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DECLINE OF THE MEADOW JUMPING MOUSE (*ZAPUS HUDSONIUS LUTEUS*) IN TWO MOUNTAIN RANGES IN NEW MEXICO

JENNIFER K. FREY* AND JASON L. MALANEY

Frey Biological Research, P.O. Box 294, Radium Springs, NM 88054 (JKF)
Department of Biology and Museum of Southwestern Biology, University of New Mexico, Albuquerque, NM 87131 (JLM)
**Correspondent: Frey_B_R@fastwave.biz*

ABSTRACT—The New Mexico meadow jumping mouse (*Zapus hudsonius luteus*) is endemic to riparian habitats in the American Southwest. We evaluated current status and habitat of this species in the Jemez and Sacramento mountains, New Mexico. We compiled historical capture localities and conducted field surveys at historical and potential new localities during 2005 and 2006. We did not find the species or its habitat at 73% of historical localities surveyed in the Jemez Mountains and 94% of historical localities surveyed in the Sacramento Mountains. It persisted in two drainages (five localities) in the Jemez Mountains and two small, isolated localities in the Sacramento Mountains. *Zapus h. luteus* was associated with tall, dense, herbaceous riparian vegetation, especially areas dominated by sedges. The lower bound to the 95% confidence interval for vertical cover at localities where *Z. h. luteus* was captured was 63 cm. Decline in distribution was due to loss of this habitat, primarily as a result of livestock grazing. However, drought, development, recreation, forest fire, and loss of the American beaver (*Castor canadensis*) also contributed. We recommend that conservation of *Z. h. luteus* will require establishment of refugial areas of suitable habitat through protection from livestock grazing.

RESUMEN—El ratón *Zapus hudsonius luteus* es endémico de hábitats riparios en el suroeste de los Estados Unidos. Evaluamos el estatus y hábitat en la actualidad de esta especie en las montañas Jemez y Sacramento en Nuevo México. Compilamos las localidades históricas de la captura e hicimos muestreos de campo en sitios históricos y en otros lugares probables durante 2005 y 2006. No encontramos la especie en su hábitat en 73% de las localidades históricas muestreadas en las montañas Jemez ni en 94% de las localidades en las montañas Sacramento. Persistió en dos desagües (cinco localidades) en las montañas Jemez y en dos localidades pequeñas y aisladas en las montañas Sacramento. *Zapus h. luteus* fue asociado con la vegetación ribereña, herbácea, densa y alta, especialmente en áreas dominadas por juncias. El límite inferior del intervalo de la confianza 95% para la cubierta vertical en las localidades donde *Z. h. luteus* fue capturado fue 63 cm. La disminución en su distribución fue debido a la pérdida de este hábitat, principalmente a consecuencia de pastoreo de ganado. Sin embargo, la sequía, el desarrollo, la recreación, el incendio forestal, y la pérdida del castor (*Castor canadensis*) contribuyeron también. Recomendamos que la conservación de *Z. h. luteus* requerirá establecimiento de áreas conservadas con hábitat adecuado y protegido del pastoreo de ganado.

In North America, humid climates occur across the eastern and subarctic regions of the continent and decline toward the south and west to the dry climates of the interior west and southwestern regions. Distribution of the meadow jumping mouse (*Zapus hudsonius*) largely is coincident with the North American distribution of Köppen climatic type D (i.e., humid continental climates; Hall, 1981; Fig. 1). Here the species occupies a wide range of habitats and sometimes has been considered a habitat generalist, although it typically is associated with dense herbaceous vegetation (e.g., Quimby, 1951; Whitaker, 1972; Choate et al., 1991). However, at the southwestern edge of its range where the climate is dry (i.e., Köppen climatic type Bsk, semiarid continental climate), the species is associated with riparian zones (Morrison, 1990, 1992; Trainor et al., 2007*a*; P. Cryan, in litt.).

Increasing habitat specialization at the southwestern limit of the range can put populations at risk because wetland habitats in arid regions typically are small, isolated, and prone to modification through land-use practices by humans. For example, Preble's meadow jumping mouse (*Z. h. preblei*), which is associated with

