



7-9-2010

Fossil history of *Notiosorex* (Soricomorpha: Soricidae) shrews with descriptions of new fossil species

Leslie N. Carraway

Oregon State University, Corvallis, carver@proaxis.com

Follow this and additional works at: <https://scholarsarchive.byu.edu/wnan>

Recommended Citation

Carraway, Leslie N. (2010) "Fossil history of *Notiosorex* (Soricomorpha: Soricidae) shrews with descriptions of new fossil species," *Western North American Naturalist*. Vol. 70 : No. 2 , Article 2. Available at: <https://scholarsarchive.byu.edu/wnan/vol70/iss2/2>

This Article is brought to you for free and open access by the Western North American Naturalist Publications at BYU ScholarsArchive. It has been accepted for inclusion in Western North American Naturalist by an authorized editor of BYU ScholarsArchive. For more information, please contact scholarsarchive@byu.edu, ellen_amatangelo@byu.edu.

FOSSIL HISTORY OF *NOTIOSOREX* (SORICOMORPHA: SORICIDAE) SHREWS WITH DESCRIPTIONS OF NEW FOSSIL SPECIES

Leslie N. Carraway¹

ABSTRACT.—*Notiosorex* shrews (Soricomorpha: Soricidae) have a fossil history that extends to the Miocene (i.e., mid-Hemphillian). In the intervening 6.69 million years, *N. repenningi*, *N. jacksoni*, and what heretofore was considered *N. crawfordi* existed with varying degrees of overlap in occurrence timewise and in geographic distribution in areas of the southwestern United States and northern Mexico. Examination of unusually small fossil specimens of *Notiosorex* indicated the presence of another species referable to this genus present in late Pleistocene- (i.e., early Wisconsinan) to Holocene-aged deposits. Based on statistical analyses, these specimens were as distinct from any of the other fossil or extant species of *Notiosorex* as any other pair of species within the genus. I referred these specimens to the new species *N. harrisi*. Analyses also indicted fossils heretofore considered *N. crawfordi* were equally distinct from other forms of *Notiosorex*. I referred them to the new species *N. dalquesti*. Individuals referred to the fossil species of *Notiosorex* range in size from the smaller *N. harrisi*, to *N. dalquesti*, to *N. jacksoni*, to the larger *N. repenningi*. This size differential could be related to changing climatic conditions with the concomitant ecological succession that occurred, which provided a driving force for speciation within the genus.

The changing climate and unique morphological and physiological adaptations allowed fossil taxa of *Notiosorex* to expand their distributions into areas subsequently less suitable for other forms of shrews. Present-day notiosoricini shrews occur throughout much of the southwestern United States and northern Mexico in a variety of habitats in association with rough, rocky terrain. Thus, if climate, even indirectly, was the driving force for speciation among fossil taxa of *Notiosorex*, other forces must have acted on the extant species *N. cockrumi*, *N. crawfordi*, *N. evotis*, and *N. villai*.

Key words: Soricomorpha, *Notiosorex*, shrews, fossil history, climate, southwestern United States, Mexico.

The tribe Notiosoricini is comprised of 2 fossil genera (*Beckiasorex* and *Hesperosorex*) and 2 extant genera (*Notiosorex* and *Megasorex*) distributed in the southwestern United States and northern Mexico (Harris 1998, Reumer 1998). The genus *Notiosorex* first appeared during the late Miocene (i.e., mid-Hemphillian, 6.69 ± 0.16 m.y. [million years]) fossil record of White Cone local fauna, Arizona, in the form of *N. jacksoni* and a much smaller unnamed form of *Notiosorex* (Baskin 1979). *Notiosorex jacksoni* persisted in the fossil record until the late Pleistocene (i.e., Rancholabrean, ca. 252 ka [thousand years]), with records from Arizona, California, Kansas, and Texas (Fig. 1A). The much larger *N. repenningi*, known only from the Concha fauna, Chihuahua, appeared in the fossil record of the early Pliocene (i.e., earliest Blancan, ca. 4.2 m.y.; Fig. 1A; Lindsay et al. 1984, Lindsay and Jacobs 1985). Following a late Pleistocene interglacial period, from 252 to 303 ka, a much smaller form of *Notiosorex*, heretofore considered *N. crawfordi*, began to

appear in fossil deposits in Arizona, California, Kansas, New Mexico, Nevada, Oklahoma, Texas, Chihuahua, Nuevo León, Tamaulipas, and Zacatecas (Fig. 1A).

Until 2000, two extant subspecies of *Notiosorex crawfordi* were recognized: the nominal *N. c. crawfordi* and the larger *N. c. evotis*. *Notiosorex c. evotis* is smaller than fossil *N. jacksoni*. In 2000, Carraway and Timm recognized a new species, *N. villai*, from extant populations in Tamaulipas and elevated *N. c. evotis* to species level. Specimens of *N. villai* are intermediate in size between *N. crawfordi* and *N. evotis* (Fig. 6; Carraway and Timm 2000). In 2003, Baker et al. used molecular genetics to recognize a fourth extant species, *N. cockrumi*. Specimens of *N. cockrumi* are intermediate in size between *N. villai* and *N. crawfordi*. Additionally, it has been suggested that, based on genetics, another distinct species of *Notiosorex* currently resides on the Baja California peninsula (Ohdachi et al. 2006, McAliley et al. 2007).

¹Nash 104, Department of Fisheries and Wildlife, Oregon State University, Corvallis, OR 97331. E-mail: carver@proaxis.com

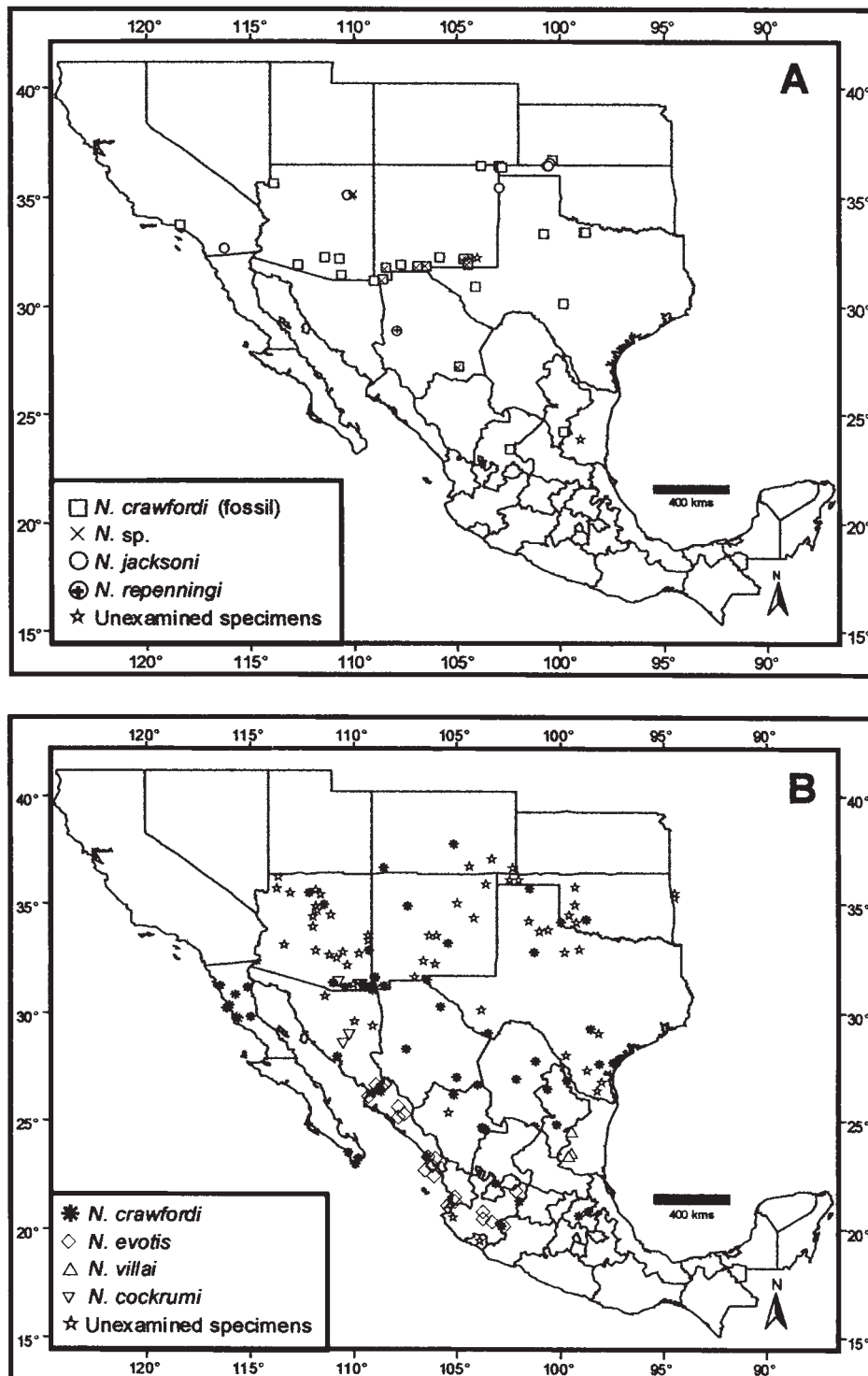


Fig. 1. Distribution of A, fossil and B, extant species of *Notiosorex* in the southwestern United States and Mexico. Open stars in B represent collection localities for unexamined specimens, as documented in Carraway and Timm (2000).

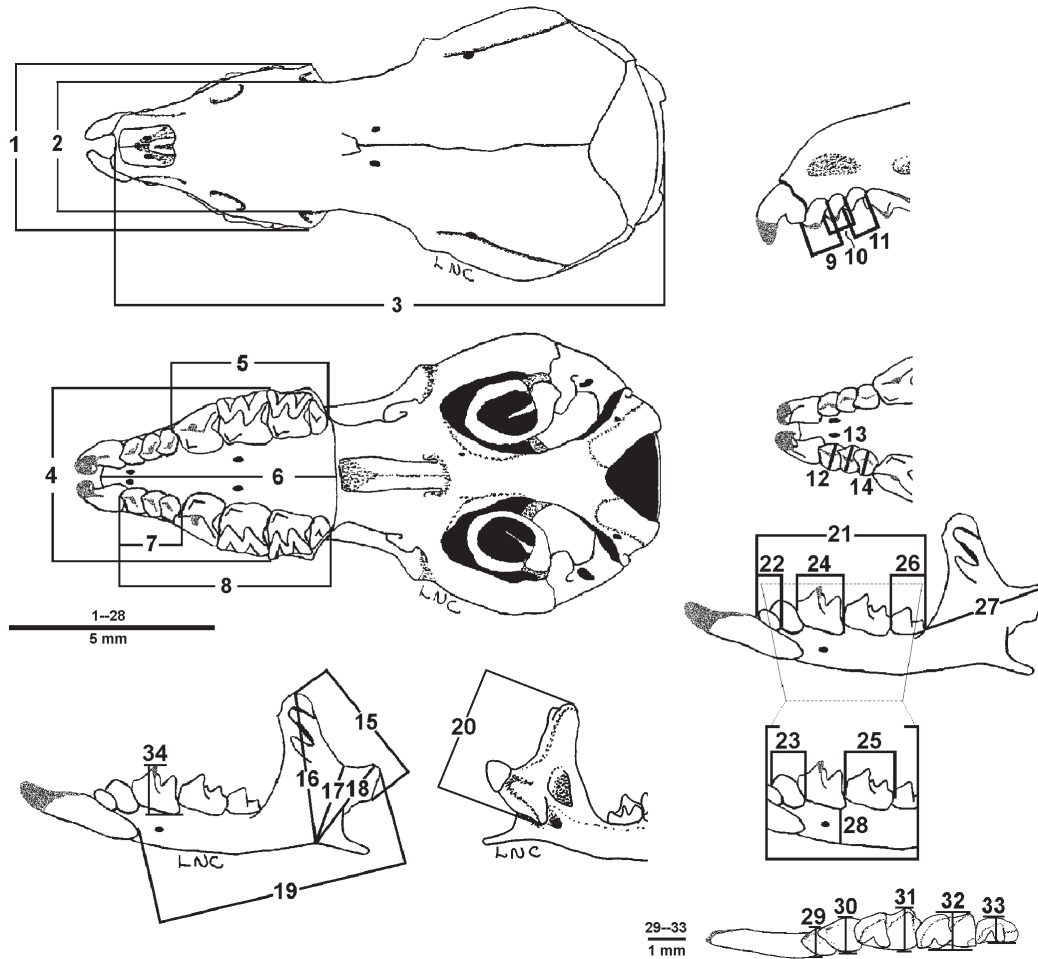


Fig. 2. Camera-lucida tracings of a *Notiosorex* skull (1–14) and mandible (15–34) to illustrate quantitative characters measured: 1, rostral breadth; 2, least interorbital breadth; 3, condylobasal length; 4, breadth across M2–M2; 5, length of P4–M3; 6, palatilar length; 7, length of unicuspid tooththrow; 8, length of U1–M3; 9, length of U1; 10, length of U2; 11, length of U3; 12, width of U1; 13, width of U2; 14, width of U3; 15, length of coronoid process–posterior point of upper condylar facet; 16, height of coronoid process; 17, height of coronoid valley; 18, height of articular condyle; 19, length of mandible; 20, length of coronoid process–ventral point of lower condylar facet; 21, length of c1–m3; 22, length of c1; 23, length of p4; 24, length of m1; 25, length of m2; 26, length of m3; 27, length from upper articular condyle to posterior edge of m3; 28, depth of dentary at m1; 29, width of c1; 30, width of p4; 31, width of m1; 32, width of m2; 33, width of m3; and 34, height of m1.

