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Analyses of predation behavior of the desert shrew *Notiosorex crawfordi*

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Abstract: The desert shrew *Notiosorex crawfordi* is the smallest mammal in the arid and semiarid areas of North America. It displays ecological adaptations that allow it to colonize environments inhospitable for other species in the Order Soricomorpha. Little is known about the natural history of this species; hence, this work reports the characteristics of foraging behavior, prey items, prey size and bite effectiveness on prey items of similar or larger size than these shrews. The behavior in captivity of two individuals of *N. crawfordi* captured in Baja California Sur was analyzed in glass terrariums, recording the locomotion, posture, food preferences, prey manipulation and bite effectiveness. Preference for prey items collected from the same transects/habitat as the shrews and differing in size and belonging to different groups of Arthropoda was evaluated, revealing a greater preference for scorpions, which were attacked within 1 min of being placed in the terrarium. Observations of foraging behavior of captive desert shrews show that prey items from the different arthropod groups and lizards become paralyzed at the first bite. The behavior displayed by the prey suggested the potential presence of toxins in the saliva of *N. crawfordi*.

Keywords: adaptation; Arthropoda; behavior; desert shrew foraging; prey size preference; soricid; venom.

Typically, shrews are associated with wet conditions where insects are an abundant resource (Getz 1961). The desert shrew, *Notiosorex crawfordi* Coues, 1877, however, is the smallest mammal in North American arid and semi-desert areas, displaying ecological adaptations that have enabled it to successfully colonize deserts (Carraway 2010).

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In North America, shrews inhabiting arid or semi-arid climates belong to the Notiosoricini tribe represented by four species of the genera *Notiosorex* and *Megasorex gigas* (Carraway 2010). Information on the diet of the Notiosoricini tribe, which is considered as an omnivore, is scarce (Armstrong and Jones 1972). Records available document the consumption of arthropods of the Orders Aranaea and Scorpiones (Punzo 2003, Álvarez-Castañeda et al. 2006).

Arachnida are a taxonomic group widely distributed worldwide. Scorpions (Scorpiones) and spiders (Araneae) are groups with high species diversity, of ~16,000 and ~39,000 species, respectively. Both groups produce specialized poisons used in foraging and as a defense (Quintero-Hernández et al. 2011). The objective of this paper is to evaluate the feeding preferences of desert shrews (*Notiosorex crawfordi*) based on observations of their predation behavior and effectiveness of the bite on a range of potential arthropod prey items that are found in their habitat.

Seven desert shrews were acclimated in terrariums. The acclimatization of this species is a complex issue, so that only two adult females survived for 32 and 68 days. The individuals were collected 1 km S, 6.6 km E of El Sargento, Baja California Sur (24.0824° N, –110.0619° W), using sampling stations with pitfall traps composed of 15 m plastic strips as drift fences in six 20-l buckets, during January and August 2016. Two females were collected: one in January (23,979) and the second in August (23,984) and were deposited in the mammal collection of the Centro de Investigaciones Biológicas del Noroeste (CIB). Body measurements are as follows: total length 81.0, 78.0 mm; vertebral tail length 23.0, 23.0; length of right hind leg 9.0, 9.0; ear length 6.0, 6.0 and mass 4.0, 4.0 g, respectively.

Shrews were kept within 51×36×26 cm glass terrariums covered with a metal mesh of 0.5 cm in hole size. A sandy substrate and vegetation from the same habitat were used. The terrarium contained a 15×5 cm polyvinyl chloride (PVC) pipe that served as a shelter and a piece of cotton to help maintain the body temperature. The ambient temperature was controlled at 24°C. Prey items were introduced into the terrarium to make observations. Shrews were treated in accordance with the American Society of Mammalogists for animal care and use (Sikes et al. 2016).

Prey items were collected from the habitat of *Notiosorex crawfordi* with a series of pitfall traps or by manual collection with ultra violet (UV) lamps at night. Dominant vegetation is xeric "sarcocaule" scrubland including the species: *Colubrina viridis*, *Fouquieria diguetti*, *Lysiloma microphyllum*, *Lysiloma candidum* and *Senna atomaria* (Leon-de la Luz et al. 2012). All specimens used as prey were collected alive and offered to shrews within 24 h of collection. Encounters were recorded to allow a detailed analysis of the strategy, locomotion, posture, food preferences, manipulation of prey items, bite effectiveness and duration of encounters. Strategies of the shrews were assessed for six Orders of arthropods represented by 12 species and two species of lizards (Table 1). Eight of the prey species produce toxins or poisons. In the periods when no arthropods were collected to feed shrews, they were fed 5 g of canned sardine in soy bean oil per day.

