George Veni & Associates

Hydrogeologists and Biologists
Environmental Management Consulting
Cave and Karst Specialists

REVISION OF KARST SPECIES ZONES FOR THE AUSTIN, TEXAS, AREA

by
George Veni, Ph.D., and Cecilio Martinez

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4200 Smith School Road
Austin, Texas 78744

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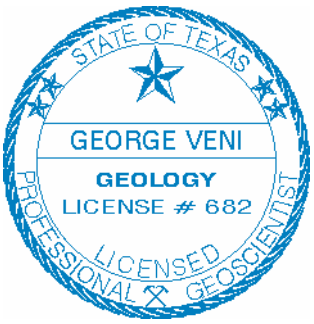

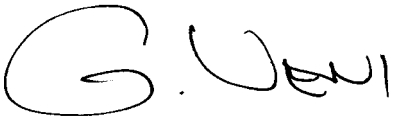

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George Veni, Ph.D., Texas Professional Geoscientist No. 682

507 E. Chapman, Carlsbad, New Mexico 88220-9283
505-234-1409 • gveni@warpdriveonline.com • 410-383-2276 (fax)

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REVISION OF KARST SPECIES ZONES FOR THE AUSTIN, TEXAS AREA

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Introduction

The Austin, Texas, region is hydrogeologically and biologically complex. Species living in its caves and related voids have become physically isolated from each other through time, resulting in genetic isolation that has produced new species known to occur only within small geographic areas. The expansion of Austin and neighboring communities onto the karst where these species occur poses a threat to their survival due to the destruction of caves, sealing of caves, changes in nutrient and moisture input into caves, contaminants introduced into caves, and competition with and predation by non-native species introduced by urbanization (Elliott, 1993 and 2000).

Seven species of karst invertebrates in the Austin region are federally listed as endangered by the U.S. Fish and Wildlife Service (USFWS) to insure their survival. Five were listed in September 1988 (USFWS, 1988) and a refinement of the taxonomy added two more species to the list in 1993 (USFWS, 1993). The species and their common names are:

Batrisodes texanus (Coffin Cave mold beetle).
Neoleptoneta myopica (Tooth Cave spider)
Rhadine persephone (Tooth Cave ground beetle)
Tartarocreagris texana (Tooth Cave pseudoscorpion)
Texamaurops reddelli (Kretschmarr Cave mold beetle),
Texella reddelli (Bee Creek Cave harvestman)
Texella reyesi (Bone Cave harvestman)

In 1992, four endangered species habitat and management zones in the Austin region were delineated for the USFWS by George Veni and Associates. Those zones were drawn on twenty-two 7.5' topographic quadrangles and were defined as:

Zone 1: areas known to contain endangered cave fauna;

Zone 2: areas having a high probability of suitable habitat for endangered or other endemic invertebrate cave fauna (refined now to only endangered cave fauna);

Zone 3: areas that probably do not contain endangered cave fauna; and

Zone 4: areas which do not contain endangered cave fauna.

Due to the absence of directly observable features to define the species' habitat, these zones were based on biological and geological factors that could be used to estimate the likely boundaries of species habitat and areas of probable and improbable habitat. These zones have since been used by USFWS in several ways, but primarily as management zones, determining what level of action and research is needed in the protection and study of areas within these zones (e.g. USFWS, 2001).

The most critical of the karst zones is Zone 1, where the species are known to occur. When the existing maps were first drafted, only 43 caves were known to contain listed species in the study area. As of 27 October 2003, 213 caves with listed species were known to the USFWS in this area (Tannika Engelhard, personal communication, 2003). Recent revision of a similar karst zone map in the San Antonio, Texas, area, found that Zone 1 was far more extensive than originally mapped based on the few initial data (Veni, 2002). This is also demonstrated in the Austin area with many caves discovered in Zone 2, since 1992, to contain listed species as predicted by the Zone 2 designation. With 180 additional localities for the species, this project was initiated to more accurately delineate Zone 1 for more effective management, study, and protection.

The need for revision is not solely due to the discovery of new species localities but also from a better understanding and mapping of the geology on which the zone mapping is strongly based. The examination of many new caves since 1992 allows for more detailed and accurate interpretation of cave origin throughout the study area and its implications on species distribution. More precise mapping of the geology south of the Colorado River in Travis County allows more precise delineation of boundaries in that area (Small, Hanson, and Hauwert, 1996). Detailed field studies in some areas north of the Colorado River have confirmed or modified the mapped geologic boundaries to affect the demarcation of all four karst zones (e.g. Veni, 2001 and 2003). Additionally, the original mapping was conducting by visually estimating geologic boundaries on various paper maps and drawing them, as they affected the karst zone boundaries, by hand on the paper topographic quadrangles. The technology is now available to digitally redraw the maps by overlaying digital geologic maps into a geographic information system (GIS) and importing digital images of paper geologic maps into a GIS for more precise delineation of those boundaries.

Consequently, the purpose of this investigation is to re-evaluate and redraw, as necessary and in a GIS, all four karst zones within the Austin region. The zone revisions will allow the USFWS to better identify and evaluate areas important to the species' management and recovery. This report will build on previous studies that conducted partial and/or initial research on this topic.

Methodology

Work to revise the delineation of karst zones began with reviews of cave and karst research conducted in the Austin region, literature related to the listed species, and consultation with other specialists and environmental management personnel as needed in order to collect as much pertinent information as possible. Most consulting studies cited in this report were copied from the files of the USFWS; other examined studies were not cited if not directly pertinent. The Texas Speleological Survey (TSS) provided access to files which include a significant amount of unpublished information on Austin region caves.

When this study was initiated, the Austin region was initially defined as the 22-quadrangle area used by Veni and Associates (1992). This investigation modifies at that definition in three ways. First, the 1992 mapping was limited to the portions of those quadrangles within Travis and Williamson counties and the Post Oak Ridge area of southwestern Burnet County. For this investigation, the mapping includes all areas of each quadrangle, including parts of southern Bell and northern Hays. Second, a 23rd quadrangle was added. Salado, in southern Bell County, is a geologically logical extension of an area potentially containing listed karst invertebrates. Third, the known range of the species has expanded adding, Pace Bend, Smithwick, and Spicewood quadrangles to the study area. Thus, the following 26 7.5' U.S. Geological Survey (USGS) quadrangles define the boundaries of the Austin region for this investigation:

Austin East	Georgetown	Mansfield Dam	Signal Hill
Austin West	Jarrell	Nameless	Smithwick
Bertram	Jollyville	Oak Hill	Spicewood
Briggs	Leander	Pace Bend	Travis Peak
Cobbs Cavern	Leander NE	Pflugerville West	Youngsport
Ding Dong	Liberty Hill	Round Rock	
Florence	Mahomet	Salado	

Revision of the karst zones was a four-step GIS process described below.

Step 1: Quality review and correction of the existing GIS file

The karst zones were originally hand-drawn on 22 paper 7.5' topographic quadrangles. Unidentified personnel from SWCA, Inc. (Jenny Wilson, USFWS personal communication, 2005) later digitally transcribed the karst zones from the 19 southernmost of the 22 quadrangles into a GIS shapefile. The shapefile contained two primary problems that had to be addressed. First, the application version was not suitable for correcting topology errors, and second, a geodatabase had to be created to identify and correct topology errors. By addressing these issues, the GIS shapefile could be updated for the creation of an accurate database and precise shapefile.

The GIS application of the original shapefile was switched from an old version, used to create that file, to a new version. The GIS application used in updating the shapefile is an Environmental Systems Research Institute (ESRI) product. Currently, ESRI has three main GIS applications: a high-end version known as ArcGIS – ArcInfo 9.1; a mid-range version known as ArcGIS – Editor 9.1; and a lower-end product known as ArcGIS – ArcView 9.1. The application used to create the original shapefile is not known but was most likely an older ESRI product like ArcView 3.x. During the initial update of the shapefile, the GIS application used was ArcGIS –

ArcView 8.3. Although a powerful application for making maps, it lacked the ability to identify and correct topology issues. It was therefore necessary to move to the high-end ArcGIS – ArcInfo 9.1 to handle the numerous errors identified through the creation of a geodatabase and application of topology rules.

A geodatabase is defined by ESRI as an "object-oriented data model introduced by ESRI that represents geographic features and attributes as objects and the relationships between objects but is hosted inside a relational database management system. A geodatabase can store objects, such as feature classes, feature datasets, nonspatial tables, and relationship classes." ESRI has two types of geodatabases, a personal geodatabase and multi-user geodatabase. For the purpose of this project, a personal geodatabase was used for identifying and correcting errors. Topology in a geodatabase allows the analysis of features (points, lines, and polygons) in a shapefile and how they relate geographically from one to another and even other shapefiles by applying topology rules. The following topology rules were used: "Must Not Overlap" and "Must Not Have Gaps."

Once the geodatabase and topology rules were applied to the original shapefile, 835 errors were displayed, consisting of 225 gaps and 610 overlaps. The majority of these errors seem to have been created when the digitized 19 quadrangles were merged to create the shapefile. Figure 1 shows the errors predominantly occur in the Bull Creek drainage basin and follow quadrangle boundaries. In several cases it would be difficult to locate the errors without the topology rules. For example, Figure 2 shows a red polygon that is hidden underneath a much larger polygon, creating two karst zone values and ambiguous zone boundaries for the area of overlap.

After the topology rules were applied and the shapefile corrected, it could be easily updated and modified. Correction of the numerous errors in the original shapefile ensures the validity of the database and the integrity of the updated shapefile for data analysis. Following these corrections, additional modifications were made to ensure the digitized karst zone boundaries accurately represent the 1992 paper map. Several minor deviations from the paper map were discovered and rectified.

Step 2: Zone boundary revisions based on digital geologic maps

The original paper karst zone maps were drawn in 1992 by interpolating the position of geologic boundaries shown on other paper maps, primarily the Geologic Atlas of Texas Austin Sheet (Barnes, 1974). Since that time, the USGS has mapped the geology of the Edwards Aquifer recharge zone in detail in Travis County south of the Colorado River (Small, Hanson, and Hauwert, 1996). That mapping is available as a shapefile. The Bureau of Economic Geology has also made Barnes' (1974) map available as a shapefile.

The shapefiles of the two geologic maps were incorporated into the project GIS. The karst zone boundaries were adjusted to precisely match the geologic boundaries where the geology determined the position of the zone boundaries. However, the accuracy of the geologic boundaries is not known and probably varies. The geologic boundaries of Small, Hanson, and Hauwert (1996) were used over those of Barnes (1974) where the two overlapped because of the former's higher level of mapping precision and detail.

