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# Rediscovery of the extinct Tule shrew (*Sorex ornatus juncencis*) in the San Quintin plains: a taxonomic reevaluation after 90 years without new records

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**Abstract:** In this study, we investigate the geographic distribution of the Tule shrew (*Sorex ornatus juncensis*), an endemic subspecies of the San Quintin plains associated with coastal vegetation. Records on this shrew are scarce; herein, we provide knowledge about its current conservation status and report the presence of one Tule shrew specimen, something that has not happened since 1926. The distribution of the Tule shrew is associated with coastal vegetation, limited to the San Quintin plains, with scarce records. Field trips were conducted during 2013–2015 in the San Quintin plains and San Pedro Martir range of the Baja California Peninsula. The sampling effort was 3250 trap nights. One specimen of *S. o. juncensis* was recorded in association with coastal sage-scrub vegetation and identified following the original description, based on its narrower skull relative to *Sorex ornatus ornatus*. We used a mitochondrial cytochrome *b* gene sequence (384 bp) to confirm this identification and compare genetic distances using the Kimura's two-parameter nucleotide substitution model vs. other populations of the *ornatus* group. We found a genetic divergence of less than 1.0% based on sequences from specimens collected from Sierra San Pedro Martir, El Rosario and Sierra La Laguna. In the locality of the *S. o. juncensis* specimen collected, the original vegetation consists of patches of coastal scrubs, which cover an area of less than 1 km$^2$, affected by agriculture and habitat fragmentation. We reallocated the taxonomic level of the Tule shrew inhabiting the plains of San Quintin in the Baja California Peninsula to subspecies as *S. o. juncensis* based on geographic isolation, morphometric characteristics and coloration differences vs. *S. o. ornatus*. The population inhabiting San Quintin plains is subjected to strong pressure due to habitat loss.

**Keywords:** extinct; insectivore; Mexico; nomenclature; rediscovery.

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*Sorex juncensis* was considered a full species by Hall (1981), first described as *Sorex californicus juncensis* (Nelson and Goldman 1909). The description was made from the only two known specimens collected. The type is from 15 miles south of San Quintin, at the El Socorro River mouth in Baja California, Mexico. No other specimens of this population are known (Maldonado 1999). Today, this taxon is considered as subspecies of *Sorex ornatus juncensis* (Junge and Hoffman 1981, Maldonado 1999, Maldonado et al. 2004). The latest specimens known from this area were collected in 1922. Subsequent collection surveys failed to detect this subspecies; two previous collection surveys have been conducted in the past, with no results about this population (Huey 1964, Maldonado 1999), and five more were undertaken by the Centro de Investigaciones Biológicas del Noroeste between 1998 and 2015. The El Socorro area used to be a marshland, which has become dry at least since 1984, and is currently the site of a small housing development. Given the extensive targeted surveys with no detection, and the major habitat reduction and alteration, the population of *S. o. juncensis* was deemed extinct (Maldonado 1999, Carraway 2007).

The San Quintin plain is located in the northwestern portion of the Baja California Peninsula and stretches from Santo Tomas River to El Socorro. The San Quintin plain includes flat areas with deep soil, suitable sites for agriculture; thus, this is the main agricultural region in the state of Baja California, a region dominated by deserts and mountains elsewhere. Also, this explains why virtually all the original habitat along coastal marshes has been destroyed, leading to a significant impact on local shrew populations (Williams 1986). The shift in the vegetation cover and agricultural activities are the main factors underlying the likely local extinction of the kangaroo rat *Dipodomys gravipes* in the same area and habitat (Álvarez-Castañeda et al. 2008). Herein, we provide noteworthy

data on the recent collection of *Sorex ornatus juncensis*, and report the first specimen known since 1922, which should be considered as belonging to a population that is highly vulnerable to extinction.

