Bone Cave Harvestman
(*Texella reyesi*)

5-Year Review:
Summary and Evaluation

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

5-YEAR REVIEW
Bone Cave Harvestman (*Texella reyesi*)

1.0 GENERAL INFORMATION

1.1 Reviewers

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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 April 15, 2015 (80 FR 20241). A species status assessment for the Bone Cave harvestman was completed by the Austin Ecological Services Field Office in 2018 (Service 2018, entire) and its methodology and results inform this 5-year review. The framework of a species status assessment (Service 2016, entire; Smith et al. 2018, entire) is intended to support an in-depth review of a species' biology and threats, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability.

1.3 Background:

The Bone Cave harvestman (Opiliones: Laniatores: Phalangodidae: *Texella reyesi* Ubick and Briggs 1992) is one of 28 species within the North American genus *Texella* (Ubick and Briggs 1992, entire; Ubick and Briggs 2004, entire). Prior to 1992, the genus contained just two described species, *T. mulaiki* and *T. reddelli* the Bee Creek Cave harvestman (Goodnight and Goodnight 1967, pp. 5-8; Ubick and Briggs 1992, pp. 155-156), both endemic to the Edwards Plateau of central Texas. Ubick and Briggs (1992, entire) revised the genus resulting in the re-description of *T. mulaiki* and the Bee Creek Cave harvestman as well as descriptions of 18 new *Texella* species from California, New Mexico, Oregon, and Texas. A subset of individuals previously assigned to *T. mulaiki* and the Bee Creek Cave harvestman were determined to constitute a new species, the Bone Cave harvestman (Ubick and Briggs 1992, p. 203).

The Bone Cave harvestman is endemic to a restricted range in the Balcones Canyonlands ecoregion of Texas, specifically portions of Travis and Williamson counties (Figure 1; Ubick and Briggs 2004, p. 114). 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 Bone Cave harvestman is a troglobite (i.e., species that spends its entire life-cycle underground) that inhabits caves and other subterranean voids (Ubick and Briggs 1992, pp. 211-221; Ubick and Briggs 2004, p. 116). The harvestman is most associated with the deep cave zone of caves (Ubick and Briggs 1992, p. 211) and displays a high degree of morphological adaptation to subterranean environments (i.e., troglomorphy) including leg elongation, increased number of tarsomeres, eye reduction, and reduced number of protuberances on the carapace (Ubick and Briggs 1992, pp. 165, 167-168, 211). Ubick and Briggs (1992, p. 211) noted that troglomorphic traits in the Bone Cave harvestman were clinal with northernmost populations in Williamson County exhibiting higher degrees of troglomorphy (i.e., partial or complete absence of cornea) than those to the south in Travis County (Ubick and Briggs 1992, p. 224).

Studies indicate that troglobitic arthropods display preferences for higher relative humidity and/or lower air temperatures, underscoring a dependence on deep cave conditions (Bull and Mitchell 1972, pp. 375, 386; Yoder et al. 2011, p. 15; Mammola et al. 2015, pp. 246-247; Mammola and Isaia 2017, p. 3). Bone Cave harvestmen likely require subterranean habitats with high humidity and stable temperatures (Curtis and Machado 2007, pp. 285-286; Machado and Macías-Ordóñez 2007, p. 409; Willemart et al. 2009, p. 219). 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).

The Bone Cave harvestman likely requires a source of food in the form of invertebrates or other organic matter (Edgar 1971, pp 29-30; Hillyard and Sankey 1989, pp. 16-17; Acosta and Machado 2007, pp. 310-320). The majority of nutrients that support cave 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 cave ecosystems 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 food 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 cave 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). The natural foraging habitat surrounding a cave is vital to the maintenance of cave cricket populations (Taylor et al. 2007, 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).

