



New records for *Cirolanides texensis* Benedict, 1896 (Isopoda: Cirolanidae), including possible extirpations at impacted Texas caves.

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Abstract: Examination of published literature and available records for the aquifer adapted isopod *Cirolanides texensis* indicates it is known from only 36 localities. Sampling over the last decade has increased the known range to 57 sites. The author counted individuals at 30 sites and recorded an average of 10.6 individuals (range 0–69) per site. For 13 sites where search effort was recorded, an average of 1.3 visits was required to locate the species and the average number of isopods found per person minute of searching was 0.68 ± 0.28 .

The species was not recorded at three cave sites historically known to contain *C. texensis* despite an average or above average search effort. These sites have also experienced the greatest human impact, suggesting that the species might have been extirpated. The human activities include the commercialization of a cave, modification of the flood regime, and in two cases those activities led to extirpation of a bat colony. At one site *C. texensis* persisted after extirpation of a bat colony, indicating that the energy regime for this species is not strictly dependent on bats, however the elevated resource availability might increase the potential for detection. In the future, resource managers should consider anthropogenic activities that might impact caves activities and cause extirpation of *Cirolanides texensis* isopods, and other hypogean species.

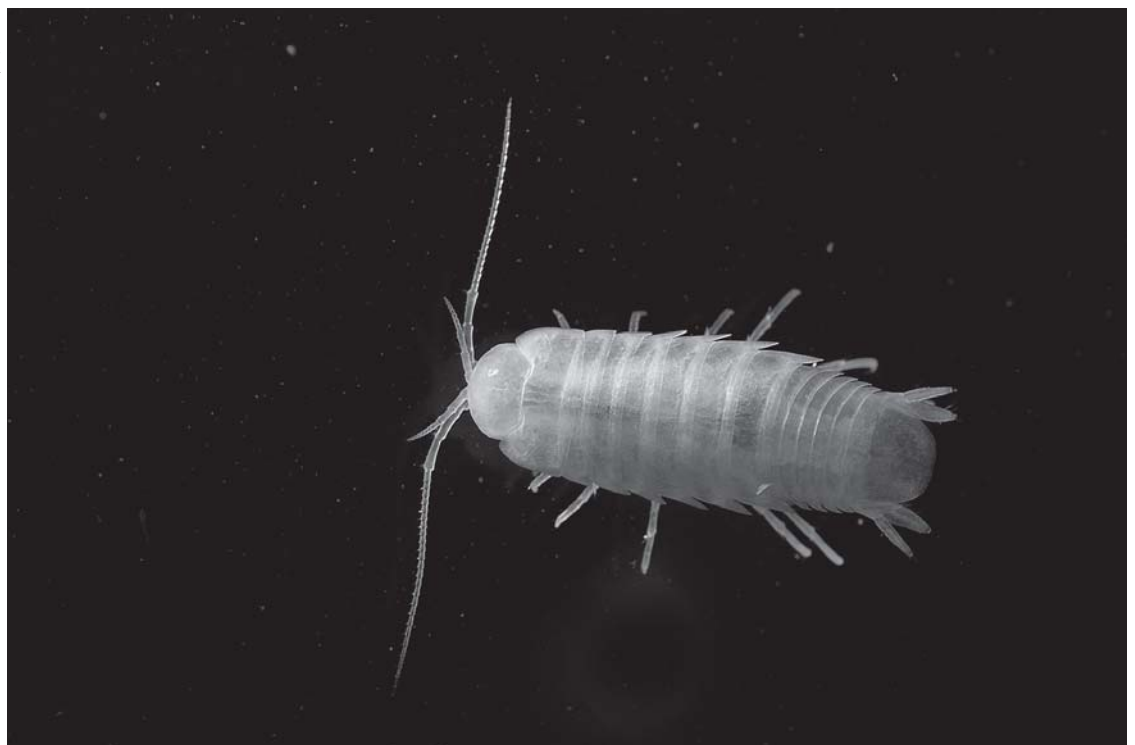
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INTRODUCTION

Benedict (1896) described the aquifer/groundwater isopod *Cirolanides texensis* from the Artesian Well at San Marcos, Hays County, Texas, a site renowned for the extremely high aquifer species diversity (Culver and Sket, 2000; Holsinger and Longley, 1980). *C. texensis* is a marine relict and an aquifer adapted species that subsequently colonized subterranean waters, most likely via the littoral interstitial zone during periods of marine regression (Boutin and Coineau, 2000). Eyeless and devoid of pigment, it is known only from subterranean karst environments (Figure 1). The species occurs throughout central and west Texas karst aquifers to the Mexico border and in adjacent groundwater basins of north Mexico.