In 1979, Baskin reported 5 specimens from the White Cone local fauna identified only as *Notiosorex* sp. He stated they were much smaller than the extant or fossil *N. crawfordi* and the much larger late Miocene to middle Pleistocene *N. jacksoni*. After comparing these specimens with a series of Pleistocene and early Holocene specimens of *Notiosorex* (also morphologically smaller than fossil *N. crawfordi*), I determined they were morphologically distinct and unlike any taxon named to date.

Thus, initially the purpose of the research reported herein was to describe this new species. Additional analyses of this new species and other fossil and extant species of *Notiosorex* indicated that specimens of fossil *N. crawfordi* were distinguishable from all species of *Notiosorex*, including the extant species considered to be *N. crawfordi*. Thus, it should be considered a second new species of fossil *Notiosorex*; consequently, I applied a new name to those fossils formerly referred to *N. crawfordi*.

METHODS

Specimens from extant populations within the ranges of *N. crawfordi* ($n = 224$), *N. evotis* ($n = 43$), and *N. villai* ($n = 3$; Carraway and Timm 2000), and of *N. cockrumi* ($n = 18$; Baker et al. 2003) were examined (Fig. 1B; Appendix 1). Fossil specimens ($n = 812$, composed of 216 rostra and 596 dentaries or parts thereof) of *Notiosorex* from sites in Arizona, California, New Mexico, Oklahoma, Texas, Chihuahua, Nuevo León, and Zacatecas were examined (Fig. 1A; Appendix 2). Included were 618 fossils identified as *N. crawfordi*, 143 as *N. jacksoni*, a cast of the type of *N. repenningi*, and 49 *Notiosorex* of unknown species affiliation (hereafter *Notiosorex* sp.). These were treated as *a priori* groups for analyses. Geochronology of time distributions of taxa are based on conclusions presented in Martinson et al. (1987) and Bell et al. (2004).

All 7 multispecimen *a priori* groups included individuals of all ages, from those with no tooth wear apparent to those with teeth worn to gum line. Rostra were identified as *Notiosorex* by the presence of 3 alveoli for unicuspid in upper jaw, minimal pigmentation on P4 and none on M1–M3, or ventral edge of sphenorbital fissure located above dorsal edge of lower glenoid furrow (Carraway 2005). Mandibles were identified as *Notiosorex* by a deeply emarginated area between the condylar processes, an alveolus of i1 extending posteriorly beneath part of alveolus of m1 (Carraway 1995), or a triangular-shaped upper condylar facet directed posteriorly (Repenning 1967). Definitive identification of specimens of *N. cockrumi* was based on 232 position differences in the mitochondrial cytochrome-*b* gene and 30 site differences in Intron 7 of the nuclear gene beta fibrinogen (Baker et al. 2003; www.nsl.ttu.edu/publicat.html). Terminology for tooth morphology and nomenclature follows that of Butler et al. (1989), Choate (1970), Dannelid (1989), and Hershkovitz (1971). Upper teeth are referred to as I1, U1, U2, U3, P4, M1, M2, and M3. Dentary teeth are referred to as i1, c1, p4, m1, m2, and m3.

The 8 *a priori* groups (*N. cockrumi*, fossil and extant *N. crawfordi*, *N. evotis*, *N. jacksoni*, *N. repenningi*, *N. villai*, *Notiosorex* sp.) were compared with a series of discriminant function analyses (DFAs). For fossil taxa, 1–7 cranial and 1–18 mandibular characters were recorded for each specimen (Fig. 2). For extant

taxa, 2 cranial and 17 mandibular characters were recorded for each specimen (Fig. 2). An additional 5 cranial and 2 mandibular characters were included subsequently for *N. cockrumi* and extant *N. crawfordi* because of difficulties in distinguishing sympatric *N. cockrumi* and *N. crawfordi* by use of the initial data set (Table 1). Because of the limited number of characters that could be recorded for many of the fossil specimens, the number of specimens included in different DFAs was dependent on those specimens with the most complete data sets and thus varied considerably. Greatest length of skull was measured to the nearest 0.01 mm with MaxFowler digital calipers. All other quantitative characters recorded were measured with an ocular micrometer (10 lines = 1 mm) mounted in a Bausch and Lomb microscope. All values reported in text are in millimeters. For dimensions in which tooth designations are separated by a plus symbol (+), the length or width of each tooth was measured individually and the values summed. All statistical analyses were performed in Statgraphics Plus 5.0 Professional Edition.

A key to the species of *Notiosorex* is provided. Characters contained within parentheses are useful for distinguishing the taxon from other species not in direct line in the key. Also included are some external characters noted in Carraway (2007) for distinguishing the extant species.

In lists of specimens examined (Appendixes 1 and 2), specimens are ordered alphabetically by taxon, state and major geographic point in specific locality of collection site, museum acronym, and catalog number. On distribution maps, symbols for localities include all specimens for which the collection locality is within the diameter of the symbol. Distribution maps were produced with ArcView 3.2. Latitudes and longitudes used for plotting specimen collection localities were obtained or calculated from values in the Internet databases Biogeomancer; FaunMap, Illinois State Museum; the USGS Geographic Names Information System (GNIS); Calle World Index; or the Georeferencing Calculator of the MaNIS project at the Museum of Vertebrate Zoology, University of California, Berkeley. Several localities listed in FaunMap were reported to contain specimens of *Notiosorex*; however, these specimens either could not be located or were unavailable for examination and thus were not included.

TABLE 1. Means (\pm SE), n , and ranges (in mm) of skull and dentary characters of the fossil species *Notiosorex harrisi*, *N. jacksoni*, *N. repenningsi*, and *N. dalquesti*, and the extant species *N. cockrumi*, *N. cratafordi*, *N. villai*, and *N. evotis* from throughout their distributions. An empty cell indicates that the character could not be measured. A single value in a cell indicates that only one specimen could be measured.

Character	Notiosorex							
	<i>harrisi</i>	<i>jacksoni</i>	<i>repenningsi</i>	<i>dalquesti</i>	<i>cratafordi</i>	<i>cockrumi</i>	<i>villai</i>	<i>evotis</i>
Length of mandible	7.32 \pm 0.084 15, 6.7-7.7	8.23 \pm 0.072 31, 7.5-8.8		7.64 \pm 0.017 249, 6.7-8.5	7.04 \pm 0.020 124, 6.4-7.7	7.08 \pm 0.050 16, 6.7-7.4	7.4 2, 7.3-7.5	7.66 \pm 0.074 17, 7.0-8.2
Depth of dentary	0.88 \pm 0.009 22, 0.8-0.9	1.37 \pm 0.013 94, 1.2-2.0	1.0	1.11 \pm 0.005 399, 0.9-1.5	1.12 \pm 0.010 89, 0.9-1.4	1.12 \pm 0.016 16, 1.0-1.2	1.2 2, 1.2-1.2	1.36 \pm 0.024 17, 1.2-1.5
Height of coronoid process	3.69 \pm 0.031 20, 3.4-3.9	4.46 \pm 0.034 57, 3.4-4.9		3.83 \pm 0.009 369, 3.1-4.4	4.02 \pm 0.019 125, 3.4-4.6	4.1 \pm 0.042 16, 3.7-4.4	4.05 2, 4.0-4.1	4.64 \pm 0.058 17, 4.2-5.0
Height of coronoid valley	2.15 \pm 0.025 19, 1.9-2.3	2.63 \pm 0.021 70, 2.2-2.9		2.29 \pm 0.007 378, 2.0-3.4	2.25 \pm 0.023 41, 1.8-2.7	2.43 \pm 0.025 15, 2.3-2.6	2.35 2, 2.3-2.4	2.69 \pm 0.042 17, 2.4-3.0
Height of articular condyle	2.68 \pm 0.016 17, 2.5-2.8	3.23 \pm 0.028 72, 2.5-3.9		2.76 \pm 0.006 372, 2.2-3.3	2.79 \pm 0.030 41, 2.5-3.5	2.9 \pm 0.031 15, 2.7-3.0	2.95 2, 2.9-3.0	3.29 \pm 0.042 17, 3.0-3.7
Length from upper articular condyle to posterior edge of m3	3.36 \pm 0.061 14, 3.0-3.8	4.09 \pm 0.031 76, 3.3-4.7		3.45 \pm 0.013 288, 2.9-4.0	3.46 \pm 0.028 41, 3.1-3.9	3.56 \pm 0.031 15, 3.4-3.7	3.45 2, 3.4-3.5	4.07 \pm 0.064 17, 3.6-4.4
Length of coronoid process-ventral point of lower condylar facet	3.37 \pm 0.066 17, 2.9-3.7	4.04 \pm 0.368 52, 3.3-4.5		3.31 \pm 0.012 371, 2.7-3.9	3.74 \pm 0.021 125, 3.2-4.3	3.77 \pm 0.052 16, 3.3-4.1	3.75 2, 3.7-3.8	4.31 \pm 0.056 17, 3.9-4.7
Length of coronoid process-posterior point of upper condylar facet	1.18 \pm 0.038 15, 0.8-1.3	1.26 \pm 0.017 87, 0.8-1.6		1.12 \pm 0.008 386, 0.5-1.4	1.19 \pm 0.020 ^a 29, 0.9-1.3			
Height of m1	0.7	0.80 \pm 0.022 19, 0.6-0.95		0.77 \pm 0.008 140, 0.5-1.0	0.76 \pm 0.297 40, 0.6-0.9	0.76 \pm 0.016 15, 0.7-0.9	0.9 2, 0.9-0.9	0.83 \pm 0.025 15, 0.7-1.0
Length of c1	0.95 \pm 0.019 8, 0.9-1.0	1.17 \pm 0.021 49, 0.7-1.4		0.99 \pm 0.008 254, 0.7-1.6	1.01 \pm 0.015 41, 0.9-1.2	1.05 \pm 0.022 15, 0.9-1.2	1.05 2, 1.0-1.1	1.11 \pm 0.014 17, 1.0-1.2
Length of p4	1.48 \pm 0.023 15, 1.3-1.6	1.57 \pm 0.011 88, 1.4-1.8	1.8	1.47 \pm 0.004 383, 1.1-1.7	1.44 \pm 0.014 41, 1.1-1.6	1.48 \pm 0.022 15, 1.4-1.7	1.45 2, 1.4-1.5	1.52 \pm 0.021 17, 1.3-1.7
Length of m2	1.39 \pm 0.022 16, 1.2-1.6	1.46 \pm 0.008 97, 1.3-1.6	1.6	1.38 \pm 0.004 375, 1.2-1.6	1.36 \pm 0.012 41, 1.2-1.5	1.38 \pm 0.022 15, 1.3-1.6	1.4 2, 1.4-1.4	1.44 \pm 0.015 17, 1.3-1.5
Length of m3	0.97 \pm 0.019 11, 0.9-1.1	1.09 \pm 0.008 79, 0.9-1.2	1.1	0.97 \pm 0.004 309, 0.8-1.5	0.98 \pm 0.006 41, 0.9-1.0	0.97 \pm 0.013 15, 0.9-1.0	1.0 2, 0.9-1.1	1.01 \pm 0.015 17, 0.9-1.1
Length of c1-m3					4.71 \pm 0.013 122, 4.4-5.1	4.72 \pm 0.033 17, 4.3-4.9	5.05 2, 5.0-5.1	5.01 \pm 0.041 16, 4.7-5.3
Width of c1	0.6	0.66 \pm 0.018 19, 0.5-0.8		0.59 \pm 0.004 136, 0.4-0.7	0.56 \pm 2.77 40, 0.4-0.7	0.59 \pm 0.009 15, 0.5-0.6	0.7 2, 0.7-0.7	0.67 \pm 0.013 15, 0.6-0.7

TABLE 1. Continued.

