Tooth Cave Ground Beetle
(*Rhadine persephone*)

5-Year Review:
Summary and Evaluation

U.S. Fish and Wildlife Service
Austin Ecological Services Field Office
Austin, Texas

5-YEAR REVIEW
Tooth Cave Ground Beetle (*Rhadine persephone*)

1.0 GENERAL INFORMATION

1.1 Reviewers

Lead Regional Office: Southwest Regional Office, Region 2
Jennifer Smith-Castro, Recovery Biologist, 281-286-8282 ext. 234

Lead Field Office: Austin Ecological Services Field Office
Michael Warriner, Supervisor, Listing and Recovery Branch 512-490-0057 ext. 236
Jenny Wilson, Listing and Recovery Biologist, 512-490-0057 ext. 231

1.2 Methodology used to complete the review:

The U.S. Fish and Wildlife Service (Service) conducts status reviews of species on the List of Endangered and Threatened Wildlife and Plants (50 CFR 17.12) as required by section 4(c)(2)(A) of the Endangered Species Act (16 U.S.C. 1531 et seq.). The Service provides notice of status reviews via the Federal Register and requests information on the status of the species. Data for this status review were solicited from interested parties through a Federal Register notice announcing this review on May 31, 2018 (83 FR 25034). This review was conducted by the Austin Ecological Field Services Office using methodology developed for a species status assessment completed for the Bone Cave harvestman (Service 2018, pp. 31-32). We considered both new and previously existing information from federal and state agencies, municipal and county governments, non-governmental organizations, academia, and the general public. Recovery criteria and guidelines from the Recovery Plan for Endangered Karst Invertebrates in Travis and Williamson Counties, Texas (Service 1994, pp. 48-58, 86-88), Bexar County Karst Invertebrates Recovery Plan (Service 2011, pp. 19-22), Karst Preserve Design Recommendations (Service 2012, entire), and Karst Preserve Management and Monitoring Recommendations (Service 2014, entire) informed this 5-year review.

1.3 Background:

The Tooth Cave ground beetle (Coleoptera: Carabidae: *Rhadine persephone* Barr 1974) is one of 18 species in the *subterranea* group of the genus *Rhadine* associated with caves in Texas (Barr 1974, pp. 7-25; Reddell and Cokendolpher 2001, pp. 110-114; Reddell and Cokendolpher 2004, pp. 154-155, 158-161, Reddell and Dupérré 2009, p. 111-114). This species was described from specimens collected from Tooth and Kretschmarr Caves in Travis County (Barr 1974, pp. 17-18).

The Tooth Cave ground beetle is endemic to a restricted range in the Balcones Canyonlands ecoregion of Texas, specifically Travis and Williamson counties (HNTB

Corporation 2005, pp. 7, 9-17, 19-20; Service 2009, pp. 13-15). The Balcones Canyonlands form the eastern to southeastern boundary of the Edwards Plateau, where the activity of rivers, springs, and streams has resulted in the formation of an extensive karst landscape of canyons, caves, and sinkholes (Griffith et al. 2007, p. 49). The term "karst" refers to a type of terrain that is formed by the slow dissolution of calcium carbonate from surface and subsurface limestone, and other soluble rock types (e.g., carbonites and evaporates), by mildly acidic groundwater (Holsinger 1988, p. 148; Culver and Pipan 2009, pp. 5-15; Stafford et al. 2014, pp. 4-5). Flow of groundwater through conduits leads to the formation of an interconnected system of subterranean voids that become larger as bedrock is dissolved (Culver and Pipan 2009, pp. 5-8; Stafford et al. 2014, pp. 8-18).

The Tooth Cave ground beetle is one of 18 troglomorphic (i.e., species adapted to subterranean habitats) *Rhadine* species occurring in Texas (Barr 1974, pp. 7-25; Reddell and Cokendolpher 2001, pp. 110-114; Reddell and Cokendolpher 2004, pp. 154-155, 158-161, Reddell and Dupérré 2009, p. 111-114; Gómez et al. 2016, p. 165). These species exhibit such troglomorphic traits as slender, elongate appendages, reduced eyes, and reduced pigmentation (Barr 1974, p. 4; Gómez et al. 2016, pp. 162-163). Studies suggest that cave-dwelling arthropods often display preferences for higher relative humidity and/or relatively narrow temperature regimes underscoring a dependence on subterranean conditions (Bull and Mitchell 1972, pp. 375, 386; Howarth 1980, pp. 397-399; Howarth 1987, pp. 5-7; Weinstein 1994, p. 369-370; Doran et al. 1999, pp. 258-259; Lavoie et al. 2007, pp. 121; Yoder et al. 2011, p. 15; Mammola and Isaia 2014, p. 350; Mammola et al. 2015, pp. 246-247).

Troglobitic *Rhadine* species, such as the Tooth Cave ground beetle, likely require subterranean habitats with high humidity and relatively stable temperatures (Barr 1974, p. 15, 24-25). Intact networks of subterranean voids provide living space and a buffer or refugia from the effects of humidity and temperature extremes (Howarth 1980, pp. 397-398; Howarth 1983, p. 373; Martín and Oromí 1986, p. 384; Holsinger 1988, p. 147; de Freitas and Littlejohn 1987, pp. 559-560; Crouau-Roy et al. 1992, pp. 13-15; Tobin et al. 2013, p. 206; Mammola et al. 2015, pp. 243, 246; Mammola and Isaia 2016, pp. 26-27). Functional surface and subsurface drainage basins supply water that aids in the maintenance of high relative humidity (Hauwert 2009, p. 84; Veni 2003, p. 7).

Rhadine can be predatory or omnivorous and the Tooth Cave ground beetle likely requires a source of food in the form of other invertebrates (Mitchell 1971, pp. 257-265; Barr 1974, p. 7; Reddell and Cokendolpher 2001, p. 114; Taylor et al. 2004, pp. 9, 29; Taylor et al. 2007b, p. 5). The majority of nutrients that support subterranean ecosystems originate from surface habitats, specifically the natural communities that overlay these systems (Barr 1968, pp. 47-48; Poulson and White 1969, pp. 971-972; Howarth 1983, p. 376; Culver and Pipan 2009, p. 23). Availability of surface nutrients is an important factor in the maintenance of species richness in caves with greater amounts of nutrients supporting higher species richness (Jaffé et al. 2016, pp. 6, 9, 11; Jiménez-Valverde 2017, pp. 10210-10212).

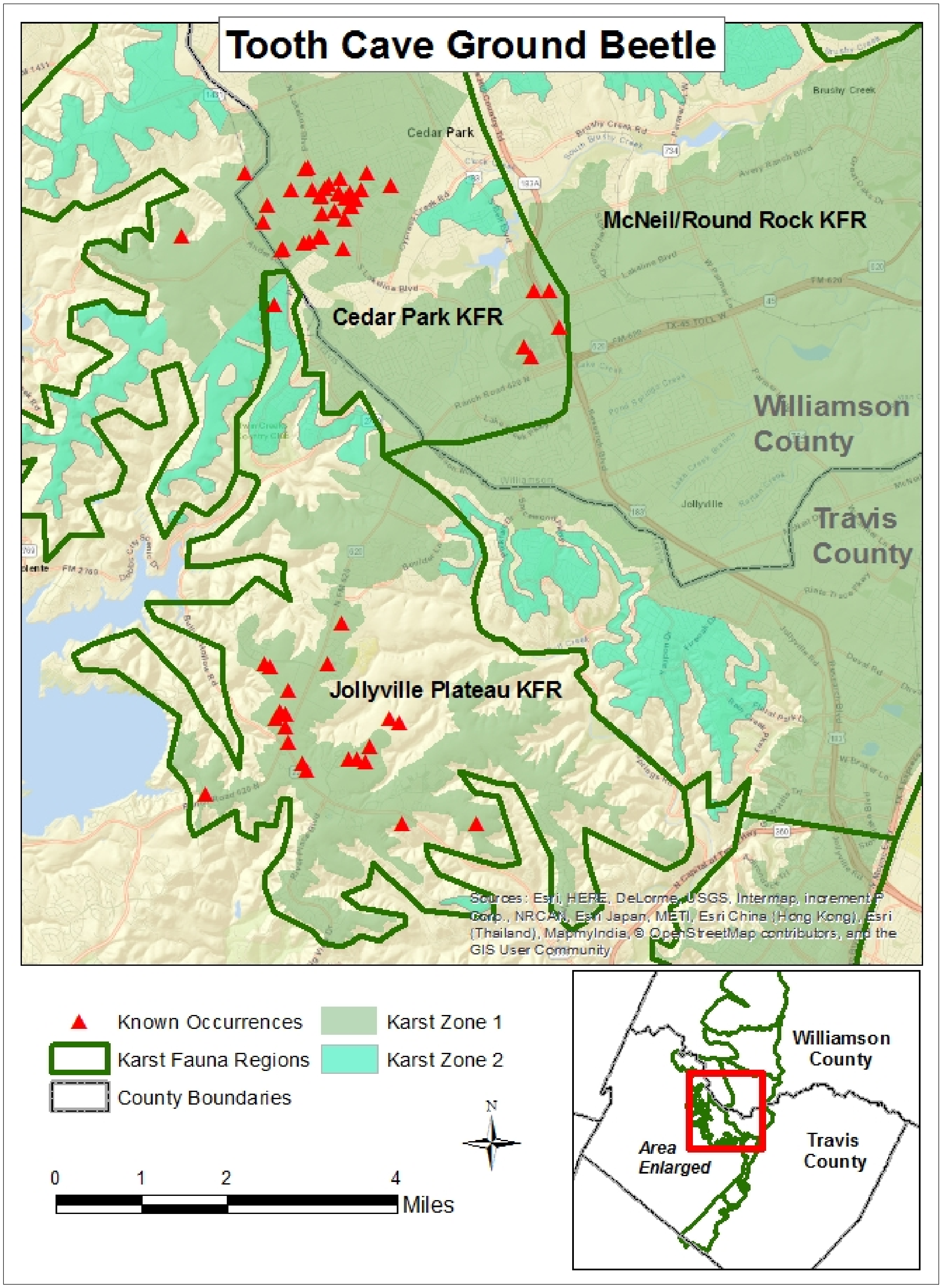
Nutrients may take the form of animal or plant material washed in by water, blown by wind, or transported by animals (Barr 1968, pp. 51, 53; Howarth 1983, pp. 376-377; Holsinger 1988, p. 147; Jasinska et al. 1996, p. 518; Culver and Pipan 2009, pp. 24, 27-39). Deposited organic matter provides a resource base for bacteria, fungi, and invertebrates that serve as prey for other invertebrates as well as vertebrates in caves (Barr 1968, pp. 53-60; Kane and Poulson 1976, pp. 799-800; Longley 1981, pp. 126-127; Howarth 1983, pp. 378-379; Ferreira et al. 2000, pp. 108-109).

