Recovery Plan for Endangered Karst Invertebrates in Travis and Williamson Counties, Texas. Bee Creek Cave harvestman (*Texella reddelli*), Bone Cave harvestman (*Texella reyesi*), Coffin Cave mold beetle (*Batrisodes texanus*), Kretschmarr Cave mold beetle (*Texamaurops reddelli*), Tooth Cave spider (*Neoleptoneta myopica*), Tooth Cave ground beetle (*Rhadine persephone*), and Tooth Cave pseudoscorpion (*Tartarocreagris texana*).

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DRAFT AMENDMENT 1

We have identified best available information that indicates the need to amend recovery criteria for these species since the Endangered Karst Invertebrates (Travis and Williamson Counties, Texas) Recovery Plan (Recovery Plan) was completed. In this proposed modification, we synthesize the adequacy of the existing recovery criteria, show amended recovery criteria, and the rationale supporting the proposed recovery plan modification. The proposed modification is shown as an appendix that supplements the Recovery Plan, superseding only Section II, pages 86-88 of the Recovery Plan.

For
U.S. Fish and Wildlife Service
Southwest Region, Region 2
Albuquerque, New Mexico

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Approved: ___________DRAFT__________________________ Date: ____________________
Regional Director, Region 2
U.S. Fish and Wildlife Service

BACKGROUND INFORMATION

Recovery plans should be consulted frequently, used to initiate recovery activities, and updated as needed. A review of the recovery plan and its implementation may show that the plan is out of date or its usefulness is limited, and therefore warrants modification. Keeping recovery plans current ensures that the species benefits through timely, partner-coordinated implementation based on the best available information. The need for, and extent of, plan modifications will vary considerably among plans. Maintaining a useful and current recovery plan depends on the scope and complexity of the initial plan, the structure of the document, and the involvement of stakeholders.

An amendment involves a substantial rewrite of a portion of a recovery plan that changes any of the statutory elements. The need for an amendment may be triggered when, among other possibilities: (1) the current recovery plan is out of compliance with regard to statutory requirements; (2) new information has been identified, such as population-level threats to the species or previously unknown life history traits, that necessitates new or refined recovery actions and/or criteria; or (3) the current recovery plan is not achieving its objectives. The amendment replaces only that specific portion of the recovery plan, supplementing the existing recovery plan, but not completely replacing it. An amendment may be most appropriate if significant plan improvements are needed, but resources are too scarce to accomplish a full recovery plan revision in a short time.

Although it would be inappropriate for an amendment to include changes in the recovery program that contradict the approved recovery plan, it could incorporate study findings that enhance the scientific basis of the plan, or that reduce uncertainties as to the life history, threats, or species' response to management. An amendment could serve a critical function while awaiting a revised recovery plan by: (1) refining and/or prioritizing recovery actions that need to be emphasized, (2) refining recovery criteria, or (3) adding a species to a multispecies or ecosystem plan. An amendment can, therefore, efficiently balance resources spent on modifying a plan against those spent on managing implementation of ongoing recovery actions.

METHODOLOGY USED TO COMPLETE THE RECOVERY PLAN AMENDMENT

This recovery plan review and modification proposes to apply the same downlisting and delisting criteria developed for the Bexar County Karst Invertebrates Recovery Plan (Service, 2011, pp. 16-23) to recovery of the listed karst invertebrate species in Travis and Williamson counties. To develop the Bexar County Karst Invertebrates Recovery Plan, the Service convened a recovery team composed of federal and state agencies, non-governmental organizations, municipalities, private companies, and researchers. A draft of the recovery plan was published and distributed for public review and comment on May 16, 2008 (73 FR 28494). The plan was peer-reviewed by 10 subject matter experts. The final recovery plan was published on October 4, 2011 (77 FR 61379). The Bexar County Karst Invertebrates Recovery Plan represents the most current information regarding recovery of listed karst invertebrates in Bexar County, Texas and is applicable to listed karst invertebrate species with similar life-histories, ecological requirements, and threats in Travis and Williamson counties, Texas.

The habitats of listed karst invertebrates in Bexar, Travis, and Williamson counties, Texas are caves and smaller subterranean voids of the Balcones Canyonlands ecoregion of central Texas. 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; Jones and White 2012, pp. 430-431; 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).

Caves, specifically those with openings to the surface, can exhibit zonation with ecological and environmental variables decreasing (e.g., light, nutrients, temperature) or increasing (e.g., humidity, carbon dioxide) in magnitude with increasing distance from the surface (Howarth

1982, pp. 20-22; Howarth 1993, pp. 69-70; Mosely 2009b, pp. 55-56; Oster et al. 2012, p. 96; Tobin et al. 2013, pp. 206-207, 211; Battiston and Marzotto 2015, p. 713; Prous et al. 2015, pp. 179-181). Deeper cave zones are habitats generally typified by perpetual darkness, high relative humidity approaching saturation, and relatively stable temperatures that lag and are buffered from seasonal shifts on the surface (Barr 1968, pp. 47-50; Poulson and White 1969, p. 972; Culver 1982, pp. 9-10; Howarth 1983, pp. 372-374; Martín and Oromí 1986, p. 384; Culver and Pipan 2009, p. 3).