Character	<i>Notiosorex</i>							
	<i>harrisi</i>	<i>jacksoni</i>	<i>repenningi</i>	<i>dalquesti</i>	<i>crayfordi</i>	<i>cochrumi</i>	<i>villai</i>	<i>evotisi</i>
Width of p4	0.65 ± 0.019 8, 0.6-0.7	0.84 ± 0.017 49, 0.6-1.4		0.70 ± 0.004 248, 0.5-0.9	0.68 ± 0.011 41, 0.5-0.8	0.71 ± 0.012 15, 0.6-0.8	0.8 2, 0.8-0.8	0.79 ± 0.016 17, 0.7-0.9
Width of m1	0.84 ± 0.021 15, 0.7-1.0	0.97 ± 0.007 89, 0.8-1.1	1.1	0.85 ± 0.004 383, 0.6-1.3	0.84 ± 0.009 41, 0.7-1.0	0.83 ± 0.013 15, 0.8-0.9	0.95 2, 0.9-1.0	0.92 ± 0.013 17, 0.8-1.0
Width of m2	0.77 ± 0.015 16, 0.7-0.9	0.93 ± 0.008 95, 0.8-1.1	1.1	0.81 ± 0.004 374, 0.6-1.0	0.81 ± 0.015 41, 0.6-1.0	0.79 ± 0.017 15, 0.7-0.9	0.85 2, 0.8-0.9	0.88 ± 0.014 17, 0.8-1.0
Width of m3	0.59 ± 0.018 12, 0.5-0.7	0.71 ± 0.007 79, 0.6-0.9	0.9	0.63 ± 0.003 309, 0.5-0.8	0.6 ± 0.009 41, 0.5-0.8	0.63 ± 0.018 15, 0.5-0.7	0.7 2, 0.7-0.7	0.68 ± 0.014 17, 0.6-0.8
Condylobasal length				16.16 ± 0.139 10, 15.46-16.73	16.08 ± 0.043 120, 14.95-17.25	16.14 ± 0.073 15, 15.71-16.78	17.11 3, 16.97-17.27	17.13 ± 0.102 15, 16.39-17.63
Palatilar length	6.68 ± 0.044 26, 6.2-7.3			6.91 ± 0.028 65, 6.2-7.4	6.79 ± 0.029 85, 6.2-7.3	7.0 ± 0.051 16, 6.5-7.3	7.2 2, 7.0-7.4	7.22 ± 0.066 16, 6.8-7.6
Rostral breadth					4.84 ± 0.014 120, 4.4-5.2	4.88 ± 0.038 17, 4.6-5.1	5.19 3, 5.0-5.3	5.29 ± 0.060 15, 5.0-5.65
Least interorbital breadth					3.76 ± 0.014 120, 3.4-4.1	3.74 ± 0.026 17, 3.5-3.9	3.83 3, 3.6-4.0	3.96 ± 0.044 15, 3.7-4.15
Breadth across M2-M2					4.83 ± 0.014 120, 4.4-5.1	4.77 ± 0.025 17, 4.6-5.0	5.0 3, 4.9-5.1	5.22 ± 0.054 15, 5.1-5.4
Length unicuspid tooththrow					1.88 ± 0.012 119, 1.5-2.2	1.96 ± 0.023 17, 1.7-2.1	2.2 3, 2.0-2.3	2.04 ± 0.031 14, 1.8-2.3
Length of P4-M3					4.31 ± 0.012 120, 4.1-4.6	4.37 ± 0.028 17, 4.1-4.6	4.6 3, 4.4-4.7	4.63 ± 0.036 15, 4.5-4.8
Length of U1-M3					6.03 ± 0.053 36, 5.1-6.8	6.18 ± 0.036 16, 6.0-6.5	6.4 2, 6.1-6.8	6.42 ± 0.044 15, 6.2-6.7
Length of U1	0.67 ± 0.028 13, 0.5-0.8	0.83 ± 0.049 5, 0.7-1.0		0.74 ± 0.015 58, 0.5-0.9				
Length of U2	0.68 ± 0.016 19, 0.5-0.8	0.82 ± 0.040 6, 0.7-0.9		0.73 ± 0.009 84, 0.5-0.9				
Length of U3	0.56 ± 0.020 22, 0.4-0.5	0.67 ± 0.21 15, 0.5-0.8		0.61 ± 0.009 95, 0.4-0.8				
Width of U1	0.65 ± 0.014 13, 0.6-0.1	0.78 ± 0.030 5, 0.7-0.8		0.66 ± 0.008 57, 0.5-0.8				
Width of U2	0.62 ± 0.012 19, 0.5-0.7	0.69 ± 0.039 7, 0.5-0.8		0.63 ± 0.007 84, 0.4-0.8				
Width of U3	0.63 ± 0.011 22, 0.5-0.7	0.68 ± 0.021 14, 0.5-0.8		0.62 ± 0.006 95, 0.4-0.7				

*Data obtained from Carraway (1995).

Dalquest and Roth (1970) reported one specimen of *N. crawfordi* from the Wisconsin-aged site of Cueva de Abra, Tamaulipas. This locality is within the distribution of *N. villai*; unfortunately, the specimen has been misplaced. Also, one specimen reported by Baskin (1979, UALP WC26) has been misplaced. Thus, it was not possible to confirm the identification of either specimen.

RESULTS

Cohesiveness of the 8 *a priori* groups, based on the 7 characters (numbered 24–26, 28, 31–33; Fig. 1, Table 1) present for all taxa, was tested in a DFA (Fig. 3A). The first 2 significant canonical-variate axes ($\chi^2 = 564.86$, $df = 49$, $P < 0.001$; $\chi^2 = 93.57$, $df = 36$, $P < 0.001$, respectively) accounted for 90.0% and 5.8% of variation, respectively, among *a priori* groups. However, only 42.4% of 418 specimens included were classified correctly into their *a priori* groups. Despite the low level of correct classification, 4 clusters based on size resulted from the analysis (Fig. 3A). Because of its much greater overall size (Fig. 6), not only was *N. repenningi* separated greatly from the other taxa, but the relationships among the remaining 7 *a priori* groups were deformed in canonical space. The 3 remaining clusters were (1) *N. jacksoni* and *N. evotis*, (2) *Notiosorex* sp., and (3) *N. cockrumi*, extant and fossil *N. crawfordi*, and *N. villai*.

To examine the relationships among the latter 3 clusters (excluding *N. repenningi*), another DFA was conducted (Fig. 3B) based on 12 characters (numbered 16–20, 22–23, 27–31; Fig. 2). The first 2 significant canonical-variate axes ($\chi^2 = 771.35$, $df = 72$, $P < 0.001$; $\chi^2 = 333.08$, $df = 55$, $P < 0.001$, respectively) accounted for 68.6% and 25.8% of variation, respectively, among the 7 *a priori* groups (Fig. 3B). However, only 82.1% of 284 specimens were classified correctly into their *a priori* groups. *Notiosorex evotis* and *N. jacksoni* formed 2 distinct clusters, whereas the remaining groups (*Notiosorex* sp., *N. cockrumi*, extant and fossil *N. crawfordi*, and *N. villai*) overlapped to some extent.

The latter *a priori* groups, named in the parenthetical, were analyzed by a DFA (Fig. 3C) based on 12 characters (numbered 16–20, 24–25, 27–28, 31–33; Fig. 2). The first 2 significant canonical-variate axes ($\chi^2 = 407.84$, $df = 48$, $P < 0.001$; $\chi^2 = 85.35$, $df = 33$, $P < 0.001$,

respectively) accounted for 87.9% and 6.9% of variation, respectively, among the *a priori* groups (Fig. 3C). With 79.15% of 253 specimens correctly classified into their *a priori* groups, 3 distinct clusters were formed: (1) *Notiosorex* sp., (2) fossil *N. crawfordi*, and (3) extant *N. crawfordi*, *N. cockrumi*, and *N. villai*.

The latter 3 taxa were analyzed by a DFA (Fig. 3D) based on 11 characters (numbered 16–18, 20, 24–25, 27–28, 31–33; Fig. 2). Only the first canonical-variate axis was significant ($\chi^2 = 42.33$, $df = 22$, $P = 0.0057$); it accounted for 69.3% of variation among the *a priori* groups (Fig. 3D). Although not statistically significant ($\chi^2 = 14.35$, $df = 10$, $P = 0.158$), the second canonical-variate axis accounted for 30.8% of variation among the *a priori* groups. *Notiosorex villai* was found to form a cluster distinct from extant *N. crawfordi* and *N. cockrumi* based on greater depth of mandible and greater widths of m1, m2, and m3.

In a previous study, I determined that characters initially recorded in this study were not sufficient to distinguish *N. cockrumi* and extant *N. crawfordi* (Carraway 2007). Thus, data for an additional 5 cranial and 2 mandibular characters were added to the initial data set, and another DFA (Fig. 4A) was conducted based on 23 characters (characters numbered 1–5, 8, 15–19, 21–23, 25–33; Fig. 2). This DFA resulted in a single significant canonical-variate axis ($\chi^2 = 46.05$, $df = 23$, $P < 0.003$; Fig. 4A). With 98.1% of specimens correctly classified into their *a priori* groups, 2 distinct clusters were formed. One *N. crawfordi* was classified as *N. cockrumi* based on a 50% probability. Because of the 50% probability, this specimen was referred to its *a priori* group in further analyses and discussion. Specimens of *N. cockrumi* were found to have a generally longer and broader skull and mandible than specimens of extant *N. crawfordi* (Table 1).

Fossil and extant groups of *N. crawfordi* included in previous analyses formed distinct clusters when other taxa were included. Thus, an additional DFA (Fig. 4B) was conducted, based on 17 characters (numbered 16–20, 22–33; Fig. 2), that included only these 2 groups to provide a closer examination of their differences. This DFA resulted in a single significant canonical-variate axis ($\chi^2 = 202.411$, $df = 17$, $P < 0.001$; Fig. 4B). With 97.9% of specimens correctly classified into their *a priori* groups, 2 distinct clusters were formed. One extant *N. crawfordi* was classified as a fossil *N. crawfordi*,

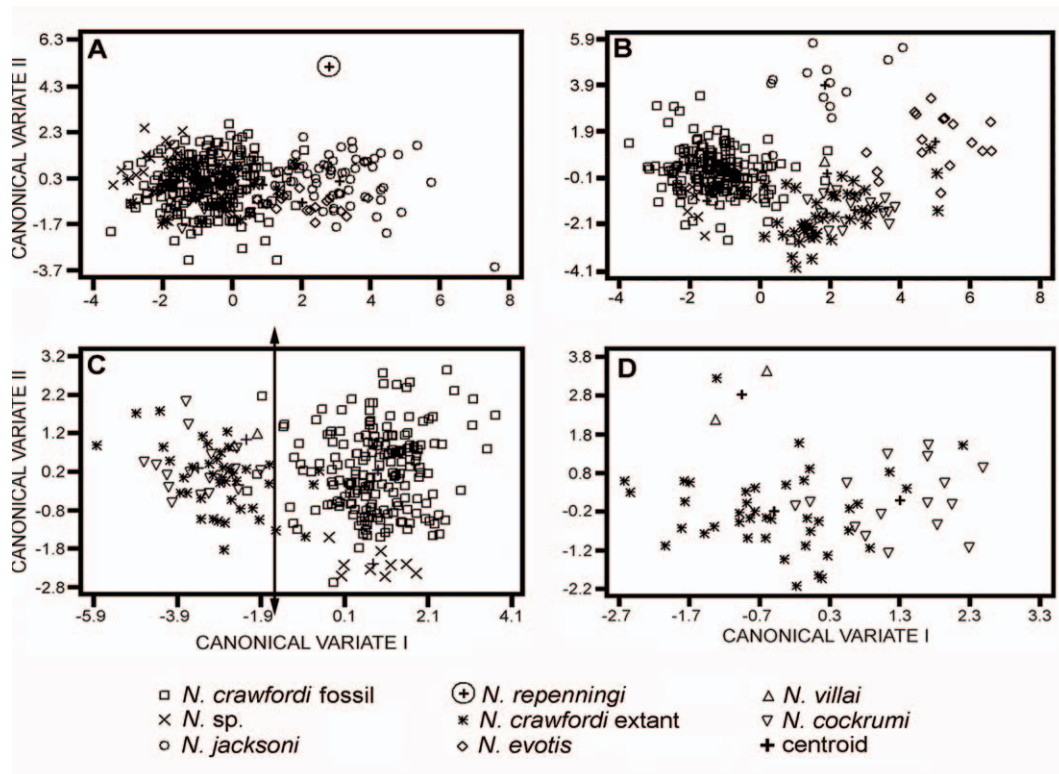


Fig. 3. Discriminant-function plots. A, all 8 *a priori* groups, of *Notiosorex*. The 2 significant canonical-variate axes ($\chi^2 = 564.86$, $df = 49$, $P < 0.001$; $\chi^2 = 93.57$, $df = 36$, $P < 0.001$, respectively) accounted for 90% and 5.8% of variation among the *a priori* groups. B, all *a priori* groups excluding *N. repenningi*. The 2 significant canonical-variate axes ($\chi^2 = 771.35$, $df = 72$, $P < 0.001$; $\chi^2 = 333.08$, $df = 55$, $P < 0.001$, respectively) accounted for 68.6% and 25.8% of variation among the 7 *a priori* groups. C, small-to-medium extant (to left of arrowed line) and fossil (to right of arrowed line) species of *Notiosorex*. The 2 significant canonical-variate axes ($\chi^2 = 407.84$, $df = 48$, $P < 0.001$; $\chi^2 = 85.35$, $df = 33$, $P < 0.001$, respectively) accounted for 87.9% and 6.9% of variation among the 5 *a priori* groups. D, *Notiosorex cockrumi*, *N. crawfordi*, and *N. villai*. The only significant canonical-variate axis ($\chi^2 = 42.33$, $df = 22$, $P < 0.0057$) accounted for 69.3% of variation among the 3 *a priori* groups; although not statistically significant ($\chi^2 = 14.35$, $df = 10$, $P = 0.158$), the second canonical-variate axis accounted for 30.8%.

based on a 50.1% probability; and 2 fossil *N. crawfordi* were classified as extant *N. crawfordi*, based on 50.0% and 50.1% probabilities. Because of the 50% or nearly 50% probabilities, these specimens were referred to their respective *a priori* groups. Dentaries of extant *N. crawfordi* specimens were found to have a much taller vertical ramus relative to the length of the horizontal ramus than dentaries of fossil *N. crawfordi* (Table 1). This is best illustrated by specimens of extant *N. crawfordi* having a much longer coronoid process–ventral point of the lower condyloid facet relative to the length of the mandible than specimens of fossil *N. crawfordi* (Table 1).

Analyses reported herein indicate there is as much morphological differentiation between

fossil specimens of *N. crawfordi* and extant specimens of *N. crawfordi* as between any other pair of species within the genus. Thus, herein I refer all fossil specimens formerly named *Notiosorex crawfordi* to the new species *Notiosorex dalquesti*. Finally, previous visual observations (with aid of a binocular microscope) and a single literature report (Baskin 1979) indicated that a very small, previously undescribed form of *Notiosorex* exists. Analyses reported herein confirmed that 49 specimens from sites in Arizona, New Mexico, and Chihuahua exhibit as much morphological difference to any other nominal notiosoricin as between any other pair of species within the genus. Thus, I refer this group of specimens to the new species *Notiosorex harrisi*.

