

EVIDENCE FOR AN HISTORICAL OCCURRENCE OF THE
MEADOW JUMPING MOUSE (*ZAPUS HUDSONIUS LUTEUS*)
IN THE VERDE RIVER WATERSHED, ARIZONA

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ABSTRACT.—The meadow jumping mouse (*Zapus hudsonius luteus*) is a riparian obligate with a fragmented distribution in the American Southwest. Because of recent rapid declines in populations, it is a candidate for federal protection under the Endangered Species Act. In Arizona, its known distribution has been restricted to the White Mountains region in the east central part of the state. I present evidence for an historical occurrence of jumping mice in the Verde River watershed, Yavapai County, in west central Arizona. Evidence includes record of a specimen collected by Edgar Mearns in the 1880s, a 1944 report of parasites collected from jumping mice in Yavapai County, and a phylogeographic history that is consistent with an occurrence in the region, including an ecological niche model that predicted suitable conditions for *Z. h. luteus* in the upper Verde River watershed during the last glacial maximum. Field surveys should be conducted to determine if *Z. h. luteus* currently exists within the Verde River watershed.

RESUMEN.—El ratón saltador de la pradera (*Zapus hudsonius luteus*) es una especie ribereña obligada con una distribución fragmentada en el suroeste de los EE.UU. Debido a recientes descensos precipitados en sus poblaciones, se encuentra como candidato para la protección federal bajo el Endangered Species Act. En Arizona, su distribución conocida se ha visto reducida a la región de la Sierra Blanca en la parte oriental del centro del estado. Presento evidencia de que estos ratones habitaron la cuenca hidrológica del río Verde, condado de Yavapai, en la parte occidental del centro de Arizona. Entre la evidencia figura el registro de un espécimen colectado por Edgar Mearns en la década de 1880, un reporte de parásitos colectados de ratones saltadores en el condado de Yavapai y una historia filogeográfica consistente con su presencia en la región, incluyendo un modelo de nicho ecológico que predice condiciones aptas para *Z. h. luteus* en la parte alta de la cuenca del río Verde durante el máximo glacial más reciente. Deben llevarse a cabo muestreos para determinar si *Z. h. luteus* actualmente está presente en la cuenca hidrológica del río Verde.

The meadow jumping mouse (*Zapus hudsonius*) has a broad distribution across much of the boreal and humid temperate zones of the northern and eastern regions of North America (Hall 1981). The species reaches its southwestern range limits in the American Southwest, where it is represented by *Z. h. luteus*, a monophyletic and morphologically distinctive form (Miller 1911, Hafner et al. 1981, King et al. 2006, Malaney et al. 2012). *Zapus h. luteus* is a habitat specialist that utilizes tall, dense herbaceous riparian vegetation on saturated soils along perennial flowing water (Morrison 1990, 1992, Frey and Malaney 2009, Frey and Wright 2012). It has a fragmented distribution that includes the White Mountains in eastern Arizona; the Sacramento, Jemez, and San Juan Mountains in New Mexico, the Sangre de Cristo Mountains in southern Colorado and northern New Mexico; the Rio Grande Valley in New Mexico; and tributaries of the San Juan

River in southwestern Colorado (Malaney et al. 2012).

Over the past 2 decades, *Z. h. luteus* has experienced a rapid rate of population extirpation as a result of habitat changes caused by livestock grazing, wildfire, climate change, irrigation canal management, altered hydrology, loss of beaver, development, and recreation (Hafner and Yensen 1998, Frey and Malaney 2009, Frey 2011, Frey and Wright 2012). In December 2007, *Z. h. luteus* was listed as a high-priority (listing priority 3) candidate for protection under the federal Endangered Species Act (U.S. Fish and Wildlife Service 2007). As of the beginning of 2011, there were 24 extant populations of *Z. h. luteus* (Frey 2011). However, during June 2011 wildfire burned over 13 of the populations, and it remains unknown if populations survived those events (Frey 2011). Given the rapid rate of population decline in *Z. h. luteus*, it would be valuable to

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delineate its historical distribution so that any remaining populations can be identified and protected. In Arizona, the species' known range has been restricted to the White Mountains region in the east central part of the state (Hall and Davis 1934, Krutzsch 1954, Cockrum 1960, Hafner et al. 1981, Hoffmeister 1986, Frey 2011). Herein, I report several lines of evidence for historical occurrence of *Z. h. luteus* in the Verde River watershed, Yavapai County, in west central Arizona.