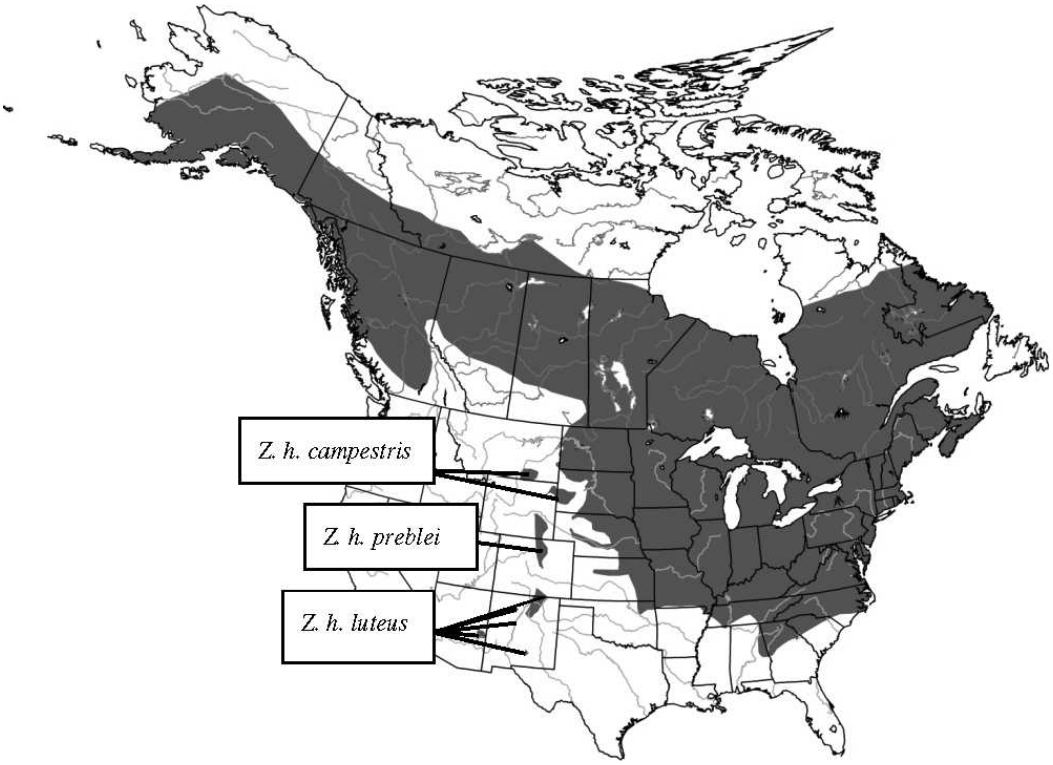

FIG. 1—Range of *Zapus hudsonius* (shaded) including names and locations of peripheral subspecies.

riparian habitats along foothills of the northeastern edge of the southern Rocky Mountains (Fig. 1), is listed as threatened under the United States Endangered Species Act due to declines associated with modification of riparian habitats (United States Fish and Wildlife Service, 1998). In comparison, the New Mexico meadow jumping mouse (*Z. h. luteus*) is a morphologically and genetically distinctive subspecies that occupies a more isolated and extreme environment in the arid American Southwest (Miller, 1911; Hafner et al., 1981; King et al., 2006). Distribution of *Z. h. luteus* primarily is associated with the Southern Intermontane Plateaus physiographic region, with records from several major mountain ranges, and the Rio Grande and adjacent Chama River valleys (Miller, 1911; Hafner et al., 1981; Hoffmeister, 1986; Morrison, 1990, 1992; Zwank et al., 1997; Jones, 1999; Fig. 1). This disjunct distribution is considered relictual from a more widespread distribution during past glacial maxima (Hafner, 1993). Currently, *Z. h. luteus* is listed as a candidate for protection under the United States Endangered Species Act, endangered in New Mexico, threatened in Arizona, sensitive by the United States Forest Service and United States Bureau of Land Management, and it has a Natural Heritage conservation status of imperiled in Arizona and critically imperiled in Colorado and New Mexico. Identified threats include negative impacts to wetland habitats from development, grazing, water diversions, and conversion of riparian habitat to agricultural crops (Hafner and Yensen, 1998; New Mexico Department of Game and Fish, 2004).

During the mid-1980s to early 1990s, Joan Morrison conducted the first intensive surveys for *Z. h. luteus*, which were detailed in Morrison (1992) and reports to agencies, and were documented by specimens deposited in the Museum of Southwestern Biology, University of New Mexico. Surveys in New Mexico during the 1980s revealed that *Z. h. luteus* persisted at all historical localities sampled (although not all historical localities were resurveyed) and was discovered at new localities, which eased conservation concerns (New Mexico Department of Game and Fish, 1998). However, subsequent surveys in the White Mountains of Arizona during 1991 failed to document *Z. h. luteus* at

19 of 24 (79%) locations surveyed, which included 2 of 4 historical localities and many areas with seemingly suitable habitat (J. L. Morrison, in litt.). Morrison concluded that the population in the White Mountains was declining and endangered as a result of habitat degradation due to livestock grazing and recreation.

The historical status of *Z. h. luteus* is best documented in the Jemez and Sacramento mountains, New Mexico, where it occupied a broad distribution (Morrison, 1992). However, the most recent captures of *Z. h. luteus* in the Jemez and Sacramento mountains were in 1989 and 1994, respectively, despite regular mammalogy fieldwork in both ranges. New Mexico Department of Game and Fish (2004) considered threats to habitat of *Z. h. luteus* likely most severe in montane areas and anecdotal observations in both ranges suggested declines in distribution and quality of riparian habitat. Consequently, the purpose of this study was to assess current status and habitat of *Z. h. luteus* in the Jemez and Sacramento mountains, New Mexico.

MATERIALS AND METHODS—*Survey*—We compiled historical locality records of *Z. h. luteus* in the Jemez and Sacramento mountains from museums, published literature, unpublished reports, and interviews with knowledgeable biologists. Field surveys at historical and potential new localities occurred 27 June–12 August 2005 in the Jemez and Sacramento mountains, and 14–19 August 2006 in the Jemez Mountains. Land ownership prevented surveying some historical localities. Survey locations were examined for potentially suitable habitat of *Z. h. luteus*, which we defined as presence of flowing surface water with riparian vegetation that provided adequate ground cover to conceal a traveling mouse (e.g., vertical cover >30 cm; Morrison, 1990).

We attempted to capture *Z. h. luteus* if potentially suitable habitat was present. Sherman (H. B. Sherman Trap, Tallahassee, Florida) live-traps were used because they allowed animals to be released unharmed and they were effective in previous inventories of *Z. h. luteus* (e.g., J. L. Morrison, in litt.; J. G. Koloszar and M. F. Ingraldi, in litt.). Traps were baited with commercial horse sweet feed (i.e., three or four types of grain mixed with molasses) and typically spaced ca. 3 m apart in transects of 40–80 traps situated within 1 m of water in the best-developed riparian vegetation. Sample sites within <1 km were considered a single location. Trapping effort at each locality was generally 200–600 trap-nights (i.e., 1 trap-night = one trap set for one night) over two nights, except where small available patches of riparian habitat were saturated with traps. Trapping ceased at a locality when *Z. h. luteus* was captured. *Zapus h. luteus* was considered functionally absent at a locality if either potentially suitable riparian habitat was absent or the species was not captured. We collected tissue samples from all captured *Z. h. luteus*, and retained at least one *Z. h. luteus* from each locality as a voucher specimen. In addition, to establish relationships between conditions of riparian habitat and communities of small mammals, we sampled some localities lacking potentially suitable habitat for *Z. h. luteus* generally using ca. 100 trap-nights. We calculated relative abundance as number of individuals captured/100 trap-nights. Trapping and euthanasia protocols followed American Society of Mammalogists guidelines (Animal Care and Use Committee, 1998).