Studies of the species include its description and redescription (Benedict, 1896; Bowman, 1964), designation of a subspecies in Mexico (Botosaneanu and Iliffe, 2002), documentation of its distribution (Reddell, 1965 and 1970; Bowman 1972), quantification of number of individuals in well samples and associated water chemistry parameters (Karnei, 1978), temperature preferences (Elliott and Mitchell, 1973) and phylogeography (Krejca, 2005). However, there is no documented information regarding how or why this species might be sensitive to habitat modification, although other researchers have recorded the possible extirpation of the species at two sites, Valdina Farms Sinkhole (Veni and Associates, 1987) and Wonder Cave (Elliott, 1994a).

Figure 1. *Cirolanides texensis* from a cave in northern Bexar County. Photograph by Jean K Krejca.



Site name	Texas County/ Mexico State	Reference for locality	Morphology verified?
Aldridge 209 Well	Bexar	New in this study	N
Artesia Pump Station Well	Bexar	Karnei 1978 (found 29 individuals), Bowman 1972 called this "Artesian Well no. 4" probably the same site	Y
Bonzai Mud Dauber Cave	Bexar	Zara Environmental and George Veni and Associates 2008, Krejca 2005	N
Boneyard Pit	Bexar	Zara Environmental and George Veni and Associates 2008	N
Cannonball Cave	Bexar	Zara Environmental and George Veni and Associates 2008	N
Flach's Cave	Bexar	Zara Environmental and George Veni and Associates 2008	N
Isopit	Bexar	Bowman 1972 found 38 individuals	Y
Leon Creek Powerplant Well No. 1	Bexar	Bowman 1972	Y
MARS Pit	Bexar	Zara Environmental and George Veni and Associates 2008	N
North Drop Zone Hall Spring	Bexar	Zara Environmental and George Veni and Associates 2008	N
O.R. Mitchell Well	Bexar	Karnei 1978 (found 7 individuals), Bowman 1972	Y
Pain In The Glass Cave	Bexar	Zara Environmental and George Veni and Associates 2008	N
Stealth Cave	Bexar	Zara Environmental and George Veni and Associates 2008	N
Twin Pits	Bexar	Elliott and Mitchell 1973, Bowman 1972	Y
Verstraeten Well No. 1	Bexar	Karnei 1978 (found 159 individuals), Bowman 1972 called this "Vertraeten Well," not clear which one he referred to	Y
Verstraeten Well No. 2	Bexar	Karnei 1978 (found 7 individuals)	Y
Longhorn Caverns	Burnet	Bowman 1972	Y
Klar Well	Comal	TMM records, Botosaneanu and Illiffe 2002, Krejca 2005	Y
LCRA Well	Comal	Bowman 1972 called this "LCRA well, New Braunfels"	Y
Panther Canyon Well	Comal	new in this study, Krejca 2005	N
Python Pit	Comal	Bowman 1972	
Honey Creek Water Cave	Comal	Bowman 1972	Y
O-9 Well	Crockett	Bowman 1972	Y
Kickapoo Ranch Cave	Edwards	TMM records (1 individual)	Y
Devil's Sinkhole	Edwards	Holsinger 1966, Reddell 1965, Bowman 1972	Y
Artesian Well at San Marcos	Hays	Benedict 1896, Reddell 1965, Bowman 1972	Y
Ezell's Cave	Hays	Reddell 1965, Bowman 1972	Y
Frank Johnson's Well	Hays	Reddell 1965	Y
Jacob's Well	Hays	new in this study (sight record only)	N
Marcia's Well	Hays	Bowman 1972	Y
Rattlesnake Cave	Hays	new in this study, Krejca 2005	N
Wonder Cave	Hays	Reddell 1965	Y
Phantom Lake Spring Cave	Jeff Davis	new in this study, Krejca 2005	N
Bufo Cave	Kendall	TMM records, Botosaneanu and Illiffe 2002, Krejca 2005	Y
Boxed Spring	Kerr	TMM records, Botosaneanu and Illiffe 2002, Krejca 2005	Y
Stowers Cave	Kerr	Reddell 1970, Bowman 1972	Y
Baker's Crossing Cave	Kinney	TMM records (3 individuals)	N
Valdina Farms Sinkhole	Medina	Bowman 1972	Y
Bonner Fallout Shelter Cave	Real	Reddell 1965, Bowman 1972	Y
Unnamed Water Cave on tributary to East Frio River	Real	new in this study (sight record only)	N
Cave Y	Schleicher	Reddell 1965, Bowman 1972	Y
Spring on Independence Creek	Terrell	new in this study, Krejca 2005	N
Carson Cave	Uvalde	TMM records, Botosaneanu and Illiffe 2002	Y
Indian Creek Cave	Uvalde	Reddell 1965, Bowman 1972	Y
McNair Cave	Uvalde	Reddell 1970, Bowman 1972	Y
Rambie's Cave	Uvalde	Bowman 1972	Y
Dandridge Spring	ValVerde	new in this study, Krejca 2005	N
Diablo Cave	ValVerde	Reddell 1965, Bowman 1972	Y
Four-Mile Cave	ValVerde	Reddell 1965, Bowman 1972	Y
H.T. Miers Cave	ValVerde	Bowman 1972	Y
Little Diablo Cave	ValVerde	Reddell 1965, Bowman 1972	Y
Slaughter Bend Springs	ValVerde	Bowman 1972	Y
Sorcerer's Cave	Terrell	TMM records, Botosaneanu and Illiffe 2002, Krejca 2005	Y
Unnamed spring on E side of Devil's River 32km north of Del Rio	ValVerde	Bowman 1972 called this "Unnamed spring, ca. 20 miles north of Del Rio, just east of Devil's River"	Y
Cueva de El Tule (Mexico)	Nuevo Leon	Botosaneanu and Illiffe 2002	Y
Cueva de la Espantosa (Mexico)	Nuevo Leon	Botosaneanu and Illiffe 2002	Y
Sotano de Amezcua (Mexico)	Coahuila	Botosaneanu and Illiffe 2002	Y