Cave crickets are contributors of nutrients in some subterranean ecosystems, including those of the Edwards Plateau (Barr 1968, pp. 51, 53; Peck 1976, p. 315; Veni et al. 1999, pp. 45-46; Sharrat et al. 2000, p. 123; Reddell and Cokendolpher 2001, pp. 132-133; Taylor et al. 2004, pp. 9, 28, 31; Lavoie et al. 2007, p. 131; Peck and Wynne 2013, p. 314). Cave crickets roost in caves during the day, leaving at night to forage on animal and/or plant matter in the surrounding plant communities (Taylor et al. 2004, pp. 37-38; Taylor et al. 2005 p. 105). Nutrients obtained during foraging are transferred into the cave through defecation (i.e., guano), laying of eggs, predation of living crickets, and carcasses of dead crickets (Barr 1968, p. 53; Mitchell 1971, p. 259; Elliott 1994, p. 16; Poulson et al. 1995, pp. 226, 229; Taylor et al. 2003, p. 47; Lavoie et al 2007, p. 131). Natural foraging habitat surrounding a cave is vital to the maintenance of cave cricket populations (Taylor et al. 2007a, pp. 2, 37, 43). Declines in cave cricket populations can potentially lead to decreased abundances for other karst invertebrates (Taylor et al 2007, pp. 2, 37, 41-44).

The stressors that most influence Tooth Cave ground beetle viability are habitat destruction, degradation, and fragmentation that results from urban development. The species' range in Travis and Williamson counties has experienced substantial human population growth and development (Theobald 2005, pp. 15, 22; Berube et al. 2006, p. 12; Neumann and Bright 2008, pp. 8-11, 13; Torrens 2008, pp. 8-9, 16, 33; Frey 2012, pp. 4, 14; Potter and Hoque 2014, pp. 2, 5; Urban Land Institute 2016, p. 9). In Travis County, the human population increased between 1980 and 2017, from 419,573 people to 1,226,698 people (U.S. Census Bureau 1982, p. 10; U.S. Census Bureau 2018c). Williamson County also experienced substantial population growth from 1980 to 2017, increasing from 76,521 people to 547,545 people over that time (U.S. Census Bureau 1982, p. 10; U.S. Census Bureau 2018e).

Expansion of urban, suburban, and exurban developments has led to loss and fragmentation of natural habitat across the species' range. Numbers of single and multi-family housing units in Travis County increased by 394% over a 46-year period, from 100,882 units in 1970 to 499,062 units in 2016 (U.S. Census Bureau 2012, p. 9; U.S. Census Bureau 2018b). In Williamson County, numbers of single and multi-family housing units increased by 1,314% over that same time span, from 13,216 units in 1970 to 186,964 units in 2016 (U.S. Census Bureau 2012, p. 9; U.S. Census Bureau 2018e).

Figure 1. Distribution of the Tooth Cave ground beetle in Travis and Williamson counties, Texas.



1.3.1 FR Notice citation announcing initiation of this review:

83 FR 25034, May 31, 2018

1.3.2 Listing history

<u>Original Listing</u>
FR notice: 53 FR 36029
Date listed: September 16, 1988
Entity listed: Tooth Cave ground beetle (*Rhadine persephone*)
Classification: Endangered

1.3.3 Associated rulemakings:

Not applicable.

1.3.4 Review history:

Status reviews for the Tooth Cave ground beetle were conducted in 1988 for the final listing of the species (53 FR 36029), 1994 for the Recovery Plan for Endangered Karst Invertebrates in Travis and Williamson Counties, Texas (Service 1994, entire), 2005 for a report prepared for the Texas Turnpike Authority (HTNB Corporation 2005, entire), and 2009 for a 5-year review (Service 2009, entire).

1.3.5 Species' Recovery Priority Number at start of 5-year review:

2C

1.3.6 Recovery Plan or Outline

Name of plan or outline: Recovery Plan for Endangered Karst Invertebrates in Travis and Williamson Counties, Texas
Date issued: 1994

2.0 REVIEW ANALYSIS

2.1 Application of the 1996 Distinct Population Segment (DPS) policy

2.1.1 Is the species under review a vertebrate?

No, this species is an invertebrate, so the DPS policy does not apply.

2.2 Recovery Criteria

2.2.1 Does the species have a final, approved recovery plan containing objective, measurable criteria?

Yes. The recovery plan identifies downlisting criteria; however, no delisting criteria were identified in the recovery plan.

2.2.2 Adequacy of recovery criteria.

2.2.2.1 Do the recovery criteria reflect the best available and most up-to date information on the biology of the species and its habitat?

No. After the recovery plan was completed, additional work on other karst invertebrates lead to the development of delisting criteria which may be applicable to this species as well.

2.2.2.2 Are all of the 5 listing factors that are relevant to the species addressed in the recovery criteria (and is there no new information to consider regarding existing or new threats)?

Yes.

2.2.3 List the recovery criteria as they appear in the recovery plan, and discuss how each criterion has or has not been met, citing information:

The Recovery Plan for Endangered Karst Invertebrates in Travis and Williamson Counties, Texas (Service 1994, pp. 86-88) only provides criteria for downlisting from endangered to threatened. The Tooth Cave ground beetle will be considered for reclassification from endangered to threatened when:

> (1) Three karst fauna areas (if at least three exist) within each karst fauna region in each species' range are protected in perpetuity. If fewer than three karst fauna areas exist within a given karst fauna region, then all karst fauna areas within that region should be protected. If the entire range of a given species contains less than three karst fauna areas, then they should all be protected for that species to be considered for downlisting.
>
> (2) Criterion (1) has been maintained for at least five consecutive years with assurances that these areas will remain protected in perpetuity.

Karst geologic areas were established for Travis and Williamson counties by Veni and Associates (1992, p. 52) and incorporated as karst fauna regions into the Recovery Plan for Endangered Karst Invertebrates in Travis and Williamson Counties, Texas (Service 1994, pp. 28-34). Geologic continuity, hydrology, and the distribution of rare karst invertebrates informed delineation of these regions (Service 1994, p. 76). The Tooth Cave ground beetle occurs in two of the eight karst fauna regions demarcated for Travis and Williamson counties (Figure 1). From north to south, the regions occupied by the beetle are the Cedar Park and Jollyville Plateau Karst Fauna Regions (Service 2009, p. 4).

A karst fauna area is a geographic area known to support one or more locations of an endangered karst invertebrate species (Service 1994, p. 87). A karst fauna area is distinct in that it acts as a system separated from other karst fauna areas by geologic and hydrologic features and/or processes or distances that create barriers to movement of water, contaminants, and troglobitic invertebrate fauna. Karst fauna areas should be far enough apart that a catastrophic event (e.g., contaminants from a spill, pipeline leak, or flooding, etc.) that may kill karst invertebrates or destroy habitat in one karst fauna area would be unlikely to affect karst invertebrates or habitat in other karst fauna areas. Within each karst fauna region, an established karst preserve may be considered a karst fauna area if it meets preserve design criteria.

Brief summary of preserve design principles:

Much of the conservation and recovery of the Tooth Cave ground beetle depends upon the long-term protection of surface and subsurface habitat. The study of troglobitic invertebrates is complicated by their cryptic nature, low observed abundances, and difficulty in accessing and adequately surveying subterranean habitats (Park 1960, p. 90; Veni et al. 1999, p. 28; Sharratt et al. 2000, pp. 119-121; Culver et al. 2004, p. 1223; Schneider and Culver 2004, pp. 42-43; Krejca and Weckerly 2007, pp. 8-10; Mosely 2009, pp. 50-51; Paquin and Dupérré 2009, pp. 6, 64; Schneider 2009, pp. 125-128; Wakefield and Zigler 2012, p. 25; Wynne 2013, p. 53; De Ázara and Ferreira 2014, p. 272; Pape and O'Connor 2014, p. 785; Stoev et al. 2015, p. 108; Souza and Ferreira 2016, p. 257; Trajano et al. 2016, p. 1822; Bichuette et al. 2017, pp. 82-83; Jiménez-Valverde et al. 2017, p. 10213; Sendra et al. 2017a, p. 101; Sendra et al. 2017b, p. 49; Nae et al. 2018, p. 22). Therefore, conservation strategies for the Tooth Cave ground beetle focus on the delineation, protection, and management of occupied karst fauna areas.

The Recovery Plan for Endangered Karst Invertebrates in Travis and Williamson Counties, Texas provides guidelines on habitat conditions that are important to karst invertebrates, including maintaining stable humidity and temperatures, nutrient input from surface plant communities, preventing surface and subsurface contamination, controlling the invasion of non-native species (i.e., red-imported fire ants), and allowing for potential nutrient and karst invertebrate movement through subterranean interstitial spaces (Service 1994, pp. 48-58). Scientific information and additional karst preserve guidelines are further detailed in the Bexar County Karst Invertebrates Recovery Plan (Service 2011, pp. 19-22), Karst Preserve Design Recommendations (Service 2012, entire), and the Karst Preserve Management and Monitoring Recommendations (Service 2014, entire). According to the Karst Preserve Design Recommendations, karst fauna areas should meet the following objectives (Service 2012, p. 1):

- Provide adequate quality and quantity of moisture to karst ecosystems
- Maintain stable in-cave temperatures
- Reduce or remove red-imported fire ant predation/competition
- Provide adequate nutrient input to karst ecosystems
- Protect mesocaverns to support karst invertebrate population needs, including adequate gene flow and population dynamics
- Ensure resiliency of karst invertebrate populations by establishing preserves large enough to withstand random or catastrophic events
- Provide a high probability of viable karst invertebrate population persistence in each preserve
- Minimize the amount of active management needed for each preserve

For a karst fauna area to count toward meeting recovery criteria that area must be of a certain quality (i.e., high or medium). A legally binding mechanism must also assure management and perpetual protection of the area. The quality of a preserve is an indicator of how likely species are to survive for the long-term. Details regarding preserve quality are as follows (Service 2012, p. 3):

I. High Quality Preserve:

High quality preserves have a higher probability of long-term survival of karst invertebrates. A high quality preserve is at least 40 hectares (ha) (100 acres [ac]) and includes the following components:

- The entire surface and subsurface drainage basin of caves and karst features
- The native surface plant and animal communities
- The cave or karst feature footprint, which should be over 105 meters (m) [345 feet (ft)] from the preserve edge

II. Medium Quality Preserve:

A medium quality preserve is 16 to 40 ha (40 to 99 ac) and includes the following components:

- The entire surface and subsurface drainage basin of caves and karst features
- The native surface plant and animal communities
- The cave or karst feature footprint, which should be over 105 m (345 ft) from the preserve edge

III. Low Quality Preserve:

A low quality preserve is less than 16 ha (40 ac). Low quality preserves should only be established in areas where conditions for high or medium quality preserves do not exist. While these preserves will not contribute to meeting the recovery criteria set forth for endangered karst invertebrate species, they help increase their probability of overall survival beyond what it would be without them; so they do have some value.

