U.S. Fish & Wildlife Service

Bexar County Karst Invertebrates

Draft Recovery Plan

March 2008

BEXAR COUNTY KARST INVERTEBRATES

DRAFT

RECOVERY PLAN

Southwest Region
U.S. Fish and Wildlife Service
Albuquerque, New Mexico

March 2008

Approved: ___DRAFT____
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U.S. Fish and Wildlife Service

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We would especially like to thank Dr. Jean Krejca and Dr. Steve Taylor at the University of Illinois for drafting the recovery plan. Additional thanks go to Cyndee Watson and Alisa Shull (in the Service's Austin Ecological Services Field Office) for their recovery planning expertise and editing of this document.

The biology, threats, and conservation needs of these species and the karst ecosystems they occur in are very similar to congeners that occur in nearby Travis and Williamson counties, Texas. Literature on the Travis and Williamson county species, including the recovery plan for those species (Service 1994), was used extensively during the creation of this document, and we thank those authors. Other reports prepared by and for the Service relating to Bexar County karst invertebrates also provided significant material for this plan (Service 2003, Veni 2003).

The Service would also like to express its appreciation for the many individuals, groups, and agencies actively involved in the recovery of the federally endangered karst invertebrate species of Bexar County. We look forward to continued collaboration with these partners and new partners to conserve these species and the ecosystem on which they depend.

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EXECUTIVE SUMMARY

Species Status - Nine Bexar County karst invertebrates were listed as endangered species on 26 December 2000 (65 FR 81419). These species inhabit caves and mesocaverns (humanly impassable voids in karst limestone) in Bexar County, Texas. *Rhadine exilis* is known from 45 caves, *Rhadine infernalis* is known from 26 caves, *Batrisodes venyivi* is known from two caves, *Texella cokendolpheri* is known from one cave, *Neoleptoneta microps* is known from two caves, *Cicurina baronia* is known from one cave, *Cicurina madla* is confirmed (based on morphological taxonomic characteristics) from eight caves, *Cicurina venii* is known from one cave, and *Cicurina vespera* is known from two caves. All species have a recovery priority of 2c[1], and critical habitat was designated on 8 April 2003 for all of the species, except the Government Canyon Bat Cave spider and meshweaver. The current status of the species in most of these cave sites is not known, however at least some of the sites are lacking a sufficiently large, healthy, and native surface plant and animal community deemed necessary for long-term support of a cave community.

Habitat Requirements and Limiting Factors - All of these invertebrates are troglobites, spending their entire lives underground. They are characterized by small or absent eyes and pale coloration. Their habitat includes caves and mesocavernous voids in karst limestone (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. Within this habitat these animals depend on high humidity, stable temperatures, and nutrients derived from the surface. Examples of nutrient sources include leaf litter fallen or washed in, animal droppings, and animal carcasses. It is imperative to consider that while these species spend their entire lives underground; their ecosystem is very dependent on the overlying surface habitat.

The primary threat to these species is habitat loss. Caves and karst habitat are lost directly by being completely filled in during development, or by quarrying away the rock that they are comprised of. Filling in cave entrances or severely altering entrances is also destructive and may result in habitat loss. Caves and karst may be lost indirectly by degrading the habitat to the point that the cave and karst can no longer support the species or the long term viability of the population is reduced. Examples of this habitat degradation include: altering drainage patterns, altering native surface plant and animal communities, reducing or increasing nutrient flow, contamination, excessive human visitation, and competition and predation from non-native, invasive species.

Recovery Strategy - The recovery strategy is to reduce threats to the species by securing an adequate quantity and quality of caves. This includes selecting caves or cave clusters that represent the range of the species and potential genetic diversity for the nine species, then preserving these caves, including their drainage basins and surface communities upon which they rely. Maintenance of these cave preserves involves keeping them free

[1]Recovery priority 2c indicates that these species face a high degree of threat with a high potential for recovery and there may be conflict between species recovery and economic development.

from contamination, excessive human visitation, and non-native fire ants by regularly tracking progress and implementing adaptive management to control these and any new threats when necessary. Monitoring the population status and threats are also components of recovery. Because many aspects of the population dynamics and habitat requirements of the species are poorly understood, recovery is also dependant on incorporating research findings into adaptive management actions. Since four of these species are known to occur in only one cave, full recovery may not be possible for these species.

Recovery Goal - Delisting.

Recovery Criteria - Delisting any of these species should be considered when threats have been removed or reduced as indicated by the following:

(1) Criterion (downlisting) – The location and configuration of at least the minimum number of Karst Faunal Areas (KFAs) in each Karst Faunal Region (KFR) is delineated (Table 1), preserves are established that fully include the KFAs, and commitments are in place for perpetual protection and management of these KFAs. To be considered for downlisting, each species should occur in six or more protected KFAs.

(2) Criterion (delisting) – In addition to the downlisting criterion, research on population trends, population viability, habitat quality, and potential threats have been completed over the course of at least 25 years to conclude with a high degree of certainty that preserve size, configuration, and management are adequate to provide a high probability of the species survival at each site. Twenty-five years was chosen as a rough estimate of the time needed to test whether the preserve characteristics outlined in this document are effective for supporting these species in the long term. Future research may show that different monitoring protocols may require a different amount of time to detect population changes in these poorly understood and long-lived species.

The preserves called for in the downlisting criterion address threats of habitat loss and degradation associated with encroaching urbanization (Factor A), overutilization of cave habitats due to human visitation (Factor B), and inadequacies of protective regulations pertaining to these nine arthropod species and their specialized habitats (Factor D).

The activities called for in the delisting criterion will help confirm the adequacy of the preserves in addressing the threats. Maintaining viable populations for each karst species as well as a high level of habitat quality at the established preserves for a minimum of 25 years will demonstrate that the threats of habitat loss and degradation (Factor A), habitat overutilization by human recreation (Factor B), predation from invasive ants (Factor C), lack of regulatory protection (Factor D), and demographic stochasticity along with impediments to genetic exchange(Factor E) have been managed and reduced to merit delisting of some of all the species.

Actions Needed
(1) Delineate and protect areas needed to meet recovery criteria
(2) Perform additional research
(3) Education
(4) Establish post delisting monitoring
(5) Monitoring

Total Estimated Cost of Recovery by Recovery Action Priority:
(dollars by 1,000)

Years	Priority 1(a) Actions	Priority 1(b) Actions	Priority 2 Actions	Priority 3 Actions	Total
1 and 2	26,961	290	17	10	27,278
3 and 4	26,945	197	17	0	27,159
5 and 6	27,190	195	17	0	27,402
7 and 8	27,190	135	17	0	27,342
9 and 10	27,190	125	17	0	27,332
11 to 25	3,750	150	255	0	4,155

Some costs for Recovery Actions were not determinable, such as costs for land acquisition; therefore, total costs for recovery are likely higher than these estimates.

Date of Recovery - If recovery actions are fully funded and carried out as outlined in this plan, criteria for downlisting could be met within ten years and delisting in about 25 years.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

The following acronyms are used in this recovery plan:

BCo	Bexar County
BLT	Bexar Land Trust
CFR	Code of Federal Regulations
COSA	City of San Antonio
DOD	Department of Defense
EAA	Edwards Aquifer Authority
GCSNA	Government Canyon State Natural Area
HCP	Habitat Conservation Plan
KFA	karst fauna area
KFR	karst fauna region
MCo	Medina County
NRCS	Natural Resource Conservation Service
RIFA	red-imported fire ant
Service	U.S. Fish and Wildlife Service
SWRI	Southwest Research Institute
TCEQ	Texas Commission on Environmental Quality
TCMA	Texas Cave Management Association
TMM	Texas Memorial Museum
TNC	The Nature Conservancy
TPL	Trust for Public Land
TPWD	Texas Parks and Wildlife Department
TSS	Texas Speleological Survey
TxDOT	Texas Department of Transportation
TU	Trinity University
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
UTSA	University of Texas at San Antonio
WKU	Western Kentucky University

1.0 BACKGROUND

1.1 Introduction

The Endangered Species Act of 1973, as amended (16 U.S.C. 1531 et seq.) (Act), establishes policies and procedures for identifying, listing, and protecting species of wildlife and plants that are endangered or threatened with extinction. The Act defines an "endangered species" as "any species which is in danger of extinction throughout all or a significant portion of its range." A "threatened species" is defined as "any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range." According to the Service's Recovery Planning Guidelines (Service 1990), recovery is defined as "the process by which the decline of an endangered or threatened species is arrested or reversed, and the threats to its survival are neutralized, so that its long-term survival in nature can be ensured." The goal of the recovery process is delisting, the restoration of the listed species to a point where they are secure, self-sustaining components of their ecosystem so that the protections of the Act are no longer necessary.

Day-to-day protection of endangered and threatened species under the Department of Interior's jurisdiction has been delegated to the Service. To help identify and guide species recovery needs, section 4(f) of the Act directs the Service to develop and implement recovery plans for listed species or **populations**[2]. Recovery plans are strictly advisory documents developed to provide recovery recommendations based on resolving the threats to the species and ensuring self-sustaining populations in the wild. As such, actions listed in recovery plans are entirely voluntary and should not be interpreted as regulations, mandates, or legal obligations.

Recovery plans are to include (1) a description of site-specific management actions necessary to conserve the species or population; (2) objective, measurable criteria that, when met, will allow the species or populations to be removed from the Federal List of Threatened and Endangered Species (List); and (3) estimates of the time and funding required to achieve the plan's goals and intermediate steps. Section 4 of the Act and regulations (50 CFR Part 424) promulgated to implement listing provisions also set forth the procedures for reclassifying and delisting species. A species can be delisted if the Secretary determines that it no longer meets endangered or threatened status based upon any of the five listing factors in section 4(a)(1) of the Act. These factors are:

Listing Factor A - the present or threatened destruction, modification, or curtailment of its **habitat** or range;
Listing Factor B - overutilization for commercial, recreational, scientific, or educational purposes;
Listing Factor C - disease or predation;
Listing Factor D - the inadequacy of existing regulatory mechanisms; and
Listing Factor E - other natural or manmade factors affecting its continued existence.

[2] Terms defined in the glossary (Appendix A) are bolded the first time they are used in the text.

1.2 Taxonomy and Description

The intent of this recovery plan is to guide the recovery of the listed **karst** invertebrates of Bexar County, Texas, so these species can be delisted. This section of the plan outlines the basic biology, ecology, status of the species and their habitats, threats to the species, and conservation actions that have already occurred. The recovery section identifies a strategy with actions that are expected to be the most effective and most efficient way of achieving recovery for these species and specific criteria for measuring when recovery has occurred. The success of this plan depends upon the collaboration of many people and organizations to ensure the future existence of these species.

Rhadine exilis (no common name) and *R. infernalis* (no common name) are small, essentially eyeless ground beetles. *Batrisodes venyivi* (Helotes mold beetle) is a small, eyeless beetle. *Texella cokendolpheri* (Cokendolpher **cave** harvestman) is a small, eyeless harvestman (daddy-longlegs). *Cicurina baronia* (Robber Baron Cave meshweaver), *C. madla* (Madla Cave meshweaver), *C. venii* (Braken Bat Cave meshweaver), *C. vespera* (Government Canyon Bat Cave meshweaver), and *Neoleptoneta microps* (Government Canyon Bat Cave spider) are all small, eyeless or essentially eyeless spiders. The first three of these are insects: two ground beetles and one mold beetle. The remaining species are arachnids, including one harvestman and five spiders (see Appendix E for detailed taxonomic descriptions). The recovery priority number for all Bexar County karst invertebrates is 2c, which means that these species face a high degree of threat with a high potential for recovery and there may be conflict between species recovery and economic development. They were listed as endangered on December 26, 2000 (Service 2000a) and Critical Habitat designated was for all species except *N. microps*, *C. baronia, and C. vespera* on April 8, 2003 (Service 2003). Taxonomic verification of these species is usually not possible in the field and usually requires examination of adult specimens under a microscope and often requires dissection of the genitalia by a taxonomic expert.

Figure 1. *Rhadine exilis* (on right) from the Stone Oak KFR. Photo by Dr. Jean Krejca.

SPECIES 1 - Scientific Name: *Rhadine exilis* (Barr and Lawrence 1960).
Common Name: This species has no common name (Service 2000a).
Original Description: This species was originally described as *Agonum exile* by Barr and Lawrence (1960). Then this species was referred to as *R. exilis* by Reddell (1966). Barr (1974) reassigned the species to the genus *Rhadine*.
Selected Characteristics: Mean length is 7.4 millimeter (mm). Body is extremely slender (Figure 1).

Figure 2. *Rhadine infernalis* from the Stone Oak KFR. Photo by Dr. Jean Krejca.

SPECIES 2 - Scientific Name: *Rhadine infernalis* (Barr and Lawrence).
Common Name: This species has no common name (Service 2000a).
Original Description: This species was originally described as *Agonum infernale* by Barr and Lawrence (1960). Barr (1974) reassigned the species to the genus *Rhadine*.
Selected Characteristics: Body is slender (Figure 2). Intraspecific Variation: There are two recognized subspecies, *R. infernalis ewersi* and *R. infernalis infernalis* (Barr 1960). A third possible subspecies of *Rhadine infernalis* ssp. from the Culebra Anticline was characterized as valid, but was not formally described (Reddell 1998).

Figure 3. *Batrisodes gravesi* to show general morphology. Photos by Dr. Jean Krejca.

SPECIES 3 - Scientific Name: *Batrisodes (Excavodes) venyivi* (Chandler).
Common Name: Helotes mold beetle (Service 2000a).
Original Description: This species was described by Chandler (1992).
Selected Characteristics: Length 2.24 mm (Chandler 1992). This is a tiny, reddish-brown beetle that superficially resembles an ant (Figure 3).

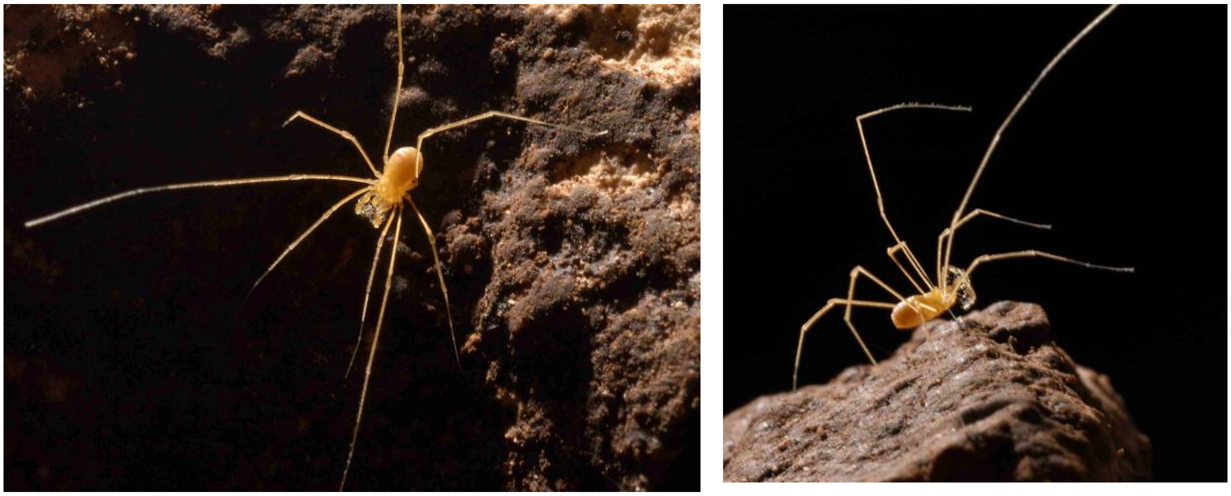

Figure 4. *Texella tuberculata* to show general morphology. Photos by Dr. Jean Krejca.

SPECIES 4 - Scientific Name: *Texella cokendolpheri* (Ubick and Briggs).
Common Name: This species has been referred to by two common names, the Robber Baron Cave harvestman (Service 2000a) and the Cokendolpher cave harvestman (Breene et al. 2003). The latter name has been accepted as the official common name (Breene et al. 2003, Service 2003).
Original Description: This species was described by Ubick and Briggs (1992).
Selected Characteristics: Pale orange in color. A specimen of *Texella tuberculata* from a cave in the Government Canyon State Natural Area is shown in Figure 4 to illustrate the general external morphology of the species.

Figure 5. *Neoleptoneta myopica* to show general morphology. Photo by Dr. Jean Krejca.

SPECIES 5 - Scientific Name: *Neoleptoneta microps* (Gertsch 1974).
Common Name: This species has been referred to by two common names, the Government Canyon cave spider (Service 2000a) and the Government Canyon Bat Cave spider (Breene et al. 2003). The latter name has been accepted as the official common name (Breene et al. 2003, Service 2003).
Original Description: *Neoleptoneta microps* was first collected in 1965 and described by Gertsch (1974) as *Leptoneta microps*. The species was reassigned to *Neoleptoneta* following Brignoli (1977) and Platnick (1986). A review of the taxonomic history of nearctic leptonetids is available in Ubick et al. (2005).
Selected Characteristics: This is a small, yellowish, short-legged, essentially eyeless **cavernicole**. A **congener** is shown to illustrate the general morphology of the species (Figure 5).
Original Description: *Neoleptoneta microps* was first collected in 1965 and described by Gertsch (1974) as *Leptoneta microps*. The species was reassigned to *Neoleptoneta* following Brignoli (1977) and Platnick (1986). A review of the taxonomic history of nearctic leptonetids is available in Ubick et al. (2005).

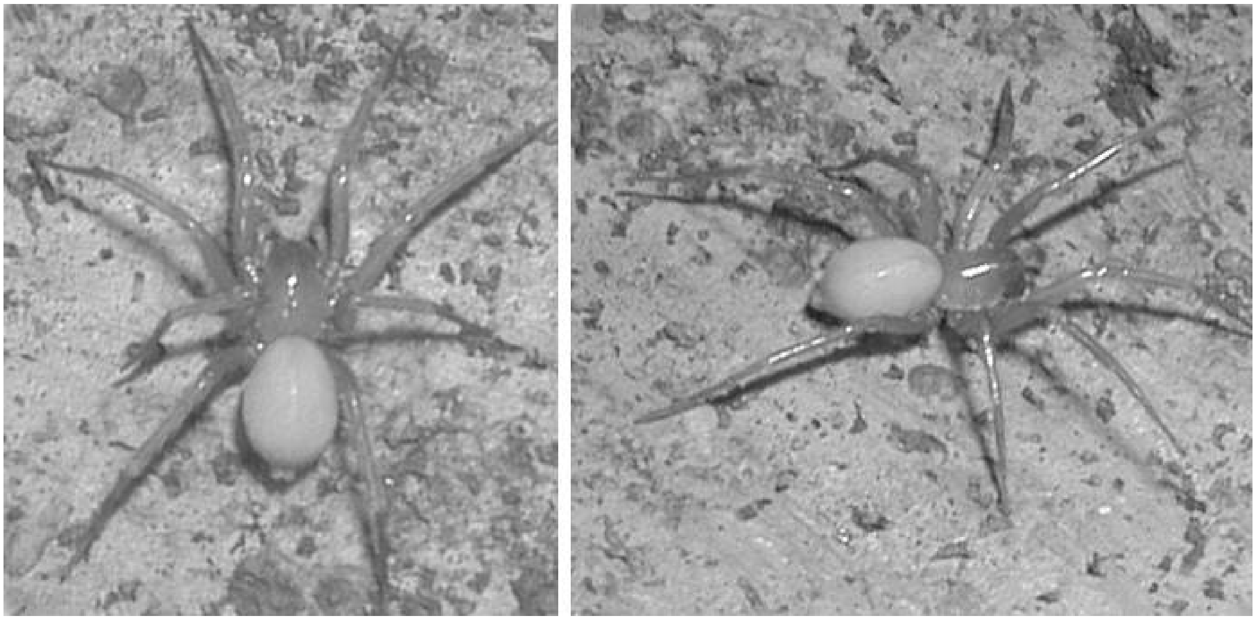

Figure 6. *Cicurina baronia* from Robber Baron Cave. Photos by Dr. Jean Krejca.

SPECIES 6 - Scientific Name: *Cicurina* (*Cicurella*) *baronia* (Gertsch 1992)
Common Name: This species has been referred to by two common names, the Robber Baron Cave spider (Service 2000a) and the Robber Baron Cave meshweaver (Breene et al. 2003). The latter name has been accepted as the official common name (Breene et al. 2003, Service 2003).
Original Description: The species was described by Gertsch (1992).
Selected Characteristics: This small, eyeless spider is known only from Robber Baron Cave. Molecular markers have been used to identify juvenile *Cicurina madla*, and these markers may be useful for other *Cicurina* species, as well (Paquin and Hedin 2004).
Original Description: The species was described by Gertsch (1992).

Figure 7. *Cicurina madla* from a cave in Government Canyon State Natural Area. Photos by Dr. Jean Krejca.

SPECIES 7 – Scientific name: *Cicurina* (*Cicurella*) *madla* (Gertsch 1992).
Common name: This species has been referred to by two common names, Madla's Cave Spider (Service 2000a) and Madla Cave meshweaver (Breene et al. 2003). The latter name has been accepted as the official common name (Breene et al. 2003, Service 2003).
Original Description: The species was described by Gertsch (1992).
Selected Characteristics: This species is eyeless and has reduced pigment (Figure 7). Molecular markers have been used to identify juvenile specimens and define boundaries for this species, and these markers may be useful for other *Cicurina* species, as well (Paquin and Hedin 2004).
Original Description: The species was described by Gertsch (1992).

SPECIES 8 - Scientific Name: *Cicurina* (*Cicurella*) *venii* (Gertsch).
Common Name: Service (2000a) listed no common name for this species. The Committee on Common Names of Arachnids (Breene et al. 2003) listed the official common name of this species as the Braken Bat Cave meshweaver, which has been accepted as the official common name (Breene et al. 2003, Service 2003).
Original description: The species was described by Gertsch (1992).
Selected Characteristics: This species is eyeless and has reduced pigment. See Figure 7 for a photograph of a congener with similar characteristics. Molecular markers have been used to identify juvenile *Cicurina madla*, and these markers may be useful for other *Cicurina* species as well (Paquin and Hedin 2004).
Original description: The species was described by Gertsch (1992).

SPECIES 9 - Scientific Name: *Cicurina* (*Cicurella***)** *vespera* (Gertsch).
Common Name: This species has been referred to by two common names, the Vesper cave spider (Service 2000a) and the Government Canyon Bat Cave meshweaver (Breene et al. 2003). The latter name has been accepted as the official common name (Breene et al. 2003, Service 2003).

Original description: The species was described by Gertsch (1992).
Selected Characteristics: This species is eyeless and has reduced pigment. See Figure 7 for a photograph of a congener with similar characteristics. A possible synonymy between *C. vespera* and *C. madla* was suggested by the molecular analysis of Paquin and Hedin (2004), however their results have not yet been confirmed by morphological analysis and no formal synonymy was set forth in their work.
Original description: The species was described by Gertsch (1992).

1.3 Population Status and Distribution

Karst Zones - Northwest Bexar County is hydrogeologically complex. Geologic faulting and surface erosion have resulted in isolation of cavernous limestone outcrops. Karst invertebrates in this area have evolved into separate species over time and some, including the nine species covered in this plan, are restricted to small geographic areas. The geologic context of the distribution of the nine species, as well as other **troglobites**, was examined by Veni (1994), who delineated five karst zones to facilitate assessment of the probability of the presence of rare or **endemic** species. These zones are:

Zone 1. Areas known to contain listed invertebrate karst species.

Zone 2. Areas having a high probability of containing habitat suitable for listed invertebrate karst species.

Zone 3. Areas that probably do not contain listed invertebrate karst species.

Zone 4. Areas that require further research but are generally equivalent to Zone 3, although they may include sections that could be classified as Zone 2 or Zone 5 as more information becomes available.

Zone 5. Areas that do not contain listed invertebrate karst species.

Geologic or topographic features that may restrict the current or past distribution of the listed species were used to determine karst zone boundaries. Evaluation of the known ranges of federally listed and non-listed troglobites was then used to test the validity of these zones. For a full description or explanation of the geologic context, refer to Veni (2002) and Veni (1994).

Under contract with the Service, Veni (2002) re-evaluated and, where applicable, redrew the boundaries of each karst zone originally delineated in Veni (1994). Revisions were based on current geologic mapping, further studies of cave and karst development, and current information available on the distribution of listed and non-listed karst species.

Karst Fauna Regions (KFR) - **Karst fauna regions** are geographic areas delineated based on discontinuity of karst habitat that may reduce or limit interaction between troglobite populations (Reddell 1993b, Veni 1994, Service 2000a). Six KFRs were established by Veni (1994) (Figure 8). The basis for these divisions is the lack of continuity between caves that may form complete barriers or significant restrictions to migration of troglobites over modern and/or geologic time scales. These discontinuities are defined based on the **lithologic**, **structural**, and **hydrologic** characteristics that affect cave development combined with the geologic history of the area. The KFRs were analyzed using the modern range of 19 troglobitic species, including the federally listed species covered in this recovery plan (Veni 1994). The six KFRs in the San Antonio area were used in the final rule to define the ranges of the listed species and are as follows: Stone

Oak, UTSA, Helotes, Government Canyon, Culebra Anticline, and Alamo Heights (Figure 8) (Service 2000a).

