.001) determinant of mean vertical cover (streamside transect: 20.8 inches where grazing not allowed versus 8.2 inches where grazing was allowed; upland transect: 17.6 inches where grazing was not allowed and 5.4 inches where grazing was allowed). Cover provided by forbs, alder, willow, and other shrubs was significantly greater (p < 0.1) where livestock grazing was not authorized, while cover provided by rush and other structure, not included in the main cover groups, was significantly greater (p < 0.1) where livestock grazing was authorized.

There were 9 surveys where *M. m. arizonensis* was captured and livestock was authorized. Two were in Arizona (Fish Creek and West Fish Creek). Four were during the surveys for the species in 2004 at San Francisco River, Flanagan Spring, Romero Creek, and Jenkins Creek below FR 220. During this survey, the species could only be found at one of those four sites (Romero Creek) in addition to Flanagan Cienega. This is strong evidence that livestock grazing policy influences habitat for *M. m. arizonensis* and its extirpation or persistence at a site.

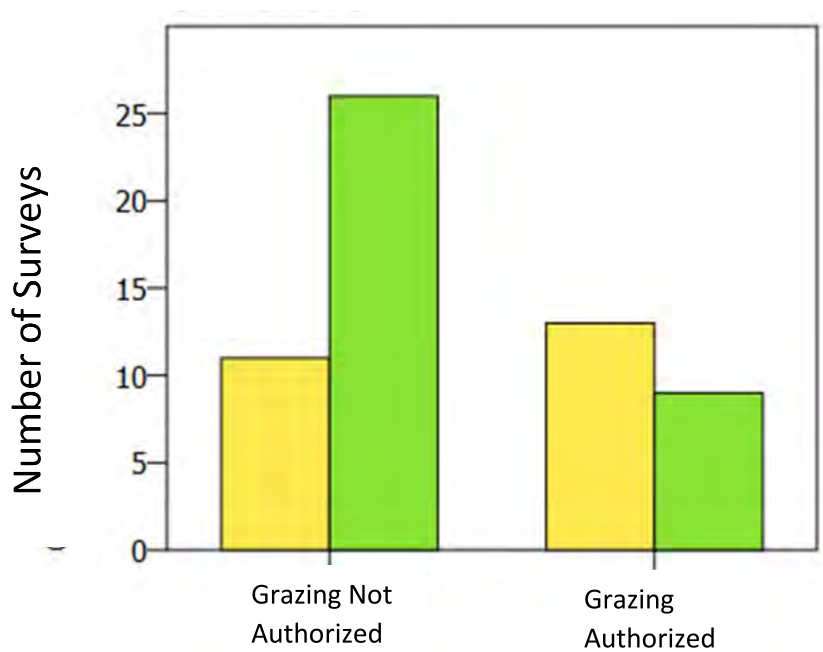

Figure 4. Relationship between surveys occasions when Arızona montane vole (*Microtus montanus Arizonensis*) was captured (green bars) or not captured (yellow bars) in relation to whether livestock grazing was authorized or not authorized by policy at the site.

DISCUSSION

The overall survey effort during this study (13 locations trapped with 1,466 trap-nights) was more extensive than in Frey (2005; 13 locations trapped with 815 trap-nights). Based on survey results, the status of the Arizona montane vole in New Mexico is declining and it is in jeopardy of becoming extirpated in the state. It was no longer found at 5 of 6 historical locations, indicating an 80% decline in occurrence over the past 16 years. Of particular concern, I was unable to document persistence of the species in the Centerfire Creek watershed (Centerfire Creek, Funderberg Creek, SA Creek), which represents a large proportion of the species' likely historical distribution in New Mexico, and which today is isolated from other source populations. Of the 4 known remaining populations, the Jenkins Creek and Trap Springs populations are likely at imminent risk of extinction due to lack of habitat. The Jenkins Creek population is of particular concern given that it is a potentially large area of habitat (if riparian vegetation is restored or partially restored), but it has no connectivity with other possible source populations. The Romero Creek and Flanagan Cienega sites represent the only populations that are likely self-perpetuating and not in imminent risk of extirpation. These two sites are located within the same grazing allotment pasture (Romero Pasture of the Underwood Lake Allotment), and Romero Creek represented a rare example of improved riparian conditions. However, based on the poor habitat conditions that previously existed at Romero Creek in 2004, it is clear that changes in grazing management or other factors could result in future threat to these populations.

Results clearly demonstrate that habitat for the Arizona montane vole is characterized by moist soil with tall, dense herbaceous plant cover, especially provided by sedges. Based on the lower 95% confidence interval for locations where the Arizona montane vole was captured, the *minimum* average vertical cover required by the montane vole was 16.1 inches across the stream reach and 10.9 inches at local used patch (represented in this analysis by traps that captured montane voles). None of the stream reaches in New Mexico met these conditions, and no site on Jenkins Creek or Flanagan Spring had even a patch of habitat that met the lower threshold for microhabitat. The rare occurrence of the Arizona montane vole on Jenkins Creek was almost certainly due to a very small area of the creek where banks provided shade and cover as an alternative to vegetation cover. However, given the species' habitat requirements of tall herbaceous vegetative cover, this situation is unlikely to be sustainable and rather likely represents the last holdouts of the process of extinction of the species on Jenkins Creek.