Figure 1
Topology errors present in initial karst zone shapefile

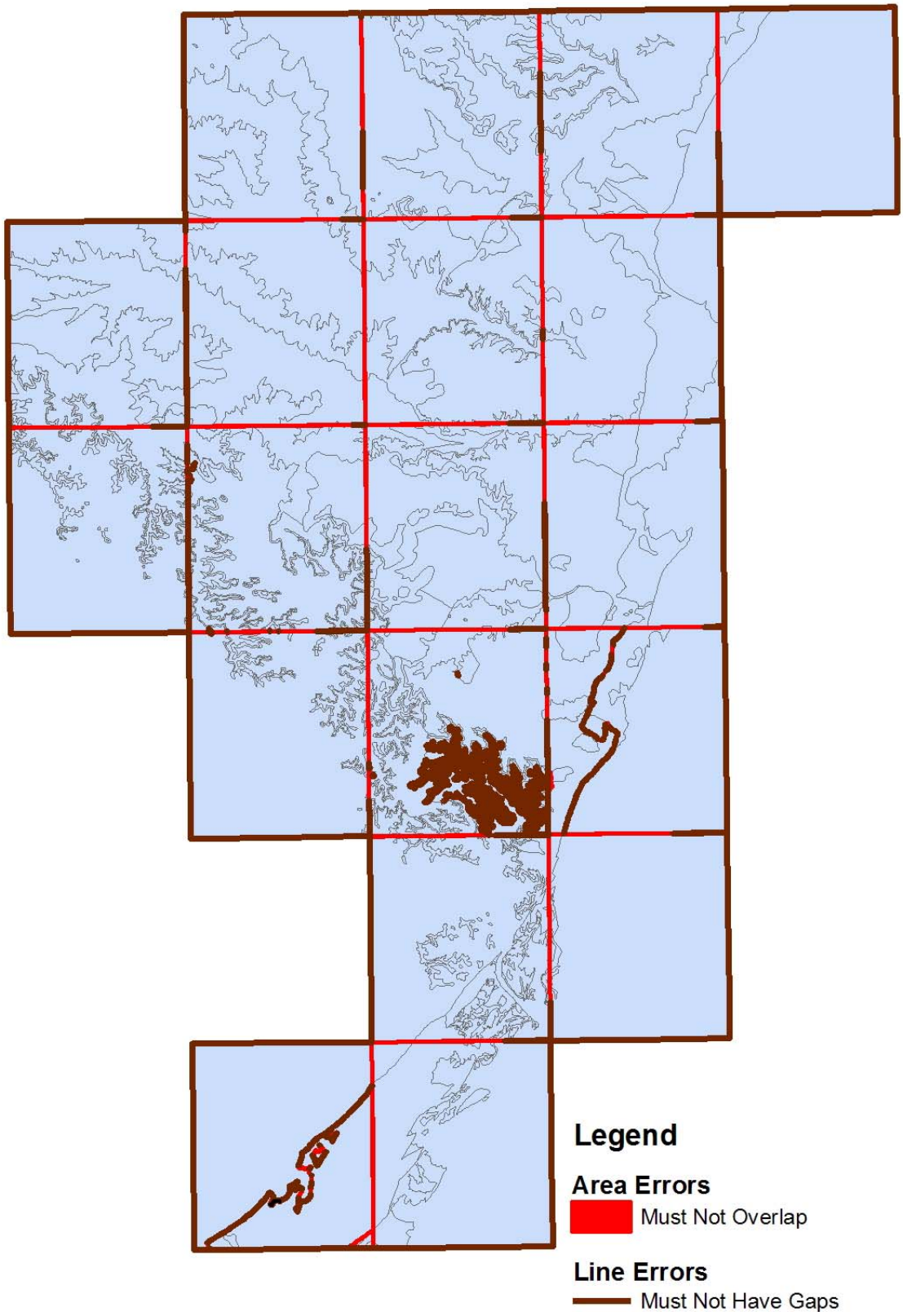
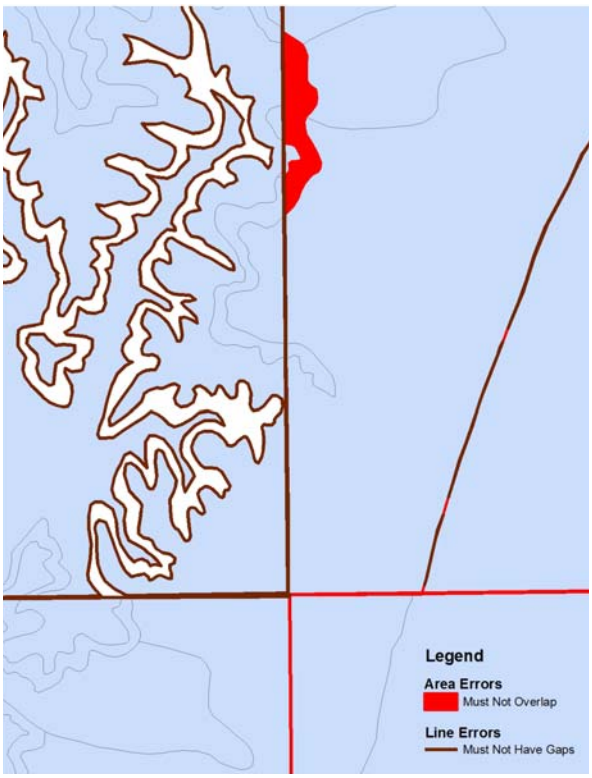


Figure 2
Example of hidden topology error that could be missed without use of topology rules



In general, the karst zones were delineated bases on lithology, with Zone 1 and 2 occurring in the Edwards Limestone Group, Zone 3 being areas of the Edwards Limestone mapped as covered by alluvium and areas of the Bee Cave Marl, Cedar Park Limestone, Comanche Peak Limestone, Georgetown Formation, and the undivided Georgetown Formation and Del Rio Clay, and Zone 4 encompassing all other units. The digital version of Barnes' (1974) geologic map included the Fredericksburg Group, which was generally classified as Zone 3 except where Barnes printed map shows Keys Valley Marl which was classified as Zone 4. This classification system is based on the presence and absence of caves and karst features in those lithologies but requires careful scrutiny of the data. For example, caves with listed species occur in some areas mapped as the Georgetown Formation where the unit is locally thin and easily breached by collapse into underlying Edwards Limestone caves. Listed species have also been discovered where quarrying has removed the Georgetown to expose the Edwards and its caves.

The result of these first two steps was a karst zone map as the 1992 map would have been if GIS technology and current geologic maps were available. Its purpose was to provide an accurate basemap where the only remaining variable for revision was the consideration of new localities of listed species and the more site-specific geologic factors affecting their distribution. Until that revision could be completed, the updated "1992" version map was released to USFWS as a shapefile on 14 December 2005 for their use and distribution. Unfortunately, it was incomplete. The original shapefile was assumed to cover all 22 topographic quadrangles, but while making the updates

described in the next steps, it was discovered that the three northernmost quadrangles were not included. The further updated "1992" shapefile was released to USFWS on 14 May 2006.

Step 3: Collection of endangered species location data

With few exceptions, the listed invertebrate species have been recorded in caves. The TSS is a non-profit corporation organized to collect, maintain, and make available information on caves and karst features in Texas. Data in the TSS files arrive from many sources. They range in age from decades to a few days old, and in quality from vague descriptions to highly specific information. The quality of the data does not necessarily correlate to age or if it was collected during professional surveys.

Location data in the TSS files is recorded as Universal Transverse Mercator (UTM) coordinates relative to a datum of NAD 1927. Each location includes an "uncertainty" field for the estimated precision of the coordinates. Locations recorded by high-precision global positioning system (GPS) units may be accurate to within a few meters while general descriptions, such as "located 8 km west of" a given location will yield coordinates accurate to perhaps 2 km or more. The TSS functions as a library and does not field-check the data in its files. That role belongs to investigators who conduct field research or review TSS data to find constraints and inconsistencies. Their results are entered into the TSS files to improve the database for future use. Several caves with endangered species were not in the TSS files but information on them was collected from consulting and other reports found in the files of USFWS.

Regardless of the data source, locations of sites with the endangered karst invertebrates were compared to each other (if more than one was noted), the methods used to identify each location, and with geological, topographical, and cultural features to determine the most accurate probable location. Many locations were available only on paper hand-drawn sketches or drawn on 7.5' topographic maps, 2-foot contour interval topographic maps, subdivision plat maps, and aerial photographs. All locations were plotted in ArcGIS on georeferenced 7.5' topographic maps and aerial photos, and recorded as NAD 1927 UTM coordinates.

In comparing the location data from sources in the TSS and USFWS files, one problem became apparent. GPS technology is relatively new and not always well understood by its users. Coordinates are sometimes considered absolute and not recognized, even by some professional environmental consultants, as relative to a datum that must be recorded since coordinates for any given datum will yield different absolute positions. Additionally, some people do not realize that the precision of their coordinates may be poor due to inadequate satellite coverage, locations under dense tree canopies or next to cliffs, or from recording the first coordinates to appear and not giving the GPS unit time to average and better process the data for more accurate results. The uncertainty of the locations used in this project is recorded with the coordinates. The delineation of karst zone boundaries, discussed below, also accounts for the estimated precision of the locations.

Step 4: Karst zone delineation methods

Zone boundaries were revised based on more recent studies of cave and karst development and on the most current biological information available on the distribution of listed and non-listed troglobite species. The principles used to delineate specific zone boundaries were to identify geologic or topographic features that may restrict the distribution of the listed species and examine

the distribution of listed and non-listed troglobites for indications that the boundaries are valid. Contacts between geologic units where caves are common versus units where caves are rare or absent are the most reliable factors in delimiting Zone 1 boundaries. These sometimes occur in valleys where erosion has removed one unit and exposed another. They also occur along some faults where one unit may be juxtaposed against another.

Many Zone 1 boundaries are not that simple to define. Where there is no known discontinuity in the cavernous limestone and for lack of other possible options, Zone 1 boundaries may be drawn along creek beds and the locally narrowest or lowest drainage divide. These locations are where the limestone is thinnest and may pose some restrictions on species distribution. Faults with cavernous rock on either side do not seem to restrict species distribution, but they may be selected as a Zone 1 boundary if other possibilities are exhausted. While some caves form along faults, fault planes filled with calcite or gouge are unlikely sites for cave development. Other factors considered in the delineation of Zone 1 boundaries include:

1) Comparing the lowest known cave elevation with the lowest topographic elevation to be sure at least the known cavernous zone in the rock is encompassed.
2) Examining the distribution of listed and non-listed troglobites in different caves. If the same troglobites, and especially the same listed troglobites, occur in different caves, those caves may warrant grouping as single Zone 1 area. The quality of the collections should also be weighed. Collections conducted only once, under poor conditions, cursorily, and/or by non-specialists in the collection of cave species, should be given greater weight for similarity of species, since more detailed studies would likely yield more similarities.
3) Evaluating the type and extent of cave development in the area will to determine how realistic it may be for cavernous voids to occur in locations considered as zone boundaries.
4) Assessing other caves in the area, especially if they occur between caves with listed species. This demonstrates the presence of potential habitat for the species, unless those caves have been carefully surveyed and the species were not found.

These factors are not always consistent. For example, the geology may suggest a restriction, but the biology may indicate the opposite. All available factors and information are considered to determine which features and locations are the mostly likely boundaries.

Table 1 is a list of all 249 sites known or reported to contain the listed species, the listed species that occur at each site, and the karst fauna regions (defined below) in which each site occurs. Three localities are from surface collections where the species were collected from solutionally enlarged bedding planes and fractures during moist conditions.

Table 1 provides the level of certainty in the identification of the species at each site. The species have been confirmed for most localities by qualified taxonomists who specialize in the identification of those animals. Morphological confirmation of the species requires adult specimens and with some animals can only be conducted with a specific gender. Species confirmation, as used in Table 1, includes instances where immature troglobites of an endangered genus, or adults but of a gender that is not in itself identifiable to species level, have been identified from sites where biological and geological evidence overwhelming indicate the specimen can only be one of the listed species.

Because caves are often assigned different names and codes by different researchers, Table 1 includes a column for all known names and codes. The primary name is that used by the TSS. The TSS has not established a written policy on which name to use when multiple names exists, but it uses the following general protocol, given here in descending level of priority:

1) Name used in a published map or report
2) Name on the cave map
3) Name assigned by the person who first reported the cave
4) Name assigned by the discoverer.

Where more than one name exists at the same priority level, such as two published reports, the name in the most widely distributed report or the name most commonly used is assigned.

Step 5: Rare Karst Species Zone delineation methods

While the scope of the project was to refine and update Zone 1 and other karst zones in the study area, two problems were apparent from the original 1992 zone delineation. First, Zone 2, as originally, defined identified potential habitat for listed and rare non-listed species. That mapping effort was the first of its kind, and since relatively little was known about the listed species, that definition was broad to minimize the likelihood that important habitat would not be overlooked. Since then, detailed biological surveys have demonstrated that some Zone 2 areas are unlikely to contain the listed species, but they do contain rare, non-listed species of interest to the USFWS.