Analysis regarding whether downlisting criteria have been met:

At the time of the 2009 5-year review for the Tooth Cave ground beetle, no karst fauna areas had been established for this species (Service 2009, p. 4). The 5-year review identified seven sites that had the potential to meet the definition of karst fauna area (Service 2009, pp. 4-6). However, insufficient information was available regarding surface and subsurface drainage basin delineations, confirmation of Tooth Cave ground beetle presence, tract acreage, management and perpetual protection mechanisms to determine if those sites met qualifying criteria.

As of 2018, no karst fauna areas have been recognized for the Tooth Cave ground beetle (Table 1). Per our methodology described in sections 2.3.1.5 and 2.3.1.6 below, the 61 caves currently thought to be occupied by the species were grouped into seven cave clusters and nine individual caves (Table 2). Of these, there are four cave clusters and five individual caves where the cave or at least one cave in a cluster occurs a sufficient distance from a developed edge and on a large enough tract of land that they may be able to be recognized as a karst fauna area. In order to be recognized, we would need additional information regarding surface and subsurface drainage basins, verified cave locations, confirmation of Tooth Cave ground beetle presence, sufficient tract acreage, appropriate long-term management and perpetual protection mechanisms.

Three cave clusters and three individual caves in the Jollyville plateau Karst Fauna Region receive some level of protection through the Balcones Canyonlands Preserve. Cuevas (Tomen Park) Cave Cluster, Down Dip and Garden Hoe Sinks, and the Four Points Cave Cluster are on parcels owned by Travis County, the City of Austin, and a private land manager. Three individual caves, Pond Party Pit, Spider Cave, and Stovepipe Cave are all on lands owned and managed by the City of Austin. Two individual caves in the Cedar Park Karst Fauna Region, Broken Arrow Cave and Rolling Rock Cave, receive some level of protection through the City of Austin on their Lime Creek Tract. Three caves within the Buttercup Cave Cluster, also in the Cedar Park Karst Fauna Region, are a sufficient distance from an edge and on large enough open space that they could contribute to a potential karst fauna area provided other criteria can be met.

Remaining sites in the Cedar Park Karst and Jollyville Plateau Karst Fauna Regions may have protection through various mechanisms but none are of sufficient quality and resiliency to potentially be considered as karst fauna areas. Thus, the recovery criteria for the Tooth Cave ground beetle have not been achieved in either of the karst fauna regions in which it occurs.

Table 1. Potential, proposed, and protected karst fauna areas by karst fauna region.

Karst Fauna Region	Potential Karst Fauna Area(s)	Proposed Karst Fauna Area(s)	Protected Karst Fauna Area(s)
Cedar Park	3	0	0
Jollyville Plateau	6	0	0

2.3 Updated Information and Current Species Status

2.3.1 Biology and Habitat

2.3.1.1 New information on the species' biology and life history:

No new information.

2.3.1.2 Abundance, population trends (e.g. increasing, decreasing, stable), demographic features (e.g., age structure, sex ratio, family size, birth rate, age at mortality, mortality rate, etc.), or demographic trends:

Annual monitoring for the Tooth Cave ground beetle was conducted at Lakeline Cave and Testudo Tube in Williamson County from 1992-2013 (Zara Environmental 2014, entire). Numbers of Tooth Cave ground beetles observed at both caves declined over that 21-year period (Zara Environmental 2014, pp. 10-11, 15). During the monitoring effort, numbers of cave crickets observed at Lakeline Cave decreased while numbers observed at Testudo Tube increased (Zara Environmental 2014, p. 12).

2.3.1.3 Genetics, genetic variation, or trends in genetic variation (e.g., loss of genetic variation, genetic drift, inbreeding, etc.):

No new information.

2.3.1.4 Taxonomic classification or changes in nomenclature:

No new information.

2.3.1.5 Spatial distribution, trends in spatial distribution (e.g. increasingly fragmented, increased numbers of corridors, etc.), or historic range (e.g. corrections to the historical range, change in distribution of the species' within its historic range, etc.):

The 2009 5-year review for the Tooth Cave ground beetle listed 54 caves with records of that species (Service 2009, pp. 5-9). Our current review documented 61 caves with records of the Tooth Cave ground beetle. Additional specimens in the Texas Memorial Museum collection were noted for Amber Cave, Dies Ranch Treasure Cave, Down Dip Sink, Garden Hoe Cave, Geode Cave, Hunter's Lane Cave and Pond Party Pit.

An important consideration for this 5-year review was whether occupied caves warranted consolidation into single populations based on geographic proximity (Service 2018, pp. 24, 49-50). Research indicates that troglobitic arachnids and insects may disperse through networks of subterranean voids (e.g., mesocaverns). In central Texas, some troglobitic beetles (i.e., *Rhadine*), bristletails (i.e., *Texoredellia*), and spiders (e.g., *Cicurina* and *Tayshaneta=Neoleptoneta*) have exhibited genetic connectivity among occupied caves (Avise and Selander 1972, p. 15; Paquin and Hedin 2004, p. 3250; Paquin and Hedin 2005, pp. 4-5, 14-15; Ledford et al. 2012, pp. 11, 18-23; Espinasa et al. 2016, pp. 233, 236, 238). In Williamson County, Texas, boreholes drilled at a development site (i.e., Lakeline Mall) with two caves, Lakeline and Underline Caves, resulted in the capture of a Tooth Cave ground beetle from a subterranean void (Service 1994, pp. 52, 72-73). The species occurred in both caves and the borehole capture point was 183 m (600 ft) to the northwest of Lakeline Cave. Avise and Sealander (1972, p. 15) noted high levels of genetic similarity between individuals of another troglobitic ground beetle species, *R. subterranea*, collected from two additional Williamson County caves (i.e., Beck Ranch and Beck Sewer Caves) 756 m (2,480 ft) apart. Subterranean dispersal of troglobitic invertebrates, along with resultant gene flow in some cases, has been suggested to occur in cave systems of Australia (Moulds et al. 2007, pp. 8, 10), Brazil (Jaffé et al. 2016, pp. 11-12), and other regions of the United States (i.e., Kentucky; Turanchik and Kane 1979, pp. 65-67).

Ledford et al. (2012, pp. 11, 18-23, 51) documented significant genetic similarity (i.e., mitochondrial and nuclear DNA) among Tooth Cave spider (*Tayshaneta myopica=Neoleptoneta myopica*) populations at Gallifer, Root, Tooth Caves and Tight Pit in Travis County. Genetic similarity among Tooth Cave spiders sampled from those sites implies dispersal of individuals between caves over time through interconnected subterranean dispersal corridors (e.g., fissures or mesocaverns)(Ledford et al. 2012, pp. 11, 51). The greatest distance between genetically similar Tooth Cave spider populations at Tight Pit and Gallifer, Root, and Tooth Caves is approximately 292 m (958 ft).

For our assessment, we assumed that populations of the Tooth Cave ground beetle, given adequate geological connectivity, are capable of subterranean dispersal and gene flow among karst features. To account for potential genetic connectivity of populations, we assigned a maximum dispersal radius of 300 m (984 ft) from each cave occupied by the species. That value is a conservative estimate that is most similar to distances exhibited by the Tooth Cave spider. Given the extent of geological connectivity surrounding caves, actual Tooth

Cave ground beetle dispersal distances may be greater or less than that value. Genetic analyses would be necessary to provide more certainty regarding actual dispersal distances.

For each cave occupied by the Tooth Cave ground beetle, we established a 300 m (984 ft) radius around individual sites in ArcGIS with the entrance as a center-point. If the respective radiuses of adjacent caves over-lapped (or caves were within 600 m (1968 ft) of each other), those sites were grouped into what we refer to as a cave cluster and those caves were assumed to be part of the same interconnected Tooth Cave ground beetle population. If a cave's radius did not overlap with any other cave, we labeled that site an individual cave and considered it an isolated population. Based on that methodology, we grouped occurrences into a total of seven cave clusters and nine individual caves (Table 2).

Table 2. Tooth Cave ground beetle cave clusters and individual caves.

Karst Fauna Region	County	Ownership
Cedar Park		
Cave Cluster(s)		
Big Oak and Raccoon Caves	Williamson	TXDOT[a]/Private
Buttercup Cave Cluster	Williamson	TXDOT[a]/Private/City
Lakeline Cave Cluster	Williamson	Private
Individual Cave(s)		
Broken Arrow Cave	Travis	City of Austin
Jug Cave[b]	Williamson	TXDOT[a]
Rolling Rock Cave	Travis	City of Austin
Jollyville Plateau		
Cave Cluster(s)		
Cuevas (Tomen Park) Cave Cluster	Travis	Travis County
Down Dip Sink and Garden Hoe Cave	Travis	City of Austin
Four Points Cave Cluster	Travis	Private
Twisted Elm Cave and Puzzle Pit	Travis	Private
Individual Cave(s)		
Dies Ranch Treasure Cave	Travis	Unknown
Geode Cave	Travis	Travis County
Lamm Cave	Travis	Unknown
Pond Party Pit	Travis	City of Austin
Spider Cave	Travis	City of Austin
Stovepipe Cave	Travis	City of Austin

[a] Texas Department of Transportation (TXDOT).
[b] Cave has been physically destroyed.

2.3.1.6 Habitat or ecosystem conditions (e.g., amount, distribution, and suitability of the habitat or ecosystem):

The population needs of the Tooth Cave ground beetle are the factors that provide for a high probability of population persistence over the long-term at an occupied location (e.g., low degree of threats and high survival and reproduction rates). Since population estimates for the Tooth Cave ground beetle are unavailable, nor do we know what reproductive rates sustain a healthy population, we applied measures of surface habitat elements (i.e., area of naturally vegetated open space, distance of cave entrance to nearest edge, and status of cave cricket foraging area) surrounding a cave as surrogates to assess population resiliency. For a full discussion of this methodology, see Service (2018, pp. 31-32).

Variables related to surface land uses and native vegetation can influence cave invertebrate communities, even at some distance (i.e., 50-250 m [164-820 ft]), from a cave's entrance (Pellegrini et al. 2016, pp. 23-34). Jaffé et al. (2018, pp. 9, 11) found that anthropogenic land use, in the form of agriculture, within 50 m (164 ft) of a cave significantly reduced troglobitic invertebrate species richness. Those researchers partially attributed reductions to chemical contamination in the form of herbicide, pesticide, and/or fertilizer use (Jaffé et al. 2018, p. 17). Reduction of nutrients into caves, due to loss of surrounding native vegetation to agricultural conversion, was cited as another potential contributor to reduced species richness (Jaffé et al. 2018, p. 17). It is likely that urbanization may have similar impacts on cave systems (Pelligrini et al. 2016, p. 28).

