Results of 2016 Biological Monitoring of Cave X, Travis County, Texas

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As a licensed professional geoscientist I attest that the contents of this report are complete and accurate to the best of my knowledge.

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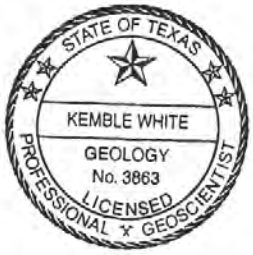

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Introduction and Background

Cave X is located on the campus of the Regents School of Austin in Travis County, Texas. Over the past decade and a half the academic and athletic facilities of the school have been developed around two environmental setbacks totaling approximately 4.5 acres provided as a conservation measure for the cave. Cave X is the third deepest known cave in Travis County (Texas Speleological Survey 2014) and is well known as a recharge feature for the Edward aquifer and for its endemic cave-adapted fauna. Species known from the cave include 11 troglobites (obligate cave-dwelling organisms), six of which are considered species of concern under the Balcones Canyonlands Conservation Plan (BCCP)[1]. The BCCP was the first regional habitat conservation plan in the country. Under the BCCP the City of Austin and Travis County have committed to protecting dozens of caves for the conservation of rare and endangered cave-adapted species including Cave X (Beatley et al., 1995). Cave X is not known to contain any endangered species, but supports conservation of rare, non-listed species in order to prevent the need to list them in the future. On 18 February 2016 geoscientists from Cambrian Environmental along with a representative of the City of Austin conducted a biological monitoring survey for karst invertebrate species in Cave X. The intent of this report is to provide a summary of findings resulting from these surveys and to provide a brief interpretation of the results in the context of previous surveys.

Cave Description and Geological Setting

Cave X is formed within the kirschberg evaporite member of the Kainer Formation of the Edwards Group Limestone[2]. The cave consists primarily of a single joint-controlled strata-bound passage running sub-parallel to the Mount Bonnell Fault (southwest to northeast). From the entrance, the cave runs more than 1,000 feet reaching a maximum depth of more than 100 feet below ground surface. The cave intersects a fault within the Mount Bonnell strand of faults at its terminal room approximately 1,070 feet from the entrance (Figure 1). The Mount Bonnell Fault strand forms the western boundary of the Barton Springs segment of the Edwards Aquifer Recharge Zone. In non-drought conditions, the passage becomes increasingly wet, transitioning into a stream passage occupied by aquatic cave fauna in its further reaches. It is one of the few explored caves in the Edwards system with a relatively diverse aquatic fauna, which can be found in a number of ephemeral pools along the length of the cave[3]. The aquatic fauna are only regularly found beyond the third drop, where the cave reaches approximately 75 feet in depth, a point about 600 feet from the cave entrance. The presence of obligate aquatic cave fauna suggests that perched groundwater occurs just below the elevation of the cave on a permanent or near-permanent basis. The cave is likely one of several groundwater conduits that feed a spring known as Backdoor Spring located along Barton Creek approximately 1.2 miles to the northeast.

Cave X is also one of several caves in the area known for bad air quality due to elevated levels of carbon dioxide and depressed levels of oxygen which presents a serious hazard to cave biologists.

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[1] https://www.austintexas.gov/page/protected-species

[2] Barton Springs/Edwards Aquifer Conservation District Hydrogeologic Map of the Barton Springs Segment of the Edwards aquifer recharge Zone, December 2002 draft.

[3] The caves of the Balcones Canyonlands Conservation Plan. Travis County, Texas, William Elliott, February 10, 1997.

The great majority of the cave consists of constricted crawl-space which is physically taxing to navigate and requires several hours to traverse while surveying. All recent attempts to conduct a full biological survey of the cave have been done with the use of ventilation equipment which is of limited effectiveness due to the length of the cave and limits on available ventilation systems.