Because USFWS needs to understand the distribution of rare species in order to prevent the need for listing, Rare Karst Species Zones were also delineated in this study to be used in conjunction with the Karst Zones. The Rare Karst Species Zones were created from the Karst Zones established for this study, but modified to reflect the distribution of rare invertebrates per the criteria of Step 4 above. Four SOC Zones were delineated and defined as:

Rare Karst Species Zone 1: areas known to contain rare cave fauna;
Rare Karst Species Zone 2: areas with a high probability of containing rare cave fauna;
Rare Karst Species Zone 3: areas that probably do not contain rare cave fauna;
Rare Karst Species Zone 4: areas which do not contain rare cave fauna.

Table 1
List of Austin Area Caves with Endangered Species as of 22 September 2006
(abbreviations are defined at the end of the table)

Cave name or locality	Alternate names or codes	KRF	Nmy	Ttx	Trd	Try	Rpr	Bcr	Btx	Tmr	Reference
Burnet County localities											
County Road 404, 5 miles northwest of Spicewood*		NA			C						Ubick and Briggs (2004)
County Road 404, 6 miles northwest of Spicewood		NA			C						Ubick and Briggs (2004)
Mean Vicious Nasty Cave	MVN Cave	NA			C						Ubick and Briggs (2004)
Waldman Cave		NA			C						Ubick and Briggs (2004)
Travis County localities											
Amber Cave		JVP		C						C	Muchmore (2001)
Bandit Cave	Amend's Cave, Rollingwood Cave	RLL			C						Ubick and Briggs (1992)
Beard Ranch Cave	Featherman's Cave	JVP				C					Ubick and Briggs (2004)
Bee Creek Cave	Pine Creek Cave, Lake Austin Inn Cave	RLL			C						Ubick and Briggs (1992)
Beer Bottle Cave		MCN				C					Ubick and Briggs (1992)
Broken Arrow Cave	Rattler Sink, W77	CPK					C				James Reddell (pers. comm., 2006)
Cold Cave		MCN				C					Ubick and Briggs (1992); Ubick and Briggs (2004)
Cotterell Cave	W98A	CA				C					Ubick and Briggs (1992); Ubick and Briggs (2004)
Disbelievers Cave		JVP					C				James Reddell (pers. comm., 2006)
Eluvial Cave	J22F	JVP				C					James Reddell (pers. comm., 2006)

Table 1 (continued)
List of Austin Area Caves with Endangered Species as of 22 September 2006

Cave name or locality	Alternate names or codes	KRF	Nmy	Ttx	Trd	Try	Rpr	Bcr	Btx	Tmr	Reference
Fossil Cave	P40A	MCN				C					James Reddell (pers. comm., 2006)
Fossil Garden Cave	P50C, W61	MCN				C					Ubick and Briggs (1992)
Gallifer Cave	Gallifrey Cave, J21E	JVP	C			C	C				James Reddell (pers. comm., 2006); Ubick and Briggs (1992); Ubick and Briggs (2004)
Geode Cave	W32	JVP	C								Mike Warton and Associates (1998b)
Hole-in-the-Road Cave	Karst Feature F20, P94C	MCN				C					Ubick and Briggs (1992); Ubick and Briggs (2004)
Homestead Cave	J22Q	JVP					C				James Reddell (pers. comm., 2006)
Japygid Cave	J22D	JVP					C			C	Chandler and Reddell (2001); James Reddell (pers. comm., 2006)
Jest John Cave	J07A, W57	JVP				C					Ubick and Briggs (2004)
Jester Estates Cave	J15A	JVP			C						Ubick and Briggs (1992); Ubick and Briggs (2004)
Jollyville Plateau Cave	J22K	JVP				C	C				James Reddell (pers. comm., 2006); Ubick and Briggs (2004)
Kretschmarr Cave	J31A	JVP					C			C	James Reddell (pers. comm., 2006)
Kretschmarr Double Pit	J31M	JVP		C			C				James Reddell (pers. comm., 2006); Muchmore (2001)
Lamm Cave	J42B	JVP					C				James Reddell (pers. comm., 2006)
Little Bee Creek Cave	Blacksmith's Cave, Boathouse Cave, W36B	RLL			C						Ubick and Briggs (2004)

Table 1 (continued)
List of Austin Area Caves with Endangered Species as of 22 September 2006

Cave name or locality	Alternate names or codes	KRF	Nmy	Ttx	Trd	Try	Rpr	Bcr	Btx	Tmr	Reference
Little Black Hole Cave	W36F	RLL			C						Ubick and Briggs (2004)
M.W.A. Cave	J22H	JVP		C		C	C			C	Chandler and Reddell (2001); James Reddell (pers. comm., 2006); Muchmore (2001); Ubick and Briggs (2004)
McDonald Cave	J51A, Schulze Cave, Yankee Cave	JVP				C					Ubick and Briggs (1992)
McNeil Bat Cave	Karst Feature 47W	MCN				C					Ubick and Briggs (1992)
Millipede Cave	H60G	MCN				C					Ubick and Briggs (2004)
Moonmilk Cave	5K-2 Cave, J09A	CA	C								James Reddell (pers. comm., 2006)
New Comanche Trail Cave	J10B	JVP	C			C					James Reddell (pers. comm., 2006); Ubick and Briggs (1992)
No Rent Cave	W62	MCN				C					Ubick and Briggs (1992)
North Root Cave	J21F	JVP					C				James Reddell (pers. comm., 2006)
Pedernales River at Highway 71		NA			C						Ubick and Briggs (2004)
Pecan Gap Cave No. 1	ACI M3, Feature 3, Karst Feature 61W, Kegger Cave, Pecan Gap Cave	MCN				C					James Reddell (pers. comm., 2006)
Puzzle Pits Cave	J22M, Puzzle Pit Cave	JVP				C	C				James Reddell (pers. comm., 2006); Ubick and Briggs (2004)
Rolling Rock Cave	J90A	CPK					C				James Reddell (pers. comm., 2006)
Root Cave	J21G	JVP				C					Ubick and Briggs (1992)

Table 1 (continued)
List of Austin Area Caves with Endangered Species as of 22 September 2006

Cave name or locality	Alternate names or codes	KRF	Nmy	Ttx	Trd	Try	Rpr	Bcr	Btx	Tmr	Reference
Spider Cave	J13H	JVP			C		C				James Reddell (pers. comm., 2006); Ubick and Briggs (2004)
Stark's North Mine	P15A	NA			C						Ubick and Briggs (2004)
Stovepipe Cave	W44	JVP				C	C			C	James Reddell (pers. comm., 2006); Ubick and Briggs (2004)
Tardus Hole	J31K, Kretschmarr Fluted Sink	JVP					C				James Reddell (pers. comm., 2006)
Tooth Cave	J21A, Russell Cave-Tooth Cave, Tooth Cave-Russell Cave	JVP	C	C		C	C			C	Muchmore (2001); James Reddell (pers. comm., 2006); Ubick and Briggs (1992)
Twisted Elm Cave	J22P	JVP				C	C				James Reddell (pers. comm., 2006); Ubick and Briggs (2004)
Two Trunks Cave	J21V	JVP					C				James Reddell (pers. comm., 2006)
Weldon Cave	P51A, W64, Weldon Rattlesnake Cave	MCN				C					Ubick and Briggs (1992); Ubick and Briggs (2004)
West Rim Cave	W98M	CA				C					Ubick and Briggs (2004)
Williamson County localities											
A.J. and B.L. Wilcox Cave		CPK					C				James Reddell (pers. comm., 2006)
Abused Cave	F-8, Williams No. 2 "Abused" Cave	NWM				C					Ubick and Briggs (2004)
Abyss Cave	The Abyss	GTN				C					Ubick and Briggs (2004)
Animal Canyon Cave		CPK					C				James Reddell (pers. comm., 2006)
Apache Cave		NWM				C					Ubick and Briggs (2004)

Table 1 (continued)
List of Austin Area Caves with Endangered Species as of 22 September 2006

Cave name or locality	Alternate names or codes	KRF	Nmy	Ttx	Trd	Try	Rpr	Bcr	Btx	Tmr	Reference
Backhoe Surprise Cave*		RR				T					James Reddell (pers. comm., 2006)
Beck Bat Cave	BCM63, Goat Shelter	RR				C					Ubick and Briggs (2004)
Beck Blowing Well	BCM61	RR				C					Ubick and Briggs (2004)
Beck Bridge Cave	BCM68	RR				C					Ubick and Briggs (2004)
Beck Crevice Cave	BCM84	RR				S					Warton and Associates (1996)
Beck Horse Cave	BCM65	RR				C					Ubick and Briggs (2004)
Beck Pride Cave	BCM64	RR				C					Ubick and Briggs (2004)
Beck Ranch Cave	BCM67	RR				C					Ubick and Briggs (1992)
Beck Rattlesnake Cave	BCM94	RR				C					Ubick and Briggs (2004)
Beck Sewer Cave	Beck Tin Can Cave	RR				C					Ubick and Briggs (1992)
Beck Tex-2 Cave	BCM62	RR				C					Ubick and Briggs (2004)
Big Oak Cave		CPK					C				James Reddell (pers. comm., 2006)
Black Cat Cave		RR				C					Ubick and Briggs (2004)
Blessed Virgin Cave	ACI G4, Feature GO 4	RR				T					James Reddell (pers. comm., 2006)
Bluewater Pit Cave No. 2		CPK					C				James Reddell (pers. comm., 2006)
Bone Cave		GTN				C					Ubick and Briggs (1992)
Boulevard Cave		CPK					C				James Reddell (pers. comm., 2006)
Broken Zipper Cave	BCM93	RR				C					Ubick and Briggs (2004)
Brown's Cave	BCM27	GTN				C					Ubick and Briggs (1992)
Buttercup Blowhole Cave	Blow Hole Cave	CPK					C				James Reddell (pers. comm., 2006)
Buttercup Creek Cave	Buttercup River Cave	CPK					C				James Reddell (pers. comm., 2006)
Buzzard Feather Cave	Karst Feature 195-4	NWM				C					Ubick and Briggs (2004)

Table 1 (continued)
List of Austin Area Caves with Endangered Species as of 22 September 2006

Cave name or locality	Alternate names or codes	KRF	Nmy	Ttx	Trd	Try	Rpr	Bcr	Btx	Tmr	Reference
Cassidy Cave		NWM				C					Ubick and Briggs (2004)
Cat Cave	Karst Feature No. 3	NWM				C					Ubick and Briggs (2004)
Cat Hollow Bat Cave	BCM84	RR				C					Ubick and Briggs (2004)
Cat Hollow Cave #1	BCM70, Cat Hollow 1 Cave	RR				C					Ubick and Briggs (2004)
Cat Hollow Cave #2	BCM69, Cat Hollow 2 Cave, W2	RR				C					Ubick and Briggs (2004)
Cat Hollow Cave #3	BCM81, Cat Hollow 3 Cave	RR				U					SWCA (1995)
Cave Coral Cave	Karst Feature 44K	RR				C					Ubick and Briggs (2004)
Cedar Elm Sink Cave	Cedar Elm Sink	CPK					C				James Reddell (pers. comm., 2006)
Chaos Cave	Karst Feature 80K	RR				C					Ubick and Briggs (2004)
Choctaw Cave		NWM				C					Ubick and Briggs (2004)
Clark Cave		RR				S					USFWS files
Cobb Caverns	Cobb Cave, Cobb Cavern	NWM				S			C		James Reddell (pers. comm., 2006); SWCA (2005)
Cobb Drain Cave	Karst Feature 195-1, Run-In Sink(?), The Funnel	NWM				C					Veni (2001)
Coffin Cave		NWM						C			Chandler and Reddell (2001)
Coke Box Cave	Karst Feature 195-3	NWM				C					Veni (2001)
Convoluted Canyon Cave		CPK					C				James Reddell (pers. comm., 2006)
Coon Crap Cave	Batrac Cave, Coon Cave #2, Coon Scat Cave	GTN				T(1)					Elliott (1992) report in USFWS files
Coon Crawl Cave		RR				S					Zarker (1996)
Cow Cave	Karst Feature 34W	RR				S					Veni (1998)
Crescent Cave		RR				C					Ubick and Briggs (2004)