Habitat—We collected habitat data at each trap where *Z. h. luteus* was captured and at a random point within the best-developed riparian habitat at sites where *Z. h. luteus* was not captured. At each point where habitat data were collected, we measured distance to surface water, estimated slope with a compass, and measured canopy cover with a densitometer in the four cardinal directions. We obtained an index of soil moisture ranging from 1 (dry) to 10 (saturated) using a soil-moisture probe inserted into the ground ca. 40 mm. We measured vertical cover with a Robel pole (Robel et al., 1970) from 4 m distance at 1 m eye level with measurements taken at three random azimuths away from and three random azimuths towards the habitat point. Vertical cover was reported for the three measurements taken at the habitat point, the three measurements taken 4 m away from the habitat point, and averaged across all six measurements.

We established four 4-m perpendicular transects at a random azimuth from the habitat point. At each 1-m interval along a transect, we used a Daubenmire (1959) frame to assess the percent of ground covered by open water, sedges and rushes, forbs, grasses, litter, rocks, gravel, bare ground, and riparian shrubs (i.e., alder *Ulnus*, willow *Salix*). 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. Within each frame, we measured soil moisture, depth of litter, and two measures of height of stubble. We measured laid-over height of stubble as height of vegetation as it naturally lay and vertical height of stubble as height of a representative blade of graminoid vegetation that was fully extended vertically from the ground. Finally, we recorded identity and number of each tree and shrub within 1 m of each transect. At some habitat points where *Z. h. luteus* was not captured, we measured habitat along two transects because preliminary analyses indicated no significant difference ($P > 0.05$) in measurements whether based on two or four transects.

We calculated statistics using SPSS 10.0 for Windows (SPSS, Inc., 1999). We assessed all variables for normality with a one-sample Kolmogorov-Smirnov test (SPSS, Inc., 1999). To test for differences in habitat variables at points where *Z. h. luteus* was captured or not captured, we used two-tailed *t*-tests and Mann-Whitney *U*-tests for parametric and non-parametric data, respectively. We used Chi-square tests to test for relationships between presence of a livestock exclosure with presence of potentially suitable riparian habitat and capture of *Z. h. luteus*.

RESULTS—*Historical Localities*—We identified 13 and 18 historical capture localities for *Z. h. luteus* in the Jemez and Sacramento mountains, respectively (Appendix 1). These included several

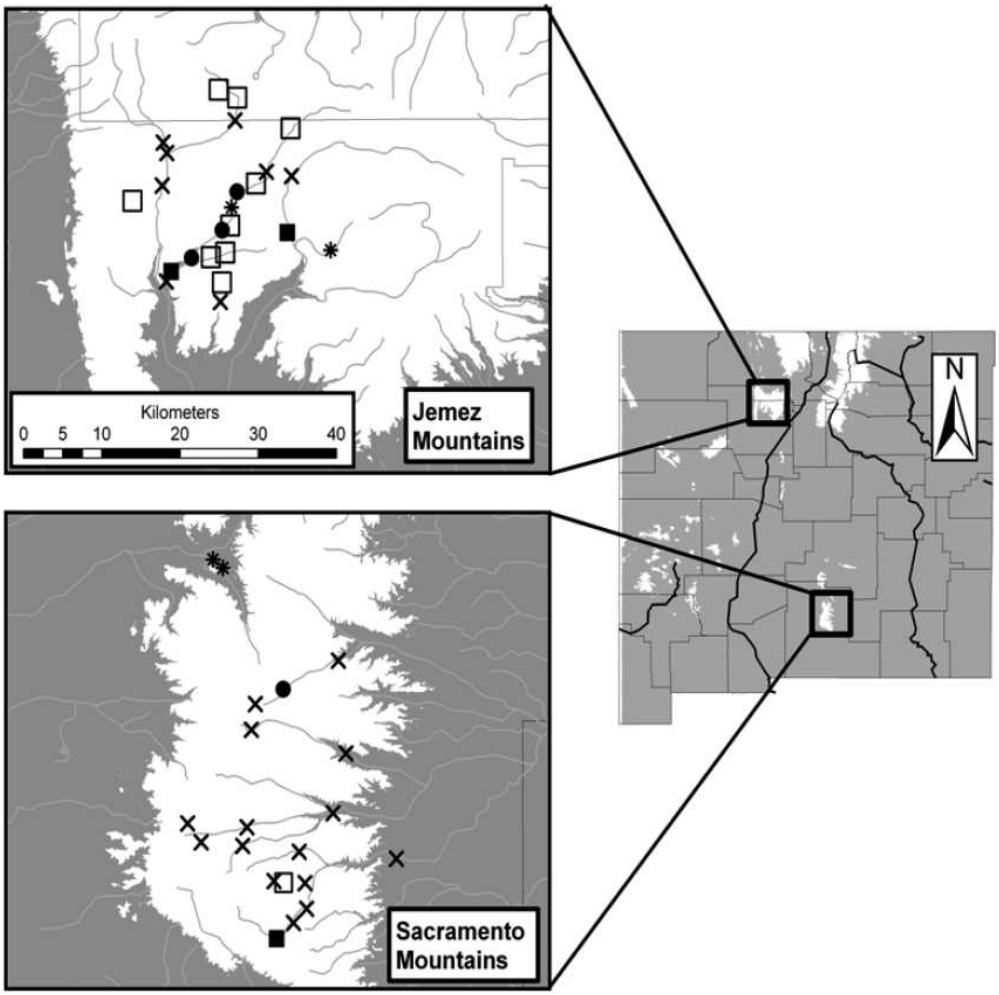

FIG. 2—Survey localities for *Zapus hudsonius luteus* in the Jemez and Sacramento mountains during 2005 and 2006. Solid symbols represent historical (circles) and new (squares) localities where the species was captured. Open symbols represent historical (X) and new (squares) localities where the species or its habitat was not found. The asterisks represent historical localities that were not surveyed. The white areas represent elevations >2,300 m.

