Bone Cave Harvestman (*Texella reyesi* Ubick and Briggs 1992)

(Opiliones: Laniatores: Phalangodidae)

Species Status Assessment

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

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Executive Summary

This report summarizes the results of a species status assessment completed for the Bone Cave harvestman (*Texella reyesi*). It is an update to version 1.0 of the Bone Cave Harvestman Species Status Assessment completed in 2018 (Service 2018, entire). The Bone Cave harvestman is an obligate subterranean arthropod with a restricted distribution in Travis and Williamson counties, Texas. The U.S. Fish and Wildlife Service (Service) listed the Bone Cave harvestman as endangered on September 16, 1988. This species status assessment provides an in-depth review of the species' taxonomy, habitat, stressors, resources needed to maintain long-term persistence, and an evaluation of its biological status.

Bone Cave harvestman. Courtesy of Colin Strickland, City of Austin..

To assess the Bone Cave harvestman's viability, we used the conservation biology principles of resiliency, redundancy, and representation. Specifically, we identified the species' ecological requirements for survival at the individual, population, and species levels and described the stressors influencing Bone Cave harvestman viability. We evaluated the current resiliency of Bone Cave harvestman populations and the redundancy and representation of those populations range-wide in order to forecast the species' persistence under three future scenarios.

The Bone Cave harvestman occurs only in subterranean habitats of the Balcones Canyonlands in portions of Travis and Williamson counties. This ecoregion forms the eastern to southeastern boundary of the Edwards Plateau, where the activity of rivers, springs, and streams has produced an extensive karst landscape of canyons, caves, and sinkholes. The term "karst" refers to a type of terrain formed by the slow dissolution of calcium carbonate from surface and subsurface limestone, and other soluble rock types, by mildly acidic groundwater. The flow of water through underground conduits leads to the formation of an interconnected system of subterranean voids that enlarge with continued dissolution of bedrock.

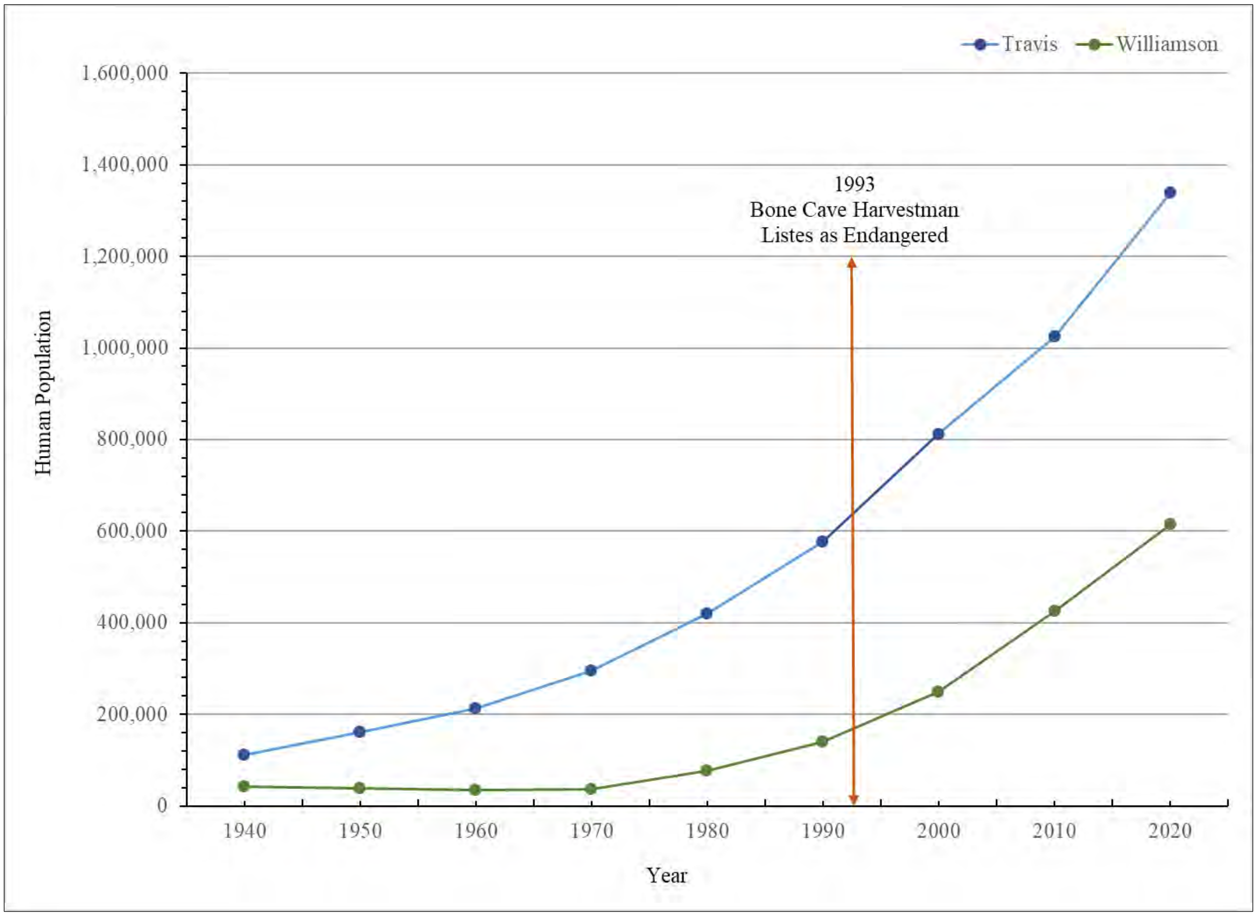
Bone Cave harvestmen spend their entire lives underground within naturally formed voids of varying sizes from caves to smaller-diameter, humanly inaccessible mesocaverns. These harvestmen are adapted to life in complete darkness, possessing such troglomorphic (i.e., adaptations to subterranean habitats) traits as lack of retinas, reduced pigmentation, increased number of tarsomeres, and elongated legs. Bone Cave harvestman populations exhibit north to south clinal variation in troglomorphic characters, with northernmost populations in Williamson County exhibiting higher degrees of troglomorphy (i.e., partial or complete absence of corneas) than those to the south in Travis County. Preliminary genetic results indicate at least three genetic clades exist across the range of the species generally corresponding to the northern, central and southern part of the species range, with a potential for at least two more. However, additional genetics work and a formal morphological analysis are needed to describe the extent of geographic variation within this species.

Resilient Bone Cave harvestman populations require subterranean habitats with high humidity and stable temperatures. Intact networks of subterranean voids provide living space and a buffer or refugia from the effects of humidity and temperature extremes. Functional surface and subsurface drainage basins supply water that aids in the maintenance of high relative humidity. The Bone Cave harvestman also require a source of food in the form of invertebrates or other organic matter. The majority of nutrients that support cave ecosystems originate from surface habitats, specifically the natural communities that overlay these systems. Nutrients may take the form of animal or plant material washed in by water, blown by wind, or transported by animals.

Resident colonies of cave crickets are important contributors of nutrients in some karst ecosystems. Cave crickets roost by the hundreds to thousands in caves during the day, leaving at night to forage on animal and plant matter in the surrounding native plant community. Nutrients obtained during foraging are transferred into the cave through defecation (i.e., guano), laying of eggs, and carcasses of dead crickets. Such organic materials provide a resource base for a suite of invertebrates that may serve as Bone Cave harvestman food. The presence of sufficient natural foraging habitat surrounding a cave is vital to the maintenance of cave cricket populations. Declines in cave cricket populations can potentially lead to decreased abundances for other karst invertebrates.

The stressors that most influence Bone Cave harvestman viability are habitat destruction, degradation, and fragmentation that results from urban, suburban, and exurban development. The species' range in Travis and Williamson counties has experienced substantial human population growth and development. 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 2019, the U.S. Census Bureau (2019a) rated the Austin-Round Rock-Georgetown area as the eighth fastest growing metropolitan area in the United States.

Expansion of urban, suburban, and exurban developments has led to significant loss and fragmentation of natural habitat across the species' range. Increased construction has accompanied population growth in Travis and Williamson counties. Based on data from the U.S. Census Bureau, 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. 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.

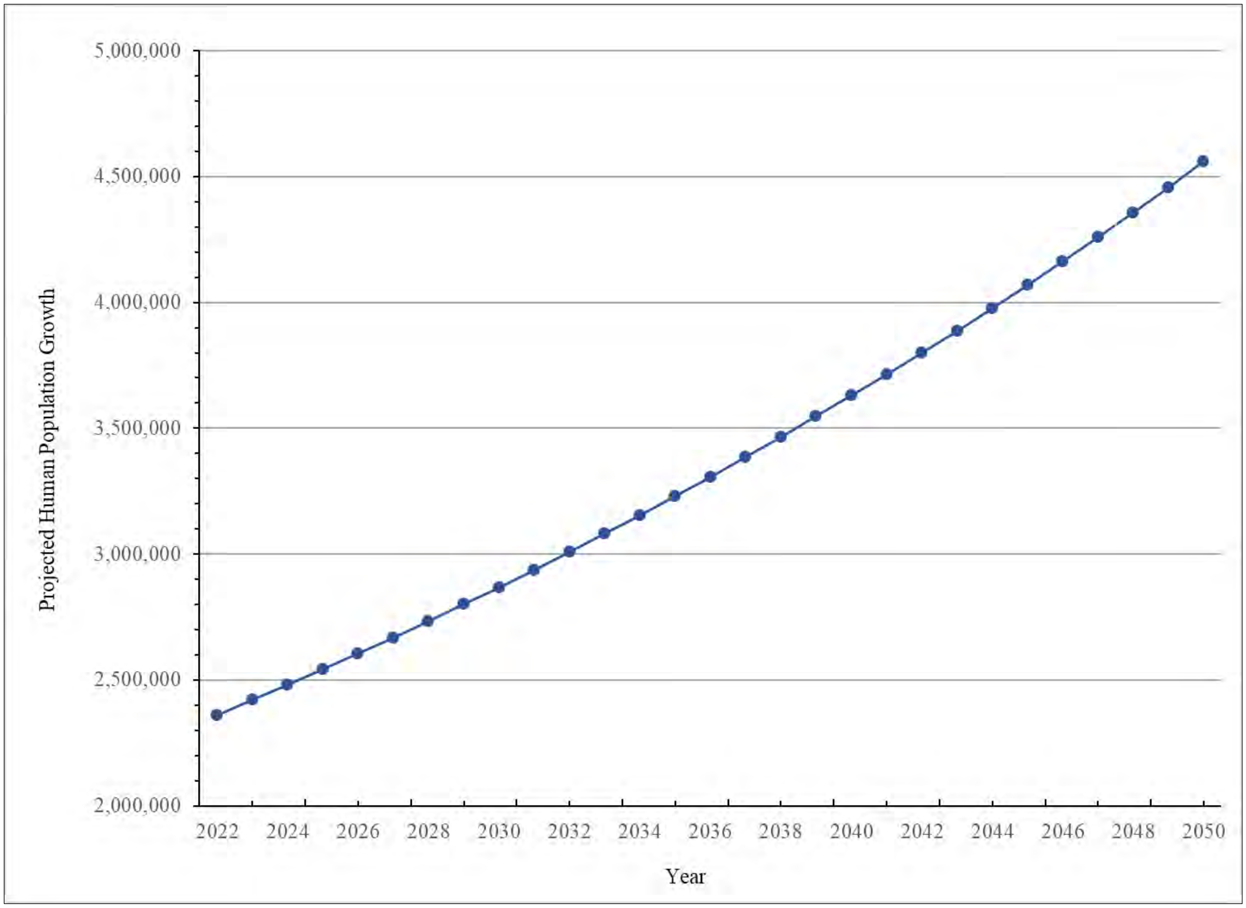


Human population growth of Travis and Williamson counties, 1940-2020.

Construction 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. By 2019, the number of housing units increased to 545,693 units (U.S. Census Bureau 2019c), an increase of 441% 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. Texas 9). From 2010 to 2019, number of housing units increased to 205,609 units (U.S. Census Bureau 2019c), an increase of 1,455% since 1970.

Projected human population growth estimates for both Travis and Williamson counties indicate substantial increases will continue over the next several decades. Population projections from the Texas Demographic Center (2018) estimate that Travis County, which was in the top ten counties in the U.S. in numeric growth from 2010 to 2019 according to the U.S. Census Bureau (2019b), will increase in population from a projected 1,317,306 people in 2021 to 1,980,918 people in 2050 (a 50% increase over the next 29 years). The City of Austin's population is expected to reach 1,372,843 people by 2050 (City of Austin 2020a), an increase of 34% over 29 years.

The Texas Demographic Center (20142018) projects Williamson County to increase in population from 499,907609,818 people in 2017 2021 to 1,645,982 either 992,814 (One-half 2000-2010 Migration (0.5) Scenario) or 1,976,958 (2000-2010 Migration (1.0) Scenario) people in 2050 (99% or 295% increase over 32 years, respectivelya 169% increase over the next 29 years). The City of Georgetown's population is expected estimated to reach grow from 96,567a population of 77,436 in 2021 to between 89,006 and 110,064 people by 2030 (City of Georgetown 202117), an increase of 60%of between 15 and 42% over 121 years.

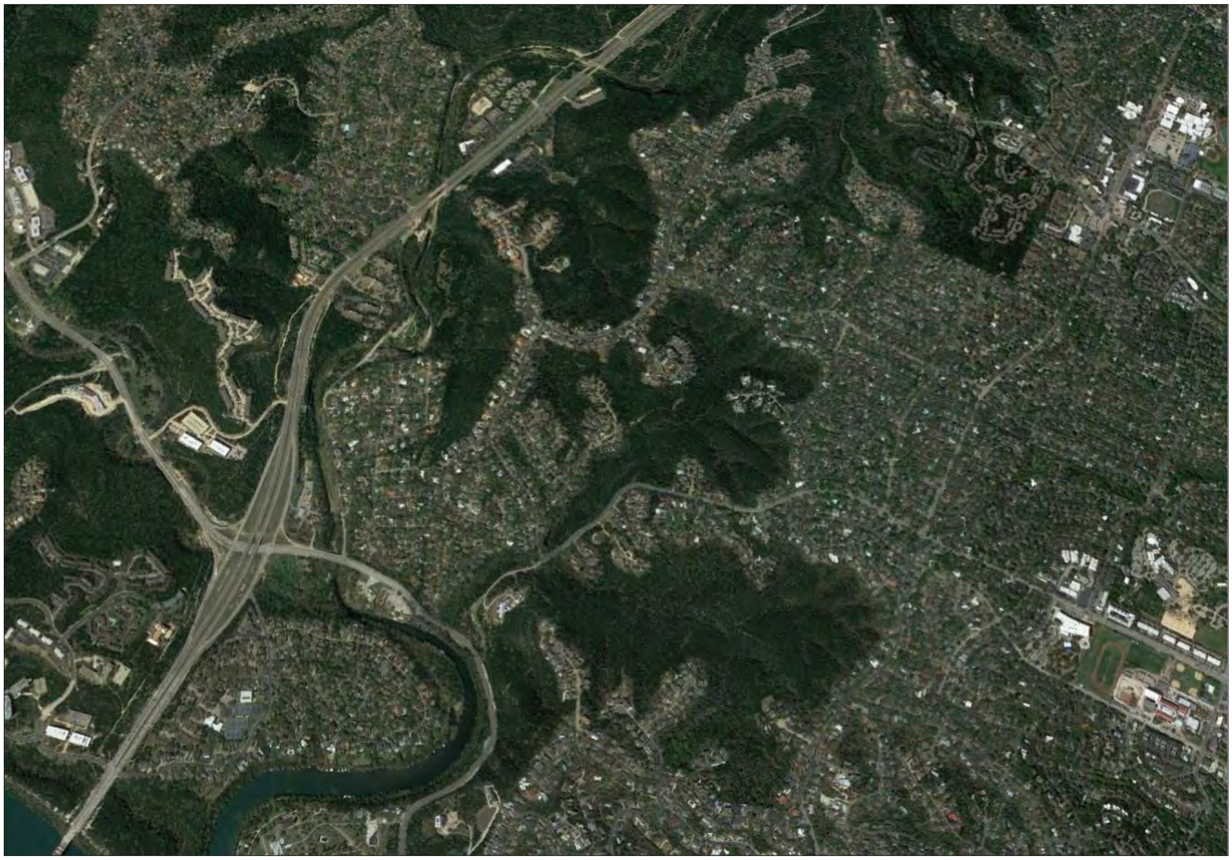


Austin-Round Rock-Georgetown Metropolitan Area Projected Human Population, 2022-2050.

To summarize the current resiliency, redundancy, and representation of the Bone Cave harvestman, we evaluated 230 occupied caves or karst features for amount of naturally vegetated open space surrounding a cave, distance of cave entrance to nearest edge, and status of cave cricket foraging area. We quantified habitat elements through a Geographic Information System-based evaluation of aerial imagery. As genetic research indicates some karst invertebrates can disperse underground between caves, we grouped caves occupied by the Bone Cave harvestman into cave clusters if they occurred no more than 600 meters (m)[1968 feet (ft0] apart. We treated groups of caves within that distance as a single population. Caves further apart than 600 m (1968 ft) were treated as individual cave populations.

We assigned cave clusters and individual caves to one of four resiliency categories, high, moderate, low, or impaired based on values generated for each habitat element. The quality of habitat elements at high to moderate resiliency sites provide a greater probability for persistence of Bone Cave harvestman populations and associated surface and subsurface ecosystems. Low resiliency and impaired sites potentially lack habitat elements of sufficient quality to support resilient populations of Bone Cave harvestman over the long-term but still provide some opportunity for survival.

Larger tracts of natural open space generally minimize effects of edge and isolation. They also increase the likelihood of dispersal and recolonization of cave crickets, provide additional karst features for cave cricket roosting, and support a diverse, self-sustaining native plant community over the long-term. Smaller areas of open space are more vulnerable to edge effects, may contain reduced cave cricket populations, are more susceptible to contamination events or an altered hydrological regime, and are potentially unable to sustain native plant community composition over the long-term.



Isolated patches of natural habitat surrounded by urban development in the City of Austin, Travis County, Texas.

The karst landscape of Travis and Williamson counties is subdivided into karst fauna regions based on geologic continuity, hydrology, and the distribution of rare karst invertebrates across the area. The Bone Cave harvestman occurs in six of those regions. From north to south, the regions it occupies are the North Williamson County, Georgetown, McNeil/Round Rock, Jollyville Plateau, East Cedar Park, and Central Austin Karst Fauna Regions. We evaluated adequate redundancy and representation of the Bone Cave harvestman in each of those regions.

Based on our methodology, 77 sites (cave clusters and individual caves) in Travis and Williamson counties contain extant Bone Cave harvestman populations. Of that total, 38 sites are of low resiliency or impaired. Open space with native vegetation has been greatly reduced at those sites with tracts of natural habitat fragmented and isolated from one another. Resiliency of these sites is unlikely to improve, as adjacent open space has largely been converted to residential or commercial development.

The remaining 39 sites are of high to moderate resiliency with potential to support Bone Cave harvestman populations over the long-term in their current state. Larger tracts of open space with natural vegetation surround these caves, providing higher quality cave cricket foraging habitat and greater potential for connectivity among cricket populations. Persistence of Bone Cave harvestman populations at these sites would be dependent upon management and perpetual protection that maintains adequate open space with natural vegetation, sufficient buffering from edge effects, intact foraging areas for cave crickets, and sufficient quantity and quality of water from intact drainage basins.

Four of the high and moderate resiliency sites have permanent protection as karst fauna areas and three additional sites may be recognized as karst fauna areas as more information becomes available. Eleven sites within the Balcones Canyonlands Preserve may approximate karst fauna areas given further assessment. The remaining 21 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.

The 15 high to moderate resiliency sites currently subject to some level of protection are unequally distributed across the six occupied karst fauna regions. Rather, four protected and one proposed sites are located at the northern extent of the species range in the North Williamson County Karst Fauna Region, with the remaining nine sites clustered in the southwestern portion of the range in the Jollyville Plateau Karst Fauna Region. Two additional karst fauna areas proposed for the Georgetown Karst Fauna Region would provide redundancy and representation in that region provided they met the necessary criteria. Increasing the number of protected sites in the Georgetown Karst Fauna Region would augment Bone Cave Harvestman population redundancy there.

The McNeil/Round Rock Karst Fauna Region, roughly in the center of the species' range, currently lacks any protected high or moderate resiliency sites that provide redundancy or representation for that region. Widespread urbanization has resulted in the loss of all high to moderate resiliency sites in the Cedar Park and Central Austin Karst Fauna Regions. Redundancy. Protection of representative sites within each occupied karst fauna regions is important given the north to south morphological variation in Bone Cave harvestman populations and the variety of ecological conditions present at each cave site throughout the range.

We forecasted future resiliency, redundancy, and representation for the Bone Cave harvestman in each occupied karst fauna region under two potential scenarios. The scenarios evaluated two levels of conservation effort with Scenario 1 exploring a status quo conservation effort and Scenario 2 no additional 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. To predict potential future changes to open space patches related to urban growth, we added preliminary and platted roads from the City of Georgetown's streets layer into our neighborhood analysis. In addition, we used layers from the U.S. Geological Survey (2019) SLEUTH Urbanization 2020-2100 dataset to map future predicted changes in urbanization with an 80% probability by the year 2050.

In order to forecast future resiliency, we evaluated the extent of existing or in-progress residential and/or commercial development surrounding patches of open space using aerial imagery of each cave cluster and individual cave site. We also noted the proximity of existing roadways or in-progress roadway construction. Finally, we 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/exurban land uses.

We assumed perpetual protection of a site by an external party would take the form of a karst fauna area or other mechanisms with comparable levels of protection. Potential targets for protection under the 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 hinges on external parties implementing adequate permanent protections that maintain high and moderate resiliency sites. Assumptions for each scenario are as follows:

Scenario 1

- Human population growth continues to increase and development expands across the species' range.
- Conservation effort to protect and manage currently known, unprotected cave clusters and individual caves continues as in the past.
- Some additional protected areas are established. Open space surrounding most unprotected high and moderate resiliency cave cluster and individual caves converts to development and degrades in quality.
- Management and protection of current and proposed karst fauna areas is adequate and perpetual.
- Open space surrounding karst fauna areas converts to development, with some sites declining in resiliency.

Scenario 2

- Human population growth continues to increase and development expands across the species' range.
- There is no additional conservation effort to protect and manage currently known, unprotected cave clusters and individual caves for Bone Cave harvestman.
- No additional protected areas are established. Open space surrounding most unprotected high and moderate resiliency cave clusters and individual caves converts to development and degrades in quality.
- Management and protection of current karst fauna areas is adequate and perpetual.
- Open space surrounding karst fauna areas converts to development, with some sites declining in resiliency.

Forecasts of future resiliency, redundancy, and representation underscore the critical role adequate habitat protection will play in securing long-term persistence of Bone Cave harvestman populations. Economic demand for converting natural open space to development is high in the Austin-Round Rock-Georgetown metropolitan area and that demand is only expected to increase in response to a growing human population. Scenarios 1 and 2 forecast persistence of sites occupied by the Bone Cave harvestman into the future. Only high and moderate resiliency sites were considered suitable targets for protection under these scenarios as these areas offer the greatest potential for Bone Cave harvestman long-term persistence.

In Scenario 1, development activities and lack of protection degrades resiliency in the North Williamson County Karst Fauna Region to three high and three 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 four moderate resiliency sites remaining in this region. The Georgetown Karst Fauna Region continues to support one high and three moderate resiliency sites. All but one high and two 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 still probable in four of the six karst fauna regions; however, the likelihood of species persistence is higher in the Jollyville Plateau and North Williamson County Karst Fauna Regions, the southwestern and northern limits of the species range, respectively. Development pressure in the Georgetown Karst Fauna Region reduces resiliency of current populations with one high and three moderate populations persisting, only two of which possess long term protections. Species representation may be maintained in the center part of the range with a potential for one high and two moderate resiliency populations in the McNeil/Round Rock Karst Fauna Area provided protections can be put in place before development affects the remaining sites. No high and moderate resiliency sites exist in either the Cedar Park or Central Austin Karst Fauna Regions.

Under Scenario 2, development activities and lack of protection degrades resiliency in the North Williamson County Karst Fauna Region to two high and four moderate resiliency sites by 2050. Most sites in the Jollyville Plateau Karst Fauna Region continue to benefit from protection within the Balcones Canyonlands Preserve, with seven high and four 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, however one high and one moderate resiliency population may be maintained. 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, and McNeil/Round Rock Karst Fauna Regions and significantly reduced in the Georgetown Karst Fauna Region.

1.0 Introduction

This species status assessment is a summary of information assembled and reviewed by the U.S. Fish and Wildlife Service (Service) and incorporates the best scientific and commercial data available. It is an update to version 1.0 of the Bone Cave Harvestman Species Status Assessment completed in 2018 (Service 2018, entire). The framework of a species status assessment (Service 2016, entire; Smith et al. 2018, entire) is intended to support an in-depth review of the species' biology and threats, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. This assessment documents the results of a comprehensive status review for the Bone Cave harvestman (*Texella reyesi*). The Bone Cave harvestman was listed as endangered on September 16, 1988 (53 FR 36029-36033).

The objective of the species status assessment is to describe the viability of the species based on the best scientific and commercial information available. Through this description, we will determine species' needs, its current condition in terms of those needs, and its forecasted future condition. In conducting this analysis, we take into consideration changes that are likely happening in the environment, past, current, and future, to help us understand what factors drive the viability of the species.

This document describes the needs of the Bone Cave harvestman at the individual, population, and species levels. In instances where information was not available for this species specifically, we have provided references for studies conducted on species that occur in similar habitat. The similarities among these species may include, shared life history (e.g., occupies subterranean habitats), similar morphology and physiology (e.g., reduced or vestigial eyes), or similar habitat and ecological requirements (e.g., dependence on stable humidity and temperatures). Depending on the amount and variety of analogous characteristics, we used these similarities as a basis to infer parallels in what a population or the species may need to be viable.

For the purpose of this document, we define viability as the ability of a species to persist and sustain populations in the wild over many generations. We use the conservation principles of resiliency, redundancy, and representation (Shaffer and Stein 2000, pp. 307, 309–310) to better inform our view of what contributes to this species' probability of persistence and how best to conserve it.