Karst Fauna of Cave X

Troglobites are obligate cave-dwelling organisms that include more than 1,200 species worldwide. They are characterized by a number of anatomical and physiologic adaptations to cave life collectively referred to as troglomorphy. Troglomorphic characters include loss of pigment and thinning of the exoskeleton, reduction or loss of eyes, elongation of appendages, lengthened life span, modified reproductive cycles, and metabolic adaptation to nutrient poor habitat conditions (Culver 1982). The cave environment is relatively monotonous compared to surface invertebrate habitats and is characterized by stable temperatures close to the mean annual surface temperature, constant near-saturation humidity, low evaporation rates, and the absence of photosynthetic nutrient production. Many troglobitic species are considered to be relicts persisting in subsurface refugia long after their surface ancestor species abandoned their geographic region due to climate change (Barr 1968). Most terrestrial troglobites are thought to have evolved from surface ancestors that were pre-adapted for cave life due to their habit of living in cool, moist soil or leaf-litter. Troglobites have, however, lost the ability to survive outside of the cave environment. Climatic oscillations, such as those during the last ice age, periodically brought suitable habitat conditions for these species into and out of geographic areas south of the glacial maxima such as central Texas. During warmer, drier intervals populations inhabiting caves and sinkholes were able to survive in isolated pockets whereas other populations were forced to migrate with the suitable habitat conditions or go extinct (Mitchell and Reddell 1971). The resulting geographic isolation, reduced population size, and restriction of gene flow combined with troglomorphic selection pressures and lead to the production of new species.

Central Texas is known internationally as a hotspot of subterranean biodiversity. Development pressure in the Austin area has lead to the listing of seven species of karst invertebrate as endangered under the Federal Endangered Species Act. Cave X contains representatives of most of the major forms of Texas troglobites. Species known from the cave include 11 troglobites, six of which the Balcones Canyonlands Conservation Plan considers species of concern. The need to list them in the future may depend on the effectiveness of conservation measures for Cave X and other caves known to contain them. Development pressure on the troglobites of the south Austin area has been significantly reduced over the last decade by conservation actions such as the purchase of approximately 26,000 acres of water quality protection lands by the City of Austin and other conservation entities.

Most caves can be divided into three habitat zones according to distance from the entrance, which represents the source of light, nutrient input, and climatic fluctuation. Zone 1 is the entrance zone, which experiences temperature and humidity fluctuation similar to those at the surface and receives some direct sunlight. This region may contain some photosynthetic organisms (commonly ferns and moss) and has invertebrate fauna dominated by surface forms and trogloxene species. Trogloxenes are animals like bats and cave crickets which spend only a portion of their lives in caves and which depend on surface habitats for food. In the case of Cave X, Zone 1 consists of the entrance room directly below the cave entrance. Surface forms occurring within this zone include earthworms,