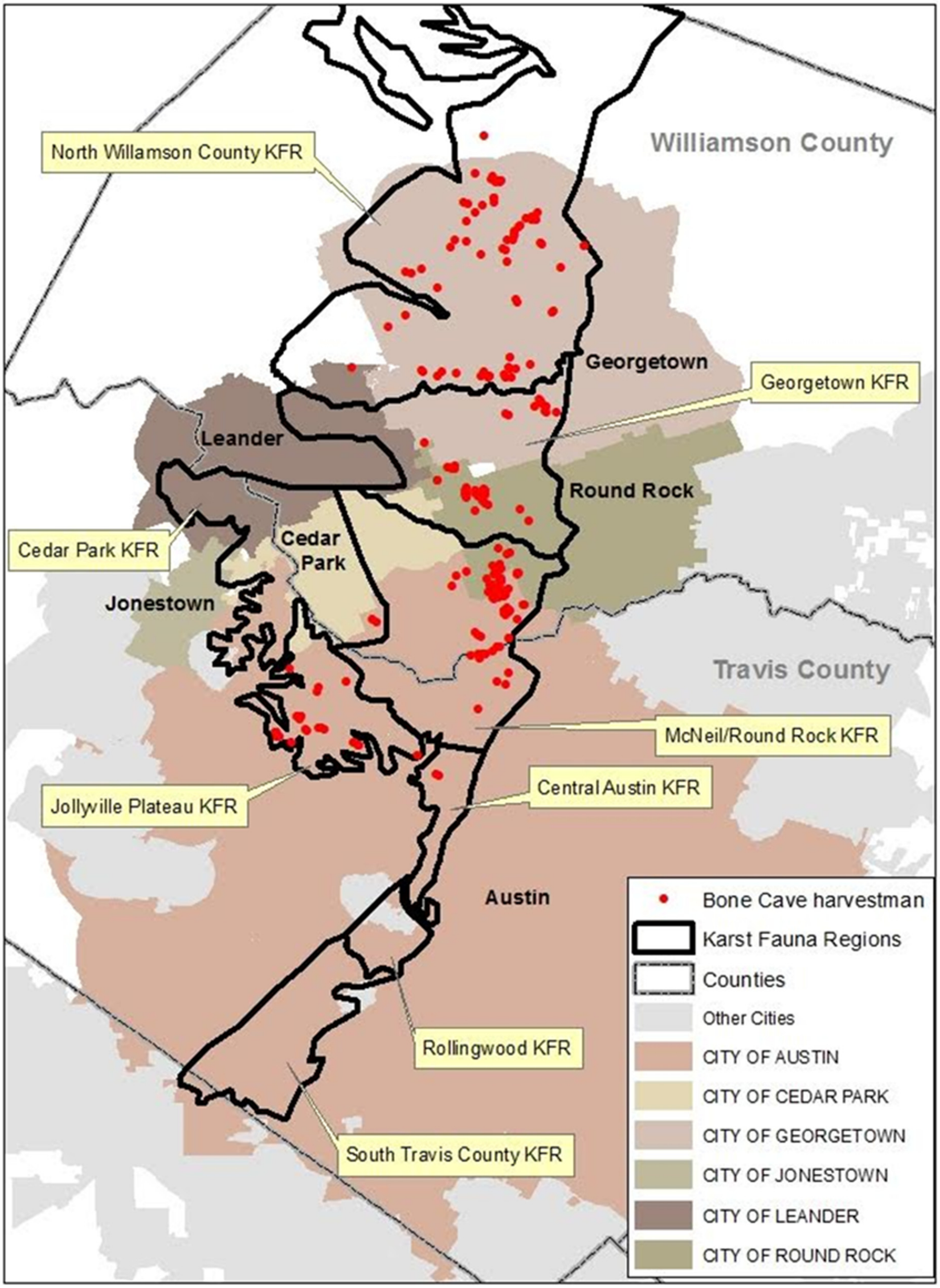
The Bee Creek Cave Harvestman was listed as endangered on September 16, 1988, due to its restricted distribution and threats from urban development (53 FR 36029-36033). A technical correction was published on August 18, 1993 (58 FR 43818-43819) that added the Bone Cave harvestman to the List of Endangered and Threatened Wildlife. The stressors that most influence Bone Cave harvestman 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). The rapidly growing municipalities of Austin, Georgetown, Leander, and Round Rock overlay the Bone Cave harvestman's distribution. 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 2018d).

Figure 1. Distribution of the Bone Cave harvestman in Travis and Williamson counties, Texas.



1.3.1 FR Notice citation announcing initiation of this review:

80 FR 20241, April 15, 2015

1.3.2 Listing history

Original Listing
FR notice: 53 FR 36029
Date listed: September 16, 1988 (Technical correction: August 18, 1993)
Entity listed: Bone Cave harvestman (*Texella reyesi*)
Classification: Endangered

1.3.3 Associated rulemakings:

A technical correction published on August 18, 1993 in the Federal Register (58 FR 43818) added the Bone Cave harvestman to the List of Endangered and Threatened Wildlife. That species had previously been listed as endangered as part of the Bee Creek Cave harvestman. The Bone Cave harvestman was described from specimens previously considered as the Bee Creek Cave harvestman. The technical correction was made to ensure that the Bone Cave harvestman continued to receive protection under the Act as it faced the same threats as the Bee Creek Cave harvestman.