The first record is an undated, fluid-preserved specimen (American Museum of Natural History [AMNH] catalog number 23014) identified as "*Zapus*" collected by Edgar A. Mearns from "Fort Verde, Arizona." The specimen is currently missing (Darrin Lunde personal communication). Mearns was a noted zoologist who served the U.S. Army as a surgeon during the late 1800s. While in that capacity, he collected thousands of natural history specimens that were sent to museums in the eastern United States. Mearns was stationed at Fort Verde from 1884 to 1888, during which time he accompanied 2 expeditions to various parts of Arizona under the command of General Crook (Mearns 1890, Richmond 1918). Later (1891–1894), he served as medical officer for the U.S.–Mexico International Boundary Commission, during which time he collected specimens along the U.S.–Mexico border. Mearns published a monograph on the mammals of the Mexican boundary (Mearns 1907), which included taxa collected throughout Arizona during both commissions. However, that volume only included Didelphidae to Muridae and hence did not include a discussion of *Zapus* (Dipodidae). The planned second volume that likely would have included jumping mice was never published (Richmond 1918, Phillips 1940).

It is possible that the catalog entry of Mearns' specimen is an error. This could result from (1) a specimen that was misidentified; (2) an error during cataloging (e.g., in museum catalogs tick marks are often used to denote the same data as the prior row; in this case, a specimen immediately below the series may also receive the tick mark as a carryover error); or (3) a specimen of *Zapus* collected elsewhere but referred to Fort Verde. It is unlikely that a specimen of *Zapus* would be misidentified in a nonteaching, professional museum setting because jumping mice are in

a morphologically distinct family (Dipodidae) that are well differentiated from all other mice and rats (Muroidea; DeBry and Sagel 2001). In addition, the handwritten catalog shows that "*Zapus*" was written in ink. In contrast, it appeared that pencil was used for catalog entries where identification was equivocal (e.g., "bat").

Based on catalog numbers, the series of specimens (AMNH 23008–23020) attributed to Mearns and Fort Verde that included the *Zapus* specimen were among the last of Mearns' Fort Verde specimens to be cataloged. Dates of collection recorded for other series of specimens on the same catalog page were from 1902 to 1904. All but one specimen in the series containing the *Zapus* were preserved in fluid. In contrast, virtually all (3 exceptions) of the earlier cataloged material were skins or skeletal remains. Thus, the difference in preparation might account for this series being cataloged later, since fluid-preserved specimens are stored separate from the main collection. The identification of one specimen (AMNH 23110) in the series as *Thomomys bottae mutabilis* confirms a tie to Fort Verde, since the type locality of *T. b. mutabilis* is "Camp Verde" and its distribution is restricted to that general region (Goldman 1933). Other specimens in the series were typical of the Fort Verde region, including *Thomomys umbrinus* (= *T. bottae*), *Peromyscus maniculatus*, *Neotoma lepida* (= *N. stephensi*), and *Sigmodon hispidus* (Hoffmeister 1986). Thus, these records corroborate the provenance of the series. However, the last 2 specimens in the series (*Cyclopes didactylus*, *Tragulus* sp.) are not native to North America and are clearly museum errors, perhaps belonging to a series of specimens from the Central Park Zoo that were cataloged on the same page.