The absence of light in deep cave zones precludes photosynthetic activity by plants and associated primary production. Rather, nutrient sources found in these subterranean habitats are those actively (e.g., animals) or passively (e.g., gravity, water, or wind) transported in from overlying surface habitats (Barr 1967, p. 476; Barr 1968, pp. 51-60; Culver 1982, pp. 11-17; Poulson 2012, pp. 328-333; Culver and Pipan 2009, pp. 23-39). Deep cave zones can be nutrient poor or limited given unpredictable inputs from the surface and the patchy distribution of resources within subterranean voids (Barr 1967, pp. 476-477; Poulson 2012, pp. 323-324).

Environmental conditions in caves can exert selective pressure on animal species that use and reside in these subterranean systems (Aden 2005, pp. 1-3; Hervant and Malard 2005, pp. 10-16; Hüppop 2012, pp. 1-9). Adaptation to cave environments can result in a convergence of behavioral, morphological, and/or physiological traits termed troglomorphism (Howarth 1993, p. 67; Moore and Wilmer 1997, p. 15; Aden 2005, p. 2; Christiansen 2012, pp. 517-528; Howarth and Hoch 2012, pp. 9-17). Troglomorphic traits may include loss or reduction of eyes, elongated antennae and/or legs, loss of pigment, thinning of the exoskeleton, lower fecundity, increased egg size, lower metabolism, slower growth rates, longer life spans, and/or smaller populations (Poulson and White 1969, p. 977; Howarth 1980, pp. 397-398; Dickson and Holsinger 1981, pp. 45-46; Howarth 1983, pp. 374-376; Hüppop 1985, pp. 144-145; Hoch and Howarth 1989, pp. 397-399; Ubick and Briggs 1992, pp. 165, 167-168; Howarth 1993, p. 70; Northup et al. 1993, p. 528; Caccone and Sbordoni 2001, p. 129; Leys et al. 2003, p. 2819; Christiansen 2012, p. 517-520; Hüppop 2012, pp. 1-9; Miller 2005, pp. 568, 570; Mejía-Ortíz et al. 2006, pp. 261, 263; Arnedo et al. 2007, pp. 652-653; Lukić et al. 2010, pp. 13-14; Gallão and Bichuette 2016, pp. 8-10; Liu et al. 2017, pp. 13-14).

Troglomorphy has been documented in a range of aquatic and terrestrial arthropods, from arachnids (Howarth 1980, pp. 398-399; Hadley et al. 1981, p. 219; Kuntner et al. 1999, pp. 145, 147; Miller 2005, pp. 570-571; Reddell 2012, pp. 786-797; Volschenk and Prendini 2008, pp. 236, 248; Vignoli and Prendini 2009, p. 3; Gallão and Bichuette 2016, pp. 8-10; Shear and Warfel 2016, p. 12; Mammola and Isaia 2017, pp. 2-5), to crustaceans (Christiansen 1965, pp. 532, 537; Dickson and Holsinger 1981, p. 45; Fišer et al. 2013, pp. 773-778), to insects (Peck 1986, pp. 1024-1029; Studier et al. 1986, p. 434; Cyr et al. 1991, pp. 236, 238; Studier 1996, pp. 101, 107; Moldovan 2012, pp. 54-62; Faile and Pluot-Sigwalt 2015, pp. 2, 9-11). Commonality of troglomorphic adaptations to subterranean conditions suggests convergence in response to similar selective pressures (Christiansen 1961, p. 301; Howarth 1983, pp. 374-375; Howarth 1987, p. 7; Howarth 1993, p. 67; Moore and Wilmer 1997, p. 15; Christiansen 2005, pp. 387-396; Miller 2005, p. 571; Hedin and Thomas 2010, p. 119; Trontelj et al. 2012, pp. 3859-3862; Klaus et al. 2013, p. 2; Shear and Warfel 2016, p. 15).

Species that use subterranean habitats are broadly classified based on their degree of use and dependence on these habitats. Troglobites are those species dependent upon and restricted to caves, specifically deeper cave zones, for their entire life-cycle (Howarth 1983, pp. 366, 373-376; Aden 2005, p. 2; Trajano 2012, p. 276). Species that can survive and complete their life-cycles in caves as well as on the surface are termed troglophiles (Howarth 1983, pp. 366; Trajano 2012, p. 276; Trajano and Carvalho 2017, pp. 4, 10, 12). Trogloxenes are those species that are frequent to infrequent visitors to caves but that must complete their life-cycle on the surface (Howarth 1983, pp. 366; Trajano 2012, pp. 275-276; Trajano and Carvalho 2017, pp. 4, 12, 14).

The listed karst invertebrates of Bexar, Travis and Williamson counties are primarily classified as troglobites with several genera shared among these three counties including multiple *Batrisodes*, *Neoleptoneta*, *Rhadine*, and *Texella* species exhibiting troglomorphic traits (Barr 1974, pp. 1-2; Ubick and Briggs 2004, p. 116; Chandler et al. 2009, pp. 127-128; Paquin and Dupérré 2009 p. 5; Ledford et al. 2011, p. 382; Ledford et al. 2012, p. 11). Adaptation to and dependence on similar subterranean habitats, taxonomic relatedness, and vulnerability to the same suite of threats validates the application of recovery criteria from the Bexar County Karst Invertebrates Recovery Plan to species covered by the Recovery Plan for Endangered Karst Invertebrates in Travis and Williamson Counties, Texas.