- **Resiliency** is the ability of a population to withstand stochastic events and persist through severe hardships. We can measure resiliency based on metrics of population health (e.g., habitat size or population connectivity). Healthy populations are more resilient and better able to withstand disturbances such as random fluctuations in birth rates (i.e., demographic stochasticity), variations in rainfall (i.e., environmental stochasticity), random fluctuations in genetic variation (i.e., genetic drift), or the effects of anthropogenic activities.

- **Redundancy** is the ability of a species to withstand catastrophic events. Redundancy protects species against the unpredictable and highly consequential events for which adaptation is unlikely. In short, it is about spreading the risk. Redundancy is best achieved by having multiple populations widely distributed across the species' range. Having multiple populations reduces the likelihood that all populations are affected simultaneously, while having widely distributed populations reduces the likelihood of populations possessing similar vulnerabilities to a catastrophic event. Given sufficient redundancy, single or multiple catastrophic events are unlikely to cause the extinction of a species. Thus, the greater redundancy a species has, the more viable it will be. Furthermore, the more populations and the more diverse or widespread that these populations are, the more likely it is that the adaptive diversity of the species will be preserved. Having multiple populations distributed across the range of the species, will help preserve the breadth of adaptive diversity, and hence, the evolutionary flexibility of the species.

- **Representation** describes the ability of a species to adapt to changing environmental conditions. Representation can be measured by the breadth of genetic or environmental diversity within and among populations and gauges the probability that a species is capable of adapting to environmental changes. The more representation, or diversity, a species has, the more it is capable of adapting to changes (natural or human caused) in its environment. In the absence of species-specific genetic and ecological diversity information, we evaluate representation based on the extent and variability of habitat characteristics across the geographical range.

2.0 Taxonomy, Description, and Listed Status

Harvestmen are members of the arachnid order Opiliones with over 6,000 species described globally (Machado et al. 2007, pp. 1-13). Opiliones is divided into four suborders, Cyphophthalmi (mite harvestman), Eupnoi (daddy longlegs), Dyspnoi (ornate harvestman), and Laniatores (armored harvestman) (Fernández et al. 2017, pp. 3-6). Harvestmen are broadly typified by the fusion of the abdomen and cephalothorax to present as a single body segment, long legs, two simple eyes, and the presence of a penis or ovipositor (Goodnight and Goodnight 1960, p. 34; Machado et al. 2007, pp. 1-12).

The Bone Cave harvestman (*Texella reyesi*) is one of 28 described species within the North American genus *Texella* (Figure 1; Ubick and Briggs 1992, entire; Ubick and Briggs 2004, entire). That genus is a member of the suborder Laniatores and family Phalangodidae (Pinto-da-Rocha and Giribet 2007, pp. 159-166, 217-221). *Texella* species occur in California, New Mexico, Oregon, and Texas and range in coloration from yellowish white to brownish orange with total body lengths of 1.2-2.7 centimeters (cm)[0.5-1 inches (in)] (Ubick and Briggs 1992, entire; Ubick and Briggs 2004, entire). Taxonomy of the genus is heavily reliant on morphological variation of male genitalic characters (Ubick and Briggs 1992, p. 158; Ubick and Briggs 2004, p. 112).

Prior to 1992, the genus *Texella* contained only two described species, *T. mulaiki* and *T. reddelli* (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 *T. reddelli*, assignment of *Sitalcina bifurcata* to *Texella*, and descriptions of 18 new species from California, New Mexico, Oregon, and Texas. *Texella reyesi*, the Bone Cave harvestman, was among those newly described species and included some populations previously assigned to *T. mulaiki* and *T. reddelli* (Ubick and Briggs 1992, p. 203). In 2004, Ubick and Briggs (2004, entire) described an additional seven *Texella* species from Texas for a total of 28 species within the genus. Texas is the center of diversity for the genus with 22 species endemic to the state (Ubick and Briggs, 2004, p. 116).

Figure 1. Bone Cave harvestman (*Texella reyesi*). Courtesy of Colin Strickland, City of Austin.

The holotype of the Bone Cave harvestman was collected from Bone Cave in Williamson County, Texas on June 4, 1989 (Ubick and Briggs 1992, p. 211). Ubick and Briggs (1992, p. 211) described the Bone Cave harvestman as follows. Individuals range in length from 1.4-2.7 cm (0.6-1 in) with a pale orange coloration. Nymphs are white to yellowish white in color. The exoskeleton is finely rugose and the eye mound is broadly conical. Retinas are absent while corneas may be well-developed, reduced, or absent. This species 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). The Bone Cave harvestman is considered to be polymorphic, exhibiting a north to south clinal variation in some morphological characters with the more northerly individuals exhibiting more troglobitic traits (Ubick and Briggs 1992, p. 211). Ubick and Briggs (2004, pp. 108-110) added a significant number of new specimens and recommended a complete character analysis of the new material to assess the affect the new material would have on the clinal variation; however, this has not been completed. Using the standard of male genitalic distinctiveness generally applied to *Texella* species, *T. reddelli* and *T. reyesi* are very similar (Ubick and Briggs 1992, p. 208). *T. reddelli*, whose range is generally further south than *T. reyesi,* is less troglobitic in character than *T. reyesi* although it too exhibits a cline in morphological characters with more troglobitic specimens found in the northern portions of its range (Ubick and Briggs 1992, p. 209). To date, the most obvious character used to separate *T. reyesi* and *T. reddelli* has been the presence or absence of a retinae (Ubick and Briggs 1992, pp. 172, 208; Ubick and Briggs 2004, p. 107). However, Ubick and Briggs (2004, p. 107) assigned several specimens without retinae to *T. reddelli* based on other morphological characteristics and, in the Jollyville Plateau area, several others since then have also been placed tentatively with *T. reddelli* based on other morphological traits (Darrell Ubick, personal communication, November 4, 2017).

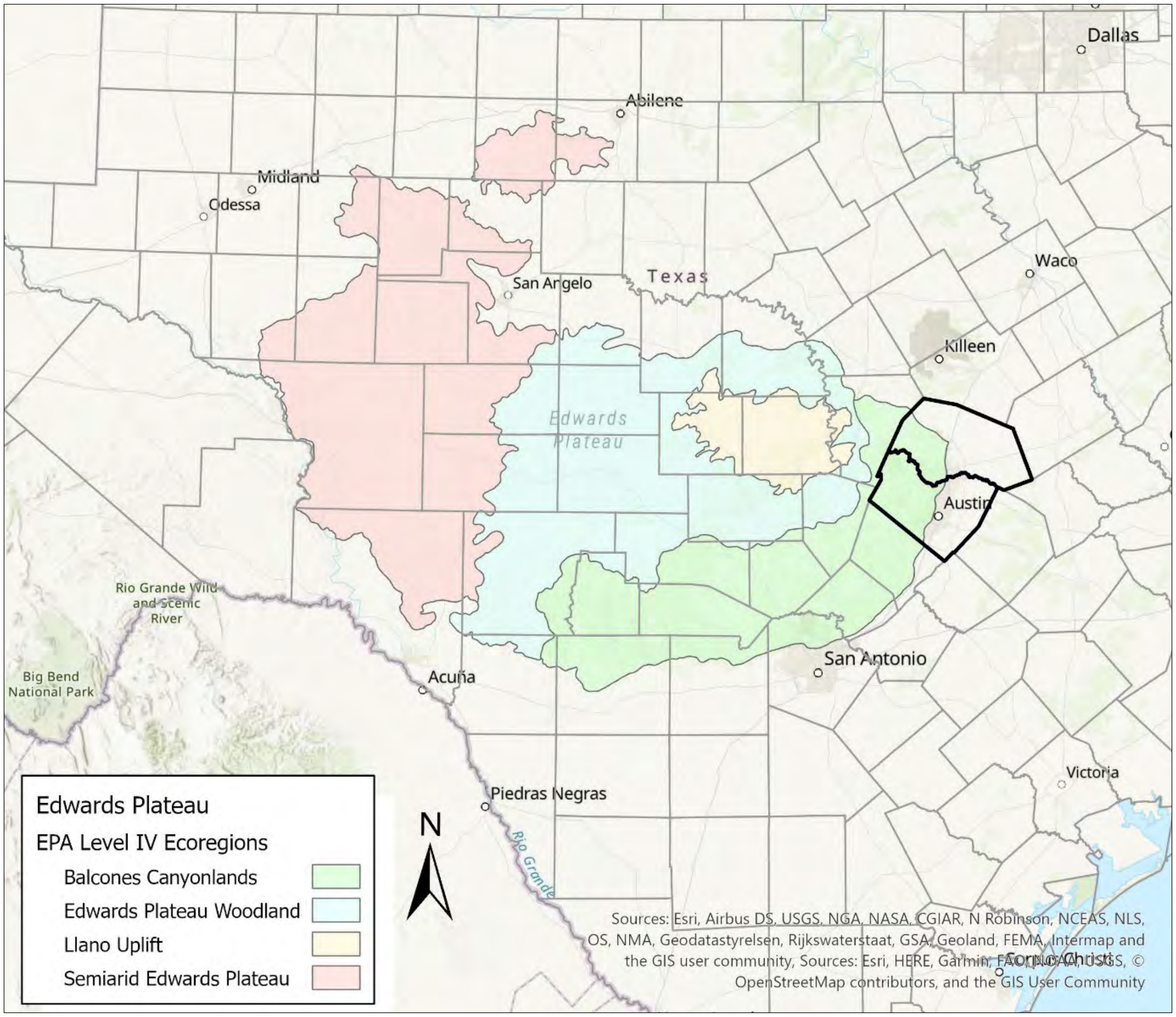
Preliminary genetics work conducted on a number of specimens of *Texella* from the Travis and Williamson counties area found that the *reddelli* infragroup, composed of *T. reddelli* and *T. reyesi*, is monophyletic within the larger *reddelli* subgroup, indicating that the two species are closely related (Hedin and Derkarabetian 2020, pp. 7-10). The results of this analysis also supports *T. reyesi* and *T. reddelli* as separate species. However, the authors hypothesize that the *T. reddelli* samples included in this study, from features north of the Colorado River, are members of *T. reyesi* as initial results indicate they either nest within a *T. reyesi* genetic clade or are associated with a *T. reyesi* genetic cluster (Hedin and Derkarabetian 2020 pp. 7-10, 12-13, 15).

Hedin and Derkarabetian (2020, p. 15) observed that, while there is clear genetic and ecological differentiation within *T. reyesi*, there is a limited male genitalic divergence within these clades and recommended treating these as different populations within a single variable species. The authors also recommend a formal morphological analyses of available specimens of both *T. reyesi* and *T. reddelli* and additional genetic sampling including outlier populations in order to formally assign *T. reddelli* specimens north of the Colorado River to *T. reyesi* and to resolve the status of the more outlying populations (Hedin and Derkarabetian 2020, pp. 14-15). For purposes of this report, we are treating specimens from the three features named in the report, and those in close geographic proximity to the named features, as part of Bone Cave harvestman populations in that area.

The Bee Creek Cave Harvestman (*T. reddelli)* was listed as endangered on September 16, 1988, due to its restricted distribution and threats from urban development (53 FR 36029-36033). Some occurrences that were included in that species' listing in 1988 were later assigned to the Bone Cave harvestman following taxonomic revision (Ubick and Briggs 1992, p. 211). 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.

3.0 Distribution

Species diversity within the genus *Texella* is greatest in the Balcones Canyonlands ecoregion of central Texas with several species endemic to restricted ranges across this region (Figure 2; 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; 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). Rising waters (i.e., hypogenic) from depth have also played a role in cave formation in this region (Schindel and Gary 2018, pp. 80, 83-85).



Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community, Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community

Figure 2. Edwards Plateau of Texas with Travis and Williamson counties (black polygons).

The karst habitats of the Balcones Canyonlands host a wide range of narrowly endemic aquatic and terrestrial invertebrates (Longley 1981, p. 127; Ubick and Briggs 1992, p. 224; Reddell 1994, p. 32; Culver et al. 1999, p. 140; Lewis 2001, pp. 3, 9; Elliott 2004, p. 166; Ubick and Briggs 2004, pp. 113, 116; Chandler et al. 2009, p. 136; Cokendolpher 2009, pp. 68-69; Paquin and Dupérré 2009, pp. 10-11, 13; Ledford et al. 2011, pp. 338, 345; Sokolov et al. 2014, p. 95; Espinasa et al. 2016, p. 237; Hutchins 2018, pp. 478, 490). Across this region of Texas, 16 *Texella* species are associated with caves and other subterranean voids and exhibit varying degrees of dependence on and adaptation to these habitats (Ubick and Briggs 2004, p. 116).

The Bone Cave harvestman is restricted in distribution to caves in Travis and Williamson counties north of the Colorado River (Figure 3; Ubick and Briggs 1992, pp. 211-221). At the time of the species' description in 1992, the Bone Cave harvestman was recorded from 13 caves in Travis County and 10 caves in Williamson County (Ubick and Briggs 1992, pp. 211, 221). In 2004, the number of locations the species was known from increased to 24 caves in Travis County and 115 caves in Williamson County (Ubick and Briggs 2004, pp. 108-110). In the 2009 and 2018 5-year reviews, the Bone Cave harvestman was noted as occurring in 168 and 203 caves respectively (Service 2009, p. 2, Service 2018, p. 12).

Although the number of karst features known to host Bone Cave harvestman populations has increased since the species description in 1992 and a few newer locations have expanded the modeled range range of the species to the north and west, Bone Cave harvestman populations are associated with specific geological regions within Travis and Williamson counties. Karst geologic areas were initially established for those 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). Veni and Jones (2021, entire) further evaluated and updated these regions. Geologic continuity, hydrology, and the distribution of rare and endemic karst invertebrates informed this regional delineation (Service 1994, p. 76).

The Bone Cave harvestman occurs in all or portions of six of the currently delineated karst fauna regions in Travis and Williamson counties. From north to south, these regions are the North Williamson County, Georgetown, McNeil/Round Rock, East Cedar Park, Jollyville Plateau, and Central Austin Karst Fauna Regions (Service 1994, p. 33; Veni and Jones 2021, pp. 24, 40).

Karst fauna regions were further divided into karst zones based on known and potential boundaries of listed karst invertebrate habitat (Veni and Associates 1992, pp. 61-62; Veni and Martinez 2007, pp. 2, 7-8; Veni and Jones 2021, pp. 5-6). In essence, while a karst fauna region may be geographically more extensive, only specific portions of a region may contain confirmed or potential habitat for karst invertebrate populations. Karst zones for Travis and Williamson counties were developed through review of the area's geology, distribution of caves, and associated distribution of listed karst invertebrate species (Veni and Associates 1992, entire; Veni and Martinez 2007, entire; Veni and Jones 2021, entire). Achieving absolute certainty regarding predictions where listed karst invertebrates may occur is not possible given the complexities inherent to karst landscapes (e.g., mesocaverns). However, karst zones provide a useful tool for assessing management, protection, and research needs within these regions. Karst zones, as revised by Veni and Jones (2021, pp. 6, 25-26) are as follows:

- Zone 1: Areas known to contain endangered cave fauna
- Zone 2: Areas having a high probability of suitable habitat for endangered or other endemic invertebrate cave fauna (refined now to only endangered cave fauna)
- Zone 3a: Areas suitable for troglobite species but which have a low probability of containing endangered karst species because the habitat is occupied by other troglobite species
- Zone 3b: Areas which have a low probability of containing endangered karst species because they are poorly suited for troglobite species
- Zone 4a: Areas suitable for troglobite species but which do not contain endangered karst species because the habitat is occupied by other troglobite species
- Zone 4b: Areas which do not contain troglobite species.

In revising the karst zones, Veni and Jones (2021, pp. 10-25) utilized confirmed species localities and a distance allocation model to estimate ranges for 39 troglobitic species occurring within the Travis and Williamson counties area. Based on this model, they predicted potential Bone Cave harvestman occupation of approximately 53,857 hectares (ha) [133,083 acres (ac)] based on proximity to known locations and cavernous or potentially cavernous rock (Veni and Jones 2021, pp. 10-14, 24). Of this, 46,354 ha (114,544 ac) is Karst Zone 1, or areas known to contain the Bone Cave harvestman and an additional 602 ha (1,488 ac) of Karst Zone 2 may contain the Bone Cave harvestman. Approximately 6,899 (17,049 ac) within the modeled range of the Bone Cave harvestman in this study fell in areas classified as Karst Zone 3b or having a low probability of containing potential habitat (Figure 3). Because areas classified as Karst Zone 3b in this study are poorly cavernous or areas of the cavernous unit covered by poorly cavernous or non-cavernous alluvium or rock we are including only Zones 1 and 2 in our analysis until further study can determine the extent to which the Bone Cave harvestman may occupy these areas.

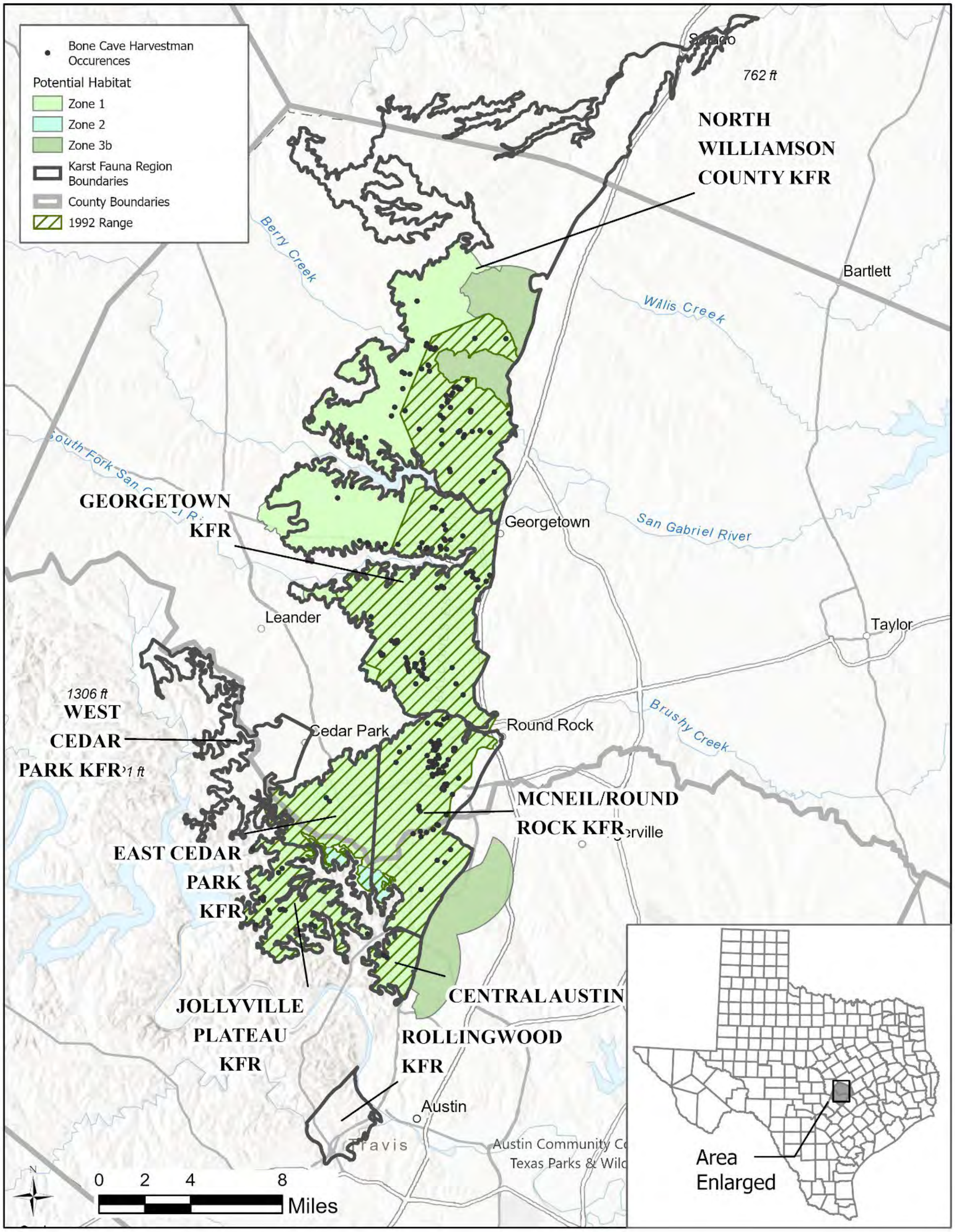


Figure 3. Bone Cave harvestman distribution (Travis and Williamson counties, Texas).

4.0 Adaptation to Subterranean Habitats

The habitat of the Bone Cave harvestman is caves and smaller subterranean voids in portions of Travis and Williamson counties. Caves, specifically those with openings to the surface, can exhibit some degree of zonation as ecological and environmental variables decrease (e.g., light, nutrients, temperature) or increase (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). The Bone Cave harvestman inhabits the deeper reaches of caves (Ubick and Briggs 1992, p. 211). These deep 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 (Figure 4; 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

Figure 4. Troglomorphic spider (*Cicurina*; top) and pseudoscorpion (*Tartarocreagris*; bottom), Travis County, Texas. Note Absence of eyes, reduced coloration, and/or elongated appendanges. Courtesy of Colin Strickland, City of Austin.

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 2012, pp. 517-528; 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).

Troglomorphic traits have evolved multiple times in a number of harvestman genera (Ubick and Briggs 1992, p. 169; Derkarabetian et al. 2010, pp. 8, 10; Hedin and Thomas 2010, pp. 108, 116, 119; Derkarabetian and Hedin 2014, p. 23). Harvestman species classified as troglobites have been described from cave systems of several nations including Australia (Shear 2001, pp. 156-157), Brazil (Pinto-da-Rocha 1996a, pp. 847-848; Hara and Pinto-da-Rocha 2008, pp. 51-57; Kury and Pérez-González 2008, pp. 259-266; do Monte et al. 2015, pp. 2-3; Pinto-da-Rocha et al. 2015, pp. 80, 83-93), Bulgaria (Mitov 2011, pp. 304-309;), Cuba (Pérez Gonzalez and Yager 2001, p. 74), Mexico (Shear 1977, pp. 172-175; Cruz-López 2013, pp. 1138-1141), Serbia (Karaman 2005, pp. 440-447), Slovenia (Novak and Kozel 2014, pp. 136-143), South Africa (Giribet et al. 2013, pp. 416-419), Spain (Prieto 1990, pp. 286-292; Luque and Labrada 2012, pp. 26-34), the United States (Briggs 1974, pp. 206-214; Cokendolpher 2004, pp. 149-150; Ubick and Briggs 2004, p. 116), and Venezuela (Pinto-da-Rocha 1996b, pp. 321-323).

Eighteen *Texella* species in Texas have some association with caves with eight of those species, including the Bone Cave harvestman, classified as troglobites (Ubick and Briggs 2004, p. 116). Traits exhibited by these troglobitic species include increased length of legs, loss or reduction of eyes, and reduced pigmentation (Goodnight and Goodnight 1960, pp. 35-36; Ubick and Briggs 1992, pp. 165-168). Along with those morphological traits, troglobitic harvestmen likely possess physiological adaptations observed in other troglophilic and troglobitic arthropods such as reduced metabolic rate, slower development, longer life spans, and/or greater energy investment in eggs (Dickson and Holsinger 1981, pp. 41, 45; Hadley et al. 1981, p. 221; Howarth 1983, pp. 374-376; Peck 1986, p. 1025; Studier et al. 1986, p. 434; Cyr et al. 1991, pp. 236, 238; Studier 1996, p. 107; Miller 2005, pp. 568, 570; Arnedo et al. 2007, pp. 652-653; Faille and Pluot-Sigwalt 2015, p. 11; Mammola and Isaia 2017, pp. 3, 5).

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). Ledford et al. (2011, p. 365; 2012, p. 10) noted similar intraspecific variation in troglomorphic traits (e.g., reduced eyes and pigmentation) for some central Texas spiders (i.e., *Neoleptoneta* and *Tayshaneta* species).

5.0 Life History

Detailed information regarding the diet, physiology, and reproduction of the Bone Cave harvestman is currently unavailable. 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; Culver et al. 2004, p. 1223; Schneider and Culver 2004, pp. 42-43; Krejca and Weckerly 2007, pp. 8-10; Mosely 2009a, 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). Availability of funding to support research is another constraining factor. Basic life-history research is needed to better understand the conservation requirements of the Bone Cave harvestman.

A substantial amount of information does exist on Opiliones biology and ecology, however (Pinto-da-Rocha et al. 2007, entire). Research has been conducted on a range of harvestman species world-wide including species within the suborder Laniatores and family Phalangodidae. Research has also been published on other troglobitic and troglophilic harvestman species. These sources of information are useful in evaluating the potential needs and requirements of the Bone Cave harvestman.

Humidity is an important influencer of harvestman spatial ecology (Edgar 1971, pp. 47-49; Martín and Oromí 1986, p. 384; Hillyard and Sankey 1989, pp. 26-27; Almeida-Neto et al. 2006, pp. 370-371; Bragagnolo et al. 2007, p. 397; Machado et al. 2007, p. 8; Stašiov 2008 p. 162; Chelini et al. 2011, pp. 396-397; Schönhofer et al. 2015, p. 49). These arachnids are considered very susceptible to desiccation and exhibit preferences for habitats that offer higher humidity (Curtis and Machado 2007, pp. 285-286; Machado and Macías-Ordóñez 2007, p. 409; Willemart et al. 2009, p. 219). In fact, captive harvestmen in lab settings exhibit preferences for more humid conditions and experience mortality within hours to days in low humidity conditions (Santos 2007, p. 482). A factor that potentially contributes to association with high humidity is the seeming inability of harvestmen to regulate the closure of tracheal spiracles to inhibit respiratory water loss (Santos 2007, p. 477). Conversely, spiders can regulate spiracle opening and closing with respiratory water loss varying from 1%-12% (Santos 2007, p. 477). However, loss or reduction of spiracle control in spiders can result in respiratory water losses over 40% (Santos 2007, p. 477). Thus, lack of spiracle control likely places harvestmen at greater risk of desiccation in low humidity environments.