Construction of development projects (e.g., single- or multi-family housing, commercial buildings, and paved roadways) often entails the partial or complete mechanical removal of natural vegetation, and potentially topsoil, from a site (Theobald et al. 1997, p. 26; Zipperer 2011, pp. 188-189) followed by replacement with built structures, impervious cover, and/or non-native, managed landscaping (McKinney 2002, pp. 884, 886; McKinney 2008, p. 168). Once completed, such urban landscape features can have long-term impacts on surrounding natural communities (Theobald et al. 1997, pp. 27-28, 31-33). Compared to some other anthropogenic drivers of species decline, including agriculture, forestry, or grazing, the impacts of urbanization on native habitats are more persistent resulting in highly modified sites with decreased potential for maintenance or reestablishment of native species (Rebele 1994, p. 177; Theobald et al. 1997, p. 33; Huxel and Hastings 1999, p. 312; Marzluff and Ewing 2001, p. 281; McKinney 2002, pp. 883-886, 889; Hansen et al. 2005, pp. 1899-1900).

For this review, we evaluated 2016 aerial imagery of areas surrounding occupied caves in ArcGIS for the following habitat elements: amount of open space with natural vegetation contiguous with a cave entrance, distance of the cave entrance to nearest edge, and status of the cave cricket foraging area (Service 2018, p. 51). As we lack maps of every cave's footprint, cave entrances served as center-points for measurements.

We assigned each cave cluster and individual cave site to one of four resiliency categories, high, moderate, low, or impaired, based on values generated for each habitat element (Service 2018, p. 52). We also noted any physically destroyed caves, if any, and assumed those caves would no longer support Tooth Cave ground beetle populations. Finally, we noted whether a site possessed legally binding perpetual protection along with the amount of acreage protected, if that information was available.

Habitat elements at high and moderate resiliency sites provide the greatest probability for persistence of Tooth Cave ground beetle populations and the associated karst ecosystem. However, a sites' continued status as high or moderate resiliency is dependent on the perpetuation of the needed surface and subsurface habitat elements. A cave cluster with a high or moderate resiliency designation may contain an individual cave or caves with lower resiliency, but if at least one cave in the cluster was potentially capable of supporting a high to moderate resiliency population, we assigned that higher resiliency category to the entire cluster. Low resiliency and impaired cave clusters and individual caves potentially lack habitat elements of sufficient quality to support persistent populations of Tooth Cave ground beetles over the long-term.

Impacts to a cave's surface or subsurface drainage basin can be a significant source of stressors for Tooth Cave ground beetle populations. To characterize habitat for a particular site, it is important to determine whether development activities are affecting drainage basins, altering either the quantity or quality of hydrologic inputs into the karst ecosystem. At this time, however, we do not have adequate assessments of drainage basins for most occupied sites. Therefore, we did not include an assessment of actual impacts to drainage basins in this evaluation. For these analyses, we assumed that larger tracts of open space were more likely to include intact drainage basins, particularly when the cave entrance was some distance from the edge. In using this approach, we recognize that drainage basin impacts may be occurring undetected even in high and moderate resiliency sites. Thus, it would be important to delineate and protect these areas in the future to ensure Tooth Cave ground beetle persistence.

Based on our review, nine of the 16 cave clusters and individual caves are currently of high or moderate resiliency with potential to support Tooth Cave ground beetle populations over the long-term (Table 3). For the most part, these sites are located in larger tracts of open space and have relatively unaltered cave cricket foraging areas.

Table 3. Current resiliency of Tooth Cave ground beetle sites (cave clusters and individual caves) by karst fauna region.

Cave Cluster or Individual Cave	Open Space Area ha (ac)	Distance of Cave to Nearest Edge m (ft)	Percent of Cave Cricket Foraging Area Impacted	Current Resiliency
Cedar Park Karst Fauna Region				
Cave Cluster(s)				
Big Oak and Raccoon Caves				**Low**
Big Oak Cave	3.6-16 (9-40)	<120 (<394)	75%-100%	Impaired
Raccoon Cave	>40 (>100)	<120 (<394)	25%-50%	Low
Buttercup Cave Cluster				**High**
A.J. and B.L. Wilcox Cave	3.6-16 (9-40)	>120 (>394)	25%-50%	Impaired
Animal Canyon Cave	<3.6 (<9)	>120 (>394)	25%-50%	Impaired
Bluewater Cave No. 2	<3.6 (<9)	>120 (>394)	25%-50%	Impaired
Boulevard Cave	<3.6 (<9)	>120 (>394)	50%-75%	Impaired
Buttercup Blowhole Cave	3.6-16 (9-40)	>120 (>394)	25%-50%	Impaired
Buttercup Creek Cave	16-40 (40-100)	>120 (>394)	0	Low
Cedar Elm Cave	3.6-16 (9-40)	>120 (>394)	75%-100%	Impaired
Convoluted Canyon Cave	16-40 (40-100)	>120 (>394)	0-25%	Low
Discovery Well Cave	>40 (>100)	<120 (<394)	0	High
Good Friday Cave	3.6-16 (9-40)	>120 (>394)	25%-50%	Impaired
Grimace Cave	<3.6 (<9)	>120 (>394)	25%-50%	Impaired
Harvestman Cave	<3.6 (<9)	>120 (>394)	50%-75%	Impaired
Hideaway Cave	16-40 (40-100)	>120 (>394)	50%-75%	Impaired
Ilex Cave	16-40 (40-100)	>120 (>394)	0-25%	Low
Marigold Cave	<3.6 (<9)	>120 (>394)	75%-100%	Impaired
May B A Cave	3.6-16 (9-40)	>120 (>394)	25%-50%	Impaired
Nelson Ranch Cave	16-40 (40-100)	>120 (>394)	25%-50%	Impaired
Pat's Pit Cave	3.6-16 (9-40)	<120 (<394)	50%-75%	Impaired
Pig Snout Cave	<3.6 (<9)	>120 (>394)	25%-50%	Impaired
Primrose Cave	<3.6 (<9)	>120 (>394)	75%-100%	Impaired
Salamander Squeeze Cave	3.6-16 (9-40)	>120 (>394)	25%-50%	Impaired
Stone Well Cave No. 1	3.6-16 (9-40)	>120 (>394)	25%-50%	Impaired
Stone Well Cave No. 2	3.6-16 (9-40)	>120 (>394)	25%-50%	Impaired
T.W.A.S.A Cave	<3.6 (<9)	>120 (>394)	25%-50%	Impaired
Testudo Tube Cave	>40 (>100)	>120 (>394)	0	High

Table 3, cont. Current resiliency of Tooth Cave ground beetle sites (cave clusters and individual caves) by karst fauna region.

Cave Cluster or Individual Cave	Open Space Area ha (ac)	Distance of Cave to Nearest Edge m (ft)	Percent of Cave Cricket Foraging Area Impacted	Current Resiliency
Treehouse Cave	3.6-16 (9-40)	<120 (<394)	25%-50%	Impaired
Two Hole Cave	<3.6 (<9)	<120 (<394)	25%-50%	Impaired
Whitestone Pit Cave	3.6-16 (9-40)	<120 (<394)	25%-50%	Impaired
Whitewater Cave	<3.6 (<9)	<120 (<394)	25%-50%	Impaired
Wilcox Cave	3.6-16 (9-40)	<120 (<394)	0-25%	Low
Lakeline Cave Cluster				**Impaired**
Lakeline Cave	<3.6 (<9)	<120 (<394)	50%-75%	Impaired
Lakeline Mall Well Trap No. 6 Cave	NA	NA	NA	Destroyed
Individual Cave(s)				
Broken Arrow Cave	>40 (>100)	>120 (>394)	0	High
Jug Cave	NA	NA	NA	Destroyed
Rolling Rock Cave	>40 (>100)	>120 (>394)	0	High
Jollyville Plateau Karst Fauna Region				
Cave Cluster(s)				
Cuevas (Tomen Park) Cave Cluster				**High**
Amber Cave	>40 (>100)	>120 (>394)	25%-50%	Low
Gallifer Cave	>40 (>100)	>120 (>394)	0	High
Kretschmarr Cave	>40 (>100)	>120 (>394)	25%-50%	Low
Kretschmarr Double Pit	>40 (>100)	>120 (>394)	25%-50%	Low
Root/North Root Cave	>40 (>100)	>120 (>394)	0	High
Tardus Hole	>40 (>100)	>120 (>394)	25%-50%	Low
Tooth Cave	>40 (>100)	>120 (>394)	0-25%	Moderate
Two Trunks Cave	>40 (>100)	>120 (>394)	0	High
Down Dip Sink and Garden Hoe Cave				**High**
Down Dip Sink	>40 (>100)	>120 (>394)	0	High
Garden Hoe Cave	>40 (>100)	>120 (>394)	0	High
Four Points Cave Cluster				**High**
Disbelievers Cave	>40 (>100)	>120 (>394)	0-25%	Moderate
Japygid Cave	>40 (>100)	>120 (>394)	0-25%	Moderate
Jollyville Plateau Cave	>40 (>100)	<120 (<394)	0	High
MWA Cave	>40 (>100)	<120 (<394)	0	High
Twisted Elm Cave and Puzzle Pit				**Impaired**
Twisted Elm Cave	3.6-16 (9-40)	<120 (<394)	50%-75%	Impaired
Puzzle Pit	NA	NA	NA	Destroyed

Table 3, cont. Current resiliency of Tooth Cave ground beetle sites (cave clusters and individual caves) by karst fauna region.

Cave Cluster or Individual Cave	Open Space Area ha (ac)	Distance of Cave to Nearest Edge m (ft)	Percent of Cave Cricket Foraging Area Impacted	Current Resiliency
Homestead Cave	NA	NA	NA	Unknown
Individual Cave(s)				
Dies Ranch Treasure Cave	NA	NA	NA	Unknown
Geode Cave	>40 (>100)	<120 (<394)	25%-50%	Low
Lamm Cave	3.6-16 (9-40)	<120 (<394)	25%-50%	Impaired
Pond Party Pit	>40 (>100)	>120 (>394)	0	High
Spider Cave	>40 (>100)	>120 (>394)	0	High
Stovepipe Cave	16-40 (40-100)	>120 (>394)	0	Moderate

2.3.1.7 Other:

No new information.