Table 1. List of all known localities for *Cirolanides texensis*, organized by county then alphabetically by site. Reference list for each site not exhaustive, rather it is intended for recording the documentation of this species at each locality. Texas Memorial Museum records are courtesy of James R. Reddell, curator. Specimens from more recent localities have not necessarily been examined in detail morphologically by a specialist; therefore the species identifications should be considered tentative.

Site name	Number of individuals	Search effort and dates	Isopods per minute	Site type
Aldridge 209 Well	1	34,819,200 gallons; March-June 2008		Well
Artesian Well at San Marcos**	0	Probable continuous driftnet for 1-2 years (2000 – 2002)		Well
Boneyard Pit	NR	25 July 2006; 4 October 2006,		Cave
Bonzai Mud Dauber Cave	2	5-10 min; 10 November 2000	0.27	Cave
Boxed Spring	2	5-10 min; 3 June 2002		Spring
Bufo Cave	4	5-10 min; 14 May 2002	0.53	Cave
Cannonball Cave	NR	21 April 2006		Cave
Cave Y	31	Approx 45 min (15 June 2002)	0.69	Cave
Cueva de El Tule (Mexico)	11	4 person hours searching pool (5-6 July 2002)	0.05	Cave
Cueva de la Espantosa (Mexico)	22	45 min (6 July 2002)	0.49	Cave
Dandridge Spring	2	1 from 2 person hrs of effort, the 2nd was in a drift net left for 18 hrs; 21-22 May 2002	0.01	Cave
Devil's Sinkhole	22	Approx 45 min; 28 February 1999	0.49	Cave
Ezell's Cave	15	Collected during dive, approx 45 min (Aug-Sept 2000)	0.33	Cave
Flach's Cave	NR	14 December 2004, 13 March 2008, 28 February 2008		Cave
Four-Mile Cave	15	3 from a bottle trap left for 4 days and 12 from a trap left for 16 hrs (no date available)		Cave
H.T. Miers Cave	9	Approx 10 min; 8 February 2003	1.2	Cave
Honey Creek Water Cave	6	Approx 45 min (in "R survey" section of cave); 9 July 2000	0.13	Cave
Isopit	38	10 min; 18 May 2002	3.8	Cave
Jacob's Well	NR	Seen/observed during one of three dives to a deep section of cave (-140 ft.) (19 October 2008)		Cave
Klar Well	20	Bottle trap left for 1 day; 11-12 July 2002		Well
LCRA Well**	0	175,320 gallons (4 September 2002), 87,000 gallons (12 March 2008).		Well
Longhorn Caverns**	0	Four visits including 1 hour of searching plus deployment of traps (17 November 1998, 18, 21, and 23 June 2002)		Cave
MARS Pit	NR	NR		Cave
North Drop Zone Hall Spring	NR	15 July 2004		Spring
O-9 Well	14	NR; 30 May 1999		Cave
Pain In The Glass Cave	NR	27 May 2005, 27 October 2005, 25 July 2006, 28 May 2007, 31 July 2007		Cave
Panther Canyon Well	9	8 from 2 bottle traps left for 1-2 days (4,6,10 and 11 September 2002), 1 from bottle trap left 6 weeks (1 April – 15 May 2008)		Well
Phantom Lake Spring Cave	7	Scuba diving for 4 hrs, searching for 2 hrs (16-17 April 2001)	0.06	Cave
Rattlesnake Cave	4	4 in bottle trap left for 3 days (2 March 2001), 5 other trips yielded no specimens (17, 29 November 2001, 6, 9 December 2001, 27 May 2002)		Cave