The electronic database of the AMNH catalog reports the locality of the *Zapus* specimen as "Fort Verde, cliff dwelling," Yavapai County, Arizona. Comparison of the handwritten and electronic catalogs revealed numerous examples where this occurred and it appeared that the locations were used interchangeably. There is little biological significance to the difference. Fort Verde (= Camp Verde) is a location (N 34.5636358°, W 111.8543178°) on the west bank of the Verde River opposite of the confluence with Beaver Creek, which flows into the Verde River from the north. "Cliff dwelling"

referred to Montezuma Castle (N 34.6122°, W 111.8416°), which is a prominent cliff dwelling built on the south-facing canyon side of Beaver Creek, that is about 5 km from Fort Verde (Protas 2002). Mearns (1890) described excavating and studying the cliff dwelling. Thus, there is no doubt that Mearns spent considerable time in the vicinity of Fort Verde and the nearby cliff dwelling.

Several lines of evidence support the vicinity of Fort Verde as the collection location of the *Zapus* record. First, during the time that Mearns was stationed at Fort Verde, the upper Verde River watershed and adjacent areas had been explored and mapped (p. 748 in Mearns 1890). There are 324 mammal specimens collected by Mearns in the AMNH that have “Fort Verde” in the descriptive locality. These include 13 different specific locations, such as “Verde River at Fort Verde,” “Fort Verde, Montezuma Well,” and “20 miles south of Fort Verde, Box Canyon of Verde River.” Thus, place names were used for documenting fairly precise localities, and the catalog data confirm that Mearns was conscious of, and reported, different unique localities associated with different specimens. Second, all of the specimens labeled as collected from “Fort Verde” or “Fort Verde, cliff dwelling” are typical of the mammal community found in that region of Arizona (Hoffmeister 1986), with exception of the 2 records that were clearly museum errors.

It could be argued that Mearns’ specimen came from the White Mountains in eastern Arizona but that the location was mislabeled. The White Mountains are the nearest location to Fort Verde where *Zapus* is known to occur. I searched the Mammal Networked Information System (MaNIS; <http://manisnet.org/>) for all mammal specimens collected by Mearns from Arizona. None of Mearns’ 962 specimens were from locations in the White Mountains, and none were species commonly captured with *Z. h. luteus* in the White Mountains, such as the montane vole (*Microtus montanus*), long-tailed vole (*Microtus longicaudus*), and montane shrew (*Sorex monticolus*) (Frey 2011). To ensure that Mearns’ collecting efforts did not include the White Mountains, I used Mearns’ travel itinerary (Phillips 1940) to map the routes and locations visited by Mearns. Based on the itinerary, the closest Mearns came to the White Mountains was a trip with General Crook to Fort Apache. They reached

Fort Apache on 13 October 1894 traveling along the Mogollon Rim from Fort Verde. From Fort Apache, they traveled south to the San Carlos Indian Agency on the Gila River (17–18 October 1894). They returned to Fort Verde via Globe, Arizona, and the Tonto Basin. Thus, the *Zapus* specimen likely did not come from the White Mountains.

Prince (1944) provided further evidence that *Zapus* existed in the Verde River watershed. Frank M. Prince was a parasitologist with the U.S. Public Health Service, and he was a specialist on the ecology and taxonomy of fleas infesting mammalian hosts. Prince (1944) described a new species of flea, *Thrassis setosis* (= *T. bacchi setosis*), found on several species of small mammals in Yuma and Yavapai counties, Arizona. The list of hosts included “*Zapus* sp.” from Yavapai County. Importantly, the jumping mouse is the only host not identified to species or subspecies. The other hosts reported for *T. setosis* in Yavapai County included the rock squirrel (*Citellus* [= *Spermophilus*] *variagatus grammurus*), Stephens’s woodrat (*Neotoma lepida stephensi* [= *N. stephensi*]), and white-footed mouse (*Peromyscus leucopus arizonae*). In 1944, no synopsis of *Zapus* had been published since Preble (1899), and hence, knowledge about the taxonomy and distribution of jumping mice was poor. Preble (1899) did not include any records of *Zapus* from Arizona or southern New Mexico. Thus, identification of the specimen only to genus would be expected. Further, in Arizona, Stephens’s woodrat and the white-footed mouse are only sympatric in a narrow band around the Mogollon Plateau, which includes the watershed of the Verde River in eastern Yavapai County. Thus, this species assemblage provides independent support of the capture location. Although no descriptive locality other than county was reported, in Yavapai County perennial streams with suitable habitat for *Z. h. luteus* are only present in the Verde River watershed.