records overlooked during previous studies. In the Jemez Mountains, this included one from the Redondo Creek drainage on the Valles Caldera National Preserve (locality J-1), while in the Sacramento Mountains this included two localities on the Rio Tularosa (localities S-1, S-2), one from Wills Canyon (locality S-12), and one from lower Aqua Chiquita Creek (locality S-19). The series of specimens from the Rio Tularosa represent the first records in the Sacramento Mountains from outside the Rio Peñasco watershed.

Field Surveys—Our survey effort involved 22 localities using 3,513 trap-nights in the Jemez Mountains and 18 localities using 2,375 trap-nights in the Sacramento Mountains, which exceeded effort during prior survey efforts in these ranges (Fig. 2; J. L. Morrison, in litt.). We captured 14 *Z. h. luteus*, which had an overall relative abundance of 0.24 captures/100 trap-nights. At localities where it occurred, relative abundance had a mean of 0.84 and range was 0.13–1.45. Lowest relative abundances were at three small, isolated localities, including Silver Springs Creek (0.13; locality S-4) and Agua Chiquita Creek (0.28; locality S-16) in the Sacramento Mountains, and San Antonio Creek

TABLE 1—Results of surveys for *Zapus hudsonius luteus* in the Jemez and Sacramento mountains, New Mexico, during 2005 and 2006.

	Historical localities					
Mountain range	Not surveyed	Present	Absent	Percent of locations surveyed where absent	New localities	Total
Jemez	2	3	8	73	2	15
Sacramento	2	1	15	94	1	19

(0.48; locality J-3) in the Jemez Mountains. In contrast, those from four localities on the Rio Cebolla in the Jemez Mountains were >1.00.

In the Jemez Mountains, we captured *Z. h. luteus* at three historical and two new localities (Table 1, Fig. 2, Appendix 1). Four localities (localities J-6, J-8, J-9, and J-10) were along a ca. 12-km reach of the Rio Cebolla, although riparian habitat within this segment was fragmented. Three of the four localities were entirely within livestock exclosures, while the fourth (locality J-9) included captures both within and outside a livestock exclosure. No *Z. h. luteus* and only poorly developed riparian habitat was found above or below this reach, although historical records attested to its former occurrence in those areas. The remaining locality was an isolated area of suitable habitat in a public campground along a 0.8-km reach of lower San Antonio Creek. Via drainages, this locality was isolated from those along the Rio Cebolla by ca. 48 km of mostly unsuitable habitat. No *Z. h. luteus* and only a few small, isolated patches of potentially suitable habitat were found within the Rio de las Vacas watershed, which accounted for 27% of historical localities in the Jemez Mountains.

In the Sacramento Mountains, we captured *Z. h. luteus* at one historical and one new locality (Table 1, Fig. 2, Appendix 1). The historical locality (locality S-4) was on a 1.8-km reach of Silver Springs Creek within a fenced livestock exclosure. A second 1.6-km reach with potentially suitable habitat was ca. 1.3 km upstream, but was not surveyed due to land ownership. On Agua Chiquita Creek, we captured *Z. h. luteus* in the second of three livestock exclosures located below a major headwater spring. Total length of the reach occupied by the three exclosures was ca. 2.6 km. Two livestock watering access points that were devoid of riparian vegetation fragmented this reach. The largest gap (between the second and third exclosure) was ca. 0.2 km, which might serve as a significant barrier to the upper two exclosures, which together were ca. 1.8 km. Although most drainages in the Rio Peñasco watershed were surveyed visually, the only other area that appeared suitable for *Z. h. luteus* was a livestock exclosure on the upper Rio Peñasco (locality S-8), but no *Z. h. luteus* was captured in 600 trap-nights.

Habitat—Sites where *Z. h. luteus* was captured had significantly greater vertical cover and vertical height of stubble (Table 2). There was a highly significant relationship between presence of a livestock exclosure with presence of potentially suitable riparian habitat ($\chi^2 = 12.108$, $df = 1$, $P = 0.001$) and capture of *Z. h. luteus* ($\chi^2 = 15.010$, $df = 1$, $P = 0.001$).

DISCUSSION—Newly discovered historical records for *Z. h. luteus* indicate that it had a broader distribution in the Jemez and Sacramento mountains than previously recognized. However, field surveys at these localities revealed a dramatic decline in distribution of *Z. h. luteus* and its habitat since the late 1980s. *Zapus h. luteus* or its habitat was not found at 73% of historical localities surveyed in the Jemez Mountains and at 94% of historical localities surveyed in the Sacramento Mountains. In both ranges, current distribution of *Z. h. luteus* was restricted to small areas of well-developed riparian habitat along isolated stream reaches. We consider the population in the Sacramento Mountains to be at serious risk of extinction because it is known to persist only within grazing exclosures along <5 km of streams. Given similar declines documented for *Z. h. luteus* in the White Mountains and for *Z. h. preblei* in the southern Rocky Mountains, these results suggest that declines might be expected for other southwestern peripheral populations of *Z. hudsonius* (United States Fish and Wildlife Service, 1998; J. L. Morrison, in litt.). Further, because the primary reason for decline of this species was loss of

TABLE 2—Habitat characteristics at sites where *Zapus hudsonius luteus* was captured ($n = 14$) or not captured ($n = 30$) in the Jemez and Sacramento mountains in 2005 and 2006.