Slaughter Bend Springs	1	NR; 4 June 2002		Spring
Sorcerer's Cave	69	NR; 22-24 September 2001		Cave
Sotano de Amezcua (Mexico)	4	NR (23 November 1998)		Cave
Spring on Independence Creek	1	NR (24 October 2002)		Spring
Stealth Cave	NR	27 October 2006		Cave
Unnamed Water Cave on tributary to East Frio River	6	5-10 min (20 September 2008)	0.8	Cave
Valdina Farms Sinkhole**	0	1 visit, approx 2-4 hrs spent searching (no date available)		Cave
Wonder Cave**	0	3 visits, approx 30 min each, including bottle trap (November 2001)		Cave

Table 2. List of 37 localities for *Cirolanides texensis* visited by the author and considered for analysis in this study, ordered alphabetically. Five sites failed to yield specimens, and they are indicated by double asterisks. NR = not recorded.

METHODS

Field sampling took place over an extended period between 1997 and 2008. Sample sites included wells, springs, vadose cave passages and phreatic cave passages accessed by cave diving. Sampling methods in caves included hand capture, and sampling with dipnets, turkey basters, and inverse funnel bottle traps baited with canned sausages. At non-flowing wells collections were made using inverse funnel bottle traps lowered into well shafts on a tether, and at flowing wells (pumped and artesian) individuals were caught in drift nets. At springs driftnets and bottle traps were used. Previous authors used custom 500 micron mesh nets similar to drift nets at flowing wells, and Surber samplers and smaller nets at springs (Karnei, 1978).

RESULTS

Locality types

Most of the records for *Cirolanides texensis* are from cave streams, with five records from springs and twelve from wells accessing subterranean aquifers. Further details and a physical description of 37 sites visited and sampling method where the specimens were recorded is outlined in Krejca (2005).

Within caves, individuals were recorded at locations where the stream was easily searched. Shallow stream pools in caves were easy to inspect because of the smooth water surface and minimal substrate. Once appropriate habitat within a cave was reached, specimens were typically found in less than an hour of searching. For the 13 cave sites where search effort was recorded, the average number of isopods found per minute of searching was 0.68 ± 0.28 . For the same 13 sites, locating *Cirolanides texensis* required an average of 1.3 visits to the cave. The numbers of specimens recorded by the author at the 30 sites examined, the number of individuals collected ranged from 0–69, with an average of 10.6 individuals per site. During the investigation the species was observed feeding on a dead *Ceuthophilus cunicularis* cricket in a drip pool in Devil's Sinkhole, Edwards County, Texas, and feeding on dead *Ceuthophilus* spp. crickets in the water of Klar Well, Comal County, Texas (Figure 2).