Troglobitic harvestman species in many areas of the world have been noted as occurring in cave microhabitats that afford higher, and potentially more stable, humidity (e.g., under decomposed plant material or rocks, on wet cave walls, near cave streams, or in narrow fissures) and include *Iandumoema setimapocu*, *I. smeagol*, and *Spinopilar moria* in Brazil (Hara and Pinto-da-Rocha 2008, p. 55; Kury and Pérez-González 2008, p. 265; Pinto-da-Rocha et al. 2015, pp. 82, 92), *Paranemastoma beroni* in Bulgaria (Mitov 2011, pp. 304, 312), *Hadzinia ferrani* in Slovenia (Novak and Kozel 2014, pp. 135, 137), *Ischyropsalis cantabrica* in Spain (Luque and Labrada 2012, p. 33), and *Taracus marchingtoni* in the United States (Shear and Warfel 2016, p. 40).

Similarly, the Bone Cave harvestman is limited to deep cave zones and has been observed from under rocks lightly covered in soil (Figure 5; Ubick and Briggs 1992, p. 211). Two other troglobitic *Texella* species from central Texas, *T. elliotti* and *T. mulaiki*, also exhibit some affinity for deeper or lower portions of caves (Ubick and Briggs 1992, p. 203; Ubick and Briggs 2004, p. 107) that likely offer higher humidity (Ubick and Briggs 2004, p. 107).

Figure 5. Bone Cave harvestman on cave floor, Travis County, Texas. Courtesy of Issac Lord.

The diet of harvestman species can be varied (Edgar 1971, pp 29-30; Hillyard and Sankey 1989, pp. 16-17). Harvestmen are generally considered predators of small, soft-bodied invertebrates though some species may opportunistically scavenge on dead animal tissue (Acosta and Machado 2007, pp. 310-320). Still other species feed on fungal or plant material (Acosta and Machado 2007, p. 320). Members of the family Phalangodidae have been reported as feeding on small beetles, collembolans, and dipteran larvae (Acosta and Machado 2007, p. 315).

Foraging for live prey may take the form of a stationary site-and-wait strategy or active wandering in search of potential food items (Acosta and Machado 2007, pp. 323-327, 332-333). Increased movement may be required of species that feed on immobile food sources (Acosta and Machado 2007, p. 332). Troglobitic harvestmen may need to search for food more intensively given potential scarcity of nutrients in subterranean systems (Hoenen and Gnaspini 1999, pp. 162-164). Unlike spiders, harvestman appear to have a limited ability to detect live prey at a distance through mechanical stimuli (Willemart et al. 2009, p. 223). The first and/or second pair of legs of harvestmen play important sensory roles and are used detect prey, or immobile food items, at close proximity (Acosta and Machado 2007, p. 322; Willemart and Chelini 2007, p. 76; Willemart et al. 2009, pp. 221-223). Chemoreception of odor molecules may represent another means harvestmen use to locate food sources, especially when scavenging for immobile food items (Acosta and Machado 2007, pp. 322-323; Willemart and Chelini 2007. pp. 76-77; Willemart et al. 2007, p. 220; Costa and Willemart 2013, pp. 360-361, Gainett et al. 2017, p. 193).

Harvestmen lack venom glands and do not envenomate prey. They also lack spinnerets and do not produce silk for prey capture (Machado et al. 2007, p. 4). Instead, harvestmen subdue prey mechanically through appendages such as pedipalps, chelicerae, and/or legs (Acosta and Machado 2007, pp. 327-328; Wolff et al. 2016, pp. 564, 578-579, 581-585, 590-591). Pedipalps of species in the suborder Laniatores, including the family Phalangodidae, are large, spiny, and raptorial for potential use in prey capture (Acosta and Machado 2007, pp. 327-328; Shultz and Pinto-da-Rocha 2007, p. 28; Wolf et al. 2016, pp. 7-8). Several *Texella* species, including the Bone Cave harvestman, possess robust, raptorial pedipalps (Ubick and Briggs 1992, pp. 175, 180, 184, 188, 202, 204, 212, 235; Ubick and Briggs 2004, pp. 105, 118, 121, 124, 128, 130, 132, 135, 138).

Harvestmen sexually reproducing though instances of parthenogenesis are known (Machado and Macías-Ordóñez 2007, pp. 414-415). Females may lay eggs immediately following copulation (Machado et al. 2015, p. 187). Species in the suborder Laniatores lay eggs singly or in batches on exposed surfaces of fallen logs, rocks, and vegetation or in shallow natural cavities (Machado and Macías-Ordóñez 2007, p. 440). Females may cover deposited eggs with debris or soil to reduce predation risk or minimize dehydration (Machado and Raimundo 2001, pp. 137, 139, 144). A number of Laniatores species exhibit parental care, with females or males actively guarding egg clusters and recently hatched nymphs (Machado and Macías-Ordóñez 2007, pp. 423, 440-452). Troglobitic species of that suborder have been observed guarding egg clusters and nymphs including *Phalangodus briareos* in Columbia (García-Hernández and Machado 2017, p. 230) and *Hoplobunus boneti* in Mexico (Mitchell 1971a, pp. 392-394).

Duration of embryonic development is dependent upon humidity and temperature with the eggs of some Phalangodidae species taking 30-70 days to hatch (Gnaspini 2007, pp. 460, 464). Over a period of four to six months, Phalangodidae nymphs may undergo four to eight molts before reaching sexual maturity (Gnaspini 2007, pp. 460, 466-471). The life span of adult Phalangodidae species may range from 18 months to nearly four years (Gnaspini 2007, p. 460).

6.0 Individual Needs

We consider the individual needs (i.e., habitat requirements) of the Bone Cave harvestman to be the resources that provide for growth, reproduction, and survival. These include resources that are necessary for breeding, feeding, and sheltering behaviors of an individual harvestman within its habitat. The following resources are necessary to sustain the species' life history processes and are the key factors that determine the health and resiliency of Bone Cave harvestman populations.

6.1 Macrocaverns and Mesocaverns

Subterranean voids in karst landscapes can be grouped into three classes, macrocaverns, mesocaverns, and microcaverns (Howarth 1983, pp. 370-371). Macrocaverns, or caves, are karst features that consist of a natural opening in solid rock larger than 20 cm (> 8 in) in diameter or cross-sectional dimension (Figure 6**;** Howarth 1983, p. 370; Culver and Pipan 2009, p. 4). Caves have historically provided the primary access points for human entry into and exploration of subterranean environments (Hamilton-Smith 2001a, p. 231). Entrances to caves can be transient with surface erosion causing collapses and infilling. Only a small percentage of macrocaverns may exhibit entrances to the surface and those entrances can be transient with surface erosion causing collapse and infilling." (Curl 1958, pp. 15-16). Caves are a focal point for input of nutrients and water into the karst ecosystem (Veni and Associates 1992, p. 43) and important habitat for a wide range of animal species (Culver and Pipan 2009, pp. 40-69).

Figure 6. Macrocavern in Travis County, Texas. Courtey of Colin Strickland, City of Austin.

Macrocaverns with entrances to the surface are broadly subdivided into zones based on an environmental gradient from the entrance to the cave's terminus (Howarth 1993, p. 69). This environmental gradient is shaped by such variables as carbon dioxide concentration, light level, temperature, and relative humidity (Mosely 2010, p. 56) and further influenced by a macrocavern's size, shape, and location of entrances and voids (Howarth 1983, pp. 373-374; Howarth 1993, p. 69). Based on Howarth (1993, p. 69) and Mosely (2010, pp. 55-56), terrestrial environmental zones within macrocaverns are as follows (Figure 7):

- Threshold: Entrance of the cave to the farthest limit of sunlight required by photosynthesizing plants.
- Twilight zone: Inner edge of the threshold to the edge of total darkness. Subject to drying winds caused by cold air sinking into the cave.
- Transition zone: A dynamic area in total darkness where the microclimate is affected by short-term effects on the surface (i.e., drying air currents pushed into the cave by climatic changes on the surface).
- Deep cave zone: An area of total darkness and long-term presence of moisture and saturated atmosphere. Air exchange with the surface keeps the air fresh.
- Stagnant air zone: An area where air is exchanged with the surface only slowly, relative humidity remains at 100%, while carbon dioxide and oxygen concentrations may fluctuate dramatically from decomposition of organic material.

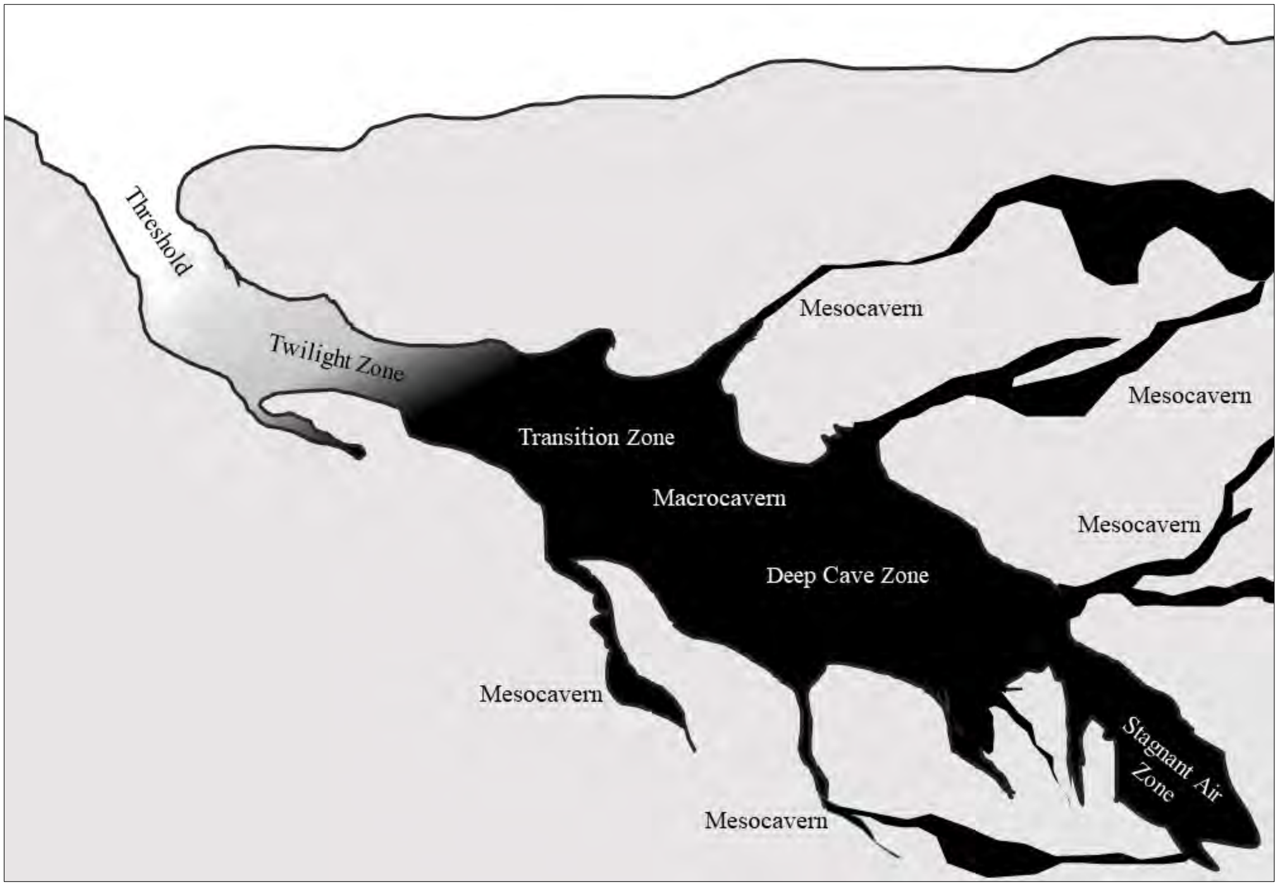


Figure 7. Stylized depiction of cave environmental zones with examples of marco- and mesocaverns.

Troglobitic invertebrates, including the Bone Cave harvestman, are generally associated with the deep cave zone and its high relative humidity and stable temperatures (Howarth 1983, p. 373; Martín and Oromí 1986, p. 384; Ubick and Briggs 1992, p. 211). Much of what is known about subterranean biodiversity has been driven by human exploration of relatively accessible macrocaverns (Mosely 2009b, p. 89; Gilgado et al. 2015, p. 344; Gilgado and Ortũno 2015, p. 86). From an invertebrate perspective, however, these larger spaces may not represent the highest-quality available habitat (Howarth 1983, p. 370-371).

Mesocaverns are humanly inaccessible voids that range in size from 0.10-20 cm (0.4-0.8 in) in diameter interconnecting with macrocaverns (Howarth 1983, pp. 370-371). This class of voids is laterally extensive near caves as the latter are sites of flow path convergence (Veni and Associates 1992, p. 43). Networks of interconnected mesocavernous voids are important, if not the preferred, habitat for many karst invertebrates (Park 1960, p. 99; Howarth 1983, p. 371; Howarth 1987 pp. 5-7; Howarth 1993, p. 69; Humphreys and Eberhard 2001, pp. 64-65; Mosely 2009b, p. 89; Gilgado et al. 2015, p. 344). Microclimatic conditions (e.g., humidity and temperature) within mesocaverns may be more favorable for karst invertebrates than larger macrocaverns that are susceptible to surface climatic conditions that reduce humidity or increase temperature (Howarth 1983, p. 7; Knapp and Fong 1999, p. 6; Humphreys and Eberhard 2001, p. 65). Mesocaverns also potentially contain and transport (e.g., via percolating groundwater) nutrients not as readily available within macrocaverns (Howarth 1987, pp. 10-11).

Karst invertebrates may occupy mesocaverns as their primary habitat, only leaving these voids intermittently to forage for food or search for mates when climatic conditions in macrocaverns are optimal (Howarth 1983, p. 371). Because metabolic rates of karst invertebrates are potentially low, they may be able to sustain long periods existing on much reduced food in mesocaverns (Howarth 1983, p. 375). Detectability data support the contention that karst invertebrates occupy mesocaverns potentially more often than they occupy macrocaverns (Krejca and Weckerley 2007, pp. 3, 7).

Along with shelter and foraging, mesocavernous networks may provide dispersal corridors for the Bone Cave harvestman, linking karst features across the landscape. Although there is no data specific to the Bone Cave harvestman, research indicates that troglobitic arachnids and insects disperse through networks of subterranean voids. Moulds et al. (2007, pp. 8, 10) postulated that low levels of genetic variation between populations (up to 6 kilometers (km) (3.7 miles [mi]) apart) of cave-dwelling pseudoscorpions (*Protochelifer* sp.) was the result of subterranean migration of individuals through mesocaverns. Populations of the troglobitic ground beetle, *Neaphaenops tellkampfii*, from caves in Kentucky up to 30km (18.6 mi) apart, were nearly identical genetically with gene flow likely facilitated through subterranean dispersal among karst features (Turanchik and Kane 1979, pp. 65-67).

In Williamson County, Texas, boreholes drilled at a development site (i.e., Lakeline Mall) with two caves, Lakeline and Underline Caves, resulted in the capture of a troglobitic ground beetle (*Rhadine persephone*) from a subterranean void (Service 1994, pp. 52, 72-73). The species occurred in both caves and the borehole capture point was 183 m (600 ft) to the northwest of Lakeline Cave. Avise and Sealander (1972, p. 15) noted high levels of genetic similarity between individuals of another troglobitic ground beetle species, *R. subterranea*, collected from two additional Williamson County caves (i.e., Beck Ranch and Beck Sewer Caves) 756 m (2,480 ft) apart.

Several additional studies indicate that gene flow has historically occurred among populations of karst invertebrates in central Texas. Paquin and Hedin (2004, pp. 3243-3244, 3247, 3250; 2005, pp. 2, 4-5, 14-15) found *Cicurina* spiders, in Bexar and Travis counties, with shared mitochondrial DNA haplotypes occurring in caves separated by several kilometers. Ledford et al. (2011, pp. 351-352; 2012, pp. 11, 51) documented identical mitochondrial and nuclear DNA haplotypes of the Tooth Cave spider (*Tayshaneta myopica=Neoleptoneta myopica*) in four Travis County caves, the most distant of which were 292 m (958 ft) apart. Espinasa et al. 2016 (pp. 233, 236, 238) noted shared or identical mitochondrial DNA haplotypes among populations of cave-dwelling bristletails (*Texoreddellia*) from sets of caves in several central Texas counties including Bell, Hays, Travis, and Williamson counties.

Microcaverns are subterranean voids smaller than 0.1 cm (0.04 in) in diameter. Little is known about the fauna that reside in microcaverns. Small space, lack of aeration, and a paucity of organic nutrients may inhibit use of these spaces by invertebrates (Howarth 1983, p. 370; Veni and Associates 1992, p. 43). That notwithstanding, a suite of species adapted to water-filled microcaverns may occur in this habitat type (Fong and Culver 1994, p. 34).

6.2 Humidity and Temperature

The climatic conditions of caves, while relatively stable compared to surface habitats, are subject to variation in prevailing relative humidity and air temperature (Culver 1982, p. 9; Culver and Pipan 2009, pp. 3-4). Cave morphology (e.g., size, shape, and volume), number and size of entrances, seasonal changes in airflow, and annual range of surface temperatures among other factors interact to influence subterranean climates (Tuttle and Stevenson 1978, pp. 110-120; de Freitas and Littlejohn 1987, p. 568). Cave zones closest to the surface (e.g. threshold and twilight zone) are most prone to rapid shifts in humidity and temperature in response to seasonal fluctuations on the surface (Holsinger 1988, p. 147; Tobin et al. 2013, pp. 206, 211; Mammola et al. 2015, p. 243; Mammola and Isaia 2016, pp. 26-27).

With increasing distance into the cave, climatic conditions stabilize within a narrow range of humidity and temperature (Poulson and White 1969, p. 972; Howarth 1980, p. 398; Howarth 1993, p. 69; Prous et al. 2004, pp. 377-378; Tobin et al. 2013, p. 206). Temperatures in the deep cave zone are relatively constant near the average annual surface temperature and relative humidity approaches saturation (Howarth 1980, p. 397; Howarth 1993, p. 69). Both parameters experience much less change in this cave zone and temporally lag seasonal changes on the surface (Howarth 1980, pp. 397-398; Howarth 1983, p. 372; 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). In a central California cave, Tobin et al. (2013, p. 206) found that average temperatures in the entrance zone varied from 6.8ºC to 22.52ºC (44.24ºF to 72.53ºF), while the deep cave zone varied only from 15.57ºC to 17.19ºC (60.03ºF to 63.00ºF) over a six-month period.

To date, all Bone Cave harvestmen observations have been in deep cave zones with the exception of an individual observed near the entrance to a Travis County cave following heavy rains (Ubick and Briggs 1992, p. 211). Thus, it is likely that this harvestman is adapted to and requires high relative humidity and stable air temperatures (Curtis and Machado 2007, pp. 285-286; Machado and Macías-Ordóñez 2007, p. 409; Willemart et al. 2009, p. 219). Studies indicate that troglobitic arthropods display preferences for higher relative humidity and/or lower air temperatures underscoring a dependence on deep cave conditions (Mitchell 1971c, pp. 300-301; 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). The loss or reduction of water-conserving mechanisms (i.e., thin, permeable cuticles) makes some troglobitic arthropods more prone to desiccation in low humidity environments (Hadley et al. 1981, p. 219; Hild et al. 2009, p. 432).

Although relatively stable, the humidity and temperature of deeper cave reaches can shift to some degree in relation to seasonal climatic conditions on the surface (Tobin et al. 2013, pp. 206-207, 211). The small, shallow caves that occur across the range of the Bone Cave harvestman potentially experience greater variation in humidity and temperature than larger cave systems (Elliott and Reddell 1989, pp. 5-6). Troglobitic and troglophilic arthropods may respond to seasonal shifts by moving to microclimates with higher humidity (i.e., mesocaverns) during dry conditions or into larger subterranean voids (i.e., macrocaverns) during wet periods (Park 1960, p. 99; Howarth 1983, p. 373; Crouau-Roy et al. 1992, p. 17; Mammola et al. 2015, p. 246).

6.3 Drainage Basins

Drainage basins that support a natural quantity and quality of water are critical as the Bone Cave harvestman requires high humidity and a potential prey base dependent upon organic material transported from the surface. Water enters the karst ecosystem through surface and subsurface (e.g., groundwater) drainage basins (Hauwert 2009, p. 84; Veni 2003, p. 7). The surface drainage basin consists of water moving over the surface and is dependent on topography and slope. It typically includes water entering the cave entrance and adjacent sinkholes and fractures known to connect to the cave (Hauwert 2009, p. 84; Veni 2003, p. 7). The topography of surface drainage basins can substantially influence the amount of surface nutrients that enter subterranean ecosystems (Souza-Silva et al. 2012, pp. 146-147). The subsurface drainage basin is often larger than the surface drainage basin and includes mesocaverns, subterranean streams, bedding planes, buried joints, and sinkholes that have a connection to the surface that is not always observable from the surface (Veni 2003, p. 7). It also includes diffuse percolation through the soil, epikarst, and other smaller recharge features (Hauwert 2009, p. 84). Note that the surface and subsurface drainage basins may not necessarily overlap and may trend in opposite directions (Veni 2003, pp. 7-8).

Defining areas contributing to the hydrologic inputs of a particular cave can be determined by mapping the surface extent of any land at a higher elevation than the cave (Hauwert and Cowan 2013, pp. 354-355) or, at a minimum, the highest elevation of the cave stream or drips (Hauwert and Cowan 2013, p. 356). As this can delineate multiple square miles of area in a relatively flat landscape, more in-depth examination of the hydrogeology of a cave would be needed to limit the size of the catchment area while still providing confidence that the source area has been captured. Such studies include mapping the cave, including the elevation of drips and streams, mapping the geologic framework surrounding the cave, water quality sampling, and conducting tracer studies (Hauwert and Cowan 2013, p. 355). Because these studies can be time-consuming and expensive, the majority of caves occupied by the Bone Cave harvestman have not had detailed hydrogeologic studies conducted and their drainage basins remain unknown.

6.4 Surface Ecological Systems

The range of the Bone Cave Harvestman lies within the Balcones Canyonlands ecoregion of the Edwards Plateau in central Texas (Griffith et al. 2007, p. 49). Terrestrial ecological systems, or plant communities, in this region historically consisted of a mix of grassland, savanna, and woodland with riparian forests along watercourses (Figure 8; Lynch 1962, pp. 679, 683; Fowler and Dunlap, 1986, p. 146; Wills 2006, pp. 223-224, 226). Today, natural vegetation types include such associations as Ashe juniper motte and woodland, deciduous oak-evergreen motte and woodland, live oak motte and woodland, and savanna grassland, among several others (Elliott et al. 2014, pp.30-36, 62-65, 98-99, 118-123).

The ecological system surrounding karst features is a vital contributor of nutrients to and stabilizer of local climatic conditions (e.g., humidity and temperature) in karst ecosystems. Plant material (e.g., branches, dead leaves, and fruit) that falls from above, is blown in by wind, or washed in by water introduces nutrient sources for karst invertebrates (Culver and Pipan 2009, pp. 33-34). Root masses that penetrate into macro- and mesocaverns through soil and rock fissures may also provide direct nutrient input to shallow karst systems (Howarth 1983, pp. 376-377; Culver and Pipan 2009, pp. 36-39). Surface ecological systems also provide essential habitat and food resources for a variety of animal species (e.g., bats and cave crickets) that directly or indirectly transfer nutrients (e.g., carcasses, eggs, guano, and uneaten food) from the surface to the karst ecosystem (Culver and Pipan 2009, pp. 34-36).

Figure 8. Oak-Hardwood motte and woodland. One of several native plant communities in Travis and Williamson counties, Texas. Courtesy of Texas Parks and Wildlife Department.

6.5 Nutrients

Surface habitats are the primary source of nutrients for subterranean ecosystems given the absence of photosynthetic activity in deep cave zones (Barr 1968, pp. 47-48; Poulson and White 1969, pp. 971-972; Howarth 1983, p. 376; Culver and Pipan 2009, p. 23). Percolating or flowing water, wind, gravity, and/or animals are major pathways for the introduction of organic material into subterranean habitats (Culver and Pipan 2009, pp. 23-39). Potential nutrient sources in karst ecosystems can take several forms and include herbaceous and woody plant debris, tree roots, animal carcasses, and guano, (Barr 1968, pp. 51, 53; Howarth 1983, pp. 376-377; Jasinska et al. 1996, p. 518; Culver and Pipan 2009, pp. 24, 27-39). In deeper cave reaches, nutrients may enter through water containing dissolved organic matter and particulate detritus percolating vertically through karst fissures and solution features (Howarth 1983, pp. 376-377; Holsinger 1988, p. 147; Elliott and Reddell 1989, p. 50).

Deposited organic matter provides a food base for bacteria, fungi, and invertebrates that serve as prey for vertebrates and other invertebrates (Figure 9; 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). Availability of surface nutrients is an important factor in the maintenance of species diversity in cave ecosystems with greater amounts of nutrients supporting higher species abundance and/or richness (Schneider et al. 2011, pp. 773-774; Jaffé et al. 2016, pp. 6, 9, 11; Jiménez-Valverde 2017, pp. 10210-10212).