2.3.2 Five-Factor Analysis (threats, conservation measures, and regulatory mechanisms)

2.3.2.1 Present or threatened destruction, modification or curtailment of its habitat or range:

The range of the Tooth Cave ground beetle in Travis and Williamson counties has experienced significant human population growth (Neumann and Bright 2008, pp. 8-11, 13; Potter and Hoque 2014, pp. 2, 5). During the period from 1980 to 2010, the Austin-Round Rock area was among the fastest growing metropolitan areas in the United States (Frey 2012, p. 4). Within that same time-span, Williamson County was the seventh fastest growing exurban/emerging suburban county nationally (Frey 2012, p. 13). In 2018, the U.S. Census Bureau (2018a) rated the Austin-Round Rock area as the ninth fastest growing metropolitan area in the United States.

In Travis County, the human population grew substantially between 1980 and 2010, from 419,573 people to 1,024,266 people, a 144% increase over 30 years (U.S. Census Bureau 1982, p. 10; U.S. Census Bureau 2012, p. 9). The county's largest city, the City of Austin, grew from 345,890 people in 1980 to a projected 949,587 people in 2017, a 174% increase over 37 years (City of Austin 2018). From 2010 to 2017, the population of Travis County increased to 1,226,698 people (U.S. Census Bureau 2018c), an increase of 192% since 1980.

Like Travis County, Williamson County experienced substantial population growth from 1980 to 2010. That county grew from 76,521 people to 422,679 people over that time, a 452% increase over 30 years (U.S. Census Bureau 1982, p. 10; U.S. Census Bureau 2012, p. 9). The population of the City of Georgetown grew from 9,468 people in 1980 to a projected 60,282 people in 2017, a 536% increase over 37 years (U.S. Census Bureau 1982, p. 27; City of Georgetown 2018). From 2010 to 2017, the population of Williamson County increased to 547,545 people (U.S. Census Bureau 2018e), an increase of 615% since 1980.

Increased conversion of natural surface habitat to development or infrastructure has accompanied human population growth in Travis and Williamson counties. Based on data from the U.S. Census Bureau (2012, p. Texas 9), numbers of single and multi-family housing units in Travis County more than tripled over a forty-year period from 1970 to 2010, from 100,882 units to 441,240 units. From 2010 to 2016, number of housing units increased to 499,062 units (U.S. Census Bureau 2018b), an increase of 394% since 1970. In Williamson County, numbers of single and multi-family housing units increased more than 10 times between 1970 to 2010 from 13,216 units to 162,773 units (U.S. Census Bureau 2012, p. 9). From 2010 to 2016, number of housing units increased to 186,964 units (U.S. Census Bureau 2018d), an increase of 1,314% since 1970.

Installation of infrastructure projects and non-residential commercial development can be expected to follow establishment of new housing units further expanding the urban, suburban, and exurban footprint (Cohen 1996 pp. 1051-1053; Brueckner 2000, pp. 166-167; Cowley and Spillette 2001, pp. 8-9; Heimlich and Anderson 2001, pp. 15, 18-19; Scheer 2001, pp. 31-35; Oguz et al. 2008, pp. 11-12; Landis 2009, pp. 157, 165). From 2009-2015, Texas was among states with the greatest annual loss in tree cover (8,413 ha/year [20,790 ac/year]) and greatest annual net increase in impervious cover (12,092 ha/year [29,880 ac/year]) in urbanized areas (Nowak and Greenfield 2018a, p. 37).

Population projections for both Travis and Williamson counties indicate substantial increases will continue over the next several decades (i.e., through 2050). Projections from the Texas Demographic Center (2014) estimate that Travis County will increase in population from 1,099,512 people in 2017 to either 1,612,674 (One-half 2000-2010 Migration (0.5) Scenario) or 2,011,009 people (2000-2010 Migration (1.0) Scenario) in 2050, a 47% or 83% increase over 33 years, respectively. The City of Austin's population is expected to reach 1,361,464 people by 2050 (City of Austin 2018), an increase of 43% over 33 years.

The Texas Demographic Center (2014) projects Williamson County to increase in population from 499,907 people in 2017 to either 992,814 (One-half 2000-2010 Migration (0.5) Scenario) or 1,976,958 people (2000-2010 Migration (1.0) Scenario) in 2050, a 99% or 295% increase over 33 years, respectively. The

City of Round Rock is expected to reach 158,217 people by 2030 (City of Round Rock 2018), an increase of 46% over 13 years.

Nowak and Greenfield (2018b, pp. 168-171) developed projections for urbanized land growth in the United States from 2010 to 2060. Texas is projected to gain the second highest amount of urbanized land in the country at 3,004,386 ha (7,424,000 ac) over that 50-year period (Nowak and Greenfield 2018b, p. 169). Percentage of urbanized land in Travis County is projected to increase from 25.1%-40% in 2010 to 60.1%-80% in 2060 (Nowak and Greenfield 2018b, p. 170). Williamson County is projected to experience increases in urbanized land from 10.1%-15% in 2010 to 40.1%-60% in 2060 (Nowak and Greenfield 2018b, p. 170).

The Tooth Cave ground beetle, and its subterranean habitat, is reliant on functional surface ecological systems. The plant communities that overlay and surround cave systems aid in buffering subterranean ecosystems from stressors, support nutrient flow, and aid in the maintenance of microclimatic conditions (Barr 1968, pp. 47-48; Poulson and White 1969, pp. 971-972; Howarth 1983, p. 376; Culver and Pipan 2009, p. 23; Simões et al. 2014, p. 168; Pellegrini et al. 2016, pp. 28, 32-34). As a site is developed, native plant communities are often mechanically cleared and replaced with a highly modified urban to exurban landscape (Theobald et al. 1997, p. 26; McKinney 2002, pp. 884, 886; McKinney 2008, p. 168; Zipperer 2011, pp. 188-189).

Construction activities may also modify cave entrances and other openings to the surface (Watson et al. 1997, p. 11; Veni et al. 1999, p. 55; Waltham and Lu 2007, p. 17; Frumkin 2013, pp. 61-62; Hunt et al. 2013, p. 97) which could affect climatic conditions within the cave as well as water infiltration (Pugsley 1984, pp. 403-404; Elliott and Reddell 1989, p. 7; Culver and Pipan 2009, p. 202). The abundance and species richness of native animals may decline due to decreased foraging or sheltering habitat, increased predation, competition with non-native species, or lack of connectivity among populations (Rebele 1994, p. 177; McKinney 2002, pp. 885-886; Taylor et al 2007, pp. 2, 37, 41-44; Pellegrini et al. 2016, pp. 28, 34).

Direct and collateral impacts to surface and subsurface habitat from urbanization have the potential to reduce Tooth Cave ground beetle population viability and the species' long-term persistence. Given population and urbanized land growth projections (Texas Demographic Center 2014; Nowak and Greenfield 2018b, p. 170), it is likely that remaining surface and subsurface habitats will be impacted in the absence of management and protection.

2.3.2.2 Overutilization for commercial, recreational, scientific, or educational purposes:

No new information.

2.3.2.3 Disease or predation:

Recent research underscores the importance of human disturbance to red-imported fire ant invasion. Although habitat disturbance facilitates red-imported fire ant establishment in affected natural communities (LeBrun et al. 2012, pp. 891-893; King and Tschinkel 2013, p. 73), the absence of disturbance does not preclude invasion of undisturbed areas. In southern Texas, LeBrun et al. (2012, pp. 891-892) noted that red-imported fire ants were able to establish colonies in undisturbed grassland and achieve abundances comparable to dominant native ant species. The prevalence of this non-native ant in those grasslands, however, was lower than in disturbed grasslands (LeBrun et al. 2012, p. 888). Red-imported fire ant prevalence can decline following the cessation of disturbance but several decades may be required before populations reach the lower levels observed in undisturbed habitats (LeBrun et al. 2012, p. 892).

Since the 2009 5-year review, a new non-native invasive ant species has established colonies at sites in Travis County. The tawny crazy ant (*Nylanderia fulva*), native to South America, was documented in Texas in 2002 and has established populations along the state's Gulf Coast and some central Texas counties (Wang et al. 2016, p. 4). This ant has exhibited a potential to affect native animal and plant communities (LeBrun et al. 2013, p. 2439; Wang et al. 2016, p. 5).

Tawny crazy ant colonies are often polygynous and can form dense infestations that dominate the local ant community (LeBrun et al. 2013, p. 2433). Arthropod species richness and abundance may decline in areas infested by tawny crazy ants (LeBrun et al. 2013, pp. 2434-2435; Wang et al. 2016, pp. 5, 7). Tawny crazy ants also appear capable of eliminating red-imported fire ants from areas where the species co-occur (LeBrun et al. 2013, pp. 2436-2437). Unlike red-imported fire ants that generally prefer open-habitat types, the tawny crazy ant can reach high densities in forested habitats along with grasslands and other open-habitat types (LeBrun et al. 2013, pp. 2439-2440). Sites with dense canopies, therefore, would be afforded some decreased susceptibility to red-imported fire ants but not the tawny crazy ant.

Tawny crazy ants have established populations at Whirlpool and No Rent Caves in Travis County (LeBrun 2017, p. 3). LeBrun (2017, entire) assessed the effects of tawny crazy ants at these caves. Based on observations at these two sites, use of caves by ants was tied to surface temperatures and moisture with tawny crazy ants most prevalent in caves during hot, dry summer conditions (LeBrun 2017, p. 35). Tawny crazy ants preyed on cave crickets and other karst invertebrates with one species, the spider *Cicurina varians*, experiencing decreased abundance associated with that ant's presence (LeBrun 2017, pp. 21-22, 35-36). No declines were noted for other karst invertebrates examined, though sample size was small (LeBrun 2017, pp. 22, 35). Additional research is needed to determine the potential for the tawny crazy ant to affect karst invertebrates.

2.3.2.4 Inadequacy of existing regulatory mechanisms:

No new information.

2.3.2.5 Other natural or manmade factors affecting its continued existence:

No new information.

2.4 Synthesis

The Tooth Cave ground beetle occurs at 16 cave clusters and individual caves in Travis and Williamson counties, Texas. Of that total, five sites are low resiliency or impaired and one is destroyed. Travis and Williamson County have experienced rapid population growth and development, which has resulted in loss and degradation of surface and subsurface habitats and is an ongoing stressor for the species. Open space with native vegetation has been reduced at low resiliency and impaired sites with tracts fragmented and isolated from one another. These sites may be unable to support viable populations of the Tooth Cave ground beetle over the long-term.

There are currently nine cave clusters and individual caves of high to moderate resiliency with potential to support viable Tooth Cave ground beetle populations over the long-term. Larger tracts of open space with natural vegetation surround these caves, providing higher quality cave cricket foraging habitat and greater potential for connectivity among karst features to support cricket populations. Persistence of Tooth Cave ground beetle populations at these sites is dependent upon management and perpetual protection that maintains adequate open space, sufficient buffering from edge effects, intact foraging areas for cave crickets, and sufficient quantity and quality of water from intact drainage basins.