Each time a prey specimen was offered, preference was evaluated by prey size, among Orders, and between species within the same Order. In each event, each shrew was offered two prey specimens differing in size, Order or species at the same time. Food preference and constancy were recorded on repeated occasions.

During the period of captivity, each shrew always used the same site of the terrarium as the latrine, concentrating all feces within an area of 3.0 cm^2. The latrine area was maintained by the shrew in spite of the routine cleaning of the terrarium and change of substrate as part of the periodic maintenance. All the different prey species collected in pitfall traps were offered as food to each shrew to explore prey selection and preference. Pitfall traps used to capture prey items were in the same transects as the pitfalls used to trap the shrews.

Our observations of the two captive desert shrews revealed that they prefer to feed on members of the Order Scorpiones over all other groups; the shrews captured and ate them a few minutes after having been introduced into the terrarium. There were 27 encounters with individuals of the Family Vaejovidae (*Vaejovis diazi*) and 16 with Buthidae (*Centruroides exiliata*). These shrews are capable of detecting both scorpion species in less than 1 min after being introduced in the terrarium, emerging immediately from the burrow (PVC pipe) to catch the prey. In the 43 attacks on scorpions, all scorpions stopped moving after the first bite. The shrew attacked, preyed on and consumed all scorpions measuring less than 125% of shrew length, whereas those larger than this proportion chased the shrew to attack it and the shrews always eluded the combat. Large scorpions were never preyed upon and were removed from the terrarium after 2 days. On one

Table 1: Species of animals that were evaluated as prey of *Notiosorex crawfordi*.

Prey	n	Venom	Size	Bite no.	Weight	Time
Arthropoda						
Araneae						
Syspira sp.	4	X	L	3	0.1–0.3	>5 min
Zelotes ubicki	8	X	S	3	0.2–0.4	>5 min
Loxosceles baja	4	X	S	4	0.2–0.3	>5 min
Aphonopelma prosoicum	1	X	L	3	6.4	>5 min
Scorpiones						
Centruroides exilicauda	16	X	Only adults	4	3.4–5.8	<1 min
Vaejovis diazi	27	X	Only adults	4	0.4–0.7	<1 min
Blattodea						
Periplaneta americana	15		S	4	2.5–3.9	>5 min
Chilopoda						
Scolopendra sp.	1	X	L	4	16	>5 min
Orthoptera						
Scudderia mexicana	3		S	2	2.4–2.8	>5 min
Coleoptera						
Elodes sp.	3		S	0	0.5–1.0	Not consumed
Hymenoptera						
Pogonomyrmex californicus	25	X	S	4	0.1–0.2	<3 min
Chordata						
Squamata						
Hemidactylus frenatus	1		L	1	6.0	>20 min
Uta stansburiana	1		L	1	7.0	>20 min

Size, smaller than the shrew (S) and larger than the shrew (L). Bite number during the encounter (Bite no.). Time to death since the first bite (Time). Weight in grams (Weight).

occasion when three mid-sized scorpions were offered at the same time, one of the shrews killed the three scorpions before starting to feed on the first. Ultimately, it ate the three scorpions after 5 min.

The attack on scorpions always took place from the front; in no instance did the shrews approach a scorpion from behind. The attacks of the shrews were always quick bites in the back of the mesosoma, which occurred when the tail moved back after a failed attack. The bite lasted a few milliseconds, after which the shrews released the prey to avoid exposure to the telson. Attacks by scorpions were multiple, whereas those by shrews were spaced in time according to bite effectiveness. There was no event where the scorpion succeeded in stinging the body of a shrew. Scorpions became paralyzed in less than 1 min after the first bite. After the scorpion was paralyzed, the shrew began to eat it rapidly starting at the posterior section of the prosoma and mesosoma. In 28% of scorpions, legs and pedipalps were not consumed.

Within the Order Araneae there were 17 encounters. In all instances, it was observed that after the first bite individuals became immobilized. The four species showed some degree of toxicity. All prey species were consumed in less than 5 min after being introduced into the terrarium. The tarantula *Aphonopelma prosoicum* is 125% larger than the shrew and the attack consisted of eight bites, each lasting a few milliseconds, and all targeting the posterior portion of the abdomen. After the first attacks, the shrew started to grind the cephalothorax and subsequently 25% of the legs were consumed. The attack on *Loxosceles baja* started in less than 1 min after being introduced into the terrarium, targeting the head, with a consumption time lasting less than 5 min. In the case of *Zelotes ubicki*, the attack approach was similar, but legs were not consumed in 35% of individuals.