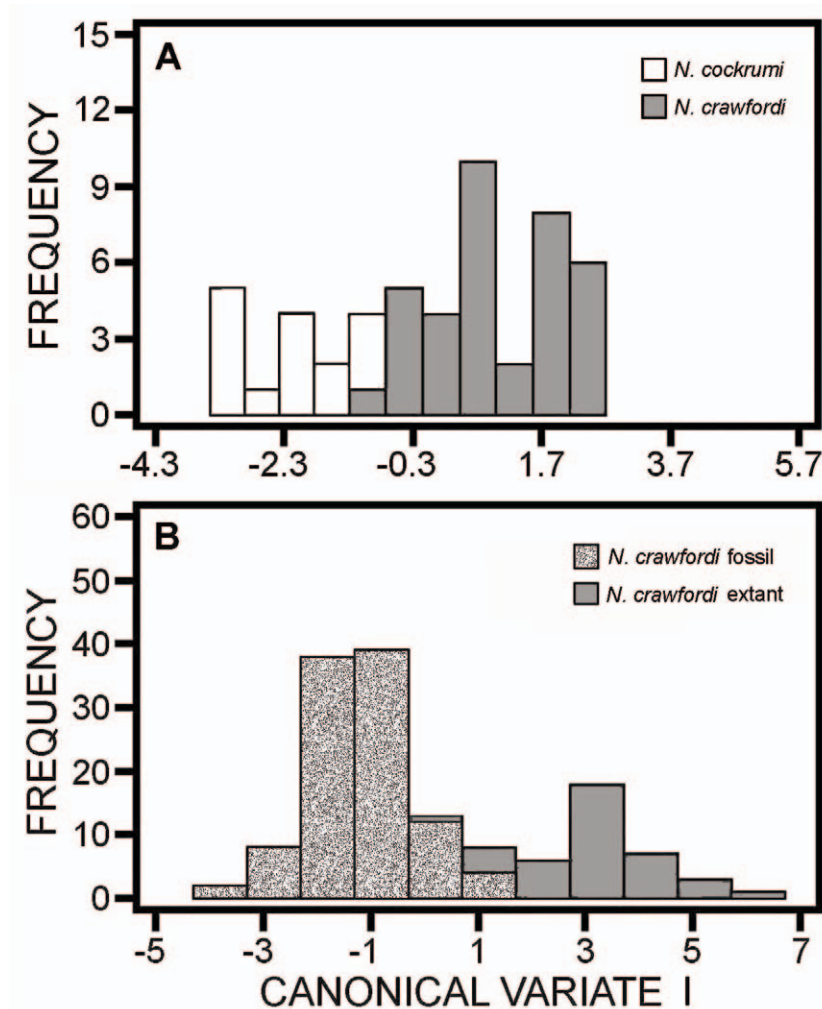


Fig. 4. Discriminant-function plots: A, *Notiosorex cockrumi* and extant *N. crawfordi*. The only significant canonical-variate axis ($\chi^2 = 46.05$, $df = 23$, $P < 0.003$) accounted for 98.1% of variation between the 2 *a priori* groups. B, fossil and extant *N. crawfordi*. The only significant canonical-variate axis ($\chi^2 = 202.41$, $df = 17$, $P < 0.001$) accounted for 97.9% of variation between the 2 *a priori* groups.

SYSTEMATIC PALEONTOLOGY

FAMILY SORICIDAE

Notiosorex harrisi, new species

Harris' Shrew, Fig. 5

Sorex (Notiosorex) crawfordi Coues, 1877:651 (part).

Notiosorex crawfordi: (Coues, 1877:652) (part).

Notiosorex crawfordi Carraway and Timm, 2000:311 (part).

HOLOTYPE.—Adult, left dentary with i1 and p4–m3, UTEP 120-2526, University of Texas at El Paso, Laboratory for Environmental Biology Paleobiology Collection, from Big Manhole

Cave, BH pit 20–30 cm, Eddy County, New Mexico, deposit dated at 2085 ± 45 BP (before present), latitude 32.2° N, longitude 104.6° W (Lear and Harris 2007).

DISTRIBUTION.—Known from the late Miocene-aged (ca. 6.69–5.3 m.y.) White Cone local fauna in northeastern Arizona and 8 late Pleistocene- to Holocene-aged (≤ 79 ka to ≤ 1360 yr) fossil deposits in Arizona, New Mexico, and Chihuahua (Fig. 1A, Appendix 2).

GENERIC COMPARISONS OF MANDIBLES.—*Notiosorex* can be distinguished from *Beckiasorex* by entoconid of m2 and talonoid of m3

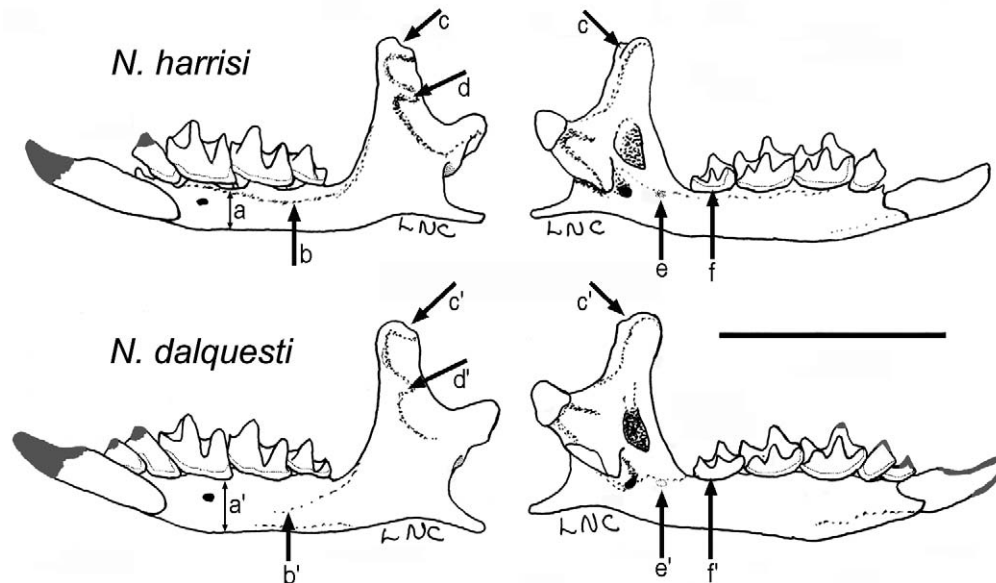


Fig. 5. Camera-lucida tracings of type specimens for *Notiosorex harrisi* (UTEP 120-2526) and *Notiosorex dalquesti* (UTEP 120-889). Diagnostic characters are the following: 1, depth of mandible beneath m1 shallow (a)/deep (a'); 2, external oblique line extends to p4 (b)/extends to m2 near ventral edge of mandible (b'); 3, tip of coronoid process notched (c)/with shallow depression (c'); 4, coronoid spicule long with tip depressed ventrad (d)/short with tip straight (d'); 5, depression anteroventral to internal temporal fossa shallow (e)/deep (e'); 6, lingual cingulum of m3 present (f)/absent (f'), respectively. Scale bar equals 5 mm.

not reduced, V of hypocondid of m3 not developed, coronoid spicule present, upper condylar facet more than half the width of the lower facet, interarticular area deep, lower condylar facet horizontal and not dorsoventrally compressed, and condylar processes separated from angular process by a groove (Dalquest 1972). *Notiosorex* differs from *Hesperosorex* by m1 and m2 with no pigmentation, tip of coronoid process spatulate and tipped anteriorly, upper condylar facet triangular in shape, and interarticular area very narrow (Hibbard 1957, Repenning 1967). *Notiosorex* can be distinguished from *Megasorex* by light-colored pigment on i1, c1, and p4; crest of entocondid of m1 high; and tip of coronoid process less spatulate and tipped anteriorly. As for all *Notiosorex*, specimens of *N. harrisi* (Figs. 5, 6) have a combination of deeply emarginated area between the condylar processes (e.g., the interarticular breadth is about half the width of the superior condylar process), alveolus of i1 extending posteriorly beneath at least part of the paracondid of m1 (Carraway 1995), pigment present on some teeth, 3 upper unicuspid, and ventral edge of the sphenorbital

fissure located at the dorsal edge of the lower glenoid furrow (Carraway 2005).

DIAGNOSIS.—*Notiosorex harrisi* can be distinguished from other taxa of *Notiosorex* by a combination of horizontal ramus beneath m1 very shallow (commonly <1.0 mm), mental foramen located within slight depression, deep notch present in top of coronoid process, coronoid spicule long with tip depressed ventrad, internal temporal fossa very broad, shallow depression anteroventrad to internal temporal fossa, m1–m3 with large entocondids (will reduce in height with wear), and lingual cingulum present on m3.

It can be distinguished from 100% of *N. dalquesti* by application of the discriminant equation: $9.06095(\text{depth of dentary at m1}) + 0.801305(\text{height of coronoid valley}) + 0.11591(\text{height of coronoid process}) - 16.2999$, scores ≤ -1.8 . All individuals with scores ≥ -1.8 are referable to *N. dalquesti*.

Notiosorex harrisi differs from *N. jacksoni* by height of coronoid process ≤ 3.9 mm and mandible posterior to m3 curved; and from *N. repenningi* by length of m1 ≤ 1.6 mm, width of m1 ≤ 1.0 mm, width of m2 ≤ 0.9 mm, and width of m3 ≤ 0.7 mm. Also, it can be distinguished

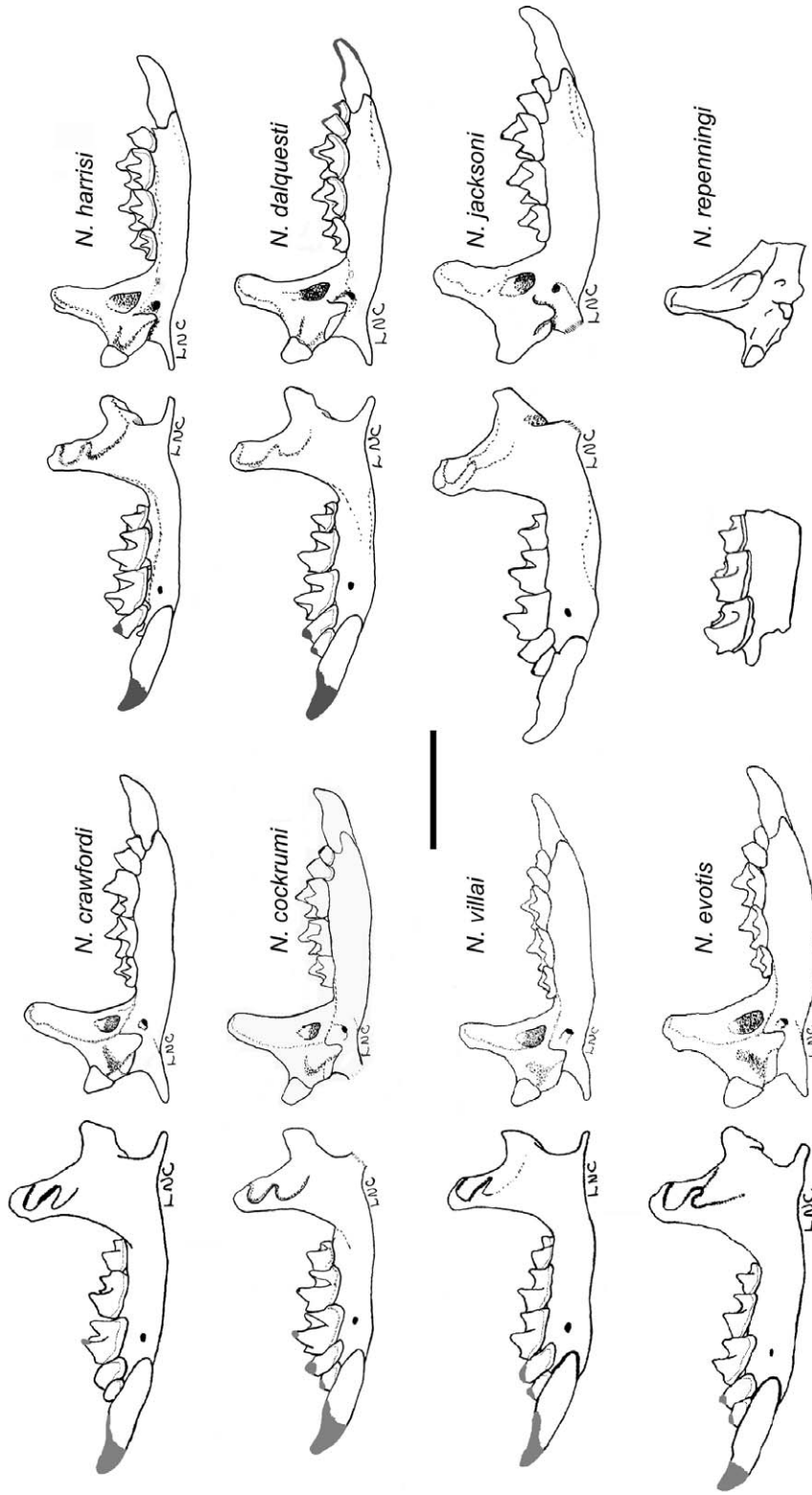


Fig. 6. Camera-lucida tracings of labial and lingual views of mandibles, or available parts, for all species of *Notiosorex*. Specimens of extant species are shown to left of scale bar: *N. crawfordi* (KU 145262), *N. cockrumi* (TTU 82981), *N. villai* (KU 54932 and 54933), and *N. evotis* (KU 89214). Specimens of fossil species are shown to right of scale bar: *N. harrisi* (UTEP 120-2526), *N. dalquesti* (UTEP 120-889), *N. jacksoni* (UM 28418), and *N. repenningi* (redrawn from Lindsay and Jacobs 1985:8). Both columns of mandibles are presented from smallest to largest from top to bottom. Cross-hatching indicates angle of jaw missing from specimen. Scale bar equals 5 mm.

from *N. villai* by height of coronoid process ≤ 3.9 mm and height of articular condyle ≤ 2.8 mm; and from *N. evotis* by height of coronoid process ≤ 3.9 mm, height of coronoid valley ≤ 2.3 mm, height of articular condyle ≤ 2.8 mm, and length of coronoid process–ventral point of lower condylar facet ≤ 3.7 mm. *Notiosorex harrisi* can be distinguished from 97.3% of *N. cockrumi* and *N. crawfordi* by application of the discriminant equation: 4.6497 (height of coronoid process) $- 5.2749$ (length of mandible) $+ 3.0542$ (depth of dentary at m1) $+ 2.4425$ (length of c1) $+ 1.5680$ (length of m2) $- 2.4884$ (width of c1) $- 3.7569$ (width of p4) $+ 2.4005$ (width of m2) $+ 15.9028$, scores < 0.6 . Individuals with scores > 0.6 are referable to *N. cockrumi* or *N. crawfordi*.