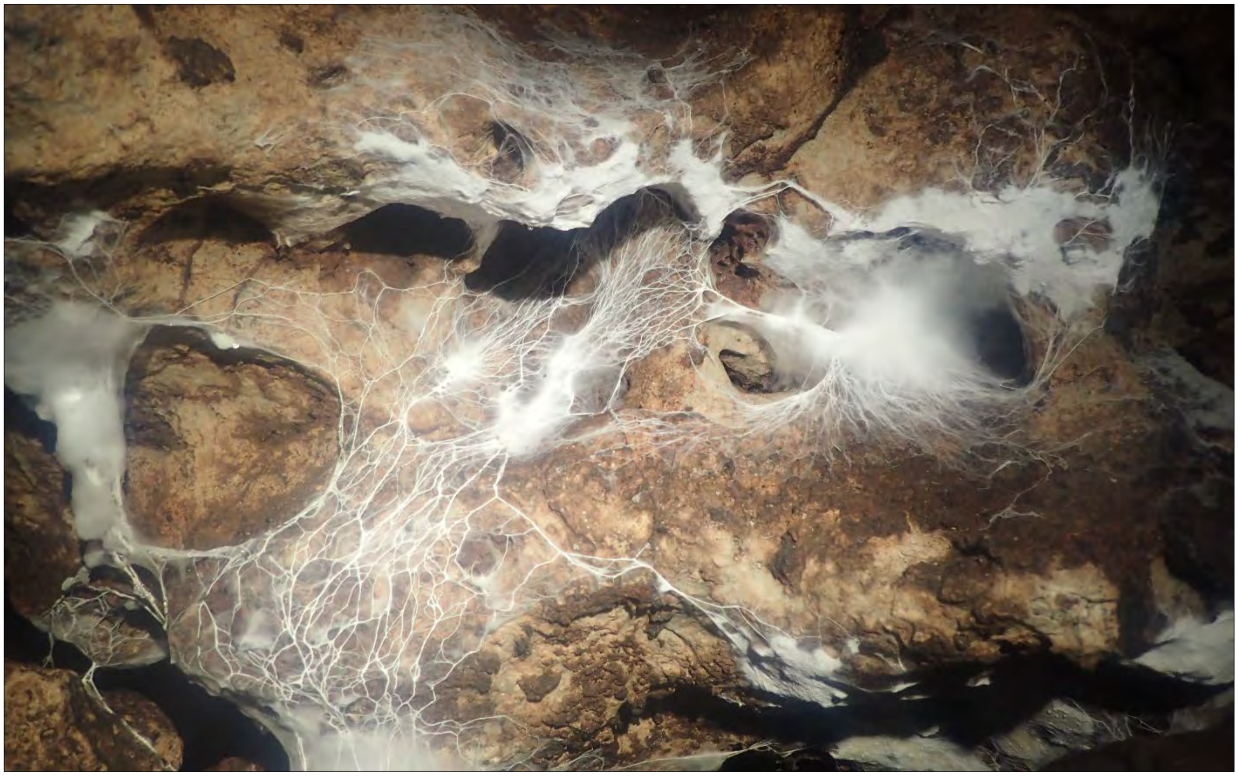


Figure 9. Fungal mycelium in a cave, Travis County, Texas. Courtesy of Colin Strickland, City of Austin.

Caves are known to host a wide range of invertebrate and vertebrate species that either occupy subterranean spaces only infrequently to forage for food or seek shelter (i.e., trogloxene), regularly move between the surface and subsurface (i.e., troglophile), or reside permanently within cave systems (i.e., troglobite) [Reddell 1994, pp. 34-42; Taylor et al. 2006, pp. 21-32, 80-106, 106-115]. Contributions to nutrient availability by these groups can consist of carcasses transported by predators, carcasses of temporary or permanent cave inhabitants, fecal material of carnivores, omnivores, and herbivores that visit or reside in the cave (Reddell 1994, p. 42; Toomey 1994, pp. 53-54, 57-58; Taylor et al. 2006, pp. 111-113). In general, these resources decrease in availability with increasing distance from a cave's entrance, with troglobites occupying more nutrient poor reaches of subterranean habitat (Schneider et al. 2011, pp. 773-774).

6.5.1 Cave Crickets

Cave crickets (Rhaphidophoridae) are nutrient contributors in many cave ecosystems, including those of central Texas (Figure 10; 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). The small, drier caves of central Texas generally do not host large bat colonies or contain subterranean streams that serve as nutrient sources (Taylor et al. 2005, p. 97). Instead, nutrient input in these cave systems is partially dependent upon the activity of cave crickets (Taylor et al. 2004, pp. 28, 31; Taylor et al. 2005, pp. 97-98; Taylor et al. 2007a, p. 3). Cave crickets are themselves dependent upon functional, stable subterranean habitats and exhibit such troglomorphic traits as elongated appendages, low metabolic rates, and sensitivity to moisture loss (Lavoie et al. 2007, pp. 120-121, 126-127).

Figure 10. Cave cricket (*Ceuthophilus secretus*), Travis County, Texas. Courtesy of Michelle (www.inaturalist.orgphotos55712346).

Two described and one undescribed cave cricket species within the genus *Ceuthophilus*, *C. secretus*, *C. cunnicularis*, and *C.* species B, inhabit karst features in Travis and Williamson counties (Taylor et al. 2007b, p. 4). *Ceuthophilus secretus* and *C.* species B leave caves to forage at night, while *C. cunnicularis* rarely, if ever, leave caves to forage (Taylor et al. 2007b, pp. 4, 6). Surface foraging *C. secretus* and *C.* species B aggregate in karst features during the day, roosting tens to hundreds of meters within a cave (Fagan et al. 2007, p. 904). Crickets exit karst features at night to feed in the surrounding surface habitat (Taylor et al. 2005, pp. 105, 107; Taylor et. al 2007a, p. 3). A cave may contain hundreds to thousands of crickets, outnumbering many other karst invertebrates (Fagan 2007, p. 904). Crickets may forage up to 80 m (262 ft) from a karst feature with some individuals moving up to 105 m (344 ft) from a cave entrance in a single night (Taylor et al. 2005, p. 104). Foraging takes place on the ground among herbaceous vegetation and leaf litter (Taylor et al. 2005 p. 105) with woodlands followed by grasslands as preferred foraging habitats (Taylor et al. 2004, pp. 37-38).

Cave crickets can exhibit high site fidelity to individual karst features (Taylor et al. 2004, p. 39) but will also disperse to use nearby features (Taylor et al 2004, p. 40) or shelter temporarily under aboveground refugia (e.g., underside of logs or rocks; Taylor et al. 2004, p. 41). Radio-tracking data indicate that cave crickets may utilize multiple karst features and suggest that cricket-inhabited caves within 100 m (328 ft) of each other comprise a single population (Taylor et al. 2004, p. 40). Crickets return to the cave during the night or early morning, where they transfer nutrients (e.g., defecate or lay eggs) acquired during foraging (Fagan et al. 2007, p. 904). A variety of troglobitic invertebrates feed on cave cricket guano (Barr 1968, p. 53; Poulson et al. 1995, pp. 226, 229; Taylor et al. 2003b, p. 47), eggs (Mitchell 1971b, p. 259), remains of dead crickets (Lavoie et al 2007, p. 131), and potentially on living cave cricket nymphs (Elliott 1994, p. 16).

Member genera within the Rhaphidophoridae, including *Ceuthophilus*, *Dolichopoda*, *Hadenoecus*, *Macropathus*, *Speleiacris*, and *Troglophilus*, are broadly considered to be omnivorous with species feeding on animal and plant matter (Banta 1907, p. 53; Richards 1954, p. 733; Barr and Reddell 1967, pp. 264-265; Campbell 1976, p. 364; Hubbell and Norton 1978, pp. 101-102; de Pasquale et al. 1995, pp. 222-223; Sharratt et al. 2000, p. 123: Cokendolpher et al. 2001, p. 100; Taylor et al. 2004, p. 29; Lavoie et al. 2007, p. 123; Di Russo et al. 2014, p. 48). Elliott (1993, pp. 22, 23) observed *Ceuthophilus* species in central Texas feeding on dead insects, fungi, and ripe fruit from Texas persimmon (*Diospyros texana*). Taylor et al. (2004, p. 30) captured an image of an individual *C. secretus* feeding on a dead bloodsucking conenose (Reduviidae: *Triatoma* species) in Coryell County, Texas. Analysis of stomach contents from surface foraging *C. conicaudus* in New Mexico revealed the presence of both animal and plant material (Campbell 1976, p. 364). When applied as baits for observational studies in Texas, *Ceuthophilus* cave crickets are attracted to and feed on a number of human foodstuffs such as canned tuna, cheese, grape jelly, and beef liver (Elliott 1993, p. 23; Cokendolpher et al. 2001, p. 100; Taylor et al. 2003b, p. 109; Taylor et al. 2005, p. 154; Taylor et al. 2007a, p. 6).

Taylor et al. (2004, pp. 5-31) and Taylor et al. (2007a, entire) analyzed stable carbon (δ13C) and nitrogen (δ15N) isotopes from a wide range of karst invertebrates to assess the trophic ecology of central Texas karst ecosystems. Results from those studies indicate that sampled *C. secretus* and *C.* species B feed at a lower trophic level (i.e., lower δ15N values) on plant material foraged from the surface plant community (Taylor et al. 2004, pp. 9-10, 28, 31; Taylor et al. 2007a, pp. 17, 21, 31). Conversely, individuals of the cave-restricted *C. cunnicularis* were noted to feed at a higher trophic level on more nitrogen-rich animal material potentially obtained through subterranean hunting and scavenging (Taylor et al. 2004, pp. 9-10, 28, 31; Taylor et al. 2007a, pp. 17, 23).

Isotopic analyses support the contention that cave crickets form the foundation of a linear nutrient pathway (Figure 11) in some central Texas caves (Taylor et al. 2004, pp. 9, 28; Taylor et al. 2007a, p. 31). The nutrients supplied by surface-foraging cave crickets from surrounding natural communities support a number of other taxa present in caves, particularly more broadly omnivorous or predaceous species such as *C. cunnicularis*, *Cicurina varians,* and *Rhadine reyesi* (Taylor et al. 2004, pp. 26-27, 28-29, 31; Taylor et al. 2007a, pp. 21, 24, 28). Surveys conducted at caves in Bexar, Hays, and Travis counties have shown that total numbers of karst invertebrates in a cave are correlated with numbers of cave crickets present (Taylor et al 2007a, pp. 2, 37, 42-44); an indicator of the vital role these insects play in some caves.

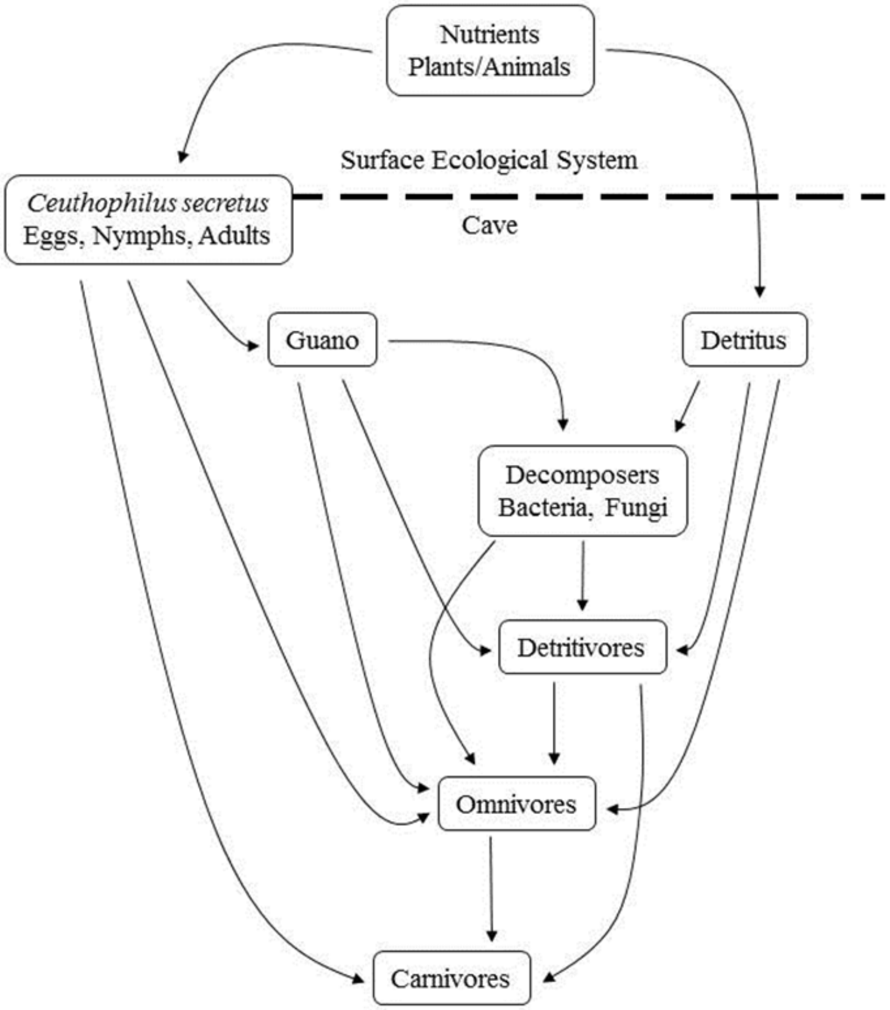


Figure 11. Generalized food pathway for a central Texas karst ecosystem. Adapted from Taylor et al. (2004, p. 31).

6.5.2 Mammals

Along with cave crickets, central Texas caves are known to be visited by mammal species, especially raccoons (*Procyon lotor*), Virginia opossums (*Didelphis virginiana*), North American porcupines (*Erethizon dorsatum*), and various rodents (Reddell 1994, pp. 41-42; Montalvo et al., 2019a, p. 12; Montalvo et al. 2019b, p. 45). Reddell (1994, p. 42) noted that raccoon fecal matter was common in caves visited by that species, even extending into the dark zone, potentially providing nutrients for cave invertebrates.

Studies of cave use by mammals in Bexar County revealed that three species, the North American porcupine, raccoon, and Virginia opossum, were the most frequent visitors to these sites (Montalvo et al. 2019a, p. 12; Montalvo et al. 2019b, p. 45). North American porcupines used caves for sheltering whereas raccoons and Virginia oppossums entered caves to forage for rodent and arthropod prey (Montalvo et al. 2019a, pp. 13-15).

While usage of caves by these mammal species provide some opportunity for them to deposit nutrients in the form of feces, the predatory behavior of raccoons and Virginia opossums may impact the abundance of other nutrient providers, such as cave crickets (Montalvo et al. 2019a, pp. 13-14). Also, as observed by Reddell (1994, p. 42), if raccoons and Virginia opossums frequently forage into the dark zone of caves they may also feed on endangered troglobitic invertebrates (Montalvo et al. 2019a, pp. 13-15).

Predation of troglobitic invertebrates by raccoons and Virginia opossums may be more prevalent in urbanized areas given those mammals association with anthropogenic habitats. In central Texas, Haverland and Veech (2017, entire) examined the occurrence of mammals within natural areas of the rapidly urbanizing Interstate-35 Corridor that included sites in Hays, Travis, and Bexar counties. Those researcher found that raccoon and Virginia opossum were significantly associated with urbanization, and more likely to occupy natural areas in highly urbanized regions versus natural areas in less urbanized locales (Haverland and Veech 2017, pp. 227-228).

Area of natural land cover, within a 400 m (1,312 ft) buffer, was an important determinate of occupation by those two mammals. Both raccoon and Virginia opossum occurrence in natural areas decreased sharply when natural land cover reached 95-100% within 400 m (1,312 ft) of a site (Haverland and Veech, 2017, pp. 226, 228). Frequency of both species increased in areas with a greater percentage of human-altered land cover (Haverland and Veech 2017, pp. 226-228). This suggests that smaller patches of natural habitat, containing caves, may be visited by raccoons and Virginia opossums at higher rates than areas with larger amounts of natural land cover. While such usage may mean increased deposition of nutrients in the form of nutrients, it also comes with potentially increased predation pressure on cave invertebrates, particularly troglobitic arthropods including the Bone Cave harvestman.

7.0 Population Needs

A population's resiliency, or the ability to be self-sustaining in the wild, is a probabilistic phenomenon influenced by demographics (e.g., survival and reproductive rates) and the environment. Estimating the resiliency of a given population involves considering the predictable responses of the population to various factors (e.g., food availability or moisture) as well as stochasticity. Stochasticity refers to the chance or random nature of demographic and environmental processes (e.g., the probability that a given individual will reproduce or the probability of drought). In general, larger populations have a higher likelihood of surviving stochastic events (O'Grady et al. 2004, pp. 516, 518; Pimm et al. 1988, pp. 774–775; van Dyke 2008, p. 217).

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). Population or demographic data for this species are very limited and generally inconclusive (i.e., lack of observable trends) given the difficulty in adequately surveying cave habitats, low detectability of troglobitic invertebrates, and absence of long-term monitoring efforts (See 9.1.2 Population Response to Surface Disturbance).

Since we do not have population estimates for the Bone Cave harvestman, nor do we know what reproductive rates sustain a healthy population, we apply measures of habitat elements as a surrogate to assess population health. Bone Cave harvestman populations need adequate surface habitat to support the native animal and plant community that provides the required nutrients to maintain or increase population size. They also need intact macro- and mesocaverns with stable humidity and temperature and intact surface and subsurface drainage basins to provide adequate quantity and quality of water to the karst ecosystem.

In our Karst Preserve Design Recommendations (Service 2012, entire), we developed criteria that protected areas should meet to sustain resilient listed karst invertebrate populations in central Texas. To provide the highest probability of long-term persistence, we recommended a protected area of at least 40 ha (100 ac) that encompasses a healthy native plant community, intact cave cricket foraging habitat, and the entire surface and subsurface drainage basins supporting at least one cave within a preserve. Additional criteria also apply to meet the high quality preserve standards (e.g., appropriate management and perpetual protection).

Although the negative effects of urbanization on karst invertebrate populations are evident in tracts of land as large as 36 ha (90 ac) (Taylor et al. 2007a, pp. 43-45), preserves 40 ha (100 ac) or more in size tend to require less active management and have a higher probability of maintaining species long-term. Protected areas with 16 to 40 ha (40 to 99 ac) that meet all other criteria of a high quality preserve are considered to be of medium quality. Tracts less than 16 ha (40 ac) are considered low quality. While they still provide some chance of survival for the Bone Cave harvestman, populations occurring in these areas have a decreased probability of persistence into the future.

We refer to protected areas meeting our high to medium quality preserve guidelines as karst fauna areas. A karst fauna area is a perpetually protected, geographic area known to support one or more locations of a listed karst invertebrate species and that includes sufficient surface and subsurface habitat to support viable populations of listed species (Service 1994, p. 76). Bone Cave harvestman populations within karst fauna areas of high to medium quality have the greatest potential to persist into the future. The availability of natural habitats, and the permanent protections afforded these areas, increases the likelihood that populations will remain viable despite increasing development pressure.

8.0 Species Needs

A variety of factors contribute to a species' resiliency including how sensitive the species is to disturbances or stressors in its environment and how specific or narrow their habitat needs are. In addition, a species' resiliency is influenced by the resiliency of individual populations, the number of populations, and their distribution across the landscape. Protecting multiple populations and the variation of a species across its range may contribute to its overall resiliency, especially if some populations or habitats are more susceptible or better adapted to certain threats (Service and NOAA 2014, p. 37581). In this section, we consider what the Bone Cave harvestman requires to persist into the future.

To ensure long-term persistence of the Bone Cave harvestman, multiple, resilient populations should be distributed across its range to provide for redundancy. Multiple, widely distributed populations reduce the risk that a large portion of the species' range will be negatively affected by natural or anthropogenic (i.e. human caused) events at any one time. Species with populations distributed across their historical range are considered less susceptible to extinction and more likely to be viable than species with populations confined to a small portion of their range (Hughes et al. 1997, pp. 73, 78-80; Fagan et al. 2002, p. 3254; Brook et al. 2008, pp. 455-456; Pimm and Jenkins 2010, pp. 186-187). Karst fauna areas, and other sites with comparable protections, serve as systems separated from other areas by geologic and hydrologic features and/or processes or distances that create barriers to movement of water, contaminants, and troglobitic fauna. In addition to guarding against a single or series of catastrophic events extirpating all Bone Cave harvestman populations, redundancy aids in the protection of irreplaceable sources of adaptive diversity.

Representation describes the ability of a species to adapt to changing environmental conditions. It is a function of ecological and genetic diversity within and among a species' populations. The Bone Cave harvestman occurs in six karst fauna regions in Travis and Williamson counties. Within these regions, the species occupies caves characterized by a range of depths, lengths, and configurations with corresponding variations in ecological and environmental conditions. In addition, the Bone Cave harvestman exhibits clinal variation in troglomorphic traits, with northernmost populations exhibiting higher degrees of troglomorphy than those to the south in Travis County.

While more study is needed to adequately characterize this morphological variation, preliminary genetic studies indicate at least three distinct genetic clusters or clades across the species' range generally conforming to karst fauna boundaries (Figure 12; Hedin and Derkarabetian 2020, p. 17). These clades included a Jollyville Plateau clade; a Georgetown and North Williamson County clade; and a Central Austin, Cedar Park, and McNeil-Round Rock clade (Hedin and Derkarabetian 2020, p. 16-17). Additional distinction is also indicated by a possible divergence in the North Williamson County/Georgetown clade at the north fork of the San Gabriel River and another possible break between the east and the west sides of the Jollyville Plateau Karst Fauna Region; however, more study would be necessary to understand these potential divergences (Hedin and Derkarabetian 2020, pp. 12, 16-17).

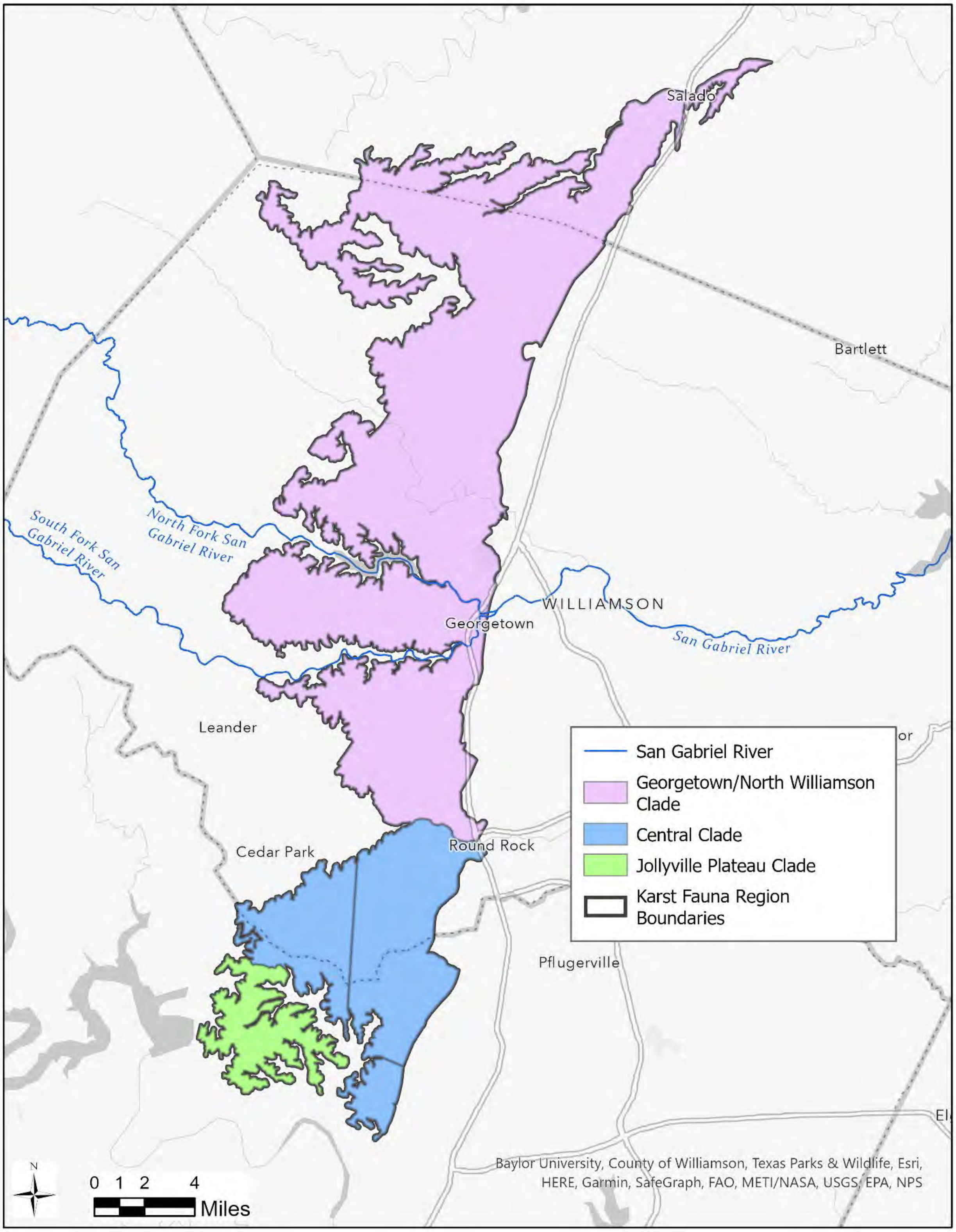


Figure 12. Karst fauna regions corresponding to three Bone Cave harvestman genetic clades identified by Hedin and Derkarabetian (2020, p. 17).

There is some disagreement in the scientific community regarding the delineation of karst fauna regions (Paquin and Hedin 2004, p. 3250; White 2006, pp. 93-99). However, they remain a useful tool to inform species conservation Ledford et al. 2012, p. 12). The protection of multiple, resilient Bone Cave harvestman populations across a range of ecological conditions and morphological variation in each occupied karst fauna region is a safeguard against future environmental change and increases the probability of long-term persistence.

9.0 Stressors

Stressors that reduce viability of Bone Cave harvestman populations are primarily tied to habitat destruction or degradation resulting from urbanization. Expansion of urban, suburban, and/or exurban development that accompany rapidly growing metropolitan populations can lead to substantial losses of natural habitat (Theobald et al. 1997, p. 26; Fahrig 2003, p. 499; McKinney 2008, pp. 162, 166-167; Aronson et al. 2014, p. 6). Those tracts of natural habitat that remain within a matrix of developed land post-construction are subject to the ecological effects of fragmentation (Theobald et al. 1997, p. 33-34; Harrison and Bruna 1999, p. 229). Other potential impacts from urbanization include changes to geomorphology (e.g., drainage patterns; Paul and Meyer 2001, pp. 338-341; O’Driscoll et al. 2010, pp. 618-623), hydrology (e.g., groundwater recharge and surface run-off; Paul and Meyer 2001, pp. 335-337; O’Driscoll et al. 2010, pp. 609-617; Sharp 2010, pp. 53-55), exposure to contaminants or pollutants (Paul and Meyer 2001, pp. 341-346), and increased human disturbance (e.g., vandalism; Czech et al. 2000, p. 599).

The range of the Bone Cave harvestman in Travis and Williamson counties has experienced significant human population growth since the mid-20th century (Figure 13; 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 2019, the U.S. Census Bureau (2019a) rated the Austin-Round Rock-Georgetown area as the eighth 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 (144% increase over 30 years; U.S. Census Bureau 1982, p. 10; U.S. Census Bureau 2012, p. Texas 9). The county’s largest city, the City of Austin, grew from 345,890 people in 1980 to a projected 1,026,833 people in 2021 (197% increase over 41 years; City of Austin 2020a). From 2010 to 2019, the population of Travis County increased to 1,273,954 people (U.S. Census Bureau 2019b), an increase of 204% 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 (452% increase over 30 years; U.S. Census Bureau 1982, p. 10; U.S. Census Bureau 2012, p. Texas 9). The population of the City of Georgetown grew from 9,468 people in 1980 to a projected 77,436 people in 2021 (718% increase over 39 years; U.S. Census Bureau 1982, p. 27; City of Georgetown 2021). From 2010 to 2019, the population of Williamson County increased to 590,551 people (U.S. Census Bureau 2019b), an increase of 672% since 1980.