Lastly, the phylogeographic history of *Z. h. luteus* is consistent with a potential occurrence in the Verde River watershed. Based on multiple lines of evidence, Malaney et al. (2012) proposed that during the last (Wisconsin) glacial event, the ancestor to *Z. h. luteus* occurred in central Texas. With onset of the Holocene, it diverged from eastern forms (i.e., *Z. h. pallidus*) as its range shifted to the west, eventually

becoming restricted to riparian zones in montane regions and along major low-elevation rivers as the climate continued to become more arid (Malaney et al. 2012). As part of the evidence, Malaney et al. (2012) used bioclimatic variables to develop an ecological niche model for the paleodistribution of *Z. h. luteus* during the last glacial maximum. That model predicted the upper Verde River watershed as suitable for *Z. h. luteus*. Thus, the model provides an independent line of evidence for an historical occurrence of the taxon in this region. In addition, Malaney et al. (2012) hypothesized the use of rivers as colonization routes associated with range shifts in *Z. h. luteus*. The Verde River drains the western edge of the Mogollon Plateau and it is a major tributary of the Salt River. The Salt River also drains large portions of the White Mountains located at the eastern edge of the Mogollon Plateau, via the Black River and White River tributaries. Thus, there is a strong biogeographic connection between the upper Verde River watershed and the White Mountains where *Z. h. luteus* is known to occur. This connection is supported by other aquatic and riparian species that have distributions in both regions, including Gila trout (*Oncorhynchus gilae*), roundtail chub (*Gila robusta*), Chiricahua leopard frog (*Rana chiricahuensis*), and narrow-headed garter snake (*Thamnophis rufipunctatus*).

The ecological setting of the Verde River and Beaver Creek seem appropriate for *Z. h. luteus*. Both are perennial streams that likely would have provided suitable herbaceous riparian habitats for *Z. h. luteus*. *Zapus h. luteus* is known to occur in other regions that are as arid (e.g., Florida River in southwestern Colorado and Rio Grande in central New Mexico) as the Fort Verde region (<http://www.wrcc.dri.edu/>). Further, the Verde River is similar to the Florida River and Rio Grande in that they are large, low-elevation rivers (i.e., high stream order) with extensive irrigation systems in the floodplains. *Zapus h. luteus* can utilize appropriate habitats along these human-made waterways (Frey and Wright 2012). With respect to Beaver Creek, most known locations for *Z. h. luteus* are on small streams, including tributaries to larger low-elevation rivers (e.g., Sambrito Creek, Archuleta County, CO). Further, Mearns (1907) described beaver as abundant on Beaver Creek, and beavers can create ideal habitat for *Z. h. luteus* on small streams (Frey 2011).

The rarity of reports of *Zapus* from the Verde River watershed is not reason to dismiss the records. *Zapus h. luteus* is difficult to capture. Most records have been obtained by biologists experienced with the taxon and during surveys that specifically target the species; most instances where it was captured during general small mammal survey work occurred prior to 1970 (Frey unpublished data). Of 72 locations where *Z. h. luteus* is known to have occurred, 46% are documented by single records (Frey unpublished data). *Zapus h. luteus* is a habitat specialist and it almost always constitutes a minor proportion of the small mammal communities in which it occurs (Frey 2011, Frey and Wright 2012). In addition, there has been little field work on small mammals in riparian habitats in Yavapai County. I searched MaNIS and museums at the University of Arizona and Arizona State University for mammal specimens collected in Yavapai County after 1900 and found only 127 records from locations near perennial streams. Of those, only 3 were small terrestrial mammals routinely found in riparian habitats (i.e., western harvest mouse [*Reithrodontomys megalotis*]). I also searched Google Scholar for "Verde Arizona mammal," which produced only a single relevant paper (i.e., Ellison and van Riper 1998).