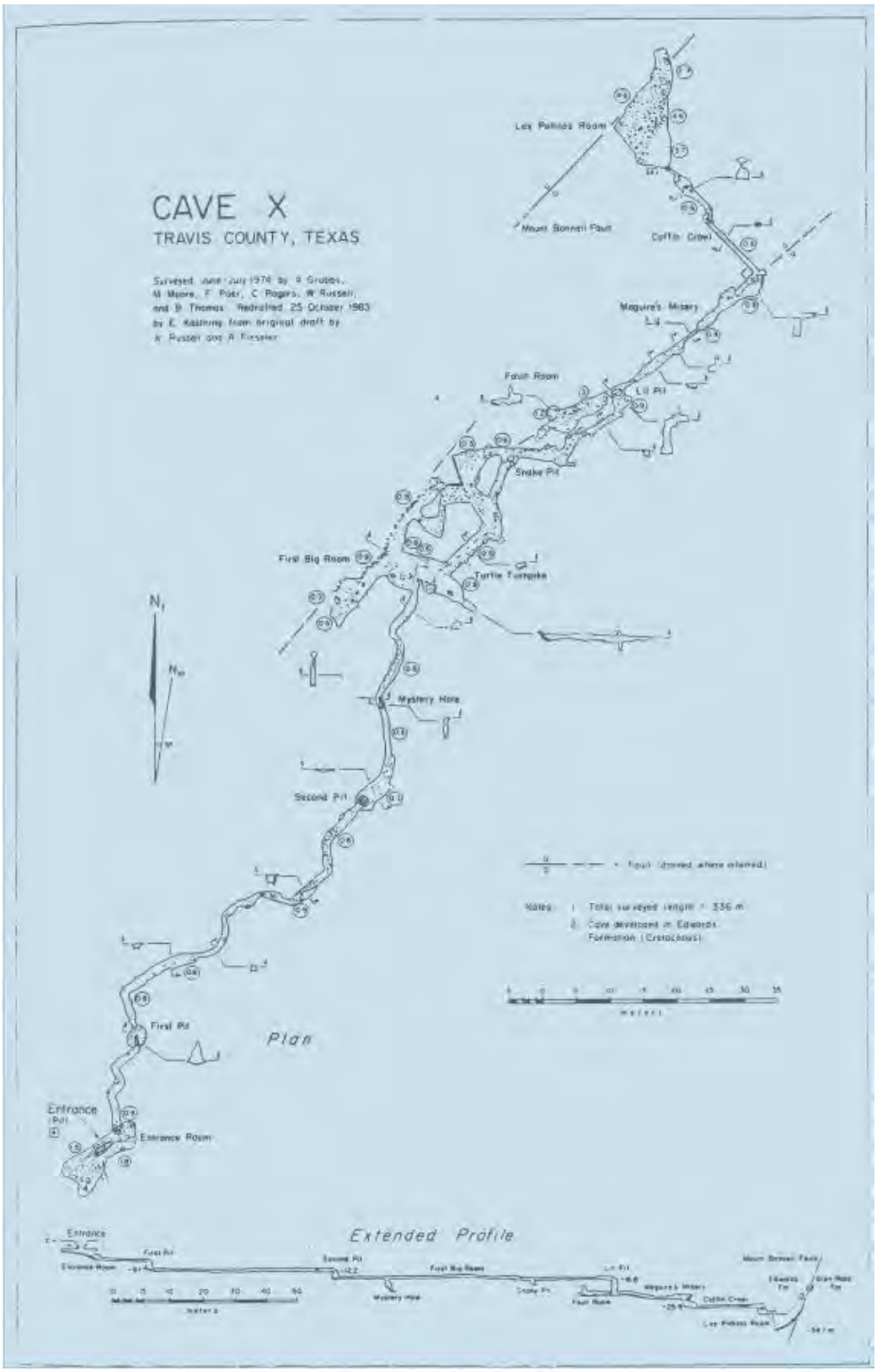

Figure 1. Map of Cave X (Kastning 1983).

several common spiders, millipedes, centipedes, cockroaches, scorpions, and bark lice. Trogloxene species in Zone 1 include cave crickets (*Ceuthophilus* sp.), daddy long-legs (*Opiliones* sp.), and raccoons (*Procyon lotor*). Zone 2 receives only some refracted light and represents a transitional zone between the entrance zone and the deeper Zone 3. In the case of Cave X, Zone 2 consists of the first section of crawling passage starting at the edge of the entrance room and leading to the first drop, approximately 100 feet from the cave entrance. Zone 2 contains deep twilight to permanent darkness and climate conditions fluctuate slightly with surface conditions, especially when cold fronts come into the area or when heavy rains occur. Species known from Zone 2 include mostly troglobitic silverfish, spiders, beetles, harvestmen, millipedes, and micro arthropods such as mites and springtails. Some troglophilic species occur in Zone 2, including species that are adapted to living in the soil column such as earthworms. Zone 3 occurs in permanent darkness and is nearly completely buffered from surface climatic fluctuations. In the case of Cave X, Zone 3 extends from the bottom of the first drop to the end of the cave. Troglobites and trogloxenes dominate Zone 3—where pools on the cave floor are less ephemeral and contain stygobites, or aquatic cave-adapted organisms. Figure 2 presents a map of the cave footprint with habitat zones labeled.

Methods

Due to recognized safety issues related to the air quality within Cave X personnel from Cambrian, Regents and the City of Austin developed an air quality monitoring plan with agreed-upon thresholds for safe access to the cave (See appendix 2). In the weeks prior to the 2016 biological survey Cambrian and City of Austin personnel monitored carbon dioxide levels within the first two rooms of the cave. We used an Amprobe CO2-100 hand-held CO2 meter which has a detection range of 0-9999 parts per million (ppm) with an accuracy of +/- 30 ppm.