ADEQUACY OF RECOVERY CRITERIA

Section 4(f)(1)(B)(ii) of the Endangered Species Act (Act) requires that each recovery plan shall incorporate, to the maximum extent practicable, “objective, measurable criteria which, when met, would result in a determination…that the species be removed from the list.” Legal challenges to recovery plans (see Fund for Animals v. Babbitt, 903 F. Supp. 96 (D.D.C. 1995)) and a Government Accountability Audit (GAO 2006) also have affirmed the need to frame recovery criteria in terms of threats assessed under the five delisting factors.

Recovery Criteria

Only downlisting criteria were established for the seven species covered in the Recovery Plan for Endangered Karst Invertebrates in Travis and Williamson Counties, Texas (Service 1994, p. 86). The Recovery Plan also defines karst fauna regions for Travis and Williamson counties (Service 1994, pp. 28-34, 86-87) and generally describes qualities of protected karst fauna areas (Service 1994, pp. 76-87). See previous version of criteria in Recovery Plan Section II, pages 86-88.

Synthesis

Additional scientific information, refined karst fauna area guidelines, and more explicit recovery criteria are 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). These more recent documents represent the best available information regarding the recovery of listed karst invertebrates in central Texas. We believe amendment of the Recovery Plan is necessary given updated information that informs downlisting and delisting criteria as applied in the Bexar County Karst Invertebrate Recovery Plan.

AMENDED RECOVERY CRITERIA

Recovery criteria serve as objective, measurable guidelines to assist in determining when an endangered species has recovered to the point that it may be downlisted to threatened, or that the Bee Creek Cave harvestman, Bone Cave harvestman, Coffin Cave mold beetle, Kretschmarr Cave mold beetle, Tooth Cave spider, Tooth Cave ground beetle, and Tooth Cave pseudoscorpion no longer meets the definition of either an endangered or threatened species and may be delisted. Delisting is the removal of a species from the Federal Lists of Endangered and Threatened Wildlife and Plants. Downlisting is the reclassification of a species from endangered to threatened. The term "endangered species" means any species (species, sub-species, or DPS) which is in danger of extinction throughout all or a significant portion of tis range. The term "threatened species" means any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range.

We provide both downlisting and delisting criteria for the Bee Creek Cave harvestman, Bone Cave harvestman, Coffin Cave mold beetle, Kretschmarr Cave mold beetle, Tooth Cave spider, Tooth Cave ground beetle, and Tooth Cave pseudoscorpion, which will supersede those included in the Recovery Plan, as follows:

Downlisting Recovery Criteria

<u>Current recovery criteria</u>

Each species 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 all karst fauna areas where that species occurs should be protected and at least two karst fauna areas should exist and be protected for that species to be considered for downlisting.

There are seven karst fauna regions (adapted from the karst fauna areas in Figure 19 of Veni & Associates' 1992 report and reproduced in Figure 2 of this recovery plan) in Travis and Williamson counties that are known to contain listed species. These regions are delineated based on geologic continuity, hydrology, and the distribution of rare troglobites (see further discussion in Section I.B).

Karst fauna regions can be further subdivided into karst fauna areas. For the purposes of this plan, a "karst fauna area" is an area known to support one or more locations of a listed species and is distinct in that it acts as a system that is separated from other karst fauna areas by geologic and hydrologic features and/or processes that create barriers to the movement of water, contaminants, and troglobitic fauna. Karst fauna areas should be far enough apart so that if a catastrophic event (for example, contamination of the water supply, flooding, disease) were to destroy one of the areas, that event would not likely destroy any other area occupied by that species.

To be considered “protected,” a karst fauna area must be sufficiently large to maintain the integrity of the karst ecosystem on which the species depend(s). In addition, these areas must also provide protection from threats such as fire ants, habitat destruction, and contaminants.

According to this criteria, all localities inhabited • by four of the listed species (*Tartarocreagris texana, Texamaurops reddelli, Neoleptoneta myopica, and Batrisodes texanus*) should be provided long-term protection (refer to figures 3-9 and Table 3 in this plan). For those karst fauna regions inhabited by *Texella reyesi*, *Texella reddelli*, and Rhadine persephone that contain more than three karst fauna areas, identification of the karst fauna areas targeted for protection is included as a recovery task in this plan.

(2) Criteria (1) has been maintained for at least five consecutive years with assurances that these areas will remain protected in perpetuity.

Amended recovery criteria

The Bee Creek Cave harvestman, Bone Cave harvestman, Coffin Cave mold beetle, Kretschmarr Cave mold beetle, Tooth Cave spider, Tooth Cave ground beetle, and Tooth Cave pseudoscorpion will be considered for downlisting when the location and configuration of at least the minimum quality and number of karst fauna areas in each karst fauna region occupied by a species are preserved. Along with meeting criteria for quality, legally binding mechanisms for perpetual protection and management must be in place for a site to qualify as a karst fauna area. Quality and quantity of karst fauna areas needed for species recovery are detailed in Table 1 and are dependent upon the number of occupied karst fauna regions.

Table 1 is based on the following overarching criteria, applied per species:

(1) at least one high quality protected karst fauna area per karst fauna region;

(2) at least three total medium or high quality protected karst fauna areas per karst fauna region;

(3) a minimum of six protected karst fauna areas rangewide;

(4) a minimum of three high quality karst fauna areas rangewide;

(5) all karst fauna areas are medium or high quality.