Projections indicate that the combined human population of the Travis and Williamson county area will grow from 1,599,419 people in 2017 to between 2,605,488 and 3,987,967 people in 2050, an increase of 63%-149% over 33 years (Texas Demographic Center 2014). Such significant human population growth is projected to result in increased conversion of natural surface habitat to urban land uses through 2060 (Nowak and Greenfield 2018b, p. 170). If adequate protections are not enacted, land clearing, residential and commercial construction, and installation of infrastructure will accompany this growth and degrade the resiliency of high and moderate resiliency sites over time.

Recovery criterion (1) in Recovery Plan for Endangered Karst Invertebrates in Travis and Williamson Counties, Texas (Service 1994, pp. 86-88) states that three karst fauna areas within each karst fauna region should be protected. Protection is defined as an area sufficiently large to maintain the integrity of the karst ecosystem on which the species depends. These areas must also provide protection from threats such as habitat destruction, red-imported fire ants, and contaminants. Recovery criterion (2) requires at least five consecutive years of a cave meeting karst fauna area status and that perpetual protection of these areas is in place.

Three cave clusters and three individual caves in the Jollyville plateau Karst Fauna Region receive some level of protection through the Balcones Canyonlands Preserve. In the Cedar Park Karst Fauna Region, two individual caves receive some level of protection through the City of Austin and three caves within the Buttercup Cave Cluster are a sufficient distance from an edge and on large enough open space that they could contribute to a potential karst fauna area provided the other criteria could be met. Additional information is needed to determine if these sites meet karst fauna area criteria and guidelines. At present, recovery criteria for the Tooth Cave ground beetle have not been achieved. In both Travis and Williamson counties, threats from increasing development due to rapidly growing human populations are projected to continue. At this time, we do not recommend a change in listing status for the Tooth Cave spider given the lack of recognized karst fauna areas.

3.0 RESULTS

3.1 Recommended Classification:

____ **Downlist to Threatened**
____ **Uplist to Endangered**
____ **Delist (*Indicate reasons for delisting per 50 CFR 424.11):***
____ *Extinction*
____ *Recovery*
____ *Original data for classification in error*
__X__ **No change is needed**

3.2 New Recovery Priority Number: No change (2C)

Brief Rationale: A Recovery Priority Number of 2C is indicative of a taxon with a high degree of threat, a high recovery potential, and the taxonomic standing of a species. The C indicates that the species' recovery conflicts with water demands, development projects, or other forms of economic activity. The Tooth Cave ground beetle continues to be threatened by a high degree of habitat destruction, disturbance, and degradation across its range. However, we consider this species' potential for recovery to be feasible through the concerted efforts of Service personnel and our partners to restore, enhance, and protect habitat.

4.0 RECOMMENDATIONS FOR FUTURE ACTIONS

I. Obtain information for high or moderate resiliency site within currently protected areas to include surface and subsurface drainage basins, potential development impacts, tract acreage, management, and perpetual protection mechanisms among others. Review information to determine the potential for these sites to be recognized as karst fauna areas.

II. Draft quantitative delisting criteria for the Tooth Cave ground beetle and other listed karst invertebrates in Travis and Williamson counties, Texas.

III. Reassess the current karst fauna regions of Travis and Williamson counties, Texas using current data and revise regions as necessary to better inform recovery efforts.

5.0 REFERENCES

Avise, J.C. and R.K. Selander. 1972. Evolutionary genetics of cave-dwelling fishes of the genus *Astyanax*. Evolution 26(1): 1-19.

Barr, T.C., Jr. 1968. Cave ecology and the evolution of troglobites. Evolutionary Biology 2: 35-102.

Barr, T.C., Jr. 1974. Revision of *Rhadine* LeConte (Coleoptera: Carabidae) I. The subterranean group. American Museum Novitates 2539: 1-30.

Berube, A., A. Singer, J.H. Wilson and W.H. Frey. 2006. Finding exurbia: America's fast-growing communities at the metropolitan fringe. Washington, DC, Metropolitan Policy Program, Brookings Institution. 47 pp.

Bichuette, M.E., A.R. Nascimento, D.M. von Schimonsky, J.E. Gallão, L.P.A. Resende, and T. Zepon. 2017. Neotropical Biology and Conservation 12(2): 75-90.

Brueckner, J.K. 2000. Urban sprawl: diagnosis and remedies. International Regional Science Review 23(2): 160-171.

Bull, E. and R.W. Mitchell. 1972. Temperature and relative humidity responses of two Texas cave-adapted millipedes, *Cambala speobia* (Cambalida: Cambalidae) and *Speodesmus bicornourus* (Polydesmida: Vanhoeffeniidae). International Journal of Speleology 4: 365-393.

City of Austin. 2018. Austin Area Population Histories and Forecasts. Retrieved on May 22, 2018 from http://www.austintexas.gov/page/demographic-data.

City of Georgetown. 2018. Population and Demographics. Retrieved May 22, 2018 at https://planning.georgetown.org/demographics-and-statistics/.

City of Round Rock. 2018. City of Round Rock and Greater Round Rock Population Projections 2010-2030. Retrieved on May 22, 2018 from https://www.roundrocktexas.gov/wp-content/uploads/2017/04/2010-2030-Population-Projections-All-Years-with-Growth-Rates-and-Adjusted-2017.pdf.

Cohen, L. 1996. From town center to shopping center: the reconfiguration of community marketplaces in postwar America. The American Historical Review 101(4): 1050-1081.

Cowley J.S. and S.R. Spillete. 2001. Exurban residential development in Texas. Real Estate Center, Texas A&M University, Technical report 1470. 22 pp

Crouau-Roy, B., Y. Crouau, and C. Ferre. 1992. Dynamic and temporal structure of the troglobitic beetle *Speonomus hydrophilus* (Coleoptera: Bathysciinae). Ecography 15(1): 12-18.

Culver, D.C. and T. Pipan. 2009. The biology of caves and other subterranean habitats. Oxford University Press. 256 pp.

Culver, D.C., M.C. Christman, B. Sket, and P. Trotelj. 2004. Sampling adequacy in an extreme environment: species richness patterns in Slovenian caves. Biodiversity and Conservation 13: 1209-1229.

De Ázara, L.N. and R.L. Ferreira. 2014. Two new troglobitic *Newportia* (Newportia) from Brazil (Chilopoda: Scolopendromorpha). Zootaxa 3881(3): 267-278.

de Freitas, C.R. and R.N. Littlejohn. 1987. Cave climate: assessment of heat and moisture exchange. Journal of Climatology 7: 553-569.

Doran, N.E., K. Kiernan, R. Swain, and A.M.M. Richardson. 1999. *Hickmania troglodytes*, the Tasmanian cave spider and its potential role in cave management. Journal of Insect Conservation 3: 254-262.

Elliott, W.R. 1994. Community ecology of three caves in Williamson County, Texas: a three-year summary. 1993 Annual Report for Simon Development Co., Inc., U.S. Fish and Wildlife Service and Texas Parks and Wildlife.

Elliott, W.R. and J.R. Reddell. 1989. The status and range of five endangered arthropods from caves in the Austin, Texas, Region. A report on a study supported by the Texas Parks and Wildlife Department and the Texas Nature Conservancy for the Austin Regional Habitat Conservation Plan. 75 pp.

Espinasa, L., N.D. Bartolo, D.M. Centone, C.S. Haruta, and J.R. Reddell. 2016. Revision of genus *Texoreddellia* Wygodzinsky, 1973 (Hexapoda, Zygentoma, Nicoletiidae), a prominent element of the cave-adapted fauna of Texas. Zootaxa 4126(2): 221-239.

Ferreira, R.L., R.P. Martins, and D. Yanega. 2000. Ecology of bat guano arthropod communities in a Brazilian dry cave. Ecotropica 6(2): 105-116.

Frey, W.H. 2012. Population growth in metro America since 1980: putting the volatile 2000s in perspective. Metropolitan Policy Program, The Brookings Institution, Washington, D.C. 27 pp.

Frumkin, A. 2013. Caves and karst hydrogeology of Jerusalem, Israel. Pages 60-65 in Filippi, M. and P. Bosák, editors. Proceedings of the 13th International Congress of Speleology. 453 pp.

Gómez, R.A., J. Reddell, K. Will, and W. Moore. 2016. Up high and down low: molecular systematics and insight into the diversification of the ground beetle genus *Rhadine* LeConte. Molecular Phylogenetics and Evolution 98: 161-175.

Griffith, G., S. Bryce, J. Omernik, and A. Rogers. 2007. Ecoregions of Texas. Report to the Texas Commission on Environmental Quality. 125 pp.

Hansen, A.J., R.L. Knight, J.M. Marzluff, S. Powell, K. Brown, P.H. Gude, and K. Jones. 2005. Effects of exurban development on biodiversity: patterns, mechanisms, and research needs. Ecological Applications 15(6): 1893-1905.

Hauwert, N. 2009. Groundwater flow and recharge within the Barton Springs segment of the Edwards Aquifer, southern Travis and northern Hays counties, Texas. University of Texas at Austin Dissertation. 645 pp.

Heimlich, R.E. and W.D. Anderson. 2001. Development at the urban fringe and beyond: Impacts on agriculture and rural land. Economic Research Service, U.S. Department of Agriculture. Agricultural Economic Report No. 803. 80 pp.

HNTB Corporation. 2005. Summary of information for assessing the status of the Tooth Cave ground beetle (*Rhadine persephone*). 16 June 2005, Austin, Texas. 75 pp.

Holsinger, J.R. 1988. Troglobites: The evolution of cave-dwelling organisms. American Scientist 76: 147-153.

Howarth, F.G. 1980. The zoogeography of specialized cave animals: a bioclimatic model. Evolution 34(2): 394-406.

Howarth, F.G. 1983. Ecology of cave arthropods. Annual Review of Entomology 28: 365-389.

Howarth, F.G. 1987. The evolution of non-relictual tropical troglobites. International Journal of Speleology 16: 1-16.

Hunt, B.B., B.A. Smith, M.T. Adams, S.E. Hiers, and N. Brown. 2013. Cover-collapse sinkhole development in the cretaceous Edwards Limestone, central Texas. Pages 89-102 in Land, L, D.H. Doctor, and J.B. Stephenson, editors. Proceedings of the 13th Multidisciplinary Conference, May 6-10, Carlsbad, New Mexico: NCKRI Symposium 2. Carlsbad (NM): National Cave and Karst Research Institute. 480 pp.

Huxel, G.R. and A. Hastings. 1999. Habitat loss, fragmentation, and restoration. Restoration Ecology 7(3): 309-315.