It could be argued that the evidence presented herein is not irrefutable proof that *Z. h. luteus* occurred in the Verde River watershed. Distributional records for small mammals are often based on specimens (e.g., Hall 1981), and currently there is no specimen of *Zapus* available for examination from the Verde River watershed. However, while specimens allow for confirmation of identification, errors in provenance (i.e., spatial and time errors sensu Graham et al. 2004) can still occur. Thus, specimens do not necessarily provide irrefutable proof of distribution. Further, in many biological disciplines, specimens are not routinely collected (e.g., ornithology, hosts of parasites, ecology), and yet data are accepted, including distributional data (e.g., Root 1988). Consequently, interpretation of distribution is often based on an accumulation of evidence (e.g., Root 1988). Thus, for this imperiled species, it would not be prudent to dismiss the fact that there are 3 independent lines of evidence indicating an historical occurrence of *Z. h. luteus* in the Verde River watershed, including Mearns' specimen record, Prince' (1944) report

of *Zapus* in Yavapai County, and the paleodistribution model of *Z. h. luteus* presented in Malaney et al. (2012). Further, each line of evidence is supported by context and consistency of other available information, including identification of the specimens only to genus, which was consistent with known taxonomy at the time; other mammal species associated with the records typical of the region; similarity of the Verde River watershed to other regions currently occupied by *Z. h. luteus*; phylogeographic history of *Z. h. luteus*; and a biogeographic pattern shared by a diverse array of other aquatic and riparian species. Taken together, these independent lines of evidence and corroborating details make a strong case for an historical occurrence of *Z. h. luteus* in the Verde River watershed. It is possible that populations of *Z. h. luteus* have persisted unnoticed in this region. However, the likely extirpation of the Arizona cotton rat (*Sigmodon arizonae arizonae*), which also occurred in riparian habitats around Fort Verde (Hoffmeister 1986), suggests that the area has experienced significant habitat alteration and that *Z. h. luteus* may no longer persist. Competent field surveys are needed to determine if any populations of *Z. h. luteus* currently occur in the Verde River watershed so that those populations can be protected and incorporated into conservation plans.