Table 1. Minimum quality and quantity of karst fauna areas (KFAs) needed per karst fauna region (KFR) for recovery (H = High quality and M = medium quality). For descriptions of high, medium, and low quality, see the Karst Preserve Design document (http://ecos.fws.gov/tess_public/).

# KFRs species occurs in	KFR 1	KFR 2	KFR3	KFR 4	KFR 5	KFR 6	Total # KFAs
1	HHHMMM						6
2	HHM	HMM					6
3	HMM	HMM	HMM				9
4	HMM	HMM	HMM	HMM			12
5	HMM	HMM	HMM	HMM	HMM		15
6	HMM	HMM	HMM	HMM	HMM	HMM	18

For example, a widely distributed species that occurs in six karst fauna regions would require 18 protected karst fauna areas in total with one high-quality and two medium quality in each occupied karst fauna region. Conversely, a species limited to one karst fauna region would require six protected karst fauna regions, with three of those sites being high quality and the remaining three sites of medium quality.

Justification:
These criteria are the same downlisting criteria established in the Bexar County Karst Invertebrates Recovery Plan (Service 2011, pp. 20-21, 25). Application of these downlisting criteria to the Recovery Plan for Endangered Karst Invertebrates in Travis and Williamson Counties, Texas is valid as listed karst invertebrates in Bexar, Travis, and Williamson counties are adapted to and dependent on similar subterranean habitats, share close taxonomic affinities, and are subject to the same set of threats. A karst fauna area is a geographic area known to support one or more locations of an endangered species. A karst fauna area is distinct in that it acts as a system that is separated from other karst fauna areas by geologic and hydrologic features and/or processes or distances that create barriers to movement of water, contaminants, and troglobitic fauna. A karst fauna region is a geographic area delineated based on discontinuity of karst habitat that may reduce or limit interaction between troglobite populations.

The Recovery Plan 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). Additional information and karst fauna area guidelines are 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).

Delisting Recovery Criteria

Current recovery criteria

None

Amended recovery criteria

The Bee Creek Cave harvestman, Bone Cave harvestman, Coffin Cave mold beetle, Kretschmarr Cave mold beetle, Tooth Cave spider, Tooth Cave ground beetle, and Tooth Cave pseudoscorpion will be considered for delisting when in addition to the downlisting criterion, monitoring and research have been completed to conclude with a high degree of certainty that karst fauna area sizes, quality, configurations, and management are adequate to provide a high probability of the species survival (greater than 90 percent over 100 years). To assess adequacy, results should be measured over a long enough time that cause and effect can be inferred with a high degree of certainty.

Justification: These criteria are the same delisting criteria established in the Bexar County Karst Invertebrates Recovery Plan (Service 2011, p. 25). For species survival, a probability of greater than 90 percent represents the most reasonable target range that can be estimated, due to the difficulty sampling for the population parameters that are necessary to calculate this probability, and our reliance on best available scientific and expert judgment.

Recovery criteria address threats to listed species habitat through perpetual protection and management of an adequate quantity and quality of habitat that spans the geographic range of each species. An “adequate” quantity and quality of habitat means that needed to provide a high probability of species survival over the long term (for example, at least 90 percent probability over 100 years). Calculating a probability for these species may not be possible with much certainty due to the difficulty sampling for the population parameters that are necessary to calculate this probability. Therefore, since we will likely be estimating this probability based on best available scientific and expert judgment, we are suggesting that a probability of greater than 90 percent is a reasonable target range to estimate.

Study of troglobitic invertebrates is complicated by their cryptic nature, low observed abundances, and difficulty in accessing and adequately surveying subterranean habitat (Park, 1960, p. 99; Veni et al. 1999, p. 28; Sharratt et al. 2000, pp. 119-121; Lakota et al. 2002, p. 23; Schneider and Culver 2004, pp. 42-43; Mosely 2009a, pp. 50-51; Paquin and Dupérré 2009, pp. 6, 64; Espinasa et al. 2012, p. 88; Souza and Ferreira 2012, p. 63; Wakefield and Zigler 2012, p. 25; Wynne 2013, p. 53; De Ázara and Ferreira 2014, p. 272; Souza and Ferreira 2016, p. 257; Trajano et al. 2016, p. 1822; Asenjo et al. 2017, p. 122; 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). As a result, several years to decades may be required to document initial presence of a species in subterranean habitats (Culver et al. 2004, pp. 1223, 1226; Taylor et al. 2006, pp. 78,80,125-126; Krejca and Weckerly 2007, pp. 8-10; Schneider 2009, pp. 125-128; De Ázara and Ferreira 2013, p. 443; Humphrey et al. 2013, p. 153; Pape and O’Connor 2014, p. 785; Stoev et al. 2015, p. 108;). Data sufficient to detect population trends at protected karst fauna areas will likely require significant survey effort and long periods of time to accumulate (ZARA Environmental 2014, pp. 10, 12).

All classification decisions consider the following five factors: (1) is there a present or threatened destruction, modification, or curtailment of the species' habitat or range; (2) is the species subject to overutilization for commercial, recreational scientific or educational purposes; (3) is disease or predation a factor; (4) are there inadequate existing regulatory mechanisms in place outside the ESA (taking into account the efforts by states and other organizations to protect the species or habitat); and (5) are other natural or manmade factors affecting its continued existence. When delisting or downlisting a species, we first propose the action in the *Federal Register* and seek public comment and peer review. Our final decision is announced in the *Federal Register*.