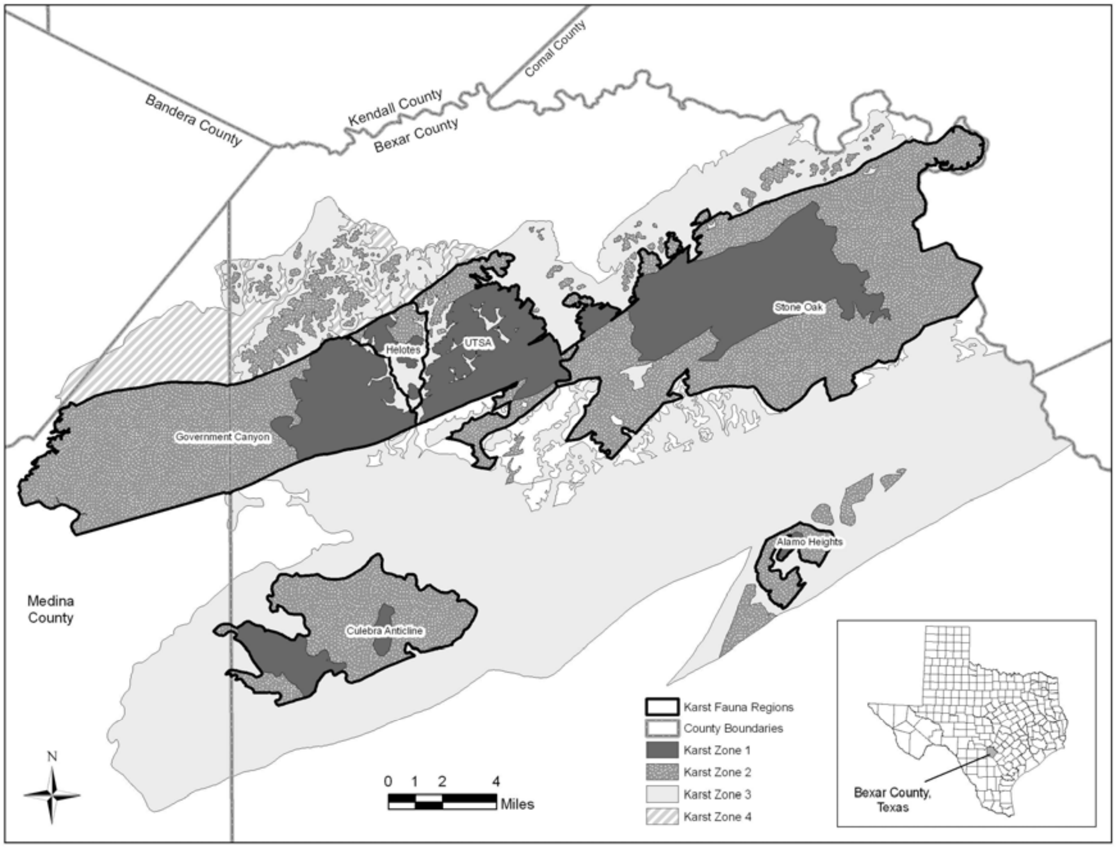

Figure 8. KFR boundaries and karst zones in the San Antonio area (Veni 1994).

Historic range - Little information on these species is available prior to the 1960s, when the study of **biospeleology** began in earnest in Bexar County.

Current range – Karst zone boundaries indicate geologic continuity and biological similarity and reflect the known range of the species. Appendix D lists the known locations of all of the listed species by cave. It is not advantageous to specifically pinpoint locations in this plan due to potential vandalism of caves. It is important to understand that the confidence level of the information in this table is highly variable. For example, some localities are regularly visited during biomonitoring therefore the cave's entrance is known to be open and the cave is known to contain karst invertebrates (e.g., caves on Camp Bullis, see Veni and Associates 2006, and at the La Cantera preserves, see SWCA 2006) while others are rarely visited or may not have been visited for many years. Other sites have cryptic names that may be synonymous with other caves on the list, and others have unknown geographic locations; therefore, the status or continued existence of these caves is uncertain.

Critical Habitat Units - Critical habitat units were designated in Bexar County (Service 2003) and are defined as areas that contain one or more of the constituent elements needed by the karst invertebrate species.

Population estimates - Population estimates are unavailable for any of these species due to lack of adequate techniques, their cryptic behavior, and inaccessibility of habitat. One or two individuals are typically observed per survey event, and it is not uncommon to observe none at all (Krejca and Weckerly 2007). Results of point counts are available for some species at some localities in unpublished literature (usually reports by endangered species permit holders, e.g. Myers et al. 2005b, Veni and Associates 2005) and a review of methods for performing surveys is provided in Appendix C. Culver et al. (2000) states that while some troglobites are known from a few specimens, detailed studies suggest that "as a rule" most troglobites "are not numerically rare and thus are not susceptible to the problems of small populations." However, considering the lack of population estimates and limited study of these species, data are insufficient to indicate whether Bexar County karst invertebrates are numerous enough to rule out small population concerns.

Techniques that may be useful for population estimates of invertebrates include mark-recapture, such as have been used for cave crickets and troglobitic crustaceans (Knapp and Fong 1999, Taylor et al. 2005) but not for any of the listed species or their relatives.

Four of the nine listed species are single site endemics (Table 1), despite the fact that a considerable amount of effort has been expended collecting cave species in Bexar County. At least two of the three sites where these four endemic species occur have been heavily impacted by urbanization and the continued existence of the species at these sites (Robber Baron Cave, Braken Bat Cave) has not been verified. Finally, among the four single-cave endemics, two (*Cicurina vespera* and *C. venii*) are known only from holotypes, (that is, only one specimen has ever been collected).

1.4 Habitat, Ecology, and Life History

All of these invertebrates are troglobites, spending their entire lives underground. They are characterized by small or absent eyes. Their habitat includes karst limestone caves and **mesocaverns** (humanly impassable voids described below). Within this habitat, these animals depend on high humidity, stable temperatures, and surface nutrients including items such as leaf litter, animal droppings, and animal carcasses. It is imperative to consider that while these species spend their entire lives underground; their ecosystem is highly dependent on the overlying surface habitat.

Cave and Karst Habitat - Terminology specific to cave habitat is not commonly used in other environments, so special treatment is given here. The term "karst" refers to a type of terrain that is formed by the slow dissolution of calcium carbonate from limestone bedrock by mildly acidic groundwater. This process creates numerous cave openings, cracks, fissures, fractures, and **sinkholes**, and the bedrock resembles a honeycomb. Caves are typically defined as naturally occurring voids traversable to a certain extent by humans. The Texas Speleological Survey (http://www.txspeleologicalsurvey.org) defines a cave as: "[In Texas], a cave is any natural occurring, humanly passable subsurface cavity which is at least 5 meters in traverse length, and where no dimension of the entrance exceeds the length." In many cases, cave entrances are transient with surface erosion causing collapses and infilling. One author has proposed that most (perhaps 10 times as many) cave-sized passages in limestone do not have entrances large enough for human entry (Curl 1958). These entranceless caves may lack surface expression, or, if they approach the surface, they can collapse and be expressed as sinkholes. Sinkholes and other karst features in Texas are commonly small and difficult to detect (Veni 2001). For the purposes of karst invertebrate recovery it is important to consider all karst features that may contain habitat, including voids that are too small to be humanly passable. These voids are sometimes referred to as interstitial spaces (Veni 1994) but because this term is frequently used in association with submerged gravel streambeds in non-karst areas, this document will use the term mesocaverns. Mesocaverns may be inaccessible spaces extending from the walls of a cave passage, or may exist farther from a cave in an area not accessible from a cave passage. A thorough discussion of mesocaverns is below.

Cave Formation - To understand cave habitat and how it affects the ecology and life history of troglobites, it is essential to consider the origin of karst features. Some are formed above the water table (**vadose**) and others form below (**phreatic**). Mildly acidic groundwater dissolves calcium carbonate from limestone bedrock, enlarging fractures and bedding planes into voids. Those that are passable by humans are called caves and those that are too small for human passage are called mesocaverns. Many caves have a history of both phreatic and vadose development, with initial phreatic development and subsequent vadose downcutting. Many details of cave formation are important to the understanding of modern surface and subsurface **drainage basins**, a critical feature for karst invertebrate habitat preservation.

Physical characteristics of caves are determined by their genesis and subsequent history or evolution. These characteristics vary significantly between caves and influence the habitat for karst-dwelling species. For example, many caves are discrete from one another because the strata containing them are dissected and isolated due to stream downcutting and/or faulting. This isolation presents a barrier to troglobite interaction and leads to the evolution of many endemics. The configuration of a cave entrance may constrain nutrient and airflow, in some cases making it extremely limited and in others drawing in an entire continuous or ephemeral surface stream. In the former case, only **taxa** adapted to the lowest energy situation exist there, and in the latter case the cave may contain a high diversity of **epigean** organisms (surface dwelling organisms). These physical variations are partially responsible for species composition and contribute to making each cave different. In the case of central Texas species, no work has been done to attempt to quantify or describe in detail the energy regimes most suitable for the species covered in this plan.

Physical factors in caves that impact the species include absence of sunlight, low nutrient flow (due to lack of primary production), and a stable environment with uniform temperatures and high humidity. These parameters favor the evolution of **troglomorphic** characteristics including reduction or loss of eyes and pigment, often coupled with enhancement of other sensory structures such as attenuated limbs and olfactory organs, and 'k-selected' life history strategies such as low metabolic and reproductive rates (Poulson and White 1969, Howarth 1983, Culver 1986, Culver et al. 1995, Jeffery 2001). Similarities in selective pressures in caves transcend geography, resulting in convergent evolution reflected in high levels of morphological similarity among troglobites (Protas et al. 2006).

The life span of troglobites is typically long relative to that of related surface species. Average life spans of the listed troglobitic invertebrates in central Texas are unknown, but are likely multiple years for some species (for example, *Cicurina* spp.), based on observations of juveniles kept in captivity (Bennett 1985, J. Reddell, Texas Memorial Museum, pers. comm. 2000, Cokendolpher 2004, Veni and Associates 2005). Reproductive rates of troglobites are typically very low (Poulson and White 1969, Howarth 1983).

Mesocaverns - Because humans rarely access mesocaverns, data about their use is lacking. It is known, however, that central Texas endangered karst invertebrates have been found in caves that immediately prior to sampling had no human entrance (Veni and Associates 2002), and that they have been found in holes drilled into the karst that intersect tiny voids away from cave entrances or cave footprints. Also, Howarth (1983) showed that the endangered Kauai Cave arthropod, occupies mesocavernous areas adjacent to larger cave passages. It is not uncommon to thoroughly survey a small cave and find no karst species and then on the next survey, many species are found. Because of these factors we know that karst invertebrates retreat into humanly inaccessible places (Krejca and Sprouse 2007). Ueno (1977) in Japan and Juberthie (1983) and Racovitza (1980) in Europe demonstrated that many troglobites live both in caves and in shallow mesocavernous habitats in neighboring rock types. If these mesocaverns and entranceless caves are an important part of the karst invertebrate population, and burying them under urbanization is detrimental, more effort should be put toward preserving contiguous karst areas when creating recovery strategies (see also future research section of recovery outline). It is conjectured that the majority of the energy is located in humanly accessible caves, with open entrances and ample nutrients, and that for this reason they are foci of troglobitic populations that may occur in low densities throughout the karst. Since metabolic rates of troglobites are typically low, they may be able to sustain periods ranging from months to years existing on lower levels of food or no food (Howarth 1983). During temperature extremes, small mesocavernous spaces connected to caves may have a physical environment with more favorable humidity and temperature levels than the cave (Howarth 1983), but where the abundance of food may be even less than in the larger cave passages. In fact, troglobites may spend the majority of their time in such retreats, only leaving them during temporary forays into the larger cave passages to forage (Howarth 1987).

Mesocavern voids can be categorized on the basis of physical characteristics, particularly in regard to water movement. Pore sizes less than 1 to 2 mm in width act as capillaries and tend to hold water. Water flow is **laminar** (smooth streamline flow) in voids less than about 5 to 10 mm in width. These smaller voids are more likely to become plugged with sediment when they carry water. They also are able to hold only minimal amounts of food resources, such as, dissolved organic matter (Howarth 1983, Holsinger 1988, Elliott and Reddell 1989). In voids greater than 10 mm in diameter, water flow becomes turbulent, which means it can carry more suspended particles, including organic debris. Some terrestrial troglobites can disperse through spaces as small as 5 mm wide. The suitability of a particular void over time is dynamic, because voids tend to fill and wash open over time, with smaller voids filling more quickly and opening more slowly. Some mesocaverns may also be created by or filled by tree roots. While roots themselves are a documented source of energy, they may also provide pathways for water and nutrient travel, or temporarily block pathways during growth then re-open them after the plant is dead and the roots decompose.

Habitat Requirements

Nutrients - Nutrients in most karst ecosystems are derived from the surface (Barr 1968, Poulson and White 1969, Howarth 1983, Culver 1986) either directly (organic material washed in or brought in by animals) or indirectly, by feeding on the karst invertebrates that feed on surface-derived nutrients. Primary sources of input include leaf litter, root masses, and **trogloxenes** such as cave crickets, small mammals, and other vertebrates that roost or die in the cave. In some cases, the most important source of nutrients for a target troglobite may be the fungus, microbes, and/or smaller **troglophiles** and troglobites that grow on the leaves or feces rather than the original material itself (Elliott 1994, Gounot 1994). In deeper cave reaches, nutrients enter through water containing dissolved organic matter percolating vertically through karst fissures and solution features (Howarth 1983, Holsinger 1988, Elliott and Reddell 1989). For predatory troglobites, accidental species of invertebrates (those that wander in or are trapped in a cave) may be an important nutrient source in addition to other troglobites and troglophiles found in the cave (Service 2000b).

The cave cricket (*Ceuthophilus* spp.) is a particularly important nutrient component (Barr 1968, Reddell 1993a) and is found in most caves in Texas (Reddell 1966). It forages on the surface at night; one study documented travel distances of at least 105 meters (344 ft) from the cave entrance (Taylor et al. 2005). Typically, cave crickets exit a cave to forage when the ambient surface temperature is close to 15 º Celsius and the relative humidity is close to 100 percent (Lavoie et al. 2007). Cave crickets are generally known to return to the cave during the day, where they lay eggs and roost. A recent radio tracking study showed that travel from cave to cave is not uncommon, and sometimes the crickets will spend their day on the surface away from a known cave, probably in a tiny crack or other protected **microhabitat** (Taylor et al. 2004). The energy input from foraging by tens to thousands of crickets is quite large, with deep cricket guano blanketing large parts of the floor of some cave passages. A variety of troglobites are known to feed on cave cricket eggs (Mitchell 1971b), feces (Barr 1968, Poulson et al. 1995), and/or on the adults and nymphs directly (Elliott 1994).

The most abundant recognized species of cave cricket in central Texas is *Ceuthophilus secretus*. There is at least one other widely recognized, but not formally described, species of cave cricket referred to as "*Ceuthophilus* species B." Both of these species are known to exit caves at night and forage on the surface, therefore they are important pathways of energy into the cave. A third species, *Ceuthophilus cunicularis*, is more troglomorphic and almost never found exiting the cave. The taxonomy of this group is not well studied and the observed morphological variation indicates there may actually be many species that occur across the state.

A cave harvestman (*Leiobunum townsendi*) is another invertebrate trogloxene that is widespread and commonly found in Texas caves (Reddell 1965). Vertebrate species that have been frequently found in caves and may be important trogloxenes in some cave systems include raccoons (*Procyon lotor*), slimy salamanders (*Plethodon albagula*), cliff frogs (*Eleutherodactylus marnocki*), and various species of mice (primarily *Peromyscus* spp.) and snakes (Reddell 1967). In some instances, **eutrophication** (excessive nutrients) of the surrounding surface environment may lead to excessive trogloxene populations inside the cave due to excess nutrient input to the cave. For example, observations of decreased troglobitic diversity have been made in some caves with excessive raccoon scat. This could be due to excessive nutrients that are typical of urban areas that favor species tolerant of high energy (Balcones Canyonlands Preserve (BCP) Annual Reports 2004, 2005, 2006). Since significant energy comes in through cave entrances; they should be protected. Cave gates should be carefully designed to restrict human access while allowing normal passage of nutrients, air, and trogloxenes.

Drainage Basins – Water enters the karst ecosystem through surface and subsurface (groundwater) drainage basins. Well-developed pathways, such as cave openings, fractures, and solutionally enlarged bedding planes, rapidly transport water through the karst with little or no purification. Caves are susceptible to pollution from contaminated water entering the ground because karst has little capacity for self-purification. The route that has the greatest potential to carry water-borne contaminants into the karst ecosystem is through the drainage basins that supply water to the ecosystem. Because of these reasons protecting caves' drainage basins may even be more important, in some cases, than many of the other habitat factors discussed here. Because cave fauna require material washed in through entrances (including humanly inaccessible cracks) and in general high humidity, it is critical to have drainage basins with a natural quantity and quality of water. The surface drainage basin consists of the cave entrance and other surface input such as neighboring sinkholes and through the soil. The subsurface or groundwater drainage basin includes mesocaverns, subterranean streams, buried joints and sinkholes that have a connection to the surface that is not always observable from the surface (the groundwater drainage basin). It is also important to note that the surface and subsurface drainage basins do not necessarily overlap. They may be of different size and direction. See discussion in Veni (2003) for more information on this topic.

Surface Vegetative Community - Surface plant communities not only provide nutrients that support trogloxene and accidental species, but also are important to caves by providing nutrients through leaf litter and root masses that grow directly into caves (Howarth 1983, 1988, Jackson et al. 1999; also see Appendix B for literature review). Because troglobites are at the top of their food chain, habitat changes that affect their food sources (including plants, cave crickets, and raccoons) can, in turn, affect the troglobites (Culver et al. 2000). Surface vegetation also acts as a buffer to edge effects (discussed in Appendix B) and to the subsurface environment against drastic changes in the temperature and moisture regime and serves to filter pollutants (to a limited degree) before they enter the karst system (Veni 1988, Biological Advisory Team 1990).

Surface Animal Community - Surface invertebrates provide food for trogloxenes, such as cave crickets, bats, toads, and frogs. They also wash or accidentally stumble into caves and are food sources for cave-limited species. A healthy native arthropod **community** may also better stave off red imported **fire ants** (*Solenopsis invicta*) (RIFA), a threat to the karst ecosystem (Porter et al. 1988, 1991). Many of the vertebrate species that occasionally use caves bring in a significant amount of energy in the form of scat, nesting material, and carcasses. Natural quantities of all of these components are an important part of a functioning ecosystem.

Humidity and Temperature - Terrestrial troglobites require stable temperatures and constant, high humidity (Barr 1968, Mitchell 1971a). The temperatures in caves are typically the average annual temperature of the surface habitat, and vary much less than the surface environment (Howarth 1983, Dunlap 1995). Relative humidity in a cave is typically near 100 percent for caves supporting troglobitic invertebrates (Elliott and Reddell 1989). Many of these species have lost the adaptations needed to prevent desiccation in drier habitat (Howarth 1983) or the ability to detect and/or cope with more extreme temperatures (Mitchell 1971a). To maintain these conditions, it is important to maintain an adequate drainage area to supply moisture to the cave and connected karst areas and to maintain the surface plant communities that insulate the karst system from excessive drying and from more extreme temperature fluctuations.

Ecology

These terrestrial troglobites are effectively top predators in their ecosystem, and like other top predators such as wolves or lions, if the rest of the ecosystem crashes, so will their own populations. Although we know little about the ecology of these species, an example of their food chain may be the following: a tree drops leaves, which decay and are eaten by small leaf litter invertebrates; cave crickets eat the surface invertebrates (and some of the fungi that grow on the leaves); the cave crickets defecate in the caves; the cave cricket feces are fed upon by collembolan, which are then captured by a predatory species such as *Cicurina* sp. or *Neoleptoneta* sp. The reality is that there is a highly complicated food web with many interrelated links instead of a simple food chain, but it is clear that cave organisms rely on energy brought in from the surface. Also, recent research (on stable isotopes) in Texas indicates a close dependence of taxa at higher trophic levels upon those at lower trophic levels within the karst ecosystem (Taylor et al. 2004).

Microhabitat has been quantified for three of the listed species that occur on Camp Bullis, *Rhadine exilis*, *Rhadine infernalis*, and *Cicurina madla*. For details on the measurement methods, exact in-cave location boundaries, and dates of observations, please see the methods section in the source document (Veni and Associates 2006).

In observations made in 13 caves, *Rhadine exilis* was seldom found near an entrance (4/64 instances), occasionally found further from the cave entrance in the **twilight zone** (18/64 instances), and more often found deeper in the cave **dark zone** (47/64 instances). Of a total of 64 sightings, 12 were in the fall, 37 were made in the spring, and 15 were in the summer. They were found in air temperatures ranging from 18.7 to 24.5º C (65.7 to 76.1º F), with a mean of 21.44º C (70.59º F) and a standard deviation of 1.24º C. Humidities measured near the species sightings ranged from 83.2 to 98.3 percent, with a mean of 93.45 percent and a standard deviation of 3.62 percent. The recorded microhabitats (53 instances) occupied by *R. exilis* were varied, with about 58 percent of them on top of the substrate and 42 percent under rocks or on the undersides of rocks or other materials (Veni and Associates 2006).

In measurements made in three caves (of which only a single observation in one cave overlaps with the observations described for *Rhadine exilis*, above), *Rhadine infernalis* was found in the entrance (6/23 instances) and twilight (10/23 instances) overall more often that the dark zone (7/23 instances) in a total of 23 observations. Sightings included fall (1/23), spring (13/23) and summer (9/23) observations. These observations included in cave air temperatures ranging from 19.0 to 27.0° C (66.2 to 80.6° F), with a mean of 22.05° C (71.69° F) and a standard deviation of 2.62° C. Humidities measured near the species sightings ranged from 81.4 percent to 93.8 percent, with a mean of 90.50 percent and a standard deviation of 3.44 percent. They were almost always found under rocks (Veni and Associates 2006).

In 75 observations made in two caves, *Cicurina madla* were found three times in the twilight and in the dark on the remainder of the occasions. These 75 sightings were divided nearly equally between observations in the spring, summer, and fall. Air temperatures ranged from 19.0 to 23.25º C (66.2 to 73.8° F), with a mean of 20.03º C (68.0° F) and a standard deviation of 0.82° C. Humidities measured near the species sightings ranged from 90.0 to 97.3 percent, with a mean of 94.01 percent and a standard deviation of 2.24 percent. The species were always found among loose rocks or mud balls. In 52 of the 72 instances where location in respect to substrate was recorded, they were underneath or on the underside of rocks, the other times they were on top of rocks. Since they typically spin their webs underneath rocks and in crevices, they are probably dependant on this type of habitat (Veni and Associates 2006).

Evolution and Life History

Terrestrial troglobites are descendants of surface-dwelling ancestors who entered cave habitats as they became available during relatively recent geologic history. Exploitation of cave environments for temporary or seasonal shelter is common among many surface-dwelling organisms, but this alone would probably not result in sufficient isolation among surface and subsurface populations for speciation to occur. However, long-term occupation of subsurface environments during periods of climate change such as Pleistocene glaciations is a plausible hypothesis for the evolution of troglobitic taxa in central Texas. In this scenario, some populations may persist in relatively mild and stable cave environments during periods of climate change, while surface populations are forced to migrate to more suitable climates or face extinction. This hypothesis leads to **vicariance** (speciation by geographic isolation) and is supported by several lines of evidence (Barr 1968). Subsequent changes to subsurface habitats, such as fragmentation and isolation due to erosion or faulting, may lead to further speciation among troglobitic taxa (Elliott and Reddell 1989, Veni 1994). In addition, this cycle may repeat over time, with multiple invasions of subsurface habitat by surface species (Cokendolpher 2004).

Physical factors in caves that affect the species include absence of sunlight, low nutrient flow (due to lack of primary production), and a stable environment with uniform temperatures and high humidity. These parameters favor the evolution of troglomorphic characteristics including reduction or loss of eyes and pigment, often coupled with enhancement of other sensory structures such as attenuated limbs and olfactory organs, and 'K-selected' life history (or low energy) strategies such as low metabolic, longer life-spans, and reproductive rates (Poulson and White 1969, Howarth 1983, Culver 1986, Culver et al. 1995, Jeffery 2001). Similarities in selective pressures in caves transcend geography, resulting in convergent evolution reflected in high levels of morphological similarity among troglobites (Protas et al. 2006).