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LITERATURE CITED

- COCKRUM, E.L. 1960. The Recent mammals of Arizona: their taxonomy and distribution. University of Arizona Press, Tucson, AZ.
- DEBRY, R.W., AND R.M. SAGEL. 2001. Phylogeny of Rodentia (Mammalia) inferred from the nuclear-encoded gene IRBP. *Molecular Phylogenetics and Evolution* 19:290–301.
- ELLISON, L.E., AND C. VAN RIPER III. 1998. A comparison of small-mammal communities in a desert riparian floodplain. *Journal of Mammalogy* 79:972–985.
- FREY, J.K. 2011. Inventory of the meadow jumping mouse in Arizona. Final report submitted to Arizona Game and Fish Department Heritage Grant I09004, 5 July 2011. 114 pp.
- FREY, J.K., AND J.L. MALANEY. 2009. Decline of the meadow jumping mouse (*Zapus hudsonius luteus*) in two mountain ranges in New Mexico. *Southwestern Naturalist* 54:31–44.
- FREY, J.K., AND G.D. WRIGHT. 2012. Multiple scale habitat selection by a small mammal habitat specialist (*Zapus hudsonius luteus*) in a managed floodplain landscape. Final Report submitted to U.S. Fish and Wildlife Service, Region 2, Albuquerque, New Mexico, 16 March 2012. 109 pp.
- GOLDMAN, E.A. 1933. Five new rodents from Arizona and New Mexico. *Proceedings of the Biological Society of Washington* 46:71–78.
- GRAHAM, C.H., S. FERRIER, F. HUETTMAN, C. MORITZ, AND A.T. PETERSON. 2004. New developments in museum-based informatics and applications in biodiversity analysis. *Trends in Ecology and Evolution* 19:497–503.
- HAFNER, D.J., K.E. PETERSEN, AND T.L. YATES. 1981. Evolutionary relationships of jumping mice (Genus *Zapus*) of the southwestern United States. *Journal of Mammalogy* 62:501–512.
- HAFNER, D.J., AND E. YENSEN. 1998. *Zapus hudsonius* (Zimmermann 1780): meadow jumping mouse. Pages 120–123 in D.J. Hafner, E. Yensen, and G.L. Kirkland Jr., editors, Status survey and conservation action plan: North American rodents. IUCN/SSC Rodent Specialist Group, IUCN, Gland, Switzerland, and Cambridge, United Kingdom.
- HALL, E.R. 1981. The mammals of North America. Wiley & Sons, New York, NY.
- HALL, E.R., AND W.B. DAVIS. 1934. Notes on Arizona rodents. *Proceedings of the Biological Society of Washington* 47:51–56.
- HOFFMEISTER, D.F. 1986. Mammals of Arizona. University of Arizona Press, Tucson, AZ. 602 pp.
- KING, T.L., J.F. SWITZER, C.L. MORRISON, M.S. EACKLES, C.C. YOUNG, B.A. LUBINSKI, AND P. CRYAN. 2006. Comprehensive genetic analyses reveal distinction of a mouse (*Zapus hudsonius preblei*) proposed for delisting from the US Endangered Species Act. *Molecular Ecology* 15:4331–4359.
- KRUTZSCH, P.H. 1954. North American jumping mice (Genus *Zapus*). University of Kansas Publications, Museum of Natural History 7:349–472.
- MALANEY, J.L., J.K. FREY, AND J.A. COOK. 2012. The biogeographic legacy of an imperilled taxon provides a foundation for assessing lineage diversification, demography, and conservation genetics. *Diversity and Distributions* 18:689–703.
- MEARNS, E.A. 1890. Ancient dwellings of the Rio Verde Valley. *Popular Science Monthly* 37:745–763.
- _____. 1907. Mammals of the Mexican boundary of the United States, a descriptive catalogue of the species of mammals occurring in that region; with a general summary of the natural history, and a list of trees. Part 1, Families Didelphiidae to Muridae. *United States National Museum Bulletin* 56:1–530.
- MILLER, G.S., JR. 1911. A new jumping mouse from New Mexico. *Proceedings of the Biological Society of Washington* 14:253–254.
- MORRISON, J.L. 1990. The meadow jumping mouse in New Mexico: habitat preferences and management recommendations. Pages 136–143 in P.R. Krausman and N.S. Smith, editors, *Proceedings of the symposium on managing wildlife in the Southwest*. Arizona Chapter, The Wildlife Society, Phoenix, AZ.
- _____. 1992. Persistence of the meadow jumping mouse, *Zapus hudsonius luteus*, in New Mexico. *Southwestern Naturalist* 37:308–311.

- PHILLIPS, A.R. 1940. Edgar Alexander Mearns (1856–1916), pioneer northern Arizona naturalist. *Plateau* 13:1–5.
- PREBLE, E.A. 1899. Revision of the jumping mice of the genus *Zapus*. *North American Fauna* 15:1–41.
- PRINCE, F.M. 1944. Descriptions of three new species of *Thrassis* Jordan and the female of *T. bacchi* (Roths) and *T. pansus* (Jordan). *Pan-Pacific Entomologist* 20:13–19.
- PROTAS, J. 2002. A past preserved in stone: a history of Montezuma Castle National Monument. Western National Parks Association. Available from: http://www.nps.gov/moca/historyculture/upload/moca_hist.pdf
- RICHMOND, C.W. 1918. In memoriam: Edgar Alexander Mearns. Born, September 11, 1856–Died, November 1, 1916. *Auk* 15:1–18.
- ROOT, T. 1988. Atlas of wintering North American birds, an analysis of Christmas Bird Count data. University of Chicago Press, Chicago, IL.
- U.S. FISH AND WILDLIFE SERVICE. 2007. Candidate Notice of Review. *Federal Register* vol. 72, no. 234. pages 69036, 69100; 6 December 2007.

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