The evidence indicates that the reason the Arizona montane vole has become extirpated from historical locations is loss of its herbaceous riparian habitat. The evidence also indicates that the ultimate reason for this loss of habitat has been livestock grazing policy. Across the range of the Arizona montane vole, most occupied sites were in areas where livestock grazing was not authorized and relative abundance of the Arizona montane vole was greater in such areas. Horncastle et al. (2019) also found higher abundance of Arizona montane voles in ungrazed meadows. Results demonstrated that the most significant influence of livestock grazing on riparian habitat was reduction of vertical cover. A loss of vertical cover height and increase in forms of cover other than riparian plants were the two most significant factors at sites where the Arizona montane vole was not captured.

Horncastle et al. (2019) conducted an occupancy study on the Arizona montane vole in the Arizona portion of its range, but none of the variables in their *a priori* models were informative. There are two possible reasons that their study did not find informative variables that predicted where voles occur, while this study did. First, it is possible their study did not include as much marginal or non-habitat as was included in this study and, consequently, that montane voles were more uniformly present at their survey sites. In order to identify variables that discriminate used versus available sites, it is necessary for the sites to represent a full range of conditions. Second, the model with the best fit in their study included only height of vegetation, though it was not appreciably better than the null model (Hormcastle et al. 2019). Their variable 'height of vegetation' was the same as 'vertical stubble height' in this study. In this study, vertical stubble height was not significantly different between capture and representative sites, while vertical cover was. Thus, although stubble height and vertical cover might seem similar because they both measure aspects of vegetation height, they are not equivalent. Vegetation height (=vertical stubble height) is a measurement taken with a ruler from the base of a plant to the tip of the leaves when fully extended vertically, while vertical cover is measured by viewing a Robel pole from 4 m away and recording the lowest 1-inch band not obscured by vegetation or other habitat structure. In this study, the two variables had only moderate correlation (r=0.637), with the two variables becoming more dissimilar with taller vegetation (Figure 5). Thus, it is possible for tall plants to fail to supply tall vertical cover if they are sparse. In addition, in many species of plants, such as some sedges, the leaves extend outward and droop over, forming a natural dense ceiling above the ground level. Thus, pulling the leaves vertical obscures the aspect of the vegetation that is functional to the voles. The critical habitat element for the Arizona montane vole is dense cover above the ground (i.e., vertical cover), which is necessary to conceal their runways.

Exclusion of cattle from riparian zones by using corridor fencing can result in rapid restoration of riparian vegetation (Baker 2001, Cram 2018). Indeed, vegetation in the livestock exclosures at SA Creek below road CO B012, Funderburg Spring, and Centerfire Creek transitioned from dry denuded ground to lush, wet sedge meadows between 2004 and 2020. These examples are important as reference conditions for what riparian zones should look like, and they provide a point of comparison for the denuded nature of the majority of stream reaches in the region. It is likely that restoration of the Arizona montane vole will require similar restoration efforts on other streams in New Mexico. However, these examples also demonstrate that restoration of the montane vole does not necessarily follow restoration of the habitat. Voles have limited dispersal capabilities and, consequently, if no nearby source population is present, restored habitat cannot be naturally recolonized. In these instances, translocations would be necessary to restore the populations.

It is not certain why montane voles were not captured in the upper SA Creek grazing exclosure (i.e., above road CO B012), given that the species was present at this site in 2004. Because of the topography of the site, habitat was mainly limited to a narrow margin of moist soil between the deep water of the wetland and the arid uplands. There was evidence of several sources of disturbance to habitat within the exclosure. There was sign of unauthorized livestock grazing, hoof prints due to elk in the narrow margins of habitat, and signs of flooding and aggradation. Vole populations are prone to large fluctuations in population size in unstable environments (Sera and Early 2003). In such conditions, spring precipitation can influence reproduction and population cycles (Pinter 1988). Thus, taken together, the factors of limited habitat, disturbance, and erratic population fluctuations driven by below normal spring precipitation could cause extirpation of a population. Because populations fluctuate, it is also possible that montane voles were present but so rare that they were not detected by the trapping effort. This seems unlikely given that sampling on SA Creek in 2020 involved 200 trapnights across 3 nights. *M. m. arizonensis* has a very high detection probability (p=0.6-0.8; Horncastle et al. 2019) and, in the prior survey work by me within the range of *M. m. arizonensis*, montane voles were caught on the first night of trapping in >95% of surveys.

Results of this study demonstrated that typical livestock grazing management on Forest Service allotments results in riparian zones that lack the plant composition and structure to support riparian mammal communities. Other studies have reached similar conclusions (Frey and Malaney 2009, Small et al. 2016, Horncastle et al. 2019). At most sites in this study, riparian conditions and small mammal communities had declined from 2004 to 2020. The exception was improvement of riparian conditions on Romero Creek. In 2004, aquatic and riparian conditions were very poor and the montane vole was rare, while in 2020, the stream was more continuous with abundant fishes and the riparian zone included extensive moist soil and patches of tall, dense herbaceous riparian vegetation and montane voles were abundant. The improved conditions are likely primarily due to a change in the manner in which cattle were permitted to graze in the Romero Pasture that occurred in 2003 and 2004. In 2003, permitted livestock numbers were decreased to 185 cow/calf pairs, an almost 17% decrease from prior numbers. Then in 2004, the season of use changed from the growing season (portions of May-August) to the post-monsoon growing season period (portions of September-October). Late growing season grazing is generally considered detrimental to riparian zones and is similar in impact to growing season grazing, which is universally considered detrimental to riparian zones (Baker 2001, Cram 2018). Thus, the overall benefit of the changed management is likely attributed to the overall total reduction of use (i.e., combination of reduction in time and numbers), with possible additional benefits due to avoiding grazing in the hot season (Swanson et al. 2015). Although conditions have vastly improved, the vertical cover on Romero Creek in 2020 was still low compared to other sites occupied by the Arizona montane vole throughout its range. This was likely due to the fact that Romero Creek continues to be depauperate in riparian shrubs. The near absence of riparian shrubs may be due to the late season grazing, which is considered detrimental to woody plant species (Baker 2001, Cram 2018, Swanson et al. 2015) and possibly lack of upstream sources for reestablishment of alders and willows.