The life span of troglobites is typically long relative to that of related surface species. Average life spans of the listed troglobitic invertebrates in central Texas are unknown, but are likely multiple years for some species (for example, *Cicurina* spp.), based on observations of juveniles kept in captivity (Bennett 1985, J. Reddell, Texas Memorial Museum, pers. comm. 2000, Cokendolpher 2004, Veni and Associates 2005). Reproductive rates of troglobites are typically very low (Poulson and White 1969, Howarth 1983).

1.5 Threats

The reasons for listing these species were described in the final rule (Service 2000a), and this discussion of threats and how they relate to the five listing criteria, is largely paraphrased from that document. Additionally, Elliott (2000) provides a thorough review of threats and conservation of North American cave species.

Listing Factor A - The present or threatened destruction, modification, or curtailment of its habitat or range

Bexar County is facing continued rapid population growth and associated urbanization. A review of new electrical connections for Bexar County from 1990-1996 showed the northwest and northeast quadrants to be the fastest growing areas in the county (San Antonio Planning Department 1997), and these areas are where endangered invertebrates are most likely to occur (see Figure 8 in Section 2.1). The northwest and northeast quadrants of Bexar County contained 69 percent of the total county population (City of San Antonio 1991). According to the San Antonio Planning Department (2005) the population of Bexar County is forecasted to reach approximately 2.37 million people by 2050. One of the main threats to the listed invertebrates is habitat loss due to this increasing urbanization and population growth. Threats associated with urbanization are discussed here.

Without proper management and protective measures, effects of urbanization on the listed species include habitat loss from filling and collapsing caves, habitat degradation through alteration of drainage patterns, alteration of surface plant and animal communities, contamination from pollutants, human visitation and vandalism, and activities associated with mining and quarrying.

Cave Filling and Collapsing - Veni (1991) estimated that about 26 percent of known caves in Bexar County had been destroyed through filling, capping or covering with roads or buildings and blasting by construction and quarrying operations. Further loss undoubtedly has occurred since that report, and will likely continue unless appropriate controls are implemented. Construction and development activities that may not destroy an entrance can still result in collapses of the cave ceiling or other adverse effects on the karst environment. On ranch land or in rural areas, it is not uncommon to use caves as trash dumps (Culver 1986, Reddell 1993a) or to cover the entrances to prevent livestock from falling in (Elliott 2000). These activities can be detrimental to the karst ecosystem by causing direct destruction of habitat or altering (increasing or decreasing) the natural passage of organisms, water, detritus, and other organic matter into a cave.

Alteration of Drainage Patterns - Cave organisms are adapted to live in a narrow range of temperature and humidity. To sustain these conditions, both natural surface and subsurface flow of water and nutrients should be maintained. Decreases in water flow or infiltration can result in excessive drying and may slow decomposition, while increases can cause flooding that drowns air-breathing species and carries away available nutrients. Water flow routes also influence the nature of impacts of nearby pollutants and spills on the karst ecosystem and can affect the amount of organic matter washed into caves. Alterations to surface topography, including decreasing or increasing soil depth or adding non-native fill, can change the nutrient flow into the cave and affect the cave community (Howarth 1983). Changes in the amount of impermeable cover, collection of water in devices like storm sewers, increased erosion and sedimentation, and irrigation and sprinkler systems can affect water flow to caves. Altering the quantity of water, its organic content, or the timing and extent of flood pulses or droughts may negatively impact the listed species.

Alterations of Surface Plant and Animal Communities - Karst ecosystems are heavily reliant on surface plant and animal communities to maintain nutrient flows, reduce sedimentation, and resist exotic and invasive species. As the surface around a cave entrance becomes developed, native plant communities are often replaced with impermeable cover or exotic plants from nurseries. The abundance and diversity of native animals may decline due to decreased food and habitat combined with increased competition and predation from urban, exotic, and pet species. As native surface plant and animal communities are destroyed, food and habitat once available to trogloxenes decreases. It is unknown whether exotic species could contribute the same quantity and quality of nutrients to the karst ecosystem. The leaf litter and wood that make up most of the detritus is also typically reduced or altered, resulting in a reduction of nutrient and energy flow into the cave. Reduced nutrient flow is often exacerbated by RIFA, which compete with some trogloxenes (e.g., cave crickets) for food that could result in less nutrient input to the karst ecosystem. Additionally, destruction of native plant communities can lead to increased erosion that causes sedimentation within caves. Since plants affect the rate and amount of water flow and sedimentation in caves, removing plant communities can alter those abiotic factors that impact karst ecosystems. It is necessary to maintain the native woodland and grassland communities; therefore a buffer area is needed to shield the core habitat from impacts associated with edge effects or disturbance from adjacent urban development (Lovejoy et al. 1986; Yahner 1988; see Preserve Design in Appendix B for more discussion). In this context, edge effects refer to the adverse changes to natural communities (primarily from increases in invasive species and pollutants, and changes in microclimates) from nearby areas that have been modified for human development. These changes are undesirable because of the potentially negative effects to species and nutrient cycling processes important in cave dynamics.

Contamination - Karst landscapes are particularly susceptible to groundwater contamination because little or no filtration occurs and water penetrates rapidly through bedrock conduits (White 1988). The ranges of these species are becoming increasingly urbanized, thereby are becoming more susceptible to contaminants including sewage, oil, fertilizers, pesticides, herbicides, seepage from landfills, pipeline leaks, or leaks in storage structures and retaining ponds. Activities on the surface, such as disposing of toxic chemicals or motor oil, can contaminate caves (White 1988). Materials like cleaning agents, industrial chemicals, and heavy metals can also easily infiltrate subterranean ecosystems. Contamination of caves can also occur from air pollutants and improper disposal of litter, motor oil, batteries, or other household products in or near caves (White 1988).

Continued urbanization will increase the likelihood that karst ecosystems are polluted by contamination from the leaks and spills which often have occurred in Bexar County (see TWC 1989, TCEQ 2006a, TCEQ 2006b for information on contamination events). The Texas Natural Resources Conservation Commission (TNRCC) summarizes information on groundwater contamination reported by a number of agencies, and lists 350 groundwater contamination cases that occurred in Bexar County between 1974 and 1994, the majority of them spills or leaks of petroleum products. Groundwater contamination poses a threat to entire karst ecosystems and is particularly difficult to manage because pollutants can originate far from the sensitive cave site and flow rapidly through the subsurface (White 1988).

Quarrying and Mining Operations - Quarries and mines exist in Bexar County, including the northern half, where the majority of the listed species occur. While quarrying activities have revealed some caves, it also completely destroyed others (Elliott 2000). As caves and mesocavernous spaces are destroyed at mines and quarries, karst invertebrates, possibly including some listed species, will also be lost.

Listing Factor B - Overuse for commercial, recreational, scientific, or educational purposes

Urbanization can lead to increased human visitation of caves for recreation as more people inhabit areas with cave entrances. Visitation can impact caves by increasing soil compaction (see discussion of substrate and microclimate in Habitat Requirements above), trash deposition, and vandalism; altering airflow as entrances are expanded and excavated; scaring away trogloxenes (Culver 1986, Elliott 2000); and may also lead to direct mortality of cave organisms crushed or trapped by human disturbance (Crawford and Senger 1988). In extreme vandalism cases, human waste may be left behind, and although the food web of troglobites frequently depends on guano, human feces may not be suitable for troglobitic invertebrates (see review in Howarth 1983).

Commercialization of caves is an extreme example of excess human visitation. It affects cave communities due to competition with introduced surface species, harmful effects of commercial lighting, substrate changes around trails, changes in microclimate due to cave ventilation and changes in the nutrient regime (Culver 1986, Northup 1988, Northup et al. 1988, Reddell 1993a, Krejca and Myers 2005).

Listing Factor C - Disease or Predation

RIFA are a pervasive, non-native ant species originally introduced to the U.S. from South America (Vinson and Sorensen 1986) over 50 years ago (Porter and Savignano 1990). This ant is an aggressive predator and competitor that has spread across the southern United States. RIFA often replace native species, and evidence shows that overall arthropod diversity, as well as **species richness** and abundance, drops in infested areas

(Vinson and Sorenson 1986, Porter and Savignano 1990). However, two recent studies, reviewed in detail below, indicate that the long-term relationship between RIFA and native ants is likely more complex than previously documented (Morrison 2002, Morrison and Porter 2003). Morrison (2002) found that RIFA presence alters native ant species richness and abundance and displaces or eliminates rare ant species. Similarity, Morrison and Porter (2003) found that a number of rare and threatened ant species may be disproportionately impacted by RIFA and this needs to be taken into account when evaluating the overall impact of RIFA. RIFA pose a major threat to the listed invertebrates in Bexar County through direct predation and competition with native species (such as cave crickets) for food resources. This threat is exacerbated by edge effects associated with the soil disturbance and disruption to native communities that accompany urbanization, e.g. waste associated with housing may attract RIFA or other surface species that prey on or compete with cave species (Reddell 1993a).

Development and edges often allow enough disruption for invasive or exotic species to displace native communities that had previously prevented their spread (Saunders et al. 1990, Kotanen et al. 1998, Suarez et al. 1998, Meiners and Steward 1999). The invasion of RIFA is aided by “any disturbance that clears a site of heavy vegetation and disrupts the native ant community” (Porter et al. 1988) such as road building and urbanization. Several native ants are known to attack and kill founding fire ant queens. These native ants are especially important in eliminating founding fire ant queens and their colonies from non-infested areas (Porter et al. 1988). RIFA are associated with open habitats disturbed as a result of human activity (for example: old fields, lawns, roadsides, ponds, and other open, sunny habitats) and tend to be absent or rare in late succession or climax communities such as mature forest (Tschinkel 1986). Although this association is not apparent in all areas, especially in central Texas, maintaining large (greater than 5 ha, approximately 12 acres), native-vegetation communities may help sustain native ant populations and further deter RIFA infestations (Porter et al. 1988, 1991). Caves on Camp Bullis, in Bexar and Comal counties, Texas, are located in large expanses of undeveloped land, and this may be why they had less RIFA infestation compared to caves in more urbanized areas even prior to beginning a RIFA treatment regime (Veni and Associates 1999).

For animal communities, reported edge effects (negative impacts or effects associated with proximity to habitat edge) are typically 50 to 100 m (164 to 328 ft) or greater (Lovejoy et al. 1986, Wilcove et al. 1986, Laurance 1991, Laurance and Yensen 1991, Kapos et al. 1993, Andren 1995, Reed et al. 1996, Burke and Nol 1998, Didham 1998, Suarez et al. 1998). In coastal southern California, Suarez et al. (1998) found that densities of another exotic ant species, the Argentine ant (*Linepithema humile*) that has a life history similar to the fire ant, are highest within 100 m and rare or absent within 200 m of an urban edge. Native ant communities tended to be more abundant in native vegetation and less abundant in areas with exotic vegetation. As areas around caves are increasingly urbanized the native ant and plant communities are often destroyed, increasing the potential for deleterious effects from RIFA on the karst ecosystem.

Karst invertebrates in central Texas are especially susceptible to RIFA predation because these caves are relatively short and shallow. The hot dry weather may also encourage RIFA to move into caves during summer months or seek refuge or prey in caves during colder periods in the winter. RIFA have been found within and near many caves in central Texas and have been observed feeding on dead troglobites, cave crickets, and other species within caves (Elliott 1992, 1994, 2000, Reddell 1993a, Taylor et al. 2003). Reddell (1993a) describes an instance in one cave where "hundreds of hard chitonous shells of the millipede *Cambala speobia* littered the floor of the cave. Fire ants were observed actively mining the millipedes…" A quantitative study of RIFA at six central Texas caves showed that they primarily used the entrance and twilight zones, but during cooler months were occasionally found deep into caves, not necessarily using human entrances as access points (Taylor et al. 2003). This study also found that foraging by RIFA around caves was inversely correlated with foraging of native ant species. Thirdly, Taylor et al. 2003 found that at baits placed above ground at night, cave crickets often arrived at the food resource before RIFA, but the arrival of RIFA corresponded to the departure of cave crickets, indicating competition for at least some food resources. Of 36 caves Veni and Reddell visited during status surveys for the nine Bexar County karst invertebrates, RIFA were found in 26 of them (Reddell 1993a). Karst fauna life stages that are most vulnerable to fire ant predation are the immature stages, eggs, and slower-moving adults (James Reddell, Texas Memorial Museum, pers. comm., 2006).

Besides direct predation, RIFA threaten listed invertebrates by reducing the nutrient input that fuels the karst ecosystem. Cave species rely on nutrients from the surface that are either washed in the entrance or carried in by trogloxenes like cave crickets. Because RIFA are voracious, they can out-compete crickets for food resources (Taylor et al. 2003), leading to a reduction in overall productivity in the caves. This can be disastrous for karst ecosystems, reducing species diversity and abundance similar to what is seen in surface communities.

Listing Factor D - Inadequacy of existing regulatory mechanisms

Neither invertebrates nor their habitat are protected by State regulations. Invertebrates are not included on the Texas Parks and Wildlife Department's (TPWD) list of threatened and endangered species and are provided no protection by the State. Furthermore, TPWD's regulations do not contain provisions for protecting habitat of any listed species.

The TCEQ regulations may give some degree of protection to significant aquifer recharge features however; the Bexar County karst invertebrates are found in many caves that do not meet the TCEQ definition of a ''sensitive feature.'' TCEQ defines a sensitive feature in their "Instructions to Geologists for Geologic Assessments on the Edwards Aquifer Recharge/Transition Zones, as a ''permeable geologic or manmade feature located on the recharge zone or transition zone where a potential for hydrologic interconnectedness between the surface and the Edwards Aquifer exists, and rapid infiltration to the subsurface may occur.'' The TCEQ regulations are designed to protect the water quality of the Edwards Aquifer. This protection is typically accomplished by prohibiting certain activities (for example, locating waste disposal wells or concentrated animal feed lots off of the recharge zone), requiring filing of a Water Pollution Abatement Plan, and through the use of Best Management Practices. Complying with TCEQ regulations may also entail the capping (concrete sealing) of some features to prevent contaminated water from entering the aquifer. Such alteration or blocking of natural drainage patterns could result in drying of the subterranean habitat and a reduction in nutrient input into the karst feature. Karst features supporting the invertebrates may also be exempted from TCEQ regulations because several are not found in either the recharge or transition zone.

The City of San Antonio regulates development and impervious cover within the recharge area of the Edwards Aquifer through Ordinance #81491, made effective January 23, 1995. This ordinance limits types of development and impervious cover within the city limits, the extraterritorial jurisdiction, and the recharge zone. This ordinance requires, in part, identification of critical environmental features and may provide some protection for caves and karst features that provide recharge to the Edwards Aquifer. Development setbacks provided for in the ordinance range from 18.3 to 30.5 m (60 to 100 ft). These setback distances translate into buffer areas of 0.13 to 0.37 ha (0.33 to 0.92 ac). Setbacks from recharge features required by the ordinance may not always be adequate to protect entire hydrogeological areas that provide surface and subsurface moisture to the cave, associated mesocaverns, and surface communities that provide nutrient input into the cave. Most of the caves known to contain the nine invertebrates are relatively small and do not provide much recharge, so it is uncertain how these caves would be considered under the ordinance.

In addition, not all development is subject to this ordinance. The ordinance classifies property into three categories. Category 1 is any property having already filed official documents, such as development plats, water or sewer contracts, water pollution abatement plans, or zoning changes, or having a valid permit with the City prior to the effective date of the ordinance. The ordinance does not apply to these properties, allowing up to 100 percent impervious cover. Category 2 properties are those not already designated as Category 1 and that lie within the corporate limits of the City of San Antonio. This category allows 30 percent, 50 percent, and 65 percent impervious cover, respectively, for single-family residential, multi-family, and commercial development. Category 3 property is not within Category 1 or 2, but is within the extra-territorial jurisdiction of the City of San Antonio and within the Edwards Aquifer Recharge Zone. Impervious cover is limited to 15 percent on Category 3 property. In an update by San Antonio Water System on January 14, 1998, they noted that from January 23, 1995 to the end of 1997, 29.25 percent (9,695 ha (23,958 ac)) of development within the recharge zone was redesignated from Category 2 or 3 to Category 1.

Listing Factor E - Other natural or manmade factors affecting their continued existence

Small Population Size

Due to inherently low sample sizes, it is difficult to detect possible impacts affecting karst invertebrates because population responses (positive or negative) may not be immediate and/or detectible (Poulson and White 1969, Howarth 1983, Miller and Reddell 2005). Frankham (2005) states, "loss of genetic diversity in small populations is expected to increase extinction risk by adversely affecting the ability of populations to evolve to cope with environmental change (evolutionary potential)." Although sample sizes are consistently small, it is not certain that these populations are at risk of losing genetic diversity.

1.6 Conservation Efforts to Date

The conservation efforts discussed in this section have occurred since the Bexar County karst invertebrates were listed as endangered. These actions may contribute to the recovery of these species.

Government Canyon Karst Management and Maintenance Plan – Some of the listed species have been verified from seven caves in the 3489 ha (8622 ac) Government Canyon State Natural Area (GCSNA). These are Bone Pile Cave, Dancing Rattler Cave, Government Canyon Bat Cave, Hackberry Sink, Lithic Ridge Cave, Lost Pothole, and Surprise Sink. An additional three caves, 10K Cave, Goat Cave, and Sure Sink, potentially have listed species, the specimens are either a sight record or awaiting verification (Miller and Reddell 2005). Four more caves (see below) containing listed species on the adjoining Lowder Tract are also managed by GCSNA. Detailed biological studies have not been conducted at GCSNA, with the exception of Government Canyon Bat Cave, Bone Pile Cave, Goat Cave, Lithic Ridge Cave, and Surprise Sink, therefore other sites for listed species may be found over time (Miller et al. 2002).

In 1998, TPWD began managing for these species, conducting RIFA control at several caves at GCSNA. In 2002 TPWD developed its Karst Management and Maintenance Plan (Kegley 2002) to protect surface and ground water quality, terrestrial and subterranean ecosystems, and to provide a natural laboratory in which to study them. Regular monitoring and RIFA control continue to be carried out at GCSNA. Sprouse (2005) shows that these efforts have resulted in reduced fire ant infestation around seven caves being treated. A cave gate has also been installed at Surprise Sink, and a bat-friendly chain link and barbed wire fence have been installed around Government Canyon Bat Cave. These gates have been maintained and have not been breached.

Section 6 Land Acquisition (Lowder Tract) – GCSNA acquired four additional caves that contain listed species in 2005. These caves were Creek Bank Cave, Pig Cave, San Antonio Ranch Pit, and Tight Cave. The Lowder Tract was jointly acquired by TPWD (70 percent ownership) under a land acquisition grant under Section 6 of the Act, by the City of San Antonio (15 percent) using funds from Proposition 3 for Edwards Aquifer recharge zone protection, and by the San Antonio Water System (15 percent). The Lowder tract comprises 421 acres adjoining and nearly surrounded by GCSNA.

Camp Bullis Management Plan for the Conservation of Rare and Endangered Karst Species - Camp Bullis Training Site is a 113.3 km^2 (43.7 mi^2) facility under the command of Fort Sam Houston (U.S. Army), Texas. It contains 22 caves with listed karst invertebrates (Table 1). After the species were petitioned for listing, Camp Bullis began karst investigations to determine the extent of these species on their property and how best to manage them. Three of the listed species, *Cicurina madla*, *Rhadine exilis*, and *Rhadine infernalis* have been discovered on Camp Bullis. A management plan was developed in 1999 (Veni and Associates 1999) and revised in 2002 (Veni et al. 2002) to eliminate, mitigate, and prevent harm to these and other rare species on Camp Bullis in perpetuity. The plan includes RIFA control, in-cave biological surveys, cave gate construction, and preservation of karst management areas around cave entrances. Since 1999, Camp Bullis has adaptively managed their RIFA treatment regime. Myers et al. (2005a) demonstrated the success of RIFA control measures at Camp Bullis from 2003 to 2005, as mound counts declined 96 percent during this time.

Proposition 3 - On May 6, 2000, the citizens of San Antonio passed a "Parks Development and Expansion Venue Project Proposition" (Proposition 3) to raise $65 million through a temporary 1/8 cent sales tax increase for the acquisition of open space over the Edwards Aquifer recharge zone and for parkland along Salado and Leon Creeks. A total of $40.5 million was reserved for the purchase of land or conservation easements in the contributing and recharge zones of the aquifer. Another $4.5 million was put into an endowment fund for the management of these properties and easements. Most of the Proposition 3 land that was purchased surrounded GCSNA and is not known to include sites for listed species. Exceptions were the Medallion and Crownridge Canyon properties. Crownridge Canyon Cave, a locality for *Rhadine infernalis infernalis*, is located on the Crownridge property (Veni 2003) and in the UTSA karst preserve. Robber's Cave, a *Cicurina madla* site, is located on the Medallion property purchase. In addition, purchase of the Thrift tract added protection to the surface drainage basin for John Wagner Ranch Cave No. 3. Much of the Proposition 3 lands remain uninvestigated for caves, and therefore have additional potential to contribute to species recovery.

La Cantera Habitat Conservation Plan (LCHCP) - Three listed karst invertebrate species, *Cicurina madla*, *Rhadine exilis*, and *R. infernalis* are known to occur on the approximately 400 ha (1000 ac) La Cantera property located in the UTSA KFR. The property contained over 400 potential karst features and three caves known to contain listed karst invertebrate species: La Cantera Cave #1, La Cantera Cave #2, and La Cantera Cave #3. A habitat conservation plan (HCP) was developed in association with a request for an incidental take permit to develop the property. The La Cantera HCP (Service 2001) resulted in the establishment of several karst preserves. Two 0.4 ha (1 ac) development setbacks were established around two on-site caves known to contain listed species, and five preserves were established on off-site mitigation properties, totaling 72 ha (179 ac). These off-site preserves include the type localities for *Rhadine infernalis* and *Cicurina madla* (Madla's Cave) and *Batrisodes venyivi* (Helotes Hilltop Cave). The large number of off-site preserves was, in part, due to the fact that the size of the on-site setbacks was considered inadequate to ensure the survival of covered species. In addition, the La Cantera HCP called for continued management and monitoring of the on-site and off-site preserves, development of an outreach program, funding for a molecular study of *Cicurina* taxonomy, and establishment of Karst Management and Monitoring Plans for all off-site preserves.

Critical Habitat Designation - The Service issued a Final Rule on April 8, 2003 designating critical habitat for seven of the nine listed species (Service 2003). Critical habitat identifies areas that are essential to the conservation of a listed species and that may require special management considerations or protection. Section 7 of the Act requires Federal agencies to ensure, in consultation with the Service, that actions they authorize, fund, or carry out are not likely to result in the destruction or adverse modification of critical habitat. The proposed critical habitat consisted of 25 units totaling 3857 ha (9516 ac), each encompassing one or more caves or karst features known to contain one or more of the listed species.

Caves in GCSNA and on Camp Bullis were excluded from the critical habitat designation (under section 3(5)(A)(i) and 4(b)(2) of the Act) because conservation plans for these areas provided adequate management and protection. Because two of these species, *Neoleptoneta microps* and *Cicurina vespera*, occur only in caves on the GCSNA, no critical habitat was designated for them. The Service also excluded lands covered by the La Cantera HCP from critical habitat designation on the basis of section 4(b)(2) of the Act.

Texas Cave Management Association (TCMA) - The TCMA owns and manages Robber Baron Cave which is the single locality for *Cicurina baronia* and *Texella cokendolpheri*. Previously, a concrete bunker gate was over the cave that provided cave cricket access via several 10 centimeter (cm) diameter PVC pipes that extended vertically through the cave's secondary and otherwise sealed entrance. In 2002 this old concrete bunker was discovered to be unstable, and therefore from mid-September 2002 through August 2004, the cave was closed to visitation; since then visitation has been limited. The primary entrance of Robber Baron was filled with sand on 5 April 2003. A 20 cm diameter PVC pipe extended through the sand for cricket access, in addition to the previously standing 4 inch (in) diameter pipes that were in the second entrance. However by the end of 2003 (it is not clear exactly when) the pipes in both entrances had been crushed by excavation around them. There was no airflow from the pipes and probably allowed little or no room for crickets to pass. Additionally, the rest of the sinkhole floor was also packed tightly; therefore most likely crickets would have been unable to reach the surface. On 16 August 2004 the cave was reopened then immediately resealed with cement and cinder blocks for security. The air quality was poor and no cave crickets were seen. On 29 August 2004 the entrance was again reopened in preparation for cave gate installation, which was funded in part by a grant from the Service Partners for Fish and Wildlife Program.

Texas Commission on Environmental Quality - The TCEQ developed optional water quality measures that, if implemented, should provide protection from water quality related impacts to some karst features that may contain listed species. These measures are voluntary and are meant to streamline the TCEQ and the Service Section 10(a)(1)(A) permitting process for development activities above the Edwards Aquifer. The measures do not apply to development projects that are within the Contributing Zone that disturb less than five acres, or those that are not part of a larger common plan of development that may disturb five or more acres. These measures are expected to provide some protection; however, they are not mandatory and do not apply to all areas where endangered karst invertebrates occur in Bexar County.