Table 1. Results of weekly carbon dioxide monitoring prior to the biological survey.

Date	Upper Room	Beginning of Crawl	Personnel
4 January	~1150 ppm	650-800 ppm	K. White, S. Pope, M. Stevens
11 January	~1049ppm	~1250 ppm	K. White, S. Pope, J. Scalice, M. Stevens
19 January	~5300 ppm	~5290 ppm	K. White, S. Pope, M. Stevens
25 January	~2950 ppm	~3500 ppm	K. White, S. Pope, M. Stevens
1 February	~2616 ppm	3493ppm	C. Crawford, S. Pope
8 February	~544 ppm	~790 ppm	K. White, S. Pope, M. Stevens
16 February	~1531 ppm	~1703 ppm	K. White, S. Pope, M. Stevens
17 February	Above 10,000 ppm	Above 10,000 ppm	K. White, R. Jones

Through January and February carbon dioxide levels in the cave did not follow a downward trend with successive cold fronts as hoped. In fact, the highest carbon dioxide levels were measured the day before the survey was planned with readings above the upper detection range of the meter. As an additional safety precaution we ventilated the first two segments of cave passage for a period of 18 hours prior to cave entry (Photo 1). An EP5 115 volt electric manhole blower manufactured by the General Equipment company was used to remove carbon dioxide laden air from the portion of the cave above the first drop[4]. The effective range of the equipment prevented deployment of hose

[4] An electric unit was selected to avoid the introduction of combustion gases from gas-powered models.

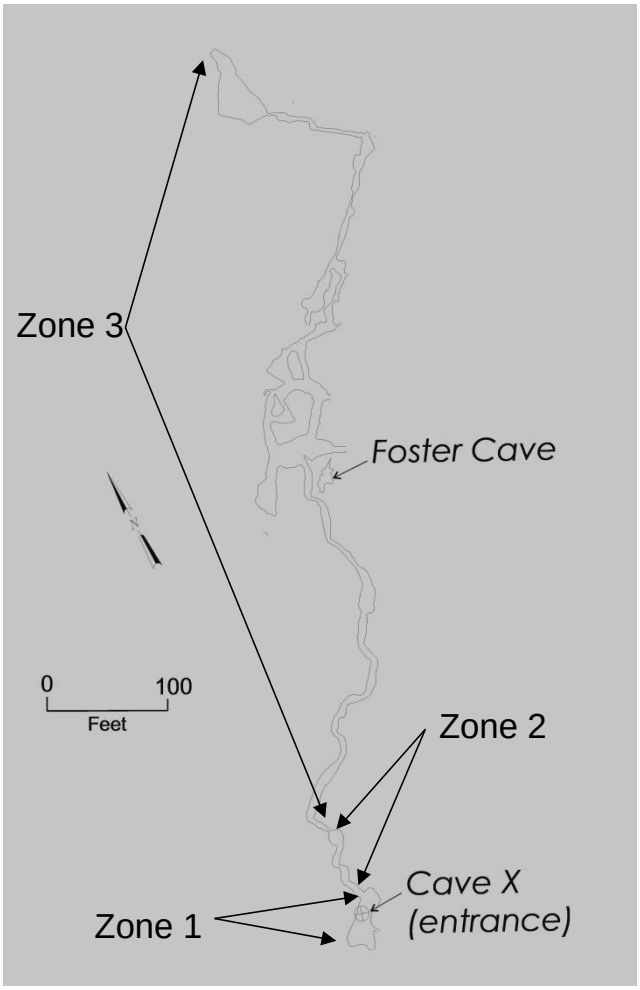

Figure 2. Ecological zones of Cave X

beyond that point. Air was evacuated from the cave from 2 pm on February 17th until 7:30 am on February 18th. During the hour prior to the survey (7:30 to 8:30 am) the ventilator was reversed to blow fresh surface air into the cave. Table 2 reports on the effectiveness of air ventilation on air quality as measures from the ventilator port. Overnight the carbon dioxide level dropped from above 10,000 parts per million (which is hazardous for long-term exposure) to approximately 430 parts per million (which is only slightly elevated when compared to the atmospheric concentration of around 400 parts per million[5]). Carbon dioxide levels were monitored during the survey as well and remained within acceptable limits although they increased with distance into the cave. At the bottom of the second drop carbon dioxide was at ~3,100 part per million.