	Not captured		Captured			
	$\bar{x}$	*SD*	$\bar{x}$	*SD*	Test statistic	*P*
Slope (°)	1.8	2.78	1.1	2.89	$z = -1.167$	0.243
Soil moisture (1–10)	8.1	2.95	9.0	1.16	$z = -0.280$	0.779
Distance to water (m)	62.3	295.40	1.6	2.78	$z = -0.771$	0.440
Canopy cover (%)	9.8	18.59	11.5	18.50	$z = -0.279$	0.780
Vertical cover (cm)						
4 m from trap or random location	49.1	31.24	82.1	35.14	$t = -3.145$	0.003
At trap or random location	53.3	33.67	83.6	34.90	$t = -2.748$	0.009
Mean	51.2	30.62	82.9	33.95	$t = -3.089$	0.004
Height of stubble (cm)						
Vertical	62.6	39.16	89.8	30.83	$t = -2.286$	0.027
Laid-over	52.2	34.61	70.5	28.61	$t = -1.717$	0.093
Depth of litter (cm)	5.7	10.82	7.6	9.09	$z = -1.285$	0.199
Ground-cover class (1–6)						
Sedge/rush	2.9	1.64	3.1	1.33	$t = 0.427$	0.672
Forb	1.8	0.87	2.0	0.97	$t = -0.645$	0.522
Grass	2.0	0.90	1.9	1.39	$z = -1.417$	0.157
Alder/willow	1.0	0.17	1.1	0.29	$z = -1.285$	0.199
Litter	1.3	0.41	1.1	0.18	$z = -0.358$	0.720
Rock	1.0	0.08	1.0	0.00	$z = -0.977$	0.328
Gravel	1.0	0.07	1.0	0.00	$z = -1.211$	0.226
Bare ground	1.3	0.62	1.1	0.12	$z = -0.119$	0.905
Open water	1.2	0.40	1.4	0.36	$z = -1.481$	0.139
Number of trees-shrubs/transect	3.4	17.59	0.1	0.23	$z = -0.206$	0.837

herbaceous riparian habitat, other species associated with these habitats (e.g., montane vole *Microtus montanus*, ermine *Mustela erminea*) also might have experienced similar declines in distribution and abundance in the American Southwest.

Sites where *Zapus h. luteus* was captured were in ungrazed, herbaceous, emergent, riparian habitats dominated by tall, dense stands of sedges on saturated soils. However, we did not find *Z. h. luteus* in sedge-dominated habitats where standing water was deep (i.e., ≥2 cm). In contrast, Morrison (1990, 1992) described *Z. h. luteus* as occupying riparian habitat dominated by grasses and forbs. However, this difference in habitat description likely was due to different methods of data collection. Data Morrison collected were from 10 plots along the stream where traps were set and at 10 locations ca. 15 m away from the stream; hence her data describe general features of the survey area (J. L. Morrison, in litt.). In contrast, our data were collected at 16 plots within a 4-m radius of locations of captures and, hence, describe specific habitat used by *Z. h. luteus*. Our assessment of habitat should be considered conservative because it remains a possibility that *Z. h. luteus* was present but not captured at some survey sites, particularly in instances where multiple sites existed within an area excluded from grazing. Consequently, *Z. h. luteus* appears to be more highly specialized on wetland associations as compared with other peripheral subspecies of *Z. hudsonius*, including *Z. h. preblei*, *Z. h. campestris*, and *Z. h. pallidus*, which use a broader array of riparian and mesic grassland habitats (e.g., Choate et al., 1991; United States Fish and Wildlife Service, 1998, 2002; Trainor et al., 2007*a*; P. Cryan, in litt.). This specialization might reflect the more arid climate occupied by *Z. h. luteus* in the American Southwest.

Reason for decline of *Z. h. luteus* was loss of tall, dense, herbaceous riparian vegetation. Our data indicated that the primary proximate cause

of this habitat loss was livestock grazing. Other studies also have demonstrated a negative response of jumping mice to grazed habitats (e.g., Hanley and Page, 1982; Giuliano and Homyack, 2004; Morrison, 1990; Schulz and Leininger, 1991). Presence of a livestock exclosure was a highly significant factor related to presence of potentially suitable riparian vegetation and presence of *Z. h. luteus*.

Morrison (1990, in litt.) noted that *Z. h. luteus* occasionally was captured where livestock occurred, but those findings cannot be interpreted given the paucity of data concerning the specific circumstances. Our only captures of *Z. h. luteus* outside of fenced livestock exclosures was on the lower Rio Cebolla in the Jemez Mountains (locality J-9). This locality was unique because *Z. h. luteus* was captured in both a livestock exclosure and the adjacent grazed area. *Zapus hudsonius* is a relatively vagile and long-lived rodent (Quimby, 1951). Thus, it is possible that captures in the grazed area represented transient individuals or individuals persisting from pregrazing periods. However, a more likely explanation was that the location was in a broad valley that had an extensive complex of dams of the American beaver (*Castor canadensis*), which created a diverse network of emergent wetland habitat. Although cattle were present in adjacent uplands and grazing was observed along the periphery of the wetland, we did not observe evidence of cattle within the wetland associated with dams of American beavers. Further, habitat at capture sites in the wetland was similar to localities within livestock exclosures. Thus, wetland associated with dams of American beavers likely served to naturally inhibit cattle; perhaps, due to reticence of cattle to walk in saturated mud and presence of ample upland forage. *Zapus h. luteus* was not captured at other areas along the lower Rio Cebolla where wetlands associated with American beavers or livestock exclosures were absent. Because American beavers can create extensive areas of suitable habitat for *Z. h. luteus*, the historical decline and current absence of American beavers from many areas likely had a negative impact on *Z. hudsonius* (Huey, 1956; pers. observ.).