The ants *Pogonomyrmex californicus* were eaten in less than 3 min of the first attacks. Five introduction events were conducted with five individuals each. In all ants, the first bite targeted the front; each ant was attacked in less than 3 min after being introduced into the terrarium, with a lethal bite in the head after rapid recognition movements by sniffing. The manipulation of prey targeted the thorax and abdomen. All ants were attacked and consumed completely.

Prey items that were consumed in the shortest time after the first bite were the cockroach *Periplaneta americana*. Cockroaches were completely immobilized after the first bite in all cases. The attacks of the shrew were directed toward the head. After being killed, the prey were consumed in their entirety in less than 5 min with exception of the antennas and hindwings.

The grasshopper *Scudderia mexicana* remained active immediately upon introduction into the terrarium. The grasshoppers clashed with the metallic mesh at the top of the terrarium when jumping, and were located in less than 1 min and attacked within 3 min. Grasshoppers were consumed in less than 5 min.

Prey with the greatest length was the centipede *Scolopendra* sp. The shrew moved quickly sniffing the terrarium and attacked the posterior portion of the prey, where it has a pair of legs with hooks for defense. The only individual supplied measured 16 cm in length, equivalent to 148.7% of the shrew body length; less than 40% of the prey segments were consumed, including the legs and antennae.

Beetles of the genus *Eleodes* sp. were introduced in three separate occasions; in all instances the beetles remained for 12 days, and none of the individuals was either attacked or consumed by the shrew. During this period, shrews were fed sardines as food supplement due to the scarcity of other prey.

Uta sansburiana specimens were attacked directly on the head on one side of the jaw, and the two lizards continued moving after the attack, dying 20 min after the first bite. Seventy percent of the body was consumed approximately in 20 min; the legs were not consumed. The attack pattern for *Hemidactylus frenatus* was the same, less than 50% of the body was consumed.

Remains of prey items not completely consumed by the shrews were left in the terrarium until its weekly cleaning, and were not consumed in spite of the lack of live food. Consequently, supplementary food had to be provided. In almost all of the species analyzed as prey of shrews, a time lapse of approximately 5 min was recorded for a prey specimen to die after the first bite.

Shrews observed in the present study were active both by day and by night, with a preference toward nocturnal activity, as has been previously reported for *Notiosorex crawfordi* (Armstrong and Jones 1972, Duncan and Corman 1991). These experiments combined different types of arthropods and squamates and revealed a feeding preference by shrews in the following order of selection: Scorpiones, Araneae, Blattodea, Insecta, Hymenoptera, Chilopoda and Squamata. By contrast, Scarabeidae were ignored.

In all instances, prey items were detected upon contacting the substrate of the terrarium. The reaction time apparently was associated with the type of prey. This suggested that detection of prey may take place through the vibrations it produces in the substrate, rather than through smell or sight. After the first bite, 68.8% of prey became paralyzed and usually died in less than 5 min. The immobility of prey suggests that *Notiosorex* might

have some sort of toxin in the saliva. The presence of a toxin would allow these shrews to prey more effectively on species of similar or larger size as well as on highly poisonous species. The presence of toxins in the saliva was previously reported for at least four species in the Order Soricomorpha (Folinsbee 2013), so *Notiosorex* is also likely to have them. In other soricids, toxins are produced in the parotid and submaxillary salivary glands, and delivered to the prey through bites in the body (Tomasi 1978).

It was noted that approximately 120% or less of the shrew length may be the range that determines the selection of prey. The largest species belonged to the following Orders: Araneae, *Syspira* sp. and *Aphonopelma prosoicum*; Scorpiones: *Centruroides exilicauda* and *Vaejovis diazi*; Chilopoda: *Scolopendra* sp.; and Squamata, *Hemidactylus frenatus* and *Uta stansburiana*. It was reported that shrews can attack and kill mice more than twice their body length (Hanski and Kaikusalo 1989, Churchfield 1990, Churchfield et al. 1997, Punzo 2003).