Table 1 (continued)
List of Austin Area Caves with Endangered Species as of 22 September 2006

Cave name or locality	Alternate names or codes	KRF	Nmy	Ttx	Trd	Try	Rpr	Bcr	Btx	Tmr	Reference
Deliverance Cave No. 1		NWM				C					Ubick and Briggs (2004)
Deliverance Cave No. 2		NWM				C		C			Chandler and Reddell (2001); Ubick and Briggs (2004)
Discovery Well Cave		CPK					C				James Reddell (pers. comm., 2006)
Do-Drop-In Cave		NWM				C					Ubick and Briggs (2004)
Double Dog Hole Cave	Double Dog Cave	NWM				C					Ubick and Briggs (2004)
Dragonfly Cave	Dragon Fly Cave	NWM				C		C			Chandler and Reddell (2001); Ubick and Briggs (2004)
Duckworth Bat Cave	Karst Feature No. 9	NWM				C					Ubick and Briggs (2004)
Dwarfs Delight Cave	Dwarves Delight Cave, F-1, F-11	NWM				U					ACI (2003)
Easter Cave	BCM79	RR				S					Mike Warton (2006 pers. comm.. to James Reddell)
El Tigre Cave		RR				C					Ubick and Briggs (2004)
Electro-Mag Cave		NWM				C		C			Chandler and Reddell (2001); Ubick and Briggs (2004)
Elm Cave		GTN				C					James Reddell (pers. comm., 2006)
Ensor Cave		RR				C					Ubick and Briggs (2004)
Eulogy Cave		RR				C					Ubick and Briggs (2004)
F62WYO Cave*		RR				T					James Reddell (pers. comm., 2006)
Fence-line Sink	Fenceline Cave	GTN				C					Ubick and Briggs (2004)
Flat Rock Cave		NWM				C					Ubick and Briggs (2004)
Flint Wash Cave	BCM71	RR				C					Ubick and Briggs (2004)
Flowstone Rift Cave	BCM76, Cave site no. 502	GTN				C					Ubick and Briggs (2004)

Table 1 (continued)
List of Austin Area Caves with Endangered Species as of 22 September 2006

Cave name or locality	Alternate names or codes	KRF	Nmy	Ttx	Trd	Try	Rpr	Bcr	Btx	Tmr	Reference
Formation Forest Cave	BCM10	GTN				C					Ubick and Briggs (2004)
Fortune 500 Cave	BCM45	GTN				C					Ubick and Briggs (2004)
Goat Cave	Feature OC-19, Spike's Goat Cave	RR				C					ACI (2004)
Good Friday Cave	Cedar Post Sink	CPK					C				James Reddell (pers. comm., 2006)
Grimace Cave		CPK					C				James Reddell (pers. comm., 2006); Mike Warton and Associates (1997, 1998) reports in USFWS files
Harvestman Cave	Harvest Man Cave	CPK					C				James Reddell (pers. comm., 2006)
Hatch Cave		CPK				C					Ubick and Briggs (2004)
Hideaway Cave	Hide A Way Cave	CPK					C				James Reddell (pers. comm., 2006)
Holler Hole		NWM				C					Ubick and Briggs (2004)
Hollow Oak Cave		RR				C					Ubick and Briggs (2004)
Hourglass Cave	Karst Feature 195-2	NWM				C		T			Ubick and Briggs (2004); Veni (2001)
Ilex Cave		CPK					S				Mike Warton and Associates (1997)
Inner Space Cavern	Corehole Cave, Laubach Cave; Vertebrate Pale-ontology Laboratory codes: 41343, 40722, 40673	GTN				C			C		James Reddell (pers. comm., 2006); Ubick and Briggs (1992)
Jack Hammer Cave	Cave site no. 410, Jackhammer Cave	RR				C					Ubick and Briggs (2004)
Joint Effort Cave	BCM92	RR				C					Ubick and Briggs (2004)

Table 1 (continued)
List of Austin Area Caves with Endangered Species as of 22 September 2006

Cave name or locality	Alternate names or codes	KRF	Nmy	Ttx	Trd	Try	Rpr	Bcr	Btx	Tmr	Reference
Joker Cave		RR				U					SWCA (1999)
Jug Cave	Bottle-Neck Cave, Copperhead Sink	CPK					C				James Reddell (pers. comm., 2006)
Karankawa Cave		NWM				C		C			Chandler and Reddell (2001);Ubick and Briggs (2004)
Killian Kavern	Killian Cavern	GTN				C					Ubick and Briggs (2004)
Kiva Cave No.1		NWM				C					Ubick and Briggs (2004)
LakeLine Cave	Lakeline Cave	CPK				C	C				James Reddell (pers. comm., 2006); Ubick and Briggs (1992)
LakeLine Mall Trap No. 6	Lakeline Mall Trap No. 6	CPK					C				James Reddell (pers. comm., 2006)
Leachate Cave		RR				C					Ubick and Briggs (2004)
Lineament Cave		RR				C					Ubick and Briggs (2004)
Little Demon Cave	BCM24	GTN				S					Mike Warton (2000) report in USFWS files
Little Lake Cave	Toungate's Drop	RR				C					William Elliott (1992) record in USFWS files
Little Surprise Cave**		NWM				C					James Reddell (pers. comm., 2006)
Lizard's Lounge Cave	F-2, F-3	NWM				T					ACI (2003)
Lobo's Lair		NWM				C					Ubick and Briggs (2004)
Man-With-A-Spear Cave	Steam Sink	GTN				C					Ubick and Briggs (1992)
Marigold Cave		CPK					C				James Reddell (pers. comm., 2006)
May B.A. Cave		CPK					C				James Reddell (pers. comm., 2006)
Mayfield Cave	BCM50	GTN				C					Ubick and Briggs (2004)

Table 1 (continued)
List of Austin Area Caves with Endangered Species as of 22 September 2006

Cave name or locality	Alternate names or codes	KRF	Nmy	Ttx	Trd	Try	Rpr	Bcr	Btx	Tmr	Reference
Mayor Elliott Cave	Mayor Rawleigh S. Elliott Cave	GTN				C					Ubick and Briggs (2004)
McNeil Quarry Cave	BCM28, Sam Bass Cave	RR				C					James Reddell (pers. comm., 2006)
Medicine Man Cave		NWM				C		C			Chandler and Reddell (2001); Ubick and Briggs (2004)
Millennium Cave	BCM23	GTN				S					Mike Warton (2000) report in USFWS files
Mongo Cave	BCM12	GTN				C					Ubick and Briggs (2004)
Mosquito Cave	BCM90	GTN				C					Ubick and Briggs (2004)
Mustard Cave		RR				C					Ubick and Briggs (2004)
Near Miss Cave		RR				C					Ubick and Briggs (2004)
Nelson Ranch Cave		CPK					C				James Reddell (pers. comm., 2006)
O'Connor Road Cave	BCM95, O'Connor Cave, W54	RR				C					Ubick and Briggs (2004)
Oakbrook Cave		RR				S					SWCA (1995) report in USFWS files
Off Campus Cave		GTN				C			C		James Reddell (pers. comm., 2006); Ubick and Briggs (1992)
Ominous Entrance Cave	BCM46	GTN				C					Ubick and Briggs (2004)
On Campus Cave		GTN				C			C		Chandler and Reddell (2001); James Reddell (pers. comm., 2006); Ubick and Briggs (2004)
Onion Branch Cave	BCM50	GTN				C					Ubick and Briggs (2004)
Outcrop Cave	F-5, Karst Feature 41K	RR				S					PBS&J (2003) report in USFWS files

Table 1 (continued)
List of Austin Area Caves with Endangered Species as of 22 September 2006

Cave name or locality	Alternate names or codes	KRF	Nmy	Ttx	Trd	Try	Rpr	Bcr	Btx	Tmr	Reference
Pat's Pit	Pat's Pit Cave	CPK					S				Mike Warton and Associates (1997)
Pencil Cactus Cave	ACI M1, Feature 1, Karst Feature 62W	MCN				C					James Reddell (pers. comm., 2006)
Pig Snout Cave	Pig's Snout Cave	CPK					C				James Reddell (pers. comm., 2006)
Plethodon Cave	Karst Feature 11W	RR				S					Veni (1998)
Poison Ivy Cave	Karst Feature 77K	RR				C					James Reddell (pers. comm., 2006)
Polaris Cave		NWM				C					Ubick and Briggs (2004)
Posh Cave	BCM88	GTN				C					Ubick and Briggs (2004)
Pow Wow Cave		NWM				C					Ubick and Briggs (2004)
Prairie Flats Cave	Prarrie Flats Cave	NWM				C					James Reddell (pers. comm., 2006)
Price Is Right Cave	BCM43	GTN				C					Ubick and Briggs (2004)
Primrose Sink	Primrose Cave	CPK					C				James Reddell (pers. comm., 2006)
Priscilla's Cave		NWM				C					Ubick and Briggs (2004)
Priscilla's Well Cave		NWM				C		C			Chandler and Reddell (2001); Ubick and Briggs (2004)
Pussy Cat Cave		NWM				C					Ubick and Briggs (2004)
Raccoon Cave	W46	CPK					C				James Reddell (pers. comm., 2006)
Raccoon Lounge Cave	El Mapache Lounge Cave	RR				T					ACI (2003) report in USFWS files; James Reddell (pers. comm., 2006)
Rattlesnake Inn Cave	Karst Feature 195-12	NWM				C		T			Veni (2001)
Reach Around Cave	Reach-Around Cave	NWM						C			Chandler and Reddell (2001)

Table 1 (continued)
List of Austin Area Caves with Endangered Species as of 22 September 2006

Cave name or locality	Alternate names or codes	KRF	Nmy	Ttx	Trd	Try	Rpr	Bcr	Btx	Tmr	Reference
Red Crevice	Red Crevice Cave	NWM				C			T		Chandler and Reddell (2001); Ubick and Briggs (2004)
Rock Fall Cave		RR				C					Ubick and Briggs (2004)
Rock Ridge Cave	BCM41	GTN				S					Mike Warton (2000) report in USFWS files
Rocky Horror Pit	Rocky Horror Cave	RR				U					Athabasca (2002)
Root Cellar Cave	F-8	RR				S					PBS&J (2003) report in USFWS files
Rootin Tootin Cave	BCM40	GTN				C					Ubick and Briggs (2004)
Round Rock Breathing Cave	BCM47, Step Down Cave, Step-Down Cave	GTN				C					Ubick and Briggs (2004)
Salamander Squeeze	Salamander Squeeze Cave	CPK					C				James Reddell (pers. comm., 2006)
Salt Lick Cave	F-6	NWM				T					James Reddell (pers. comm., 2006)
Sam Bass Hideaway Cave	Karst Feature 55K	RR				C					Ubick and Briggs (2004)
Scoot Over Cave		RR				C					Ubick and Briggs (2004)
Serta Cave		RR				C					Ubick and Briggs (2004)
Shaman Cave		NWM				C		C			Chandler and Reddell (2001); Ubick and Briggs (2004)
Short Stack Cave		GTN				C					Ubick and Briggs (2004)
Sierra Vista Cave		GTN				C					James Reddell (pers. comm., 2006)
Six Meter Sink	Karst Feature 40K	RR				C					Veni et al. (2002)
Snow Melt Cave	BCM02	GTN				T					Paul Price Associates (2004)
Sore-ped Cave		NWM				C					Ubick and Briggs (1992)
Stalagroot Cave		NWM				C					Ubick and Briggs (2004)