Livestock grazing can exert many influences on riparian habitats (Elmore and Kauffman, 1994; Ohmart, 1996; Cartron et al., 2000). For example, we determined that habitat within livestock exclosures had significantly higher soil moisture ($z = -3.001$, $P = 0.003$), vertical cover ($t = -7.703$, $P < 0.001$), vertical height of stubble ($t = -7.028$, $P < 0.001$), sedge-rush ground cover ($t = -4.404$, $P < 0.001$), and depth of litter ($z = -3.810$, $P < 0.001$), but significantly less bare ground cover ($z = -3.716$, $P < 0.001$) and distance to water ($z = -2.503$, $P = 0.012$). Livestock exclosures can promote stream flow, which is required by *Z. h. luteus* (Morrison, 1990), by reducing soil compaction and evaporation. Second, livestock exclosures allow development of tall, dense, herbaceous cover by reducing grazing and trampling (Wyman et al., 2006). This and other studies have concluded that adequate herbaceous cover is required to maintain populations of *Z. hudsonius* (Whitaker, 1963).

Climatic variation likely exerts an important influence on distribution and abundance of *Z. h. luteus*. Wet periods result in increased herbaceous growth in uplands and wetlands due to increased availability of surface water (Trainor et al., 2007*b*). Relative to *Z. h. luteus*, dense herbaceous vegetation might function to decrease risk of predation and competition with aggressively dominant voles (*Microtus*), and increase food resources, exploratory behavior, and quality of adjacent upland habitat used for hibernation (Boonstra and Hoyle, 1986; Meaney et al., 2003; Trainor et al., 2007*a*, 2007*b*). Movement, dispersal, and gene flow in riparian jumping mice are largely determined by habitat connectivity with most movements along riparian corridors (Vignieri, 2005; J. L. Morrison, in litt.). Thus, wet periods might provide longer, more continuous stretches of suitable riparian habitat allowing *Z. h. luteus* to expand its distribution, including marginal localities that might be suitable only during wet periods. In contrast, drought might shrink and isolate suitable habitat, possibly resulting in local extirpations (Bessinger, 2000). This might explain the apparent absence of *Z. h. luteus* from the grazing exclosure on the upper Rio Peñasco in the Sacramento Mountains (locality S-8). Finally, *Z. h. luteus* might be better able to co-exist with livestock during wet periods due to increased availability of wetland habitat and upland forage. However, livestock grazing should be more carefully controlled during droughts. Given projected climatic warming (Intergovernmental Panel on Climate Change, 2001), we expect that drought will become an increasing problem for *Z. h. luteus*.

Based on Palmer drought data, previous surveys for *Z. h. luteus* in the Jemez Mountains

during 1985–1986 and 1989, and in the Sacramento Mountains during 1988 occurred during or immediately following periods of above-average moisture (National Climatic Data Center, http://lwf.ncdc.noaa.gov/oa/climate/onlineprod/drought/xmgr.html). In contrast, surveys in the White Mountains, during 1991, occurred during a period of near-normal conditions following 1.5 years of severe-to-extreme drought. Our study was conducted during unusually moist conditions, but most of the preceding 5 years were during severe-to-extreme drought. Thus, the restricted distribution and rarity of *Z. h. luteus* during this and the previous survey in the White Mountains might have been influenced by drought.

We observed localities where habitat of *Z. h. luteus* was lost due to development, recreation, and forest fires. In the Sacramento Mountains, we observed many springs that were capped and diverted for development of residential and city infrastructure and streams that were diverted for irrigation. In the Jemez Mountains, we observed loss of riparian habitat due to off-road vehicles, camping, and human-social trails, which result in soil compaction, erosion, and destruction of vegetation. Finally, we observed areas (e.g., locality S-15) where riparian habitat had been eliminated due to erosion or aggradation resulting from flooding following forest fire.

Recommendations—Conservation and management of montane populations of *Z. h. luteus* must focus on maintaining and enhancing the distribution of undisturbed, herbaceous riparian habitat. Although appropriate grazing management can maintain the ecological integrity of some riparian ecosystems (Baker et al., 2001), presence of cattle in riparian zones during the growing season might negatively impact habitat of *Z. h. luteus* through reductions in vegetative cover due to grazing and trampling. Maintenance of undisturbed riparian habitat might only be possible through creation of refugial areas by complete exclusion of livestock from the riparian zone, particularly in areas where there is passive-continuous grazing during the growing season (Elmore and Kauffman, 1994; Ohmart, 1996; Wyman et al., 2006). Exclusion fencing can be the most practical means for achieving rapid recovery of riparian habitat, and loss of forage on degraded streams may be negligible (Wyman et al., 2006). Giuliano and Homyack (2004) demonstrated that small mammals, including *Z. hudsonius*, respond quickly to establishment of livestock exclosures. We recommend establishment of refugial areas that are large enough to sustain a local population throughout the longest anticipated drought cycle and spatially arranged to maintain viable metapopulations throughout the historical range. *Zapus hudsonius* is unwilling to cross even small areas with little or no cover (Quimby, 1951). Because unmanaged grazing by livestock results in excessive use of riparian areas with concomitant degradation, grazing management should include measures such as growing-season rest to enhance riparian vegetation outside refugia to promote dispersal among refugia (Ohmart, 1996). Given the recent and rapid decline in distribution of *Z. h. luteus*, it is important to conduct additional inventory work to identify any additional populations that have persisted, to initiate long-term monitoring of populations and riparian habitat, and to restore riparian habitat and repatriate key populations of *Z. h. luteus*. Finally, additional studies are needed on relationships among livestock grazing, habitat, and *Z. h. luteus*, including potentially important factors such as activity by American beavers, conditions of upland habitat, and climate.