DESCRIPTION.—Individuals referable to *N. harrisi* are smaller overall than those of any other fossil or extant species of *Notiosorex* (Table 1). This size difference is most apparent when comparing the length of the mandible and dimensions for m1–m3 to the vertical dimensions of the mandible. For members of *N. harrisi*, the length of the mandible and the length and width of m1–m3 and height of m1 are similar to those of *N. dalquesti*, *N. crawfordi*, *N. cockrumi*, and *N. villai*. However, overall the vertical dimensions of the mandible are less than expected for *N. harrisi* when compared with the same dimensions of the 4 other species. These differences in size are visually obvious when comparing the height of m1 to the shallow horizontal ramus of the mandible below the m1 (Fig. 6).

On the mandible, the external oblique line (attachment site of buccinator muscle) descends along the anterior edge of the labial side of the coronoid process. It then extends anteriorly on the horizontal ramus parallel and proximate to the molar tooththrow ending at p4 (Fig. 5).

ETYMOLOGY.—The species epithet is a patronymic to honor Arthur H. Harris for his decades of work on the paleontology of mammals in the southwestern United States.

REMARKS.—The 4 small specimens of *Notiosorex* from the late Miocene (i.e., Hemphillian-aged) White Cone local fauna, Arizona, are morphologically indistinguishable from Pleistocene-aged (i.e., Wisconsinan-aged) *N. harrisi*. There are no known specimens referable to *N. harrisi* from the intervening 5.3 m.y.–79 ka (Fig. 7).

Notiosorex harrisi and *N. dalquesti* appeared in deposits of 7 sites (Appendix 2), however,

they overlap in time at only 5 of those sites. Their greatest aggregation occurred in Big Manhole Cave, Eddy County, New Mexico. In this cave, both species occurred in each 10-cm level of the BH pit from 10 to 80 cm, covering a time span of 1360–4170 + 195/–190 BP.

Notiosorex dalquesti, new species

Dalquest's Shrew, Fig. 5

Sorex (*Notiosorex*) *crawfordi* Coues, 1877:651 (part).

Notiosorex crawfordi: (Coues, 1877:652) (part).

Notiosorex crawfordi Carraway and Timm, 2000:311 (part).

HOLOTYPE.—Adult, left dentary with i1–m3; UTEP 120-889, University of Texas at El Paso, Laboratory for Environmental Biology Paleobiology Collection; from Big Manhole Cave, BH pit 20–30 cm, Eddy County, New Mexico; deposit dated at 3035 ± 60 BP, latitude 32.2° N, longitude 104.6° W.

DISTRIBUTION.—*Notiosorex dalquesti* is known from at least 47 late Pleistocene- (i.e., early Wisconsinan) to Holocene-aged (≤ 79 ka–565 yr) fossil deposits in Arizona, California, Kansas, New Mexico, Nevada, Oklahoma, Texas, Chihuahua, Nuevo León, and Zacatecas (Fig. 1A, Appendix 2). It has the most widespread distribution of any known species of fossil *Notiosorex*.

GENERIC COMPARISONS.—Refer to *N. harrisi* account.

DIAGNOSIS.—*Notiosorex dalquesti* can be distinguished from other taxa of *Notiosorex* by a combination of mental foramen located within slight depression, shallow depression present in top of coronoid process, coronoid spicule short with tip directed posteriorly, internal temporal fossa narrow, deep depression anteroventrad to internal temporal fossa, m1–m3 with large entoconids (will reduce in height with wear), and no lingual cingulum present on m3.

It can be distinguished from *N. jacksoni* by length from upper articular condyle to posterior edge of m3 usually < 3.8 mm and mandible posterior to m3 curved; and from *N. repenningi* by length of m1 ≤ 1.7 mm, width of m2 ≤ 1.0 mm, and width of m3 ≤ 0.8 mm. *Notiosorex dalquesti* can be distinguished from 90.1% of *N. harrisi* by application of the discriminant equation: 9.06095 (depth of dentary at m1) $+ 0.801305$ (height of coronoid valley) $+ 0.11591$ (height of coronoid process) $- 16.2999$, scores ≥ -1.8 . All individuals with scores ≤ -1.8 are referable to *N. harrisi*.

Notiosorex dalquesti differs from *N. villai* by condylobasal length ≤ 16.73 mm; and from

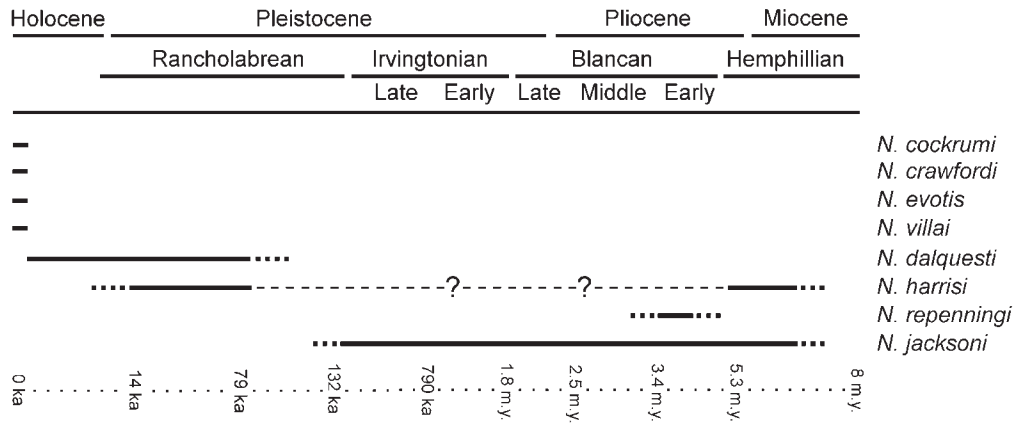


Fig. 7. Land-mammal timescale based on data from Martinson et al. (1987) and Bell et al. (2004) for extant and fossil species of *Notiosorex* shrews. *Notiosorex dalquesti* has been documented from sites dated ≤ 79 ka to 565 BP. *Notiosorex harrisi* has been documented from sites dated ≤ 79 ka to ≤ 1360 BP and approximately 6.69–5.3 m.y. Dashed line with question marks indicates no fossils for that taxon are known for indicated time span. Dotted lines indicate the relative time of appearance or disappearance of a taxon is unknown.

N. evotis by height of coronoid process usually ≥ 4.3 mm and length of coronoid process–ventral point of lower condylar facet ≤ 3.9 mm. Further, 97.3% of *N. dalquesti* can be distinguished from *N. cockrumi* and *N. crawfordi* by application of the discriminant equation: 4.6497 (height of coronoid process) $- 5.2749$ (length of mandible) $+ 3.0542$ (depth of dentary at m1) $+ 2.4425$ (length of c1) $+ 1.5680$ (length of m2) $- 2.4884$ (width of c1) $- 3.7569$ (width of p4) $+ 2.4005$ (width of m2) $+ 15.9028$, scores < 0.6 . Individuals with scores > 0.6 are referable to *N. cockrumi* or *N. crawfordi*.

DESCRIPTION.—Members of *N. dalquesti* are larger than those of *N. harrisi*, but smaller than those of all other species of *Notiosorex* (Table 1). Similar to that of *N. harrisi*, the external oblique line (attachment site of buccinator muscle) of the mandible descends along the anterior edge of the labial side of the coronoid process. However, unlike *N. harrisi*, it then extends anteriorly on the horizontal ramus descending almost to the attachment ridge for the anterior M. digastricus beneath the midpoint of m2 (Fig. 5).

ETYMOLOGY.—The species epithet is a patronymic to honor Walter Woelber Dalquest for his decades of work on the extant and fossil mammals of Mexico.

REMARKS.—According to the known fossil record, *N. jacksoni* was no longer present in mammal communities by 252 ka. However,

N. dalquesti is not known to have appeared before 79 ka. No records of *Notiosorex* shrews are known in the fossil record during the intervening 173 ka.

DISCUSSION

Shrews of the genus *Notiosorex* have diversified sufficiently that 4 fossil and 4 extant species are recognized. These species have varying degrees of overlap in time (Fig. 7) and in geographic (Fig. 1) distribution throughout the southwestern United States and northern Mexico. Fossil specimens referable to *Notiosorex* first appeared in the fossil record in the late Miocene (i.e., mid-Hemphillian, ca. 6.69 ± 0.16 m.y.) as the fairly large *N. jacksoni*. For a short time span, *N. harrisi* occurred with *N. jacksoni* in the White Cone local fauna, Arizona, then *N. harrisi* disappeared from the known fossil record. During the Pliocene (i.e., earliest Blancan, ca. 4.9–4.1 m.y.), the much larger *N. repenningi* appeared for a short time in the Concha Fauna, Chihuahua. However, by the mid-Blancan (ca. 4.1 m.y.) only *N. jacksoni* is represented in the fossil record. It remained the only known representative of the genus *Notiosorex* for the following 3.75 m.y., well into the middle Pleistocene. By earliest Wisconsinan (ca. 79 ka), the smaller *N. dalquesti* appeared and the still smaller *N. harrisi* reappeared in the fossil record. These 2

taxa appeared concurrently at 5 late Pleistocene- (i.e., early Wisconsinan) and Holocene-aged fossil sites in New Mexico (Fig. 1A). *Notiosorex dalquesti* appeared without *N. harrisi* in at least 47 late Pleistocene- (i.e., early Wisconsinan) to Holocene-aged fossil sites in Arizona, California, Kansas, New Mexico, Nevada, Oklahoma, Texas, Chihuahua, and Zacatecas (Fig. 1A). *Notiosorex harrisi* appeared without *N. dalquesti* in the late Miocene (i.e., late Hemphillian) White Cone local fauna, Arizona, and in the late Pleistocene (i.e., Wisconsinan) Shelter Cave, New Mexico (Fig. 1A); it disappeared from the fossil record by the late Holocene (ca. 3 ka). During the late Holocene (less than ca. 3 ka), only fossils identified as *N. dalquesti* appear in the fossil record at 9 sites in Arizona, New Mexico, Oklahoma, Texas, and Chihuahua (Fig. 1A).

It can be hypothesized that the limited known occurrence of *N. repenningi* and the initial brief appearance of *N. harrisi* are either anomalies of the low number of fossil sites examined from some time periods or that samples from fossil sites are not representative of the actual faunas that were present. Further, only a limited number of geographic areas at which the correct environmental conditions existed allowed for the occurrence of fossil deposition. These problems make determination of the actual extent of occurrence in time and space of *N. repenningi*, *N. jacksoni*, *N. harrisi*, and *N. dalquesti* unlikely.

That taxa of notiosoricin shrews in the known fossil record include a wide range of sizes and morphologies (Fig. 6, Table 1) could be related to changing climatic conditions with the concomitant ecological succession that occurred. Cave faunas and paleoflora and pollen records for low-elevation habitats in western Utah indicate that during the latest Pleistocene to early Holocene, the environment was “cool and moist and supported grasses and stands of *Artemisia*” (Schmitt et al. 2002:259). However, by the middle Holocene (ca. 8 ka), evidence indicates an environmental shift to increasing aridity, as indicated by the presence of xerophytic scrub communities dominated by *Sarcobatus vermiculatus* and *Atriplex* sp. (Schmitt et al. 2002). By 8.3 ka, evidence indicates continued drying of the environment, with the presence of open desert habitats and reduced mammalian species richness characteristic of such habitats (Schmitt et al. 2002). Mammalian

faunal layers at Schulze Cave in Edwards Plateau, Texas, also provide an indication of cooler temperatures, with dense grassland annuals and open woodland habitat in the earliest Holocene and warmer temperatures with semiarid habitat by the middle Holocene (Dalquest et al. 1969). The same can be stated for the geographic area of Arkansas, Kansas, and Oklahoma (Sealander 1952, Clark 1953, Hibbard and Taylor 1960). Thus, certainly by the middle Holocene if not earlier, low- to mid-elevation habitats in the southwestern United States southward into Mexico would have faced the same environmental changes in flora from moist grassland-sagebrush to xerophytic scrub to open desert communities (Lundelius 1979, Harris 1987, 1989, Van Devender and Bradley 1990, Smith et al. 1995). The changing climate allowed fossil taxa of *Notiosorex* to expand their distributions into areas subsequently less suitable for other forms of shrews and provided a driving force for morphological change (i.e., speciation) within the genus (Fig. 1B; Smith et al. 1995).

Present-day notiosoricin shrews occur throughout much of the southwestern United States and northern Mexico in a broad range of habitat types: from deserts, mixed desert-shrub, mesquite (*Prosopis*) or yucca (*Yucca*) grasslands, and mesquite mudflats to pine (*Pinus*)–oak (*Quercus*) forests (Carraway 2007) “always located in rough, rocky terrain” (F.B. Stangl personal communication). It would be reasonable to hypothesize that the fossil taxa had a similar tolerance for a wide variety of habitat types.

Extant *Notiosorex* shrews possess morphological and physiological adaptations that enable them to tolerate well environments inhospitable to other genera of shrews. These adaptations include the following: the shield of the curly overhairs having a smooth structure “with, at most, shallow U-shaped notches” (Ducommun et al. 1994:623); water-conserving kidneys and a tolerance for “much higher ambient temperatures as well as greater radiant energy loads” (Lindstedt 1980a:94); and regulated hypothermia used during times of low food availability (Lindstedt 1980b). It is reasonable to hypothesize that fossil *Notiosorex* either developed or actually possessed the same beneficial adaptations. These characteristics probably allowed *Notiosorex* shrews to expand their distributions into areas subsequently less suitable for other forms of shrews (Fig. 1B; Lindstedt 1980a).