Table 1 (continued)
List of Austin Area Caves with Endangered Species as of 22 September 2006

Cave name or locality	Alternate names or codes	KRF	Nmy	Ttx	Trd	Try	Rpr	Bcr	Btx	Tmr	Reference
Steam Cave		GTN				C					Ubick and Briggs (1992)
Stepstone Cave	Karst Feature 51K	RR				C					Ubick and Briggs (2004)
Stone Well Cave No.1		CPK					C				James Reddell (pers. comm., 2006)
Stone Well Cave No.2		CPK					C				James Reddell (pers. comm., 2006)
Sunless City Cave	F14	NWM				U					SWCA (2001)
Swarm Cave	Karst Feature 56K	RR				C					Ubick and Briggs (2004)
Testudo Tube	Testudo Tube Cave, Turtle Trot Cave	CPK					C				James Reddell (pers. comm., 2006)
Texella Cave		NWM				C					Ubick and Briggs (2004)
Thin Top Cave	BCM44, Thin Roof Cave	GTN				C					Ubick and Briggs (2004)
Thor Cave	Temples of Thor Cave	NWM				C					Ubick and Briggs (2004)
Through Trip Cave	BCM21, BCM 22, Thru Trip Cave	GTN				S					Paul Price Associates (2004)
Trail of Tears Cave		NWM				S					James Reddell (pers. comm., 2006)
Tree House Cave	Treehouse Cave	CPK					C				James Reddell (pers. comm., 2006)
Tres Amigos Cave		GTN				C					Ubick and Briggs (2004)
Turner Goat Cave		NWM				C					Ubick and Briggs (2004)
T.W.A.S. A Cave	TWAS Cave, TWASA Cave, TWAS A Cave	CPK					C				James Reddell (pers. comm., 2006)
Two Hole Cave		CPK					C				James Reddell (pers. comm., 2006)
Under-the-Fence Cave	Fenceline Sink, Karst Feature 57K, Under-the-Fence Sink	RR				C					Ubick and Briggs (2004)

Table 1 (continued)
List of Austin Area Caves with Endangered Species as of 22 September 2006

Cave name or locality	Alternate names or codes	KRF	Nmy	Ttx	Trd	Try	Rpr	Bcr	Btx	Tmr	Reference
Underdeveloped Cave		RR				C					Ubick and Briggs (2004)
Underline Cave	W42	CPK				C					Ubick and Briggs (2004)
Undertaker Cave		RR				C					Ubick and Briggs (2004)
Unearthed Cave		NWM				C		C			Chandler and Reddell (2001); Ubick and Briggs (2004)
Unemployment Cave		NWM				C					
Ute Cave		NWM				C					James Reddell (pers. comm., 2006)
Varicose Cave	Vericose Cave	RR				C					Ubick and Briggs (2004)
Venom Cave		NWM				C					Ubick and Briggs (2004)
Venturi Cave	BCM39	GTN				C					Ubick and Briggs (2004)
Viper Cave		NWM				C		C			James Reddell (pers. comm., 2006); Chandler and Reddell (2001)
War Party Cave		RR				C					Ubick and Briggs (2004)
Waterfall Canyon Cave		NWM				C					Ubick and Briggs (2004)
Whitewater Cave		CPK					S				Jerry Fant (2003) report in USFWS files
Wilco Cave	BCM15	GTN				S					Mike Warton (2000) report in USFWS files
Wilcox Cave		CPK					C				James Reddell (pers. comm., 2006); Mike Warton and Associates (1998a)
Wild Card Cave		RR				C					Ubick and Briggs (2004)
Wild West Cave	BCM13	GTN				S					Mike Warton (2000) report in USFWS files

Table 1 (continued)
List of Austin Area Caves with Endangered Species as of 22 September 2006

Cave name or locality	Alternate names or codes	KRF	Nmy	Ttx	Trd	Try	Rpr	Bcr	Btx	Tmr	Reference
Williams Cave No. 1	F-7, Willliams Cave, Seven Room Cave	NWM				C					Ubick and Briggs (2004)
Wolf's Rattlesnake Cave	Big Root Cave	NWM				C					Ubick and Briggs (2004)
Woodruff's Well Cave		NWM				C					Ubick and Briggs (2004)
WS5-7		RR				U					Athabasca (2003)
WS54		RR				U					Athabasca (2003)
WS65		RR				U					Athabasca (2003)
WS71a		RR				U					Athabasca (2003)
Yamas Cave	BCM38, Yammas Cave	GTN				C					Ubick and Briggs (2004)
Yellow Hand Cave		NWM				C					Ubick and Briggs (2004)
You-Dig-It Cave		NWM				C					Ubick and Briggs (2004)
Zapata Cave		GTN				C					Ubick and Briggs (2004)
Totals: 249 localities			**5**	**4**	**12**	**187**	**52**	**11**	**5**	**6**	

Note: (1) A report by William R. Elliott (1992) in the USFWS files indicates this species is *Texella reddelli*. This is almost certainly a reporting error for *Texella reyesi* since *T. reddelli* is not otherwise known from the area and several *T. reyesi* localities surround this cave. However, confirmation of the record from the cave is recommended

KRF = Karst Fauna Region
NA = No assigned karst fauna region
CPK = Cedar Park KFR
CA = Central Austin KFR
GTN = Georgetown KFR
JVP = Jollyville Plateau KFR
MCN = McNeil KFR
NWM = North Williamson County KFR
RLL = Rollingwood KFR
RR = Round Rock KFR

Nmy = *Neoleptoneta myopica*
Ttx = *Tartarocreagris texana*
Trd = *Texella reddelli*
Try = *Texella reyesi*
Rpr = *Rhadine persephone*
Bcr = *Batrisodes cryptotexanus*
Btx = *Batrisodes texanus*
Tmr = *Texamaurops reddelli*
* = location is not precisely known; probably within 500-2,000 m
** = location is not known except to county level

C = species confirmed for the locality by a qualified taxonomist
T = species tentatively confirmed for the locality by a qualified taxonomist but further research is needed
S = sight record for a locality by a person knowledgeable about the species but not a qualified taxonomist
U = species records where the degree of examination or taxonomic expertise is not known

Karst Zone Delineation

Veni (1992) divided the Austin area karst into 11 karst fauna regions within the outcrop of the Edwards Limestone Group that were defined in south to north order as:

> ***North Hays County***. *Bounded to the north by Bear Creek, southern boundary undetermined; possibly drainage divide of the San Antonio and Barton Springs segments of the Edwards Aquifer. Limestone thinning due to erosion on San Marcos Arch. Intensely faulted.*
>
> ***South Travis County***. *Bounded to the south by Bear Creek and to the north by Barton Creek. Intensely faulted area.*
>
> ***Rollingwood***. *Bounded to the south by Barton Creek and to the north by the Colorado River. Intense faulting. Area of discharge from Barton Creek Segment of aquifer.*
>
> ***Central Austin***. *Bounded to the south by the Colorado River and to the north by thin section of Edwards Limestone near the McNeil area. Intense to moderate faulting.*
>
> ***McNeil***. *Bounded by narrow exposure of Edwards Limestone near east end of Travis-Williamson County line along Edwards outcrop. Moderate to intense faulting.*
>
> ***Round Rock***. *Bounded to the north by Brushy Creek and to the south and west near the Brushy Creek drainage divide. Moderate faulting.*
>
> ***Georgetown***. *Bounded to the south by Brushy Creek and to the north by the San Gabriel River. Moderate faulting. Groundwater discharge area along San Gabriel River.*
>
> ***Cedar Park***. *Bounded by area of complex stratigraphy. Little faulting.*
>
> ***Jollyville Plateau***. *Bounded by connection of plateau to other Edwards outcrops along Travis-Williamson County line. Little faulting.*
>
> ***North Williamson County***. *Area north of San Gabriel River; northern boundary undetermined, probably near Williamson-Bell County line where limestone thins and becomes marly. Little to moderate faulting.*
>
> ***Post Oak Ridge***. *Isolated exposure of Whitestone Lentil of Walnut Formation along ridgetop. Little faulting.*

Based on more recent geologic studies and mapping, some of these definitions could be refined but remain generally adequate. Veni, Reddell, and Cokendolpher (2002), following intensive study of related endangered species in caves in Bexar County, Texas, found justification for subdividing some of the karst fauna regions in that county according to lesser geologic features and species distribution that have little apparent geologic basis. Such delineation is beyond the scope of this report and is not discussed below, although recommendations for further research are made.

Overall, compared to the size and distribution of the original Zone 1 areas from 1992, the new Zone 1 areas validate the original mapping. The intent of the distinction between Zone 1 and Zone 2 areas was that Zone 2 occurred where no known reason precluded the presence of the listed species, but that the listed species were not known. In most cases, Zone 2 areas were places where caves were not known and/or biological surveys in the caves had not been conducted. After 14 years of additional study, it is now clear that in areas where adequate biological surveys for the species have been conducted in Zone 2, listed species have been found to redesignate them as Zone 1. This does not mean that listed species were found in every Zone 2 cave, since not all caves possess suitable conditions for the species. It does mean that Zone 1 boundaries delineated in this report are less conservatively drawn than in 1992, having a much stronger technical basis (in some cases) to fill gaps between known sites of endangered species and to extend zone boundaries further out from known localities.

There are two exceptions to the above description of Zone 2 as essentially unproven Zone 1 areas. First, hydrogeologically isolated Zone 2 areas were designed in 1992 for their potential to contain rare species. Many of these areas have since been demonstrated as having little potential for listed species, although non-listed rare species are present in some and might be found in others. Second, the South Travis County Karst Fauna Region's northeast boundary along Barton Creek is now almost certainly recognized as the southern limit for the distribution of the listed species. While Zone 2 in the South Travis County and Northern Hays County Karst Fauna regions have now been downgraded to Zone 3, non-listed rare species have been found in the South Travis Karst Fauna Region, and a high potential for rare species exists in the Northern Hays County Karst Fauna Region. A likely third exception is where Zone 2 extends north from Williamson County. Geological mapping and hydrogeologic interpretation suggests Zone 2 may become Zone 3 where Salado Creek cuts across the Edwards Limestone in northern Williamson County and southern Bell County, but there is insufficient biological or cave distribution information to establish a boundary at this time. To err on the side of species protection, all of the Edwards Limestone in that area is still considered Zone 2 until proven otherwise.

It is beyond the scope of this report to describe the rationale for each zone boundary. However, a general description of and explanation for the Zone 1 boundaries in each of the alphabetically listed karst fauna regions is provided below.

Zone 1 in the Cedar Park Karst Fauna Region

One well and 37 caves with listed species occur in two Zone 1 areas in the Cedar Park Karst Fauna Region. Thirty caves with *Rhadine persephone* are clustered in the Buttercup Creek area. To the northwest, south, and southeast are narrow outcrops of Edwards Limestone that may restrict the distribution of some troglobites. This seems especially true to the southeast, where the outcrop extends to the region's second Zone 1 area where *Texella reyesi* is present in addition to *Rhadine persephone*. This Zone 1 area extends south into the Jollyville Plateau Karst Fauna Region, southeast into the McNeil and Central Austin karst fauna regions, and northwest into the Round Rock, Georgetown, and North Williamson County karst fauna regions.

Zone 1 in the Central Austin Karst Fauna Region

Three caves with listed species occur in a cluster in along the west-central edge of this karst fauna region: Cotterell Cave, Moonmilk Cave, and West Rim Cave. Their Zone 1 area extends north and west through the Cedar Park, Georgetown, Jollyville Plateau, McNeil, North Williamson County, and

Round Rock karst fauna regions. This large Zone 1 is based mainly on the distribution of *Texella reyesi* which is not limited by geological or topographic features in and between these regions.