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Appendix 1—Localities where *Zapus hudsonius luteus* was captured in the Jemez Mountains, Sandoval County, and the Sacramento Mountains, Otero County, New Mexico. For museum records, locality data are from specimen tags and museum records; brackets include other locality information. Specimen catalog numbers are from University of Kansas Museum of Natural History (KU), the Museum of Southwestern Biology, University of New Mexico (MSB), New Mexico Department of Health Zoonoses Program (NMDH), United States National Museum (USNM), and Academy of Natural Sciences of Philadelphia (ANSP).

Locality	Results of current survey	Drainage	Locality	Reference	Date	Notes
Jemez Mountains						
J-1	Not surveyed	San Antonio Creek	Beaver pond in geothermal well area on a gentle northwest slope of Redondo Peak, elevation ca. 8,500 feet	W. Whitford, pers. comm.	Mid-1970s	
J-2	No suitable riparian habitat	San Antonio Creek	T20N, R3E, south central Sec 20 San Antonio Creek	MSB 56991–56992	5 September 1985	
J-3	Present at new locality	San Antonio Creek	Jemez Mountains, San Antonio Creek, south end San Antonio Campground, 1.2 mile N, 0.5 mile W junction NM Hwy 4 and NM Hwy 126; T19N, R3E, NE1/4 of NW 1/4 of NW 1/4 Sec 17	Current study	28 June 2005	1 captured
J-4	No suitable riparian habitat	Guadalupe River	Virgin Canyon, T18N, R2E [lower Virgin Canyon, below old cabins near spotted owl site; J. L. Morrison, in litt.]	MSB 62096	2 August 1989	
J-5	Species absent	Rio Cebolla	Rio Cebolla, T20N, R2E, Sec 24 near Hay Canyon	MSB 62101	4 August 1989	
J-6	Present at historical locality	Rio Cebolla	T20N, R2E, NW 1/4 Sec 35 Seven Springs Fish Hatchery	MSB 56993–56994	23, 27 August 1985	
			Jemez Mountains, Seven Springs State Fish Hatchery; T20N, R2E, SE 1/4 of NE 1/4 of NE 1/4 Sec 34	Current study	1 July 2005	2 captured
J-7	Not surveyed	Rio Cebolla	1 mile S Seven Springs Hatchery	NMDH	17 September 1969	
J-8	Present at historical locality	Rio Cebolla	Fenton Lake, Jemez Mountains	MSB 41055	5 August 1979	
			T19N, R2E, SW 1/4 Sec. 10 Fenton Lake, marsh E of lake, W of Route 126	MSB 56979–56983	23, 27–28 August 1985	
			Jemez Mountains, Fenton Lake State Park, marsh at upper end of lake along Rio Cebolla above NM Hwy 126; T19N, R2E, Sw1/4 of NW I/4 of SW 1/4 of SW 1/4 Sec 10	Current study	29 June 2005	2 captured
			Fenton Lake—creek that runs into lake from south, T19N, R2E, NW 1/4 Sec 15	MSB 56984	27 August 1985	
			Jemez Mountains, Fenton Lake State Park, Lake Fork Day Use Area, mouth of small tributary that flows W along NM Hwy 126 and entering S side Fenton Lake; T19N, R2E, SE 1/4 of NE 1/4 of NE 1/4 Sec 16	Current study	29 June 2005	1 captured

Appendix 1—Continued.

Locality	Results of current survey	Drainage	Locality	Reference	Date	Notes
J-9	Present at historical locality	Rio Cebolla	Rio Cebolla at intersection of Route 376 & Lake Fork Creek, T19N, R2E, NE 1/4 Sec 30	MSB 56985	30 August 1985	
			Jemez Mountains, Rio Cebolla at junction with Lake Fork Canyon, above Forest Service Road 376 bridge; T19N, R2E, SW 1/4 of SW 1/4 of SW 1/4 Sec 20 and SE 1/4 of SE 1/4 of SE 1/4 Sec 19	Current study	5 July 2005	2 captured
			Rio Cebolla, 0.6 mile (by Forest Road 376) southwest of Forest Road 376 bridge over Rio Cebolla, which is located at the junction of Lake Fork Canyon, 9.5 km N, 6.5 km W Jemez Springs, T19N, R2E, W 1/2 of NE 1/4 Sec. 30	Current study	15 August 2006	3 captured
J-10	Present at new locality	Rio Cebolla	Jemez Mountains, Rio Cebolla, 1.7 N, 0.4 mile W jct Rio Cebolla and Rio de las Vacas; T19N, R1E, SE 1/4 of SE 1/4 Sec 25	Current study	4 July 2005	1 captured
J-11	Species absent	Rio Cebolla	Rio Cebolla, T19N, R1E, 1 mile up from Rio de las Vacas	MSB 62097–62098	24 August 1989	
J-12	Species absent	Rio de las Vacas	T20N, R2E NE 1/4 Sec 3 Rito Penas Negras 8,360 feet	MSB 56987–56990	5–6 September 1985	
J-13	No suitable riparian habitat	Rio de las Vacas	17 km SE Cuba, T20N, R1E, S 12, elevation 2,600 m	MSB 67525	12 July 1985	
J-14	No suitable riparian habitat	Rio de las Vacas	Rito Penas Negras, T20N, R1E, Sec 13, int. Rio de las Vacas [Rito Penas Negras at the junction of Forest Road 126; J. L. Morrison, in litt.]	MSB 62102	3 August 1989	
J-15	No suitable riparian habitat	Rio de las Vacas	T20N, R1E west central Sec 25 Rio de las Vacas x Turkey Creek	MSB 56986	6 September 1985	
—		Unknown	Unknown	MSB 56995–56997	unknown	Collected by J. Morrison; not a new locality.
Sacramento Mountains						
S-1	Not surveyed	Rio Tularosa	Bank of Tularosa Creek, 1 mile above Mescalero	ANSP 15771–15772	18 June 1932	
S-2	Not surveyed	Rio Tularosa	Bank of Tularosa Creek, 2 mile above Mescalero	ANSP 15573–15579	27 June, 1 July, 2 August 1932	
S-3	No suitable riparian habitat	Silver Springs	Silver Springs Canyon, intersection Forest Road 24 & 1 [Silver Springs, T15S, R13E, Sec 29, 8,400 feet; J. L. Morrison, in litt.]	MSB 61700–61702	22 July 1988	

Appendix 1—Continued.