Rationale for Recovery Criteria

Karst invertebrate populations, especially troglobites (i.e., species restricted to and dependent upon subterranean habitats), require subterranean habitats with high humidity and stable temperatures (Bull and Mitchell 1972, pp. 375, 386; Hadley et al. 1981, p. 219; Yoder et al. 2011, p. 15; Hild et al. 2009, p. 432; Mammola et al. 2015, pp. 246-247; Mammola and Isaia 2017, p. 3). 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).

Karst invertebrates also require a source of food in the form of herbaceous or woody plant debris, tree roots, animal carcasses, guano, or other invertebrates (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; 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). The majority of nutrients that support cave ecosystems originate from surface habitats, specifically the natural communities that overlay these systems (Barr 1968, pp. 51, 53; Peck 1976, p. 315; Howarth 1983, pp. 376-377; Holsinger 1988, p. 147; Elliott and Reddell 1989, p. 50; Jasinska et al. 1996, p. 518; Culver and Pipan 2009, pp. 24, 27-39).

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). Along with shelter and foraging, networks of subterranean voids provide dispersal corridors, facilitating genetic interchange among karst features (Avise and Selander 1972, p. 15; Turanchik and Kane 1979, pp. 65-67; Paquin and Hedin 2004, p. 3250; Paquin and Hedin 2005, pp. 4-5, 14-15; Moulds et al. 2007, pp. 8, 10; Ledford et al. 2012, pp. 11, 18-23; Espinasa et al. 2016, pp. 233, 236, 238; Jaffé et al. 2016, pp. 11-12).

Protection of adequate amounts of functional surface and subsurface habitat is a critical component of these recovery criteria given the rapid human population growth and increasing development occurring across these species ranges in Travis and Williamson counties, Texas (U.S. Census Bureau 1982, p. 10; U.S. Census Bureau 2012, p. 9; Texas Demographic Center 2014; City of Austin 2016; City of Cedar Park 2016; City of Georgetown 2017; City of Round Rock 2017; Nowak and Greenfield (2018, pp. 168-171; U.S. Census Bureau. 2018a; U.S. Census Bureau 2018b; U.S. Census Bureau 2018c; U.S. Census Bureau 2018d; U.S. Census Bureau 2018e). 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 agricultural land use 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).

The reasons for listing (threats) these species as endangered were described in the final rule (53 FR 36031-36032) and are still applicable today. Without proper management and protection, these threats will continue to impact these species. The information below consists of a brief discussion of existing threats, updated information on these threats, and new threats identified since the time of listing. Threats are discussed below in relation to the five factors (factors A-E) considered when listing or delisting a species. For more information on threats, see the final rule (53 FR 36031-36032) and the most recent 5-year status reviews for the Bee Creek Cave harvestman, Bone Cave harvestman, Coffin Cave mold beetle, Kretschmarr Cave mold beetle, Tooth Cave spider, Tooth Cave ground beetle, and Tooth Cave pseudoscorpion.

A. Present or threatened destruction, modification or curtailment of the species habitat or range.

The primary threat to the listed karst invertebrates is habitat loss due to rapidly growing human populations and increasing urban, suburban, and exurban development in Travis and Williamson counties, Texas. Effects of development on the listed species include habitat loss from filling and collapsing caves, habitat degradation through alteration of drainage patterns, alteration of surface plant and animal communities, edge effects, contamination from pollutants, human visitation, vandalism, and activities associated with mining and quarrying.

The ranges of the Bee Creek Cave harvestman, Bone Cave harvestman, Coffin Cave mold beetle, Kretschmarr Cave mold beetle, Tooth Cave spider, Tooth Cave ground beetle, and Tooth Cave pseudoscorpion in Travis and Williamson counties have 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. 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/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 listed species, and their subterranean habitat, are 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 listed species viability and 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.

Nutrient availability is an important factor in the maintenance of species richness in cave ecosystems (Jaffé et al. (2016, pp. 6, 11; Jiménez-Valverde 2017, pp. 10210-10212). Nutrients transported by cave crickets into caves, including those in central Texas, can play a substantial role in supporting subterranean biodiversity (Barr 1968, p. 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). How urbanization and alteration of surface ecological systems may affect these insects is a vital consideration for listed karst invertebrate populations.

Cave crickets are relatively large, wingless insects (Lavoie et al. 2007, p. 114) whose dispersal and movement across the landscape is limited to crawling or jumping. Another feature influencing these insect's distribution is that cave crickets are central-place foragers, moving out to forage from a single point (e.g., karst feature) on the landscape and then returning to that location to shelter and reproduce (Fagan et al. 2007, p. 912). Cave crickets exhibit high site fidelity to individual karst features (Taylor et al. 2004, p. 39) but will disperse to use nearby features (Taylor et al 2004, p. 40) or shelter temporarily under aboveground refugia (e.g., underside of logs or rock; Taylor et al. 2004, p. 41). Their dependence upon and fidelity to karst features are an important determinant in their distribution across the landscape.