Dense urban development may limit access and adversely affect biological research conditions in accessible caves in the Central Austin Karst Fauna Region. The southern part of the region could be biologically distinct, but the degree of urban development makes it difficult to evaluate. A suspected *Texella* harvestman was observed by members of the Texas Cave Conservancy in one of the three Lake Austin caves in that area (Texas Cave Conservancy report in the USFWS files), but James Reddell feels this is unlikely given the poor habitat within the caves (personal communication, 2006).

Zone 1 in the Georgetown Karst Fauna Region

All but the northwest corner of the Georgetown Karst Fauna Region has been designated Zone 1. Forty caves with listed species occur mostly in the western, southern, and northeast portions of the region. Relatively few caves are known or biologically studied in the east-central portion, at least partly due to the presence of a large limestone quarry. Few and small caves are currently known in the northwest corner of the region, but it seems likely that further study of that locale will extend Zone 1 to fully cover the region.

Zone 1 in the Jollyville Plateau Karst Fauna Region

Nearly the entire outcrop of the Edwards Limestone is designated as Zone 1 in this region based on its 27 caves with listed species. Three Zone 2 Edwards Limestone areas occur. One is an isolated hilltop of Edwards Limestone at the south-central end of the region between FM 2222 and Cow Fork Bull Creek; no caves are known on this hill. The second and third Zone 2 areas are narrow bands of Edwards Limestone that extends northwest and east, from the northern portion of the Jollyville Plateau Karst Fauna Region, into the Cedar Park and McNeil karst fauna regions. These sections of Edwards Limestone are sandwiched between overlying and underlying beds of the poorly cavernous Comanche Peak Limestone, which interfingers with the Edwards in those areas. Unmapped details of the area's complex stratigraphy may restrict cave development and karst species distribution.

Zone 1 in the McNeil Karst Fauna Region

Eleven caves with listed species are known in this region. Its entire Edwards Limestone outcrop is designated as Zone 1, except for the southwest margin along the Bull Creek valley. In that area, a narrow band of Edwards Limestone extends northwest to the Jollyville Plateau Karst Fauna Region. This section of Edwards is sandwiched between overlying and underlying beds of the poorly cavernous Comanche Peak Limestone, which locally interfingers with the Edwards. Unmapped details of the area's stratigraphy may restrict cave development and karst species distribution.

Zone 1 in the North Hays County Karst Fauna Region

No Zone 1 areas occur in this region, although many caves are known and have been biologically studied.

Zone 1 in the North Williamson County Karst Fauna Region

Fifty-six caves with listed karst invertebrates are known from this karst fauna region. Although it is the largest of the karst fauna regions, a review of the distribution of its listed and non-listed troglobites does not suggest that subdivision into smaller karst fauna regions is warranted. Two Zone 1 areas occur in the region. The larger one is the northern extension of the large Zone 1 area that includes all or part

of Central Austin, Cedar Park, Georgetown, Jollyville Plateau, McNeil, and Round Rock karst fauna regions. The Middle Fork of the San Gabriel River currently serves as the major boundary for this Zone 1, with the Edwards Limestone outcrop north of the river's western 10 km designated as Zone 2. This area has not been well studied for caves, and only two are known. Further study will likely discover listed species and convert this Zone 2 into Zone 1. North of the North Fork of the San Gabriel River are two Zone 2 areas that extend west from Zone 1; they likewise have seen little exploration for caves, and only one is known.

The northern limit of the large Zone 1 is based on the location of Cobb Caverns. Further north, the Edwards Limestone outcrop is designated as Zone 2 to the northern limit of the study area. Few caves are known in that zone, with just one in Williamson County and 12 in Bell County (McKenzie and Reddell, 1964); most have not had detailed biological study. The southern portion of this Zone 2 area separates the second Zone 1 of this karst fauna region from the larger Zone 1. Coffin Cave, the type locality for the listed Coffin Cave mold beetle, is the only cave in the smaller Zone 1 area. This Zone 1 remains unchanged since it was delineated in 1992 and is bounded by the limit of the Edwards outcrop and a fault at its northwest end.

Zone 1 in the Post Oak Ridge Karst Fauna Region

No Zone 1 areas occur in this region, although many caves are known and have been biologically studied.

Zone 1 in the Rollingwood Karst Fauna Region

Rollingwood is the smallest of the karst fauna regions; its entire outcrop of the Edwards Limestone Group is designated as Zone 1. Only four caves with listed species are known: Bandit Cave, Bee Creek Cave, Little Bee Creek Cave, and Little Black Hole. While they occur on the east side of the region, the degree of urbanization of the area is potentially limiting access to other caves or adversely affecting biological conditions for research in accessible caves, and there is no clearly identifiable feature that would prevent their distribution throughout that region.

Zone 1 in the Round Rock Karst Fauna Region

This karst fauna region has the most caves known to contain the federally listed invertebrate species. Its 66 caves are concentrated in the northeast portion of the region, with many along its eastern side. The entire region is designated as Zone 1, even though few caves are known in its western section. Only one cave is known within a roughly rectangular area that extends about 2 km north and south from the intersection of State Highway 183 and FM 620, and from that junction about 3 km to the east; the cave is not known to contain listed species. This area coincides with the boundary between the Round Rock and Cedar Park Karst Fauna Regions. The reason for the lack of caves is not clear. It could be due to limited exploration for caves, but that area is an apparent barrier to the eastward distribution of *Rhadine persephone* beetles. However, the presence of *Texella reyesi* harvestman and the rare but non-listed *Cicurina buwata* spider on either side of the area, and the absence of any clear hydrogeological factor that would restrict cave development strongly suggest that listed species are present.

Zone 1 in the South Travis County Karst Fauna Region

No Zone 1 areas occur in this region, although many caves are known and have been biologically studied. Ubick and Briggs (2004) reported *Texella reyesi* from Barker Ranch Cave No. 1 at the southern end of this region. James Reddell (personal communication, 2006) stated this is almost certainly an error because the species is far removed from other localities for the species and due to the dominant presence of *Texella mulaiki* in that area. His assessment agrees with the distribution patterns for *Texella* proposed by Ubick and Briggs (2004). Until this record is confirmed, that locality is not recognized as valid in the delineation of Karst Zone 1 boundaries.

Zone 1 areas outside the karst fauna regions

Listed karst invertebrates have been found since 1992 in three areas outside of the established karst fauna regions:

1) *Texella reddelli* was found in Stark's North Mine, a largely excavated cave in the Austin Chalk about 5 km east of the Central Austin and McNeil karst fauna regions.
2) *Texella reddelli* was found on the surface in solutionally enlarged fractures in the Cow Creek Limestone along the Pedernales River where intersected by State Highway 71, approximate 20 km west of the Jollyville Plateau.
3) *Texella reddelli* was found in the Marble Falls Limestone in Mean Vicious Nasty Cave, Waldman Cave, and solutionally enlarged fractures approximately 30 km west of the Cedar Park Karst Fauna Region.

The hydrogeological origin of these caves and karst areas is not known. The few known caves in those areas have had little geological or biological study. Zone 1 areas have been tentatively established for this investigation. Limited study of caves in Ordovician limestones near the Marble Falls Limestone suggests they may be biologically distinct, so they have been tentatively delineated as Zone 3. Delineation of karst fauna regions for these zones and possible associated Zone 2 or additional Zone 3 areas are beyond the limit of available data.

Rare Karst Species Zone Delineation

This section is similar to the previous part of the report, but focuses on explaining the delineation of Rare Karst Species Zone 1 for the Karst Fauna regions. Many of the boundaries are the same as their Karst Zone counterparts and for the same reasons, so only the differences are described. Overlaps in the distribution of rare and endangered species further demonstrate biological continuity, affirming the validity of the shared Karst Zone 1 and Rare Karst Species Zone 1 boundaries.

Rare Karst Species Zone 1 in the Cedar Park Karst Fauna Region

The boundaries for this zone are nearly identical to those for Karst Zone 1, except for an additional Rare Karst Species Zone 1 area at the northwest end of the Cedar Park Karst Fauna Region. Thirty caves with rare species occur in the three Rare Karst Species Zone 1 areas in the Cedar Park Karst Fauna Region. All but six caves also contain listed species; four of the 30 caves are located beyond the area where caves with listed species are known, and two of those define the northwestern area that is located beyond Karst Zone 1. Rare species include *Cicurina buwata* (six caves), *Cicurina travisae* (two caves), *Aphrastochthonius* n. sp. 3 (one cave), *Tartarocreagris infernalis* (one cave), *Arrhopalites texensis* (one cave), *Rhadine* n. sp. nr. *subterreanea* (23 caves), *Rhadine russelli* (one cave), *Rhadine subterreanea mitchelli* (two caves), and *Batrisodes reyesi* (two caves).

Rare Karst Species Zone 1 in the Central Austin Karst Fauna Region

The boundaries for this zone are identical to those for Karst Zone 1. Five caves with rare species occur in the Rare Karst Species Zone 1 area in the Central Austin Karst Fauna Region. Only one also contains listed species; four of the five caves are located beyond the area where caves with listed species are known. Rare species include *Cicurina buwata* (one cave), *Cicurina reddelli* (one cave), *Cicurina travisae* (one cave), *Eidmanella reclusa* (one cave), *Speodesmus bicornorus* (three caves), and *Rhadine subterreanea subterreanea* (one cave).

Rare Karst Species Zone 1 in the Georgetown Karst Fauna Region

The boundaries for this zone are identical to those for Karst Zone 1. Thirty-two caves with rare species occur in the Rare Karst Species Zone 1 area in the Georgetown Karst Fauna Region. All but 11 also contain listed species; two of the 11 caves are located beyond the area where caves with listed species are known. Rare species include *Cicurina browni* (one cave), *Tartarocreagris infernalis* (six caves), *Speodesmus bicornorus* (six caves), *Oncopodura fenestra* (one cave), and *Rhadine subterreanea mitchelli* (28 caves).

Rare Karst Species Zone 1 in the Jollyville Plateau Karst Fauna Region

The boundaries for this zone are identical to those for Karst Zone 1. Twelve caves with rare species occur in the Rare Karst Species Zone 1 area in the Jollyville Plateau Karst Fauna Region. All but three also contain listed species; none are located beyond the area where caves with listed species are known. Rare species include *Cicurina buwata* (one cave), *Cicurina travisae* (eight caves), *Cicurina wartoni* (one cave), *Neoleptoneta devia* (one cave), *Eidmanella reclusa* (six caves), *Aphrastochthonius* n. sp. 2 (one cave), *Tartarocreagris attenuata* (one cave), *Tartarocreagris infernalis* (one cave), *Speodesmus bicornorus* (five caves), *Rhadine subterreanea mitchelli* (four caves), and *Rhadine subterreanea subterreanea* (one cave).

Rare Karst Species Zone 1 in the McNeil Karst Fauna Region

The boundaries for this zone are identical to those for Karst Zone 1. Seven caves with rare species occur in the Rare Karst Species Zone 1 in the McNeil Karst Fauna Region. All but one also contain listed species; one of the caves is located beyond the area where caves with listed species are known. Rare species include *Cicurina buwata* (one cave), *Tartarocreagris domina* (one cave), *Speodesmus bicornorus* (one cave), and *Rhadine subterreanea subterreanea* (seven caves).

Rare Karst Species Zone 1 in the North Hays County Karst Fauna Region

No Rare Karst Species Zone 1 areas occur in this region, although many caves are known and have been biologically studied.