The ability of these taxa to survive in such ecological settings is reflected by their possession of morphologically unique characteristics that mitigate the effects of the harsh environment they inhabit (Fig. 1B; Lindstedt 1980a, 1980b, Ducommun et al. 1994). Thus, if climate, even indirectly, was the driving force for speciation among fossil taxa of *Notiosorex*, then other forces have acted on the extant species *N. cockrumi*, *N. crawfordi*, *N. evotis*, and *N. villai*.

KEY TO THE SPECIES OF THE
GENUS *NOTIOSOREX*

1. Largest *Notiosorex* (Fig. 6); length m1, 1.8 mm; (length m2, 1.6 mm); (depth of dentary at m1, 1.0 mm); fossil
 *N. repenningi* (Lindsay and Jacobs)
 — Length of m1 usually <1.8 mm 2
2. Length from upper articular condyle to posterior edge of m3 usually >3.8 mm
 3 *N. evotis* and *N. jacksoni*
 — Length from upper articular condyle to posterior edge of m3 usually <3.8 mm 4
3. Application of discriminant equation (100% correct classification): 4.1747 [height of coronoid process] $- 5.3328$ [length of mandible] $+ 2.8894$ [width of c1] $+ 21.2901$, scores > -0.5 ; (roof of glenoid fossa extending laterally from cranium when skull viewed from dorsal aspect); (breadth of zygomatic plate, usually 2.1–2.4 mm, 13%–15% of condylobasal length); (depth of dentary at m1, 1.2–1.5 mm); (height of coronoid process ≥ 4.2 mm); (can be distinguished from *N. cockrumi* by condylobasal length 16.5–18.4 mm, cranial breadth usually 8.2–9.0 mm, breadth across M2–M2 5.1–5.4 mm, length of c1–m3 usually 4.9–5.3 mm, height of coronoid process usually 4.3–5.0 mm, height of articular condyle 3.0–3.7 mm); extant *N. evotis* (Coues)
 — Application of discriminant equation (100% correct classification): 4.1747 [height of coronoid process] $- 5.3328$ [length of mandible] $+ 2.8894$ [width of c1] $+ 21.2901$, scores < -2.0 ; (length of mandible, 7.5–8.8 mm); (depth of dentary at m1, 1.2–2.0 mm); (height of coronoid process, ≥ 3.9 mm); (length of U3, 0.5–0.8 mm); (width of U1, 0.7–0.85 mm); (width of p4 + width of m1 + width of m2 + width of m3, ≥ 3.2 mm); fossil *N. jacksoni* (Hibbard)
4. Application of discriminant equation (97.3% correct classification): 4.6497 [height of coronoid process] $- 5.2749$ [length of mandible] $+ 3.0542$ [depth of dentary at m1] $+ 2.4425$ [length of c1] $+ 1.5680$ [length of m2] $- 2.4884$ [width of c1] $- 3.7569$ [width of p4] $+ 2.4005$ [width of m2] $+ 15.9028$, scores < 0.6 ; fossil 5 *N. harrisi* and *N. dalquesti*
 — Application of discriminant equation (96.5% correct classification): 4.6497 [height of coronoid process] $- 5.2749$ [length of mandible] $+ 3.0542$ [depth of dentary at m1] $+ 2.4425$ [length of c1] $+ 1.5680$ [length of m2] $- 2.4884$ [width of c1] $- 3.7569$ [width of p4] $+ 2.4005$ [width of m2] $+ 15.9028$, scores > 0.6 ; extant 6
 5. Smallest *Notiosorex* (Fig. 6); horizontal ramus beneath m1 very shallow ($<$ height of m1); external oblique line extends anteriorly to p4; deep notch present in top of coronoid process; coronoid spicule long with tip depressed ventrad; internal temporal fossa very broad; no depression anteroventrad to internal temporal fossa; lingual cingulum present on m3; fossil *N. harrisi*, new species
 — Horizontal ramus beneath m1 deeper than height of m1; external oblique line extends anteriorly to midpoint of m2; shallow depression present in top of coronoid process; coronoid spicule short with tip directed posteriorly; internal temporal fossa narrow; deep depression anteroventrad to internal temporal fossa; no lingual cingulum present on m3; fossil.
 *N. dalquesti*, new species
 6. Roof of glenoid fossa not extending laterally from cranium when skull viewed from dorsal aspect; (breadth of zygomatic plate, 1.7–2.2 mm, 8% of condylobasal length); (can be distinguished from *N. cockrumi* and *N. crawfordi* by condylobasal length ≥ 16.97 mm); (can be distinguished from *N. cockrumi* by cranial breadth 8.1–8.5 mm, breadth across M2–M2 usually 4.9–5.1 mm, and length of c1–m3 usually 5.0–5.1 mm); (can be distinguished from *N. evotis* by length of upper unicuspid toothrow ≥ 2.0 mm, height of coronoid process < 4.2 mm, length of coronoid process–posterior point of upper condylar facet < 3.9 mm, and length of coronoid process–ventral point of lower condylar facet 3.3–3.4 mm); extant
 *N. villai* Carraway and Timm
 — Roof of glenoid fossa extending laterally from cranium when skull viewed from dorsal aspect; extant 7 *N. crawfordi* and *N. cockrumi*
7. Total length, usually 84–100 mm, most individuals are > 88 mm; length of claw on middle digit of manus 1.0–1.2 mm and 1.57%–1.82% of total length; (breadth of zygomatic plate, usually 1.7–2.0 mm, 10%–13% of condylobasal length); (depth of dentary at m1, ≥ 0.9 mm); extant *N. crawfordi* (Coues)
 — Total length, 78–86 mm; length of claw on middle digit of manus 1.0–1.2 mm and 1.28%–1.52% of total length; (breadth of zygomatic plate, 1.7–2.2 mm); (depth of dentary at m1, ≤ 1.2 mm); (width of p4 + width of m1 + width of m2 + width of m3, ≤ 3.1 mm); (can be distinguished from *N. evotis* and *N. villai* by condylobasal length usually 15.76–16.51 mm, cranial breadth 7.8–8.1 mm, breadth across M2–M2 usually 4.6–4.9 mm, and length of c1–m3 usually 4.6–4.8 mm); (can be distinguished from *N. evotis* by height of coronoid process usually 3.7–4.3 mm and height of articular condyle 2.7–3.0 mm); extant
 *N. cockrumi* Baker, O'Neill, and McAliley

ACKNOWLEDGMENTS

Special thanks must be given to A.H. Harris for his loan of more than 600 fossil *Notiosorex* housed in the Laboratory for Environmental Biology Paleobiology Collection, Centennial Museum, University of Texas at El Paso (UTEP). Without the loan of these specimens, this research could not have been conducted. For loan of or access to specimens in their care, I thank the following: D. Long, California Academy of Sciences (CAS); K.J. Morris, U.S. Army Air Defense Artillery Center and the Fort Bliss Curatorial Facility, El Paso, Texas (FTBL); F.B. Stangl Jr., Midwestern State University, Wichita Falls, Texas (MWSU); B. Lundrigan, Michigan State University Museum (MSU); J. Arroyo-Cabrales, Laboratorio de Paleozoología, Instituto Nacional de Anthropología y Historia (INAH); T. Alvarez (deceased), Colección Mastozoológica de la Escuela Nacional de Ciencias Biológicas, Instituto Politécnico Nacional (CB); A.H. Harris, Museum of New Mexico (MNM); R.D. Fisher and A.L. Gardner, Mammal Division, and R. Purdy, Vertebrate Paleontology, National Museum of Natural History, Washington, DC (USNM); N.J. Czaplewski, Oklahoma Museum of Natural History (OMNH); J. Shaw, Oklahoma State University, Collection of Vertebrates (OSU); G.D. Baumgardner and D.A. Schlitter, formerly of the Texas Cooperative Wildlife Collection, Texas A&M University (TCWC); R.J. Baker and H. Garner, Mammal Collection, The Museum, Texas Tech University (TTU); F. Cervantes and J. Vargas Cuenca, Colección Nacional de Mamíferos, Instituto de Biología, Universidad Nacional Autónoma de México (CNMA); E. Lindsay, University of Arizona Laboratory of Paleontology (UALP); B.R. Stein, formerly of the Museum of Vertebrate Zoology, University of California, Berkeley (MVZ); R.M. Timm and T. Holmes, Mammals, and L. Martin, Paleontology, Natural History Museum, University of Kansas (KU); P. Gingerich and G.F. Gunnell, Museum of University of Michigan (UM); E. Birney (deceased), J.F. Bell Museum of Natural History, Collection of Mammals, University of Minnesota (MMNH); P. Myers, Museum of Zoology, University of Michigan (UMMZ); P.W. Freeman, University of Nebraska State Museum of Vertebrate Paleontology Collections (UNSM); T.L. Yates (deceased), Museum of Southwestern Biology, Division of Mammals, University of New

Mexico (MSB); and G. Schugart, James R. Slater Museum of Natural History, University of Puget Sound (PSM). I thank A. Carlson, Department of Geosciences, Oregon State University, for his assistance in establishing the chronostratigraphy. I thank 2 anonymous reviewers for their helpful suggestions. A.H. Harris, F.B. Stangl Jr., and B.J. Verts read an earlier draft of this manuscript.

LITERATURE CITED

- BAKER, R.J., M.B. O'NEILL, AND L.R. MCALILEY. 2003. A new species of desert shrew, *Notiosorex*, based on nuclear and mitochondrial sequence data. Occasional Papers, Museum of Texas Tech University 222:1–12.
- BASKIN, J.A. 1979. Small mammals of the Hemphillian age White Cone local fauna, northeastern Arizona. *Journal of Paleontology* 53:695–708.
- BELL, C.J., E.L. LUNDELIUS JR., A.D. BARNOSKY, R.W. GRAMHAM, E.H. LINDSAY, D.R. RUEZ JR., H.A. SEMKEN JR., S.D. WEBB, AND R.J. ZAKRZEWSKI. 2004. The Blancan, Irvingtonian, and Ranchoabrean mammal ages. Pages 232–314 in M.O. Woodburne, editor, *Late Cretaceous and Cenozoic mammals of North America: biostratigraphy and geochronology*. Columbia University Press, New York, NY.
- BUTLER, P.M., R.S. THORPE, AND M. GREENWOOD. 1989. Interspecific relations of African crocidurine shrews (Mammalia: Soricidae) based on multivariate analysis of mandibular data. *Zoological Journal of the Linnean Society* 96:373–412.
- CARRAWAY, L.N. 1995. A key to Recent Soricidae of the western United States and Canada based primarily on dentaries. Occasional Papers of the Natural History Museum, The University of Kansas 175:1–49.
- _____. 2005. Comparative osteology of the glenoid fossa and condyloid process in North American soricinae shrews (Soricomorpha: Soricidae). Pages 75–84 in V. Sánchez Cordero and R. Medellín Legorreta, editors, *Contribuciones Mastozoológicas en Homenaje a Bernardo Villa*. Instituto de Biología e Instituto de Ecología, Universidad Nacional Autónoma de México, México City, México.
- _____. 2007. Shrews of Mexico. *Monographs of the Western North American Naturalist* 3:1–91.
- CARRAWAY, L.N., AND R.M. TIMM. 2000. Revision of the extant taxa of the genus *Notiosorex* (Mammalia: Insectivora: Soricidae). *Proceedings of the Biological Society of Washington* 113:302–318.
- CHOATE, J.R. 1970. Systematics and zoogeography of Middle American shrews of the genus *Cryptotis*. University of Kansas Publications, Museum of Natural History 19:195–317.
- CLARK, W.K. 1953. Gray shrew, *Notiosorex*, from eastern Oklahoma. *Journal of Mammalogy* 34:117–118.
- COUES, E. 1877. Precursory notes on American insectivorous mammals, with descriptions of new species. *Bulletin of the United States Geologic and Geographical Survey of the Territories* 3(3):631–653.
- DALQUEST, W.W. 1972. A new genus and species of shrew from the upper Pliocene of Texas. *Journal of Mammalogy* 53:570–573.