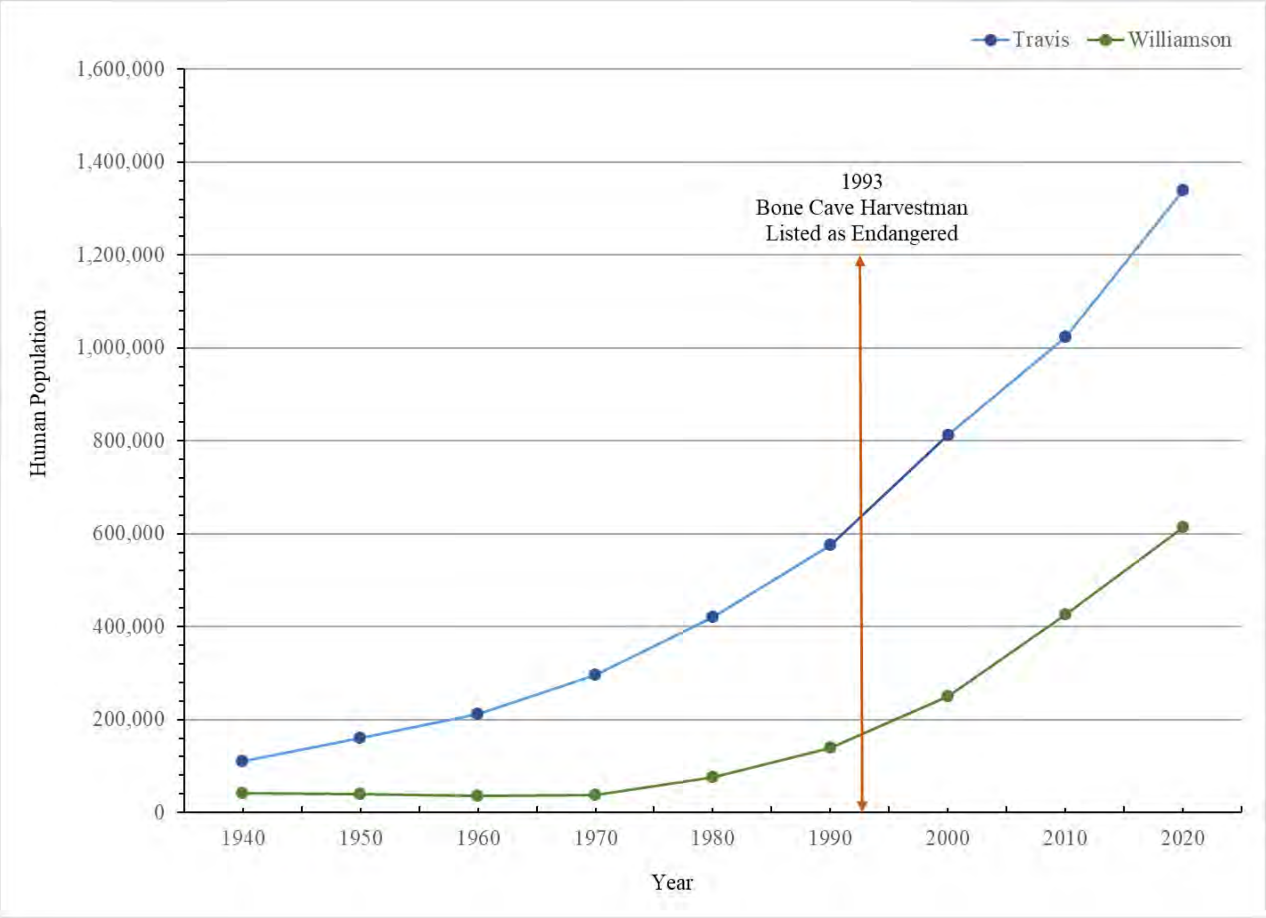


Figure 13. Human population growth of Travis and Williamson counties, Texas, 1940-2020 (U.S. Census Bureau 2021).

Construction 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. By 2019, the number of housing units increased to 545,693 units (U.S. Census Bureau 2019c), an increase of 441% 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. Texas 9). From 2010 to 2019, number of housing units increased to 205,609 units (U.S. Census Bureau 2019c), an increase of 1,455% 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/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).

Rapid population growth and development have led to urban sprawl for the Austin-Round Rock metropolitan area (Theobald 2005, pp. 15, 22; Torrens 2008, pp. 8-9, 16, 33). Suburban and exurban developments have significantly expanded the area's urban fringe (Theobald 2005, pp. 15, 22). Nationally, growth of exurban housing area has far out-paced that of urban areas (91,709,000 ha (226,617,874 ac) to 12,572,900 ha (31,068,312 ac), respectively) and accounts for greater land consumption per capita (Theobald 2005, p. 14). Berube et al. (2006, p. 7) estimated the average exurban census tract encompassed 5.6 ha (14 ac) per home compared to the national average of 0.32 ha (0.8 acres) per home. Kahn (2000, p. 575) noted that suburban development may consume twice as much land when compared to urban development.

Texas was ranked nationally in 2000 as the state with the highest proportion of its population (6%) classified as exurban (Berube et al. 2006, p. 10). The proportion of the exurban population in the Austin-Round Rock metropolitan area in 2000 was nearly three times greater than the state average at 17.7% (Berube et al. 2006, p. 12). In Texas, the trend of increased exurban development (Cowley and Spillette 2001, pp. 1, 4-5; Berube et al. 2006, pp. 10-11) is contributing to the loss of native rangeland and other forms of rural, open space (Wilkins et al. 2000, p. 3; Theobald 2001, pp. 554-555; Kjelland et al. 2007, p. 232) with potential negative repercussions for native biodiversity (Hansen et al. 2005, pp. 1901-1903). Over 20% of the Austin-Round Rock metropolitan area is composed of exurban development (Urban Land Institute 2016, p. 9) with most developments of this type occurring in western Travis County and west-central Williamson County (RCLCO 2017).

A significant portion of the Bone Cave harvestman's range in Travis and Williamson counties is overlain with a matrix of urban, suburban, and exurban development interspersed with tracts of natural to semi-natural habitat (Figure 14). Specific stressors for the Bone Cave harvestman related to urbanization include direct destruction of macro- and mesocaverns, alteration of drainage patterns, degradation of native plant communities, increased edge effects, contamination, human visitation and vandalism, and invasive species. These stressors, along with others, are discussed below.

Figure 14. Bone Cave harvestman occurrences (red triangles) surrounded by residential development.

9.1 Alteration of Surface Ecological Systems

Urbanization is one of the most pressing threats to native species (Wilcove et al. 1998, pp. 607, 612-613; Marzluff and Rodewald 2008, p. 3) and has been identified as the leading factor in the endangerment of nearly 300 species in the continental United States (Czech et al. 2000, pp. 596, 599). 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 (e.g., 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).

Urban development can reduce native animal and plant species richness and abundance through the direct destruction and removal of natural habitat and degradation of habitat remaining near development (Paul and Meyer 2001, pp. 348-353; McKinney 2002, pp. 885-886; Riley et al. 2005, pp. 1901-1905; Price et al. 2006, pp. 439-440; O'Driscoll et al. 2010, pp. 630-631; Aronson et al. 2014, pp. 5-7). Sites cleared of natural vegetation can experience rapid deficits in the resources (e.g., food or shelter) native animal species require for survival (Rebele 1994, p. 177; McKinney 2002, pp. 885-886). Urbanization also tends to favor a subset of animal and plant species (e.g., non-native species) tolerant of human-activity or that prefer disturbed habitats (Rebele 1994, p. 176; Theobald, et al. 1997, p. 27; McKinney 2002, pp. 887-888; McKinney 2006, p. 248; King and Tschinkel 2008, p. 20340). These species often replace less tolerant species (e.g., habitat specialists) in the urbanized landscape, leading to an overall homogenization of animal and plant species diversity (Marzluff and Ewing 2001, pp. 283-285; Holway and Suarez 2006, pp. 322-323; Devictor et al. 2007, pp. 747, 749; McKinney 2006, pp. 249-254; Olden et al. 2006, pp. 268-269; Marzluff and Rodewald 2008, p. 6).

Undeveloped tracts of natural habitat, embedded within a matrix of developed land (Figure 15), are often fragmented (i.e., disjunct from other patches of natural habitat) and more susceptible to edge effects (i.e., changes to the animal and plant communities where different habitats meet). Edge effects may include invasion by non-native species, increased predation, and shifts in native animal and plant species diversity (Bender et al. 1998, pp. 525-527; McKinney 2006, p 249; Haddad et al. 2015, pp. 4-5). Additional edge effects include increases in solar radiation, changes in soil moisture due to elevated levels of evapotranspiration, wind buffeting, changes in nutrient cycling, and changes in the rate of leaf litter decomposition (Ranny et al. 1981, p. 69; Saunders et al. 1991, pp. 20, 22; Didham 1998, p. 397; Debinski and Holt 2000, pp. 347-348; Fischer and Lindenmayer 2007, p. 271).

The Bone Cave harvestman is reliant on functional surface ecological systems. The native plant community that overlays and surrounds cave systems aid in buffering subterranean ecosystems from stressors, supports nutrient flows, and maintains 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. 2007a, pp. 2, 37, 41-44;

Pellegrini et al. 2016, pp. 28, 34). Such 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.

Figure 15. Fragmented patches of natural habitat in Williamson County, Texas.

9.1.1 Surface Disturbance and Nutrient Input

Variables related to surface land uses and native vegetation can influence cave invertebrate and verterbrate communities, even at some distance (i.e., 50-250 m (164-820 ft) and 1 km (0.6 mi), respectively), from a cave's entrance (Pellegrini et al. 2016, pp. 23-34; Phelps et al. 2016, pp. 205-207). In an analysis of 473 caves in Brazil, 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 these 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).

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 Bone Cave harvestman 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. (2007a, 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. 2007a, 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. (2007a, 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. (2007a, 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. Both Taylor (2007a, pp. 2, 37, 41-44, 46) and Jaffé et al. (2018, pp. 9, 11) indicate that human land uses near caves can negatively impact cave faunal communities through stressors that include loss or degradation of surrounding surface habitats.

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).

9.1.2 Population Response to Surface Disturbance

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 (Figure 16), 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).

Figure 16. Natural surface habitat (1.2 ha (3 ac); red polygon), containing Lakeline Cave, surrounded by commercial development, Williamson County, Texas.

Other caves inhabited by the Bone Cave harvestman and cave crickets, with adjacent commercial and/or residential development, have been monitored over the past 12 years in Travis and Williamson counties. The Brushy Creek Municipal Utility District, City of Austin, and Williamson County Conservation Foundation have conducted annual surveys at several caves owned and managed by those entities (City of Austin 2020b, p. C-1; SWCA Environmental Consultants 2020a, pp. 1, 4; Zara Environmental 2020, p. 2).

The Brushy Creek Municipal Utility District has surveyed 35 caves located within several residential subdivisions in Williamson County, on a rotating basis (i.e., once every three years), since 2013 (Zara Environmental 2020, pp. A-1-A-7). Development of the subdivisions within the District's 931 ha (2,300 ac) service area were developed in phases through the late 1980s through the late 2010s (Brushy Creek Municipal Utility District 2021a). Caves surveyed within the District are located within small patches of natural surface habitat surrounded by single-family housing (Brushy Creek Municipal Utility District 2021b). Surveys from just over 20 caves, with historical records of the Bone Cave harvestman, failed to observed that species (Zara Environmental 2020, pp. A-1-A-7). Counts of the harvestman from the remaining caves were highly variable with observations in some years and no detections in others (Zara Environmental 2020, pp. A-1-A-7.

The City of Austin has monitored caves inhabited by the Bone Cave harvestman within the Balcones Canyonlands Preserve in Travis County since 2011 (City of Austin 2020b, p. C-1, C-6-C-11). None of the caves monitored for Bone Cave harvestman experienced any significant reduction in natural surface habitat due to development. Survey results indicate an increase in total number of that species observed in five of 12 surveyed caves from 2011 to 2019 (City of Austin 2020b, p. C-3). The City of Austin (2020b, p. C-3-C-4) attributes increased numbers of observed Bone Cave harvestman to increasing canopy cover, amount of surrounding natural surface habitat, and management of red-imported fire ants at those sites.

The City of Austin also detailed numbers of observed cave crickets observed during monitoring efforts (City of Austin 2020b, pp. C-1, C-17-C-25). Two sites monitored for cave crickets, Cotterell and Testudo Caves, exhibited increases and decreases, respectively, in numbers of those insects. Both caves occur on protected lands near development. Cotterell Cave is near a residential housing development constructed in the late 1960s. An apartment complex was constructed to the northeast in the early 1990s. Today that cave is located within an area of over 20 ha (50 ac) of protected natural surface habitat. The City of Austin (2020b, p. C-5) recorded an increase in cave cricket numbers from 2011 to 2019. Conversely, declines in cave cricket numbers were observed for Testudo Cave. Up to 2005, the area around that cave consisted of an 85 ha (210 ac) block of contiguous natural surface habitat. By 2013, residential housing was constructed to the north of Testudo Cave, reducing the area of natural surface habitat to 53 ha (131 ac). Surveys by the City of Austin indicate that numbers of cave crickets declined after 2015 (City of Austin 2020b, p. C-3, C-25).

The Williamson County Conservation Foundation has monitored four cave systems, with adjacent development and limited areas of natural open space, since 2009, 2012, 2014, and 2018 (SWCA Environmental Consultants 2020a, pp. 20-21, 65-66, 84-85). Specific numbers of observed Bone Cave harvestman are reported by these efforts but comparable data for cave crickets are not provided. Beck Preserve consists of 18 ha (44 ac) of natural surface habitat, surrounded by development, with four caves monitored for the Bone Cave harvestman (SWCA Environmental Consultants 2020a, pp. 11-21; SWCA Environmental Consultants 2020b, pp. 12-18). Surveys have documented the species in each cave with high variability in annual number of observed individuals (SWCA Environmental Consultants 2020a, pp. 20-21). The caves at

Beck Preserve were largely surrounded by natural surface habitat, of at least 3.5 ha (8.6 ac), through 1995 with the exception of a roadway (i.e., Ranch Road 620 North) bisecting one area (i.e., Beck Bat Cave). Development began to encroach into some of that natural surface habitat by 2002 at Beck Pride Cave and 2003 at Beck Bat Cave, by 0.40 ha (1.0 ac) and 0.20 ha [0.5 ac], respectively). By 2019, only Beck Bat Cave saw an increase in development by just over 1 ha (2.5 ac).

Beck Commons Preserve contains the smallest amount of natural surface habitat (i.e., 1.7 ha [4.2 ac]) of the sites monitored by the Williamson County Conservation Foundation (Figure 17; SWCA Environmental Consultants 2020b, pp. 83-84). Annual counts of the Bone Cave harvestman, at Beck Sewer Cave within the preserve, have noted individuals every year from 2014 to 2019 but with no clear trend in numbers (SWCA Environmental Consultants 2020a, pp. 84-85). In 1995, the area around that cave consisted of a 135 ha (332 ac) block of contiguous natural surface habitat. By the early 2000s, only 8 ha (20 ac) of that habitat remained around Beck Sewer Cave. Continued development resulted in the preserve's current size.

Figure 17. Beck Commons Preserve (1.7 ha (4.2 ac); red polygon) and adjacent commercial and residential development.

The remaining sites monitored by the Williamson County Conservation Foundation are located in the Woodland Park Cave Preserve which contains Cat and Duckworth Bat Caves, with 1.9 ha

(4.6 ac) and 2.3 ha (5.6 ac) of natural surface habitat, respectively (SWCA Environmental Consultants 2020b, pp. 64-69). Like the other monitored caves, number of individuals observed has been variable since surveys were initiated at Cat Cave in 2018 and 2014 at Duckworth Bat Cave (SWCA Environmental Consultants 2020a, pp. 65-66). The area around both of these caves remained largely undeveloped up to 2001, with a 250 ha (618 ac) contiguous block of natural surface habitat surrounding those caves. After 2001, development of that area for residential housing increased through 2015 leaving the natural surface habitat that remains at present.

Results of monitoring efforts detailed above depict a relative lack of discernable trends (e.g., declining, stable, or increasing) in observed Bone Cave harvestmen (Cambrian Environmental 2017, pp. 4, 6; City of Austin 2020b, p. C-2-C-4; SWCA Environmental Consultants 2020a, pp. 9-10, 20-21, 25-26, 37, 46-47, 51, 65-66, 75-76, 84-85, 90-91). Assessment of the impact of urbanization on the Bone Cave harvestman at these sites is hampered by the absence of baseline data on the species' abundance in these caves prior to development. Surveys at several caves in Travis and Williamson counties did not begin until well after commercial and/or residential developments were completed. In addition, many sites have been monitored for only a limited amount of time, especially in relation to time since surrounding natural surface habitat was converted to commercial and/or residential development. Lakeline Cave is one of the few Bone Cave harvestman sites where pre- and post-surveys exist in relation to development of surrounding natural surface habitat.

Another confounding factor that limits assessment of urbanization at Bone Cave harvestman monitored sites is the individual nature of each cave. Caves inhabited by Bone Cave harvestman differ significantly in their depth, length, number and size of entrances, substrate complexity, and other characteristics. Cave area, especially length, can influence amount of habitat available to troglobitic invertebrates due to the likelihood of more stable climatic conditions in larger and/or longer caves. Several researchers have documented higher numbers of invertebrate species in larger or longer caves than in smaller or less extensive caves presumably due to the former's greater habitat heterogeneity (Schneider and Culver 2004, pp. 41-43; Souza Silva 2011, p. 1721; Simões et al. 2015, pp. 112, 114-115; Jaffé et al. 2018, p. 9; Rabelo et al. 2020, p. 7; Souza-Silva et al. 2020a, pp. 6-7; Souza Silva et al. 2020b, pp. 34, 36). Number of entrances to a cave may influence species richness through higher rates of nutrient from increased connectivity to surface habitats (Rabelo et al 2020, pp. 7, 10; Souza-Silva 2020, p. 6). Substrate complexity in a cave can also affect invertebrate species diversity. Higher species richness and abundance of subterranean invertebrates have been documented on more complex cave substrates, such as rocky material and organic matter versus soil (Bichuette et al. 2017, pp. 81-82, 84; Zepon et al. 2017, pp. 1619-1620, 1625; Pacheco et al. 2020, p. 165). Troglobitic invertebrate faunal composition, in particular, can be tied to greater substrate heterogeneity (Pacheco et al. 2020, pp. 165-166).

A robust assessment of the impact of urbanization on Bone Cave harvestman populations will require a detailed evaluation of individual cave dimensions, entrances, substrates, climatic conditions, and other variables. It is essential that pre-development surveys are conducted of Bone Cave harvestman to estabilish baseline conditions for comparison as development occurs. However, given the rapid pace of urbanization in Travis and Williamson counites, fewer sites suitable for such efforts will exist into the future.

The rapid development activities occurring across the range of the Bone Cave harvestman 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. (2007a, 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 Bone Cave harvestman populations.

9.2 Alteration of Drainage Patterns and Contamination Risks

The Bone Cave harvestman is likely adapted to and requires high relative humidity (Curtis and Machado 2007, pp. 285-286; Willemart et al. 2009, p. 219). Alterations to surface and subsurface drainage basins (i.e., excavation, trenching, filling, increased impervious cover and soil compaction) may alter drainage patterns or decrease water infiltration leading to reductions in subterranean moisture (Elliott 2000, p. 674; van Beynen and Townsend 2005, p. 105). Karst invertebrates are also susceptible to groundwater contamination as water penetrates rapidly through karst with little to no filtration (White 1988, p. 388; Stafford et al. 2014, pp. 25, 28). The range of the Bone Cave harvestman is experiencing rapid urban, suburban, and exurban development, which heightens the risk of contaminants entering karst systems (Texas Water Commission 1989, pp. 95-134, 165-168; Graniel et al. 1999, p. 311; Paul and Meyer 2001, pp. 344-346; Carle et al. 2005, pp. 704, 706; Stafford et al. 2014, pp. 28-29, 32-33).

9.3 Invasive Ant Species

The red-imported fire ant (*Solenopsis invicta*) is a South American ant species introduced to the southeastern U.S. in the mid-1940s (Figure 18; 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).

Three native fire ant (*Solenopsis*) species occurred in Texas prior to the arrival of the red-imported fire ant, *S. aurea*, *S. geminata*, and *S. xyloni* (Hung et al. 1977; p. 18). *Solenopsis geminata* and *S. xyloni* occur in Travis and Williamson counties (O'Keefe et al. 2000, pp. 71, 75), while *Solenopsis aurea* is rare in central Texas (Hung et al. 1977, p. 18; O'Keefe et al. 2000, p. 68). The spread of the red-imported fire ant across the southeastern U.S. resulted in reductions or complete displacement of native fire ant populations (Wilson and Brown 1958. pp. 217-218; Tschinkel 2006, pp. 21, 558-567). The red-imported fire ant has largely replaced *S. geminata* and *S. xyloni* in Texas (Hung et al. 1977, p. 19; Porter and Savignano 1990, p. 2102; Porter et al. 1997, p. 376; Porter et al. 1988, pp. 914-915; Morrison 2002, p. 2342).

Figure 18. Red-imported fire ants feeding on a dead dragonfly (Odonata), Travis County, Texas. Courtesy of Becky Brenner.

In the U.S., the red-imported fire ant displays traits of a species that has experienced ecological release (i.e., greater abundance in introduced versus native range) from competitors, diseases, and parasites in its native range (Torchin et al. 2003, pp. 628-629; Krushelnycky et al. 2010, pp. 256-258). Comparisons of red-imported fire ant populations in Argentina/Brazil and the U.S. revealed that mound densities in the U.S. were 4-7 times greater than densities observed in the species' native range (Porter et al. 1997, pp. 375-376, 378). Red-imported fire ants dominated ant assemblages recruiting to U.S. sampling stations (i.e., baits), occurring at 97% of sites versus 68% of sites in South America (Porter et al. 1997, p. 375). Densities in U.S. grazing lands were six times higher than grazing lands in South America (Porter et al. 1997, p. 379). Porter et al. (1997, p. 380) estimated average red-imported fire ant density in the U.S. at 1,220±120 ants per square meter (m^2) compared with 230±40 ants per m^2 in Argentina/Brazil.

A number of factors contribute to higher population densities in areas where this species is not native. Red-imported fire ants in the U.S. lack a robust contingent of natural enemies to modulate populations (Porter et al. 1997, p. 376; Yang et al. 2010, pp. 3313-3315). Over 30 pathogens and parasites have been recorded as attacking red-imported fire ants in South

America, most of which do not occur in this country (Jouvenaz et al. 1980, pp. 345-346; Jouvenaz 1983, pp. 112-119; Williams et al. 2003, pp. 146-150; Oi and Valles 2009, pp. 239-247; Patrock et al., 2009, pp. 5, 11, 16; Briano et al. 2012, pp. 3-12). The U.S. hosts only a small number of native natural enemies of this ant (Jouvenaz et al. 1977, pp. 277-279; Pereira 2004, p. 42; Valles et al. 2004, p. 154; Oi and Valles 2009, p. 240; Yang et al. 2010, p. 3313).

A generalist diet and ability to dominate food resources can also enable red-imported fire ants to reach high densities where it is not native (Wilder et al. 2011, pp. 20641-20642; Roeder and Kaspari 2017, pp. 300-301). Foraging workers exploit a wide range of food from seeds, honeydew (i.e., sugar-rich secretions from plant-feeding insects), to dead and living invertebrates and vertebrates (Wojcik et al. 2001, pp. 17-19; Vogt et al. 2002, pp. 51-52; Allen et al. 2004, pp. 90-95; Tschinkel 2006, pp. 121-124). Roeder and Kaspari (2017, p. 299) demonstrated that red-imported fire ant colonies in an Oklahoma population fed across three trophic levels, from primary consumer to secondary predator. Those authors postulated that the species' broadly generalist diet is reflective of an assemblage of trophic specialists that exploit multiple food resources thereby minimizing intraspecific competition (Roeder and Kaspari 2017, pp. 300-301). Wilder et al. (2011, pp. 20639-20640) found that red-imported fire ants dominated 75% of honey-dew producing insect (e.g., aphids, mealybugs, and planthoppers) aggregations at sites in the U.S. (i.e., Louisiana, Mississippi, and Texas) with native ants controlling the remainder. In Argentina, red-imported fire ants dominated only 2% of those aggregations. Monopolization of high-reward food sources, in the absence of robust interspecific competition, likely confers a competitive advantage to this species in the U.S (Wilder et al. 2011, pp. 20641-20642; Wilder et al. 2013, pp. 202-203).

The social form of the red-imported fire ant present can also augment population densities. Two social forms of this ant exist, monogyne colonies, with a single queen whose workers actively compete with adjacent colonies, and polygyne colonies, composed of multiple, unrelated queens whose workers are not territorial (Tschinkel 2006, pp. 93-246, 403-500). Polygyne populations can achieve colony densities two to three times higher than monogyne populations (Porter 1992, p. 255; Porter et al. 1991, p. 874). In Florida, Macom and Porter (1996, p. 539) estimated that polygyne populations contained 35 million workers per hectare compared to 18 million workers per hectare for monogyne colonies. Porter et al. (1991, pp. 870, 872) noted that polygynous red-imported fire ants were more prevalent in Texas when compared to other southeastern U.S. states. Polygynous red-imported fire ants replaced colonies of *S. geminata* at a ratio of 6:1 at a Travis County site (Porter et al. 1988, pp. 914-915).