Table 2. Hourly carbon dioxide monitoring during period of mechanical ventilation.

Date	Time	Concentration (Parts Per Million)
17 February	2:15 pm	+10,000 ppm
	3:30 pm	+10,000 ppm
	4:30 pm	3,400 ppm
	5:30 pm	2,700 ppm
	6:30 pm	1,400 ppm
18 February	7:30 am	430 ppm

The biological survey was conducted in general accordance with the USFWS Terrestrial Karst Invertebrate Survey Protocols issued in May 2014. Surveys were conducted by Kemble White who is permitted by the U.S. Fish and Wildlife Service under threatened and endangered species permit TE37416B. The surveyor moved slowly through the cave making observations of general numbers of species encountered taking care to flip rocks and pieces of organic matter to look for more cryptic individuals. Invertebrate samples of interest were collected with a hand-held aspirator and preserved in 100% ethanol. Most common species were identified visually and not collected. Field identifications presented in Table 3 were made by Kemble White. Samples will be sent to James Reddell of the Texas Memorial Museum (all other samples) for further identification and curation.

Survey Results and Discussion

The cavernicole fauna of Cave X have been studied as early as 1959 by various cave explorers including a study concentrating on aquatic fauna by Dr. Basset Maguire of the University of Texas. Prior to 2004 a total of 30 species were known from the cave and the total currently stands at 36. Cave X's ecological condition appears to be healthy and suffering no apparent degradation. All of the major troglobitic forms that have been previously documented from the cave were found during our study. The exception being the copepods and ostracods which are likely still present but were not observed due to lack of access to the area of the cave beyond the third drop where permanent water occurs. This portion of the cave was not accessed due to concerns over prolonged exposure to carbon dioxide. Species encountered included *Stygobromus russelli* amphipods, isopods, *Cambala* spp. and *Speodesmus* spp. millipedes, *Texoreddellia* spp. silverfish, *Texella mulaiki* harvestmen, *Rhadine austinica*, and *Cicurina bandida*. Cave crickets of at least two species appear to have robust populations as indicated by direct observation of large numbers of crickets and by the presence of

[5] http://www.esrl.noaa.gov/gmd/ccgg/trends/index.html

fresh cricket guano deposits throughout the cave. No signs of trespassing or vandalism were observed and the cave was free of any litter. Table 3 presents a synopsis of species encountered during the 2016 survey and during previous surveys. Troglobitic species are shaded in gray. BCCP species of concern are marked with an asterisk. Photos 1 through 12 along with their captions provide additional detail regarding general results and specific information on specimens collected.

Reliable trends of species abundance are difficult to infer from a small number of surveys. The question that is most reliably answered with these surveys is "Are the troglobitic species still present?". As of 2016 the answer is yes. The results of this survey indicate that the conservation measures for Cave X have been effective and continue to support the ecology of rare karst fauna more than fifteen years after the development of the Regents School campus.

Table 3. Cumulative Results of Biological Surveys of Cave X.

Taxon	Survey				Characteristics
Genus/Species	Pre-2004	2004	2014	2016	Notes from 2016 survey
Aquatic Fauna					
Crustacea					
Eucopepoda (Copepods)					
Cyclops Bicuspidatus thomasi	x				N/A
Paracyclops fimbriatus poppei	x				N/A
Podocopa (ostracods)					
Candona sp. nr. *stagnalis**	x				N/A
Isopoda (Isopods)					
*Caecidotea reddelli**	x			X	Two individuals observed below second pit
Miktoniscus n.sp.*	x			X	Many tens of individuals observed in association with decaying woody debris in zones 2 and 3