At the two of the three well sites where isopods were recorded in the current study, individuals were captured in bottle traps. At Panther Canyon Well the bottle traps were left for 1–2 days on two occasions and for 6 weeks on another occasion. At Klar Well the trap was left for 1 day. Aldridge 209 is a well that flows or is



Figure 2. Two *Cirolanides texensis* isopods found feeding on a dead *Ceuthophilus cunicularis* cricket in a drip pool near the aquifer level at Devil's Sinkhole, Edwards County, Texas. The author observed a similar event at Klar Well in Comal County, Texas. Photograph by Jean K Krejca.

pumped nearly constantly to supply a storage tank for a nursery, and a single individual was found after approximately 34,819,200 gallons flowed through the net. Because of the high flow at Aldridge 209 it is possible that some specimens were destroyed before they could be collected. One well site historically known to support the species, LCRA Well, did not yield any specimens after approximately 175,320 gallons of water passed through the net on one occasion, or after 87,000 gallons passed through on a second occasion. A final well site, Artesian Well at San Marcos, has a permanent drift net fixed at the site that was regularly inspected over two years by Texas State University personnel. However, no specimens were recorded during this period, although it was unclear whether all invertebrates were sampled. In addition, there might have been problems with a hole in the well casing that allowed an unknown volume of flow to be diverted around the net. Given these problems, this site is not considered further in this paper.

Search effort was only recorded at one spring, and two individuals were found in 5 to 10 minutes of searching (Boxed Spring, Kerr County, Texas). This spring site is slightly anomalous because it has an enclosed concrete cover that makes a small cave like area at the mouth, probably extending the area this species occupies. Therefore the number of individuals found for a given search effort is likely to be similar to that of a cave.

Site by site treatment

Cirolanides texensis has been recorded from a total of 57 localities (Table 1), and this study considers the characteristics of 37 of those sites visited by the author (Table 2). Of the 37 sites that were searched for *Cirolanides texensis*, five historical localities failed to yield specimens (localities with asterisks in Table 2). Two of these sites were wells. The LCRA Well in New Braunfels, Comal County, did not yield specimens after two sampling events. The Artesian Well at San Marcos did not yield specimens after two years of sampling with a drift net, but there were potential problems outlined above. The other three sites are caves, described below.

Wonder Cave was visited three times, with visual searches and a

bottle trap placed in the small pool at the "wishing well" of the cave (also known as Bever's Well in Elliott, 1994a). The water level in this lower part of the cave is contiguous with phreatic water. Water tracing experiments demonstrated connections with the nearby Ezell's Cave and San Marcos Springs (Ogden *et al.*, 1986); the water level fluctuates with groundwater conditions. This cave has been developed into a show cave with infrastructure including doors, lights, a ventilation system, walkways and handrails. According to a Texas Historical Survey Committee landmark at the cave, commercial use of the cave began in about 1900, however the infrastructure in the cave has increased since the first tours began. The installation of doors and walkways alters the potential influx of nutrients into the cave pools from troglonexes or flood debris, and the ventilation system potentially dries the cave, impacting other species that live in the cave and might have contributed energy to the aquatic community. The cave is not known to have had a bat colony. Whereas the lack of specimens from this cave does not definitively prove absence, local extirpation is possible, particularly given that the cave was visited three times and for the average number of visits for other sites where the taxa was recorded was 1.3. Additionally, other authors have noted the lack of recent sightings of *C. texensis* and other aquatic species including the shrimp *Palaemonetes antrorum* and the salamander *Eurycea rathbuni* at this site (Elliott, 1994a).

Longhorn Caverns was visited four times, including one visit searching minor streamways near the wishing well (map in back pocket of Elliott and Veni, 1994) and three visits searching the major streamway near catfish lake. The stream passage between "the wiggles" and the siphon at the north end of the cave was not searched. This cave has also been developed into a show cave, with infrastructure including gates, lights, walkways and handrails. Longhorn Caverns is known to have had a large maternity colony of Mexican free-tailed bats (*Tadarida brasiliensis*) that was extirpated when the show cave was developed in the late 1940s (Craun, 1948; Elliott, 1994b). In some aquatic cave communities, guano from bat colonies is an important part of the food chain (Fenolio *et al.*, 2005).