1.3.4 Review history:

Status reviews for the Bone Cave harvestman 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), 2009 for a 5-year review (Service 2009, entire), and 2018 for a species status assessment (Service 2018, 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 Bone Cave harvestman 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 Bone Cave harvestman occurs in six of the eight karst fauna regions demarcated for Travis and Williamson counties (Figure 1). From north to south, the regions occupied by the harvestman are the North Williamson County, Georgetown, McNeil/Round Rock, Cedar Park, Jollyville Plateau, and Central Austin Karst Fauna Regions (Service 1994, p. 33).

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 impact 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 Bone Cave harvestman 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 (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 Bone Cave harvestman 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 temperature
- 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 Bone Cave harvestman, one karst fauna area, Priscilla's Well Karst Fauna Area, had been established in the North Williamson County Karst Fauna Region (Service 2009, p. 5). No karst fauna area(s) had been proposed or established in the Cedar Park, Central Austin, Georgetown, Jollyville Plateau, or McNeil/Round Rock Karst Fauna Regions. The 5-year review identified 20 sites that had the potential to meet the definition of karst fauna area (Service 2009, pp. 5-12). However, insufficient information was available regarding surface and subsurface drainage basin delineations, confirmation of Bone Cave harvestman presence, tract acreage, management and perpetual protection mechanisms to determine if those sites met qualifying criteria.

As of the 2018 species status assessment (Service 2018, pp. 54, 71), four karst fauna areas have been established in the North Williamson County Karst Fauna Region and are Cobb's Cavern, Karankawa, Priscilla's Well, and Twin Springs Karst Fauna Areas (Table 1). A fifth site, Shaman Karst Preserve, has been proposed for designation as a karst fauna area in that same region and is pending final recognition. Two sites, Millennium and Wilco Cave Clusters, have been proposed for recognition as karst fauna areas in the Georgetown Karst Fauna Region. No karst fauna areas have been established or proposed in the Cedar Park, Central Austin, Jollyville Plateau, or McNeil/Round Rock Karst Fauna Regions.

The species status assessment identified 28 sites, of sufficient resiliency (i.e., high or moderate), which have potential to be karst fauna areas. Nine sites in the Jollyville Plateau Karst Fauna Region receive some level of protection through the Balcones Canyonlands Preserve. Most remaining sites in the Georgetown, McNeil/Round Rock, and North Williamson County Karst Fauna Regions are not protected and susceptible to conversion to development. Although of sufficient quality and resiliency, none of these sites are recognized karst fauna areas at present. To receive that recognition, we would need additional information to determine if these sites meet qualifying criteria including surface and subsurface drainage basin delineations, cave location(s), confirmation of Bone Cave harvestman presence, tract acreage, management and perpetual protection mechanisms, among others.

Of the six karst fauna regions occupied by the Bone Cave harvestman, the North Williamson County Karst Fauna Region is the only region that has met recovery criterion 1 with at least three karst fauna areas protected in perpetuity. At least three of these sites have been karst fauna areas for more than five years meeting recovery criterion 2.

Table 1. Potential, proposed, and protected karst fauna areas by karst fauna region (Source: Service 2018).

Karst Fauna Region	Potential Karst Fauna Area(s)	Proposed Karst Fauna Area(s)	Protected Karst Fauna Area(s)
North Williamson County	8	1	4[a]
Georgetown	2	2	0
McNeil/Round Rock	9	0	0
Jollyville Plateau	9	0	0
Cedar Park	0	0	0
Central Austin	0	0	0

[a] Recovery criteria 1 and 2 achieved.