Field trips were conducted from 2013 to 2015 to the San Quintin plains and San Pedro Martir range in the northwestern portion of the Baja California Peninsula. The sampling effort was 650 trap nights during 5 days for a total of 3250 trap nights in five localities: Santo Tomas, San Telmo, San Quintin, El Socorro and San Pedro Martir (Figure 1). All specimens are deposited in the mammal collection at Centro de Investigaciones Biológicas del Noroeste (CIB). Collection records of the species for the northwestern region of the Baja California Peninsula were obtained using the VertNet database (www.vertnet.org).

One adult male was collected in Santo Tomas (CIB 27879) and identified as *Sorex ornatus juncensis*, using the original description of the subspecies (Nelson and Goldman 1909). *Sorex ornatus juncensis* is characterized based on a narrower skull relative to other members of *Sorex ornatus*; in addition, it was compared to the type material deposited at the National Museum of Natural History of the Smithsonian Institution (USNM 139594). Eleven morphometric measurements were recorded from skull photographs using the software TPSDig, ver. 2.16 (Rohlf 2010) and compared with two *Sorex ornatus ornatus* individuals (CIB 23392, 29050) from Sierra de San Pedro Martir. These measures were greatest skull length (GSL); skull breadth (SB); interorbital width (IW); width across the first upper incisors (W11-11); nasal length (NL); width across molars (WM); width across the fourth unicuspids (WU4-U4); unicuspid tooth row length (URL); molariform tooth row length (ML); palatal length (PL); and post-palatal length (PPL). Five somatic measurements were taken from the labels total length (LT); tail length (LC); hind foot length (LP); ear length (LO); and weight in grams (Figure 2).

The pelage color pattern of the collected specimens and the holotype were recorded under uniform light conditions through direct visual comparison using Munsell Soil Color Charts (Munsell Color Co. 1975). For each color, the key, chart hue, chroma and color name (i.e. 10YR 8/4, chart hue/chroma) were used.

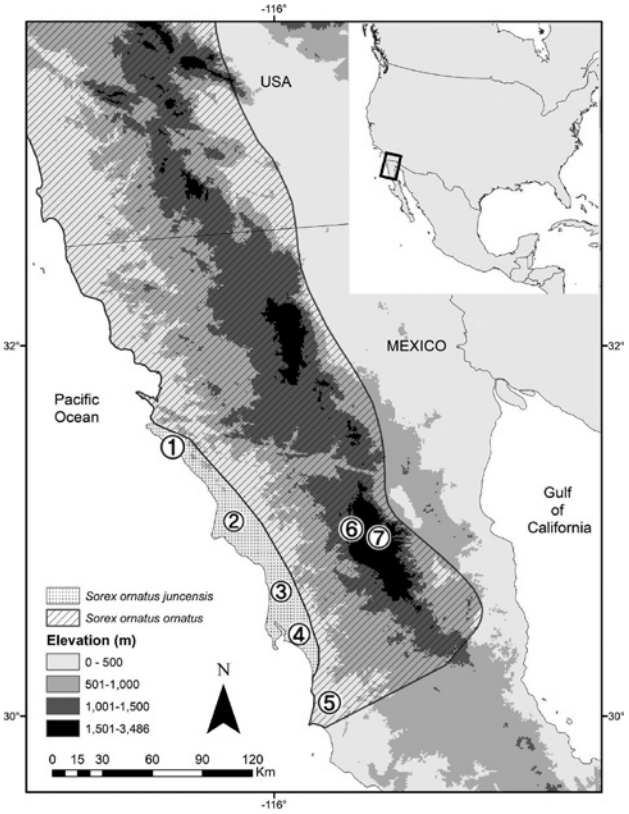


**Figure 1:** Distribution of *Sorex ornatus* in northwestern Mexico, modified from Hall 1981, Maldonado 1999.
The dotted area is the San Quintin plains and the distribution of *S. juncensis*. Numbers represent records: (1) Santo Tomas, the new record and extension of the previous distribution. (2) San Telmo and (3) San Quintin are records obtained through databases. (4) El Socorro; type locality of the Tule shrew. Diagonal lines depict the distribution range of *S. o. ornatus*. (5) El Rosario. (6) Locality sampled in San Pedro Martir and (7) recorded locality in San Pedro Martir.