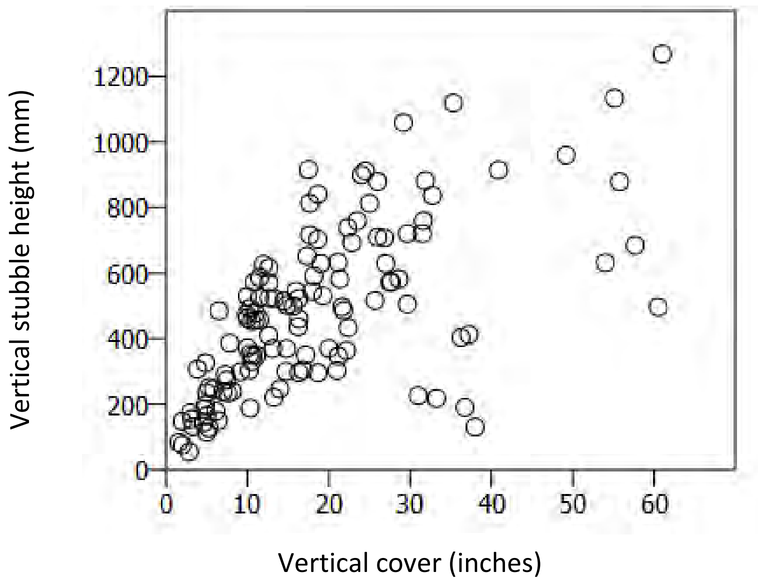

Figure 5. Relationship between mean vertical cover and mean vertical stubble height on microhabitat plots. Above 10 inches of vertical cover, the relationship between the two variables becomes more diffuse. Vertical cover is a better measure of habitat for the Arizona montane voles (*Microtus montanus arizonensis*) than vertical stubble height.

Conclusions

The Arizona montane vole is a bellweather of riparian conditions. In healthy riparian zones within its range, the Arizona montane vole is typically the most abundant small mammal species. Because of their usual high population densities, they are critical to ecosystem functioning, such as serving as prey to a host of small predators such as hawks and owls, improvements to soil conditions through burrowing activity, and influence on plant community composition and structure, such as through the dispersal of hypogeous fungi (Frey 2018). Further, riparian zones that are incapable of supporting Arizona montane voles are almost certainly incapable of supporting an entire range of other species, such as shrews, jumping mice, weasels, and native frogs. The current status of the Arizona montane voles is a testament to these degraded stream systems. Restoration of habitat for the Arizona montane vole will benefit a myriad of species.

Recommendations

1. Tangible and urgent management actions are needed to prevent extirpation of *M. m. arizonensis* from New Mexico.

2. Restoration of riparian habitat on Jenkins Creek should become a priority for immediate action. Jenkins Creek is a key population of Arizona montane voles in New Mexico, but it is likely at immediate risk of extirpation due to severely degraded riparian vegetation. The immediate goal should be to use temporary fencing (e.g., electric tape, cattle panels, buck and pole, etc.) to create corridor habitat enclosures that can support tall, dense herbaceous vegetation. To provide redundancy, several such enclosures should be created. The creation of these temporary enclosures should be considered a stopgap measure to prevent immediate extirpation. In parallel, plans should be developed for permanent habitat restoration on Jenkins Creek, such as by permanent corridor exclosures or use of riparian pastures with greatly reduced total AUMs (perhaps mimicking Romero Pasture of the Underwood Lake Allotment).

3. Given that montane vole populations can fluctuate and may be tied to disturbance and weather events, additional surveys in future years should be conducted on the San Francisco River and in the Centerfire Creek watershed.

4. If future surveys fail to detect *M. m. arizonensis* in the exclosures on Centerfire Creek, Funderburg Spring, and SA Creek, the use of translocation should be investigated to restore those populations.

5. Riparian habitat restoration on Stone Creek and San Francisco River should be implemented. This should include controlling livestock grazing to facilitate restoration of herbaceous vegetation.

6. Beaver dam analogs should be used on Romero Creek, Jenkins Creek, Centerfire Creek, and other small order streams, to increase moist soil area and facilitate restoration of riparian vegetation. Beaver dam analogs are artificial structures that have been proven effective in restoring incised stream (Pollock et al. 2014).

7. The lower portion of the exclosure on Centerfire Creek (below FS Road 4029L) requires additional management in order to restore riparian habitat. The stream in this section is channelized and there is no opportunity for the water to spread out to form moist soil. The upper portion of this reach could be restored using beaver dam analogs to facilitate restoration. However, the lowest portion is more deeply entrenched. The use of machinery to build dikes and recontour the valley should be investigated.