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 Bone Cave harvestman was conducted at Lakeline and Temples of Thor Caves in Williamson County from 1992-2013 (Zara Environmental 2014, entire). Numbers of Bone Cave harvestman observed at Lakeline Cave declined over that 21-year period (Zara Environmental 2014, p. 10). The numbers of observed Bone Cave harvestmen at Temples of Thor Cave increased over that same time span (Zara Environmental 2014, p. 11). During the monitoring effort, numbers of cave crickets observed at both sites declined (Zara Environmental 2014, p. 12). However, cave cricket numbers were substantially lower most years at Lakeline Cave. In 2013, for example, 87 cave crickets were tallied at Lakeline Cave while 955 crickets were counted at Temples of Thor Cave (Zara Environmental 2014, pp. 12-13, 16). Zara Environmental (2014, pp. 14-16) postulated that Temples of Thor Cave may have benefited from additional nutrient input in the form of vertebrate (i.e., mammal) carcasses and scats, red-imported fire ant control, and the caves location in a larger tract of natural surface habitat (40+ ha (100+ [ac]). Lakeline Cave is surrounded by a very small patch of surface habitat (1.2 ha [3 ac]) and may have been impacted by increased urbanization although that was not directly assessed during these monitoring efforts (Zara Environmental 2014, p. 15).

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

Hedin and Thomas (2010, entire) examined phylogenetic relationships among southeastern North American genera of the family Phalangodidae using mitochondrial and nuclear DNA. The Bone Cave harvestman, and some other more western taxa, were included in those analyses (Hedin and Thomas 2010, pp. 108, 110, 112-115, 117-119). Genetic analyses did not find conclusive support for a bifurcate clade, per Ubick and Briggs (2008, pp. 2), that includes *Texella* (Hedin and Thomas 2010, pp. 112-113, 117).

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 Bone Cave harvestman listed 168 caves with records of that species (Service 2009, pp. 2, 5). That total number of caves was in error with the review actually listing 165 caves. The 2018 species status assessment completed for the Bone Cave harvestman compiled and reviewed records for the species across its range. We assessed confirmation of the harvestman at a site through vouchered specimens of adult males, females, or unsexed juveniles deposited in museum collections or documented sight records where no specimens were collected.

Review for the species status assessment resulted in a list of 203 individual caves or karst features with records of the Bone Cave harvestman (Service 2018, pp. 127-157). Five caves cited in the 5-year review (i.e., Barker Ranch No. 1, Joker, Snake Dancer, Step Down, and Through Trip Caves), were excluded as we could not verify species presence at those sites. Six caves treated as individual sites (i.e., Beck Bat, Beck Crevice, Beck Tin Can, Beck Sewer, North Root, and Root Caves) in the 5-year review were determined to be entrances or openings to the same cave systems. We combined those six caves into three caves (i.e., Beck Bat/Beck Crevice, Beck Sewer, and Root/North Root Caves). Nine caves were physically destroyed but are included in the total number of caves.

The list of 203 individual caves includes 46 sites identified since the 5-year review. These 46 occurrences represent records that were not documented during the 5-year review, new occurrences discovered or reported since 2009, and/or instances where identity of collected species were confirmed by experts after 2009. The increase in confirmed occurrences does not extend the species' range beyond Travis and Williams counties. Several sites documented since 2009 occur in close proximity to previously known locations. The Bone Cave harvestman was determined to not occur at Barker Ranch No. 1 Cave in the South Travis County Karst Fauna Region, which removes that region from the species' distribution. As a result, the Bone Cave harvestman is considered to occur in six karst fauna regions instead of the seven regions noted in the 5-year review (Service 2009 pp. 4-5).

An important consideration of the species status assessment was whether occupied caves warranted consolidation into single populations based on geographic proximity (Service 2018, pp. 24, 49-50). Although there is no data specific to the Bone Cave harvestman, 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). 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 such as 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 Bone Cave harvestman, 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 Bone Cave harvestman 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 Bone Cave harvestman, 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 Bone Cave harvestman 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 71 cave clusters and individual caves (Table 2; Service p. 71). Of that total, four individual caves have been physically destroyed bringing the number of extant occupied sites to 67 cave clusters and individual caves.

Table 2. Cave clusters and individual caves by karst fauna region (Source: Service 2018).

Karst Fauna Region	**Cave Cluster(s)**	**Individual Cave(s)**
North Williamson County	14	18
Georgetown	5	5
McNeil/Round Rock	7	10
Jollyville Plateau	6	4
Cedar Park	1	0
Central Austin	1	0

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

The 2018 species status assessment evaluated the condition (i.e., resiliency) of sites (i.e., cave clusters and individual caves) occupied by the Bone Cave harvestman (Service 2018, pp. 49-71). The population needs of the Bone Cave harvestman 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 Bone Cave harvestman are unavailable, nor do we know what reproductive rates sustain a healthy population, the species status assessment 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 the species status assessment methodology, analysis, and results, see Service (2018, pp. 31-32, 49-71).