- DALQUEST, W.W., AND E. ROTH. 1970. Late Pleistocene mammals from a cave in Tamaulipas, Mexico. *Southwestern Naturalist* 15:217–230.
- DALQUEST, W.W., E. ROTH, AND F. JUDD. 1969. The mammal fauna of Schulze Cave, Edwards County, Texas. *Bulletin of the Florida State Museum, Biological Sciences* 13:205–276.
- DANNELID, E. 1989. Medial tines on the upper incisors and other dental features used as identification characters in European shrews of the genus *Sorex* (Mammalia, Soricidae). *Zeitschrift für Säugetierkunde* 54:205–214.
- DUCOMMUN, M.-A., F. JEANMAIRE-BESANÇON, AND P. VOGEL. 1994. Shield morphology of curly overhair in 22 genera of Soricidae (Insectivora, Mammalia). *Revue Suisse de Zoologie* 101:623–643.
- HARRIS, A.H. 1987. Reconstruction of mid-Wisconsin environments in southern New Mexico. *National Geographic Research* 3(2):142–151.
- _____. 1989. The New Mexican late Wisconsin—east versus west. *National Geographic Research* 5(2):205–217.
- _____. 1998. Fossil history of shrews in North America. Pages 133–156 in J.M. Wójcik and M. Wolsan, editors, *Evolution of shrews*. Mammal Research Institute, Polish Academy of Sciences, Białowieża, Poland.
- HERSHKOVITZ, P. 1971. Basic crown patterns and cusp homologies of mammalian teeth. Pages 95–150 in A.A. Dahlberg, editor, *Dental morphology and evolution*. University of Chicago Press, Chicago, IL.
- HIBBARD, C.W. 1957. Notes on late Cenozoic shrews. *Transactions of the Kansas Academy of Science* 60:327–336.
- HIBBARD, C.W., AND D.W. TAYLOR. 1960. Two late Pleistocene faunas from southwestern Kansas. *Contributions from the Museum of Paleontology, The University of Michigan* 16:1–223.
- JAU-MEXIA, N., O.J. POLACO, AND J. ARROYO-CABRALES. 2000. New mammals for the Pleistocene of Zacatecas, Mexico. *Current Research in the Pleistocene* 17:124–125.
- LEAR, L.L., AND A.H. HARRIS. 2007. Holocene fauna of Big Manhole Cave, Eddy County, New Mexico. *Southwestern Naturalist* 52:110–115.
- LINDSAY, E.H., AND L.L. JACOBS. 1985. Pliocene small mammal fossils from Chihuahua, Mexico. *Paleontologica Mexicana* 51:1–59.
- LINDSAY, E.H., N.D. OPDYKE, AND N.M. JOHNSON. 1984. Blancan-Hemphillian land mammal ages and late Cenozoic mammal dispersal events. *Annual Review of Earth and Planetary Science* 12:445–488.
- LINDSTEDT, S.L. 1980a. Energetics and water economy of the smallest desert mammal. *Physiological Zoology* 53:82–97.
- _____. 1980b. Regulated hypothermia in the desert shrew. *Journal of Comparative Physiology B* 137:173–176.
- LUNDELIUS, E.L., JR. 1979. Post-Pleistocene mammals from Pratt Cave and their environmental significance. Pages 239–258 in H.H. Genoways and R.J. Baker, editors, *Biological investigations in the Guadalupe Mountains National Park, Texas*. National Park Service Proceedings and Transactions, Series 4:1–442.
- MARTINSON, D.G., N.G. PISIAS, J.D. HAYS, J. IMBRIE, T.C. MOORE JR., AND N.J. SHACKLETON. 1987. Age dating and the orbital theory of the ice ages: development of a high-resolution 0 to 300,000-year chronostratigraphy. *Quaternary Research* 27:1–29.
- MCALILEY, L.R., M.B. O'NEILL, AND R.J. BAKER. 2007. Molecular evidence for genetic subdivisions in the desert shrew, *Notiosorex crawfordi*. *Southwestern Naturalist* 52:410–417.
- OHDACHI, S.D., M. HASEGAWA, M.A. IWASA, P. VOGEL, T. OSHIDA, L.-K. LIN, AND H. ABE. 2006. Molecular phylogenetics of soricid shrews (Mammalia) based on mitochondrial cytochrome *b* gene sequences: with special reference to the Soricinae. *Journal of Zoology* 270:177–191.
- REPENNING, C.A. 1967. Subfamilies and genera of the Soricidae. *Geological Survey Professional Paper* 565:1–74.
- REUMER, J.W.F. 1998. A classification of the fossil and Recent shrews. Pages 5–22 in J.M. Wójcik and M. Wolsan, editors, *Evolution of shrews*. Mammal Research Institute, Polish Academy of Sciences, Białowieża, Poland.
- SCHMITT, D.N., D.B. MADSEN, AND K.D. LUPO. 2002. Small-mammal data on early and middle Holocene climates and biotic communities in the Bonneville Basin, USA. *Quaternary Research* 58:255–260.
- SEALANDER, J.A., JR. 1952. *Notiosorex* in Arkansas. *Journal of Mammalogy* 33:105–106.
- SMITH, F.A., J.L. BENTANCOURT, AND J.H. BROWN. 1995. Evolution of body size in the woodrat over the past 25,000 years of climate change. *Science* 270:2012–2014.
- STEADMAN, D.W., J. ARROYO-CABRALES, E. JOHNSON, AND A. FABIOLA GUZMAN. 1994. New information on the late Pleistocene birds from San Josecito Cave, Nuevo León, Mexico. *Condor* 96:577–589.
- VAN DEVENDER, T.R., AND G.L. BRADLEY. 1990. Late Quaternary mammals from the Chihuahuan Desert: paleoecology and latitudinal gradients. Pages 350–362 in J.L. Betancourt, T.R. Van Devender, and P.S. Martin, editors, *Packrat middens: the last 40,000 years of biotic change*. University of Arizona Press, Tucson, AZ.

Received 18 November 2008

Accepted 30 November 2009

Appendixes follow on pages 161–163.

APPENDIX 1.—Specimens from extant populations of *Notiosorex* examined or measured. Specimens are ordered alphabetically by country, state, county (for United States), collection locality, and catalog number. A *T* immediately following a catalog number indicates a type specimen.

Notiosorex cockrumi ($n = 18$)

MEXICO: SONORA: 14.6 mi E Mazocahui (MVZ 148830); 4.1 mi NW (by road) Nacori Chico (MVZ 148831).

UNITED STATES: ARIZONA: *Cochise Co.*: Leslie Canyon National Wildlife Reserve, T21S, R28E, NE 1/4 Sec. 20, 4660 m (TTU 82981–82984, 82986–82987, 82991, 82993–82994, 82996, 82998, 83502–83505, 100000T).

Notiosorex crawfordi ($n = 224$)

MEXICO: BAJA CALIFORNIA: 9 mi N Catavina on Mexico Hwy. 1 (MVZ 159725); 10 mi SE El Rosario (MVZ 159726); San Martín Island, 300 yards inland from Hassler's Cave (MVZ 136207); San Quintín (CAS 52); San Quintín, San Simon River (USNM 139592–139593); San Tomas (USNM 137142). BAJA CALIFORNIA SUR: Santa Anita (USNM 74550, 79088–79092, 146693, 146933–146934, 146936, 147352, 147421). CHIHUAHUA: 3.5 mi ESE Los Lamentos (KU 76488); 2 mi W Minaca (KU 109475). COAHUILA: 3 mi NW Cuatrociénegas (KU 51571–51572); El Gorrion Hwy. 54, km marker 80 (TTU 9728); Sabinas (USNM 277621). DURANGO: km 1134, Hwy. 45 (TTU 6284); 2 km SE Atotonilco, 6680 ft (MSU 13887–13888); 4.8 km SE Atotonilco, 6680 ft (MSU 13889–13890); 7 mi NNE Boquilla, 6400 ft (MSU 10260). HIDALGO: 11 km S, 1 km W Zacualtipán, ca. 1700 m (TTU 24185). NUEVO LEÓN: 3 mi SW Galeana, 5100 ft (MSU 10260, 11238). SINALOA: 5 mi WNW El Carrizo (KU 105409); El Fuerta (KU 75184); on Hwy. 15, 0.25 mi S Sonora line (UMMZ 109403). SONORA: 14.6 mi NW [by road] Nacori Chico (MVZ 148831); Rio Alamos (TTU 6323). ZACATECAS: Plateado (USNM 90845).

UNITED STATES: ARIZONA: *Apache Co.*: 1 mi N Spigerville (UMMZ 80236). *Cochise Co.*: 9.1 mi S Chiricahua (USNM 552386); Huachuca Mountains (MSB 62141–62144, 62146–62148, 62150, 62154–62155, 62158–62159, 62161–62166, 62168, 62171–62173, 62175–62177, 62179, 62183–62184, 62188–62189, 62210–62215, 62218–62219, 62223–62238); 20 mi E Pearce, Pinery Canyon, 6500 ft (UMMZ 64102). *Coconino Co.*: 10 mi SW Black Falls (USNM 244129); Grand Canyon (USNM 250676). *Crawford Co.*: Natural Dam (USNM 286549). *Greenlee Co.*: Blue River (USNM 144533). *Maricopa Co.*: Phoenix South Mountain (CAS 13928). *Pima Co.*: 36 mi S Tucson (USNM 272515–272516); 40 mi S Tucson (USNM 272844). *Santa Cruz Co.*: no locality (USNM 289955). *Yuma Co.*: Yuma (USNM 120357). ARKANSAS: *Crawford Co.*: Natural Dam (USNM 286549). CALIFORNIA: *Inyo Co.*: Panamint Range, Cottonwood Canyon (CAS 23228–23230); Saline Valley (CAS 21270); Saline Valley, Grapevine Canyon, 4036–5750 ft (CAS 21249–21269, 23231–23232); Silver Canyon Rd., 4.3 mi E [by road] jct. with California Hwy. 6 (MVZ 158116). *Riverside Co.*: Millard Canyon (CAS 23240). *San Bernardino Co.*: Cottonwood (CAS 23242); Deep Canyon (CAS 23238); Kingston Range (CAS 21518); San Gorgonia, Cottonwood (CAS 23233–23237, 23241); San Bernardino (USNM 187011). *San Diego Co.*: no locality (USNM 62619); Escondido (MVZ 33582); 9 mi W Escondido (MVZ 33388); Lakeside, head of Wildcat Canyon, 2100 ft (KU 92627); Santer Mountains (USNM 62919); Lakeside, head of Wildcat Canyon, 2100 ft (KU 92627).

COLORADO: *Baca Co.*: 14 mi N, 4 mi E Springfield (KU 116960). *Fremont Co.*: Phantom Canyon, Eightmile Creek (KU 125348–125367); Wet Mountain (KU 125368–125379). *Montezuma Co.*: Mesa Verde National Park (KU 105109). *Otero Co.*: 3 mi NW Higbee (KU 51673). NEW MEXICO: *Grant Co.*: San Luis Spring, Mexican Boundary, 1577 m (USNM 38250). *Hidalgo Co.*: no locality (KU 145266; MSB 46468); 7 mi W Animas, Peloncillo Mountains (KU 145265); 0.5 mi N Hwy. 9, 7.5 mi W Animas, Antelope Pass, Animas Mountains (KU 145258–145259); Cienega Ranch ruins, 8.7 mi N jct. I-80 and NM Hwy. 9 (KU 144031); Guadalupe Canyon, Peloncillo Mountains (ca. 30 mi E Douglas, AZ) (KU 145260–145265); San Luis Spring, Mexican Boundary (USNM 38250). *Lincoln Co.*: Capitan Mountains (USNM 127229); Shafer Ranch (UMMZ 114784). *Otero Co.*: 3 mi N Tularosa (UMMZ 81380). *Union Co.*: Tollgate Canyon, 10 mi N Folsom (MWSU 15900). *Valencia Co.*: Juan Tofoya (USNM 147966). NEVADA: *Nye Co.*: 1 mi N, 5 mi E Grapevine Peak, 5000 ft (MVZ 92391). OKLAHOMA: *Cimarron Co.*: 2 mi N Kenton (MWSU 15867–15868, 15895); 3 mi N Kenton (MWSU 15902); 4 mi N Kenton (MWSU 15779). *Comanche Co.*: Wichita Mountains National Wildlife Refuge (USNM 271959). *Harmon Co.*: 4 mi S Hollis (OSU 5823). TEXAS: *Archer Co.*: jct. U.S. 82 and 277, 22 mi SW Holliday (UMMZ 167208–167209); 14 mi WNW Archer City (MWSU 8584, 8586); Lake Kickapoo (MWSU 7016, 11106). *Bexar Co.*: San Antonio (USNM 125708). *Brewster Co.*: Burro Mesa, 3500 ft (MVZ 80281). *Brisco Co.*: Tule Canyon (UMMZ 67277). *Cottle Co.*: 8 mi ESE Paducah (KU 64560). *Dickens Co.*: 1 mi E Dickens (MWSU 2543). *El Paso Co.*: near Fort Bliss, about 2 miles above El Paso (USNM 2653/4437T). *Garza Co.*: no locality (MMNH 12502–12503); 1 mi SE Post (PSM 13878). *Hansford Co.*: 10 mi S, 3 mi W Gruver (KU 119395). *Howard Co.*: Big Spring (UMMZ 80248). *Jim Wells Co.*: near Alice (TCWC 53283). *Knox Co.*: 4 mi E Benjamin (MWSU 16023). *Nueces Co.*: Corpus Christi (USNM 120087).

Notiosorex evotis ($n = 43$)

MEXICO: JALISCO: area of Chapala and Ajijic (K. Wilkins private collection, 3 specimens from containers on roadsides); 13 mi S, 15 mi W Guadalajara (KU 33318); 21 mi SW Guadalajara (KU 42583–42585); La Unión, 28 km S Lagos (CB 2410). MICHOACÁN: 2 mi E La Palma, SE side of Lago de Chapala (KU 42586–42588). NAYARIT: 31 km S, 44.3 km W Compostela (CB 18864); El Refilion (USNM 508358); Tepic (USNM 314064). SINALOA: 20 km N, 5 km E Badiraguato (KU 96419); Hwy. 15, 0.25 mi S Sonora line, El Carrizo, 50 ft (UMMZ 109403); 5 mi WNW El Carrizo (KU 105409); Laguna, 17 mi SW Choix, 500 ft (KU 89215); 16 km NNE Choix, 1700 ft (KU 89210–89213); 1 mi SE El Cajón, 1800 ft (KU 100319); 15 mi SE Escuinapa (MSU 5691); Isla Palmito del Verde, 6 mi NNW Teacapan (KU 98880); Laguna, 17 mi SW Choix, 500 ft (KU 89214–89216); Mazatlán (KU 85533–85536; USNM 9066); 1 mi N Mazatlán, 25 ft (MSU 8149); 3 mi SW Pánuco (CNMA 26554); Rosario, 500 ft (KU 90581); 10 km S, 38 km E Sinaloa (KU 125475–125479); 44 km ENE Sinaloa, 600 ft (KU 89998); on Hwy. 15, 0.25 mi S Sonora line (UMMZ 109403).

Notiosorex villai ($n = 3$)

MEXICO: TAMAULIPAS: Jaumave, 2400 ft (KU 54932T); Palmillas, [23°18'N, 99°33'W], 4400 ft (KU 54933); 0.3 mi

SW Rancho Carricitos, San Carlos Mountains, 1900 ft (TCWC 30492).

APPENDIX 2.—Fossil specimens of *Notiosorex* examined or measured. Specimens are ordered by country, state, county (for United States), collection locality, catalog number, and estimated date of deposit from which specimen was obtained.