8. All livestock exclosures had sign of livestock use, and in some cases the sign was abundant, suggesting heavy prior use by cattle. In sedge meadows, cattle can remove virtually all cover in a short amount of time (<8 weeks), which leaves small mammals exposed to predation (Frey 2011). Exclosures should be monitored and livestock immediately removed when incursions occur. The exclosure fence at Trap Spring should be repaired.

9. Grazing management in the Romero Creek allotment should not become more permissive as current conditions have improved but are still not meeting the minimum threshold of vertical cover at occupied sites across the range of *M. m. arizonensis*. Further restoration of riparian conditions on Romero Creek may be facilitated with beaver dam analogs, planting riparian shrubs, and use of corridor fencing. Flanagan Cienega should be protected from livestock grazing in order to maintain this unique ecological site (fen).

10. Upland range conditions in the Centerfire Creek watershed appear poor and may be contributing to flooding and excessive erosion. Management to improve upland conditions will likely improve riparian conditions.

11. Riparian restoration should target a minimum of 16 inches mean vertical cover along stream reaches taken with a Robel pole every 20 m 0.5 m from the stream edge. This target will assure that riparian vegetation is functioning to support small mammal populations, including Arizona montane voles.

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Centerfire Creek (#2)

Centerfire Creek is the principal stream in the northern portion of the Gila National Forest. This site is currently located in a grazing exclosure at FS Road 4029L (Freeman Mountain Trail Road), near trail 33 trailhead. In 2004, I visited this site and found that riparian conditions were poor and I could not find any vole runways because the herbaceous vegetation was very short; consequently, it was not trapped. I described the stream as confined to a narrow channel (1 m wide), which limited the moist soil areas needed to produce montane vole habitat. I concluded that the site had potential to produce quality montane vole habitat if livestock grazing was restricted. In 2020, this area was within a livestock grazing exclosure and the riparian vegetation had dramatically improved. FS Road 4029L formed an elevated dike, and, above the road, an extensive, luxuriant wet meadow with fen characteristics had developed. Vole runways were abundant in the dense sedges on moist soil, which is typical of sites where *M. montanus* is expected to occur. Below the FS Road 4029L grade, the stream was confined to a narrow channel with limited development of herbaceous riparian vegetation due to a narrow band of moist soil. This site was surveyed 12-13 June 2020 using 36 trap-nights of effort, all placed above the road on vole runways in ideal habitat for *M. montanus*. Surprisingly, no *M. montanus* were captured. The vole runways instead were occupied by an exceptionally high abundance of Mogollon voles (22.2 per 100 trap-nights). Given these results, it is unlikely that montane voles were present since the vegetation was quintessential montane vole habitat and they are a larger vole that can competitively exclude *M. mogollonensis* from favored sites. Across the entire reach, the mean vertical cover was below the 95% confidence interval for occupied sites (Figure 2). However, this was primarily due to conditions below the FS Road 4029L. For instance, the mean vertical cover on the stream edge transect was 15.1 inches above the road, but was 9.6 inches below the road. Further, the cover at all the points above the road were dominated by sedges or rushes, while below the road there was no cover provided by sedges and, at 39% of the points, the cover was provided by banks rather than vegetation. These results demonstrate that wetland habitat can be restored if livestock grazing is eliminated and structures are built (in this case the road grade) that can back up the water. The road has stopped a head cut in the upper portion of the exclosure below the road, but the lowest portion of the reach has a deeper headcut that must be stopped to allow the riparian habitat to develop. It might be possible to use machinery to create a short dike and contour the floodplain in the lower portion of the area to allow for riparian habitat restoration. The upper portion below the road (above the second headcut) could potentially be restored by using beaver dam analogs.

Wet meadow on Centerfire Creek above FS Road 4029L (Freeman Mountain Trail Road), view looking downstream towards road.

Centerfire Creek grazing exclosure below FS Road 4029L (Freeman Mountain Trail Road), looking downstream from road. In this upper section below the road, the incision is only moderate and habitat restoration might be accomplished using beaver dam analogs.

The lower portion of the Centerfire Creek exclosure is severely incised and has no opportunity to develop herbaceous riparian vegetation in its current condition. Action is needed to prevent the headcut from extending further upstream into the valley.

Funderburg Spring (#3)

This site is currently located in a grazing exclosure below County Road B025. In 2004, I considered this site to lack potential habitat. In 2020, the area was in a grazing exclosure and herbaceous riparian vegetation had dramatically improved, forming a wet meadow with fen characteristics. Due to site characteristics, which resembled a bowl, most of the area was covered by shallow water, leaving only certain spots with moist soil where voles could find dry borrows under herbaceous cover. Vole runways were abundant in these patches of dense sedges on moist soil, which is typical of sites where *M. montanus* is expected to occur. This site was surveyed 14-15 June 2020 using 80 trap-nights of effort. However, no *M. montanus* were captured and the capture rate for Mogollon voles was low (5.0 per 100 trap-nights). The mean vertical cover of the reach (14.8) was just below the 95% confidence interval for occupied sites, which reflects that fact that, while there was an extensive wet meadow, the moist soil edge was narrow due to the bowl shape of the main wetland area. Vertical cover of microhabitat in the patches with vole runways was consistent with other places montane voles have been captured (Figure 3). Like SA Creek, Funderberg Spring flows into a deep, narrow, rocky canyon below the wetland, and eventually junctions with Centerfire Creek.

The Funderburg Spring grazing exclosure had a well-developed, herbaceous wetland. View looking downstream toward canyon.

Measuring habitat at Funderburg Spring with Robel pole, Daubenmire frame, soil moisture meter, and meter ruler. The Robel pole provides the best measurement of montane vole habitat.