The analysis conducted here shows that *Notiosorex crawfordi* feed quickly, preyed upon and preferentially fed on Scorpiones compared to the seven other Arthropod orders that were presented to them in our experimental terrarium environment. The diversity of Scorpiones in the Baja California Peninsula is one of the largest in the world (Williams 1980), and has been explained as a result of the complex geological history of the peninsula and the variety of available habitats (Hafner and Riddle 2011). This could be extrapolated to also reflect their feeding preferences in a natural setting because the diversity of scorpions varies according to the geomorphology, geographical conditions and floristic composition, with a heterogeneous ecological pattern (Jiménez-Jiménez and Palacios-Cardiel 2010). These conditions make scorpions an abundant resource (Due and Polis 1986), and preferentially used in wildlife by *Notiosorex* in desert areas. This feeding adaptation may be associated with other desert shrews that inhabit arid areas throughout their distribution, in contrast with other species in the Family Soricidae, in which the diet consists primarily of small insects and annelids (Hanski and Kaikusalo 1989, Churchfield et al. 1997).

Desert shrews have a series of behavioral and physiological adaptations that make it possible for them to survive in the desert. The presence of toxins in desert shrews needs to be further examined using biochemical analyses to determine if it is similar to that of other soricids; further studies on the presence of toxicity in *Notiosorex crawfordi* may allow a better understanding of the biology and evolution of these organisms in the arid zones of North America.

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References

Álvarez-Castañeda, S.T., M.M. Correa-Ramírez and A.L. Trujano-Álvarez. 2006. Notes on *Notiosorex crawfordi* (Coues) from two oases in the Baja California Peninsula, Mexico. J. Arid Env. 66: 773–777.

Armstrong, D.M. and J.K. Jones. 1972. *Notiosorex crawfordi*. Mamm. Species 17: 1–5.

Carraway, L.N. 2010. Fossil history of *Notiosorex* (Soricomorpha: Soricidae) shrews with descriptions of new fossil species. West. North American Nat. 70: 144–163.

Churchfield, S. 1990. The natural history of shrews. Cornell University Press, London. pp. 178.

Churchfield, S., B.I. Sheftel, N.V. Moraleva and E.A. Shvarts. 1997. Habitat occurrence and prey distribution of a multi-species community of shrews in the Siberian taiga. J. Zool. 241: 55–71.

Due, A. and G. Polis. 1986. Trends in scorpion diversity along the Baja California Peninsula. Amer. Naturalist. 128: 460–468.

Duncan, D.K. and T.E. Corman. 1991. Relative abundance of desert shrews (*Notiosorex crawfordi*) within the San Pedro Riparian National Conservation Area, Arizona. Southwest. Nat. 36: 119–121.

Folinsbee, K.E. 2013. Evolution of venom across extant and extinct eulipotyphlans. Comp. Rendus Palevol. 12: 531–542.

Getz, L.L. 1961. Factors influencing the local distribution of shrews. Amer. Midland Nat. 65: 67–88.

Hafner, D.J. and B.R. Riddle. 2011. Boundaries and barriers of North American warm deserts: an evolutionary perspective. In: (P. Upchurch, A.J. McGowan and C.S. Slater, eds.) Palaeogeography and paelobiogeography: diversity in space and time. CRC Press, Florida, B.R. pp. 75–113.

Hanski, I. and A. Kaikusalo. 1989. Distribution and habitat selection of shrews in Finland. In: (Annales Zoologici Fennici) Finnish Zoological Publishing Board, formed by the Finnish Academy of Sciences, Societas Scientiarum Fennica, Societas pro Fauna et Flora Fennica and Societas Biologica Fennica Vanamo. pp. 339–348.

Jiménez-Jiménez, M.L. and C. Palacios-Cardiel. 2010. Scorpions of desert oases in the southern Baja California Peninsula. J. Arid Env. 74: 7074.

Leon-de la Luz, J.L., R. Domínguez-Cadena and A. Medel-Narváez. 2012. Florística de la selva baja caducifolia de la Península de Baja California, México. Bot. Sci. 90: 143–162.

Punzo, F. 2003. Natural history and ecology of the desert shrew, *Notiosorex crawfordi* from the Northern Chihuahuan Desert, with notes on captive breeding. Mammalia 67: 541–550.

Quintero-Hernández, V., E. Ortiz, M. Rendón-Anaya, E.F. Schwartz, B. Becerril, G. Corzo and L.D. Possani. 2011. Scorpion and spider venom peptides: gene cloning and peptide expression. Toxicon 58: 644–663.

Sikes, R.S. and The Animal Care and Use Committee of the American Society of Mammalogists. 2016. Guide-lines of the American Society of Mammalogists for the use of wild mammals in research and education. J. Mamm. 97: 663–688.

Tomasi, T.E. 1978. Function of venom in the short-tailed shrew, *Blarina brevicauda*. J. Mamm. 59: 852–854.

Williams, S.C. 1980. Scorpions of Baja California, Mexico and adjacent islands. Occas. Pap. Calif. Acad. Sci. 135: 1–127.