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 the Bone Cave harvestman's species status assessment, 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 physically destroyed caves and assumed those caves would no longer support Bone Cave harvestman 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 Bone Cave harvestman 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 Bone Cave harvestman over the long-term.

Impacts to a cave's surface or subsurface drainage basin can be a significant source of stressors for Bone Cave harvestman 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 Bone Cave harvestman population persistence.

The analyses indicate that 26 of the 67 extant Bone Cave harvestman cave clusters and individual cave sites are impaired (Table 3, Figure 2). Several of those sites fall below 3.6 ha (9 ac) in size and, due to degraded cave cricket foraging area, potential edge effects, and isolation from other habitat patches, may be unable to support Bone Cave harvestman populations over the long-term. We do not expect these sites to increase in resiliency in the future. These sites are adjacent to commercial development, single and multi-family housing, and/or roadways that are unlikely to be restored to natural or semi-natural habitats. Five sites are considered low resiliency with reduced open space and altered cave cricket foraging areas. It is unlikely that these sites would improve in resiliency given adjacent development and may decline in quality over time. In summation, 31 of the 67 extant occupied sites range-wide have reduced potential for species persistence.

Based on our review, 36 cave clusters and individual caves are currently of sufficient resiliency (i.e., high to moderate) to potentially support Bone Cave harvestman populations over the long-term. For the most part, these sites are located in larger tracts of open space and have relatively unaltered cave cricket foraging areas. Four of these sites have perpetual protection as karst fauna areas and three additional sites may be recognized as karst fauna areas as more information becomes available. Nine sites within the Balcones Canyonlands Preserve may approximate karst fauna areas given further assessment. The remaining 20 unprotected high to moderate resiliency sites are potentially of sufficient quality to support persistent Bone Cave harvestman populations. However, in the absence of perpetual protection, it is unlikely that the current resiliency of those sites can be maintained over the long-term given rapid human population growth and increasing development pressures.

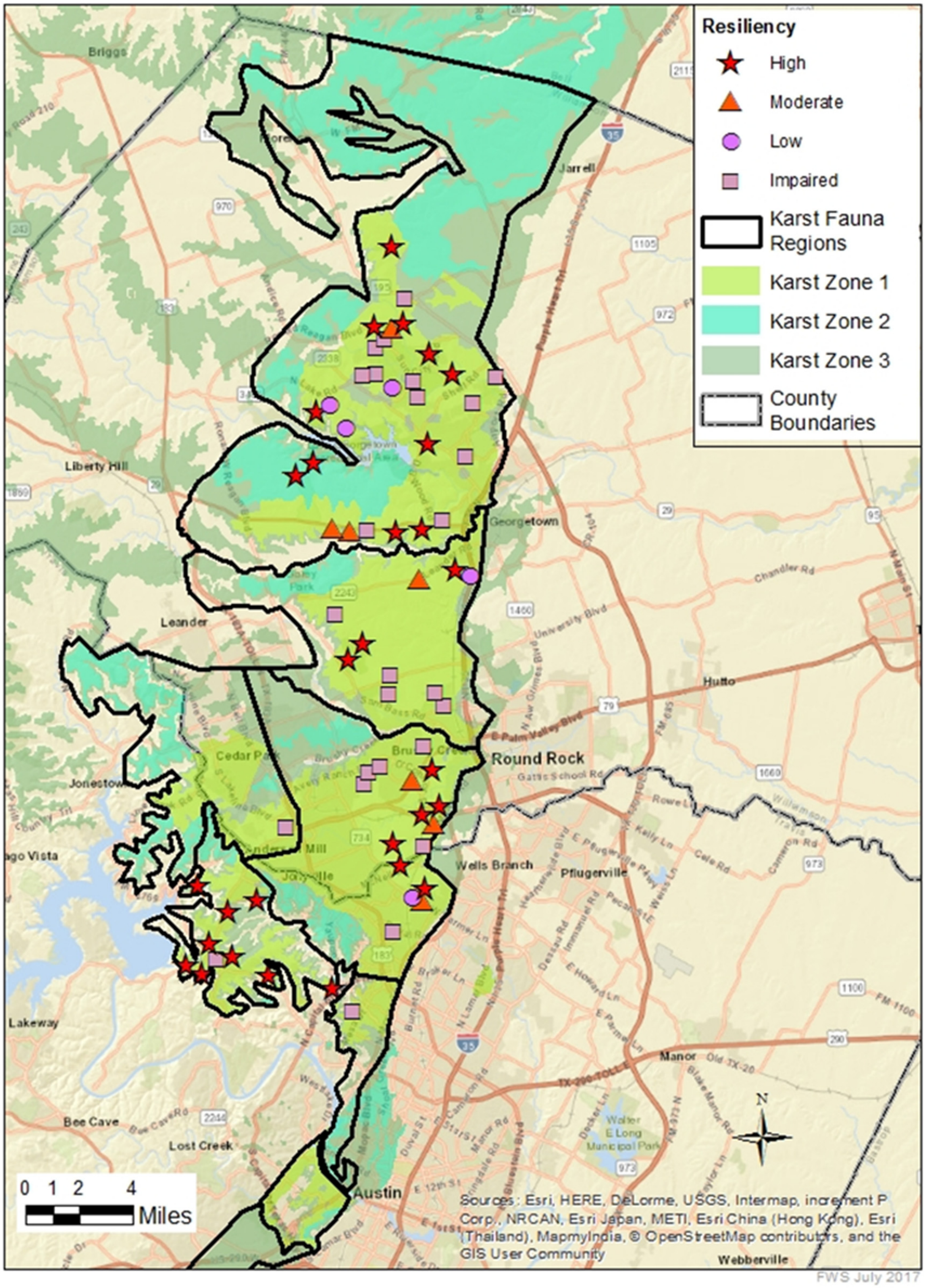
Table 3. Current resiliency of Bone Cave harvestman sites (cave clusters and individual caves) by karst fauna region (Source: Service 2018).