Rare Karst Species Zone 1 in the North Williamson County Karst Fauna Region

The boundaries for this zone are similar to those for Karst Zone 1. Fifty-four caves with rare species occur in the Rare Karst Species Zone 1 area in the North Williamson County Karst Fauna Region. Twenty do not contain listed species; five are located beyond the area where caves with listed species are known and expand the Rare Karst Species Zone 1 beyond the limits of Karst Zone 1 by including the outcrop of the Edwards Limestone north of the Middle Fork of the San Gabriel River and the area between Berry Creek and Jennings Branch of Cowan Creek. No rare species are currently known in the Karst Zone 1 area along the Smalley Branch of Dry Berry Creek, so it is designated as Rare Karst Species Zone 2. Rare species include *Cicurina vibora* (nine caves), *Neoleptoneta anopica* (one cave), *Aphrastochthonius* n. sp. 1 (five caves), *Tartarocreagris infernalis* (11 caves), *Speodesmus bicornorus* (four caves), *Oncopodura fenestra* (two caves), *Arrhopalites texensis* (one cave), *Rhadine noctivaga* (41 caves), *Rhadine subterreanea mitchelli* (four caves), and *Batrisodes reyesi* (one cave).

Rare Karst Species Zone 1 in the Post Oak Ridge Karst Fauna Region

Karst Zone 2, as established for Post Oak Ridge in 1992, has been revised as Karst Zone 3. However, most of that Karst Zone 2 is now Rare Karst Species Zone 1. Excluded areas, delineated as Rare Karst Species Zone 2, include the far western portion of Post Oak Ridge, three narrow ridges with thin caps of Edwards Limestone, and several caps of Edwards Limestone on isolated hilltops. Nine caves with rare species occur in the Rare Karst Species Zone 1 area in the Post Oak Ridge Karst Fauna Region. Rare species include *Speodesmus bicornorus* (two caves), *Rhadine russelli* (four caves), and *Batrisodes reyesi* (five caves).

Rare Karst Species Zone 1 in the Rollingwood Karst Fauna Region

The boundaries for this zone are identical to those for Karst Zone 1. Nine caves with rare species occur in the Rare Karst Species Zone 1 area in the Rollingwood Karst Fauna Region. Three also contain listed species, and the rest are located beyond the area where caves with listed species are known. Rare species include *Cicurina bandida* (one cave), *Cicurina reyesi* (one cave), *Neoleptoneta concinna* (one cave), *Mexichthonius exoticus* (one cave), *Tartarocreagris altimana* (one cave), *Tartarocreagris intermedia* (one cave), *Texalla spinoperca* (one cave), *Speodesmus* n. sp. (one cave), *Speodesmus bicornorus* (five caves), and *Rhadine austinica* (nine caves).

Rare Karst Species Zone 1 in the Round Rock Karst Fauna Region

The boundaries for this zone are identical to those for Karst Zone 1. Thirty-six caves with rare species occur in the Rare Karst Species Zone 1 area in the Round Rock Karst Fauna Region. All but eight also contain listed species; two of the eight caves are located beyond the area where caves with

listed species are known. Rare species include *Cicurina buwata* (two caves), *Tartarocreagris infernalis* (seven caves), *Speodesmus bicornorus* (six caves), *Rhadine noctivaga* (one cave), and *Rhadine subterreanea subterreanea* (29 caves).

Rare Karst Species Zone 1 in the South Travis County Karst Fauna Region

Karst Zone 2, as established for the South Travis County Karst Fauna Region in 1992, has been revised as Karst Zone 3. However, all of that Karst Zone 2 is now Rare Karst Species Zone 1. Nineteen caves with rare species occur in the Rare Karst Species Zone 1 area in the South Travis County Karst Fauna Region. Rare species include *Cicurina bandida* (one cave), *Cicurina cueva* (two caves), *Tartarocreagris proserpina* (one cave), *Texalla spinoperca* (one cave), *Speodesmus* n. sp. (five caves), *Speodesmus bicornorus* (three caves), *Oncopodura fenestra* (one cave), *Arrhopalites texensis* (one cave), and *Rhadine austinica* (16 caves).

Rare Karst Species Zone 1 areas outside the karst fauna regions

The rare spider *Neoleptoneta concinna* occurs outside the established karst fauna regions in Stark's North Mine, a largely excavated cave in the Austin Chalk about 5 km east of the Central Austin and McNeil karst fauna regions. None of the other rare invertebrates evaluated for this report were found in the Cow Creek Limestone along the Pedernales River or in the Marble Falls Limestone where listed invertebrate species were discovered.

Recommendations

1) A statistical reevaluation of the Austin area's karst fauna regions based on geological, topographical, and biological factors is needed, including results of DNA research that provides insight into the biogeography and evolution of the species (e.g. Paquin and Hedin, 2004). Such an analysis should include the distribution of rare, non-listed troglobites for insight into region boundaries not evident by data from the listed species alone, and for use in management to potentially preclude the need to list those species. Specific recommendations are given below for some of the karst fauna regions which can be pursued without an overall reevaluation.

2) Combining the Karst Zones and Rare Karst Species Zones in a GIS, with each zone weighted according to USFWS species management priorities, would create a hybrid zone map that identifies areas of greater or lesser concern relative to both listed and non-listed rare species.

3) The reported presence of *Texella reyesi* from Barker Ranch Cave No. 1 (Ubick and Briggs, 2004) is likely an error but should be confirmed. If the record is correct, then the boundaries of the North Hays County and South Travis County karst fauna regions should be reevaluated.

4) Veni (1992) found the McNeil and Round Rock karst fauna regions were biologically similar. They were established as two regions to test the hypothesis that the some possible biological differences occurred across an intensely faulted area. While the hypothesis was disproved, the regions were still considered distinct in management strategies for the species (e.g. O'Donnell, Elliott, and Stanford, 1994). While this investigation did not statistically analyze species distribution in the regions, the observed distribution of caves and species strongly support the 1992 results that the two regions are not distinct. Future management of the species should consider these a single karst fauna region, the McNeil-Round Rock Karst Fauna Region.

5) The Cedar Park Karst Fauna Region should probably be managed as two distinct karst fauna regions, as indicated by the new Zone 1 boundaries, distribution of listed and non-listed troglobites, and the geological and topographical features that affect karst species distribution. Analysis of troglobites in these zones and the adjoining karst fauna regions, per recommendation #1 above, is especially warranted.

6) The northern boundary of the study area is indistinct. The outcrop of the Edwards Limestone continues north into Bell County but the lack of information on caves and their fauna in this area makes it currently impossible to identify the range limit of the listed invertebrates here. Efforts should be made to find and biologically evaluate caves north of Cobb Caverns and Coffin Cave in order to define the boundary of the species' distribution.

7) Hydrogeological and biological study of the Zone 1 areas outside of the currently defined karst fauna regions is needed to establish revised karst fauna region boundaries and/or potentially new karst fauna regions, to better delineate the Zone 1 boundaries and potential Zone 2 and Zone 3 areas, and to assess their implications for the overall understanding and management of the listed species.

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APPENDIX A

Glossary of Geologic, Karst, and Biological Terminology

This glossary is broad in scope to assist nonspecialists reviewing this report, but is not meant to cover all possible terms. Additional karst definitions and geologic terms can be found in the geologic dictionary of Jackson (1997); for biospeleological terms see Culver (1982).

Alluvium: Stream-deposited sediments, usually restricted to channels, floodplains, and alluvial fans.

Aquiclude: Rocks or sediments, such as shale or clay, which do not conduct water in significant quantities.

Aquifer: Rocks or sediments, such as cavernous limestone and unconsolidated sand, which store, conduct, and yield water in significant quantities for human use.

Aquitard: Rocks or sediments, such as cemented sandstone or marly limestone, that transmit water significantly more slowly than adjacent aquifers and that yield at low rates.

Artesian: Describes water that would rise above the top of an aquifer if intersected by a well; sometimes flows at the surface through natural openings such as fractures.

Arthropod: An animal of the Phylum Arthropoda; member species are invertebrate, have segmented bodies and jointed legs, and include animals such as insects, crustaceans, and arachnids.

Bedding plane: A plane that divides two distinct bedrock layers.

Breccia: A rock composed of broken, angular fragments of a pre-existing rock that were cemented to form the present rock unit.

Calcite: The predominant mineral in limestone. It is relatively soluble compared to other common minerals, and allows for the dissolution of limestone and the precipitation of calcite speleothems.

Cave: A naturally occurring, humanly enterable cavity in the earth, at least 5 m in length and/or depth, in which no dimension of the entrance exceeds the length or depth of the cavity (definition of the Texas Speleological Survey).

Cavernicole: A species of animal that spends at least part of its life cycle in the subterranean environment.

Conduit: A subsurface bedrock channel formed by groundwater solution to transmit groundwater; often synonymous with cave and passage, but generally refers to channels either too small for human entry, or of explorable size but inaccessible. When used to describe a type of cave, it refers to base level passages that were formed to transmit groundwater from the influent, upgradient end of the aquifer to the effluent, downgradient end.

Conduit flow: Groundwater movement along conduits; usually rapid and turbulent.

Cretaceous: A period of the geologic time scale that began 135 million years ago and ended 65 million years ago.

Depth: In relation to the dimensions of a cave or karst feature, it refers to the vertical distance from the elevation of the entrance of the cave or feature to the elevation of its lowest point. See *vertical extent* for comparison.

Drainage basin: A watershed; the area from which a stream, spring, or conduit derives its water.

Drainage divide: Location where water diverges into different streams or watersheds. On the surface they usually occur along ridges or elevated areas. In aquifers, they occur along highs in the potentiometric surface between groundwater basins.

Endemic: Biologically, refers to an organism that only occurs within a particular locale.

Endogean: Pertaining to species living beneath the surface of the earth, although not necessarily in a cave.

Epigean: Pertaining to species living on the surface of the earth.

Epikarst: The highly solutioned zone in karst areas between the land surface and the predominantly unweathered bedrock.

Facies: The characteristic appearance or aspect of a rock unit; often subclassified or described based on stratigraphy, fossils, mineralogy, lithology, and other similar factors.

Fault: Fracture in bedrock along which one side has moved with respect to the other.

Floodplain: The flat surface that is adjacent and slightly higher in elevation to a stream channel, and which floods periodically when the stream overflows its banks.

Flowstone: A speleothem, usually of calcite and formed by sheets of water depositing successive thin layers of mineral over horizontal to steeply sections of cave floors and sediments.

Fracture: A break in bedrock that is not distinguished as to the type of break (usually a fault or joint).

Fracture flow: Groundwater movement along fractures and bedding planes that usually have been enlarged by solution. Flow is laminar to turbulent, and generally constitutes a moderate to large volume of groundwater in karst aquifers.

Gouge: The finely ground material that forms along some fault planes by the grinding of one plane against the other.

Grade: The continuous descending profile of a stream; graded streams are stable and at equilibrium, allowing transport of sediments while providing relatively equal erosion and sedimentation. A graded profile generally has a steep slope in its upper reaches and a low slope in its lower reaches.

Groundwater drainage basin: Area where surface water enters the ground and flows into a cave via fractures, conduits, and passages whose connection to the surface is inferred but not observed. It includes areas that drain into cave passages beyond the physically explored portion of a cave, where evidence suggests the likely presence of such passages.

Honeycomb: An interconnected series of small voids in rock, commonly formed in karst by near-surface (epikarstic) solution, or by phreatic groundwater flow.

Hydrogeology: The study of water movement through the earth, and the geologic factors that affect it.

Hydrology: The study of water and its origin and movement in atmosphere, surface, and subsurface.

Impermeable: Does not allow the significant transmission of fluids.

Karst: A terrain characterized by landforms and subsurface features, such as sinkholes and caves, which are produced by solution of bedrock. Karst areas commonly have few surface streams; most water moves through cavities underground.