SA Creek above CR B012 (#4a)

In 2004, this site was in a relatively newly created livestock exclosure located above County Road B012. At that time, the site had a large (ca 100 x 200 m) wetland formed by the road grade and a constriction in the local topography. In 2004 I found vole runways around the periphery on saturated soils with dense rushes, and I captured 2 *M. m. arizonensis* in these areas, along with a single Mogollon vole in sparser vegetation near rock cover. Based on my observations, I concluded that voles avoided areas with ungulate hoofing since it disrupts their runways. In 2020, conditions at this site had notably changed. There was evidence of significant flooding and aggradation of soil. The original T-posts along the county road were mostly buried in sediments. It appeared that the reason for the flooding and aggradation was due to poor range conditions above the exclosure. In addition, there was sign of livestock grazing and heavy use by elk inside the exclosure. In 2020 vole runways were difficult to find and were mainly found in the drier uplands adjacent to the wetland, although some runs extended to the narrow margin of moist soil between the uplands and the deeper water of the wetland, or within shallower areas of the wetland. The margins with saturated soil were heavily hoofed by ungulates. This site was surveyed 12-15 June using 200 trap-nights of effort with most traps set on vole runways. No *M. montanus* were captured, despite using ca three times the effort as in 2004. The vole runs were occupied by *M. mogollonensis* (7.0 per 100 trap-nights), which is more tolerant of upland conditions than is *M. montanus*. These results indicate a decline in habitat conditions for *M. m. arizonensis* within the exclosure.

SA Creek grazing exclosure above County Road B012, looking downstream towards road. Habitat for *Microtus montanus arizonensis* is limited to a narrow band between the deeper water in the middle and the arid barren uplands.

SA Creek grazing exclosure above County Road B012 showing aggradation due to flooding, likely due to degraded upland conditions.

Lower exclosure fenceline along County Road B012 in 2004 (top) and 2020 (bottom). The original green t-posts from 2004 were nearly completely buried by sediments in 2020 as the wetland has filled in with sediments. The large influx of sediments may be due to poor upland conditions in the watershed.

SA Creek below CR B012 (#4b)

This site was located in a livestock grazing exclosure below County Road B012 and adjacent to the exclosure where *M. m. arizonensis* was captured in 2004 (Frey 2005). In 2004, I described the area as heavily grazed by livestock with virtually no herbaceous cover. Because it lacked suitable riparian habitat, I did not trap it in 2004. In contrast, in 2020, I found that the riparian vegetation had dramatically improved, was extensive throughout the area, and had fen characteristics. The stream appeared perennial and contained fishes and crayfish. There was sign that the exclosure had been heavily grazed by cattle in the recent past, but during my survey, there were no livestock present and the herbaceous vegetation appeared ungrazed. The main wetland area was located in the upper portion of the exclosure and above a constriction formed by adjacent cliff walls. This area had shallow standing water with dense sedges and rushes extending between the cliffs. Because of the topography, vole runways were limited to small areas of slightly higher ground where voles could find dry places for burrows. These areas were also heavily hoofed by elk, and voles seemed to avoid such areas. A few runways were found, mostly emerging from the rock cliffs in places largely inaccessible to ungulates; burrows in rocks are more typical of *M. mogollonensis* than *M. m. arizonensis*. This site was surveyed 12-15 June 2020 using 100 trap-nights of effort. No *M. montanus* were captured and Mogollon voles were rare (3.0 per 100 trap-nights) due to the limited habitat. Because of the configuration of the wetland, it was not possible to measure stream-reach habitat. However, the microhabitat surveys indicate that the area had vertical cover (16.3 inches) that was near the mean of occupied sites (Figure 3). Downstream of the wetland, SA Creek entered a narrow rocky canyon with cottonwoods and coyote willows but limited herbaceous vegetation. It eventually junctions with Centerfire Creek.

SA Creek grazing exclosure below County Road B012 showed signs of extensive unauthorized livestock use.

SA Creek below County Road B012 in 2004 (top) and 2020 (bottom). Livestock exclusion resulted in a dramatic improvement in riparian habitat. However, uplands remained in poor condition, resulting in flooding and aggradation within the SA Creek exclosures. Note the reduction in valley depth. No *Microtus montanus* were captured at this site.

Jenkins Creek below FR 385 (#5)

This site was located along Jenkins Creek, below the FR 385 road bridge. In 2004, riparian conditions were poor at this site and lacked both riparian species composition and structure. However, at that time I still captured a single *M. m. arizonensis*, along with other species of vole at a total relative abundance of 7.0 per 100 trap-nights. The 2004 montane vole was captured in an undercut bank that provided necessary cover, indicating a population nearing extinction. In 2020, riparian conditions appeared similar to those in 2004. The stream was intermittent and pools contained crayfish. This site was surveyed 10-12 June 2020 using 160 trap-nights of effort, including clusters of traps on available vole runways. I did not capture any montane voles and the Mogollon vole was rare (1.3/100 trap-nights) and restricted to places where rocks provided cover. Water was present intermittently, but the riparian conditions remained extremely poor as the herbaceous vegetation was very short and the plant composition lacked riparian obligate species, such as sedges, riparian forbs, alders, and willows. The survey results indicate that riparian conditions at this site have declined even further from what they were in 2004.