Jaffé, R., X. Prous, A. Calux, M. Gastauer, G. Nicacio, R. Zampaulo, P.W.M. Souza-Filho, G. Oliveira, I.V. Brandi, and J.O. Siqueira. 2018. Conserving relics from ancient underground worlds: assessing the influence of cave and landscape features on obligate iron cave dwellers from the eastern Amazon. PeerJ 6:e4531;DOI 10.7717/peerj.4531.

Jaffé, R., X. Prous, R. Zampaulo, T.C. Giannini, V.L. Imperatriz-Fonesca, C. Maurity, G. Oliviera, I.V. Brandi, J.O. Siqueira. 2016. Reconciling mining with the conservation of cave biodiversity: a quantitative baseline to help establish conservation priorities. PLoS ONE 11 (12): e0168348. doi:10.1371/journal.pone.0168348.

Jasinska, E.J., B. Knott, and A.J. McComb. 1996. Root mats in ground water: a fauna-rich cave habitat. Journal of the North American Benthological Society 15(4): 508-519.

Jiménez-Valverde, A., A. Sendra, P. Garay, and A.S.P.S. Reboleira. 2017. Energy and speleogenesis: key determinants of terrestrial species richness in caves. Ecology and Evolution 7: 10207-10215.

Kane, T.C. and T.L. Poulson. 1976. Foraging by cave beetles: spatial and temporal heterogeneity of prey. Ecology 57(4): 793-800.

King, J.R. and W.R. Tschinkel. 2013. Experimental evidence for weak effects of fire ants in a naturally invaded pine-savanna ecosystem in north Florida. Ecological Entomology 38: 68-75.

Krejca, J.K. and F.W. Weckerly. 2007. Detection probabilities of karst invertebrates. Report prepared for Texas Parks and Wildlife Department and U.S. Fish and Wildlife Service.

Landis, J. 2009. The changing shape of metropolitan America. Annals of the American Academy of Political and Social Science 626: 154-191.

Lavoie, K.H., K.L. Helf, and T.L. Poulson. 2007. The biology and ecology of North American cave crickets. Journal of Cave and Karst Studies 69: 114-134.

LeBrun, E. 2017. Mitigating impact of tawny crazy ant populations on endangered karst invertebrates: quantifying harm and designing environmentally safe control methods. Final Performance Report Grant No. TX E-172-R. Texas Parks and Wildlife Department. 41 pp.

LeBrun, E. G., J. Abbott, and L. E. Gilbert. 2013. Imported crazy ant extirpates imported fire ant, diminishes and homogenizes native ant and arthropod assemblages. Biological Invasions DOI 10.1007/s10530-013-0463-6.

LeBrun, E.G., R.M. Plowes, and L.E. Gilbert. 2012. Imported fire ants near the edge of their range: disturbance and moisture determine prevalence and impact of an invasive social insect. Journal of Animal Ecology 81: 884-895.

Ledford, J., P. Paquin, J. Cokendolpher, J. Campbell, and C. Griswold. 2012. Systematics, conservation and morphology of the spider genus *Tayshaneta* (Araneae, Leptonetidae) in central Texas caves. ZooKeys 167: 1-102.

Longley, G. 1981. The Edwards Aquifer: Earth's most diverse groundwater ecosystem? International Journal of Speleology 11: 123-128.

Mammola, S. and M. Isaia. 2014. Niche differentiation in *Meta bourneti* and *M. menardi* (Araneae, Tetragnathidae) with notes on the life history. International Journal of Speleology 43(3): 343-353.

Mammola, S. and M. Isaia. 2016. The ecological niche of a specialized subterranean spider. Invertebrate Biology 135(1): 20-30.

Mammola, S., E. Piano, P.M. Giachino, and M. Isaia. 2015. Seasonal dynamics and micro-climatic preference of two Alpine endemic hypogean beetles. International Journal of Speleology 44(3): 239-249.

Martín, J.L. and P. Oromí. 1986. An ecological study of Cueva de los Roques lava tube (Tenerife, Canary Islands). Journal of Natural History 20: 375-388.

Marzluff, J.M. and K. Ewing. 2001. Restoration of fragmented landscapes for the conservation of birds: a general framework and specific recommendations for urbanizing landscapes. Restoration Ecology 9(3): 280-292.

McKinney, M.L. 2002. Urbanization, biodiversity, and conservation. BioScience 52(10): 883-890.

McKinney, M.L. 2008. Effects of urbanization on species richness: a review of plants and animals. Urban Ecosystems 11: 161-176.

Mitchell, R.W. 1971. Food and feeding habits of the troglobitic carabid beetle *Rhadine subterranea*. International Journal of Speleology 3: 249-270.

Mosely, M. 2009. Estimating diversity and ecological status of cave invertebrates: some lessons and recommendations from Dark Cave (Batu Caves, Malaysia). Cave and Karst Science 35: 47-52.

Moulds, T.A., N. Murphy, M. Adams, T. Reardon, M.S. Harvey, J. Jennings, and A.D. Austin. 2007. Phylogeography of cave pseudoscorpions in southern Australia. Journal of Biogeography 34(6): 951-962.

Nae, A., S.M. Sarbu, and I. Weiss. 2018. *Kryptonesticus georgescuae* spec. nov. from Movile Cave, Romania (Araneae: Nesticidae). Arachnology Letters 55: 22-24.

Neumann, M. and E. Bright. 2008. Texas urban triangle: framework for future growth. Report to the Southwestern Region University Transportation Center. 34 pp.

Nowak, D.J. and E.J. Greenfield. 2018a. Declining urban and community tree cover in the United States. Urban Forestry and Urban Greening 32: 32-55

Nowak, D.J. and E.J. Greenfield. 2018b. US urban forest statistics, values, and projections. Journal of Forestry 116(2): 164-177.

Oguz, H., A.G. Klein, and R. Srinivasan. 2008. Predicting urban growth in a US metropolitan area with no zoning regulation. International Journal of Natural and Engineering Sciences 2(1): 9-19.

Pape, R.B. and B.M. O'Connor. 2014. Diversity and ecology of the macro-invertebrate fauna (Nemata and Arthropoda) of Kartchner Caverns, Cochise County, Arizona, United States of America. Check List 10(4): 761-794.

Paquin, P. and N. Dupérré. 2009. A first step towards the revision of *Cicurina*: redescription of type specimens of 60 troglobitic species of the subgenus *Cicurella* (Araneae: Dictynidae), and a first visual assessment of their distribution. Zootaxa 2002: 1-67.

Paquin, P. and M. Hedin. 2004. The power and perils of 'molecular taxonomy: a case study of eyeless and endangered *Cicurina* (Araneae: Dictynidae) from Texas caves. Molecular Ecology 13(10): 3239–3255.

Paquin, P. and M. Hedin. 2005. Genetic and morphological analysis of species limits in *Cicurina* spiders (Araneae, Dictynidae) from southern Travis and northern Hays counties (TX), with emphasis on *Cicurina cueva* Gertsch and relatives. Special report for the Department of Interior, United States Fish & Wildlife Service Contract No. 201814G959. Revised version 10 May 2005. 12 pp.

Park, O. 1960. Cavernicolous pselaphid beetles of the United States. The American Midland Naturalist 64(1): 66-104.

Pavićević, D. and R. Ozimec. 2013. *Seracamaurops* (*Seracamaurops*) *cadmei* n. sp. (Coleoptera: Staphylinidae: Pselaphinae: Amauropini) from Mt. Snježnica (Konavle): first representative of the genus in Croatia. Biologia Serbica 35(1-2): 62-67.

Peck, S.B. 1976. The effect of cave entrances on the distribution of cave-inhabiting terrestrial arthropods. International Journal of Speleology 8: 309-321.

Peck, S.B. and J.J. Wynne. 2013. *Ptomaphagus parashant* Peck and Wynne, new species (Coleoptera: Leiodidae: Cholevinae: Ptomaphagini): the most troglomorphic cholevine beetle known from western North America. The Coleopterist's Bulletin 687(3): 309-317.

Pellegrini, T.G., L.P. Sales, P. Aguiar, and R.L. Ferreira. 2016. Linking spatial scale dependence of land-use descriptors and invertebrate cave community composition. Subterranean Biology 18: 17-38.

Potter, L.B. and N. Hoque. 2014. Texas population projections, 2010 to 2050. Office of the State Demographer. 5 pp.

Poulson, T.L. and W.B. White. 1969. The cave environment. Science 165: 971-981.

Poulson, T.L., K.H. Lavoie, and K. Helf. 1995. Long-term effects of weather on the cricket (*Hadenoecus subterraneus*, Orthoptera, Rhaphidophoridae), guano community in Mammoth Cave National Park. American Midland Naturalist 134: 226-236.

Pugsley, C. 1984. Ecology of the New Zealand glowworm, *Arachnocampa luminosa* (Diptera: Keroplatidae), in the Glowworm Cave, Waitomo. Journal of the Royal Society of New Zealand 14(4): 387-407.

Rebele, F. 1994. Urban ecology and special features of urban ecosystems. Global Ecology and Biogeography Letters 4: 173-187.

Reddell, J.R. and J.C. Cokendolpher. 2001. A new species of troglobitic *Rhadine* (Coleoptera: Carabidae) from Texas. Texas Memorial Museum, Speleological Monographs 5: 109-114.

Reddell, J.R. and J.C. Cokendolpher. 2004. New species and records of cavernicole *Rhadine* (Coleoptera: Carabidae) from Camp Bullis, Texas. Texas Memorial Museum, Speleological Monographs 6:153-162.

Reddell, J.R. and N. Dupérré. 2009. A new species of troglobitic *Rhadine* (Coleoptera: Carabidae) from Hays County, Texas. Texas Memorial Museum Speleological Monographs, 7. Studies on the cave and endogean fauna of North America, V. Pp. 111-114.

Scheer, B.C. 2001. The anatomy of sprawl. Places 14(2): 28-37.

Schneider, K. 2009. How the availability of nutrients and energy influence the biodiversity of cave ecosystems. Ph.D. Dissertation. University of Maryland, College Park. 174 pp.

Schneider, K. and D.C. Culver. 2004. Estimating subterranean species richness using intensive sampling and rarefaction curves in a high density cave region in West Virginia. Journal of Cave and Karst Studies 66 (2): 39-45.

Schomann, A., K. Afflerbach, and O. Betz. 2008. Predatory behaviour of some central European pselaphine beetles (Coleoptera: Staphylinidae: Pselaphinae) with descriptions of relevant morphological features of their heads. European Journal of Entomology 105: 889-907.