Karst Fauna Region	High	Moderate	Low	Impaired	Destroyed
North Williamson County	11	3	3	12	3
Georgetown	3	1	1	5	0
McNeil/Round Rock	6	3	1	6	1
Jollyville Plateau	8	1	0	1	0
Cedar Park	0	0	0	1	0
Central Austin	0	0	0	1	0
Total	**28**	**8**	**5**	**26**	**4**

2.3.1.7 Other:

No new information.

Figure 2. Current resiliency of Bone Cave harvestman caves and cave clusters in Travis and Williamson counties, Texas (Source: Service 2018).



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 Bone Cave harvestman 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 2016). 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 2017). 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. 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/yr [20,790 ac/yr]) and greatest annual net increase in impervious cover (12,092 ha/yr [29,880 ac/yr]) 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 1,367,879 people by 2045 (City of Austin 2016), an increase of 44% over 27 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 Georgetown's population is expected to reach 96,567 people by 2030 (City of Georgetown 2017), an increase of 60% over 12 years. Projections suggest other cities in Williamson County will grow substantially in population as well. Round Rock is expected to reach 158,217 people by 2030 (City of Round Rock 2017), an increase of 46% over 12 years. Cedar Park is expected to reach 85,619 people by 2030 (City of Cedar Park 2016), an increase 21% of over 12 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 Bone Cave harvestman, 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 Bone Cave harvestman population viability and the species' long-term persistence. Land conversion to development has already reduced and degraded surface habitats surrounding a large number of occupied sites (Service 2018, p. 71). Given population and urbanized land growth projections (Texas Demographic Center 2014; Nowak and Greenfield 2018, p. 170), it is likely that remaining surface and subsurface habitats will be impacted in the absence of management and protection.

The Bone Cave harvestman's species status assessment (Service 2018, pp. 73-88) forecasted future resiliency, redundancy, and representation for the Bone Cave harvestman in each occupied karst fauna region under three potential scenarios. The scenarios evaluated three levels of conservation effort with Scenario 1 exploring increased conservation effort, Scenario 2 reduced conservation effort, and Scenario 3 no conservation effort. These scenarios forecast viability of the species from the present to the year 2050, the end date for Travis and Williamson counties human population projections.

We evaluated aerial imagery of each cave cluster and individual cave site for extent of existing or in-progress residential and/or commercial development. Patches of surrounding open space were assessed for the presence of existing roadways or in-progress roadway construction that may influence future development of those sites. We also applied information from our files regarding approved or proposed development projects to evaluate potential future impacts to open space surrounding cave clusters or individual cave sites.

We assumed that, in the absence of protection, open space with natural vegetation adjacent to development or moderately to heavily travelled roadways would be susceptible to conversion to urban, suburban, or exurban land uses. Potential targets for protection under the three scenarios were restricted to high and moderate resiliency sites as these areas offer the greatest potential for Bone Cave harvestman persistence. The actuality of these scenarios depends on external parties implementing sufficient permanent protection for high and moderate resiliency sites.