Jenkins Creek below Forest Road 385 in 2004 (top) and 2020 (bottom); view from road looking downstream. In 2004 this site had marginal habitat for the Arizona montane vole and one was captured. In 2020 the area lacked habitat and none were captured.

Sole capture location for *Microtus montanus* on Jenkins Creek below Forest Road 385 in 2004.

Conditions at the same location on Jenkins Creek below Forest Road 385 in 2020 (bottom). Riparian habitat is in very poor condition and no *Microtus montanus* were caught at this location in 2020.

Range monitoring location on Jenkins Creek below Forest Road 385 in 2020. The monitoring cage is in disrepair and so may under represent utilization. Vertical cover within the cage is ca 12 inches and outside the cage is ca 1 inch. Note the Sherman traps (3.5 inches tall) plainly visible in the background.

Jenkins Creek, draw (#6)

This site was located in a shallow draw connected to and 0.2 km away from Jenkins Creek. In 1994, I captured a montane vole at this site and described the habitat as follows: "The collection locality was a mesic meadow with dense, tall grass in a slight depression draining into Jenkins Creek. No surface water was present, but the soil was wet in some areas" and vole runways were abundant in the tall grass (Frey et al. 1995:421). In 2004, when the same site was resurveyed, the soil was dry and the vegetation was dominated by forbs with a thin growth of grasses and rushes. Vertical cover was short (2.2 inches), but a single *M. mogollonensis* was captured, which is a species that can tolerate more arid conditions and more sparse cover. In 2020, the soil was dry and there was no riparian vegetation. Herbaceous vegetation was very poor and vertical cover was 1.7 inches at the historical capture location. I found old, unused vole runways in the same location where the montane vole was captured in 1994 and the Mogollon vole was captured in 2004 (Frey et al. 1995). I surveyed the site 11-12 June 2020 using 80 trap-nights of effort, including a concentrated effort on the old vole runways. No *M. m. arizonensis* or any other mammals were captured (Table 2). This demonstrates that herbaceous vegetation conditions have declined to the point that small mammals were not detectable.

View of Jenkins Creek draw from Forest Road 385. In 1994 this area had moist soil and tall, dense herbaceous vegetation and *Microtus montanus arizonensis* was captured. Jenkins Creek is a short distance (200 m) downstream.

Jenkins Creek below FR3050 (#7)

This site was located in a small portion of the mainstem of Jenkins Creek in a different grazing allotment (Underwood Lake Allotment) from the other sites on Jenkins Creek (Spur Lake Allotment). In 2004, I surveyed this site, but only captured *M. mogollonensis* (5.8 captures per 100 trap-nights). At that time, I targeted an area on the floodplain that had the tallest vegetation available, though it was short relative to the needs of *M. m. arizonensis*. In 2020, riparian conditions were very poor, but marginally better than other sites along Jenkins Creek. Soils were mostly dry, vegetation was short, and there were few vole runways. The site was surveyed 10-11 June 2020 using 80 trap-nights, which extended across most of the entire area. Two *M. montanus* were captured at a relative abundance of 2.5%. These were captured on the north-facing aspect of an undercut bank that provided shade and a small area where conditions were cooler and wetter than other locations. Vertical cover along this reach was very low (4.9 inches). At the capture locations, vertical cover was higher (8.3 and 9.0 inches), although still below the 95% confidence interval for occupied sites. Importantly, most of the cover was due to bank rather than vegetation. This was the only place *M. m. arizonensis* was captured on Jenkins Creek in 2020. These results suggest that this population could become extirpated in the near future unless habitat conditions improve.

Capture location (at Robel pole) for *M. montanus arizonensis* at Jenkins Creek in 2020. This small area in the Underwood Lake Allotment represented the best developed riparian vegetation on Jenkins Creek but was marginal for *M. montanus*. Vole runways were limited to this undercut bank, which provided cover.

Upper Jenkins Creek (#8)

In 1998 and 2002, the New Mexico Department of Game and Fish documented *M. m. arizonensis* at several locations along Jenkins Creek (NMDGF 2002). Information about the exact locations is not available, but it is possible some were on the upper portion of Jenkins Creek, which runs along FS Road 3050. During 2020, water was found on the upper reach around a stock pond and in a seep below the stock pond's earthen dam. Otherwise, most of upper Jenkins Creek was dry and lacked riparian vegetation. The riparian vegetation around these water features was heavily grazed and degraded and no vole runways were found. This site was surveyed 10-12 June 2020 using 160 trap-nights of effort. No *M. montanus* were captured. This reach had the second lowest mean vertical cover (3.2 inches), far below the lower 95% confidence interval for occupied sites. This reach is unlikely to harbor the species.

Sherman traps set in the best developed herbaceous cover on upper Jenkins Creek. The Sherman traps are 3.5 inches tall, but plainly visible, demonstrating the lack of suitable herbaceous cover.