Locality	Results of current survey	Drainage	Locality	Reference	Date	Notes
S-4	Present at historical locality	Silver Springs	Silver Creek, 8 miles NE Cloudcroft	MSB 36142	21 July 1977	
			8 miles E Cloudcroft	MSB 37154–37155	21 July 1977	
			Silver Springs Canyon, boundary Mescalero Apache Reservation T15S R13E Sec 22	MSB 61703–61704	22 July 1977	
			Sacramento Mountains, Silver Springs Creek at jct Turkey Pen Canyon and Forest Service Road 405 (=County Road C7), 2.9 miles N, 4.6 miles E Cloudcroft; T15S, R13E, SE 1/4 of NW 1/4 Sec 22	Current study	22 July 2005	1 captured
S-5	No suitable riparian habitat	Silver Springs	10 miles NE Cloudcroft [10 miles NE Cloudcroft, 8,500 feet; Bailey, 1931]	USNM 118798	10 Sepember 1902	Locality is in Silver Springs Canyon near junction with Poison Spring and Indian Joe canyons (J. K. Frey et al., in press)
S-6	No suitable riparian habitat	James Canyon	Int. Pumphouse Canyon, Route 82 [Pumphouse Canyon, T16S, R12E, Sec 3, 8,300 feet; J. L. Morrison, in litt.]	MSB 61684	15 July 1988	
			3.2 miles (by road) E Cloudcroft	MSB 37323–37326, 41058–41066	3 September 1978, 17–18 August 1979	
S-7	No suitable riparian habitat	James Canyon	12 miles E Cloudcroft, 7,500 feet [Penasco Creek, 12 miles E Cloudcroft, 7,500 feet; Bailey, 1931]	USNM 119032–119033	7 September 1902	Locality is in James Canyon near junction of Eightmile Canyon (J. K. Frey et al., in press)
S-8	Species absent	Upper Rio Peñasco	Rio Penasco, Int. Route 164 & Route 64 [Rio Penasco, T17S, R11E, Sec 11, 8,600 feet; J. L. Morrison, in litt.]	MSB 61678–61680, 61687	13, 16 July 1988	
S-9	No suitable riparian habitat	Upper Rio Peñasco	Water Canyon [Water Canyon, T17S, R11E, Sec 24, 8,600 feet; J. L. Morrison, in litt.]	MSB 61690, 62095	17 July 1988, 18 July 1989	

Appendix 1—Continued.

Locality	Results of current survey	Drainage	Locality	Reference	Date	Notes
S-10	No suitable riparian habitat	Upper Rio Peñasco	Rio Penasco [Rio Penasco, T17S, R12E, Sec 10, 8,000 feet; J. L. Morrison, in litt.]	MSB 61686	16 July 1988	
S-11	No suitable riparian habitat	Upper Rio Peñasco	Rio Penasco, T17S, R13E, Int. with Route 541 [Rio Penasco at Cox, T17S, R13E, Sec 3, 7,200 feet; J. L. Morrison, in litt.]	MSB 61696	18 July 1988	
S-12	No suitable riparian habitat	Upper Rio Peñasco	Wills Canyon, UTM E4331, N36311	P. Ward, pers. comm.	11 July 1992, 11 July 1993, 13–14 July 1994	4 captures
S-13	Species absent	Agua Chiquita	Hay Canyon, int. 257, 541, T17S, R12E, Sec. 19 [Masterson Springs, T17S, R12E, Sec 19, 8,000 feet; J. L. Morrison, in litt.]	MSB 61712	31 July 1988	Locality is likely Prestridge Spring, T17S, R13E, Sec. 20
S-14	No suitable riparian habitat	Agua Chiquita	Spring Canyon [Spring Canyon, T17S, R12E, Sec 36, 8,400 feet; J. L. Morrison, in litt.]	MSB 61693	19 July 1988	
S-15	No suitable riparian habitat	Agua Chiquita	Potato Canyon T18S R13E Sec 5 [Potato Canyon, T18S, R13E, Sec 5, 8,200 feet; J. K. Morrison, in litt.] [Potato Creek; Morrison, 1992]	MSB 61688–61689	17 July 1988	
S-16	Present at new locality	Agua Chiquita	Sacramento Mountains, Agua Chiquita Creek, 5.75 miles S, 6.5 miles W Sacramento; T18S, R12E, SE 1/4 of NE 1/4 of SW 1/4 Sec 25	Current study	19 July 2005	1 captured
S-17	No suitable riparian habitat	Agua Chiquita	Agua Chiquita [upper Aqua Chiquita, T18S, R13E, Sec 19, 8,000 feet; J. L. Morrison, in litt.]	MSB 61692	18 July 1988	
S-18	No suitable riparian habitat	Agua Chiquita	Agua Chiquita [lower Agua Chiquita, T18S, R13E, Sec 17, 8,000 feet; J. L. Morrison, in litt.]	MSB 61691	18 July 1988	
S-19	No suitable riparian habitat	Agua Chiquita	Weed, east of Cloudcroft, Sacramento Mountains	ANSP 14779	July 1931	