Amphipoda (Amphipods)					
Stygobromus russelli	x	X		X	Tens of individuals observed in leaf litter within pool at base of second pit
Terrestrial Fauna					
Gastropoda (Snails)					
Helicodiscus eigenmanni	x	x		x	Hundreds seen throughout zones 2 and 3
Annelida Oligochaeta (Earthworms)					
Allolobophora trapezoids	x	x		x	Tens of individuals seen in soil deposits under rocks throughout the cave
Diplocardia sp.	x	x		x	Tens of individuals seen in soil deposits under rocks throughout the cave
Arthropoda arachnida					
Araneae (Spiders)					
*Cicurina bandida**	x	x	x	x	Many tens of primarily immature specimens observed throughout zones 2 and 3 typically under rocks
Cicurina varians		x		x	Tens of individuals observed in zones 1 and 2 typically under rocks
Eidmanella pallida	x	x		x	Tens observed in zone 1
cryptachaea porteri	x	x		x	Tens observed in zone 1
Surface orb weaver		x		x	Tens observed in zone 1
Scorpionida (Scorpions)					
Pseudouroctonus reddelli	x	x	x	x	Tens observed in zones 2 and 3
Opiliones (Harvestmen)					
Lieobunum townsendii		x		x	Tens observed in zone 1
Texella mulaiki	x	x		X	Six individuals observed in zone 3
Chilopoda (Millipedes)					
Cambala speobia	x	x	x	x	Tens observed in zones 2 and 3
Oxidus gracilis			x	x	Tens observed in zones 1 and 2
Parajulidae genus and species	x			x	Tens observed in zone 1
Speodesmus n.sp.*	x			x	Several individuals observed in zones 2 and 3
Speodesmus bicornorus	x			x	Tens observed in zones 2 and 3
Diplopoda (Centipedes)					
Lithobiomorpha undetermined	x			x	Tens of individuals observed in zones 1 and 2 typically under rocks

Scolopendra sp.		x			
Hexapoda, Collembola (Springtails)					
Pseudosinella sp.		x	24	x	Hundreds seen throughout zones 2 and 3
Insecta					
Thysanura (Silverfish)					
Texoreddellia texensis	x	x	x	x	Many tens observed throughout zones 2 and 3 typically under rocks
Orthoptera (Crickets)					
Ceuthophilus secretus	x	x	x	x	Hundreds of all age classes observed throughout the cave
Ceuthophilus cunicularis	x	x	x	x	Many tens observed throughout zones 2 and 3
Bark lice					
Pseudoseopsis hellmani	x	x	x	x	Tens observed primarily in zone 2 on organic debris
Coleoptera (Beetles)					
*Rhadine austinica**	x			x	One individual observed in the first big room
Batrisodes uncicornis	x			x	Four individuals observed in zone 3
Diptera (Flies)					
Diptera spp.	x	x	x	x	Tens observed in zones 1 and 2
Chordata					
Amphibia (Salamander)					
Plethodon glutinosis albagula	x	x			Not seen in 2016
Mammalia					
Didelphis marsupialis (opposum)	x				Not seen in 2016
Pyromyscis sp. (field mouse)		x			Not seen in 2016
Reptilia					
Thamnophlius (garter snake)		x			Not seen in 2016



Photo 1. Entrance of Cave x with ventilation equipment.



Photo 2. Carbon dioxide meter at the edge of a pool of perched groundwater at the bottom of the second drop. Cave-adapted amphipods (*Stygobromus russelli*) and the BCCP SOC *Caecidotea reddelli,* (a cave-adapted isopod) were observed in this pool.



Photo 3. Interior of the "first big room" of Cave X with Johnny Scalise of the City of Austin (left) and Cambrian karst technician Ryan Jones (right).



Photo 4. Cambrian karst technician observing drip water from the ceiling of the "first big room" as described on the cave map. This room is approximately 75 feet below the surface.