Romero Creek above FR 220 (#9)

This site is located along Romero Creek above FR 220. In 2004, Romero Creek held only rare pools of water and riparian conditions were very poor. At that time, I described the area as having little moist soil and the vegetation was heavily grazed, resulting in virtually no herbaceous cover (Frey 2005). Vole runways were uncommon and usually associated with cover provided by rocks or other structures. I captured a single montane vole and Mogollon voles were uncommon (6.8 per 100 trap nights). I concluded that, based on the conditions in 2004, Romero Creek likely could not support a self-perpetuating population of montane voles, but rather represented a sink (Frey 2005). In contrast, during 2020 surveys, riparian and aquatic conditions at this site had notably improved compared to conditions in 2004. The stream appeared perennial and held abundant fishes. Moist soil and herbaceous riparian vegetation were extensive and well-developed, and vole runways were abundant. There were a few individual riparian shrub saplings (as well as a few old caged shrubs). This site was surveyed 8-9 June 2020 using 80 trap-nights of effort. Nine *M. m. arizonensis* were captured at a relative abundance of 11.2%. The mean vertical cover along the stream reach (10.6 inches) was below the 95% confidence interval for occupied streams (Figure 2), indicating that riparian restoration is still far from complete. However, patches of tall, dense herbaceous vegetation for voles was present and the vertical cover at capture sites (16.0 inches) was approximately at the mean for occupied sites across the species range (15.9 inches; Figure 3). This is an important example of how riparian vegetation conditions can be improved to support robust populations of montane voles.

Measuring habitat at a capture location for *Microtus montanus arizonensis* on Romero Creek in 2020. The person is walking in the stream, which is obscured by vegetation. This tall, dense herbaceous vegetation was not present in 2004 and is a result of changed livestock management.

Sole capture location for *Microtus montanus* on Romero Creek in 2004 (top) and conditions at the same location in 2020 (bottom). Note the reduced erosion and increased height, density, and extent of riparian vegetation in 2020. *Microtus montanus* was abundant along Romero Creek in 2020.

Close up of riparian vegetation conditions at a capture site for *M. m. arizonensis* on Romero Creek in 2004 (top) and in 2020 (bottom). In 2004, the creek was dry, soils were dry, and vegetation was closely cropped due to livestock grazing (note it was not possible to conceal traps in vegetation). In 2020, the riparian vegetation was tall and dense (note person's boots) and the creek (here obscured due to the tall vegetation) was narrow, deep, and had abundant schools of small fishes.

Upper Romero Creek. Riparian vegetation could be improved and expanded with use of beaver dam analogs or corridor fencing.

Flanagan Cienega (#10)

This site was located at the lower (northern) end of the former meadow and cienega system that also includes Flanagan Spring at the upper (southern) end. The two locations are 0.7 km apart but separated by unsuitable habitat. This site was located in a different grazing allotment (Underwood Lake Allotment) than was Flanagan Spring (Luna Allotment). This site was a relatively well-developed cienega with fen characteristics. Mean vertical cover (11.1 inches) was below the 95% confidence interval for occupied sites (Figure 2) and vole runways were uncommon. The site was surveyed 8-9 June 2020 using 70 trap-nights. Two *M. montanus* were captured at a relative abundance of 2.9%. The microhabitat had vertical cover (12.0 inches) that was typical (i.e., within the 95% CI) of other locations where the montane vole has been captured (Figure 3).

Flanagan Cienega has fen characteristics. View from within the fen looking downstream.

Flanagan Spring (#11)

In 2004, Flanagan Spring had a small (ca 20x 40 m) isolated patch of herbaceous riparian vegetation dominated by a dense thatch of tall rushes and grasses (vertical cover 7.1 inches). Vole runways were abundant on the wet soil under the cover of deep vegetation, and the capture rate of montane voles was high (15.1 per 100 trap-nights). In 2020, the seep was heavily grazed by cattle, trampled, contaminated with excrement, and lacked developed riparian vegetation and vole runways. Habitat for *M. m. arizonensis* was entirely lacking and I visually confirmed that no voles of any species occupied the site. The site could not be trapped because it was adjacent to a road and there was no cover to conceal traps.

Historical location for *Microtus montanus* at Flanagan Spring in 2004 (top) and the same location in 2020 (bottom). In 2004, the vegetation was tall and dense, concealing the traps. In 2020, the vegetation was heavily cropped by cattle resulting in an absence of vertical cover (note persons shoes).

"Unnamed Creek" (#12)

This site (here named "Unnamed Creek") was located on an unnamed tributary to the San Francisco River. Specimens of putative *M. montanus* in the MSB were collected from this area. I surveyed this area on public land along the intermittent creek that seeps from below a large stock tank. There was abundant sign of livestock and elk grazing. The riparian vegetation was poorly developed and limited and had few vole runways. This site was surveyed 5-7 June 2020 using 80 trap-nights of effort. No *M. montanus* were captured, but Mogollon voles were captured at a moderate rate of 10 per 100 trap-nights. Downstream of the trapping area, the stream became confined to a narrow canyon, which is not typical habitat for *M. montanus* but is typical for *M. longicaudus*. Based on external measurements, I concluded that two of the putative specimens from this location could be referable to *M. longicaudus*. Habitat on the forest service portion of "Unnamed Creek" did not appear suitable for *M. m. arizonensis* during 2020. I did not investigate conditions on the adjoining private property where the tank was located due to landownership.

"Unnamed Creek" survey sites were on an unnamed tributary to the San Francisco River. This was a capture location for a Mogollon vole (*Microtus mogollonensis*); no *M. montanus* were captured at this site and habitat was not suitable at the time due to low vertical cover.

Trap Spring (#13)

This site was in an elk and livestock grazing exclosure established around Trap Spring, which is part of an intermittent tributary to the San Francisco River. This site was visited in 2004 but not trapped because there was no wet soil at the time. During 2020, the exclosure fencing was in disrepair and there was evidence of use of the exclosure by both elk and cattle. The area of developed herbaceous riparian vegetation was very small, but vole runways were relatively abundant on moist soil with well-developed vegetation. This site was surveyed 5-7 June 2020 using 160 trap-nights of effort, with most traps set on vole runways. One *M. montanus* was captured at a relative abundance of 0.6%. The overall reach had very low mean vertical cover (5.1 inches), indicating that, in general, the drainage has poor habitat for *M. m. arizonensis*. The capture location was in the area of highest vertical cover (23.7 inches) within the exclosure, due to both the spring seep being in an undercut bank that was also overlaid by vegetation.