Under Scenario 1, development activities and lack of protection degrades resiliency in the North Williamson County Karst Fauna Region to four high and eight moderate resiliency sites. Most sites in the Jollyville Plateau Karst Fauna Region continue to benefit from protection within the Balcones Canyonlands Preserve, with seven high and two moderate resiliency sites remaining in this region. The Georgetown Karst Fauna Region continues to support one high and one moderate resiliency site. One high resiliency site in that karst fauna region degrades in quality to low resiliency in the absence of protection. Development activity degrades resiliency of several sites in the McNeil/Round Rock Karst Fauna Region with only five moderate resiliency sites remaining in that region. No high to moderate resiliency sites exist in either the Cedar Park or Central Austin Karst Fauna Regions.

In this scenario, three of the six karst fauna regions occupied by the Bone Cave harvestman are characterized by multiple resilient populations. Low redundancy in the Georgetown Karst Fauna Region reduces species representation in that region as catastrophic events could eliminate one or both protected sites due to their close proximity. Stability and potential long-term persistence of the Bone Cave harvestman is most probable in the Jollyville Plateau and North Williamson County Karst Fauna Regions with the protection of numerous high resiliency sites. The McNeil/Round Rock Karst Fauna Region contains only moderate resiliency sites. These sites may require intensive management and monitoring to maintain ecological integrity and ensure Bone Cave harvestman persistence. Species representation at high and moderate resiliency sites is lost in the Cedar Park and Central Austin Karst Fauna Regions.

In Scenario 2, development activities and lack of protection degrades resiliency in the North Williamson County Karst Fauna Region to three high and five moderate resiliency sites. Most sites in the Jollyville Plateau Karst Fauna Region continue to benefit from protection within the Balcones Canyonlands Preserve, with seven high and two moderate resiliency sites remaining in this region. The Georgetown Karst Fauna Region continues to support one high and one moderate resiliency site. One high resiliency site in this karst fauna region degrades in quality to impaired in the absence of protection. High and moderate resiliency sites in the McNeil/Round Rock Karst Fauna Region decline in quality to low resiliency or impaired due to increased development. No high to moderate resiliency sites exist in either the Cedar Park or Central Austin Karst Fauna Regions.

In this scenario, stability and potential long-term persistence of the Bone Cave harvestman is only probable in the Jollyville Plateau and North Williamson County Karst Fauna Regions, the southwestern and northern limits of the species range, respectively. Low redundancy in the Georgetown Karst Fauna Region reduces species representation in that region as catastrophic events could eliminate one or both protected sites due to their close proximity. Species representation at high and moderate resiliency sites is lost in the Cedar Park, Central Austin, and McNeil/Round Rock Karst Fauna Regions.

In Scenario 3, development activities and lack of protection degrades resiliency in the North Williamson County Karst Fauna Region to three high and four moderate resiliency sites. Most sites in the Jollyville Plateau Karst Fauna Region continue to benefit from protection within the Balcones Canyonlands Preserve, with seven high and two moderate resiliency sites remaining in this region. In the Georgetown Karst Fauna Region, high and moderate resiliency sites degrade in quality to impaired or are destroyed due to development activities. High and moderate resiliency sites in the McNeil/Round Rock Karst Fauna Region decline in quality to low resiliency or impaired due to increased development. No high to moderate resiliency sites exist in either the Cedar Park or Central Austin Karst Fauna Regions.

In this scenario, stability and potential long-term persistence of the Bone Cave harvestman is only probable in the Jollyville Plateau and North Williamson County Karst Fauna Regions, the southwestern and northern limits of the species range, respectively. Species representation at high and moderate resiliency sites is lost in the Cedar Park, Central Austin, Georgetown and McNeil/Round Rock Karst Fauna Regions.

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

No new information.

2.3.2.3 Disease or predation:

The 2018 species status assessment contains a detailed discussion of the potential impacts of red-imported fire ants on the Bone Cave harvestman (Service 2018, pp. 39-46). 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), the latter cave occupied by the Bone Cave harvestman. 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 Bone Cave harvestman populations.

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 Bone Cave harvestman occurs at 67 extant cave clusters and individual caves in Travis and Williamson counties (Service 2018, p 71). Of that total, 31 sites are low resiliency or impaired. Urban, suburban, and exurban development in the rapidly growing Austin-Round Rock metropolitan area has resulted in loss and degradation of surface and subsurface habitats and is an ongoing source of stressors 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 Bone Cave harvestman over the long-term.