The prevalence of red-imported fire ants in the southeastern U.S. has resulted in impacts to native invertebrate communities through reduced species richness and/or abundance (Nichols and Sites 1989, pp. 347-349; Allen et al. 2001, p. 254; Holway et al. 2002, pp. 198, 201-202, 205; Calixto et al. 2006, p. 1121; Epperson and Allen 2010, pp. 60-61). Studies in Texas have documented the effect of red-imported fire ants on native arthropods. In Travis County, Porter and Savignano (1990, pp. 2098-2102) examined a red-imported fire ant invasion advancing into a woodland/grassland community with resultant declines in ground-dwelling native ants and other arthropods. Kaspari (2000, pp. 120-121) sampled canopy arthropods in the same Travis County woodland and found lower arboreal native ant species richness at sites with red-imported fire ants. At a blackland prairie in Colin County, Texas, red-imported fire ants reduced native ant species richness and abundance with the former accounting for 99% of individuals sampled in infested sites (Morris and Steigman, 1993, pp. 138-139).

A follow-up study to Porter and Savignano (1990), conducted 12 years later at the same Travis County site, revealed a relative recovery of native ground-dwelling arthropod populations that accompanied a reduction in red-imported fire ant density over time (Morrison 2002, pp. 2339-2341). Those results suggest that the acute effects of red-imported fire ant invasion on native arthropod species richness and abundance may be temporary (Morrison 2002, p. 2344) in certain contexts (e.g., level of habitat disturbance, social form present) and moderate over time. Some studies have noted the co-existence of native ants with red-imported fire ants (Helms and Vinson 2001, p. 398; Morrison and Porter 2003, pp. 550-552) or competitive exclusion of the latter by native ants (Rao and Vinson 2004, pp. 595-597). An important qualifier for the research referenced above is that the respective study sites examined had generally not been subject to recent, intense habitat disturbance.

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. 2003a, 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).

Disturbances that accompany urban development can reduce native ant species richness and abundance, providing opportunities for red-imported fire invasion. Buczkowski and Richmond (2012, entire) examined changes in native ant communities within forested sites converted to residential housing. Disturbances included vegetation clearing, topsoil removal, construction, and installation of landscaping. Post-construction, only three of the 20 native ant species documented before construction remained (Buczkowski and Richmond 2012, pp. 3-4). The ant species present post-disturbance were species tolerant of human-activity. Construction-related disturbance of over 30-40% of a site appeared to be the level above which native ants declined (Buczkowski and Richmond 2012, p. 7). Urban development and road construction also increases the probability that adjacent undisturbed natural habitat will be invaded by red-imported fire ants (Forys et al. 2002, pp. 30-31).

The red-imported fire ant occurs across the range of the Bone Cave harvestman. 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. 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. Colonies of red-imported fire ants, established in or near karst features, may affect Bone Cave harvestman 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, p. 2).

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.

The native army ant, *Labidus coecus*, the next most frequently observed ant species in Texas caves, is recorded from 13 caves in Travis and Williamson counties (Reddell and Cokendolpher 2001, p. 138; Cokendolpher et al. 2009, p. 154). The native fire ants, *S. geminata* and *S. xyloni* were recorded from four caves in Travis and Williamson counties (Reddell and Cokendolpher 2001, pp. 144-145, 148; Cokendolpher et al. 2009, p. 164) potentially reflecting one or both species' displacement by red-imported fire ants. *Solenopsis geminata* specifically may have occurred more frequently in central Texas caves prior to that species arrival. Reddell and Cokendolpher (2001, p. 131) found *S. geminata* to be the most common ant species in caves of the Yucatan Peninsula of southeastern Mexico (Reddell and Cokendolpher 2001, p. 131), an area devoid of red-imported fire ants.

Predation by the red-imported fire ants is a potential factor in the decline or extirpation of some rare invertebrates in the U.S. (Forys et al. 2001a, p. 257; Forys et al. 2001b, p. 375). In agroecosystems, this ant is an effective predator reducing populations of both herbivorous and predaceous insects (Eubanks 2001, pp. 40-41; Eubanks et al. 2002, pp. 1172-1173; Rashid et al. 2013, p. 470). In central Texas, karst invertebrates are subject to predation by red-imported fire ants. Elliott (1993, p. 23) reported red-imported fire ants feeding on a cave-associated scorpion (i.e., *Pseudouroctonus reddelli*), troglobitic millipedes (i.e., *Speodesmus bicornourus* and *Cambala speobia*), and a troglobitic bristletail (i.e., *Texoreddellia texensis*) among others. Red-imported fire ants have also preyed upon the cave cricket, *C. secretus* and harvestman, *Leiobunnum townsendi* (Cokendolpher et al. 2009, p. 165). Native ants prey on karst invertebrates in central Texas as well. *Solenopsis geminata* individuals have fed on karst invertebrates in a Travis County cave (Reddell and Cokendolpher 2001 p. 131). In Coryell and

Williamson counties, *L. coecus* fed on cave crickets (i.e., *C. secretus*) (Cokendolpher et al. 2009, pp. 154-157). In caves in Arizona, Pape (2016, pp. 191-192, 193-194), observed native ants (e.g., *Neivamyrmex* species and *Pheidole rhea*) preying on cave-inhabiting invertebrates.

Cokendolpher et al. (2009, p. 152) considered the red-imported fire ant and *L. coecus* as the primary ant species that foraged to some depth in central Texas caves. To directly impact the Bone Cave harvestman through predation, either species would need to forage into or near the deep cave zone. Taylor et al. (2003b, pp. 38-92) examined red-imported fire ant use of caves in Bell and Coryell counties, Texas. In that study, red-imported fire ants occurred most frequently in cave entrances and as far into as cave as 18 m (59 ft) and to a depth of 13 m (43 ft). Red-imported fire ants were most associated with the higher temperatures and drier conditions of those cave zones versus the cooler, more humid deep cave zone used by troglobitic invertebrates (Taylor et al 2003a, pp. 45, 49-50). Elliott (1993, p. 23) also noted that red-imported fire ants were frequently active at cave entrances. Taylor et al. (2003b, pp. 48-50) suggests that ant foraging activity occurs primarily in shallower cave reaches that share little overlap with the deep cave zones inhabited by karst invertebrates of conservation concern. Those authors posit that red-imported fire ants either do not interact with troglobitic invertebrates or that the presence of these ants in shallower cave zones has potentially displaced opportunistic use of these areas by foraging troglobites (Taylor et al. 2003a, pp. 49-50).

While most observed red-imported fire ants accessed caves through the entrance, they can occur at greater cave depths. Elliott (1993, p. 22) observed these ants at a depth of 30 m (98 ft) in the same cave reach occupied by Bone Cave harvestmen. Entry points other than humanly accessible cave entrances, such as tree roots penetrating into subterranean voids and small fractures or fissures, allow foraging ants to enter deep cave zones (Elliott 1993, pp. 23-24, Taylor et al. 2003a, p. 48). In those instances, the Bone Cave harvestman would be susceptible to red-imported fire ant predation (Taylor et al. 2003b, p. 49). Less extensive, shallow caves may also be more accessible to foraging ants increasing the likelihood of overlap with troglobites. Reddell and Cokendolpher (2001, p. 132) noted that red-imported fire ant activity increased during drought with ants being found in all humanly-accessible reaches of caves during dry, warm conditions.

Labidus coecus can occur some distance into central Texas caves with foragers observed 25 m (82 ft) from the entrance and 5 m (16 ft) below ground (Cokendolpher et al. 2009, pp. 154, 157). Army ants are mostly active in the soil profile and may intersect macro- and mesocaverns as they forage for food or water (Gotwald 1982, pp. 203-205; Pape 2016, p. 196). As a result, these ants may use access points other than cave entrances more frequently. Cokendolpher et al. (2009, p. 154) observed *L. coecus* entering through a cave wall. Foraging *L. coecus* that enter deeper cave zones could prey on invertebrates like the Bone Cave harvestman (Pape 2016, p. 197). In comparison to the red-imported fire ant, *L. coecus* is much less common in Travis and Williamson county caves (i.e., 13 caves compared to 140 caves documented for red-imported fire ant). If *L. coecus* infrequently forage in caves for food, as the small number of records from these counties suggests (Reddell and Cokendolpher 2001, p. 138; Cokendolpher et al. 2009, p. 154), then we expect the predation risk to Bone Cave harvestmen to be correspondingly lower. Sporadic predation events could still represent a threat to declining or small, isolated populations of the Bone Cave harvestman, however.

Solenopsis geminata was potentially more frequent in Travis and Williamson county caves prior to the red-imported fire ant's arrival. This species is the most common ant in caves of southeastern Mexico where the red-imported fire ant is absent (Reddell and Cokendolpher 2001, p. 131). No detailed observations are available for *S. geminata* regarding foraging activity in Texas caves. In addition, few estimates of population density exist for this species in Travis and Williamson counties prior to invasion by the red-imported fire ant. Porter et al. (1988, entire) examined the response of *S. geminata* to an advancing red-imported fire ant invasion in Travis County. *Solenopsis geminata* density at their study site was 90 mounds/ha while the invading red-imported fire ants reached over 600 mounds/ha (Porter et al. 1988, pp. 914-915). Travis and Williamson counties are at the northern extent of *S. geminata*'s range (O'Keefe et al. 2000, p. 71) and the species was potentially more prevalent in southern or coastal regions of the state (Smith 1936, p. 164). Unlike the red-imported fire ant, *S. geminata* also possesses a contingent of natural enemies that play some role in constraining populations across the southeastern U.S. (Wetterer 2011, p. 29).

Prior to the red-imported fire ant's arrival, karst invertebrates were exposed to some level of predation from native foraging ants such as *L. coecus* and *S. geminata*. The potential predatory pressure of red-imported fire ants, however, is likely anomalous to the pressure historically applied by native ants. The superabundance of red-imported fire ants imparts a much-heightened risk of predation. Red-imported fire ants have achieved population densities 4-7 times greater in the southeastern U.S. than in its native range (Porter et al. 1997, pp. 375-376, 378). In the span of nearly 50 years, this ant has become the most frequently observed ant species in central Texas caves. Based on a 2009 review, the red-imported fire ant occurred in 11 times as many caves in Travis and Williamson counties as the next most commonly observed ant species, *L. coecus* (Cokendolpher et al. 2009, pp. 154, 164-167).

No observations exist to date of red-imported fire ants preying or feeding on Bone Cave harvestmen. Given the harvestman's rarity, low observed abundances, and infrequency of surveys, opportunities for such documentation are limited (Elliott 1993, pp. 2, 22). Red-imported fire ants have subdued and fed on karst invertebrates including other harvestman species and can access deep cave zones. Bone Cave harvestmen are slow moving invertebrates that would be vulnerable to attack (Elliott 1993, p. 22). If Bone Cave harvestmen display the same life-history traits as other as other troglobitic arachnids, such as reduced egg number, delayed maturation of juveniles, and longer life spans (Mammola and Isaia 2017, p. 3), frequent or intense predation events may have a significant impact on local populations.

How frequently red-imported fire ants invade caves and to what extent is likely site-specific and a function of factors such as frequency and intensity of habitat disturbance, surface habitat size, condition of native vegetation, adjacent land uses, colony densities, social form present, food and water availability, cave length and depth, availability of access points, and climatic conditions. Caves nested within in a large block of naturally vegetated habitat, with little history of disturbance, may be at reduced risk to incursion by red-imported fire ants. Conversely, small, fragmented patches of natural habitat subject to intense disturbance or adjacent to intensively disturbed areas may be at higher risk of these ants establishing colonies, reaching high densities, and foraging into caves supporting karst invertebrates.

Red-imported fire ants can also indirectly affect Bone Cave harvestman populations through effects to invertebrates that support nutrient flow into karst ecosystems. Use of caves by red-imported fire ants overlaps with zones inhabited and used by cave crickets and other invertebrates (i.e., Collembola) that play important roles in cave food webs (Taylor et al. 2003b, pp. 47, 50, 73-74). Foraging red-imported fire ants feed on adult and immature cave crickets (Elliott 1933, p. 23; Cokendolpher et al. 2009, p. 165) with predation on the latter reported as sometimes substantial (Reddell and Cokendolpher 2001, p. 132). Cave crickets within caves and those foraging in surface habitat would be vulnerable to attack by red-imported fire ants. Cave crickets may also compete with red-imported fire ants for food resources, which could further influence nutrient transfer.

Surface-foraging *Ceuthophilus* in Texas appear to be omnivorous feeding on both animal and plant matter (Campbell 1976, p. 364; Elliott 1993, pp. 22, 23; Taylor et al. 2004, p. 30), though some populations have exhibited stronger affinities for plant material (Taylor et al. 2004, pp. 9-10, 28, 31; Taylor et al. 2007a, pp. 17, 21, 31). Taylor et al. (2004, pp. 5-31) and Taylor et al. (2007a, entire) assessed the trophic ecology of surface-foraging cave crickets and red-imported fire ants at sites in central Texas using stable nitrogen (δ15N) isotopes. Red-imported fire ants were present at all study sites.

Results of this study indicate that sampled *C. secretus* and *C*. species B fed principally on plant material (Taylor et al. 2004, pp. 9-10, 26-29; Taylor et al. 2007a, pp. 17, 21, 31). Surface-foraging red-imported fire ants were omnivorous to carnivorous, and appeared not to compete with those *Ceuthophilus* species for plant material (Taylor et al. 2004, pp. 9-10, 26-29; Taylor et al. 2007a, pp. 23, 28-29, 31). However, the foraging strategies of social ant colonies, such as recruitment to high-reward food sources (Detrain and Deneubourg 2008, pp. 127-128, 144-146) and shifting colony nutritional needs (Detrain and Deneubourg 2008, p. 133), can confound dietary comparisons with solitary foraging insects (Tillberg et al. 2006, p. 65). Individual ant colonies can display significant intraspecific variability in nutrient composition due to differential selection of food resources (Tillberg et al. 2006, p. 68; Roeder and Kaspari 2017, p. 301).

Since Taylor et al. (2004, pp. 5-31) and Taylor et al. (2007a, entire) did not include control sites that lacked red-imported fire ants, we do not know if surface-foraging *Ceuthophilus* species feed at a higher trophic level (i.e., more animal matter) in the absence of those ants. More study will be necessary to determine if red-imported fire ants competitively displace *Ceuthophilus* species from more protein-rich food sources. Human-food stuffs rich in protein (i.e., cheese, tuna, and liver) are attractive to surface-foraging *Ceuthophilus* (Elliott 1993, p. 23; Cokendolpher et al. 2001, p. 100) and cave crickets feed on other insects (Campbell 1976, p. 364; Taylor et al. 2007a, p. 110; Taylor et al. 2004, p. 30). Using bait stations placed aboveground, Taylor et al. (2003b, p. 3) found that foraging cave crickets visited baits used concurrently by red-imported fire ants but as worker ants recruited to baits, cave cricket use declined. In addition, as these ants forage during the day as well as night, red-imported fire ant colonies may monopolize discrete, high-reward food sources before nocturnally foraging cave crickets emerge (Taylor et al. 2003b, p. 110).

Red-imported fire ants are successful in locating and securing food resources sometimes at the expense of native insects and other arthropods. Scott et al. (1987, entire) examined competition between burying beetles (*Nicrophorus* species) and red-imported fire ants for small vertebrate carcasses (i.e., chicks and mice) in Florida. Red-imported fire ants dominated most available carcasses precluding use by burying beetles (Scott et al. 1987, pp. 327-329). Burying beetles buried 10% of available carcasses in Florida compared to 42% in New Hampshire where red-imported fire ants do not occur (Scott et al. 1987, p. 327). Calixto et al. (2006, entire) assessed the response of earwig species, *Labidura riparia* and *Euborellia annulipes* in Robertson County, Texas to chemical suppression of red-imported fire ants. Numbers of *L. riparia* increased in plots with reduced numbers of those ants suggesting that red-imported fire ants were preying on those earwigs or competing with them for food resources (Calixto et al. 2006, p. 99). *Euborellia annulipes* numbers only responded to suppression efforts in the final year of the effort indicating that species continued to be affected by the ants or by the increased numbers of *L. riparia* (Calixto et al. 2006, p. 99).

Competition with non-native, invasive ant species can also force native species to feed at lower trophic levels due to exclusion from high reward food resources. The yellow crazy ant (*Anoplolepsis gracilipes*), a non-native, invasive ant species introduced to the Tokelau Islands in the Pacific Ocean, competitively excluded three hermit crab species (i.e., *Coenobita brevimanus*, *C. perlatus*, and *C. rugosus*) from artificial baits and naturally occurring invertebrate and vertebrate carrion (McNatty et al. 2009, p. 190). Competitive exclusion from protein-rich food resources resulted in all three crab species feeding at lower nutrient levels (i.e., less nitrogen rich) when they co-occurred with that ant species.

Reductions in cave cricket numbers through predation or the competitive exclusion of crickets from food resources could result in declines in nutrients transported into caves, with cascading effects on troglobitic invertebrate populations given the availability of alternative nutrient sources. Again, the extent and frequency of red-imported fire ant predation is likely dependent upon several interacting climatic, habitat, population, and resource variables that are specific to individual sites. Cave systems in urban habitat fragments, with isolated cave cricket populations that do not receive recruitment from adjacent populations, would be at heightened risk of red-imported fire ant incursion and nutrient deficits.

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 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.

9.4 Quarrying and Mining

Extraction of rock during quarrying or mining operations can result in substantial alterations to surface vegetation, landforms, and subsurface habitat (Urich 2002, pp. 26-27; Parise and Pascali 2003, p. 250; Pulido-Bosch et al. 2004, p. 588; van Beynen and Townsend 2005, p. 101). The blasting, cutting, drilling, and earth-moving activities that accompany quarrying can lead to the partial or complete destruction of macro- and mesocaverns (Iliffe 1979, p. 184; Clarke 1999, p. 26; Elliott 2000, p. 682; Langer 2001, pp. 6-8; Parise and Pascali 2003, p. 250; Parise et al. 2004, p. 577; Calò and Parise 2006, p. 51). Karst invertebrates can be subject to direct mortality due to collapse of cave passages or indirectly through changes to groundwater quantity and quality, nutrient flow, and/or climatic conditions (Langer 2001, p. 6). Quarrying in karst landscapes has been implicated as contributing to the extinction or extirpation of some associated invertebrates (Vermeulen 1994, pp. 106, 110; Cardoso and Scharff 2009, p. 55; Taylor and Niemiller 2016, p. 21). In Italy, the loss of a population of the cave-dwelling spider, *Histopona palaeolithica* likely occurred due to quarrying that altered air flow patterns, within a cave inhabited by that species, that greatly reduced humidity (Mammola et al. 2019a, pp. 320-321). Quarries exist within Travis and Williamson counties (Figure 19) and have the potential to impact Bone Cave harvestman populations (Elliott 2000, p. 682).

Figure 19. Limestone quarry in Williamson County, Texas.

9.5 Human Visitation and Vandalism

A number of potential threats are associated with human activity in caves, ranging from displacement or direct mortality (e.g., trampling) of resident invertebrates (Gray 1973, p. 69; Howarth and Stone 1982, p. 96; Cigna 1993, p. 178; Doran et al. 1999, p. 259; Hamilton-Smith 2001b, p. 89; Krejca and Taylor 2003, pp. 32-33; Pellegrini and Ferreira 2012, pp. 361-363; Simões et al. 2014, p. 163; Pellegrini and Ferreira 2016, p. 33), alteration of microclimate conditions (de Freitas 2010, p. 481), to accumulation of artificial food sources, non-biodegradable materials, and/or pollutants (Iliffe 1979, p. 184; Howarth and Stone 1982, p. 96; Reddell 1993, p. 7; Ubick 2001, p. 5; Moulds et al. 2010, pp. 22-24). Cave size, natural disturbance regime, and scale, timing, and intensity of activity will influence the degree to which human visitation affects subterranean habitats (Reddell 1993, pp. 7-8; Pulido-Bosch et al. 1997, pp. 144-145; Calaforra et al. 2003, pp. 165-166; Gillieson 2011, pp. 143-145, 147; Pellegrini and Ferreira 2016, p. 34). Commercialization of caves for high-traffic tourism can alter humidity and temperature regimes of subterranean spaces through artificial lighting, human presence, and/or ventilation changes (Cigna 1993, pp. 176-178; Pulido-Bosch et al. 1997, pp. 144-146, 148; Gillieson 2011, p. 145; Lamprinou et al. 2014, p. 340). In tourist-visited caves, the introduction of human food items and other organic matter may affect foraging patterns of resident invertebrates (Krejca and Myers 2005, pp. 24-27; Eberhard et al. 2014, p. 38).

Artificial lighting in commercial caves may promote the growth of cyanobacteria, algae, and other photosynthetic taxa termed lampenflora in deep cave zones (Smith and Olson 2007, pp. 107-111; Mulec and Kosi 2009, pp. 109-111; Hauer et al. 2015, p. 770). At Inner Space Caverns, a commercial cave in Williamson County, researchers observed larger numbers of Bone Cave harvestmen near artificial lights during surveys (Paquin 2007, pp. 3-4). Paquin (2007, p. 7) postulated that observed harvestmen may feed on lampenflora and that the presence of that artificial light dependent growth may be altering the species' foraging habits. Meyers et al. (2017, p. 1040) found that cave-dwelling Collembola (i.e., *Tomocerus celsus*) collected from lampenflora in a California cave did not preferentially feed on that material and shared a diet similar to individuals sampled from cave reaches without artificial lights. Whether lampenflora represents a food source for Bone Cave harvestman and shifts their foraging behavior will require additional investigation.

The implementation of best management practices may ameliorate some effects of commercialization on cave fauna (Taylor et al. 2008, p. 35; Moulds et al. 2010, p. 27; Pape and O'Connor 2014, p. 783; Cigna 2016, pp. 218-219, 227-228, 230-231). For example, lower levels of visitation in commercial caves may aid in the maintenance of stable habitat conditions for some karst invertebrates (Barciová et al. 2010, pp. 272, 281-282). Only one cave system (i.e., Inner Space Caverns) inhabited by the Bone Cave harvestman is subject to commercial tourism. Most currently known harvestman caves are too small to accommodate large-scale commercial activity.

Smaller caves, especially those with easy access, little to no oversight, and close to developed areas, are vulnerable to the effects of intermittent to frequent human activity, however (Reddell 1993, pp. 6-7; Kramer 2003, pp. 740-741; Kennedy 2015, p. 87). Little research is available on impacts to small caves from human visitation and/or vandalism compared to large commercial caves. The range of human activities that could occur in small caves with no management are likely more diverse and less predictable than those observed in managed commercial caves. Activities could range from infrequent, recreational caving by a few individuals, sporadic entry by small groups, regular dumping of waste or other fill material, to malicious destruction. Reduction of undisturbed microhabitats or refugia in smaller caves may exacerbate the effects (e.g., uncompacted substrates or voids under loose rocks) of such activities on resident karst invertebrates.

9.6 Climate Change

Anthropogenic climate change has the potential to impact the subterranean ecosystem the Bone Cave harvestman depends upon for survival (Sánchez-Fernández et al. 2016, pp. 3-5; Mammola et al. 2017 pp. 237-241; Mammola et al. 2019b, pp. 1645-1648; Mammola et al. 2019c, pp. 104, 106, 108; Mammola et al. 2019d, p. 646). Troglobitic arthropods inhabit systems typified by relatively stable temperatures and relative humidity (Poulson and White 1969, p. 972; Howarth 1980, pp. 397-398; Howarth 1993, p. 69; Prous et al. 2004, pp. 377-378; Tobin et al. 2013, p. 206). Warmer and drier conditions within subterranean voids may exceed the species' physiological tolerances and reduce availability of suitable habitat.

9.6.1 Climate Projections

Over the last 115 years, the global averaged surface air temperature has increased by 1.0°C (1.8°F) with recent decades being the warmest in 1,500 years (Vose et al. 2017, pp. 186, 188). In the U.S., annual average air temperature increased by 1.0°C (1.8°F) between 1901 and 2016 with temperatures expected to rise by 1.4°C (2.5°F) between 2021 and 2050 (U.S. Global Change Research Program 2017, p. 17). The historical temperature trend for Texas, in all seasons and regions, is 0.28°C (0.51°F) per decade; an increase of 0.22°C (0.40°F) since 1895 (Nielsen-Gammon et al. 2020, pp. 4-5). Annual average temperature in Travis and Williamson counties increased by 0.33-0.4°C (0.60-0.70°F) between 1975 and 2018 (Nielsen-Gammon et al. 2020, p. 5). Between 1895 to 2020, the average maximum tempertures in both counties increased from (75.8-77.1°F) to (79.9-80.9°F) [Figures 20 and 21; NOAA National Centers for Environmental information 2021]. Since 2000, this region of central Texas has experienced the warmest temperatures on record, with six of the warmest years occurring between 2000 and 2019 (Brandt et al. 2020, p. 17). Greater temperature increases are projected for 2017-2100 (U.S. Global Change Research Program 2017, p. 17).

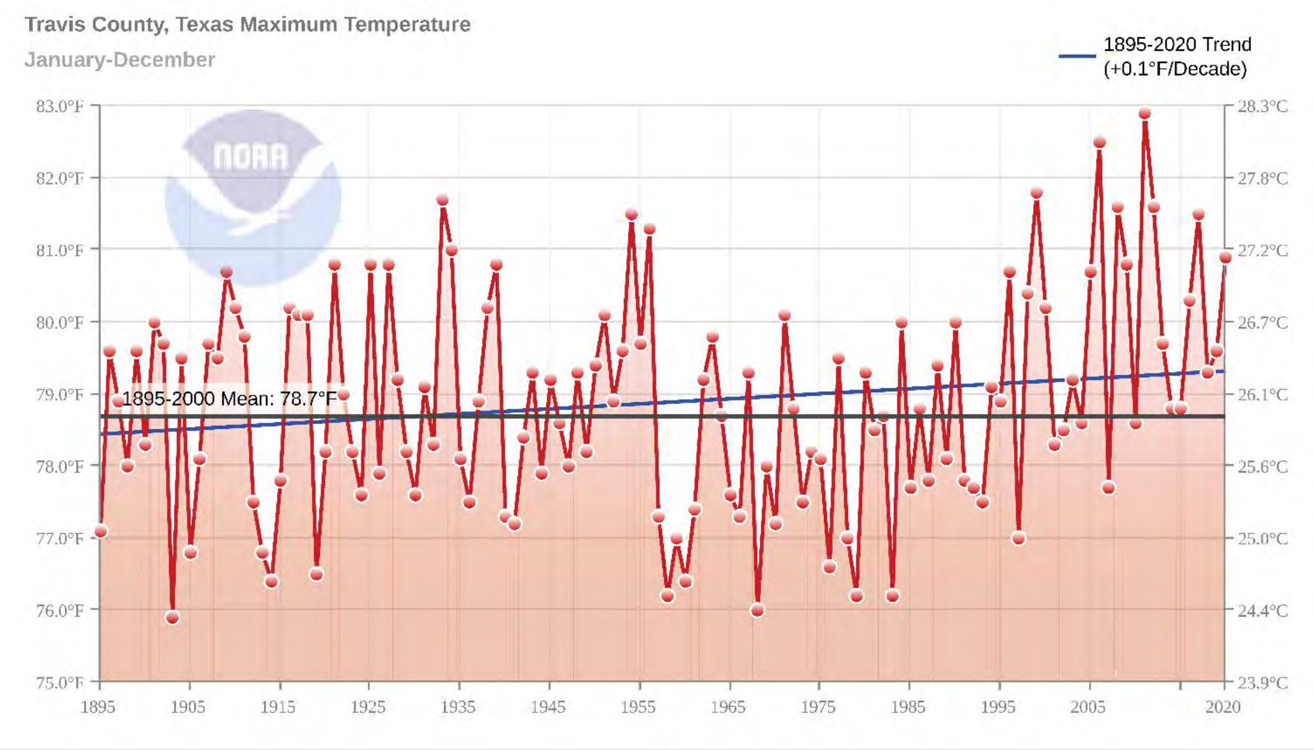


Figure 20. Average maximum temperature for Travis County, Texas from 1895 to 2020 (NOAA National Centers for Environmental information 2021).