The lack of specimens encountered does not prove absence, considering that inaccessible refugia might exist; but local extirpation is a possibility, particularly considering the energy regime changes and high detection rates at other caves.

Valdina Farms Sinkhole is a historical locality for two aquatic isopods, *C. texensis* and *Lirceolus pilus*, as well as the type locality for a cave salamander, *Eurycea troglodytes* (Baker, 1957), and other aquatic crustaceans including copepods, ostracods and amphipods (Veni and Associates, 1987). A diversion dam was installed to direct floodwater from a nearby creek into the cave in 1982, changing the hydrological regime and causing the extirpation of a large bat colony consisting of three species of bats (*Tadarida brasiliensis*, *Myotis velifer*, and *Mormoops megalophylla*). Investigators searched the cave in 1987 after a large flood event and found none of these cave adapted aquatic species (Veni and Associates, 1987). During my subsequent visit, 32 *Lirceolus pilus* isopods and one unidentified amphipod were recorded – but not *C. texensis*. Possibly the abundance of *C. texensis* has changed so that it is difficult to detect, or the cirolanid isopod might be more sensitive to impacts such as the bat colony extirpation and flood regime changes than the *Lirceolus* isopod and amphipod.

Following the extirpation of the bat colony at Ezell's Cave in Hays County (Texas), cirolanid isopods were still recorded. The bat colony left in the mid 1960s due to an improperly designed cave gate, and this along with over exploitation by collectors might have caused a decline in the population of Texas blind salamanders (Davis, 1971; Elliott and Veni, 1994; Russell, 1976). The persistence of *C. texensis* at this site and at aquifer localities (wells and springs) demonstrates the species is not strictly tied to bat populations. At Ezell's Cave the aquatic habitat is close enough to the entrance that there might still be allochthonous energy from other troglonexes such as cave crickets or small mammals, or there might be sufficient energy from the aquifer flow that goes through the cave (Ogden *et al.*, 1986) to support high numbers of crustaceans. This cave is also known for having the highest aquatic biodiversity of any cave in Texas.

The remainder of the 37 sites where *C. texensis* was recorded are not strictly without environmental impacts (many have some of their drainage basin in an agricultural or urban landscape, or are impacted by groundwater pumping), although they are generally not as heavily impacted as those discussed above and remain undeveloped "wild caves".

DISCUSSION

After visits to numerous sites supporting populations of the isopod *Cirolanides texensis*, it is likely that the pattern of presence and absence (or detectability) and possible extirpation of the species is related to habitat modification. Disruption of the natural flow of water and trophic resources, either through show cave development, the loss of a bat colonies, or alteration of the hydrological regime, or a combination of these factors, appears to be the common impact. This dataset does not specifically prove or disprove this point because no specific data were collected about historical and modern nutrient flow, nor were alternate hypotheses tested. The strength in this dataset lies with the large number of sites visited (37) and common threads in the small number of cave sites (3) with apparent extirpation of the species. These findings corroborate those of prior investigations at two of those three cave sites (Valdina Farms Sinkhole and Wonder Cave).

In order to assess extirpation more definitively, additional visits to all of the sites should be conducted. Detectability for cave species is low (Krejca and Weckerly, 2007), and many visits, sometimes over 100, are required to detect very rare species (Culver *et al.*, 2004). Nutrient input, for example from bats, might increase population sizes and therefore increase detection probability at some sites. Genetics studies demonstrate that phylogenetic patterns of *C. texensis* match groundwater patterns (Krejca, 2005). This suggests that in some cases subsurface migration between sites (caves, wells or springs) could facilitate re-colonization of degraded sites, following remediation, from populations within groundwater dominated habitats in the vicinity.

The trends of species presence and absence at the sites examined should be used as an indicator by managers of karst ecosystems.

Show cave development and the installation of recharge dams are activities that could lead to the extirpation of *Cirolanides texensis* isopods and possibly other species.

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