There are currently 36 cave clusters and individual caves of high to moderate resiliency with potential to support viable Bone Cave harvestman 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 Bone Cave harvestman 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.

Since the Bone Cave harvestman's 5-year review in 2009, there has been substantial progress in the establishment of karst fauna areas in the North Williamson County Karst Fauna Region. Significant efforts by the Williamson County Conservation Foundation have resulted in the perpetual protection of four karst fauna areas in that region. A fifth site is pending final recognition in that region as well. At least three karst fauna areas in the North Williamson County Karst Fauna Region have held that status for five or more years. At present, the North Williamson County Karst Fauna Region is the only region, of the six occupied karst fauna regions, that has met recovery criterion 1 and 2.

The Williamson County Conservation Foundation has initiated protection efforts in the Georgetown Karst Fauna Region. Two sites there are proposed for recognition as the region's first karst fauna areas. The Balcones Canyonlands Preserve contributes to the current resiliency of nine sites in that region. Those Bone Cave harvestman sites are located in areas of Travis County that have experienced substantial urban development. The protections provided by the preserve system have maintained large amounts of open space surrounding most of these caves and the integrity of cave cricket foraging habitat. If at least three sites in the Balcones Canyonlands Preserve qualified and were recognized as karst fauna areas, recovery criterion 1 could be met for the Jollyville Plateau Karst Fauna Region. If those sites are determined to be karst fauna areas, information related to recovery criterion 2 (i.e., criterion (1) has been maintained for at least five consecutive years with assurances that these areas will remain protected in perpetuity) should be gathered and implemented if achieved.

Distribution of the five currently protected karst fauna areas does not adequately capture Bone Cave harvest representation across the species' range. North Williamson County Karst Fauna Region represents the northern extent of the species' range, while the Jollyville Plateau Karst Fauna Region comprises the southwestern portion. Protection of representative sites within each occupied karst fauna region is important given the north to south morphological variation in Bone Cave harvestman populations. Establishment of sufficient karst fauna areas in the Georgetown Karst Fauna Region would provide critical representation for a north-central portion of the species' range

The McNeil/Round Rock Karst Fauna Region, also in the center of the species' range, lacks any karst fauna areas or protected areas. Absence of representation and redundancy in that region reduces the probability of Bone Cave harvestman persistence given the potential for increased development. Several high and moderate resiliency sites exist in the McNeil/Round Rock Karst Fauna Region that could be candidates for protection. Conservation efforts are critically needed in this region to secure representation of the species across its range and meet recovery criteria. Urbanization has resulted in the loss of high to moderate resiliency sites, potential candidates for karst fauna areas, in the Cedar Park and Central Austin Karst Fauna Regions.

Additional karst fauna areas are needed in other karst fauna regions occupied by the species to meet recovery criterion 1 as well as to enhance species redundancy and representation. Remaining unprotected high to moderate resiliency sites are potentially of sufficient quality to support persistent Bone Cave harvestman populations. However, in the absence of management and protection, it is unlikely that the current resiliency of most of these sites will be maintained over the next three decades given rapid human population growth and increasing development pressures (Texas Demographic Center 2014; Nowak and Greenfield 2018b, p. 170; Service 2018, pp. 72-90). At this time, we do not recommend a change in listing status for the Bone Cave harvestman.

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 Bone Cave harvestman 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. Following submission, review needed information to recognize Millennium, Shaman, and Wilco Karst Preserves as karst fauna areas.

II. Obtain information for nine sites within the Balcones Canyonlands Preserve (Jollyville Plateau Karst Fauna Region) 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 sites to be recognized as karst fauna areas.

III. Increase efforts to establish karst fauna areas or other protected sites for the Bone Cave harvestman in the Georgetown and McNeil/Round Rock Karst Fauna Regions. Protected areas in the latter region are especially needed to secure representation of the species across its range.

IV. Draft quantitative delisting criteria for the Bone Cave harvestman and other listed karst invertebrates in Travis and Williamson counties, Texas.

V. Apply recovery criterion 2 to karst fauna areas that qualify.

VI. 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.

VII. Assess genetic variation of Bone Cave harvestman populations across their range and evaluate in light of north to south morphological variation.

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U.S. FISH AND WILDLIFE SERVICE

5-YEAR REVIEW of the Bone Cave Harvestman (*Texella reyesi*)

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 June 28, 2018