Sendra, A., A. Jíménez-Valverde, J. Rochat, V. Legros, S. Gasnier, and G. Cazanove. 2017a. A new and remarkable troglobitic *Lepidocampa* Oudemans, 1890 species from La Réunion Island, with a discussion on troglobiomorphic adaptations in campodeids (Diplura). Zoologischer Anzeiger 266: 95-104.

Sendra, A. B. Sket, and P. Stoev. 2017b. A striking new genus and species of troglobitic Campodeidae (Diplura) from central Asia. Subterranean Biology 23: 47-68.

Service (U.S. Fish and Wildlife Service). 1994. Recovery plan for endangered karst invertebrates in Travis and Williamson counties, Texas. 25 August 1994. USFWS Region 2 Office, Albuquerque, NM. 154 pp.

Service (U.S. Fish and Wildlife Service). 2009. Tooth Cave ground beetle (*Rhadine persephone*) 5 year review: Summary and evaluation. USFWS, Austin Ecological Services Field Office, Austin, TX. 15 pp.

Service (U.S. Fish and Wildlife Service). 2011. Bexar County karst invertebrates recovery plan. USFWS, Southwest Region, Albuquerque, NM. 53 pp.

Service (U.S. Fish and Wildlife Service). 2012. Karst preserve design recommendations. Austin Ecological Services Field Office. 25 pp.

Service (U.S. Fish and Wildlife Service). 2014. Karst preserve management and monitoring recommendations. Austin Ecological Services Field Office. 12 pp.

Service (U.S. Fish and Wildlife Service). 2018. Species status assessment for the Bone Cave harvestman (*Texella reyesi*). Version 1.0 April 2018. Austin, TX. 157 pp.

Sharratt, N.J., M.D. Picker, and M.J. Samways. 2000. The invertebrate fauna of the sandstone caves of the Cape Peninsula (South Africa): patterns of endemism and conservation priorities. Biodiversity and Conservation 9: 107-143.

Simões, M.H., M. Souza-Silva, and R.L. Ferreira. 2014. Cave invertebrates in northwestern Minas Gerais State, Brazil, Endemism, threats and conservation priorities. Acta Carsologica 43(10): 159-174.

Souza, M.F.V.R. and R.L. Ferreira. 2016. Tw new troglobitic palpigrades (Palpigradi: Eukoeneniidae) from Brazil. Zootaxa 4171(2): 246-258.

Stafford, K.W., K. Arens, A. Gluesenkamp, O. Knox, J. Mitchell, J. Reddell, A.M. Scott, J. Kennedy, M. Miller, W.H. Russell, P. Sprouse, and G. Veni. 2014. Karst of the Urban Corridor: Bell, Bexar, Comal, Hays, Travis, and Williamson Counties, Texas. Karst Awareness and Education Series, 1: Austin, Texas, Texas Speleological Survey. 110 pp.

Stoev, P., N. Akkari, A. Komerički, G.D. Edgecombe, and L. Bonato. 2015. At the end of the rope: *Geophilus hadesi* sp. n. – the world's deepest cave-dwelling centipede (Chilopoda, Geophilomorpha, Geophilidae). ZooKeys 510: 95-114.

Taylor, S.J., K. Hackley, J. Krejca, M.J. Dreslik, S.E. Greenberg, and E.L. Raboin. 2004. Examining the role of cave crickets (Rhaphidophoridae) in central Texas cave ecosystems: isotope ratios (δ 13C, δ15N) and radio tracking. Illinois Natural History Survey, Center for Biodiversity Technical Report 2004 (9): 1-128.

Taylor, S.J., J.K. Krejca, and M.L. Denight. 2005. Foraging range and habitat use of *Ceuthophilus secretus* (Orthoptera: Rhaphidophoridae), a key trogloxene in central Texas cave communities. American Midland Naturalist 154: 97-114.

Taylor, S.J., J.K. Krejca, and K. Hackley. 2007. Examining possible foraging distances in urban and rural cave cricket populations: carbon and nitrogen isotope ratios (δ13C, δ15N) as indicators of trophic level. Illinois Natural History Survey Technical Report 2007(59): 1-97.

Taylor, S.J., J.K. Krejca, J.E. Smith, V.R. Block, and F. Hutto. 2003. Investigation of the potential for Red Imported Fire Ant (*Solenopsis invicta*) impacts on rare karst invertebrates at Fort Hood, Texas: a field study. Illinois Natural History Survey, Center for Biodiversity Technical Report 2003(28):1-153.

Taylor, S.J., J.D. Weckstein, D.M. Takiya, J.K. Krejca, J.D. Murdoch, G. Veni, K.P. Johnson, and J.R. Reddell. 2007b. Phylogeography of cave crickets (*Ceuthophilus* spp.) in central Texas: a keystone taxon for the conservation and management of federally listed endangered caved arthropods. Illinois Natural History Survey, Center for Biodiversity Technical Report 2007(58): 1-45

Texas Demographic Center. 2014. Texas Population Projections Program. Retrieved on May 13, 2018 from http://osd.texas.gov/Data/TPEPP/Projections/.

Theobald, D.M. 2005. Landscape patterns of exurban growth in the USA from 1980 to 2020. Ecology and Society 10(1): 32. [online] URL: http://www.ecologyandsociety.org/vol110/iss1/art32/.

Theobald, D.M., J.R. Miller, and N.T. Hobbs. 1997. Estimating the cumulative effects of development on wildlife habitat. Landscape and Urban Planning 39: 25-36.

Tobin, B.W., B.T. Hutchins, and B.F. Schwartz. 2013. Spatial and temporal changes in invertebrate assemblage structure from the entrance to deep-cave zone of a temperate marble cave. International Journal of Speleology 42(3): 203-214.

Torrens, P.M. 2008. A toolkit for measuring sprawl. Applied Spatial Analysis and Policy 1: 5-36.

Trajano, E., J.E. Gallão, and M.E. Bichuette. 2016. Spots of high diversity of troglobites in Brazil: the challenge of measuring subterranean diversity. Biodiversity and Conservation 25: 1805-1828.

Turanchik, E.J. and T.C. Kane. 1979. Ecological genetics of the cave beetle *Neaphaenops tellkampfii* (Coleoptera: Carabidae). Oecologia 44(1): 63-67.

U.S. Census Bureau. 1982. 1980 Census of Population, Characteristics of the Population, Chapter A Number of Inhabitants, Part 45 Texas. U.S. Government Printing Office, Washington, D.C. 49 pp.

U.S. Census Bureau. 2012. 2010 Census of Population and Housing, Population and Housing Unit Counts, CPH-2-45, Texas. U.S. Government Printing Office, Washington, D.C.

U.S. Census Bureau. 2018a. New census bureau population estimates show Dallas-Fort Worth-Arlington has largest growth in the United States. Retrieved on May 3, 2018 at https://www.census.gov/newsroom/press-releases/2018/popest-metro-county.html.

U.S. Census Bureau. 2018b. Travis County: annual estimates of housing units for the United States, regions, divisions, states, and counties: April 1, 2010 to July 1, 2016. Retrieved on May 3, 2018 at https://factfinder.census.gov.

U.S. Census Bureau. 2018c. Travis County: annual estimates of the resident population: April 1, 2010 to July 1, 2017. Retrieved on May 3, 2018 at https://factfinder.census.gov.

U.S. Census Bureau. 2018d. Williamson County: annual estimates of housing units for the United States, regions, divisions, states, and counties: April 1, 2010 to July 1, 2016. Retrieved on May 3, 2018 at https://factfinder.census.gov.

U.S. Census Bureau. 2018e. Williamson County: annual estimates of the resident population: April 1, 2010 to July 1, 2017. Retrieved on May 3, 2018 at https://factfinder.census.gov.

Urban Land Institute. 2016. Housing in the Evolving American Suburb. Washington, DC: Urban Land Institute. 47 pp.

Veni, G. 2003. Delineation of hydrogeologic areas and zones for the management and recovery of endangered karst invertebrate species in Bexar County, Texas. Report for U.S. Fish and Wildlife Service, Austin, Texas. Dated 23 December 2002 with minor revisions submitted 12 April 2003.

Veni and Associates. 1992. Geologic controls on cave development and the distribution of cave fauna in the Austin, Texas, region. Revised February 1992. USFWS Austin, Texas. 77 pp.

Veni, G., J.R. Reddell, and J.C. Cokendolpher. 1999. Management plan for the conservation of rare and endangered karst species, Camp Bullis, Bexar and Comal counties, Texas. Report prepared for Garrison Public Works, Fort Sam Houston, Texas. 160 pp.

Wakefield, K.R. and K.S. Zigler. 2012. Obligate subterranean fauna of Carter State Natural Area, Franklin County, Tennessee. Speleobiology Notes 4: 24-28.

Waltham, T. and Z. Lu. 2007. Natural and anthropogenic rock collapse over open caves. Pages 13-21 in Parise, M. and J. Gunn, editors. Natural and Anthropogenic Hazards in Karst Areas: Recognition, Analysis and Mitigation. Geological Society, London, Special Publications. 202 pp.

Wang, Z., L. Moshman, E.C. Kraus, B.E. Wilson, N. Acharya, and R. Diaz. 2016. A review of the tawny crazy ant, *Nylanderia fulva*, an emergent ant invader in the southern United States: is biological control a feasible option? Insects 7(4): 1-10.

Watson, J., E. Hamilton-Smith, D. Gillieson, and K. Kiernan. 1997. Guidelines for cave and karst protection. International Union for Conservation of Nature and Natural Resources. 53 pp.

Weinstein, P. 1994. Behavioral ecology of tropical cave cockroaches: preliminary field studies with evolutionary mechanisms. Journal of Australian Entomological Science 33: 367-370.

Wynne, J.J. 2013. Inventory, conservation, and management of lava tubes at El Malpais National Monument, New Mexico. Park Science 30(1): 45-55.

Yoder, J.A., J.B. Benoit, M.J. LaCagnin, H.H. Hobbs III. 2011. Increased cave dwelling reduces the ability of cave crickets to resist dehydration. Journal of Comparative Physiology B 181: 595-601.

Zipperer, W.C. 2011. The process of natural succession in urban areas. Pages 187-197 in Douglas, I., D. Goode, M. Houck, and R. Wang, editors. The Routledge Handbook on Urban Ecology. Routledge Taylor and Francis Group, London. 688 pp.

U.S. FISH AND WILDLIFE SERVICE
5-YEAR REVIEW of the Tooth Cave Ground Beetle (*Rhadine persephone*)

Current Classification: Endangered

Recommendation resulting from the 5-Year Review:

____ Downlist to Threatened
____ Uplist to Endangered
____ Delist
__X__ No change needed

Review Conducted By: Michael Warriner and Jenny Wilson, Austin Ecological Services Field Office.

FIELD OFFICE APPROVAL:

Lead Field Supervisor, Fish and Wildlife Service

Approve________________________________ Date July 6, 2018