The pink flagging is at the capture location of a *Microtus montanus arizonensis*. This precise spot had the tallest vertical cover available due to a combination of herbaceous vegetation and an undercut bank.

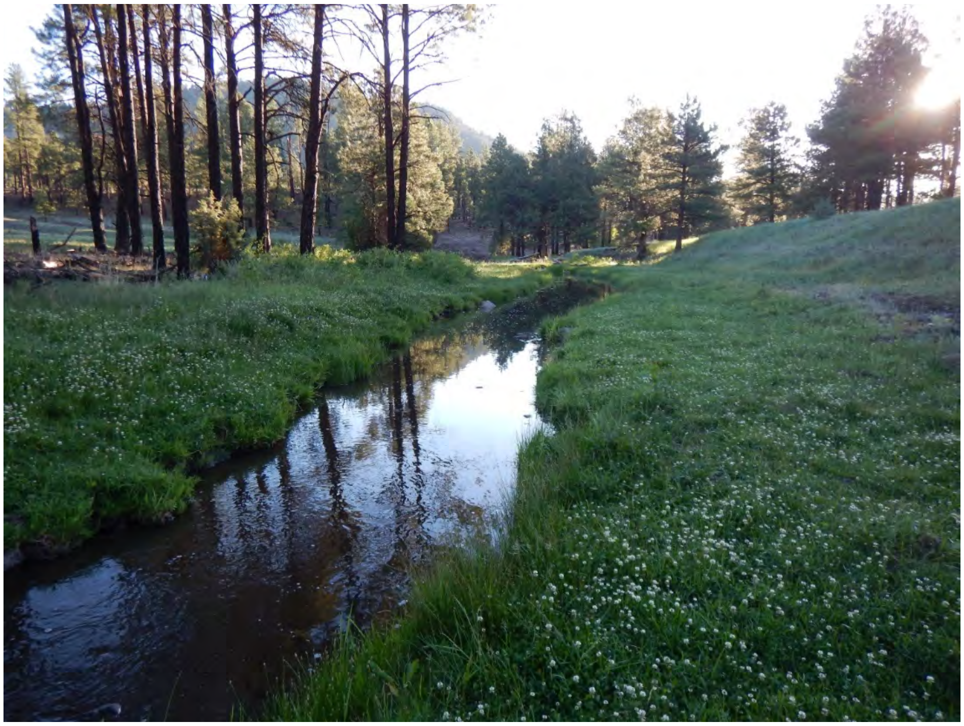
Trap Spring exclosure in 2004. During 2004 the area lacked moist soil and tall herbaceous vegetation and so was not surveyed in that year.

The Trap Spring exclosure fencing was in disrepair and non-functional in several locations along the Trap Spring drainage in 2020.

San Francisco River (#14)

In 2004, I captured an equal abundance of *M. m. arizonensis* and *M. mogollonensis* (13.2 captures per 100 trap-nights) on the San Francisco River near the confluence with its major tributary, Stone Creek. I described the riparian zone in 2004 as being dominated by diverse and abundant grassy herbaceous vegetation with scattered stands of willows. Vertical cover at capture sites was 10 inches (Frey 2005). In 2011, the San Francisco River was impacted by the 2011 Wallow Fire, which led to flooding and erosion. The putative *M. montanus* specimens in MSB from Stone Creek and San Francisco River in 2008 (i.e., 8 km W Luna) were from near the historical location, but both were within the burn scar (the historical location was just outside the burn scar). In 2020, the stream appeared to be downcut and the riparian vegetation appeared to be impacted by heavy livestock grazing. The dominant vegetation in the riparian zone was low mats of white clover. Areas with well-developed riparian vegetation (e.g., sedges or willows) were patchy and vole runways were only found within these small patches. This site was surveyed 6-8 June 2020 using 280 trap-nights of effort. The traps extended across a relatively large area from near the historical location, near the junction of the San Francisco River and Stone Creek, upstream to near the putative MSB *M. montanus* specimen location. No *M. montanus* were captured in an effort that was more than twice that put forth in 2004 (106 trap-nights in 2004 versus 280 trap-nights in 2020). The mean vertical cover along the stream reach (13.0 inches) was lower than the 95% confidence interval for sites occupied by *M. m. arizonensis* (Figure 2). There were small patches of tall dense herbaceous vegetation on seeps, islands, and inside bends, but these were occupied by *M. mogollonensis*, which is better able to persist through disturbances and with heavy grazing. These results indicate substantial declines in riparian conditions and potential extirpation of *M. m. arizonensis* for this area.

Capture locations (red flags) for two Arizona montane voles (*Microtus montanus arizonensis*) on the San Francisco River near the mouth of Stone Creek in 2004.



The dominant vegetation in the riparian zone along the San Francisco River in 2020 was short mats of white clover, which does not provide habitat for *Microtus montanus arizonensis*.

Patches of tall, dense herbaceous vegetation suitable for *Microtus montanus arizonensis* were rare on the San Francisco River in 2020. This patch was on an island and occupied by *M. mogollonensis*.