2.0 RECOVERY

The following sections present a strategy to recover the species, including objective and measurable recovery criteria to achieve downlisting and delisting, and site-specific management actions to monitor and reduce or remove threats, as required under section 4 of the Act. The Recovery Plan also addresses the five statutory listing/recovery factors (section 4(a)(1) of the Act) to demonstrate how the recovery criteria and actions will lead to removal of the Bexar County Karst Invertebrates from the lists of Threatened and Endangered Species.

2.1 Recovery Strategy

The recovery strategy includes the perpetual preservation and management of an adequate quantity and quality of habitat that spans the geographic range of each of the species. Adequate quantity of habitat refers to both size of preserve areas that are sufficient for supporting the karst ecosystems and number of preserve areas that provide a buffer against risk that a catastrophic event may extirpate one population. Multiple preserve areas across the species' ranges may also protect the genetic diversity and allow possible migration or population dynamics necessary for long-term viability. Adequate quality of habitat refers to the condition and orientation of preserve land with respect to the known cave localities for the species. Preserving habitat, management, monitoring, and research to refine our understanding of the species are key components of recovery.

This section and Appendix B discuss the reasoning and scientific support behind defining adequate quantity and quality of habitat. The tasks to accomplish this are outlined in sections 2.3 and 2.4.

Selecting Areas for Preservation

Conservative Estimates for Preserve Design - The basic strategy for designing a karst ecosystem preserve is to protect the surface and subsurface drainage basins of an occupied karst feature and adequate surface habitat to maintain native plant and animal communities around the feature. Details of the minimum area needed to protect the feature are difficult to define due to limited information on the dynamics of the species and ecosystem processes. Furthermore, population trends of all the listed invertebrates are difficult to obtain due to small sample sizes. This means that the only way to determine with certainty that a preserve is insufficient to support karst invertebrates is to document the extinction of a population by observing no specimens over the course of many years. Because it is unknown if these species can be reintroduced or migrate (except over the course of evolutionary or geologic time) into existing habitat, this is not an acceptable method. In addition, if a preserve is later found to be insufficient to support the species due to surrounding developments being either too close or too dense, the potential for preserving that land is lost (the potential for adaptive management will be gone). Because these species have relatively long life-spans and low requirements for food, a decline in population size or even the complete extinction of the population may take years or even decades. Observations of a listed species over several years on a preserve that is too small for perpetual species preservation may not reveal declines that are actually occurring. If these observations are used as evidence that a preserve size was inadequate, then the potential for long-term preservation of that species may become lost due to irreversible development surrounding the preserve.

To provide long-term conservation of these species, consideration needs to be given to the population dynamics and population genetics of these species. To preserve the genetic diversity of the species, caves should be selected based on population genetics analyses, barriers or restrictions to travel, species distributions, and the range of the species. These barriers divide the ranges of the species into KFR and karst zones (see Section 1.3 for discussion). Some species-level genetic work has been done on *C. madla* (Paquin and Hedin 2004); however, no population genetics research has been done on any of the species. The process used to ensure that genetic diversity is conserved is based on barriers and restrictions to travel and on species distributions. These barriers divide the ranges of the species into KFR and karst zones (see Section 1.3 for discussion).

Karst Fauna Areas (KFA) – For the purpose of this plan a **karst fauna area** (Service 1994) is a geographic area known to support one or more locations of an endangered species and is distinct in that it acts as a system that is separated from other KFAs by geologic and hydrologic features and/or processes that create barriers to movement of water, contaminants, and troglobitic fauna. KFAs should be far enough apart that a catastrophic event (such as contamination, quarrying, flooding, etc.) that may kill species or destroy habitat in one area would be unlikely to impact species or habitat in other areas.

Full implementation of the recovery criteria should lead to downlisting and then to delisting the species. Because karst ecosystems can not be recreated once destroyed, an adequate number of KFAs per KFR should be protected in perpetuity. Preserving KFAs involves designing preserves that include the surface and subsurface drainage basins and surface communities that the species rely on. Preserves with occupied habitat should be connected to mesocaverns to support population dynamics of troglobites (see discussion below and Appendix B). Larger preserves are more stable, require less active management and have a higher likelihood of supporting the listed species in perpetuity. Where development has precluded high quality preserves, or where effects of urbanization and exotic species are impacting preserves, management will be a critical component of recovery. Management includes:

- keeping preserves free from contamination;
- controlling RIFA infestation;
- preventing excessive human visitation;
- maintaining surface native plant and animal communities.

Monitoring population status and applying adaptive management are critical components of the recovery strategy for these species. To be considered protected, a KFA should be sufficiently large and of adequate quality to maintain the integrity of the ecosystem on which the species depend and meet the preserve guidelines in Appendix B. The KFA should also have protection and management established in perpetuity.

Quantity and Quality of KFAs - To be considered for downlisting, each species should occur in six or more protected KFAs rangewide and distributed as discussed below. This number was chosen to match The World Conservation Union (IUCN) criteria for redlist categories (IUCN 2001). It also ensures the species is not in the critical (G1) designation, which is defined by occurring in five or fewer localities. We recognize that within KFRs opportunities will vary for recovering the karst invertebrates; therefore, various distributions and qualities of KFAs in each KFR that would meet these criteria are discussed in Table 2. Overarching criteria that are reflected in each option (Table 2) (applied per species) include:

1) at least one high quality KFA per KFR;
2) at least three total KFAs per KFR;
3) a minimum of six KFAs rangewide per species

To understand Table 1, it may be helpful to also examine Table 2, which gives the actual number of KFRs that each species occurs in. For example, a species that occurs in only one KFR, such as *Texella cokendolpheri*, would need at least six KFAs with at least three being high quality and the other three at least medium quality to be considered for downlisting (see below and Appendix B for description of high, medium, and low quality).

Table 1 shows options for the minimum number and quality of high quality KFAs that need to be preserved in each KFR for a species to be considered for downlisting. The left column indicates the number of KFRs each species could occur in as presented in Table 3. The center column illustrates the configuration of the minimum number and minimum quality of KFAs within the possible total number of KFRs. The right column indicates the total number of KFAs required to be considered for downlisting.

Table 1. Quality and quantity of preserves.

# of KFRs per species	Configuration of KFAs within KFRs					Total No. of KFAs
1	KFR #1: 3 High (H) + 3 Medium (M)					6
2	KFR #1: HMM	KFR #2: HHM			Plus in either KFR: MM	8
3	KFR #1: HMM	KFR #2: HMM	KFR #3: HMM		Plus in either KFR: M	10
4	KFR #1: HMM	KFR #2: HMM	KFR #3:HMM		KFR #4: HMM	12
5	KFR #1: HMM	KFR #2: HMM	KFR #3: HMM	KFR #4: HMM	KFR #5: HMM	15

Table 2. Distribution of species in KFRs.

Species	KFR	Number of KFAs to protect
Rhadine exilis	Government Canyon	12
	UTSA	
	Helotes	
	Stone Oak	
Rhadine infernalis	Government Canyon	15
	UTSA	
	Helotes	
	Stone Oak	
	Culebra Anticline	
Batrisodes venyivi	Government Canyon	8
	Helotes	
Texella cokendolpheri	Alamo Heights	6
Neoleptoneta microps	Government Canyon	6
Cicurina baronia	Alamo Heights	6
Cicurina madla	Government Canyon	12
	UTSA	
	Helotes	
.	Stone Oak	
Cicurina venii	Culebra Anticline	6
Cicurina vespera	Government Canyon	8
	UTSA	

The quality of KFAs is defined based on probability of long-term survival of the species in that area and the amount of active management necessary to maintain those species. High quality KFAs tend to be larger and require less active management. Medium quality KFAs have some compromised characteristics of a high quality preserve, but still have potential for reasonable remediation. Low quality KFAs are impacted and have low potential for reasonable remediation. They may have some chance of long-term survival, but do not count toward meeting the minimum recovery criteria. These KFAs will not be considered toward species downlisting, but may be important study sites to document the thresholds for species survival or extinction.

Accepting any number of medium quality KFAs in place of high quality KFAs, is accepting a higher risk of extirpation of that population, and thus, a higher risk of extinction for the species. Ideally, all recovery KFAs would be high quality. However, two reasons to accept a medium quality KFA (and a higher risk of extinction) are: 1) often there are not six high quality habitat patches remaining, and 2) there is considerable uncertainty as to the exact probability of extinction at KFAs of various sizes and configurations. This uncertainty is due in part to lack of research on KFAs of intermediate sizes over the long term. It is important to base decisions about preserve size on data that demonstrate decades of success because the long-lived nature and difficulty in sampling these organisms and the current inability to detect population trends indicate there will likely be some time between an environmental cause and a detectable population effect (also see sections 2.3 and 2.4 for description of a recovery action to clarify this uncertainty). For a detailed discussion on how the recovery team defined high, medium, and low quality preserves see Appendix B.

Research Needs

In a global context, cave fauna are not well studied and these species are no exception. Generally, any given species has fewer than five peer-reviewed publications that even mention their names, and most of these species are represented in the scientific literature by only their species description. This lack of knowledge contrasts the high diversity of troglobites and high threats from habitat destruction that occur in central Texas. In a study that compared the cavernicole diversity of every single county in the 48 contiguous United States, Texas ranked among the highest for diversity locations of both troglobites and **stygobites** (aquatic troglobites) with Travis, Williamson, Bexar, Comal, and Hays counties suggested as the focus of conservation efforts due to the high diversity and concentration of taxa (Culver et al. 2000). This same study found that over 50 percent of troglobites occurred in less than 1 percent of the land area, stressing the importance of high diversity areas to the conservation of subterranean species.

Several research priorities detailed in section 2.4 may yield results that may change management recommendations or may prompt revision of downlisting and delisting criteria. The research objectives detailed below will fill large gaps in our knowledge of these species and create a more efficient recovery process.

2.2 Goals, Objectives, and Criteria

Goal - The goal of this recovery plan is to reduce or remove threats to the species such that their long-term survival is secured; the species are no longer endangered or threatened and can be delisted.

Objective – Preserve a sufficient number of KFAs that span the range, and therefore most likely span the genetic diversity of the species. This number of KFAs should also provide an adequate number of locations to ensure the species survival in the event of a catastrophic or other unforeseen disturbance to one of the sites. When preserved, these sites should ensure a high probability of the survival of the species in perpetuity.

(1) Criterion (downlisting) – The location and configuration of at least the minimum number of KFAs in each KFR (Table 1) is delineated, preserves are established that fully include the KFAs, and commitments are in place for perpetual protection and management of these KFAs.

(2) Criterion (delisting) – In addition to the downlisting criterion, research on population trends, population viability, habitat quality, and potential threats have been completed over the course of at least 25 years to conclude with a high degree of certainty that preserve size, configuration, and management are adequate to provide a high probability of the species survival at each site. Twenty-five years was chosen as a rough estimate of the time needed to test whether the preserve characteristics outlined in this document are effective for supporting these species in the long term. Future research may show that different monitoring protocol may require a different amount of time to detect population changes in these poorly understood and long-lived species.

The recovery criteria above are based on addressing threats (see Section 1.5) to karst invertebrates. Cumulatively, they address the five listing factors (A-E) identified in Section 4(a)(1) of the Act that were considered when these species were listed. The preserves called for in the first recovery criterion address threats of habitat loss and degradation associated with encroaching urbanization (Factor A), overutilization of cave habitats due to human visitation (Factor B), and inadequacies of protective regulations pertaining to these nine arthropod species and their specialized habitats (Factor D). Preserves will need to be designed, established, and managed in such a way that the species' long-term survival is no longer threatened.

The activities called for in the second criterion will help confirm the adequacy of the preserves in addressing the threats. Maintaining viable populations for each karst species as well as a high level of habitat quality at the established preserves for a minimum of 25 years will demonstrate that the threats of habitat loss and degradation (Factor A), habitat overutilization by human recreation (Factor B), predation from invasive ants (Factor C), lack of regulatory protection (Factor D), and demographic stochasticity along with impediments to genetic exchange(Factor E) have been managed and reduced to merit delisting of some of all the species. Appendix B Preserve Design and Appendix C

Management, Maintenance and Monitoring include guidance, based on best available science at this time, on how to design and manage preserves to address the threats. The Plan calls for an adaptive management approach to revise management, if necessary, to meet the recovery goals.

2.3 Recovery Program Outline

The actions needed to implement the recovery strategy for these species and meet recovery criteria are organized below into: (1) habitat (protection, management, and monitoring), (2) species monitoring and research, (3) public outreach and education, and (4) post-delisting monitoring. Habitat management and species monitoring and research will generate information that assists with management of the species and assessment of the recovery program success. Monitoring the implementation of habitat management should ensure that management tools are appropriately and effectively addressing impacts and threats to the species. If the tools are not effective, then changes in management should be made and additional planning and scientific research may be necessary. This section provides an outline of the recovery program. The Narrative of Recovery Actions (Section 2.4) discusses the outline in more detail. The listing factor(s) (see page 1.1-1) to be addressed by the recovery actions listed below are identified in parenthesis after each action. As discussed in Section 1.1, implementation of this recovery plan is dependent on the voluntary participation and cooperation and commitment of numerous conservation partners.

Outline of Recovery Actions

1.0 Habitat Protection, Management, and Monitoring

- 1.1 Delineate conservation areas needed to meet recovery criteria
  - 1.1.1 Review critical habitat units for eligibility as KFAs, and refine boundaries for the KFA (not critical habitat) as necessary to include the appropriate quantity and quality of habitat to meet recovery criteria (A)
  - 1.1.2 Develop a plan to protect non-cave/karst areas (mesocaverns) in between caves or KFAs (A, D)
  - 1.1.3 Determine vegetation community size and composition needed to support karst invertebrates (A)
- 1.2 Protect conservation areas needed to meet recovery criteria
  - 1.2.1 Purchase or otherwise implement measures to protect KFAs in perpetuity (A, D)
  - 1.2.2 Secure resources for long-term management (A)
  - 1.2.3 Implement plan for protecting mesocaverns to connect habitat (A, D)

2.0 Species monitoring and research

- 2.1 Distribution information (A)
  - 2.1.1 Perform a new analysis of endemicity to refine the KFR boundaries (A, E)
  - 2.1.2 Conduct additional karst and biospeleological surveys (A, E)
- 2.2 Examine population genetics and habitat connectivity for listed species (A, C, E)
- 2.3 Determine the use of mesocaverns and habitat connectivity (A, C, E)
- 2.4 Population dynamics and habitat requirements to sustain viable populations
  - 2.4.1 Determine what natural factors affect populations (A, E)
  - 2.4.2 Determine what anthropogenic factors affect populations (A, B, C, D, E)
  - 2.4.3 Assess the detectability of the listed karst invertebrates (A, D, E)
  - 2.4.4 Determine appropriate interval for monitoring (A, D, E)
  - 2.4.5 Develop marking techniques for mark/recapture research (A, E)
  - 2.4.6 Conduct population viability analyses for listed karst invertebrates (A, E)
  - 2.4.7 Design and implement a study to determine the appropriate size and quality of a KFA (A, C, D, E)
- 2.5 Biology and ecology of karst invertebrates (A, C)
  - 2.5.1 Life history research (A, C)
  - 2.5.2 Research the ecology of the species (A, C)
- 2.6 Hydrogeologic research (A, D)
- 2.7 Research the interaction of surface plant and animal communities with the subsurface (A, C, D, E)

3.0 Public outreach and education

3.1 Educate the public about the listed invertebrates and their habitat (A, B)

3.2 Provide instruction and information to private landowners (A, B, C, D)

3.3 Provide educational opportunities for professionals regarding karst ecosystems and listed species (A, C)

4.0 Develop a post-delisting monitoring plan (A, B, C, D, E)

2.4 Narrative of Recovery Actions

Underlined recovery actions represent the most stepped-down levels of the Recovery Program Outline and Narrative. These items are discrete, specific actions and are listed in the Implementation Schedule with associated time and cost estimates and potential partners or responsible parties.

1.0 Habitat Protection, Management, and Monitoring

1.1 Delineate conservation areas needed to meet recovery criteria

This document provides a framework for delineating the number of KFAs (Table 1 and Section 2.1) and the characteristics of cave preserves (Section 2.1 and Appendix B) needed to meet recovery criteria. However, the exact on-the-ground boundaries of these conservation areas need to be delineated.

1.1.1 Review critical habitat units for eligibility as KFAs, and refine boundaries for the KFA (not critical habitat) as necessary to include the appropriate quantity and quality of habitat to meet recovery criteria (A)

The critical habitat units already defined may be appropriate KFAs and are an excellent starting point for this process. These sites should be reviewed to determine whether they could qualify as high, medium, or low quality preserves, and whether they qualify as independent KFAs according to their proximity to each other and threats; and therefore, their likelihood of being impacted by a single catastrophic event. Tables 2 and 3 outline how many KFAs are needed for each species. The proper number, configuration, and quality of KFAs need to be delineated according to the characteristics provided in Section 2.1 and Appendix B. These areas may extend beyond the critical habitat units.

1.1.2 Develop a plan to protect karst areas (mesocaverns) in between caves or KFAs (A, D)

It is generally understood in the conservation community that single locality approaches to conservation are less valuable without a landscape based conservation vision. To this end, a plan should be developed that will conserve karst habitat between known endangered species localities and preserved KFAs. These intervening areas can serve as corridors for trogloxenes, habitat for wide ranging species that may be important for the cave system (e.g. cave crickets, raccoons, or bats not living in caves with endangered species), sources of genetic diversity for maintaining native flora and fauna in the KFAs, protection for mesocaverns that may support listed species or be corridors for migration, and buffers for overall water quality and quantity entering the subsurface. There are many possible approaches, including limits on percentage of impervious cover for new development (particularly in karst zones 1 and 2), purchase of additional karst landscape, or other landscape level solutions.

1.1.3 Determine vegetation community size and composition needed to support karst invertebrates

Species specific research is needed to determine the importance of grassland and woodland communities and their importance to conserving karst invertebrates.

1.2 Protect conservation areas needed to meet recovery criteria

To consider species for downlisting, the KFAs need to be protected in perpetuity.

1.2.1 Purchase, or otherwise implement measures to protect these KFAs in perpetuity (A, D)

These properties could be acquired and protected in perpetuity by non-profit conservation groups or by governmental or private agencies. It is also possible to set aside KFAs as conservation easements on private property. Regardless of the owner, property use should restrict any activity that would threaten the species or their habitat, as outlined in the recovery strategy section.

1.2.2 Secure resources for long-term management (A)

KFAs require management, particularly those isolated from external patches of natural habitat. Management activities include invasive species control, restricting human visitation, and performing species monitoring that provides feedback on the efficacy of management techniques. Additionally, the management guidelines in Appendix C may be found to be inadequate or outdated in the future, therefore funding should be in place for adaptive management.

RIFA are typically the most laborious management task. Larger preserves with native flora and fauna may be less susceptible to RIFA. See Appendix C on preserve management and maintenance for detailed methodology.

Human visitation can directly or indirectly harm karst invertebrates through alteration of their habitat. Funding should be in place for fencing and a cave gate, if needed, to deter human visitation. Details on fencing and cave gating are in Appendix C.

As determined by monitoring activities and new research on karst invertebrate habitat, other management of the native flora and fauna may include but is not limited to: planting native flora, remediation after a contamination event, etc.

Monitoring should involve counting all cave species, measuring habitat parameters, and assessing threats (including toxins) (see Appendix C and the Service 10(a)(1)A) Scientific Permit requirements 2006).

1.2.3 Implement plan for protecting mesocaverns to connect habitat (A, D)

The plan developed in item 1.1.2, should be implemented. Many partners will be needed for this task.

2.0 Species monitoring and research

Many aspects of karst ecosystems in central Texas are poorly understood, particularly those relating to long-term survival of isolated KFAs. Ongoing research is essential to increasing our confidence in estimations of probability of survival in these KFAs. The research needs below are listed in no particular order, but some projects naturally follow others because the results of one will affect the design of another.

2.1 Distribution information (A)

As properties are available for survey, quantified biospeleological inventories should be performed to increase our understanding of species distribution. Due to the cryptic nature of karst invertebrates, additional surveys should be performed at previously surveyed caves, because it is possible to visit a site several times before discovering a listed species. As they are discovered, location and habitat information should be integrated into a central repository in order to keep management priorities and the species known ranges up to date. Collection and observation data for each of the sites should be assembled, as is partially completed in Appendix E of this document. This would include dates, observers, and collection or observation data including where in the cave and when each individual was seen. For all collections, a list of museum accession numbers is needed to verify the species presence at particular sites. Sites should be visited on a regular basis to assess their health and potential future function for recovery.

2.1.1 Perform a new analysis of endemicity to refine the KFR boundaries (A, E)

To converge on the most accurate KFR boundaries possible, and the most responsible mitigation strategies, a new endemicity analysis of the listed karst invertebrates needs to be performed. This analysis should be performed following methods in Veni (1994) or by using other similar clustering techniques. The results of this project should address uncertainties about KFRs discussed in section 2.1.

2.1.2 Conduct additional karst and biospeleological surveys (A, E)

Efforts should be made to find additional localities of listed karst invertebrates. This will help identify areas that may serve as karst fauna areas and will help determine which areas are most important for recovery.

2.2 Examine population genetics and habitat connectivity for listed species (A, C, E)

A major component of recovery centers on maintaining adequate representation of the species to provide for long-term species viability and adaptability. Genetic diversity should be part of that consideration for each species. Presently, little is known about variation among and within populations. One of the largest concerns, that has not been addressed, is the level of connectivity or migration between sites. For example, if a catastrophic event extirpates a population from one cave, will individuals from nearby caves eventually re-colonize the impacted cave if remediated? What are the migration patterns and geological barriers that would dictate this re-colonization? Individual, population, and species level genetic data would help define conservation units and answer questions such as how much do karst invertebrates use mesocavern habitats between known caves and how much area is needed to support a viable population of these species? Answers to these questions may indicate whether more effort should be put toward preserving those intervening habitats. These data will also be important when performing a population viability analysis.

2.3 Determine the use of mesocaverns and habitat connectivity (A, C, E)

As mentioned in section 2.2, mesocaverns may be important corridors connecting KFAs, or may even be significant population centers. Efforts should be made to assess populations in these spaces via drilled boreholes, investigation of voids encountered during construction excavations, and population genetics. An agreement to allow sampling of voids encountered during construction should be created to allow for data collection on mesocaverns. A set of guidelines should be established with multiple partners, such as TCEQ, City of San Antonio (COSA), or other site inspection entities, so that a construction site can be sampled for karst invertebrates by qualified personnel. Analysis of these data could help determine mesocavern use.

2.4 Population dynamics and habitat requirements to sustain viable populations

While basic monitoring of cave species, habitat parameters, and toxins should be undertaken as part of the long-term management for KFAs, additional research aimed at determining what factors impact population trends, how best to monitor them, and what the population viability is should be performed. The results from these studies should be used to adjust the basic monitoring and management of cave species, habitat, and toxins (and other threats) discussed in item 1.2.2.

2.4.1 Determine what natural factors affect populations (A, E)

Natural factors that may affect populations include but are not limited to the physical characteristics of the cave, season and weather, microhabitat, nutrient quantity and quality, characteristics of the natural surface habitat (vegetation, epigean fauna, etc.), and proximity to source populations. Each of these factors may warrant an independent study or detailed analysis. A large dataset will likely be necessary to tease apart these factors and test how they affect cave communities and endangered species. These data will be invaluable for refining population monitoring methods, recommending ideal time of year and condition for presence/absence surveys, and designing karst preserves.

2.4.2 Determine what anthropogenic factors affect populations (A, B, C, D, E)

Anthropogenic factors that may affect populations include such things as surface habitat fragmentation, non-native flora and fauna, changes in water quantity and quality that enters the cave, adding a cave gate, substrate trampling inside the cave, and others. Effects from potential impacts need to be measured and analyzed in a different way (to compare results) and may warrant independent study. Research on habitat fragmentation will increase understanding on how much fragmentation is tolerable within a properly designed karst preserve, or among karst preserves that may rely on one another as source populations. Studying how varying levels of non-native flora and fauna affect cave populations will help guide karst preserve design and management. For example, some invasive plants and animals may be more important to control than others, particularly in smaller KFAs that are more impacted and may need more management. Determining the invasive species that should be controlled and how will be important especially for small KFAs. Research on changes in water quantity and quality can indicate how these changes may be mitigated or avoided. For example, if part of a cave drainage basin will be crossed by a highway, should the drainage from that highway be routed elsewhere to prevent contamination, or is water quantity an equally or more important factor for the species? If so, should the drainage be maintained at the risk of contamination? Cave gating is commonly used to limit human visitation in caves, and while the effect of gates has been examined for bats, there is no research to examine the effect they have on invertebrates or the characteristics cave gates should have for invertebrate conservation. Due to this lack of research, caves should be gated only after other management (e.g., fencing) has been unsuccessful at limiting human visitation.