Taylor et al. (2007, entire) compared diversity of karst invertebrates among caves in Bexar, Hays, and Travis counties exposed to high, medium, and low levels of human impact. Human impacts (e.g., building/structure and paved road/lot) and land cover (e.g., tree/shrubs natural and grass/herb natural) were assessed around each cave entrance at radiuses of 120 m (394 ft) and 340 m (1115 ft); surface areas totaling 4.5 ha (11.2 ac) and 36.4 ha (90 ac), respectively. As the percentage of impervious cover and modified habitat increased at a site, the total number of cave crickets and other invertebrate species present in a cave decreased (Taylor et al. 2007, pp. 2, 37). The researchers also found that total number of invertebrates present in a cave was correlated with the total number of cave crickets (Taylor et al 2007a, pp. 2, 37, 42-44). Both spatial scales examined exhibited these trends.

Taylor et al. (2007, p. 41) observed few, if any, cave crickets at highly impacted cave sites with the greatest number of crickets recorded from sites with little human impact. Caves with lower numbers of cave crickets, in turn, hosted smaller numbers of other invertebrates. Even caves surrounded by relatively undisturbed habitat, but still adjacent to urbanization, hosted fewer karst invertebrates (Taylor 2007a, p. 46). For central Texas karst systems, these data suggest the effects of urbanization extend well beyond the boundaries of a development's footprint and into surrounding natural habitat consistent with the concept of an edge effect or disturbance zone (Theobald et al. 1997, pp. 27-28). Taylor et al. (2007, p. 43) suggests that karst preserves less than 4.5 ha (11.2 ac) may not be of sufficient size to maintain a functional karst invertebrate community.

Construction of urban, suburban, and exurban developments results in the replacement of native plant communities with a matrix of land uses that can be inhospitable to species dispersal (McKinney 2002, pp. 884-885; McKinney 2008, pp. 162, 166-167). Given the severity of land cover change, species may be unable to disperse or have reduced success moving through the surrounding matrix to adjacent habitat fragments (Bierwagen 2007, p. 30, 37; Fischer and Lindenmayer 2007, p. 269; Knapp et al. 2008, pp. 1608-1609; Soga et al. 2013, p. 425). Populations that persist in isolated fragments are vulnerable to stochastic events that could reduce numbers of individuals (Fahrig 2003, p. 505).

Recolonization of declining populations may be low if dispersal from adjacent habitat fragments is reduced (Theobald 1997, pp. 33-34). Whether or not individuals are successful in dispersing through an intervening matrix is partially dependent upon the habitat quality of the matrix and degree of similarity between the matrix and natural habitat (Ewers and Didham 2005, pp. 125-127; Prevedello and Vieira 2010, pp. 1215-1217). Allegrucci et al. (1997, p. 672) suggested that gene flow between populations of *Dolichopoda* cave crickets was supported by surface migration through native woodlands. A matrix that is structurally dissimilar to natural habitat decreases the likelihood of species dispersal (Eycott et al. 2012, pp. 1274-1275). Over time, the absence of new individuals into the population (e.g., recolonization) may lead to increased inbreeding, reduced genetic variability, and localized extirpation (Keller and Largiadèr 2003, p. 422; Vandergast et al. 2007; p. 987; Dixo et al. 2009; pp. 1566-1567).

Research indicates that cave crickets, and some other flightless Orthoptera, are sensitive to changes in habitat availability or quality that decrease inter-patch dispersal success. Hutchison et al. (2016, entire) examined gene flow among cave cricket (i.e., *C. secretus*) populations at Fort Hood Military Reserve in Bell and Coryell counties, Texas. Cave crickets inhabiting caves in continuous habitat lacked strong genetic differences indicating that individual crickets are capable of dispersing among caves and successfully reproducing at those sites (Hutchison et al. 2016, p. 980). However, those researchers also found low genetic connectivity in cave crickets from isolated caves with degraded or limited surface habitat. Hutchison et al. (2016, pp. 981-982) suggests that if crickets were extirpated from such sites, recolonization may be reduced due to decreased habitat connectivity.

Vandergast et al. (2007, entire; 2009, entire) analyzed genetic structure in two flightless Jerusalem crickets (*Stenopelmatus* “mahogani” and *Stenopelmatus* n. sp. “santa monica”) in response to urbanization and habitat fragmentation. Those studies found that urban development increased genetic differentiation among populations (Vandergast et al. 2009, p. 337). Crickets from small, isolated fragments had lower levels of genetic diversity compared to those from larger fragments with more continuous habitat (Vandergast et al. 2007, pp. 984-987; Vandergast et al. 2009, pp. 336-338). Roadway structures and other urban landscape features presented barriers to Jerusalem cricket movement leading to increased mortality risk for dispersing individuals and a disruption of genetic connectivity among habitat fragments (Vandergast et al. 2009, p. 349-350).

A habitat conservation plan and accompanying section 10(a)(1)(B) permit was issued in 1992 for development of Lakeline Mall in Williamson County. This site contained two caves, Lakeline and Underline Caves, occupied by the Bone Cave harvestman. Commercial development cleared much of the vegetation surrounding Lakeline Cave in 1994. Underline Cave was destroyed by this development. Construction of the mall decreased natural surface habitat surrounding Lakeline Cave to 1.2 ha (3 ac), an inadequate size to fully accommodate potential cave cricket foraging activity (i.e., 3.5 ha [8.6 ac]). The reduction in natural vegetation at this site also likely affected nutrient input into the cave through wind-blown or water-borne detritus.