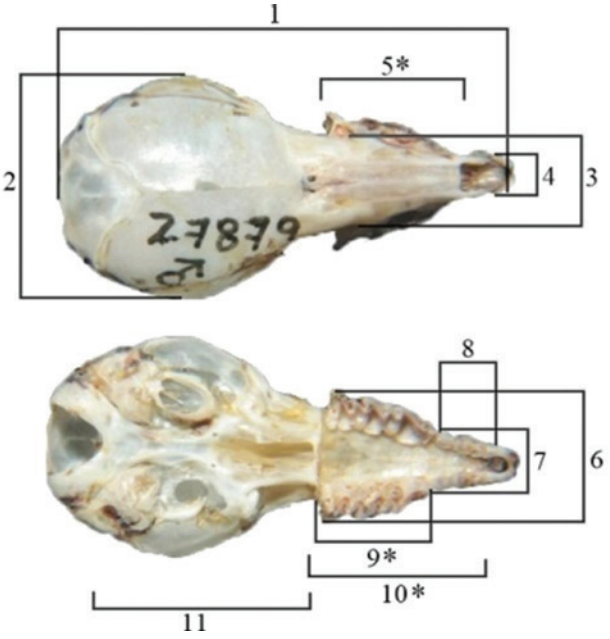


**Figure 2:** Dorsal and ventral view of measurements of *Sorex ornatus*: (1) greatest skull length; (2) skull breadth; (3) interorbital width; (4) width across the first upper incisors; (5) nasals length; (6) width across molars; (7) width across the fourth unicuspids; (8) unicuspid tooth row length; (9) molariform tooth row length; (10) palatal length; (11) post-palatal length.
Asterisks indicate the measures that are unique to the Tule shrew.

The taxonomic identification was confirmed by the amplification of the mitochondrial cytochrome *b* gene using primers MVZ05 and MVZ16 (Smith and Patton 1993) following the protocol used by Álvarez-Castañeda and Murphy (2014). Sequences were run on an ABI 3730 sequencer (Applied Biosystems) at the Museum of Vertebrate Zoology. The sequences obtained were compared with previous sequences recorded in the GenBank for the *ornatus* species group *Sorex ornatus, Sorex monticula* and *Sorex vagrans* (Maldonado et al. 2001). Pairwise evolutionary distances between haplotypes were determined using the Kimura two-Parameter method (Kimura 1980) using the software program MEGA v6 (MEGA Inc., Englewood, NJ, USA) (Tamura et al. 2013). A VertNet search yielded 19 specimens collected from the San Quintin plains, northwestern Baja California Peninsula (from Santo Tomas to El Socorro), all identified as *Sorex ornatus juncensis* (n = 2, 15 mi S of San Quintin, 30.316° N, –115.821° W, 139594, 147400 United States National Museum; n = 1, San Quintin, 30.575° N, –115.933° W; 4138 California Academy of Sciences, July 22, 1922), 126 km away from our new record, and 16 were identified as *Sorex ornatus ornatus* (n = 10, San Telmo 30.966° N, –116.100° W, 35396–35405 Museum of Vertebrate Zoology, April 7, 1925; and n = 3, San Telmo 30.966° N, –116.100° W, 79586–79588 University of Michigan, Museum of Zoology, January 27, 1926; Santa Quintin, n = 3, *ca* 30.560° N, –115.942° W, 10843–10845 Field Museum of Natural History, from 31 July, 1 to 2 August 1902).

From an effort of 3250 trap nights in four localities in Baja California, *Sorex ornatus* specimens were collected from the San Pedro Mártir range (30.966° N, –115.350° W; n = 2, CIB 23392, 29050), Santo Tomas (31.534° N, –116.657° W; n = 1, CIB 27879), on November 29, 2015, along with the desert shrew *Notiosorex crawfordi* from the San Quintin area (30.333° N, –115.8333° W; n = 3, CIB 27880–27882). No shrew records were obtained from Colonet (30.973° N, –116.272° W; Figure 1).