Karst fauna area: An area known to support one or more locations of endangered species and is distinct in that it acts as a system that is separated from other karst fauna areas by geologic and hydrologic features and/or processes that create barriers to the movement of water, contaminants, and troglobitic fauna. The purpose of the karst fauna areas in managing the karst species is to establish areas where a catastrophic event (i.e., contamination, quarrying, flooding, etc.) that may kill species or destroy habitat in one area, would not impact species or habitat in other areas

Karst fauna region: Regions defined by the U.S. Fish and Wildlife Service, based on hydrogeological barriers and/or restrictions to the migration of troglobites over evolutionary time, that result in speciation between regions and the creation of similar groups of troglobites within the caves of a particular region.

Karst feature: Generally, a geologic feature formed directly or indirectly by solution, including caves; often used to describe features that are not large enough to be considered caves, but have some probable relation to subsurface drainage or groundwater movement. These features typically include but are not limited to sinkholes, enlarged fractures, noncavernous springs and seeps, soil pipes, and epikarstic solution cavities.

Length: In relation to the dimensions of a cave or karst feature, it refers to the summed true horizontal extent of the cave's passages or the feature's extent.

Lineament: A linear feature, usually observed in aerial photographs, which likely represents a geologic feature such as a fault, joint, or lithologic contact.

Lineation: A linear alignment of features that may indicate control by fractures or other geologic features or processes.

Lithology: The description or physical characteristics of a rock.

Marl: Rock composed predominantly of a mixture of clay and limestone.

Normal fault: A fault where strata underlying the fault plane are higher in elevation than the same strata on the other side of the fault plane.

nr.: Taxonomic abbreviation for "near;" precedes the name of a similar species.

n. sp.: Taxonomic abbreviation for "new species;" used when a species name has not been published.

Ordovician: A period of the geologic time scale that began 510 million years ago and ended 440 million years ago.

Passage: An elongate, humanly traversable, roofed portion of a cave or karst feature; usually a conduit for groundwater flow.

Perched groundwater: Relatively small body of groundwater at a level above the water table; downward flow is impeded within the area, usually by impermeable strata.

Permeable: Allows the significant transmission of fluids.

Permeability: Measure of the ability of rocks or sediments to transmit fluids.

Phreatic: The area below the water table, where all voids are normally filled with water.

Pit: A vertical cavity extending down into the bedrock; usually a site for recharge, but sometimes associated with collapse.

Porosity: Measure of the volume of pore space in rocks or sediments as a percentage of the total rock or sediment volume.

Potentiometric surface: A surface representing the level to which underground water confined in pores and conduits would rise if intersected by a borehole. See *water table*.

Recharge: Natural or artificially induced flow of surface water to an aquifer.

Room: An exceptionally wide portion of a cave, often at the junction of passages; commonly indicative of either the confluence of groundwater flowpaths or of slow, nearly ponded, groundwater flow. Generally synonymous with chamber, except that chamber is usually reserved for relatively large rooms.

Shaft: See *pit*.

Sink: See *sinkhole.*

Sinkhole: A natural indentation in the earth's surface related to solutional processes, including features formed by concave solution of the bedrock, and/or by collapse or subsidence of bedrock or soil into underlying solutionally formed cavities.

Solution: The process of dissolving; dissolution.

sp.: Taxonomic abbreviation for "species;" when following a genus name, it indicates lack of identification to species level. Plural is spp.

Speleogenesis: The process of cave origin and development.

Strata: Layers of sedimentary rocks; usually visually distinguishable. Often called beds. The plural of stratum.

Stratigraphic: Pertaining to the characteristics of a unit of rock or sediment.

Stratigraphy: Pertaining to or the study of rock and sediment strata, their composition and sequence of deposition.

Structure: The study of and pertaining to the attitude and deformation of rock masses. Attitude is commonly measured by strike and dip; deformational features commonly include folds, joints, and faults.

Stygobite: A species of animal that is restricted to the aquatic subterranean environment and which typically exhibits morphological adaptations to that environment, such as elongated appendages and loss or reduction of eyes and pigment.

Surface water drainage basin: The area where surface water flows into a cave's entrance(s) or into karst features directly associated and known to connect to the cave, such as sinkholes and solutionally enlarged fractures.

Taxa: Taxonomic categories, such as species, genus, etc.; taxon is a singular category.

Taxonomy: A system for classifying organisms into related groups and in descending order.

Troglobite: A species of animal that is restricted to the subterranean environment and which typically exhibits morphological adaptations to that environment, such as elongated appendages and loss or reduction of eyes and pigment. It can generally apply to either an aquatic or terrestrial species, or when used specifically it refers to terrestrial animals; see *stygobite.*

Troglomorphy: A particular suite of traits commonly expressed in organisms restricted to subterranean habitats; frequently characterized by reduction or loss of eyes and pigment, often accompanied by attenuation of the body and/or appendages.

Troglophile: A species of animal that may complete its life cycle in the subterranean environment but which may also be found on the surface.

Trogloxene: A species of animal that inhabits caves but which must return to the surface for food or other necessities.

?troglobite, ?troglophile, ?trogloxene, ?accidental: Taxonomical abbreviations for uncertain ecological status relative to cave ecosystems.

Type locality: The location or area from which a species is first found and described, or where a section or unit of bedrock is described as the typical example; more commonly called type area or type section when used in a geologic context.

Unconfined: Pertaining to aquifers having no significant impermeable strata between the water table and the land surface.

Vadose: Pertaining to the zone above the water table where all cavities are generally air-filled, except during temporary flooding.

Vertical extent: In relation to the dimensions of a cave, refers to the vertical distance from the highest elevation to the lowest elevation of the cave. Generally used when a portion of a cave extends above its entrance. See *depth* for comparison.

Vug: A small cavity in rock, often lined with crystals, and generally not significantly related to groundwater movement.

Water table: The boundary of the phreatic and vadose zones. A potentiometric surface that is specific to unconfined aquifers.

APPENDIX B

Conversions:
International System of Units to English Units

MULTIPLY	BY	TO GET
	Length	
centimeters (cm)	0.3937	inches (in)
meters (m)	3.281	feet (ft)
kilometers (km)	0.621	miles (mi)
	Area	
square meters (m^2)	10.76	square feet (ft^2)
square kilometers (km^2)	0.3861	square miles (mi^2)
square kilometers (km^2)	247.1	acres (ac)
	Volume	
liters (L)	0.264	gallons (gal)
cubic meters (m^3)	264.17	gallons (gal)
cubic meters (m^3)	0.00081	acre-feet (a-f)
	Flow	
liters per second (L/s)	0.0353	cubic feet per second (cfs)
liters per second (L/s)	15.85	gallons per minute (gpm)
cubic meters per second (m^3/s)	35.31	cubic feet per second (cfs)
cubic meters per second (m^3/s)	1,585	gallons per minute (gpm)
cubic meters per second (m^3/s)	70.05	acre-feet per day (a-f/d)
	Temperature	
degrees Celsius	multiply by 1.8 then add 32	degrees Fahrenheit

APPENDIX C

Biographies of Key Research Personnel

The appendix provides brief biographical information on the personnel who assisted with or wrote or conducted key research for the report. This appendix also meets the U.S. Fish and Wildlife Service guidelines for biographical data on personnel associated with the collection, study, and related research on the endangered karst invertebrates that occur in the study area (USFWS, 2001). In meeting with those guidelines, the author of this report certifies direct responsibility for this report, that it is true, complete, and accurate to the best of his knowledge.

Jerry W. Fant is a geologist who received his Bachelor's degree from Memphis State University and also took one year of biology courses at Pennsicola Christian College. He began exploring and studying caves in 1980 and has focused his efforts primarily in Alabama, Arkansas, Georgia, Tennessee, Texas, and Mexico. He has served as a member and officer in several caving organizations and is currently a director of the nonprofit Texas Speleological Survey. Prior to moving to Texas, he owned Alpha Environmental Services, Inc., which specialized in the removal of underground storage tanks and other contaminant sources found in karst areas. In 1991, he began collecting vertebrate and invertebrate species from caves for taxonomists to study, primarily in Arkansas, Texas, and Mexico. He began work as karst technician, subcontracting to George Veni and Associates in 2001. In 2003, he formed and became co-owner of Karst-Tec Consulting. He is certified for confined space entry. His work has included grid-searches for caves, excavation of caves and karst features, cave surveying, tracer studies, and downhole camera evaluations.

Bruce Johnson is a physical geographer, having received his Bachelor's degree in 1986 and conducted graduate studies through 1993. He worked as a geography teaching assistant from 1987 through 1993, has been a member of the Gamma Theta Upsilon, International Geography Honors Society since 1986 and a Vice-President of the Kappa Upsilon Chapter. In 1988 he began exploring and studying caves, which led to working as an intern at the Barton Springs/Edwards Aquifer Conservation District. He has worked as a karst technician since 1994, subcontracting primarily to George Veni and Associates. In 1994 he also began professionally collecting invertebrate species from caves for taxonomists to study. His biological studies include undergraduate and graduate level courses, including a paper on the biospeleology of the Edwards Plateau region. He has taken the Karst Hydrology course taught through the Center for Cave and Karst Studies and Western Kentucky University. His work as a karst technician has included grid-searches for caves, excavation of caves and karst features, cave surveying, dye tracing, cave gating, downhole camera evaluations, geophysical surveys for caves, and collection of invertebrate karst species for study.

Cecilio "Chopper" Martinez is a geologist who worked as a GIS specialist for nine years for the U.S. Geological Survey and since 2002 has worked in the same capacity for the Metropolitan Planning Organization of San Antonio. He an expert is the use of all ArcGIS packages, as well as Adobe Illustrator and Photoshop, and is skilled in several other GIS, drawing, and related programs. He is experienced in developing databases, processing complex spatial data, and presenting them clearly for technical analysis by experts and for illustration to the general public in both multi-media and printed form. Since 2003, he has subcontracted his services to George Veni and Associates.

James R. Reddell is internationally recognized as the foremost authority on the cave and karst fauna of Texas, Mexico, and northern Central America. Forty-two species and three genera have been named in his honor. He received his Bachelor's degree from The University of Texas in 1962 and conducted graduate studies in biology through 1978. Since 1983 he has primarily been employed as the Curator of Invertebrate Zoology for the Texas Memorial Museum and has worked as a consultant since 1987 when he began working for George Veni and Associates. Although specializing in the study of cave crickets and *Rhadine* beetles, he has described 61 invertebrate species. He has published nearly 90 papers and books on caves and cave biology, compiles the New World Bibliography of Biospeleology, and is a director of the nonprofit Texas Speleological Survey which he co-founded in 1961. The federally listed endangered invertebrate cave species in Texas were so designated primarily based on his studies.

Dr. George Veni is an internationally recognized hydrogeologist specializing in caves and karst terrains (Texas registered professional geologist license no. 682). He received his Master's degree from Western Kentucky University in 1985 and his Ph.D. from the Pennsylvania State University in 1994. Since 1987 he has owned and served as principal investigator of George Veni and Associates. Much of his work has been in central Texas, but he has also conducted extensive karst research throughout the United States and in several other countries. In 2007 he became Executive Director of the National Cave and Karst Research Institute and decreased his consulting work to project reviews, oversight, and expert testimony. Among his organizational activities, he served as the Executive Secretary of the National Speleological Society's Section of Cave Geology and Geography for 11 years and President of the Texas Speleological Survey for 13 years, and is currently a member of the governing board of the International Union of Speleology and President of the upcoming 2009 International Congress of Speleology. He serves as a doctoral committee advisor for geological and biological dissertations at The University of Texas and teaches karst geoscience courses as an adjunct professor for Western Kentucky University. He has taken college level biology courses, including Karst Ecology at Western Kentucky University, and has been collecting cave species and assisting in the study of cave ecosystems since 1976. Three cave-dwelling species have been named in his honor. He has published and presented nearly 120 papers, including four books, on hydrogeology, biology, and environmental management in karst terrains. He holds U.S. Fish and Wildlife Service Permit TE026436-0 (expires 10/01/2009) to collect and study federally listed endangered Texas karst invertebrate species.