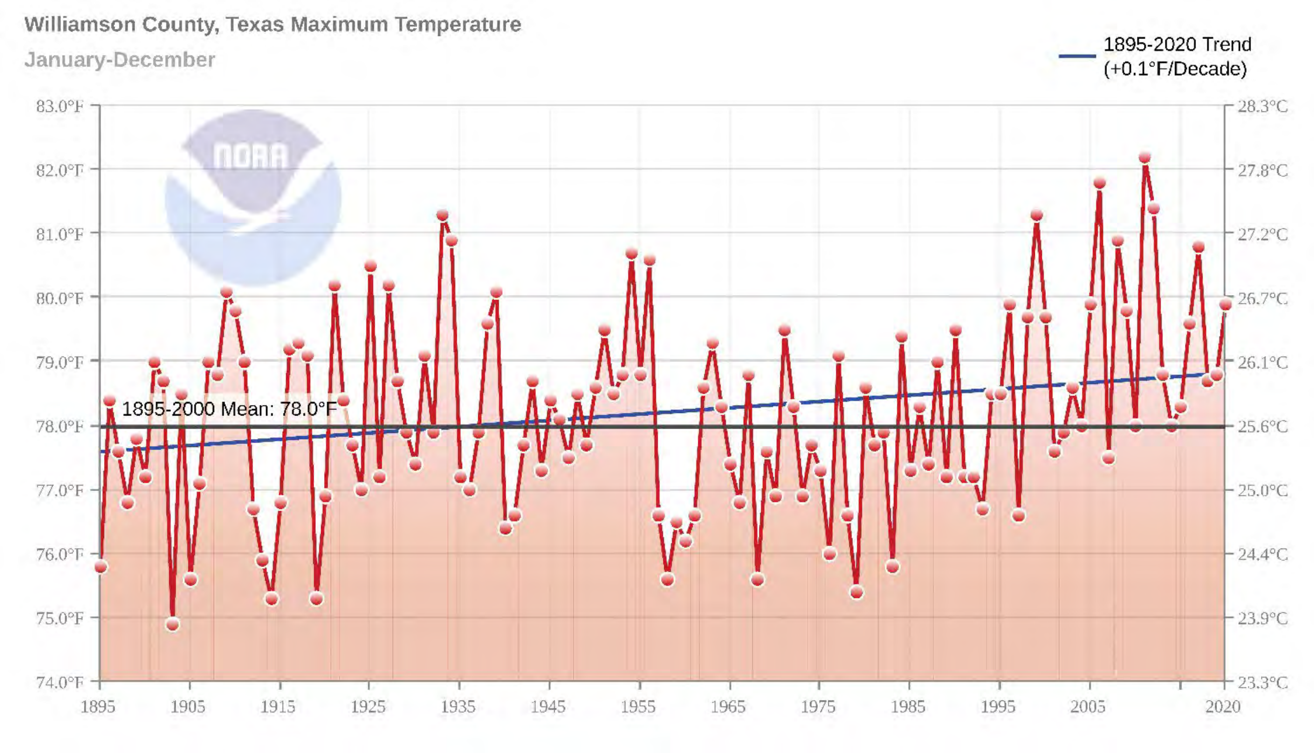


Figure 21. Average maxmimum temperature for Williamson County, Texas from 1895 to 2020 (NOAA National Centers for Environmental information 2021).

Annual average air temperatures in the southern Great Plains are projected to increase by 2.0-2.8°C (3.6-5.1°F) by the mid-21st century (Kloesel et al. 2018, p. 995). In Texas, average temperatures in 2036 are projected to increase by 0.89°C (1.6°F) compared to 2000 to 2018 (Nielsen-Gammon et al. 2020, p. 5). Periods of extreme heat are expected to be more frequent, with number of days exceeding 38°C (100°F) increasing by an additional 30-60 days per year by the end of the 21st century (NOAA 2016, pp. 1, 3; Kloesel et. al. 2018, pp. 990, 996). By 2036, the number of days with extreme temperatures in Texas are expected to increase from 12 days per year to 21 per year compared to 2000 to 2018 (Nielsen-Gammon et al. 2020a, p. 6).

The increase in number of extreme temperatures days is expected to be greater (i.e., 25 days per year by 2036) in Texas' metropolitan areas due to the urban heat island effect, (Nielsen-Gammon et al., 2020, pp. 6, 8). Urban heat islands are urbanized areas that generally experience warmer temperatures than surrounding undeveloped or less developed areas (Howard 1818, pp. 89-12; Heisler and Brazel 2010, pp. 29-32, 49). Conversion of natural land cover to impervious cover is a contributor to the increased temperatures of urban heat islands (He et al. 2007, pp. 221-225; Rinner and Hussain 2011, pp. 1257-1258, 1261-1262; Xiong et al. 2012, pp. 2043-2048, 2051-2052; Yang et al. 2017, pp. 9-10, 13-14; Zhao et al. 2018, pp. 9, 13, 15). This phenomenon has been documented in several of Texas's metropolitan areas, including the Austin-Round Rock Metroplitan Area (Streutker 2003, p. 288; Boice et al. 2018, pp. 7-9, 11; Zhao et al. 2018, p. 9).

The affect climate change will have on precipitation is less clear. From 1901 to 2015, the United States is estimated to have experienced a 4% increase in annual precipitation (Easterling et al.

2017, pp. 208-209). Extreme precipitation events have also increased in some regions of the country since 1997 (Easterling et al. 2017, pp. 210-212). Precipitation trends in central Texas also indicate historical increases in precipitation with counties in this region experiencing a 10-15% increase in annual precipitation between 1895 and 2018 (Nielsen-Gammon et al. 2020, pp. 10-11). Projected precipitation trends in Texas are also not clear, varying across the state with the potential for regional decreases or increases in rainfall (Jiang and Yang 2012, pp. 241-242; Kloesel et al. 2018, p. 996; Nielsen-Gammon et al. 2020, pp. 10-13). Extreme or heavy precipitation events are projected to increase across Texas for the remainder of the 21st century (Kirchmeier-Young and Zhang 2020, pp. 13309. 13311-13312; Nielsen-Gammon et al. 2020, p. 13).

Accompanying projected higher temperatures is the potential for more frequent drought and increasing aridity for Texas and the southwestern U.S. (Seager et al. 2007, pp. 1181, 1183; NOAA 2016, p. 3; Park et al. 2017, pp. 71-72; Wendt et al. 2018, p. 587; Marvel et al. 2019, p. 64). Increased temperatures have the potential to offset stable to increased annual precipitation due to increased evapotranspiration and decreased infiltration (Cook et al. 2015, pp. 2-3; Yoon et al. 2018, pp. 5-6; Cook et al. 2019, p. 5426, 5429-5430). Severe droughts in Texas are now much more probable than they were 40 to 50 years ago (Rupp et al. 2012, pp. 1053–1054). In 2011, Texas experienced the worst annual drought since record-keeping began in 1895 (NOAA 2012, p. 4; Nielsen-Gammon 2012, pp. 61-94). Drought severity and length are both projected to increase significantly across the southwestern United States into the late 21st century, with the potential for multi-decade long periods of drought (Cook et al. 2015, pp. 4-6).

Downscaled climate projections for Travis and Williamson counties were obtained from the U.S. Climate Resilience Toolkit (Tables 1 and 2; U.S. Federal Government, 2020). For the period 2022 to 2099, projections indicate that daily maximum temperatures (i.e., weighted means) will increase in those counties by approximately 4°C (7.5°F) under high emissions (Representative Concentration Pathway [RCP] 8.5) and 1.5°C (2.6°F) under low emissions (RCP 4.5). By 2099, under high emissions, number of days annually with extreme heat (i.e., Maximum temperature >40.6°C (105°F) is projected to increase by 42 days and by 11 days under low emissions. Numbers of days annually with minimum temperatures (i.e., >26.7°C [80°F]) is also projected to increase under high emissions by 63 days and 10 days under low emissions.

Under either emissions scenario, Travis and Williamson counties are projected to become warmer into the future with more days of extreme temperature. This is consistent with downscaled projections for the City of Austin that likewise indicate an increase in temperatures by 2100 (Brandt et al. 2020, pp. 19, 21). Temperature increases will be further compounded by the urban heat island effect as urbanization increases across the Austin-Round Rock Metropolitan Area (Brandt et al. 2020, p. 21).

Total annual precipitation under high emissions declines only slightly by 2.03 cm (0.8 in) and increases by 9.0 cm (3.5 in) under low emissions. Numbers of days per year with rainfall over >2.54 cm (1 in) also increases roughly 0.65 days under high emissions and 1.4 days under low emissions. Number of dry days per year (i.e., precipitation less than 0.02 cm [0.01 in]) increases by approximately 10 days under high emissions and decreases by five days under low emissions. These downscaled data project differing potentialities for precipitation in Travis and Williamson counties. Under low emissions, these data project an increase in rainfall for those counties, while precipitation declines by a smaller amount under high emissions. The increased temperatures projected for Travis and Williamson counties may overcome increases in precipitation due to the effect of higher rates of evapotranspiration leading to greater aridity (Cook et al. 2015, pp. 2-4; Yoon et al, .2018, pp. 5-6).

Table 1. Projected change in select climate variables for Travis and Williamson counties, Texas, between 2022 and 2099 under Representative Concentration Pathway 4.5 Downscaled data obtained from Climate Explorer (U.S. Federal Government 2020).

Climate Variable	**Travis 2022**	**Travis 2099**	**Williamson 2022**	**Williamson 2099**
Daily Maximum Temperature	27.8°C (82°F)	29.2°C (84.5°F)	27.6°C (81.7°F)	29.1°C (84.4°F)
Number of Days with Maximum Temperature >40.6°C (105°F)	2.4	12.4	2.4	15.1
Number of Days with Minimum Temperature >26.7°C (80°F)	6	15.3	1.8	13.3
Total Precipitation	73.0 cm (28.7 in)	82.0 cm (32.3 in)	75.4 cm (29.7 in)	84.0 cm (33 in)
Number of Days with >2.54 cm (1 in) of Precipitation	5.4	6.7	4.7	6.2
Number of Dry Days	253.5	249	250.2	245.6

Table 2. Projected change in select climate variables for Travis and Williamson counties, Texas, between 2022 and 2099 under Representative Concentration Pathway 8.5 Downscaled data obtained from Climate Explorer (U.S. Federal Government 2020).

Climate Variable	Travis 2022	Travis 2099	Williamson 2022	Williamson 2099
Daily Maximum Temperature	27.6°C (81.6°F)	31.6°C (88.9°F)	27.3°C (81.2°F)	31.7°C (89°F)
Number of Days with Maximum Temperature >40.6°C (105°F)	3.9	43.9	4.3	48.7
Number of Days with Minimum Temperature >26.7°C (80°F)	3.2	70	2.3	61.5
Total Precipitation	80.3 cm (31.6 in)	78.5 cm (30.9 in)	83.6 cm (32.9 in)	81.3 cm (32 in)
Number of Days with >2.54 cm (1 in) of Precipitation	6.1	6.5	5.8	6.7
Number of Dry Days	250.1	259.3	245.9	256.1

9.6.2 Subterranean Climate and Troglobitic Arthropods

The climatic conditions of caves and other subterranean voids, while relatively stable compared to surface habitats, are subject to variation in prevailing air temperature and relative humidity (Culver 1982, p. 9; Culver and Pipan 2009, pp. 3-4). Cave morphology (e.g., size, shape, and volume), number and size of entrances, seasonal changes in airflow, and annual range of surface temperatures among other factors interact to influence subterranean climate (Tuttle and Stevenson 1978, pp. 110-120; de Freitas and Littlejohn 1987, p. 568). With increasing distance into the cave, climatic conditions stabilize within a narrow range of humidity and temperature (Poulson and White 1969, p. 972; Howarth 1980, p. 398; Howarth 1993, p. 69; Prous et al. 2004, pp. 377-378; Tobin et al. 2013, p. 206).

Subterranean temperatures are influenced by the average annual temperature of the surface, with deep cave settings varying much less than surface environment (Howarth 1983, pp. 374-375; Dunlap 1995, pp. 76; Badino 2010, p. 429; Covington and Perne 2015, p. 365, Mammola et al. 2017, p. 7- EV). The thermal stability of deep subterranean spaces is attributable to the buffering effect of heat accumulation and conduction from overlying bedrock (Domínguez-Villar et al. 2015, pp. 578-579). Shifts in subterranean temperatures, driven by changes on the surface, are typically of reduced intensity and time-lagged with increasing depth underground (Domínguez-Villar et al. 2013, pp. 164-165-167; Tobin et al. 2013, p. 206, 211; Domínguez-Villar et al. 2015, pp. 576-578). Any potential increases in surface temperature may take months to years to increase temperatures deep subterranean voids, depending upon void depth and/or distance from surface as well as duration of temperature change (Domínguez-Villar et al. 2015, pp. 164; Tobin et al. 2013, p. 206; Domínguez-Villar et al. 2015, pp. 577; Mammola et al. 2019c, p. 101-103).

The adaptation of troglobitic arthropods to relatively stable temperatures has been suggested as imparting restricted thermal tolerances that may reduce a species' ability to survive temperatures outside those limits (Novak et al. 2014, pp. 267-270; Mammola et al. 2019c, p. 104; Mammola et al. 2019d, p. 646). Some studies suggests that arthropod species with greater degrees of troglomorphy are more sensitive (i.e., mortality to sub-lethal effects) to temperature extremes (Pallarés et al., 2019, pp. 13735-13736; Pallarés et al., 2020 pp. 5-8). Mammola et al. (2019d, entire) examined the thermal tolerance of cave-inhabiting spiders, in the genus *Troglohyphantes*, with representative species exhibiting varying degrees of troglomorphy. In that study, *Troglohyphantes* species with moderate to high degrees of subterranean specialization displayed the most limited tolerance to increased temperatures (Mammola et al., 2019b, pp. 1645-1646). Those species reached their critical temperature at 1-4°C (1.8-7.2°F) above natural ambient temperatures while less specialized were able to withstand increases of 7-19°C (12.6-34.2°F) (Mammola et al. 2019b, p. 1646).

The regional and downscaled climate projections discussed above indicate that conditions across the Bone Cave harvestman's range in Travis and Williamson counties will be become warmer and drier into the 22nd century. Over time, this increased heat will be conducted underground to the habitat of the Bone Cave harvestman. Warmer subterranean temperatures have the potential to drive decreases in relative humidity, especially if accompanied by long-periods of predicted drought. Troglobitic arthropods, such as the Bone Cave harvestman, may respond to seasonal climatic shifts by moving to microclimates with preferred temperatures and/or humidity (Park 1960, p. 99; Howarth 1983, p. 373; Crouau-Roy et al. 1992, p. 17; Mammola et al. 2015, p. 246; Mammola et al., 2019d, p. 646); however, the specific temperature and/or humidity physiological tolerances for this species are unknown. Unlike more mobile species that may disperse to suitable habitat under a changing climate, the Bone Cave harvestman will only persist within its current geographic range. The subterranean voids the species occupies, particularly shallower caves, may become uninhabitable due to climatic conditions that exceed the species' physiological tolerances (Tobin et al. 2013, p. 212; Mammola et al. 2019c, p. 104). Permanent occupation of deeper subterranean spaces, if available, may not be realistic given decreasing availability of nutrients with depth or increasing distance from openings to the surface (Tobin et al. 2013, p. 212; Mammola et al. 2019c, p. 106).

10.0 Current Conditions

The Bone Cave harvestman was recorded from 23 caves in Travis and Williamson counties at the time of the species description in 1992 (Ubick and Briggs 1992, pp. 211, 221). Ubick and Briggs (2004, pp. 108-110) increased the number of known locations to a total of 139 caves for both counties. In this assessment, we compiled Bone Cave harvestman records of occurrence from our files and from the University of Texas at Austin's Entomology Collection via James Reddell, Curator of Cave Invertebrates. In 2020, through cooperation with the Texas Speleological Society, these records were updated to support the karst fauna region revision for Travis and Williamson counties (Veni and Jones 2021, entire). The species resiliency tables included in this analysis reflect any additions and corrections made as a result of this effort and any new information in our files through February 2021. Identifications based on adult males provide the highest level of confidence regarding species occupancy as *Texella* taxonomy is heavily reliant on male genitalic characters (Ubick and Briggs 1992, p. 158; Ubick and Briggs 2004, p. 112). Thus, we noted whether species occupancy at each cave was based on vouchered and identified adult males, females, or juveniles deposited in museum collections or on sight records of living individuals where no voucher specimen was collected. Including four specimens previously identified as the Bee Creek Cave harvestman, we identified a total of 230 caves or karst features with records for the Bone Cave harvestman.

10.1 Cave Analysis Methodology

An important consideration in our assessment of the Bone Cave harvestman was whether occupied karst features warranted consolidation into single populations based on geographic proximity. Some populations of troglobitic arachnids (e.g., *Cicurina* and *Tayshaneta*= *Neoleptoneta*) and beetles (i.e., *Rhadine*) in central Texas have exhibited genetic connectivity among karst features (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). Ledford et al. (2012, pp. 11, 18-23, 51) documented high degrees of genetic similarity among Tooth Cave spider populations at Gallifer, Root, and Tooth Caves and Tight Pit in Travis County. Genetic similarity among Tooth Cave spiders sampled from those sites implies dispersal of individuals between caves over time through interconnected subterranean dispersal corridors (e.g., mesocaverns). No comparable genetic data are available to indicate how far Bone Cave harvestmen may move through subterranean dispersal corridors. However, since the Bone Cave harvestman also occurs at Gallifer, Root, and Tooth Caves, we expect there has been some level of genetic exchange among Bone Cave harvestman populations there as well as at other caves systems with subterranean connectivity.

Female Tooth Cave spiders and other *Tayshaneta=Neopleptoneta* species are relatively sedentary, spending most of their lives in webs (Ledford et al. 2012, pp. 12, 15, 53). Little is known regarding the movement patterns of males or juveniles of that genus. 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). Greater distances between genetically similar troglomoprhic *Tayshaneta=Neoleptoneta* (i.e., *T. anopica* and *T. sandersi*)species were noted by Ledford et al. (2012, pp. 11, 18-23) in Travis and Williamson counties. Individuals of *T. sandersi* sampled from three caves (i.e., District Park Cave, Slaughter Creek, and Whirlpool

Caves) in Travis County were found to be genetically identical, with an average distance of 698 m (2,290 ft) between those karst features (Ledford et al. 2012, p. 57).

Texella are not web-builders and may opportunistically combine capturing live prey with scavenging immobile food items. Like other harvestman, Bone Cave harvestman may employ stationary sit-and-wait ambush techniques to capture live prey (Acosta and Machado 2007, pp. 323-324, 332). Live prey and immobile food sources may also be located through active movement and exploration (Acosta and Machado 2007, pp. 326, 332-333, 327; Willemart et al. 2009, p. 222). Hoenen and Gnaspini (1999, pp. 161-164) suggest that troglobitic harvestman may need to move and search more intensively for food due to nutrient scarcity in subterranean habitats. For those reasons, we assumed that Bone Cave harvestman populations have at least as much, if not a greater, subterranean dispersal capacity than troglobitic *Tayshaneta*= *Neolopetoneta* species. Genetic analyses of the troglobitic ground beetle *R. subterranea*, a predatory insect, support the supposition that populations of more vagile karst invertebrates can disperse along subterranean distances greater than 292 m (958 ft) provided adequate connectivity is present. Avise and Selander (1972, p. 15) noted gene flow between populations of that beetle species from two caves in Travis County over 750 m (2,460 ft) apart.

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 or karst feature 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.

To summarize the current condition of Bone Cave harvestman populations, we evaluated 2020 aerial imagery (ESRI 2021) 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. As we lack maps of every cave's footprint, cave entrances served as center-points for measurements where footprints were not available.

We assigned the population of 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 (Table 3). 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.

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. Results of this review by karst fauna region are in Appendix B, Tables 7-12. Additional details regarding habitat elements are below.

I. Open space area: We considered open space as an area of natural vegetation devoid of human-related activities (e.g., construction, housing, impervious cover, soil disturbance, or vegetation removal). Larger tracts of open space generally minimize effects of edge and isolation around a particular cave opening. They also increase the likelihood of dispersal and recolonization of cave crickets, providing connectivity between additional karst features for cave cricket roosting, and support a diverse, self-sustaining plant community over the long-term (Service 2012, Appendix pp. 1-4). Smaller areas of open space would be more vulnerable to reduced cave cricket recolonization, invasion by red-imported fire ants, contamination events due to lack of drainage basin protection, and/or unable to sustain native plant community composition over the long-term. We assigned each cave to one of the following four categories based on the amount of open space available surrounding the entrance: 1) >40 ha (>100 ac), 2) 16-40 ha (40-100 ac), 3) 3.6-16 ha (9-40 ac), or 4) <3.6 ha (<9 ac).

II. Distance of cave entrance to nearest edge: Distance from the cave entrance to the nearest edge (i.e., boundary between open space and areas of human impact) was measured for each cave. Taylor et al. (2007a, p. 2) found that numbers of individuals of all cave taxa, including cave crickets are correlated with the level of human impact surrounding the cave. As the percentage of impervious cover and percentage of impacted area around a cave increased, the total number of cave taxa decreased. This trend was present at both 120 m (394 ft) and 340 m (1,115 ft) around a cave (Taylor 2007a, p. 43-46). For this analysis, we noted whether cave entrances were more or less than 120 m (394 ft) from an edge. We assumed that caves less than 120 m (394 ft) from an edge were experiencing affects from adjacent urban land uses. Caves were assigned to the next lower resiliency classification when they were less than 120 m (394 ft) from an edge. If a feature occured on a preserve managed specifically for karst invertebrates, however, we did not also reduce its resiliency if it was less than 120 m (394 ft) from an edge if neither the cave cricket foraging area or drainage basins were impacted.

III. Status of cave cricket foraging area and/or drainage basins: To assess the status of the cave cricket foraging area, we analyzed a 105 m (345 ft) radius area, a maximum observed value for cave cricket foraging activity (Taylor et al. 2005, p.104), around each cave footprint or entrance if the footprint was unknown. By examining aerial imagery, we evaluated each cave cricket foraging area for evidence of human impacts (e.g., construction, housing, impervious cover, soil disturbance, and vegetation removal). We assigned each cave to one of the following three categories based on the percent of that area impacted by human disturbance(s), 0%, 0-25%, 26-50%, or 76-100%.

Because impacts to a cave's surface or subsurface drainage basin can be a source of stressors for Bone Cave harvestman populations, 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, for most sites, we did not include an assessment of actual impacts to drainage basins in this evaluation. For these analyses, if a drainage basin for a cave was unknown, 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. If a cave's drainage basins were known, we examined aerial imagery to evaluate whether they had been impacted by development activities. The resiliency category of caves that had more than 25% of their cave cricket foraging area impacted and/or had impacts to their surface or subsurface drainage basins were reduced to the next lower category. 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 at any particular site.

Table 3. Habitat element criteria used to evaluate resiliency of individual Bone Cave harvestman cave sites.

Open Space Area ha (ac)	**Distance of Cave to Nearest Edge m (ft)**	**Percent of Cave Cricket Foraging Area Impacted****	**Resiliency**
>40 (>100)	>120 (>394)	0%	High
>40 (>100)	<120 (<394)*	0-25%	Moderate
>40 (>100)	<120 (<394)	>25%	Low
16-40 (40-100)	>120 (>394)	0%	Moderate
16-40 (40-100)	<120 (<394)*	0-25%	Low
16-40 (40-100)	<120 (<394)	>25%	Impaired
3.6-16 (9-40)	>120 (>394)	0%	Low
3.6-16 (9-40)	<120 (<394)	>0%	Impaired
<3.6 (<9)	NA	NA	Impaired

* If a feature was on a preserve that was managed for karst and its drainage basins and cave cricket foraging areas were unimpacted, we did not reduce the resiliency value for that feature if it was less than 120 m from an edge.

** If a feature's drainage basin was impacted, resiliency was reduced by one value even if the cave cricket foraging area was not impacted.

We also evaluated land cover in Karst Zones 1 and 2, for each karst fauna region occupied by the Bone Cave harvestman, using data from the United States Geological Survey's National Landcover Database (U.S. Geological Survey 2016). Descriptions of vegetation and human-related land cover types are in Jin et al. (2019, pp. 27-28). We used the following land cover categories from this dataset in our assessment of human impacts:

- Open water
- Developed, Open Space
- Developed, Low Intensity
- Developed, Medium Intensity
- Developed, High Intensity
- Barren Land

Developed, high and medium intensity includes built areas and transportation corridors dominated by impervious cover. Developed, low intensity includes built areas not entirely covered by impervious cover, including much of the area within cities and towns. Developed, open space includes areas with up to 20% impervious cover as well as other human modifications that maintain the area in something other than native vegetation. Barren land cover includes areas with little to no vegetation such as large areas cleared for development, roads, buildings, quarries and agricultural lands, such as fallow fields or heavily grazed pastures with bare soil. Cultivated crops, while less intensive than urban land uses, can still result in significant modifications to native plant and animal communities and are subject to management throughout the year that can further disturb vegetation and soils. Developed, open space, open water, and barren land cover types were included along with other urbanized areas as they reflect some degree of human activity on the landscape that modifies soils and vegetation. These activities may decrease potential surface habitat to buffer and support karst ecosystems.