The specimen from Santo Tomas was found dead in a Sherman trap (H. B. Sherman Traps, Inc., Tallahassee, FL, USA), along with coastal sage scrub vegetation (*Artemisia californica*, *Salvia apiana*, *Salvia munzii* and *Rhus integrifolia*), under a stream willow (*Salix lasiolepis*), a site 152 km away from the type locality. Other mammal species collected in the area are *Notiosorex crawfordi*, *Neotoma bryanti, Peromyscus californicus, Peromyscus maniculatus, Peromyscus truei, Peromyscus fraterculus* and *Reithrodontomys megalotis*.

The morphometric analyses showed differences greater than 10% in the width across incisors, width across unicuspids and length of the unicuspid tooth row between the Santo Tomas specimen and *Sorex ornatus ornatus*, but less than 1.6% vs. the holotype of *Sorex ornatus juncensis* (Table 1). The most representative variation in measures between the subspecies of *Sorex ornatus* are the nasal length, molariform tooth row length and palatal length (Table 1).

**Table 1:** Measurements (mm) obtained from the comparison of *Sorex o. juncensis* with *S. o. ornatus*.

| | *S. o. juncensis* | | *S. o. ornatus* | | Difference (%) |
|---|---|---|---|---|---|
| | USNM 139594 | CIB 27879 | CIB 23392 | CIB 29050 | |
| LT | 101 | 105 | 101 | 97 | –3.88 |
| LC | 41 | 45 | 38 | 31 | –19.77 |
| LP | 12.5 | 12 | 11 | 10 | –14.29 |
| LO | 6 | 4 | 5 | 5 | 0.00 |
| Weight | 5 | – | 5 | 5 | 0.00 |
| GSL | 161 | 160 | 164 | 163 | 1.87 |
| SB | 76 | 75 | 83 | 82 | 9.27 |
| IW | 30 | 33 | 34 | 32 | 4.76 |
| W11-11 | 13 | 13 | 15 | 14 | 11.54 |
| NL | 52 | 50 | 48 | 47 | –6.86 |
| WM | 44 | 46 | 49 | 48 | 7.78 |
| WU4-U4 | 20 | 21 | 23 | 23 | 12.20 |
| URL | 21 | 20 | 24 | 23 | 14.63 |
| ML | 42 | 42 | 40 | 40 | –4.76 |
| PL | 63 | 64 | 58 | 60 | –7.09 |
| PPL | 68 | 69 | 69 | 70 | 1.46 |

LT, Total length; LC, tail length; LP, hind foot length; LO, ear length; weight in grams; GSL, greatest skull length; SB, skull breadth; IW, interorbital width; W11-11, width across the first upper incisors; NL, nasals length; WM, width across molars; WU4-U4, width across the fourth unicuspids; URL, unicuspid tooth row length; ML, molariform tooth row length; PL, palatal length; PPL, post-palatal length. The far right column shows the relative value of the average for *S. o. juncensis* minus the average for *S. o. ornatus*, in percent.

The pelage of the *Sorex ornatus ornatus* specimens from San Pedro Martir (CIB 23392, 29050) following the nomenclature of Munsell Soil Color Charts is as follows: back, rump and sides black (10YR 2/1) and underparts yellowish brown (10YR 5/4). In the *Sorex ornatus juncensis* specimen from Santo Tomas (CIB 27879), the back is intensely dark brown (10YR 3/1), rump black (10YR 2/1), sides very dark grayish (10YR 4/2) and underparts yellowish brown (10YR 5/4); the pectoral region and both forelimbs are white, a condition known as leucism.

The Tule shrew (GenBank MH420446) shows genetic distances (cytb) of 9.04% with *Sorex monticula* (GenBank AF300653), 8.71% with *Sorex vagrans* (GenBank AF300657) and less than 1% with populations of *Sorex ornatus* from the Baja California Peninsula (GenBank AF300695, AF300693, AF300676, AF300677, AF300675) and from the Heart bar

campground, San Bernardino National Forest (Museum Southwestern Biology 40419, GenBank KF302839; 34.1586° N, –116.7859° W). The genetic distances using the Kimura's two-parameter substitution model of *Sorex ornatus juncensis* in relation to *S. vagrans* are 8.71, with *S. monticolus* 9.04, with *Sorex ornatus lagunae* 0.02, and with *Sorex ornatus ornatus* from San Pedro Martir 0.01 and from El Rosario 0.04.