Human visitation can cause impacts including soil compaction (e.g. compacting loose soil, rocks with spaces underneath) and may have other impacts that are difficult to measure (e.g., light, heat, or noise disturbing normal behavior). A study is needed to specifically answer the question about how much impact is acceptable for the variety of substrates and conditions in central Texas caves. The results of this study may indicate the species tolerance to human visitation.

2.4.3 Assess the detectability of the endangered karst invertebrates (A, D, E)

To determine how reliable or meaningful population monitoring results are, it is important to determine the species detectability. Some taxa may be much more readily detected while others are more cryptic and therefore should be monitored in a different way. Also, factors that affect populations (discussed in 2.4.1) may influence detection and should be considered for each taxa. These results can be applied to future recommendations for appropriate sampling conditions.

2.4.4 Determine appropriate interval for monitoring (A, D, E)

Population monitoring intervals need to be determined (in part by 2.4.3) and may be based on aspects of the species biology, such as longevity and **fecundity**, and also to aspects of physiology, such as response time to introduction of toxins or loss of energy flow. The ideal monitoring interval is frequent enough to detect population trends before they are catastrophic, but sparse enough to minimize the impact of researcher visitation due to substrate trampling or other effects. As mentioned in 2.4.2, different caves may have different tolerances for visitation because of their size or air flow and different species may have different characteristics that call for custom monitoring intervals.

2.4.5 Develop marking techniques to conduct mark/recapture research (A, E)

Mark and recapture techniques are not commonly used with invertebrate species, but have been employed for some cave species (Knapp and Fong 1999, Taylor et al. 2005). These techniques may be useful for cave species because of their longevity, infrequent molting, and the stable climate of a cave. Mark and recapture data can be used to estimate population size and migration, and may be helpful for performing a population viability analysis. In addition to studies of the listed species (or congeners), further mark recapture studies of cave cricket population dynamics are needed to determine habitat and area requirements to maintain viable populations of this food source.

2.4.6 Conduct population viability analyses for listed karst invertebrates (A, E)

Information collected during implementation of other actions (e.g., 2.3, 2.4.5, and 2.5) should be used to conduct species specific population viability analyses. These analyses will provide extinction probabilities considering the state of conservation lands and help direct future recovery actions.

2.4.7 Design and implement a study to determine the appropriate size and quality of a KFA (A, C, D, E)

Using data from 2.4.1 and 2.4.2, design a study to help determine the necessary characteristics (including size (acreage), setbacks, and other factors discussed in Section 2.1 and Appendix B) of a KFA that will provide perpetual protection for the karst invertebrates.

2.5 Biology and ecology of listed karst invertebrates (A, C)

Since the species descriptions, some research has been conducted on *Cicurina* species and cave crickets, but more information is needed on the biology of karst invertebrates. The two items below are a starting point for understanding characteristics of these species that are relevant to management decisions.

2.5.1 Life history research (A, C)

More information is needed on the life history of these species to make better informed management decisions. Research on the following life history aspects is needed: longevity, fecundity, reproductive cues (e.g., flooding, nutrient pattern changes, weather or season), mating, egg-laying (e.g., substrate type), factors influencing hatchling success (e.g., predation, nutrient needs), and others. These data will also be useful for conducting a population viability analysis.

2.5.2 Research the ecology of the species (A, C)

Many aspects of the ecology of these taxa are lacking that are relevant to making educated management decisions, including evaluating the health of a cave community that is being considered for a high quality KFA. Examples of ecological data of interest are species ratios, species assemblages, prey and predators (including the variation for different life stages), and indicator species (for healthy/diverse communities and impacted communities). These data will be useful for conducting a population viability analysis, as well.

2.6 Hydrogeologic research (A, D)

Information on the evolution of caves in specific KFAs and their surface and subsurface drainage basins is important for preserving these sites.

2.7 Research the interaction of surface plant and animal communities with the subsurface (A, C, D, E)

Research is needed to assess the interaction of the surface plant and animal communities with subsurface ecosystems. For example, does surface plant diversity affect cave cricket foraging and if so does it result in less nutrient input into a cave? This research should guide land management efforts and help ensure more beneficial karst ecosystem management. It will also help determine if preserve size and configuration guidelines need revision or are adequate.

3.0 Public outreach and education

Successful recovery involves an outreach program that solicits and encourages support from the public.

3.1 Educate the public about endangered karst invertebrates and their habitat (A, B)

Long-term survival of listed species depends on an educated and concerned public; therefore it is important to develop programs to educate all ages of people about karst biology, geology, and ecology. These programs should disseminate information on creatures of the karst ecosystem and how they interact with each other and the surface, their relationship to the aquifer, and the threats to karst ecosystems. They should also detail how people can contribute to conservation efforts.

This can be accomplished via websites, brochures, signs (e.g., at parks and preserves), workshops, classes, videos, and other avenues of public outreach. The San Antonio Virtual Nature Center (sponsored by the Bexar Audubon Society) or other similar websites may be useful venues for spreading information online and classes on karst ecosystems may be incorporated into existing natural history courses such as the Texas Master Naturalist Program.

Educational programs exist in other areas and may be used as models for outreach in Bexar County. The Sheffield Education Center in Zilker Park, Austin, home of "Splash into the Edwards Aquifer" exhibit, hosts a cave education day for first through third graders called "Deep Down Underground." This involves an artificial cave, information sessions, and aquaria that give children an opportunity to view karst organisms. The Village of Western Oaks Karst Preserve in south Austin has an open house that gives local residents an opportunity to visit and learn about karst conservation in their neighborhood. The City of Austin takes students into Wildflower Cave in south Austin on a weekly basis as part of the City's Earth Camp Program. Preserve managers should partner with local caving clubs, government agencies, conservation organizations, schools, and landowners to provide similar, on-the-ground opportunities to teach people about karst ecosystems in Bexar County.

Impacts of human visitation are always a concern in caves, and caution should be taken when any event allows visitors into caves or onto karst preserves.

3.2 Provide instruction and information to private landowners (A, B, C, D)

Develop programs and materials for private landowners in karst areas. These materials should contain much of the general information from 3.1, with an emphasis on landowners and specific management activities they can implement on their property. Management guidelines should include information on how to identify a karst feature, avoidance of insecticides and pollutants, and the importance of native surface communities. Also, educate landowners on the Act and their rights and responsibilities under it to encourage responsible stewardship. This task can be accomplished through informational websites, classes, brochures, workshops, and other forms of outreach. Landowners should be instructed on where they can obtain additional information and ask questions relating to karst ecosystems.

3.3 Provide educational opportunities for professionals regarding karst ecosystems and listed species (A, C)

Develop educational programs for preserve managers, biology and geology teachers, consultants, and other professionals. Materials and efforts should be designed to expand knowledge of karst ecosystems. Teachers can incorporate karst education into existing programs by creating new curricula that encompasses aspects of the species biology, range, habitat requirements, and threats. Applied techniques should be taught to professionals including species identification, survey methodology, and preserve design; these techniques should be covered using field visits whenever possible. Organizations such as universities, government agencies, the Texas Speleological Survey, and the Texas Cave Management Association may be of assistance with these efforts.

4.0 Develop a post-delisting monitoring plan (A, B, C, D, E)

Section 4(g)(1) of the Act requires that the Service monitor the status of all recovered species for at least five years following delisting. In keeping with this mandate, a post-delisting monitoring plan should be developed by the Service in cooperation with TPWD, Federal agencies, academic institutions, and other appropriate entities. This plan should outline indicators that will be used to assess the status of the delisted species (considering population numbers and threat monitoring), develop monitoring protocols for those indicators, and evaluate factors that may trigger consideration for relisting. Tasks under 2.4 may be helpful in designing this plan and it should be developed in advance of delisting to provide for baseline monitoring.

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4.0 IMPLEMENTATION SCHEDULE

The Implementation Schedule follows the outline in Section 2.3 and estimates costs for implementing this recovery plan. It is a guide for meeting the objectives discussed in the recovery section (Section 2.2). This schedule indicates action priorities, action numbers, action descriptions, action duration, potential partners, and estimated costs. When these actions are complete they should accomplish the objectives of this plan. The Service has identified agencies and other potential partners to help implement the recovery of these species. This plan does not commit any partners to actually carry out a particular recovery action or expend funds. Likewise, this schedule does not preclude or limit other agencies or parties from participating in the recovery program.

The estimated cost of recovery, according to each priority, is provided below. The Implementation Schedule contains the estimated monetary needs for all parties involved in recovery for the first 10 years only. Estimated funds for agencies include only project specific contracts, staff, or operations costs in excess of base budgets. They do not include budgeted amounts that support ongoing agency staff responsibilities.

The term “continuous” is used to denote actions that are expected to require constant attention throughout the recovery process and have an indefinite duration.

Priorities in column one of the following Implementation Schedule are assigned using the following guidelines:

Priority 1(a) - An action that must be taken to prevent extinction or to prevent the species from declining irreversibly in the foreseeable future.

Priority 1(b) - An action that by itself will not prevent extinction, but is needed to carry out a Priority 1(a) action.

Priority 2 - An action necessary to prevent a significant decline in species population/habitat quality, or some other significant negative impact short of extinction.

Priority 3 - All other actions necessary to meet the recovery objectives.

Actions and action numbers are taken from the Recovery Action Outline and Recovery Action Narrative (Sections 2.3 and 2.4). The terms and acronyms used for the potential partners for implementation are listed on p. *x* of the recovery plan:

Table 3. Implementation Schedule for the Nine Bexar County Karst Invertebrates Recovery Plan												
(Species: *Rhadine exilis, R. infernalis, Batrisodes venyivi, Texella cokendolpheri, Neoleptoneta microps, Cicurina baronia, C. madla, C. venii, and C. vespera*)												
								Cost Estimate by FY (by $1,000s)				
Priority Number	Action Number	Action Description	Species Benefiting (if multi-species plan)	Action Duration (Years)	Responsible Parties	Is FWS Lead?	Total Cost ($1,000s)	FY 1-2	FY 3-4	FY 5-6	FY 7-8	FY 9-10
1(a)	1.1.1	Review critical habitat units for eligibility as KFAs, and refine boundaries for the KFA (not critical habitat) as necessary to include the appropriate quantity and quality of habitat to meet recovery criteria	all	2	Service and others	yes	20	15	5	0	0	0
1(b)	1.1.2	Develop a plan to protect non-cave/karst areas (mesocaverns) in between caves or KFAs	all	2	COSA, TCMA, TNC, TPL, TCEQ, Service	no	7	5	2	0	0	0
1(a)	1.1.3	Determine vegetation community size and composition needed to support karst invertebrates	all	2	Universities	no	6	6	0	0	0	0

1(a)	1.2.1	Purchase, or otherwise implement measures to protect these KFAs in perpetuity	all	10	BCo, BLT, COSA, MCo, TxDOT, TCMA, TNC, TPL, TPWD, Service, UTSA	no	134,700	26,940	26,940	26,940	26,940	26,940
1(a)	1.2.2	Secure resources for long-term management	all	continuous	BCo, COSA, DOD, MCo, TCMA, TPWD, Service	no	750	0	0	250	250	250
1(b)	1.2.3	Implement plan for protecting mesocaverns to connect habitat	all	10	BCo, COSA, DOD, MCo, TCMA, TNC, TPL, TPWD, Service, UTSA	no	25	10	5	5	5	5
1(b)	2.1.1	Perform a new analysis of endemicity to refine the KFR boundaries	all	10	DOD, TPWD, TSS, UTSA, Service	no	25	5	5	5	5	5
1(b)	2.1.2	Conduct additional karst and biospeleological surveys	all	10	COSA, DOD, TPWD, TSS, UTSA, Service	no	25	5	5	5	5	5
1(b)	2.2	Examine population genetics and habitat connectivity for listed species	all	6	DOD, TPWD, UTSA, Service	no	150	50	50	50	0	0

1(b)	2.3	Determine the use of mesocaverns and habitat connectivity	all	continuous	BCo, COSA, MCo, TCEQ, Service, USGS	no	60	0	15	15	15	15
1(b)	2.4.1	Determine what natural factors affect populations	all	10	DOD, TPWD, UTSA, Service	no	100	20	20	20	20	20
1(b)	2.4.2	Determine what anthropogenic factors affect populations	all	10	DOD, TPWD, UTSA, Service	no	100	20	20	20	20	20
1(b)	2.4.3	Assess the detectability of listed karst invertebrates	all	2	DOD, TPWD, UTSA, Service	no	40	40	0	0	0	0
1(b)	2.4.4	Determine appropriate interval for monitoring	all	5	DOD, TPWD, Service	no	60	30	20	10	0	0
1(b)	2.4.5	Develop marking techniques for mark/recapture research	all	3	DOD, TPWD, Service	no	30	20	10	0	0	0
1(b)	2.4.6	Conduct population viability analyses for listed karst invertebrates	all	5	DOD, TPWD, UTSA, Service	no	60	0	0	30	20	10

1(b)	2.4.7	Design and implement a study to determine the appropriate size and quality of a KFA	all	5	DOD, TPWD, UTSA, Service	no	25	5	5	5	5	5
1(b)	2.5.1	Life history research	all	10	DOD, TPWD, UTSA, Service	no	60	20	10	10	10	10
1(b)	2.5.2	Research the ecology of these species	all	10	DOD, TPWD, UTSA, Service	no	60	20	10	10	10	10
1(b)	2.6	Hydrological research	all	2	DOD, EAA, SWRI, TCEQ, USGS	no	60	40	20	0	0	0
1(b)	2.7	Research the interaction of surface plant and animal communities with the subsurface	all	5	TPWD	no	50	0	0	10	20	20
2	3.1	Educate the public about endangered karst invertebrates and their habitat	all	continuous	EAA, TCMA, TPWD, USGS, Service	no	25	5	5	5	5	5
2	3.2	Provide instruction and information to private landowners	all	continuous	EAA, TCMA, TPWD, Service	no	10	2	2	2	2	2

2	3.3	Provide educational opportunities for professionals regarding karst ecosystems and listed species	all	continuous	EAA, TCMA, TPWD, WKU	no	50	10	10	10	10	10
3	4.0	Develop a post-delisting monitoring plan	all	1	Service, TPWD	yes	10	10	0	0	0	0

APPENDICES

Appendix A – Glossary

biospeloeology The study of subterranean living organisms, particularly in caves, karst or groundwater.
cave A naturally occurring, humanly enterable cavity in the earth, at least 5m in length and/or depth, in which no dimension of the entrance exceeds the length or depth of the cavity. This definition is from the Texas Speleological Survey and is commonly used in central Texas to distinguish caves from other types of karst features or man-made openings.
cavernicole An animal that normally lives in caves for all or part of its life cycle.
community An interacting population of various species in a common location.
congener Belonging to the same genus.
dark zone An area of a cave typified by total darkness, stable humidity and temperature, and troglobitic organisms.
drainage basin A watershed; the area from which a stream, spring, or conduit derives its water.
endemic Peculiar to a country or district, and not native elsewhere. May be very limited in extent, e.g., to a single cave system.
epigean Pertaining to, or living on, the surface of the Earth.
eutrophication An increase in chemical nutrients; typically compounds containing nitrogen or phosphorus in an aquatic or terrestrial ecosystem. The term also means the resultant increase an ecosystem's primary productivity, i.e., excessive plant growth and decay and further impacts, including lack of oxygen and severe reductions in water quality and in fish and other animal populations.
fecundity The number of young produced by a species or individual. Derived from the word *fecund*, generally refers to the ability to reproduce. In biology and demography, fecundity is the potential reproductive capacity of an organism or population, measured by the number of gametes (eggs), seed set or asexual propagules.
fire ant Members of the ant genus *Solenopsis*. *S. invicta* is a species of ant introduced from South America that threatens native plant and animal communities. There are other native *Solenopsis* spp. in Texas.
habitat The place or environment where a plant or animal naturally or normally lives and grows.
hydrology, hydrologic The study of water and its origin and movement of water in atmosphere, surface, and subsurface.
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 A geographic locale known to support one or more locations of an endangered species that is distinct because it is separated by geologic or hydrologic features and/or processes that create barriers to the movement of water, contaminants, and troglobitic fauna.
karst fauna region A geographic area delineated 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 area. The ranges of the nine federally listed species in San Antonio fall into six regions: Stone Oak, UTSA (University of Texas at San Antonio), Helotes, Government Canyon, Culebra Anticline, and Alamo Heights.
laminar Sometimes known as streamline flow, occurs when a fluid flows in parallel layers, with no disruption between the layers.
lithology, lithologic The description or physical characteristics of a rock.
mesocavern Includes all cavities in rock that are smaller than 20 cm in diameter and larger than 0.1 cm in diameter. Not large enough to be considered as a cave in the usual sense (also see discussion in habitat requirements section of text).
microhabitat A miniature habitat within a larger one; a restricted area where environmental conditions differ from those in the surrounding area.
phreatic Cave conceived and developed by dissolution, usually below the water table, where all voids are water filled. Phreatic caves may include loops deep below the water table, particularly in dipping limestone with widely spaced bedding-related fissures. Characteristics of phreatic caves are blind dissolution pockets on walls and ceilings, branching and looping of passages, and overall switchback gradients as phreatic flow may be uphill under pressure. The most common passage form is a tube, though crosssectional shape reflects local geological factors.
population A group of individuals of the same species living and interacting in the same geographic area at the same time.
sinkhole Sites of sinking water in a karst area
species richness The simplest measure of biodiversity and is simply a count of the number of different species in a given area.
structural Of, relating to, or affecting the attitude and deformation of rock masses. Attitude is commonly measured by strike and dip; deformational features commonly include folds, joints, and faults.
stygobite An aquatic troglobite restricted to subterranean waters and having troglomorphic features.
taxa (plural) Taxonomic categories, such as species, genus, etc.
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.
troglomorphy, troglomorphic The physical characteristics of an obligate subterranean organism, including eyelessness, attenuated appendages, depigmentation, delicate exoskeleton, and greater development of some sensory structures.
troglophile A species of animal that may complete its life cycle in the subterranean environment but which may also be found in similar dark, moist environments on the surface.
trogloxene Species that spend part of their life underground (hibernation, shelter) and part on the surface (feeding, reproduction)
twilight zone An area of a cave typified by very little light and more stable humidity and temperatures than the entrance area.
vadose A cave that underwent most of its development above the water table.
vicariance The process whereby speciation occurs due to geographic isolation.

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Appendix B – Preserve Design

Introduction

Since no available research pinpoints the exact size and attributes of a medium and low quality preserve, the Karst Invertebrate Recovery Team used the Simple Multiple Attribute Ranking Technique (Yoon and Hwang 1995), a decision analysis tool to converge on approximate probabilities for survival of populations in preserves with different characteristics. This tool is designed to survey expert opinion, initiate discussion concerning criteria necessary to meet species needs, and make the decision process transparent.

First, goals for maintaining a healthy karst ecosystem were identified by the recovery team. Although, they may not address every aspect of cave community health, including a natural quantity of water flow to the cave. These 12 goals are given in no particular order below:

High humidity
Stable temperatures
High water quality of surface drainage basin
High water quality of subsurface drainage basin
Low red-imported fire ant (RIFA) predation
Healthy cave cricket population
Natural quantities of native vertebrate matter input
Natural quantities of native plant matter input
Healthy native surface arthropod community
Healthy native surface plant community
Adjacent karst features for cave cricket metapopulations[1]
Good connectivity with mesocaverns for population dynamics of troglobites

Second, the recovery team identified multiple options for preserve design, including size, location of the cave within the preserve relative to the edge of the preserve (near or within 50 meters (m) or far meaning over 100 m from an edge), and inclusion of the surface and subsurface drainage basins. They also assigned probabilities of accomplishing the stated goals for each preserve design option on a matrix of 12 goals and 18 preserve options, for a total of 216 probabilities. The preserve design options are given in Table B-1 and the mean results of each researcher and of the entire team survey are in Figure B-1.

[1] Metapopulation - A group of populations which may have gene flow, extinction and colonization.

Table B-1. Preserve design options for decision analysis.

Option number	**Preserve size**	**Inclusion of surface and groundwater drainage basin**		**Cave footprint position**	
		Not all	**All**	**Near edge (within ~50 m)**	**Far from edge (over ~100 m)**
1	0.01 to 10 acres (0.004 to 4 ha)	X		X	
2	"		X	X	
3	10 to 20 acres (4 to 8 ha)	X		X	
4	"	X			X
5	"		X	X	
6	"		X		X
7	20 to 40 acres (8 to 16 ha)	X		X	
8	"	X			X
9	"		X	X	
10	"		X		X
11	40 to 60 acres (16 to 24 ha)	X		X	
12	"	X			X
13	"		X	X	
14	"		X		X
15	60 to 90 acres (24 to 36 ha)	X		X	
16	"	X			X
17	"		X	X	
18	"		X		X

Figure B-1. Results of Recovery Team Decision Analysis

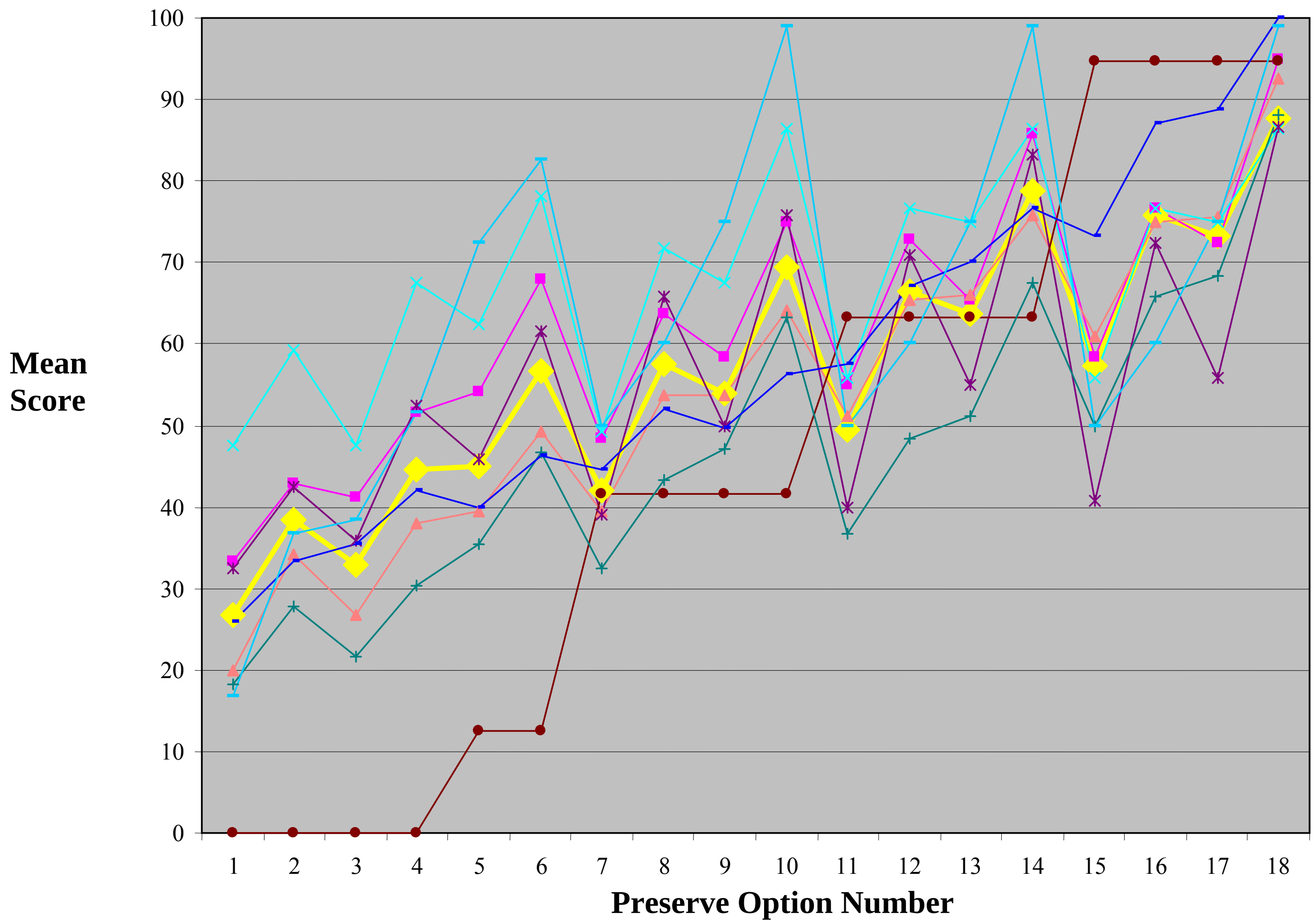

Figure B-1. Results of the recovery team decision analysis. Preserve option numbers are on the X axis and correspond to Table B-1. The mean probability for attaining all 12 goals for each preserve option, as determined by each researcher, is on the Y axis. Different lines represent different researcher responses (eight total respondents), and the yellow center line with diamonds is the mean of all the respondents mean scores.