Annual monitoring conducted at Lakeline Cave, over a more than 20-year period (1992-2013), documented a decline in cave cricket abundance (ZARA Environmental 2014, pp 10, 12). This reduction in cave crickets likely represents an instance where an isolated population in a low quality (e.g., insufficient foraging area) habitat fragment declined in the absence of recolonization. The apparent lack of recolonization at Lakeline Cave by cave crickets, coupled with loss of natural surface habitat, seemingly had spillover effects on other subterranean fauna. Monitoring data indicated that numbers of observed Bone Cave harvestman, the federally endangered Tooth Cave beetle (*Rhadine persephone*), and another troglobitic ground beetle (*R. subterranea*) declined at Lakeline Cave (ZARA Environmental 2014, pp. 10, 12).

The rapid development activities occurring across the range of listed karst invertebrates in Travis and Williams counties is leading to reduced open space surrounding occupied caves, habitat fragmentation, and an expansion of the urbanized matrix. Insect species with low powers of dispersal (e.g., flightless) and/or some level of habitat specialization are less likely to persist in fragmented natural or urbanized landscapes (Tscharntke et al. 2002, pp. 232-233; Kotze and O'Hara 2003, pp. 144-145; Keller et al. 2005, pp 97-98; Marini et al. 2010, p. 2169; Kotze et al. 2011, pp. 160-161; Penone et al. 2012, p. 323; Gaublomme et al. 2013, pp. 478-480). Loss of natural vegetation to development reduces available cave cricket foraging habitat and an expanding urban matrix decreases dispersal opportunities to adjacent habitat fragments. Declines in karst invertebrate populations as exhibited in Bexar, Hays, and Travis counties by Taylor et al. (2007, pp. 37-46) and at Lakeline Cave by ZARA Environmental (2014, pp. 10, 12) will potentially occur at other sites exposed to similar pressures with implications for the persistence of listed karst invertebrate populations.

Recovery criteria address threats to listed species habitat through perpetual protection and management of an adequate quantity and quality of habitat that spans the geographic range of each species. An "adequate" quantity and quality of habitat means that needed to provide a high probability of species survival over the long term (for example, at least 90 percent probability over 100 years). Calculating a probability for these species may not be possible with much certainty due to the difficulty sampling for the population parameters that are necessary to calculate this probability. Therefore, since we will likely be estimating this probability based on best available scientific and expert judgment, we are suggesting that a probability of greater than 90 percent is a reasonable target range to estimate.

Adequate quantity of habitat refers to both size and number of preserved and areas that are sufficient for supporting the karst ecosystems. The number of preserves called for in the recovery criterion 1 provides redundancy to the species by providing a sufficient number of populations to provide a margin of safety for these species to withstand a catastrophic event. The size of preserves should be adequate to ensure resiliency of the population so that they are large enough to withstand stochastic events. Multiple karst fauna areas across the species' ranges should provide representation of the breadth of their genetic diversity to conserve their adaptive capabilities. Adequate quality of habitat refers to (1) the condition and orientation of preserved lands with respect to the known localities for the species and (2) the ability of the species' needs to be met to sustain viable populations.

B. Overutilization for commercial, recreational, scientific, or educational purposes.
No threat from overutilization of these species is known to exist at this time. Collection for scientific or educational purposes could become a threat if localities become generally known.

C. Disease or predation
The red-imported fire ant (*Solenopsis invicta*) is a South American ant species introduced to the southeastern U.S. in the mid-1940s (Buren 1972, p. 13; Buren et al. 1974, p. 114). First documented in Texas in 1953, it has since established populations across much of the state

(Cokendolpher and Phillips 1989, p. 445; Callcott and Collins 1996, pp. 243-247; O'Keefe et al. 2000, p. 71). The red-imported fire ant arrived in Travis and Williamson counties in the 1970s (Hung and Vinson 1978, p. 207; Cokendolpher and Phillips 1989, p. 444).

The red-imported fire ant occurs across the ranges of the listed species. Conversion of natural surface habitat in Travis and Williamson counties to urban, suburban, and exurban development has been significant and projected to continue into the next several decades. A major driver of red-imported fire ant invasion into natural communities in the southeastern U.S. is anthropogenic habitat disturbance (Stiles and Jones 1998, pp. 338-339; Taylor et al. 2003b, p. 8; Todd et al. 2008, p. 545; King and Tschinkel 2008, p. 20340; LeBrun et al. 2012, pp. 891-893; King and Tschinkel 2013, p. 73). The clearing of vegetation and soil disturbances that accompany conversion of natural habitat to human land uses create conditions that favor red-imported fire ant dispersal and colony establishment. Vegetation removal creates the open, sunlit conditions preferred for colony establishment (Stiles and Jones 1998, pp. 339-340; Brown et al. 2012 p. 146). Monogyne and polygyne queens are attracted to open, disturbed habitats during dispersal to found new colonies (DeHeer et al. 1999, p. 669; King and Tschinkel 2016, p. 246). Soil disturbance reduces native ant species richness and abundance enabling red-imported fire ants to establish colonies and reach high population densities (King and Tschinkel 2008, p. 20340; LeBrun et al. 2012, p. 891; King and Tschinkel 2016, p. 246).