In the original description (Nelson and Goldman 1909), no color differences were described between *Sorex ornatus ornatus* and *Sorex ornatus juncensis*. However, the analyses of specimens show that *S. o. ornatus* is lighter than *S. o. juncensis* and can be differentiated by its color pattern. The most important differences between both subspecies, which can be used as distinctive traits, are the rostrum length and skull width. The nasal length, molariform tooth row length and palatal length are all proportionately larger in *S. o. juncensis*, while in *S. o. ornatus* these are shorter, with a wider skull (Table 1).

Santo Tomas, the area where *Sorex ornatus juncensis* was collected, has a coastal scrubland microhabitat of less than 1 km$^2$. This locality is in the same floristic region (González-Abraham et al. 2010) as the type locality where *Sorex juncensis* was collected (Nelson and Goldman 1909). The genetic distance of *S. o. juncensis* is lower than 1% with the southern clade (sensu Maldonado et al. 2001) and 0.62% with *Sorex ornatus ornatus* form San Pedro Martir, located less than 50 km in straight line in the highlands. The population identified as *Sorex ornatus* from El Rosario is associated with mountainous areas, similar to *S. o. ornatus*.

*Sorex ornatus ornatus* is distributed throughout the Baja California Peninsula, associated with mountainous areas. While *Sorex ornatus juncensis* is restricted to the San Quintin plains, the 14 known specimens of *Sorex ornatus* from Santo Tomas, San Telmo, San Quintin and El Socorro should be considered to be *S. o. juncensis*, because all were collected in a very specific habitat and are ecologically isolated.

The record reported here is the first *Sorex ornatus juncensis* specimen spotted since 1926 (90 years ago) when an individual was captured in the San Quintin plains, northwestern Baja California Peninsula. *Sorex ornatus juncensis* is a subspecies which was previously deemed extinct (Maldonado 1999, Carraway 2007). The loss of habitat is a threat to biodiversity, and scientific collections can document the pace of these changes over time, as well as their impact on the environment. We propose that additional specimens should be collected for the determination of differences between these populations, as information is essential for understanding the taxonomic status of poorly studied groups such as shrews. The specimen collected evidences that *S. o. juncensis* is not yet extinct and broadens its distribution range to areas with less human impact within the San Quintin plains, from Santo Tomas to El Socorro. Therefore, we consider that the Tule shrew populations should be considered as highly vulnerable to extinction by habitat loss that restrains the connectivity across its range and with other populations of *Sorex ornatus*. Other shrew subspecies threatened as a result of the destruction of wetlands and riparian habitats are *Sorex ornatus relictus, Sorex ornatus salicornicus, Sorex ornatus sinuosus, Sorex ornatus relictus* and *Sorex ornatus willetti* (Maldonado 1999).

It is likely that the distribution patches of the Tule shrew are too small; in some populations, the urbanization of this area together with the high agricultural activity could be seriously affecting this taxa. However, we believe that remnant populations similar to the one found in Santo Tomas may still exist. Through our updated biological inventory, we conclude that (i) the Tule shrew is locally extinct from "El Socorro", its type locality; (ii) there are fragmented populations vulnerable to extinction due to the marked changes in land use and intensive agriculture in the San Quintin plains; (iii) it is important to mention that the newly recorded population deserves to be listed in the special protection category, hence ensuring the conservation of this highly fragile population within the San Telmo-San Quintin priority region for conservation (Arriaga et al. 2000), as doing so increases the conservation value of this area; (iv) considering the ecological aspects that restrain the connectivity between the populations of Tule shrew, we suggest the classification of this taxon as in "danger of extinction" under NOM-059-SEMARNAT-2010, based on its geographical isolation that threatens the biological viability of this shrew due to factors such as the destruction or drastic modification of the habitat.

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