The results of the decision analysis show an overall increase in probability of attaining goals as the preserve size increases. Peaks in the graph in Figure B-1 at option numbers 6, 10, 14, and 18 indicate that technical experts believe inclusion of the entire drainage basin of a cave as well as situating the cave footprint far from an edge may be more important than an overall large acreage.

When examined separately the graphs show that some goals have low probabilities of ever being attained. The three goals with the lowest probabilities of being attained are low RIFA predation, natural quantities of native vertebrate matter input, and good connectivity with mesocaverns for population dynamics of troglobites (Table B-2). The three goals with the highest probabilities of being attained were high humidity, stable temperatures, and high water quality of surface drainage basin. Goals with low probabilities of being attained may represent the greatest challenge for cave preserves, and therefore require the most active management when designing a preserve. However, implementing management techniques may help attain the goal of low RIFA predation, (see Appendix C for RIFA control techniques). Increased management of native vertebrates could help attain the goal of natural quantities of native vertebrate matter input. The final factor with a low probability, good connectivity with mesocaverns for population dynamics of troglobites, cannot be attained with additional management. This is one of the primary reasons that non-cave karst habitat between KFAs needs some form of protection (see discussion in this Appendix titled "Continuity of Habitat and Edge Effects"). The specific responses to these different goals are given in Table B-2.

About 80 percent was used as an acceptable probability of attaining the goals listed above (see Figure B-1). With mean group scores of 79 percent and 88 percent for options 14 and 18, respectively, a medium quality preserve could be defined as follows: 16 to 24 ha (40 to 60 ac), including the entire surface and subsurface drainage basin of the cave, and having the cave footprint situated over 100 m from the preserve edge. A high quality preserve could be defined the same way, but with a size of 24 to 36 ha (60 to 90 ac).

Table B-2. Mean of all responder probability scores. Scores are arranged by preserve option number and goal. Numbers in each cell that are not bold represent the mean value of responses from eight participants. These values represent the probability of achieving each goal (top row) given each preserve option (first column - these options are defined in Table B-1). Numbers in bold in the last column represent the average of all eight responders evaluating 12 goals, and they are the average of 96 values (12 objectives and 8 reviewers).

Preserve option number	**High humidity**	**Stable temps**	**High WQ of surface drainage basin**	**High WQ of subsurface drainage basin**	**Low RIFA predation**	**Healthy cave cricket population**	**Natural quantities of native vertebrate**	**Natural quantities of native plant matter input**	**Healthy native surface arthropod community**	**Healthy native surface plant community**	**Adjacent karst features for cave cricket metapopulation**	**Good connectivity with mesocaverns for troglobite populations**	**Mean of all means**
1	46	44	21	20	21	18	34	26	22	23	21	25	**27**
2	69	52	62	60	23	20	34	39	25	25	23	30	**38**
3	49	50	26	28	23	29	33	32	29	31	31	35	**33**
4	64	74	38	38	33	38	48	45	41	37	39	41	**45**
5	71	61	65	63	25	32	36	37	34	36	35	45	**45**
6	82	87	76	75	36	44	53	48	48	42	42	49	**57**
7	54	53	31	30	25	46	41	42	40	42	52	48	**42**
8	69	80	43	41	43	60	58	58	59	53	66	61	**58**
9	76	63	68	66	28	54	44	46	44	45	56	57	**54**
10	91	89	83	78	46	67	63	64	63	55	68	66	**69**
11	56	60	33	31	29	60	50	50	48	54	63	59	**50**
12	74	87	47	43	53	76	68	69	69	66	76	71	**66**
13	82	73	80	75	33	68	53	54	56	57	67	66	**64**
14	95	94	89	87	59	81	72	75	73	69	78	75	**79**
15	58	63	38	34	33	68	53	58	63	73	76	74	**57**
16	76	89	51	48	58	88	78	77	83	86	91	86	**76**
17	84	76	86	78	37	76	59	74	72	78	79	81	**73**
18	97	95	93	90	60	92	77	90	90	90	90	88	**88**

Preserve Design Principles

Conservative Estimates for Preserve Design - The basic strategy for designing a karst ecosystem preserve is to protect the surface and subsurface drainage basins of an occupied karst feature and adequate surface habitat to maintain native plant and animal communities around the feature. Details of the minimum area needed to protect the feature are difficult to define due to limited information on the dynamics of the species and ecosystem processes. Furthermore, population trends of all the listed invertebrates are difficult to obtain due to small sample sizes. This means that the only way to determine with certainty that a preserve is insufficient to support karst invertebrates is to document the extinction of a population by observing no specimens over the course of many years. Because it is unknown if these species can be reintroduced or migrate (except over the course of evolutionary or geologic time) into existing habitat, this is not an acceptable method. In addition, if a preserve is later found to be insufficient to support the species due to surrounding developments being either too close or too dense, the potential for preserving that land is lost (the potential for adaptive management will be gone). Because these species have relatively long life-spans and low requirements for food, a decline in population size or even the complete extinction of the population may take years or even decades. Observations of a listed species over several years on a preserve that is too small for perpetual species preservation may not reveal declines that are actually occurring. If these observations are used as evidence that a preserve size was adequate, then the potential for long-term preservation of that species may become lost due to irreversible development surrounding the preserve.

Because of the unique considerations of population viability and habitat requirements for this suite of species, the design of preserves should be based on estimates and assumptions that favor the highest probability for conservation of the species and the ecosystem upon which they depend. If further study proves our knowledge or assumptions are excessively conservative, adaptive management can still be applied.

The concept of "how much is enough" should always be answered in the context of the surrounding conditions (Harris l984). Three critical elements identified for maintaining habitat islands are the actual habitat size, the distance from similar habitat, and the degree of difference in the intervening matrix. Lord and Norton (1990) also cite ecosystem vulnerability to extrinsic disturbances. Because karst ecosystems can not be recreated once destroyed, preserves should be designed and configured conservatively and incorporate the suite of biotic and abiotic factors needed to promote the integrity of fully-functioning ecosystems. To promote long-term, sustainable conservation of the karst species and ecosystems, preserves should be designed to rely on minimal management rather than frequent human intervention to control multiple and complex threats to the system.

Size and Shape of Preserves - Based on existing literature (summarized below) on habitat patch size, fragmentation, isolation, edge effects, corridors, and other factors considered in minimizing threats to ecosystem stability, a karst preserve should ideally be at least 28 to 40 ha (69 to 99 ac), including both a core and buffer area, to protect the integrity of the plant and animal communities that support the karst ecosystem. In determining the actual size and configuration of a karst preserve, all of the factors listed below on designing cave preserves should be incorporated into the preserve design.

Protection of Water Quality and Quantity – It is imperative to protect the surface and subsurface drainage basin to adequately protect karst invertebrates. The hydrology of karst systems is more difficult to predict than that of surface water or of porous media groundwater movements. In general, land bounded by the contour interval at the cave floor is the area where contaminants moving over the surface or through the karst could move toward the cave. Outside this area, contaminants are not as likely to move into the known extent of the cave and its associated mesocaverns. A detailed and appropriate hydrogeologic investigation should be conducted to determine the surface and subsurface drainage basin of a cave, local recharge areas, and direction of groundwater movement. It is often challenging to accurately map these basins. For example, Flint Ridge Cave in Travis County was initially mapped as having a 0.75 acre drainage basin (State Department of Highways and Transportation 1989), later mapped as 39 acres (Veni 2000), and most recently found to be 54 acres in size as verified by extensive land surveying (Hauwert et al. 2005). For general information on how to determine subsurface drainage basins see Veni 2003, Veni 2004, and Veni and Associates 2002.

In addition to preserving water quality, it is important to maintain water quantity. Often, natural drainage to the cave is altered by roads, railroads, constructed channels, and other modifications. It is often possible to design solutions for maintaining or restoring natural drainage patterns if the surface drainage basin is properly delineated.

Protection of Habitat Area Needed to Sustain Viable Native Plant Communities

A minimum of 28 to 40 ha (69 to 99 ac) is likely needed to support a self-sustaining woodland-grassland mosaic community (see also Service 2003). This includes a core area of 24 to 36 ha (59 to 89 ac) and a minimum 20 m (66 ft) buffer to protect this core plant community from detrimental edge effects. These figures represent the minimum size needed for an isolated preserve. Preserves that are immediately adjacent to and share a large portion of their perimeter with another large preserve, or that are surrounded by low levels of development and native vegetation in perpetuity may be smaller. A preserve should be larger the more isolated it is from similar plant communities, or where it may become isolated in the future due to development. Long, narrow corridors that have some advantages to the vertebrate community of the preserve are not likely to be effective in maintaining the native plant community over the long term because this configuration may be more vulnerable to edge effects and this may favor exotic species invasion (Saunders et al. 1990, Kotanen et al. 1998, Saurez et al. 1998, Meiners and Steward 1999).

Information to Support Habitat Area Needed to Maintain Native Plant Communities - The surface plant community supports the karst ecosystem function both directly and indirectly (see habitat requirements in Section 1.4 in the Recovery Plan). Dead and decaying plant material can fall or be washed into caves. Root masses that penetrate into caves through soil and rock fissures may also provide direct nutrient input to shallow caves. For example, tree roots have been found to provide a major energy source in shallow lava tubes in Hawaii (Howarth 1981). A survey of 21 caves on the Edwards Plateau revealed that roots of six species reached caves, including plateau live oak (*Quercus fusiformis*), post oak (*Q. sinuata*), cedar elm (*Ulmus crassifolia*), American elm (*U. americana*), sugar hackberry (*Celtis laevigata*), and ashe juniper (*Juniperus asheii*) with ashe juniper being the most common tree. The deepest rooting tree was the live oak that was found at depths of as much as 25 m (82 ft) (Jackson et al. l999). These tree species are constituents of the oak/juniper woodland community type of the Edwards Plateau, which is a woodland-grassland mosaic type. In addition, surface vegetation provides habitat and food sources for the animal communities that contribute nutrients to the karst ecosystem (including cave crickets, small mammals, and other invertebrates and vertebrates). This direct nutrient input supports the importance of maintaining a balanced native woodland community over the karst ecosystem (including caves and mesocaverns supporting karst communities).

When plant species composition is altered due to edge effects, changes also occur in the surface animal communities (Lovejoy and Oren 1981, Harris 1984, Mader 1984, Thompson 1985, Lovejoy et al. 1986, Yahner 1988, Fajer et al. 1989, Kindvall 1992, Tscharntke 1992, Keith et al. 1993, Hanski 1995, Lindenmayer and Possingham 1995, Bowers et al. 1996, Hill et al. 1996, Kozlov 1996, Kuussaari et al. 1996, Turner 1996, Mankin and Warner 1997, Burke and Nol 1998, Didham 1998, Suarez et al. 1998, Crist and Ahern l999, Kindvall 1999). These changes are undesirable because of the potentially negative effects to species and nutrient cycling processes important in cave dynamics. To prevent these undesirable shifts in species composition and dynamics, the community area encompassed by the preserve should be large enough to support a self-sustaining native plant community and have sufficient buffer to offset edge and urbanization effects. Another effect of surface vegetation is that it acts as a buffer for the subsurface environment against drastic changes in the temperature and moisture regime and serves to filter pollutants before they enter the karst system (Veni 1988, Biological Advisory Team 1990).

Self sustaining habitat areas for both grassland and woodland should be included. It is important to note that we recommend both of these community types because the long-term effects of individual species on karst ecology are unknown; therefore, we are taking the most conservative approach to conservation of these areas. The woodland-grassland mosaic community typical of the Edwards Plateau is a patchy environment with distinct heterogeneous areas. Patchy systems require larger minimum areas for conservation than do more homogeneous environments due to the need to include the spatial pattern of all of the patch types and transition zones over the landscape to replicate natural processes (Lovejoy and Oren l981). The preserve areas needed to replicate grassland elements are estimated to be about 4 ha (10 ac) (Robertson et al. l997), and the preserve area needed to support viable isolated woodland components is 20 to 32 ha (49 to 79 ac) of core area (see Derivation of Habitat Area Needed below). In combination, an estimated preserve area of 24 to 36 ha (59 to 89 ac) is needed to capture the majority of the species composition of both community elements in viable numbers. For karst ecosystems that will be effectively isolated by current and/or future development, the habitat area should be large enough to contain a self-replicating plant community.

Derivation of Habitat Areas Needed - The figures for the woodland component were derived from applying published rules of thumb for minimum populations sizes for plant species of different life history strategies (Pavlik 1996), and then examining published species lists for the woodland-grassland community-type (Lynch 1962, 1971; Smeins et al. l976; Van Auken et al. l979, l980, l981).

A rule of thumb for a minimum viable population size is 50 reproductive individuals for a species that has very stable life history and environmental conditions (Franklin 1980). Pavlik (1996) states that long-lived, woody, self-fertile plants with high fecundity would be expected to have minimum viable population sizes in the range of 50 to 250 reproductive individuals.

Fifty reproductive individuals is a low, but reasonable, figure for one of the dominant species of the community, ashe juniper, based on reproductive profiles found in Van Auken et al. (l979, l980, l981). This figure would likely be an underestimate for other woody species present in central Texas woodlands (subdominant and understory species) because they are more sensitive to environmental instability in central Texas woodlands. Also, many of these species would not meet several of the life history criteria for the lowest minimum viable population size. Although these species may in fact require populations sizes at the higher end of Pavlik's (1996) range (that is, near 250 individuals) to be viable, a working estimate of the minimum viable population size for smaller, short-lived species with different reproductive strategies was taken to be 80 to 100 individuals. The lower number of this range was chosen for two reasons. First, there are no data available to support the higher number, and secondly, input from a botanist with expertise in the Edwards Plateau (Dr. Kathryn Kennedy, Center for Plant Conservation, pers. comm. 2002) suggested considering a minimum viable population size for individual plant species composing a typical oak/juniper woodland found in central Texas to be 80 individuals per species. This estimate is based on a habitat type that, as a whole, is fairly mature, and on knowledge that the species are relatively long-lived and reproductively successful.

We extrapolated the area needed to approach 50 and 80 reproductive individuals from recorded densities for dominant and important woody species based on analyses by Van Auken et al. (1979, 1980, 1981). This is a low estimated area because Van Auken et al. (1979, 1980, 1981) included all individuals above 2.5 cm (1 in) diameter that likely included non-reproductive individuals. We used correction factors to estimate the number of reproductive individuals from size class analyses of Van Auken et al. (1979, 1980, 1981). Where no size class analysis was available, a correction factor of 50 percent was used to derive the likely number of reproductive individuals.

In evaluating the species composition of a community, it is important to understand that community structure is more complicated than simply identifying the dominants or even subdominants of the community. Other less frequent species are also indicators of community type. They are diagnostic and integral to overall community structure and function, particularly if they are consistently present in analyses across the community type. Analysis of the published species composition literature in light of minimum viable population sizes needed showed that to encompass the community structure of the top 15 to 20 woodland species present in this community type, a core area ranging from 13 to 32 ha (33 to 79 ac) is needed for the woodland component. If a target population size of 50 mature individuals was to be achieved for these species, 20 ha (49 ac) of core area would be needed. If a target population of 80 mature individuals was to be achieved, a core area of 32 ha (79 ac) would be needed. Also, see Service (2003) for estimated area requirements for specific taxa.

If the final preserve design is substantially less than 20 ha (49 ac), erosion of habitat quality can be expected. For approximately one-third of the component species, population levels will be below the lowest estimated minimum viable population levels. These species will be subject to documented small population effects including reduced germination (Menges l995), genetic variation erosion (Bazzaz l983, Menges l995, Young l995), and reduced pollinator effectiveness (Jennersten l995, Groom l998, Bigger 1999). If additional woodland or mosaic preserve areas are established nearby, seed dispersal of some species may occur by bird and mammal activity and may allow periodic recolonization. However, for the other understory species (and if seed dispersal sources for animal-dispersed seed are not available) periodic management intervention may need to be undertaken.

Preserving grassland areas in perpetuity presents challenges, because many grass species are predominantly wind dispersed and have relatively short maximum dispersal distances (on the order of meters). The process of expansion through rhizomes is very slow and is clonal, which affects genetic variability. Primary recruitment of new individuals in grasslands is from seedling establishment. Seed dispersal, soil texture, and suitable soil moisture profiles at critical times are important factors for grassland renewal (Coffin et al. 1993). Urbanization may impact critical soil moisture levels and the dispersal mechanisms needed for protection. Therefore, recolonization by grasses is likely to be impaired, and including sufficient area of grassland habitat to support viable populations is a priority.

Most literature on central Texas native grasslands is descriptive and not quantitative in the treatment of species composition and dispersion. No species area curves or quantitative species density tables are available for the central Texas area. A 3-ha (8-ac) tract had 123 species over time, but it also had a high species turnover (Lynch 1962, 1971). High species turnover can be indicative of a habitat area that is too small. However, pre- and post-drought conditions may also have affected this case. In a slightly more mesic grassland habitat, Robertson et al. (l997) found that a 4-ha (10 ac) site captured most of the species diversity (100 species) present in much larger patches and a 6 ha (14 ac) tract increased species representation to 140. However, they did not address population sizes or persistence in isolation. Smeins et al. (l976) recorded 157 taxa in a 16 ha (40 ac) exclosure in the grasslands of central Texas, which was a more westerly and drier location than studied by Robertson et al. (1997).

Based on this information, we estimate that 4 ha (10 ac) of total grassland area within the woodland-grassland mosaic is needed in the preserves. This figure was derived by adding a 0.8-ha (2-ac) margin to the 3-ha (8-ac) tract (see previous paragraph) with typical species diversity from the Lynch (1962, 1971) studies to provide additional area that would aid community stability if the high species turnover there was not due to regional drought influences alone. This area is similar to areas reported in general grassland literature.

Summary - For a preserve design that encompasses the grassland and woodland components of the central Texas woodland-grassland mosaic, a grassland area and a woodland area are needed. Two scenarios were examined, one using a target of 50 individuals per woodland species for minimum viable population size, and one using 80 individuals per woodland species to achieve a viable population size.

Using the lowest minimum viable population size of 50 individuals of each constituent woodland species, we estimate that a minimum of 4 ha (10 ac) of grassland area in mosaic openings and 20 ha (49 ac) of woodland habitat is needed for a total core preserve area of 24 ha (59 ac).

Using a minimum viable population size of 80 individuals of each constituent woodland species, we estimate that a minimum of 4 ha (10 ac) of grassland area in mosaic openings and 32 ha (79 ac) of woodland habitat is needed for a total core preserve area of 36 ha (89 ac).

In addition to these core areas, a buffer of at least 20 m (66 ft) was determined to be reasonable (see discussion in edge effects section, below) and this adds another 10 acres to the overall size. Thus, the total acreage range, including woodland, grassland, and buffer is 30 to 40 ha (69 to 99 ac).

Protection of Habitat Area Needed to Sustain Viable Native Animal Communities

Cave Crickets - The native animal community important for sustaining karst ecosystems includes cave crickets and surface invertebrates and vertebrates (see Section 1.4 in the Recovery Plan). The foraging area of cave crickets and a protective buffer should be encompassed in the boundaries of the preserve. Foraging area has been measured using several different methods. Earlier studies by Elliott (1994a) tracked individuals to 50 to 60 m (164 to 197 ft). A recent study using fluorescent paint and marking thousands of individuals found crickets moving up to 105 m (345 ft) from the cave they emerged from with relatively even densities out to 80 m (262 ft) (Taylor et al. 2005). The minimum area to protect for cave crickets is the observed distance they have traveled (105 m or 345 ft). This area is likely underestimating the area needed to maintain metapopulations of cave crickets. Also, the decision analysis did favor cave entrances located far from preserve edges (> 100 m, or 330 ft) (see "Selecting Areas for Preservation," in Section 2.1 of the Recovery Plan).

In addition to considering the foraging area for crickets at the target cave in a preserve design, there is evidence that cave cricket populations may have a metapopulation or source-sink population structure. Therefore, it may be important to include multiple karst features that support cave crickets in a preserve. More is known about the population structure of species of cave crickets found in the eastern United States and in Europe than of those in Texas. Allegrucci et al. (1997) found that a species of cave cricket (*Dolichopoda schiavazzii*) endemic to Tuscany, Italy had a metapopulation structure. Using genetics, they found that populations of cave crickets from two caves 20 km (12 mi) apart, but connected by woodlands had 54 migrants per generation and probably had an active exchange of individuals. Cockley et al. (1977) studied a cave cricket of the eastern United States, *Ceuthophilus gracilipes*. That species is limited to humid, dark, and temporally stable habitats. It is found both in caves and in the forest under logs and loose bark. Cockley et al. (1977) found limited genetic differentiation of the cave crickets in caves over a 1000 km^2 (386 mi^2) area and suggested that while any significant migration between caves could be ruled out, "the forest populations may serve as genetic bridges" between caves. Caccone and Sbordoni (1987) studied nine species of North American cave crickets in the genera *Euhadenoecus* and *Hadenoecus* from sites in eight states (North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia, Kentucky, and Alabama). Two of the species studied are forest species and do not use caves. The remaining seven species are obligate cave-dwelling species, although they do emerge at night to feed. Through genetic analysis, they found high genetic exchange among sites in areas with continuous limestone for the cave-dwelling species, but low genetic exchange among sites in areas with discontinuous limestone, indicating that dispersal on the surface through non-karst forest habitat was negligible for the cave-dwelling species. It is inconclusive whether cave-dwelling crickets migrate through the subsurface, or if there is some other aspect of the karst environment that they require for dispersal (for example, nearby refuges with cave microclimate, soil chemistry, specific vegetation). The apparent differences in dispersal rates among caves between the Caccone and Sbordoni (1987) and Allegrucci et al. (1997) studies may be due to the fact that Caccone and Sbordoni (1987) dealt with dispersal over distances of hundreds of kilometers whereas Allegrucci et al. (1997) found active dispersal over only 20 km.

Helf et al. (1995) suggested that an eastern species of cave cricket (*Hadenoecus subterraneus*) may be at risk because they cannot recover quickly after disasters that preclude or greatly diminish foraging opportunities. These cave cricket populations may show source-sink population dynamics, with some karst features acting as sources and the majority of karst features acting as sinks. However, Helf et al. (1995) recommend that even sink populations should be protected because their emigrants can revive source populations that may become locally extirpated. A recent study using radio tracking of central Texas cave crickets found that 9 percent (3/34) of tagged crickets moved over the surface from one cave to another 90 m (295 ft) away during the period they were tracked (ranging from 4 to 21 days) (Taylor et al. 2004), indicating a large amount of migration between sites. Taken together, these studies suggest that it is important to preserve habitat between karst features that contain crickets to allow for population interactions.

Terrestrial Vertebrates - Species that occasionally use caves such as raccoons (*Procyon lotor*), white throated salamander (*Plethodon albagula*), cliff frog (*Eleutherodactylus marnocki*), and various species of snakes and mice, may play an important role in the ecology of cave systems. Where these species are present in caves or where there is evidence of current or past use in caves, sufficient area to sustain use by these species should be incorporated into the preserve plan.

Mammals typically use caves for shelter from the temperature extremes and aridity of the surface environment. Many endangered species caves are frequented by mammals, though each one may have a slightly different assemblage and use pattern. Though we know of no studies delineating the exact role of mammals in central Texas cave ecology, the presence of a large amount of mammal-derived energy indicates their importance. This energy is in the form of scat, nesting materials, and dead bodies. Cave collembolan or springtails, are frequently seen feeding on the scat (and associated fungus and microorganisms) and dead bodies of mammals. Collembolans are one of the food sources for endangered cave adapted predators.

A general rule of thumb for determining habitat patch size is to use the largest home range size of the species inhabiting that patch. For karst ecosystems, the raccoon has one of the largest home ranges of the species known to frequently be a contributor to the nutrient regime. Home range sizes for this species were reported ranging from 7 to 137 ha (19 to 339 ac) in Toronto, Canada (Rosatte et al. 1991), and from 5 to 110 ha (13 to 271 ac) in Washington, D.C. (Shirer and Fitch 1970). For an isolated preserve to support individual raccoons, it would at least have to fall within that range. However, to support a viable raccoon population, a preserve should be connected to other preserves (either directly or through corridors) or be surrounded by low density development over a landscape area many times larger than these figures. For KFAs where there is no evidence that raccoons are part of the karst ecosystem, home range sizes of other important vertebrate trogloxenes should be used.

Densities of mice of the genus *Apodemus*, which are habitat generalists, tend to be lowest in large (>100 ha or 247 ac) habitat patches and highest in smaller patches (Diaz et al. 1999). A number of species of mice of the genus *Peromyscus* are known from central Texas. Some of these species have been found to travel up to 50 or 100 m (164 or 328 ft) and have home ranges of approximately 0.2 ha (0.5 ac) (Davis 1978). In low densities, mice provide a source of nutrients for karst ecosystems. However, mice have been observed preying on cave crickets and other invertebrates. It is unknown whether their presence in high densities would be detrimental to the karst ecosystem.