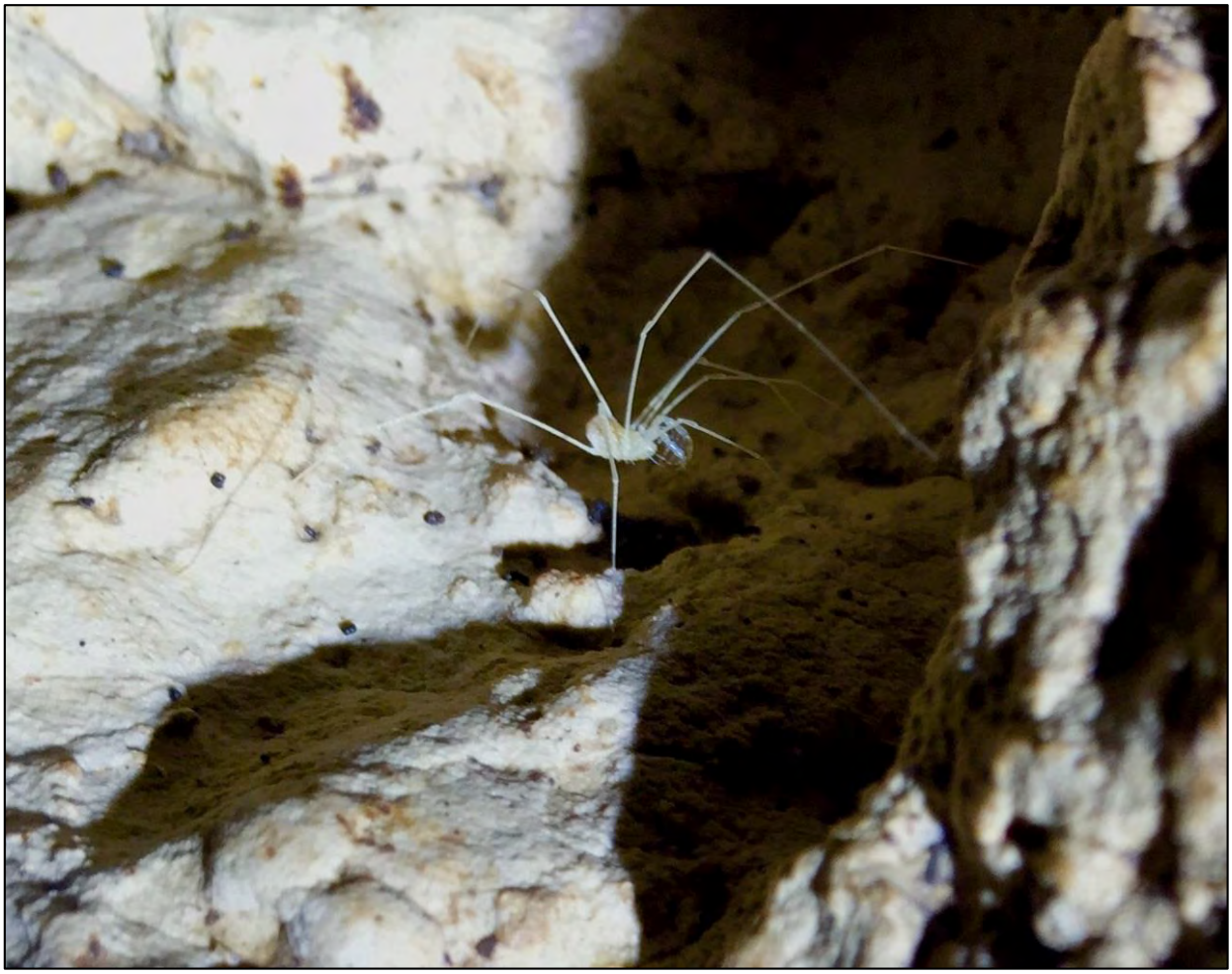

Photo 5. One of five *Texella mulaiki* specimens encountered during the survey. *T. mulaiki* is not a BCCP SOC, but it is considered the most extremely cave adapted of the numerous troglobitic *Texella* cave harvestman known from Texas (See also photos 9 and 10). *T. mulaiki* are thought to be scavengers preying on organic matter and microarthropods. Each black spec in this image is a *Ceuthophilus* spp. fecal pellet (cricket guano). Cricket guano is one of the primary sources of fuel for the troglobitic ecosystem.



Photo 6. *Cicurina bandida* (formerly C. Cueva) is likely the apex predator of the Cave X troglobitic community. Eyes are entirely lacking which indicates an extreme degree of cave adaptation.



Photo 7. The troglobitic millipede *Cambala speobia* lacks pigment and has elongated legs.