Although habitat disturbance facilitates red-imported fire ant establishment in affected natural communities, 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. Prevalence in those grasslands was lower than in disturbed grasslands, however (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).

Ongoing habitat disturbances associated with development increases the likelihood of this ant invading and establishing colonies in fragments of natural surface habitat that persist post-development. Since its arrival in Travis and Williamson counties, the red-imported fire ant has become the most frequently observed ant species in caves, reported from over 140 caves in Travis and Williamson counties (Cokendolpher et al. 2009, pp. 164-167). Reddell and Cokendolpher (2001, p. 131-133) considered the red-imported fire ant as the most important cave-associated ant in Texas. Colonies of red-imported fire ants, established in or near karst features, may affect listed species populations directly through predation or indirectly through impacts to nutrient flow (e.g., predation or competition with cave crickets) from surface ecological systems (Elliott 1993, pp. 2, 23; Reddell and Cokendolpher 2001, p. 132; Taylor et al. 2003a, p. 110; Cokendolpher et al. 2009, p. 165).

Red-imported fire ants were first reported from central Texas caves in the late 1980s (Elliott 1993, p. 2); roughly a decade after the species estimated arrival in the region. Over 40 ant species have been recorded from caves in Texas (Reddell and Cokendolpher 2001, entire; Cokendolpher et al. 2009, entire). However, the majority of these species are not closely associated with caves and their occurrence in these systems is generally accidental or incidental

(Reddell and Cokendolpher 2001, pp. 130-131; Cokendolpher et al. 2009, p. 152). Since its arrival in Travis and Williamson counties, the red-imported fire ant has become the most frequently observed ant species in caves, reported from over 140 caves in Travis and Williamson counties (Cokendolpher et al. 2009, pp. 164-167). Reddell and Cokendolpher (2001, p. 131-133) considered the red-imported fire ant as the most important cave-associated ant in Texas.

While the red-imported fire ant is the dominant ant in Travis and Williamson county caves, another non-native ant species displays a propensity to forage in the area's caves. 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.

Recovery criteria address threats to listed species from non-native, invasive ant species through management and protection of karst fauna areas that encompass adequate quality and quantity of natural habitat (i.e., 16-40+hectares [ha] (40-100+ acres [ac]) and that are relatively free of human disturbances. The quality of a karst fauna area is an indicator of how likely species are to survive for the long-term. Information regarding karst fauna area quality is detailed in Service (2012, entire). Karst fauna areas located within a larger tract of natural habitat may be at reduced rick of incursion by red-imported fire ants. If present, however, recovery criteria address management activities to control populations of red-imported fire ants (Service 2011, p. 22).

D. Inadequate existing regulatory mechanisms.

Karst invertebrates and their habitats are not protected by State of Texas regulations. Terrestrial invertebrates are excluded from placement on Texas Parks and Wildlife Department's list of state threatened and endangered species (Parks and Wildlife Code Title 5, Subtitle B, Chapter 58). Texas Commission on Environmental Quality water quality regulations do not provide adequate protection for karst invertebrate habitat (65 FR 81419–81433). For example, while some that state agency's practices provide protection from water quality impacts, others, such as sealing cave entrances for water quality reasons, can harm karst invertebrates. Sealing cave entrances can be harmful by blocking off water (leading to drying) and nutrient input to the karst invertebrate habitat. At the municipal level, few protections are afforded karst invertebrate habitat. Setback distances surrounding caves in the City of Austin's Environmental Criteria Manual (City of Austin 2014, p. 13-3) are insufficient to protect cave cricket foraging area, and potentially does not include surface and subsurface drainage basins. Further, it is not applicable across the ranges of all listed karst invertebrates in Travis and Williamson counties. Likewise, the City of Georgetown Water Quality Management Plan for the Georgetown Salamander only provides protections for sites occupied by that species in Williamson County with few karst invertebrates occurring near Georgetown salamander locations. The proposed recovery criteria address these threats by ensuring that an adequate quantity and quality of habitat is preserved throughout the range of these species to provide a high probability of survival over the long term regardless of jurisdiction or other regulatory measures in place.

E. Other natural or manmade factors.

These species are extremely vulnerable to losses because of their severely limited range and habitat and because of the naturally limited ability to colonize new habitats. These troglobitic species have little or no ability to move appreciable distances on the surface. Moisture regimes, food supply, and other factors may also limit subsurface migrations and may account for the different distribution patterns seen among these species. The specific climatic factors within the caves, such as humidity, are affected by input through the cave entrance, the overlying soils, and the rocks in which the caves are formed. Surface alterations can affect these conditions, as well as facilitate the flow of pollutants into the habitat. The very small size of these habitats, in addition to the fragile nature of cave ecosystems in general, make these species vulnerable to even isolated acts of vandalism. As the human population of the area increases, the likelihood of such acts also increases. Recovery criteria reduce threats to the species by protecting an adequate quantity and quality of karst areas to ensure a high probability of the species' long-term survival. This includes protecting caves or cave clusters and the associated mesocaverns necessary to support populations that represent the range of the species and their potential genetic diversity.

ADDITIONAL SITE SPECIFIC RECOVERY ACTIONS

Not applicable.

COSTS, TIMING, PRIORITY OF ADDITIONAL RECOVERY ACTIONS

Not applicable.

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