Notiosorex dalquesti ($n = 618$)

MEXICO: CHIHUAHUA: Jiménez Cave (UTEP 91-29, 91-386, 91-485, 91-540–91-543 [probably <30,000 BP to present]); Jiménez Cave (UTEP 91-544, 91-546–91-547, 91-674, 91-1050 [Pleistocene/Holocene]). NUEVO LEÓN: San Josecito Cave (INAH 6 specimens [<45,000 BP, Steadman et al. 1994]). ZACATECAS Municipal Panuco, 23°05'15"N, 102°31'20"W, 2150 m (Jau-Mexia et al. 2000).

UNITED STATES: ARIZONA: *Pima Co.*: Silverbell Mountains, Wolcott Peak (UALP 7240/5669 [12,130 BP, RanchoLabrean]). *Santa Cruz Co.*: Papago Springs Cave, Canelo Hills, V008 (OMNH 51482–51488, 52743, 53069–53070, 53220–53221, 53228, 53427 [Quaternary, 42,000 BP, mid-Wisconsinan]). KANSAS: *Meade Co.*: Cragin Quarry (UM 35557–35560, 35561 [includes 3 specimens; Pleistocene]). NEW MEXICO: *Dona Ana Co.*: Khulo site, I (UTEP 21-314, 21-324 [mid- or early Holocene]); Khulo site, III (UTEP 21-1, 21-3, 21-6–21-7, 21-11, 21-13, 21-15, 21-21–21-50 [possibly Wisconsin, probably early Holocene]); Khulo site, III (UTEP 21-316–21-323, 21-326–21-346 [mid- or early Holocene]). *Eddy Co.*: Algerita Blossom Cave (UTEP 119-34 [late Pleistocene]); Big Manhole Cave, BH pit 0–10 cm (UTEP 120-408, 120-447–120-449 [¹⁴C of 565 BP]); Big Manhole Cave, BH pit 10–20 cm (UTEP 120-255–120-256, 120-258–120-260, 120-310, 120-312–12-314, 120-322, 120-463–120-465, 120-473–120-474, 120-826–120-828, 120-2739–120-2741 [¹⁴C of 1360 BP]); Big Manhole Cave, BH pit 20–30 cm (UTEP 120-249–120-250, 120-253, 120-365, 120-367–120-368, 120-397, 120-498–120-499, 120-502–120-503, 120-543–20-544, 120-1311, 120-2525, 120-2527–120-2528 [2085 ± 45 BP]); Big Manhole Cave, BH pit 30–40 cm (UTEP 120-337–120-342, 120-551, 120-644–120-646, 120-648–120-653, 120-655–120-656, 120-884–120-889, 120-891–120-893, 120-895, 120-929–120-930, 120-2356–120-2361, 120-2827, 120-2859–120-2862 [3035 ± 60 BP]); Big Manhole Cave, BH pit 40–50 cm (UTEP 120-211, 120-371–120-372, 120-1451, 120-2144, 120-2583 [Holocene]); Big Manhole Cave, BH pit 40–50 cm (UTEP 120-210, 120-425–120-427, 120-431–120-434, 120-734–120-735, 120-740–120-741, 120-2311–120-2316, 120-2760–120-2765, 120-2802–120-2803 [3580 ± 75 BP]); Big Manhole Cave, BH pit 50–60 cm (UTEP 120-461, 120-1176–120-1179, 120-1540, 120-2095–120-2098, 120-2209–120-2210, 120-2969–120-2970 [4020 ± 120/–115 BP]); Big Manhole Cave, BH pit 60–70 cm (UTEP 120-804–120-805, 120-1079 [includes 2 specimens], 120-1471, 120-1507, 120-1984, 120-1986–120-1988, 120-2176–120-2177 [4025 ± 75 BP]); Big Manhole Cave, BH pit 70–80 cm (UTEP 120-693, 120-1402–120-1403, 120-1810–120-1815, 120-2633 [4170 ± 195/–190 BP]); Big Manhole Cave, BH pit 90–100 cm (UTEP 120-747, 120-975, 120-1014, 120-1051, 120-1277, 120-1292, 120-1450, 120-1518, 120-1644–120-1645, 120-1906–120-1910, 120-1975, 120-2143, 120-2335, 120-2584, 120-2653–120-2654, 120-2682–120-2683, 120-2693, 120-2875, 120-3005 [Holocene]); Big Manhole Cave, survey point F4-C (UTEP 120-150 [early, ca. 30,000 BP]); Burnett Cave, near Carlsbad (UNB-ZM

1161-5 [7432 BP]); Dark Canyon Cave (UTEP 75-352 [probably ca. 20,000 BP]); Dry Cave, Balcony Room, grid 6 L1, test trench (UTEP 12-141, 12-289, 12-294, 12-297 [probably ca. 12,000 BP]); Dry Cave, entrance chamber (UTEP 24-16 [probably mid-Holocene]); Dry Cave, entrance chamber (UTEP 24-33 [late Holocene]); Dry Cave, entrance chamber (UTEP 24-69 [mid- or late Holocene]); Dry Cave, second test pit Bison Chamber (UTEP 4-450 [11,000–14,000 BP]); Muskox Cave, Carlsbad Caverns National Park (NMNH-C-33 [18,140–25,500 BP]). *Grant Co.*: Howell's Ridge Cave (UTEP 32-4, 32-6–32-23, 32-26–32-27 [mixed Wisconsin/Holocene]); Howell's Ridge Cave (UTEP 32-518, 32-520, 32-525 [Wisconsin or Holocene]). *Hidalgo Co.*: Guadalupe Canyon (KU 145262 [late Holocene?]); U-Bar Cave (LA 5689) (MNM 5689-162-4 [13,000–14,000 BP]); U-Bar Cave (LA 5689) (MNM 5689-99-26 [13,000–15,000 BP]); U-Bar Cave (LA 5689) (MNM 5689-98-18, 5689-98-24, 5689-109-58, 5689-109-62, 5689-109-63, 5689-109-72, 5689-109-94, 5689-162-56 [14,000–15,000 BP]); U-Bar Cave (LA 5689) (MNM 5689-153-7, 5689-153-216, 5689-153-255 [15,000–18,000 BP]); U-Bar Cave (LA 5689) (MNM 5689-153-236, 5689-153-249 [18,000–22,000 BP]); U-Bar Cave (LA 5689) (MNM 5689-4-29, 5689-4-54, 5689-4-55, 5689-4-74, 5689-6-34–5689-6-37, 5689-9-12, 5689-9-14, 5689-9-22, 5689-9-26, 5689-12-01, 5689-71-11, 5689-71-12, 5689-73-15, 5689-73-16, 5689-73-40, 5689-78-34, 5689-80-01, 5689-81-04, 5689-81-29, 5689-86-17 [>25,000 BP]); U-Bar Cave (LA 5689) (MNM 5689-111-5, 5689-130-12–5689-130-16, 5689-130-18–5689-130-19, 5689-133-13, 5689-133-39, 5689-140-7, 5689-140-62, 5689-140-63, 5689-145-4–5689-145-6 [late "late" Pleistocene]). *Luna Co.*: Baldy Peak Cave (UTEP 94-02 [late Pleistocene to late Holocene]); Baldy Peak Cave (UTEP 94-03 [Wisconsin/Holocene]). *Otero Co.*: Pendejo Cave (FTBL 9366.G.0717.337.001 [probably modern intrusive]); Pendejo Cave (FTBL 9366.G.1072.337.001, 9366.G.9949.337.013 [30,210 to >55,000 BP]); Pendejo Cave (FTBL 9366.G.1480.337.001, 9366.G.1883.337.001 [1780–16,410 BP]); Pendejo Cave (FTBL 9366.G.2143.337.012 [19,360–28,430 BP]); Pendejo Cave (FTBL 9366.G.9976.337.002 [30,210 to >55,000 BP]). *Union Co.*: Tollgate Canyon, 10 mi N Folsom (MWSU 15900 [late Holocene]). OKLAHOMA: *Cimarron Co.*: 2 mi N Kenton (MWSU 15779, 15867–15868, 15895, 15902 [late Holocene]); Tesequite Canyon, 6 km SSE Kenton, ca. 5000 ft. (MWSU 12410 [31,360 ± 570 BP, early–late Wisconsinan]). TEXAS: *Archer Co.*: 14 mi WNW Archer City (MWSU 8584, 8586 [late Holocene]); Lake Kickapoo (MWSU 5614 [late Holocene]); NW side Lake Kickapoo (MWSU 7016, 11106 [late Holocene]). *Culberson Co.*: Fowlkes Cave, 6 mi N Kent (MWSU 662 [includes 16 specimens; Holocene]); Fowlkes Cave, 6 mi N Kent (MWSU 662-4 [includes 5 specimens; <4000 BP, Holocene]); Fowlkes Cave, 6 mi N Kent (MWSU 11930-1–11930-3, 11930-4 [includes 10 specimens], 11930-5 [includes 10 specimens], 11930-6–11930-18, 11930-19 [includes 10 specimens], 11930-20 [includes 10 specimens], 11930-21 [includes 11 specimens], 11930-22 [includes 10 specimens], 11930-23 [includes 10 specimens], 11930-24 [includes 5 specimens], 11930-25 [includes 10 specimens], 11930-26 [includes 10 specimens], 11930-27 [includes 9 specimens], 11930-28 [includes 10 specimens; late "late" Pleistocene]). *Dickens Co.*: 1 mi E Dickens (MWSU 2543 [late Holocene]). *Edwards Co.*: Schultz Cave, 45 km E Rockspring (MWSU 7259-1–7259-64 [8000–9310 BP, RanchoLabrea, Pleistocene]). *El Paso Co.*: Anthony Cave (UTEP 29-101–29-102, 29-151 [<35,000, Wisconsin, Pleistocene]).

Notiosorex harrisi (n = 49)

MEXICO: CHIHUAHUA: Jiménez Cave (UTEP 91-545, 91-591 [Pleistocene/ Holocene]).

UNITED STATES: ARIZONA: *Navajo Co.*: White Cone local fauna (UALP WC-22 [II], WC-23 [R P4], WC-24 [L P4], WC-25 [Hemphillian]). NEW MEXICO: *Dona Ana Co.*: Khulo site, III C/3 (UTEP 21-14 [possibly Wisconsin, probably early Holocene]); Khulo site, III C/6 (UTEP 21-315 [mid- or early Holocene]); Khulo site, III C/7 (UTEP 21-325 [mid- or early Holocene]); Shelter Cave, W face Bishop's Cap (UTEP 30-1 [Wisconsin or Holocene]). *Eddy Co.*: Big Manhole Cave, BH pit 10–20 cm (UTEP 120-261, 120-311, 120-824, 120-825 [¹⁴C of 1360 BP]); Big Manhole Cave, BH pit 20–30 cm (UTEP 120-357, 120-362, 120-366, 120-1312, 120-1313, 120-2526 [2085 ± 45 BP]); Big Manhole Cave, BH pit 30–40 cm (UTEP 120-336, 120-647, 120-654, 120-883, 120-890, 120-894 [3035 ± 60 BP]); Big Manhole Cave, BH pit 40–50 cm (UTEP 120-2310 [3580 ± 75 BP]); Big Manhole Cave, BH pit 60–70 cm (UTEP 120-803, 120-1078, 120-1472, 120-1473, 120-1983, 120-1985 [4025 ± 75 BP]); Big Manhole Cave, BH pit 70–80 cm (UTEP 120-1809 [4170 + 195/–190 BP]); Big Manhole Cave, BH pit 90–100 cm (UTEP 120-973, 120-974, 120-1068 [Holocene]); Big Manhole Cave, BH pit 120–130 cm (UTEP 120-1643 [Holocene]); Big Manhole Cave, BH pit 140–150 cm (UTEP 120-1276 [Holocene]); Burnett Cave, near Carlsbad (UNSM-ZM 1162-5 [7432 BP]); Dry Cave (UTEP 54-1227 [terminal Pleistocene, ¹⁴C 10,730 BP]); Dry Cave, Harris' Pocket (UTEP 6-5810 [¹⁴C of 14,470 BP]); Dry Cave, beyond Balcony Room (UTEP

3-31 [probably late Wisconsin, possibly Holocene]). *Grant Co.*: Howell's Ridge Cave (UTEP 32-5, 32-25 [mixed Wisconsin/Holocene]). *Hidalgo Co.*: U-Bar Cave, LA 5689, D-246 minimum contamination (MNM 5689-006-07 [>25,000 BP]); U-Bar Cave, LA 5689, P-300 SE 1/9=P-299-3 20–30 cm (MNM 5689-15-01 [>18,000, possibly <25,000 BP]); U-Bar Cave, LA 5689, F-227-1 F-227-2 near top (MNM 5689-86-10 [>25,000 BP]); U-Bar Cave, LA 5689, layer E-246-1 –0.8 to –1.3 m (MNM 5689-133-33 [late "late" Pleistocene]); U-Bar , LA 5689, layer H-231-2 –0.45 to –0.5 m (MNM 5689-153-61 [late "late" Pleistocene]).

Notiosorex jacksoni (n = 143)

UNITED STATES: KANSAS: *Meade Co.*: Cottrell Pasture, Rexroad, [T33S, R29W, NW 1/4 SE 1/4 Sec. 16] (UM 50874 [Pliocene]). *Meade Co.*: Fox Canyon, XI Ranch, loc. UM-K1-47, T34S, R30W, Sec. 35 (UM 9835, 24348, 24350–24351, 24354–24358, 24356, 24360–24363, 27257–27261, 27263–27265, 27293, 27294 [includes 12 specimens], 27295 [includes 37 specimens], 27296, 27297–27304, 28415 [includes 44 specimens], 28416–28421, 28422–28428, 39664, 39665 [includes 2 specimens; Upper Pliocene, 3.70 ± 0.72 m.y.]); Keefe Canyon, loc. 22 (KU 7011 [Pliocene]).

Notiosorex repenningi (n = 1)

MEXICO: CHIHUAHUA: Concha fauna, CH-17, near Yepómera, locality 8222, Y40, cast of holotype (UALP 14723 [Blancan]).