Photo 8. The troglobitic beetle *Rhadine austinica* has reduced eyes and elongated legs.



Photo 9. Troglobitic harvestman *Texella mulaiki* with penny for scale.



Photo 10. Detail of troglobitic harvestman *Texella mulaiki.*


Photo 11. Troglobitic isopod *Miktoniscus* sp. with penny for scale.



Photo 12. Cave amphipod *Stygobromus russelli* with penny for scale. *S. russelli* is essentially a cave shrimp that feeds on organic matter in cave pools and streams.

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Appendix 1

Qualification of personnel responsible for conducting biological survey and field identifications

Kemble White Ph.D., P.G. – Prior to starting Cambrian Environmental Dr. Kemble White served for 15 years as senior geologist, karst specialist, and project manager for one of the largest ecological consulting firms in the country. Over the course of his career Dr. White has made a significant contribution to the state of Texas cave science and to the conservation of karst resources. His doctorate was on biospeleology, the study of caves and cave life. His research on Cicurina spp. cave spider genetics and the evolution of their habitat was published in Geology, the world's flagship peer-reviewed earth sciences journal. He has discovered many new locations for rare and endangered species and two new species have been named in his honor. His experience with invertebrates began in the early 1990's when he participated as a field technician in a National Geographic-funded research project on wolf spider speciation.

His karst survey work has contributed to the establishment of thousands of acres of preserve land within the Edwards Aquifer recharge and contributing zones through land acquisitions programs including the USFWS Section 6 program. From 2002-2013 he served on the USFWS recovery team for the Bexar County endangered karst invertebrates. Many of the critical habitat units in Bexar county were delineated based in part on data from his reports. Dr. White has been a primary author of several EA/HCPs including the Williamson County Regional Habitat Conservation Plan. Since 2008 he has worked with USFWS staff and the Wilco RHCP to develop four Karst Fauna Areas contributing to the recovery of the endangered Bone Cave harvestman and the Coffin Cave mold beetle. He has actively participated in the construction of the Wilco RHCP land bank and has conducted the sub-surface biological monitoring on those preserves (including dozens of caves) since 2008.

Since 2012 he has served in a technical working group for *Eurycea* spp. in Williamson County, TX along with USFWS Austin ESFO staff. He has documented many new locations for *Eurycea* salamanders in Hays and Williamson counties and several critical habitat units in Williamson county have been shaped by his work. He has participated in visual encounter surveys at more than six springs occupied by the Georgetown, Jollyville Plateau, and Salado salamanders.

Appendix 2:

Monitoring conditions for the Cave X biological survey as summarized by Sylvia Pope by email on 6/9/2015

Condition 1. Cave team will travel as far as Maguire's Misery, or approximately ¾ of the total length of the cave, or until encountering a groundwater-sustained pool with *Stygobromus* species (amphipods) and a transect of 10 m is available to survey at a shorter distance. Regents School will submit a report that includes the biological survey results and carbon dioxide measurements. This will fulfill the obligation for conducting biological monitoring in Cave X.

Condition 2. Cave team will attempt a survey when atmospheric carbon dioxide levels are below 3 % (30,000 ppm) with mechanical ventilation or below 1 % (10,000 ppm) without mechanical ventilation or other breathing air supply. Cave team will decide their own thresholds for work termination between 1 and 3 % concentration of carbon dioxide past the entry room. Cave team will also decide their own thresholds for oxygen levels.

If one attempt, with mechanical ventilation, reaches the second pit of Cave X but terminates the survey due to elevated carbon dioxide (CO2); the biological survey will include the area from the entrance to the top of the second pit and will be considered a full survey. However, CO2 instrument readings and locations must be documented in the final report.

Condition 3. Cave team will initiate weekly CO2 measurements the week of January 4, 2016. Measurements will be taken in the first crawlway at a time no later than 8 a.m. If CO2 levels are above 3 % for each of the 9 weeks from January 4 to early March, no further measurements are required and the biological monitoring will be considered fulfilled. Regents School will submit a report documenting the CO2 levels for each date. The report will include the instrument manufacturer, model number, detection range and calibration records.