Terrestrial Invertebrates - Surface arthropod species may be an important component of the cave cricket diet (see habitat requirements Section 1.4 of Recovery Plan). Natural levels of the native surface arthropod fauna should be maintained, and there is evidence that overall invertebrate biomass may be lower in small habitat fragments (Burke and Nol

1998). This may result in fewer accidentals (species that do not frequently enter caves) in a cave or reduced food availability for cave crickets. Burke and Nol (1998) working in southern Ontario, Canada, found a higher biomass of leaf litter invertebrates in larger (20 ha [49 ac] core area) forest fragments than in smaller (< 20 ha core area) forest fragments (core area was defined as areas at least 100 m [328 ft] from the forest edge). Zanette et al. (2000) working in New South Wales, Australia, found that the volume of ground-dwelling invertebrates was 2.0 times greater and the biomass of ground dwelling invertebrates was 1.6 times greater in large (> 400 ha [988 ac]) versus small (55 ha [136 ac]) forest fragments. Haskell (2000), examining the effect of habitat fragmentation by roads in the southern Appalachian Mountains, found reduced soil invertebrate species richness and abundance up to 100 m (328 ft) into the forest.

Karst preserves that incorporate the area requirements for plant communities and cave-associated vertebrates will most likely also be sufficient to maintain the surface arthropod fauna. However, factors such as edge effect and fragmentation that might affect the population viability of surface arthropod species should be accounted for in the karst preserve design. This is particularly important when areas sufficient to support plant communities and cave associated vertebrates have not been included.

Continuity of Habitat and Edge Effects

All areas needed to protect water quality and quantity of the karst ecosystem and the surface plant and animal communities needed to maintain the nutrient regime, should be combined into one large preserve whenever possible. This will serve to minimize effects of habitat fragmentation and isolation, and to allow for dispersal and recolonization of fauna should they disappear from one or more local areas within the preserve. A karst preserve that is isolated will need to be much larger to sustain the plants and animals within it in comparison to one that shares a large percent of its perimeter with a large protected area. Preferably, the combined preserve will be in an approximately circular or square configuration, to minimize the amount of edge.

The more edge a habitat fragment or patch has, the larger the patch or fragment size should be to protect the core area from the deleterious edge effects (Ranny et al. 1981, Lovejoy et al. 1986, Yahner 1988, Laurance 1991, Laurance and Yensen 1991, Kelly and Rotenberry 1993, Holmes et al. 1994, Reed et al. 1996, Turner 1996, Suarez et al. 1998). Minimizing edge effects in a preserve design means keeping the edge-to-area ratio low through increasing the patch size (Holmes et al. 1994) and/or using optimal preserve shapes. Circular preserves, or ones that are connected to other preserves, are preferable (Diamond 1975, Wilcove et al. 1986, Kelly and Rotenberry 1993, Wigley and Roberts 1997, Kindvall 1999). A preserve with a circular configuration will have less edge than a preserve of equal size with any other configuration.

“Edge effects” are changes to the floral and faunal communities where different habitats meet. The length and width of the edge, as well as the contrast between the vegetational communities, all contribute to the amount of impacts (Smith 1990, Harris 1984). Some types of edge effects include increases in solar radiation, changes in soil moisture due to elevated levels of evapotranspiration, wind buffeting (Ranny et al. 1981), changes in nutrient cycling and the hydrological cycle (Saunders et al. 1990), and changes in the rate of leaf litter decomposition (Didham 1998). These edge effects alter plant communities, which in turn impact the associated animal species. Edge effects can also affect animal species directly. The changes caused by edge effects can occur rapidly. Vegetation 2 m (6.6 ft) from an edge can be visibly affected within days (Lovejoy et al. 1986).

Hard edges can act as a barrier to distribution and dispersal patterns of birds and mammals (Hansson 1998, Yahner 1988). Invertebrate species are also affected by edges. Mader et al. (1990) found that carabid beetles and lycosid spiders avoided crossing unpaved roads that were less than 3 m (9 ft) wide. Roads can also constitute a hindrance to movement in forest-inhabiting mice and other small mammals (Mader et al. 1990). Increases in predation (Andren 1995, Bowers et al. 1996, Suarez et al. 1998) and competition for food sources (Hanski 1995) and den sites (Rosatte et al. 1991) also occur in the edge of habitat fragments. Saunders et al. (1990) suggest that as little as 100 m (328 ft) of agricultural fields may be a complete barrier to dispersal for small organisms such as invertebrates and some species of birds.

Edges often allow just enough disruption for invasive or exotic species to gain a foothold where the native vegetation had previously prevented their spread (Saunders et al. 1990, Kotanen et al. 1998, Suarez et al. 1998, Meiners and Steward 1999). The invasion of RIFA, an aggressive predator and threat to the karst invertebrates (Elliott 1994b, Service 1994), is known to be aided by "any disturbance that clears a site of heavy vegetation and disrupts the native ant community" (Porter et al. 1988).

Mathematical models have been developed to estimate the amount of core area available in a designed preserve. The Core Area Model developed by Laurance and Yensen (1991) takes into consideration the length of the total preserve perimeter, the distance of the edge effect, the shape of the preserve, and the total area of the preserve. The type and extent of edge effects are dependent upon the type of edge, the type of habitat (forest vs. grasslands), and the type of species (birds vs. insects). Edge effects on various habitats and taxa vary from as little as 15 m (49 ft) to as much as 5 km (3 mi) (Laurance and Yensen 1991). The effects of edge on fauna generally exceed the effects on vegetation.

For vegetation, edge effects of 10 to15 year old clear-cuts in Douglas Fir forests extended from the margin to between 16 m and 137 m (52 to 449 ft) (Chen et al. 1992). Edge effects included decreased vegetation density, increased tree mortality rates, and increased growth rates and recruitment of dominant species (Chen et al. 1992). Stefan and Fairweather (1997) examined the suburban edge effects of an arid bushland in Australia and found most exotic plant species were concentrated within 30 m (98 ft) of the suburban edge. Older suburbs showed an increased proportion of exotic species and extirpation of some native species in adjacent bushland sites. In New Jersey woodlands, Meiners and Steward (1999) demonstrated that exotic species are typically found within 20 m (66 ft) of the edge.

A rule of thumb for the protection of a forest from a clear-cut edge is the "three tree height" rule (Harris 1984). Tree heights for the Edwards woodland association in Texas are 3 to 9 m (10 to 30 ft) (Van Auken et al. 1979). An average tree height of 6.6 m (22 ft) was used, and therefore an edge effect of approximately 20 m (66 ft) is estimated. The ''three tree height'' approach described by Harris (1984) was based on the distance that effects of storm events (''wind-throw'') from a surrounding clear-cut ''edge'' will penetrate into an old-growth forest stand. Since the effects of edge on woodland/grass land mosaic communities have not been well studied, the ''three tree height'' recommendation is considered to be the best available peer-reviewed science to protect woodland areas from edge effects (Dr. Kathryn Kennedy, Center for Plant Conservation, pers. comm. 2003). Some other studies, found that invasive species were within 16 to 137 m (52 to 449 ft) and 20 to 30 m (66 to 99 ft) from an edge; therefore, we are likely underestimating the area needed to buffer against invasive species.

For animal communities, reported edge effects are typically 50 to 100 m (164 to 328 ft) or greater (Lovejoy et al. 1986, Wilcove et al. 1986, Laurance 1991, Laurance and Yensen 1991, Kapos et al. 1993, Andren 1995, Reed et al. 1996, Burke and Nol 1998, Didham 1998, Suarez et al. 1998). In coastal southern California, Suarez et al. (1998) found that densities of another exotic ant species, the Argentine ant (*Linepithema humile*), that has a life history similar to RIFA, are highest within 100 m (328 ft) and rare or absent less than 200 m (656 ft) of an urban edge. Native ant communities tended to be more abundant in native vegetation and less abundant in areas with exotic vegetation.

<u>Avoiding Internal Roads and Habitat Fragmentation</u> - Because roads may hinder movement of several species of invertebrates and small mammals, no internal roads or other permanent habitat fragmentation should occur within the karst ecosystem. Where human access is critical, a bridge could be installed in lieu of a road, provided it does not alter a critical component of the karst ecosystem, such as the quality and quantity of water entering the subsurface. Internal clearing activities and other disturbances of soil and native vegetation should also be avoided to help minimize fire RIFA infestations. Urban runoff should be diverted away from the karst ecosystem to avoid contamination and increased RIFA activity.

<u>Preserve Non-cave Karst Areas Between Known Cave Localities</u> - One of the specified twelve goals necessary to achieve the first component of the decision analysis tool called the Simple Multiple Attribute Ranking Technique, was to maintain a good connectivity with mesocaverns for population dynamics of troglobites. The analysis (described above) found that this is one of the goals that would be most difficult to achieve within the context of site by site cave preservation. For this reason, and others, additional conservation actions are called for in karst areas between preserves.

Current development regulations in the City of San Antonio and TCEQ call for some restrictions of impervious cover and the use of Best Management Practices in the recharge zone of the Edwards Aquifer. Regulations similar to these, but extending to the entire range of the listed species, would provide some landscape scale consideration to the species that may otherwise be susceptible to problems caused by isolation.

Appropriate development guidelines should be developed and are generally described in sections 2.3 and 2.4 (recovery task 1.1.2) of the Recovery Plan.

These additional conservation actions will not only help maintain healthy mesocaverns that support and potentially supply corridors for migration of troglobites (and possibly population concentrations), but will also provide surface corridors for trogloxenes, habitat for wide ranging species that may be important for the cave system (for example, raccoons, bats, populations of cave crickets not living in caves with endangered species), sources of genetic diversity for maintaining native flora and fauna in the preserves, and buffers for overall water quality and quantity entering the subsurface.

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Appendix C – Management, Maintenance, and Monitoring Karst Preserves

Maintaining Karst Preserves

Where a karst preserve is less than the minimum needed to maintain a high probability of long-term viability and encourage passive management of the karst ecosystem, more frequent human intervention may be necessary to minimize threats. Examples may include eradicating non-native plants and animals, planting native flora, performing prescribed burns, or remediation after a chemical contamination event. Active management will likely be more frequent and intensive the smaller the preserve. It is also important to recognize that some effects of small preserve size will be difficult or impossible to mitigate with active management, and these factors will always make the inhabitants of smaller preserves have a lower probability of long-term survival. In general, active management is considered a lesser choice for preserves because of the inconsistencies of funding and execution of the maintenance protocol.

Control of the Red Imported Fire Ant (RIFA) - Control of RIFA near caves is essential as they pose a major threat to listed species. Control efforts around caves with endangered invertebrates should consist of a multi-faceted approach combined with regular monitoring to assess the success of the methods. General aspects of RIFA control include a minimization of ground disturbance that is known to promote RIFA activity (for example, vehicular traffic) and promotion of a natural landscape that is known to encourage native arthropod diversity (for example, native flora and high connectivity with other habitat patches). It is also important to ensure that personnel conducting RIFA treatment are able to identify native and non-native fire ants.

Methods to Control Red Imported Fire Ants – Adequate RIFA control involves the following (Myers et al. 2005a):

1. Mound counts - Counts of RIFA mounds should be conducted each month noting the number of mounds found within 10 m and 50 m (33 and 164 ft) of cave entrances. These inspections should consist of walking the entire site while visually scanning for mounds and marking them with wire flags, paying particular attention to likely places for colonies such as clearings, stumps, cracks in rocks, road edges, and rotting logs. The time it takes to fully search a site depends on the vegetation, season, and number of searchers. Detectability changes throughout the year, as colonies are more difficult to see in dry conditions. When temperatures are cool and rains return (in spring and fall) RIFA begin rebuilding their mounds (Vinson and Sorensen 1986) hence, they are easier to locate.

2. Mound eradication interval - Eradication with hot water drenching of all RIFA mounds within 50 m (164 ft) of a cave entrance should occur twice per year, during the spring and fall, regardless of infestation level. Infestation threshold levels for the areas within 10 m (33 ft) and 50 m (164 ft) of an entrance trigger additional control efforts when reached, and mounds are counted monthly to ensure that infestation remains below those levels. The threshold for the area within 50 m (164 ft) of an entrance is 80 mounds, and the threshold for the area within 10 m (33 ft) of an entrance is 1 mound. Whenever threshold

levels are reached, mounds should be treated within 15 days. Technicians conducting RIFA surveys as well as those conducting routine maintenance and other biological surveys should be trained to distinguish imported RIFA and their mounds from native ants and their mounds to ensure that only RIFA are treated. Efforts have shown these methods to be effective at maintaining mound density below 80 mounds in a 50 m radius for 92.6 percent (64 out of 74 total sites) of all sites (Myers et al. 2005a).

RIFA have their worst effect immediately after invasion, and over many years their effect declines (Morrison 2002). For that reason, the effort of mound eradication should be highest immediately following invasion. In a general sense, Texas is basically "invaded," however there remain specific microhabitats, particularly those under dense overstory and within large preserves, where RIFA mounds are not generally found; even though this does not mean that RIFA do not actively forage in those areas from neighboring mounds. When surface habitat near endangered species sites is cleared of vegetation or otherwise disturbed to a level that may encourage RIFA invasion, control efforts should be increased, possibly to a regimen of two or more times per month. If some time has passed since the initial invasion event, and ant diversity has increased to pre-invasion levels, RIFA control regimens can be decreased to 1 or fewer times per month.

3. Boiling water treatment - At present the only acceptable method of eradicating RIFA colonies around caves with endangered invertebrates is by drenching the mounds with boiling water. Extremely hot water kills ants on contact and is generated in the field using two methods. The first is to heat metal buckets on propane-fired burners and the second method uses a diesel-fired pressure washer. The latter method is required in roadless areas where equipment must be backpacked in. In this situation rain collection barrels are highly desirable to avoid the need to carry water to the site. Boiling water treatments are best done during early to mid-morning when the queen(s) and larvae are likely to be near the top of the mound (Vinson and Sorensen 1986). During long periods of drought or cold, the queen(s) and larvae will most likely retreat deep within the mound, making them more difficult to eradicate (Vinson and Sorensen 1986). Mounds should not be disturbed before treatment as this causes the ants to move the queen(s) and larvae to deeper locations within the mound or to a remote location. Ants that are outside of the mound may survive such treatments and attempt to re-colonize, but if the queen(s) is destroyed the reproductive capacity of the colony is neutralized.

In areas where RIFA are established, the same environmental factors that impact overall species diversity probably also impact RIFA density (Morrison and Porter 2003). Low RIFA density may be expected to accompany low native ant diversity. This highlights the fact that in areas with low RIFA density (for example, dense overstory), extra caution should be taken to protect the few native ants that may be there. Eliminating use of growth regulator bait may be appropriate in these environments.

Cave Gating and Perimeter Fencing - All preserves should include fencing to deter trespass, dumping, and other forms of vandalism. Perimeter fences may be low-security and designed to be inconspicuous or aesthetically pleasing to fit with an adjacent development. However, high-security fencing should be placed around the more sensitive features of the preserve. A large enough area around the cave entrance should be fenced so that the entrance (and gate, if applicable) is not noticeable from outside the preserve. Ideally, the entire cave footprint and drainage basin will be fenced and this should be done if there is a history of vandalism in the area. The high-security fence should be at least 2 m (6.5 ft) high and of such a design that neither adults nor children could easily climb over or crawl under the fence. However, the fence should also be designed so as not to prevent or deter small to medium-sized vertebrates that are important components of the karst ecosystem from passing through the fence. This can easily be accomplished by leaving animals access holes, similar to those used in cave gates, at ground level for at least every 5 m (16 ft) of fence.

Preserve funding should include money set aside to gate all caves supporting the listed species (see below for gate design). However, because the potential impacts of gating cave entrances on the terrestrial troglobites in central Texas are unknown and because gating a cave necessitates the alteration of the immediate entrance area, gating may affect the community of the cave entrance (Culver et al. 2000). Gating of caves should only be done as a last resort and only for caves where there is a threat of vandalism that is both detrimental to the cave-dwelling invertebrates and can be prevented by gating the cave. Examples of detrimental vandalism include littering with toxic substances (such as cigarettes, batteries, carbide, fuel, metals, household chemicals, or appliances) or frequent visitation of any passage that is very tight (crawling passage) where the listed species are found that would result in the direct destruction of individuals of the listed species or their habitat. Deliberate dumping of toxic materials such as gasoline into the cave entrance is an example of detrimental vandalism that cannot be prevented by gating the cave. Vandalism in the form of graffiti, theft of cave formations, or leaving inert trash, such as glass or plastic, may be less detrimental to the listed species and their ecosystem than the installation of a cave gate. Some vandalism, such as the addition of food, can impact the ecosystem by attracting RIFA or excessive use by trogloxenes that normally would not venture far into the cave. Significant alteration of the entrance area such as cementing or filling should be avoided. In evaluating whether to gate a cave, the potential benefits of gating the cave should be weighed against the potential negative effects.

At this time, gating a cave should be considered a last option, and should only be used when attempts to increase the level of security of the fence have failed. Gating may also be appropriate where human health or safety may be at risk. These recommendations may change when more evidence is available on the long-term effects of gating a cave on the karst ecosystem. Gate designs should follow the recommendations of Bat Conservation International www.bci.org and the American Cave Conservation Association www.cavern.org. Gates should have bar spacing close enough to discourage human passage, while maximizing normal passage of air, water, organic material, bats, and small terrestrial mammals such as raccoons. A gate that was improperly installed at Shelta Cave in Alabama was a contributing factor to the extirpation of some of the fauna in the cave (Culver 1999). To prevent paint chips from entering the karst ecosystem, gates should not be painted. All gates and fences should be subject to a regular maintenance schedule to ensure that they are functioning correctly, are not blocked by debris, locks are regularly lubricated, and inspected for breaches and breach attempts.

Monitoring Karst Preserves

Long-term monitoring of endangered invertebrate populations, cave ecosystems and the surface ecosystem is needed to determine if management activities are adequate or if adaptive management is necessary. Monitoring should be considered standard protocol for the management of karst preserves.

Examples of monitoring objectives and generalized methods for cave biota include:

1. Biodiversity - survey for all species
2. Population levels - quantify numbers of species observed
3. Habitat - track visitation, quantify changes to entrances and in-cave substrates as well as humidity, air and water temperatures
4. Nutrient input – record changes in surface flora and fauna and quantify nutrient sources in the cave (trogloxene guano, leaf litter, flood debris)
5. Toxins – identify threatened areas, record contamination events, perform restoration, and monitor long-term effects

Monitoring endangered invertebrate populations is problematic because of low population sizes and the small, cryptic nature of these species. Nevertheless, several authors have performed long-term monitoring of the endangered invertebrates and their ecosystems in Bexar County (Veni and Associates 2006), as well as Travis and Williamson Counties (Elliott 2000, Myers et al. 2005b). The Service provides survey requirements for Section 10(a)(1)(A) Scientific Permit holders for determining the presence or absence of species in karst features, and these requirements include the number of sampling occasions, proper sampling weather conditions, sampling diligence and thoroughness, specimen collection and preservation, baiting, reporting, and observer qualifications (Service 2006). Many of these permit requirements may be applied to monitoring.

Monitoring cave fauna is a recent phenomenon, therefore few examples of other guidelines exist that could be used to draft uniform, highly repeatable, and accurate survey methodology. The cave environment is not conducive to long hours of observations due to observer impact on the species (for example, light, heat or movement scaring organisms away), nor is it possible to make frequent repeated visits to the same area in a cave without damaging the habitat by compacting soil, embedding rocks into the substrate, or physically abrading the surfaces that are home to target species. Various researchers have attempted to solve these problems in a variety of ways, and the discussion below will cover the highlights of those methods.

Many researchers choose to monitor only certain taxa in a cave and develop their techniques around the habits of those organisms. For example, several authors have monitored aquatic species in certain sections of a cave, such as in a mark-recapture study of amphipods, or a count of *Eurycea* salamanders in small pools in central Texas caves (Veni and Associates 2005). Another example is the use of cricket exit counts to monitor these trogloxenes that are important contributors to the karst ecosystem in central Texas (Elliott 2000, Myers et al. 2005b, Taylor et al. 2005, Veni and Associates 2005). Bat researchers place traps in front of cave entrances or use infrared lights and binoculars to count bats as they exit the cave. With practiced, consistent techniques and limited areas of habitat available to search, repeatable population estimates can be made. There are several obvious problems to applying these techniques when monitoring the entire cave fauna. First, terrestrial invertebrate fauna is not limited to small pools within the cave as are aquatic species; they frequently occur throughout the cave and retreat into crevices that are inaccessible to humans. Also, unlike bats, their life cycles do not always require exiting the cave each night where they can easily be counted. An alternative used by many cave researchers to detect terrestrial invertebrates includes use of non-lethal pitfalls or other types of traps in several areas in a cave. Traps require little training to properly place, can be placed in the same area during each monitoring event, and their contents are easy to quantify and consistent among personnel. The downsides of traps are that they attract only a certain suite of species and can accidentally cause damage or death if they are left in the cave too long or if a predator makes its way into the trap. Additionally, as food availability changes around the trap locations, fauna entering the trap will change. Therefore, results of trap content changes over time must be interpreted carefully to avoid bias. Generally speaking, predators, like the endangered Bexar County karst invertebrates, are unlikely to be found in pitfall traps.

Other studies focus on repeatable quantification of species observed by using quadrats (measuring frames) to intensively sample measured areas of a cave (Taylor et al. 2003). This provides exact data on abundance and diversity per unit area, and can be timed and combined with substrate observations to provide an accurate picture of substrate use versus availability. The method is also useful for large caves where observing the substrate of the entire cave is extremely time consuming. There are several downsides to this method. First, the placement of quadrats should ideally be random, and dividing the cave into random plots may be difficult. Another option is for the plots to be regular (e.g. one every 10 m as you go into the cave). In either case, it would probably be difficult to determine if there are enough plots to detect the target species. The root of this problem is that energy is seldom distributed evenly or consistently throughout a cave. More often there is an energy concentration, such as a pile of leaves at the bottom of a pit, an area with trogloxene guano, or a dead animal where the majority of the cave fauna are concentrated. If the quadrat system misses energy hotspots, the cave fauna will not be counted. One quadrat study of central Texas cave species found that troglobitic predators were almost never counted in quadrats spaced every 2 m (6.5 ft), but they were not uncommonly seen outside of the boundaries of the quadrat (Taylor et al. 2003), indicating this method may not be ideal for detecting endangered Bexar County species.

Another alternative for monitoring all cave fauna that has been used for recreational cavers for non-listed species is to provide each team entering a cave with a standard observation form. Many state cave surveys follow this method, including the Missouri Cave and Karst Conservancy (Elliott 2003), the Texas Speleological Survey (form available at: http://www.utexas.edu/tmm/sponsored_sites/tss/ tssdatareportform.htm), and Carlsbad Caverns National Park. Each of these forms vary, but basically rely on the researcher filling out the form to identify encountered taxa and to record various aspects of that observation, including personnel, date, temperature, habitat, number observed, location in cave, and nearest survey stations. These forms include observations about everything from archaeology to mineralogy to biology. The downside to this method is that it typically does not provide a consistent way to accurately quantify search effort, and surveyors vary in their observation skills (ability to identify the species) and effort which causes bias. These types of forms should be considered useful only as spot records and not in a serious monitoring effort.

Based on this review of cave fauna monitoring techniques, the best available monitoring techniques are those already in use in the area. These protocols require personnel that meet surveyor qualifications that are based on a combination of academic training and/or years of experience with the species being monitored (Service 2006). Explicit details are found in various reports (Elliott 2000, Myers et al. 2005b, Veni and Associates 2005), but are generally as follows. The cave is divided into zones that are approximately 4-20 m (13-65 ft) of cave passage distance, with more complex substrates and areas near the entrance comprising smaller zones. Timed visual searches are performed in each zone, typically between 15 and 60 person-minutes. Abundance and diversity of all organisms and nutrient sources are recorded. Temperature and relative humidity of the surface (outside of the cave, in the shade) and cave (usually three measurements) are recorded. Substrates for listed species are recorded. Additionally, cricket exit counts are performed between sunset (or just prior to sunset) and two hours after sunset. Cricket exit counts include numbers and lifestage of individuals exiting per ten minute increments to track demographics and activity peaks. Observations of predation, mating, foraging, or other behaviors for both in cave and exit counts are important. Frequency of monitoring events ranges from two to four times per year, but this interval is not based on any analysis of power of detection of population trends. The interval should be based on maximizing the ability to detect declines in populations and minimizing impacts on the cave environment.

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Appendix D – Distribution

The distribution of each of the Bexar County endangered karst invertebrates is as follows:

Unnamed ground beetle (*Rhadine exilis*): Known from 50 caves in north and northwest Bexar County. Table D-1 gives five possible additional caves the species may occur in.

Unnamed ground beetle (*Rhadine infernalis*): Known from 36 caves. Taxonomists have delineated three subspecies (*R. infernalis ewersi*, *R. infernalis infernalis*, and *R. infernalis* ssp.). Two have been formally described (Barr 1960). In a more recent report, the third subspecies was characterized as valid, but was not formally described (Reddell 1998). D-1 also shows three other potential localities for the species. *Rhadine infernalis ewersi* has been found in only three caves in the Stone Oak Karst Fauna Region (KFR): Flying Buzzworm Cave, Headquarters Cave, and Low Priority Cave. These three sites are all on the same hill on the Camp Bullis Training Site. *Rhadine infernalis infernalis* is found in a number of caves across the Stone Oak, University of Texas at San Antonio (UTSA), Government Canyon, and Helotes KFRs. An undescribed population (*R. infernalis* n. ssp.) that exists in the Culebra Anticline KFR is likely a new species or subspecies.

Helotes mold beetle (*Batrisodes venyivi*): Known from eight caves. As of 2004, J. Cokendolpher (Museum of Texas Tech University, pers. comm., 2004) lists the following known collections of adults:

> Helotes Hilltop Cave (1 male, 29 Sept. 1984); [Type Specimen]
> Christmas Cave (1 specimen, 6 Sept. 1993);
> Grubbs' Cave 189 (1 specimen, 20 Oct. 1994).

Cokendolpher cave harvestman (*Texella cokendolpheri*): Known from Robber Baron Cave in the Alamo Heights KFR. Although the entrance to this cave is protected as a preserve by the Texas Cave Management Association (TCMA), this cave is relatively large, and the land that overlies the cave is heavily urbanized. The cave has also been historically subject to extensive commercial and recreational use (Veni 1988).

While no regular biomonitoring occurs in Robber Baron Cave, there are no records of specimens of *T. cokendolpheri* collected since October 1993. As of 2004, J. Cokendolpher (Museum of Texas Tech University, pers. comm., 2004) lists the following known collections of adults, all from Robber Baron Cave:

> 1 female, April 1969; [Type Specimen]
> 1 female, 3 April 1982;
> 1 male, 9 or 11 Dec. 1983;
> 1 female; 16 October 1993.

On April 20, 2001, a (then) Service employee (J. Krejca) and two TCMA representatives (L. Palit and G. Veni) toured the more easily accessible parts of the cave looking for troglobites and saw one *C. baronia*, and another troglobitic spider (probably *Eidmanella rostrata)* but no *T. cokendolpheri* were seen and no notes were made on cave crickets. On Dec 6, 2005, two cave biologists (J. Krejca and S. Taylor) visited the same easily accessible parts of the cave in search of cave crickets and troglobites. No *C. baronia* or *T. cokendolpheri* were seen, and no cave crickets (*Ceuthophilus secretus*) were verified. Fewer than six undetermined cave cricket (*Ceuthophilus* sp.) nymphs were seen and 2 to 3 adult cave crickets (*C. cunicularis*) were seen.

Government Canyon Bat Cave spider (*Neoleptoneta microps)*: Known from two caves in the Government Canyon KFR (Government Canyon Bat Cave, Surprise Sink). An unidentified *Neoleptoneta* collected in Madla's Cave may turn out to be *N. microps*, which would extend its range into the Helotes KFR (K. White, SWCA Environmental Consultants, pers. comm. 2006). As of 2004, J. Cokendolpher (Museum of Texas Tech University, pers. comm., 2004) lists the following known collections of adults, all from Government Canyon Bat Cave:

1 female, 11 August 1965; [Type Specimen]
3 females, 24 May 1993.

Robber Baron Cave meshweaver (*Cicurina baronia*): Known from Robber Baron Cave, and therefore has the same range, threats, and discussion as *T. cokendolpheri*. The last collection of this species was made in 1983, although they have been observed more recently (see discussion above). As of 2004, J. Cokendolpher (Museum of Texas Tech University, pers. comm., 2004) lists the following known collections of adults, all from Robber Baron Cave:

1 female, April 1969; [Type Specimen]
1 female, 3 April 1982;
1 male, 9 or 11 Dec. 1983.

Madla Cave meshweaver (*Cicurina madla*): Known from eight caves. Table D-1 indicates possible localities based on Paquin and Hedin's (2004) molecular analysis of cave-dwelling *Cicurina* in central Texas. This research suggests that additional Bexar County populations of this species occur in Helotes Hilltop Cave, La Cantera Cave #1, Lithic Ridge Cave, Fatman's Nightmare Cave, John Wagner Ranch Cave #3, Pig Cave, San Antonio Ranch Pit, Scenic Overlook Cave, Surprise Sink, "Unnamed Cave, Helotes Area", and UTSA Feature #50. They also found that a specimen from Margaritaville Cave, Uvalde County was indistinguishable from *C. madla* although none of these new localities have been confirmed by morphological analysis. The Habitat Conservation Plan for La Cantera (Service 2001) indicates that this species also may occur in La Cantera Cave #2 and La Cantera Cave #3, but the specimens have not been verified using morphologic or genetic techniques. In addition, D-1 indicates two other specimens that may represent new localities for this species, but the specimens have not been verified.

As of 2004, J. Cokendolpher (Museum of Texas Tech University, pers. comm., 2004) lists the following known collections of adults:

Christmas Cave (1 female, 6 Sept. 1993);
Headquarters Cave
(1 female, 16 June 1993;
1 female, 26 Oct. 1995;
1 male, 14 Nov. 1995);
Helotes Blowhole (1 female, 18 Feb. 1999);
Hills and Dales Pit (1 female, 28 Oct. 2000);
Lost Pothole (= Lost Pot) (1 female, 4 Feb. 1995);
Madla's Cave (1 female, 4 Oct. 1963); [Type Specimen]
Madla's Drop Cave (1 female, 8 June 1993);
Robber's Cave (1 female, 14 July 1993).

Braken Bat Cave meshweaver (*Cicurina venii*): Known from Braken Bat Cave, located on private property in the Culebra Anticline KFR. As of 2004, J. Cokendolpher (Museum of Texas Tech University, pers. comm., 2004) lists only one specimen ever collected the female holotype. The cave entrance was filled during construction of a home in 1990. Without re-excavating the cave, it is difficult to determine what effect this incident had on the species. There may still be some surface nutrients introduced from a reported small side passage. It should be noted that this is not known to be a bat cave; the name is a wordplay on a similarly named cave in Comal County, Texas.

Government Canyon Bat Cave meshweaver (*Cicurina vespera*): Known from Government Canyon Bat Cave in the Government Canyon State Natural Area. As of 2004, J. Cokendolpher (Museum of Texas Tech University, pers. comm., 2004) lists only one specimen ever collected, the female holotype. Two subsequent visits on 24 May 1993 and 24 May 1998 by J. Reddell and M. Reyes yielded no specimens. A second cave, "unnamed cave 5 miles northeast of Helotes," in the UTSA KFR, was once thought to contain the species but later found to be incorrectly identified from the cave and actually represent a new species (James Cokendolpher, pers. comm., 2002). A possible synonymy between *C. vespera* and *C. madla* was suggested by the molecular analysis of Paquin and Hedin (2004), however their results have not yet been confirmed by morphological analysis and no formal synonymy was set forth in their work.

Table D-1. All known localities for the listed karst invertebrates. X if it is present, a "P" if potential ID or location (based on genetics for *Cicurina*). For *R. infernalis*, codes indicate subspecies (e.g. I for infernalis, E for ewersi, N for new, X for generalized "infernalis"). Question marks are unverified collections, refer to notes column. Data are derived from Service karst files, Critical Habitat designation (Service 2003), Texas Memorial Museum database as of January 2007, and Veni 2003. Preserve status indicates the management regime and/or owner of the site.

Cave Name	KFR	*R. exi*	*R. inf*	*B. venyivi*	*T. coke*	*N. micro*	*C. bar*	*C. mad*	*C. venii*	*C. vesp*	Preserve Ownership or Management	Sources and Notes
Robber Baron Cave	Alamo Heights				X		X				TCMA	
Braken Bat Cave	Culebra Anticline								X			
Caracol Creek Coon Cave	Culebra Anticline		N									*R. infernalis* specimen in TMM collections.
Game Pasture Cave No. 1	Culebra Anticline		N									*R. infernalis* specimen in TMM collections.
Isopit	Culebra Anticline		N									*R. infernalis* specimen in TMM collections.
King Toad Cave	Culebra Anticline		N									*R. infernalis* specimen in TMM collections.
Max and Roberts Cave	Culebra Anticline		N									*R. infernalis* specimen in TMM collections.
Obvious Little Cave	Culebra Anticline		N								TCMA	*R. infernalis* specimen in TMM collections.
Stevens Ranch Trash Hole Cave	Culebra Anticline		N									*R. infernalis* specimen in TMM collections.
Wurzbach Bat Cave	Culebra Anticline		N									*R. infernalis* specimen in TMM collections.
10K Cave	Government Canyon		I?								GCSNA	*R. infernalis* a sight record only. Reported in Miller and Reddell (2005).
Bone Pile Cave	Government Canyon		I								GCSNA	*R. infernalis* specimen in TMM collections.

Cave Name	KFR	*R. exi*	*R. inf*	*B. venyivi*	*T. coke*	*N. micro*	*C. bar*	*C. mad*	*C. venii*	*C. vesp*	Preserve Ownership or Management	Sources and Notes
Canyon Ranch Pit	Government Canyon		X?								LCHCP	TMM has no collections from this site, Veni (2003) reports that these species are probably *R. infernalis* inf., but are either not fully identified or reported.
Continental Cave	Government Canyon		I									*R. infernalis* specimen in TMM collections. Specimen from Kemble White.
Creek Bank Cave	Government Canyon	X									GCSNA	
Dancing Rattler Cave	Government Canyon		I								GCSNA	*R. infernalis* specimen in TMM collections. Reported in Miller and Reddell (2005).
Fat Man's Nightmare Cave	Government Canyon		I					P			LCHCP	*R. infernalis* specimen in TMM collections. *C. madla* identification based on genetics only, Paquin and Hedin (2004)
Goat Cave	Government Canyon							?			GCSNA	Troglobitic *Cicurina* awaiting identification. Reported in Miller and Reddell (2005).
Government Canyon Bat Cave	Government Canyon	X	I			X				X	GCSNA	*R. infernalis* specimen in TMM collections.
Hackberry Sink Cave	Government Canyon		I								GCSNA	*R. infernalis* specimen in TMM collections. Reported in Miller and Reddell (2005).
Lithic Ridge Cave	Government Canyon	X	I					P			GCSNA	*R. infernalis* specimen in TMM collections. *C. madla* identification based on genetics only, Paquin and Hedin (2004)
Lost Pothole	Government Canyon							X			GCSNA	

Cave Name	**KFR**	***R. exi***	***R. inf***	***B. venyivi***	***T. coke***	***N. micro***	***C. bar***	***C. mad***	***C. venii***	***C. vesp***	**Preserve Ownership or Management**	**Sources and Notes**
Pig Cave	Government Canyon	X	I					P			GCSNA	*R. infernalis* specimen in TMM collections. *C. madla* identification based on genetics only, Paquin and Hedin (2004). Vial labels for collections housed in the TMM also refer to this cave as "HPD Cave" and the cave is currently referred to as "Javalina Cave". These two cave site names are synonymous with Pig Cave (K. White, pers. comm. 2007).
San Antonio Ranch Pit	Government Canyon	X	I	X				P			GCSNA	*R. infernalis* specimen in TMM collections. *C. madla* identification based on genetics only, Paquin and Hedin (2004). Vial labels for collections housed in the TMM also refer to this cave as "Cave Site #2201" for a R. exilis collection and "Cave Site #2202" for a B. venyivi collection. These two cave site names are synonymous with San Antonio Ranch Pit (K. White, pers. comm. 2007).
Scenic Overlook Cave	Government Canyon		I	X				P			LCHCP	*R. infernalis* specimen in TMM collections. *C. madla* identification based on genetics only, Paquin and Hedin (2004)
Sure Sink	Government Canyon		I?								GCSNA	*R. infernalis* a sight record only. Reported in Miller and Reddell (2005).

Cave Name	KFR	*R. exi*	*R. inf*	*B. venyivi*	*T. coke*	*N. micro*	*C. bar*	*C. mad*	*C. venii*	*C. vesp*	Preserve Ownership or Management	Sources and Notes
Surprise Sink	Government Canyon		I			X		P			GCSNA	*R. infernalis* specimen in TMM collections. *C. madla* identification based on genetics only, Paquin and Hedin (2004)
Tight Cave	Government Canyon	X		X							GCSNA	Not all sources list *Batrisodes venyivi* here
unnamed cave no. 1 in Iron Horse Canyon	Government Canyon											It is unknown what species may occur in this cave. Veni (2003) reports the cave has an unspecified listed species reported, but not yet confirmed, from this site.
Sir Doug's Cave	Helotes		I					?				*R. infernalis* specimen in TMM collections. Cave name from K. White. This cave may have been renamed or may be synonymous with another cave on this list from Government Canyon KFR. Vial labels for collections housed in the TMM also refer to this cave as "Cave site #802, west of Helotes" for a collection of *R. infernalis* and a blind *Cicurina*, and as "Cave site # 801" for a collection of *Texella* and *Neoleptoneta*. These two cave site names are synonymous with Sir Doug's Cave (K. White, pers. comm. 2007).

Cave Name	KFR	*R. exi*	*R. inf*	*B. venyivi*	*T. coke*	*N. micro*	*C. bar*	*C. mad*	*C. venii*	*C. vesp*	Preserve Ownership or Management	Sources and Notes
unnamed cave no. 2 in Iron Horse Canyon	Government Canyon											It is unknown what species may occur in this cave. Veni (2003) reports the cave has an unspecified listed species reported, but not yet confirmed, from this site.
Christmas Cave	Helotes	X	I	X				X				*R. infernalis* specimen in TMM collections.
Helotes Blowhole	Helotes	X	I					X			LCHCP	*R. infernalis* specimen in TMM collections.
Helotes Hilltop Cave	Helotes	X		X				P			LCHCP	*C. madla* identification based on genetics only, Paquin and Hedin (2004)
Logan's Cave	Helotes	X	I									*R. infernalis* specimen in TMM collections.
Madla's Cave	Helotes		I			?		X			LCHCP	Unidentified *Neoleptoneta* collected here (Kemble White, pers. comm., 2006). *R. infernalis* specimen in TMM collections.
Madla's Drop Cave	Helotes		I					X				*R. infernalis* specimen in TMM collections.
Unnamed Cave 1/2 mile N. of Helotes	Helotes	X		X								*R. exilis* referred to in Barr (1974)
Unnamed Cave 1/2 mile NE of Helotes	Helotes			X								
Unnamed Cave Helotes Area	Helotes							P				*C. madla* identification based on genetics only, Paquin and Hedin (2004)
40mm Cave	Stone Oak	X									Camp Bullis	
B-52 Cave	Stone Oak	X									Camp Bullis	
Backhole	Stone Oak	X									Camp Bullis	
Hairy Tooth Cave	Stone Oak	X										

Cave Name	KFR	*R. exi*	*R. inf*	*B. venyivi*	*T. coke*	*N. micro*	*C. bar*	*C. mad*	*C. venii*	*C. vesp*	Preserve Ownership or Management	Sources and Notes
Black Cat Cave	Stone Oak	X										
Blanco Cave	Stone Oak	X										SWCA 2005 Annual Report; species confirmed by J. Reddell
Boneyard Pit	Stone Oak	X									Camp Bullis	
Genesis Cave	Stone Oak		I									
Bunny Hole	Stone Oak	X									Camp Bullis	
Cross the Creek Cave	Stone Oak	X									Camp Bullis	
Dos Viboras Cave	Stone Oak	X									Camp Bullis	
Eagles Nest Cave	Stone Oak	X									Camp Bullis	
Flying Buzzworm Cave	Stone Oak		E					?			Camp Bullis	An immature *C. madla* specimen was collected from this cave and has not been verified (Veni and Associates 2005).
Headquarters Cave	Stone Oak	X	E					X			Camp Bullis	
Hilger Hole	Stone Oak	X									Camp Bullis	
Hold Me Back Cave	Stone Oak	X									Camp Bullis	
Hornet's Last Laugh Pt	Stone Oak	X										
Isocow Cave	Stone Oak	X									Camp Bullis	
Kick Start Cave	Stone Oak	X										
Low Priority Cave	Stone Oak		E								Camp Bullis	
MARS Pit	Stone Oak	X									Camp Bullis	
MARS Shaft	Stone Oak	X									Camp Bullis	
Pain in the Glass Cave	Stone Oak	X									Camp Bullis	

Cave Name	KFR	*R. exi*	*R. inf*	*B. venyivi*	*T. coke*	*N. micro*	*C. bar*	*C. mad*	*C. venii*	*C. vesp*	Preserve Ownership or Management	Sources and Notes
Platypus Pit	Stone Oak	X									Camp Bullis	
Poor Boy Baculum Cave	Stone Oak	X									Camp Bullis	
Ragin' Cajun Cave	Stone Oak	X										
Root Canal Cave	Stone Oak	X									Camp Bullis	
Root Toupee Cave	Stone Oak	X									Camp Bullis	
Springtail Crevice	Stone Oak	X										
Strange Little Cave	Stone Oak	X									Camp Bullis	
Up the Creek Cave	Stone Oak	X									Camp Bullis	
Crownridge Canyon Cave	UTSA		I									*R. infernalis* specimen in TMM collections.
Feature #50	UTSA							P				*C. madla* identification based on genetics only, Paquin and Hedin (2004)
Hills and Dales Pit	UTSA	X						X			LCHCP	
John Wagner Ranch Cave No. 3	UTSA	X	I					P			LCHCP	*C. madla* identification based on genetics only, Paquin and Hedin (2004).
Kamikaze Cricket Cave	UTSA	X	I									*R. infernalis* specimen in TMM collections.
La Cantera Cave No. 1	UTSA	X						P			LCHCP - take cave	*C. madla* identification based on genetics only, Paquin and Hedin (2004). *R. infernalis* specimen in TMM collections.
La Cantera Cave No. 2	UTSA	X						?			LCHCP - take cave	*C. madla* not verified using morphology or genetics.
La Cantera Cave No. 3	UTSA							?			LCHCP - take cave	*C. madla* not verified using morphology or genetics.

Cave Name	**KFR**	***R. exi***	***R. inf***	***B. venyivi***	***T. coke***	***N. micro***	***C. bar***	***C. mad***	***C. venii***	***C. vesp***	**Preserve Ownership or Management**	**Sources and Notes**
Mastodon Pit	UTSA	X										
Mattke Cave	UTSA		I									*R. infernalis* specimen in TMM collections.
Porcupine Squeeze Cave	UTSA	?										Veni (2003) reports this species is reported, but not yet confirmed, from this site.
Robber's Cave	UTSA	X	I					X				*R. infernalis* specimen in TMM collections.
Scorpion Cave	UTSA		I									*R. infernalis* specimen in TMM collections.
Sunray Cave	UTSA	?										Veni (2003) reports this species is reported, but not yet confirmed, from this site.
Three Fingers Cave	UTSA	X	I									*R. infernalis* specimen in TMM collections.
Unnamed Cave 5 miles NE of Helotes	UTSA			X						?		According to Veni 2003, This species was incorrectly identified from this cave and actually represents a new species (James Cokendolpher, pers. comm., 2002).
Young Cave No. 1	UTSA	X										
Margaritaville Cave	Uvalde County							P				*C. madla* identification based on genetics only, Paquin and Hedin (2004)
Grubbs' Cave 189	Not specified			X?								A collection exists for this locality, but the physical cave location is unknown, therefore the cave name may be synonymous with another.

Cave Name	KFR	*R. exi*	*R. inf*	*B. venyivi*	*T. coke*	*N. micro*	*C. bar*	*C. mad*	*C. venii*	*C. vesp*	Preserve Ownership or Management	Sources and Notes
Marnock Cave	Not specified	X?										R. exi. referred to in Barr (1974); this cave is the type locality but the physical cave location is unknown, therefore the cave name may be synonymous with another.
Totals[4] (93 Caves)		**49 to 55**	**36 to 39**	**8 to 9**	**1**	**2 to 3**	**1**	**8 to 25**	**1**	**1**		

[4] The totals row at the bottom of the table gives a range of possible numbers, the lowest indicating verified sites and the highest indicating verified and unverified sites.

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Appendix E - Taxonomic Descriptions

Unnamed ground beetle (*Rhadine exilis*)

Taxonomic Classification: Class Insecta (insects), Order Coleoptera (beetles), Suborder Adephaga, Family Carabidae (ground beetles), Tribe Agonini (agonines).
Original Description: This species was originally described as *Agonum exile* by Barr and Lawrence (1960). This species was later referred to as *R. exilis* by Reddell (1966). Barr (1974) reassigned the species to the genus *Rhadine*.
Type Specimen: The holotype (a male) was collected from Marnock Cave, 1.6 kilometers (km) north of Helotes, Bexar County, Texas on 2 July 1959 by J. F. Lawrence and F. Moore (Barr 1974).

Unnamed ground beetle (*Rhadine infernalis*)

Taxonomic Classification: Class Insecta (insects), Order Coleoptera (beetles), Suborder Adephaga, Family Carabidae (ground beetles), Tribe Agonini (agonines).
Original Description: This species was originally described as *Agonum infernale* by Barr and Lawrence (1960). Barr (1974) reassigned the species to the genus *Rhadine*.
Type Specimen: The male holotype was collected from Madla's Cave, 5 km north of Helotes, Bexar County, Texas on 6 and 7 July 1959 by J. F. Lawrence and J. R. Reid (Barr 1974).

Helotes mold beetle (*Batrisodes venyivi*)

Taxonomic Classification: Class Insecta (insects), Order Coleoptera (beetles), Suborder Polyphaga, Family Pselaphidae (mold beetles), Tribe Batrisini, Genus *Batrisodes*, Subgenus *Excavodes*.
Original Description: This species was described by Chandler (1992).
Type Specimen: The holotype (a male) was collected from Helotes Hilltop Cave, Bexar County, Texas on 29 September 1984 by J. Ivy and G. Veni (Chandler 1992).

Cokendolpher cave harvestman (*Texella cokendolpheri*)

Taxonomic Classification: Class Arachnida (arachnids), Order Opiliones (opilionids, or harvestmen), Suborder Laniatores, Family Phalangodidae.
Original Description: This species was described by Ubick and Briggs (1992).
Type Specimen: The holotype (a male) was collected from Robber Baron Cave, Bexar County, Texas, on 3 April 1982 by A. Grubbs (Ubick and Briggs 1992).

Government Canyon Bat Cave spider (*Neoleptoneta microps*)

Taxonomic Classification: Class Arachnida (arachnids), Order Araneae (spiders), Infraorder Araneomorphae (true spiders), Family Leptonetidae.
Original Description: *Neoleptoneta microps* was first collected in 1965 and described by Gertsch (1974) as *Leptoneta microps*. The species was reassigned to *Neoleptoneta* following Brignoli (1977) and Platnick (1986). A review of the taxonomic history of nearctic leptonetids is available in Ubick et al. (2005).
Type Specimen: The female holotype was collected from Government Canyon Bat Cave, Bexar County, Texas on 11 August 1965 by J. Fish and J. Reddell (Gertsch 1974).

Robber Baron Cave meshweaver (*Cicurina baronia*)
Taxonomic Classification: Class Arachnida (arachnids), Order Araneae (spiders), Family Dictynidae, Genus *Cicurina*, Subgenus *Cicurella*.
Original Description: The species was described by Gertsch (1992).
Type Specimen: Female holotype collected by R. Bartholomew from Robber Baron Cave, Bexar County, Texas, in April 1969 (Gertsch 1992).

Madla Cave meshweaver (*Cicurina madla*)
Taxonomic Classification: Class Arachnida (arachnids), Order Araneae (spiders), Family Dictynidae, Genus *Cicurina*, Subgenus *Cicurella*.
Original Description: The species was described by Gertsch (1992).
Type Specimen: Female holotype collected by D. McKenzie and J. Reddell in Madla's Cave, 5 km north of Helotes, Bexar County, Texas on 4 October 1963 (Gertsch 1992).

Braken Bat Cave meshweaver (*Cicurina venii*)
Taxonomic Classification: Class Arachnida (arachnids), Order Araneae (spiders), Family Dictynidae, Genus *Cicurina*, Subgenus *Cicurella*.
Original description: The species was described by Gertsch (1992).
Type Specimen: Female holotype collected in Braken Bat Cave on 22 November 1980 by G. Veni. The specimen was to be placed in the American Museum of Natural History Gertsch (1992) but the specimen presently cannot be located (N. Platnick, American Museum of Natural History, and J. Cokendolpher, Museum of Texas Tech University, pers. comm. 1995, 1996).

Government Canyon Bat Cave meshweaver (*Cicurina vespera*)
Taxonomic Classification: Class Arachnida (arachnids), Order Araneae (spiders), Family Dictynidae, Genus *Cicurina*, Subgenus *Cicurella*.
Original description: The species was described by Gertsch (1992).
Type Specimen: The female holotype was collected from Government Canyon Bat Cave on 11 August 1965 by J. Fish and J. Reddell (Gertsch 1992).

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