Land cover totals for Karst Zones 1 and 2 do not necessarily represent single, contiguous blocks of a particular cover type. Rather, vegetation and human-related land cover exists as a mosaic across these zones. There is a potential for fragments of natural habitat that persist in Karst Zones 1 and 2 to host undiscovered Bone Cave harvestman populations. In particular, existing tracts of land 16-40 ha (40-100 ac) or more in size may represent additional moderate to high resiliency sites that could serve as targets for protection. To gauge this potential, we utilized a neighborhood analysis of 120 m (394 ft) circles to highlight larger (i.e. greater than 16 ha [40 ac]) areas of unimpacted habitat in Karst Zones 1 and 2 within the range of the species.

These analyses provide only a coarse estimate of the current existing area of open space and include areas with and without known Bone Cave harvestman populations. In addition, the large parcels identified did not all represent areas of open space unaffected by human activity. Because the NLCD data represents land cover as of 2016, additional impacts occurring in the intervening years are not accounted for in this analysis. Quality of remaining surface and subsurface habitat for Bone Cave harvestman populations likely varies considerably (e.g., history of human impact, extent of fragmentation, and condition of native plant community) on the ground. In addition, identification of previously undocumented Bone Cave harvestman populations will be dependent upon survey effort and stability of suitable habitat conditions that enable populations to persist.

Below we describe the current conditions for each karst fauna region overall and an assessment of sites currently occupied by the Bone Cave harvestman. 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.

Karst fauna areas are high and moderate resiliency sites established by external parties and recognized by the Service as possessing the needed criteria (i.e., habitat elements, management, and legally binding, perpetual protection) to support Bone Cave harvestman persistence. Proposed karst fauna areas represent sites submitted to the Service by external parties for review and recognition. Potential karst fauna areas are sites that have have an increased probability of long-term persistence and a potential to support a high to moderate resiliency Bone Cave harvestman populations but currently lack permanent protection, sufficient knowledge of whether their drainage basins are intact or both. Numbers of currently protected, proposed, and potential karst fauna areas are listed in Table 4.

Table 4. Potential, proposed, and protected karst fauna areas by karst fauna region.

Karst Fauna Region	Potential Karst Fauna Area(s)	Proposed Karst Fauna Area(s)	Protected Karst Fauna Area(s)
North Williamson County	5	1	4
Georgetown	9	2	0
McNeil/Round Rock	7	0	0
Jollyville Plateau	11	0	0
Cedar Park	0	0	0
Central Austin	0	0	0

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. In addition, it is unlikely that resiliency of these sites will improve as surrounding open space has been developed or highly modified. Destroyed caves are those karst features that have been built over, filled in, or sealed in a way that likely resulted in loss of the Bone Cave harvestman population in that cave.

Because Travis and Williamson counties are experiencing rapid human population growth and development, resiliency of a site can decline rapidly as construction activity and land conversion intensifies. Most of the remaining high and moderate resiliency sites in the Georgetown, McNeil/Round Rock, and North Williamson County Karst Fauna Regions are on privately owned tracts of land that are susceptible to land use changes. In the absence of protective measures, the resiliency of cave clusters or individual caves at these sites may be susceptible to decline over a short time span.

Locations of all high, moderate, low, and impaired sites within Travis and Williamson counties are mapped in Figure 22. Figures 23, 25, 27, 29, 31, and 33 depict site resiliency for each individual karst fauna region.

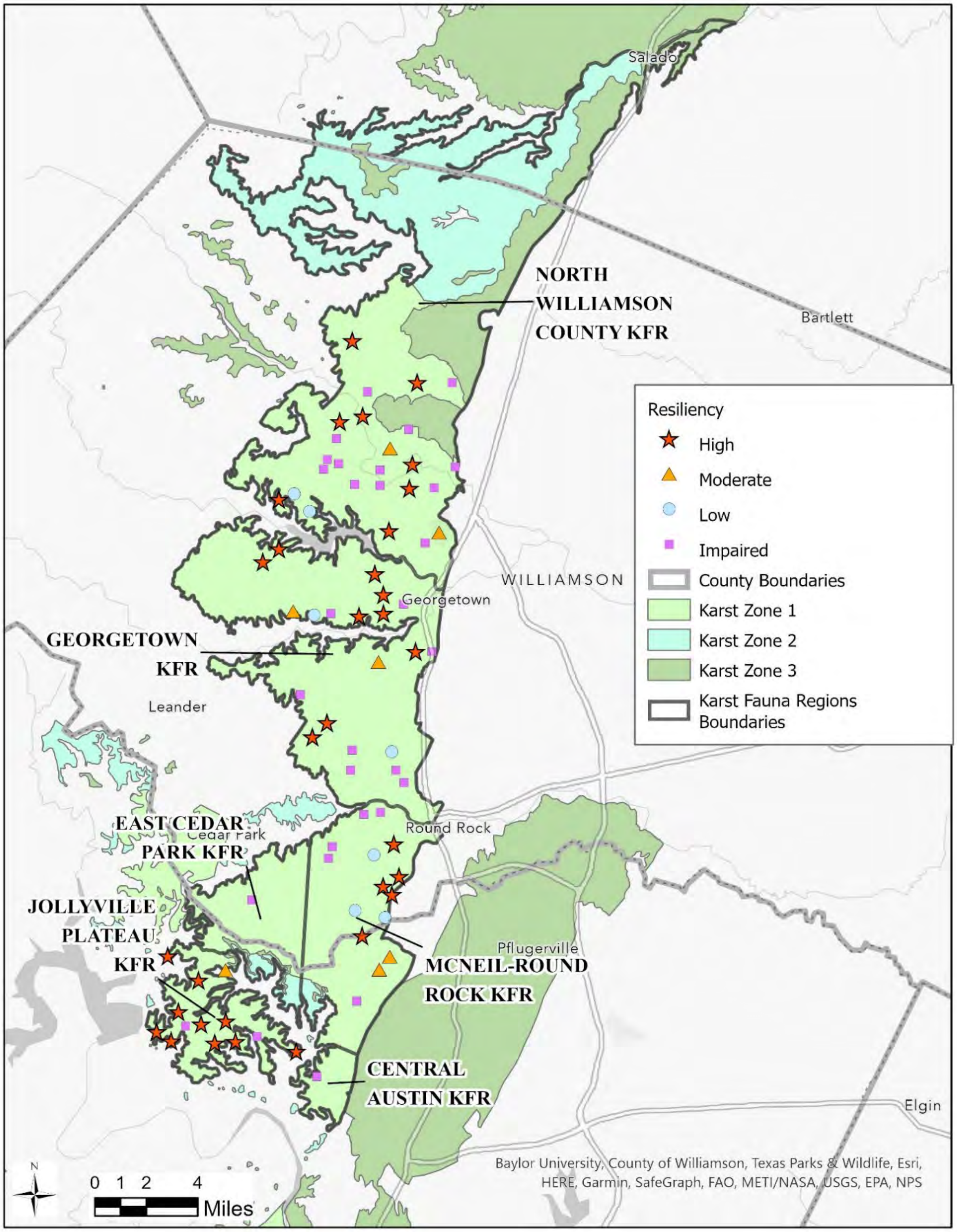


Figure 22. Current resiliency of Bone Cave harvestman caves and cave clusters in Travis and Williamson counties, Texas.

10.2 North Williamson County Karst Fauna Region

The North Williamson County Karst Fauna Region encompasses 33,819 ha (83,571 ac) in the northern portion of Williamson County and southern portion of Bell County generally west of Interstate 35 (Figure 23). This is the northernmost known extent of the Bone Cave harvestman's range and extends from Buttermilk and Salado Creeks just north of the Bell and Williamson County line southward to the North Fork of the San Gabriel River. Karst Zones 1 and 2 cover an area of 26,280 ha (66,280 ac) or 79% of the region and the modeled range of the Bone Cave harvestman covers approximately 13,454 ha (33,245 ac) of that area (Veni and Jones 2021, p. 24).

Human modifications have impacted almost 30% (3,911 ha [9,664 ac]) of the Bone Cave harvestman's range in this karst fauna region (U.S. Geological Survey 2016). Of the remaining unimpacted areas, approximately 50% (6,769 ha [16,727 acres]) occur in patches 16 ha (40 ac) or greater. Several karst fauna areas provide protection in a few of the remaining large parcels in this region (Figure 24).

A total of nine cave clusters and 16 extant individual caves occupied by the Bone Cave harvestman are located in the North Williamson County Karst Fauna Region (Appendix B, Table 7). This karst fauna region, followed by the Georgetown Karst Fauna Region, contains the largest number of known Bone Cave Harvestman populations. Based on our review of habitat elements, five cave clusters are high resiliency, one is moderate resiliency, and three are impaired.

Two of the high resiliency cave clusters, Karankawa and Priscilla's Well, are currently on preserves established by the Williamson County Conservation Foundation and have been recognized as karst fauna areas. A third high resiliency cave cluster, Shaman Karst Preserve, is proposed for karst fauna area status by the Williamson County Conservation Foundation and is pending final recognition. Another high resiliency cave cluster, Godwin Ranch, is owned and managed by the Texas Cave Management Association as a part of mitigation for the Lakeline Mall 10 (a)(1)(B) permit. We currently lack the needed information (e.g., extent of surface and subsurface drainage basins, management activities, and details regarding perpetual protection) to determine whether it would meet our definition of a karst fauna area.

The remaining high (i.e., Georgetown Village Cluster) and moderate (i.e., Ute Cave Cluster) resiliency cave clusters could be potential candidates for establishment as karst fauna areas provided drainage basins are unimpacted and perpetual management and protection can be obtained. Three cave clusters (i.e., Jack Frost Elementary, Kiva Cave No. 1 and Yellow Hand Cave, and SH 195 Cave Clusters) are impaired due to significantly reduced open space (i.e., some less than 3.6 ha [9 ac]), insufficient distance of cave entrance to edge, and altered to highly impacted cave cricket foraging areas.

Three individual caves in this region are high resiliency. The Williamson County Conservation Foundation protects the high resiliency Cobbs Cavern and Whitney West Cave on the Cobbs Cavern and Twin Springs Preserves, respectively. These preserves have both been recognized as karst fauna areas. Blowhole Cave is the remaining high resiliency cave in this region with over 40 ha (100 ac) of open space, sufficient distance of cave entrance to edge, and minimally altered cave cricket foraging area. Willow the Wisp Cave is of moderate resiliency. These two caves, however, are unprotected and their surface and subsurface drainage basins are unknown.

Twelve of the 16 extant individual cave sites are low resiliency or impaired. Human impacts to cave cricket foraging areas at most of these sites were significant and all lacked sufficient distance from cave entrance to edge. In addition, most of the impaired sites contained less than 3.6 ha (9 ac) of open space surrounding the cave openings. Two individual cave sites occupied by the Bone Cave harvestman in this region have been destroyed by human activity.

In summary, this karst fauna region has the potential for protection of eight high and two moderate resiliency Bone Cave harvestman populations, including six cave clusters and four individual cave sites,.given maintenance of current ecological conditions. Of the high resiliency populations, two cave clusters and two individual cave sites are recognized as protected karst fauna areas with one additional cave cluster cluster proposed to be recognized. Two additional clusters have the potential to support high resiliency populations and one cave cluster and one individual cave site have moderate potential to support self-sustaining populations of this species. However, many of the currently unprotected sites are adjacent to development and subject to land conversion. Human activities have significantly impacted three of the Bone Cave harvestman-occupied cave clusters and 12 of the 16 extant individual caves.

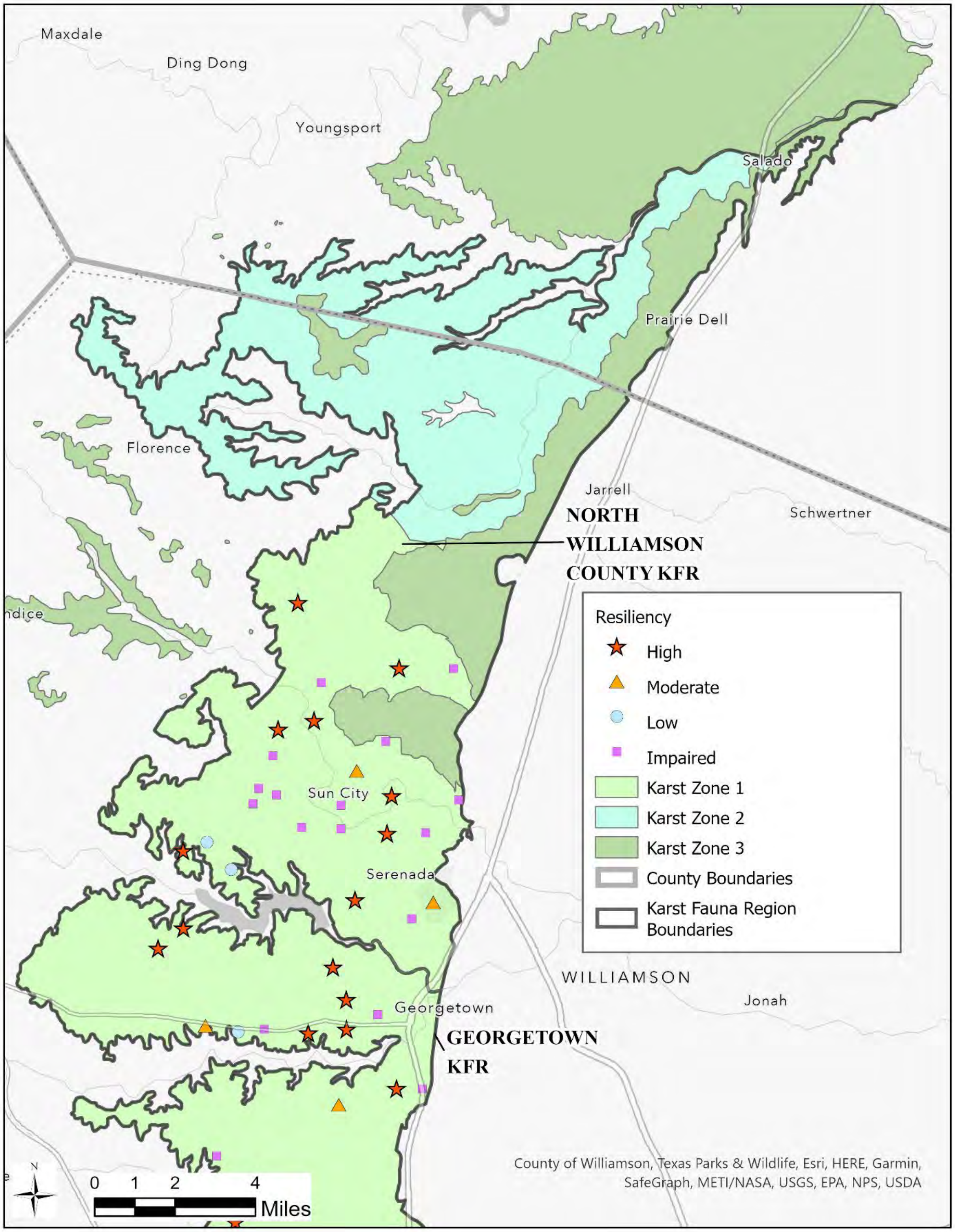
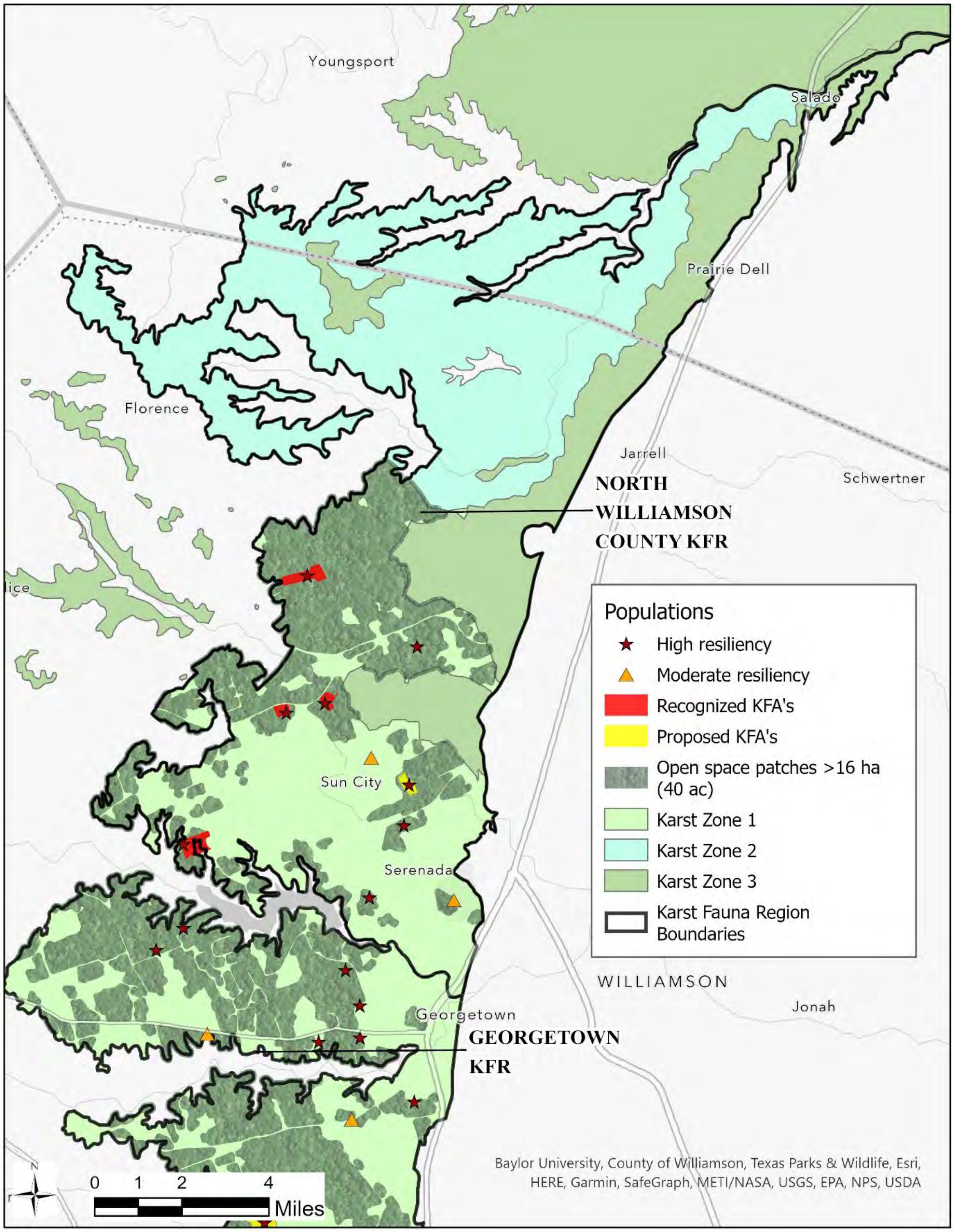


Figure 23. Current resiliency of Bone Cave harvestman caves and cave clusters in the North Williamson County Karst Fauna Region.



Baylor University, County of Williamson, Texas Parks & Wildlife, Esri, HERE, Garmin, SafeGraph, METI/NASA, USGS, EPA, NPS, USDA

Figure 24. Proposed and recognized karst fauna areas and patches of unimpacted habitat greater than 16 ha (40 ac) within the range of the Bone Cave harvestman.

10.3 Georgetown Karst Fauna Region

The Georgetown Karst Fauna Region encompasses 16,351 ha (40,405 ac) generally west of Interstate 35 from the North Fork of the San Gabriel River southward to Brushy Creek (Figure 25). Karst Zones 1 covers the entire region and the modeled range of the Bone Cave harvestman includes all but 230 acres at the western edge of this region.

Just over 30% (4,993 ha, [12,339 ac]) of the Bone Cave harvestman's range has been modified by human development in the Georgetown KFR (U.S. Geological Survey 2016). Of the remaining area, approximately 58% (8,582 ha [21,207 ac]) remains in patches greater than 16 ha (40 ac) [Figure 26]. Quarrying activities are impacting some large parcels in this region.

A total of 12 cave clusters and 10 individual caves occupied by the Bone Cave harvestman are located in the Georgetown Karst Fauna Region (Appendix B, Table 8). Based on our review of habitat elements, seven cave clusters are high resiliency, two are moderate, one is low, and two are impaired. Two of the seven high resiliency cave clusters (i.e., Millennium and Wilco Cave Clusters) are proposed to be recognized as karst fauna areas by the Williamson County Conservation Foundation. The remaining high resiliency clusters (Cassidy Cave and Dead Man's Cave, DB Wood, Georgetown Bypass, Shadow Canyon, and Steam Cave Clusters) have the potential to support high resiliency Bone Cave harvestman populations provided protection of adequate habitat can be secured. Bone Cave and Cole's Cavern Clusters are moderate resiliency and Burled Oak and Four-Mile Cave Cluster is low resiliency. Mayfield Cave and Inner Space Caverns and Shamrock Cave Clusters are impaired due to reduced open space, insufficient distance of cave entrances to edge, and significantly altered cave cricket foraging areas.

Of the 10 individual caves in the Georgetown Karst Fauna Region, only two (i.e., Jensen, and Harrison Caves) currently have the potential to support high resiliency populations of Bone Cave harvestman. One individual cave is low resiliency (i.e., Keyhole Drop Cave) and the remaining seven individual caves (i.e., Broken Glass Cave, Brown's Cave, Paradox Cave, Short Stack Cave, Snowmelt Cave, Tres Amigos Cave and Waterline Cave) are impaired due to reduced open space (i.e., less than 3.6 ha [9 ac]), insufficient distance of cave entrance to edge, and significantly altered cave cricket foraging areas. In summary, nine cave clusters and two individual cave clusters in the Georgetown Karst Fauna Region have the potential to support high or moderate resiliency Bone Cave harvestman populations given maintenance of current ecological conditions. Two of the cave clusters are pending review as either one or two protected karst fauna areas. The remainder of the currently unprotected sites are adjacent to development and subject to land conversion. Human activities have significantly impacted three of the Bone Cave harvestman-occupied cave clusters and eight of the ten extant individual caves.

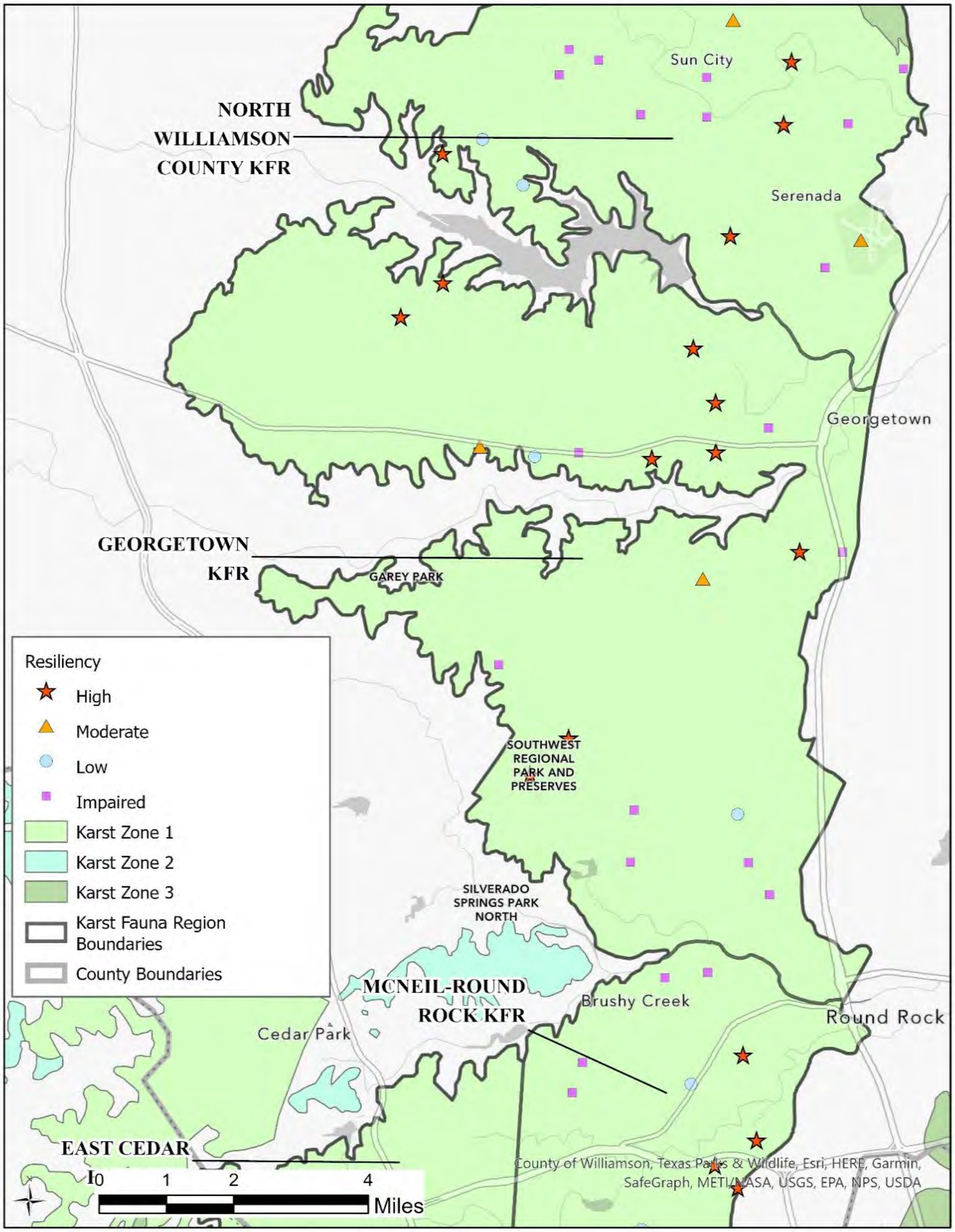


Figure 25. Current resiliency of Bone Cave harvestman caves and cave clusters in the Georgetown Karst Fauna Region.

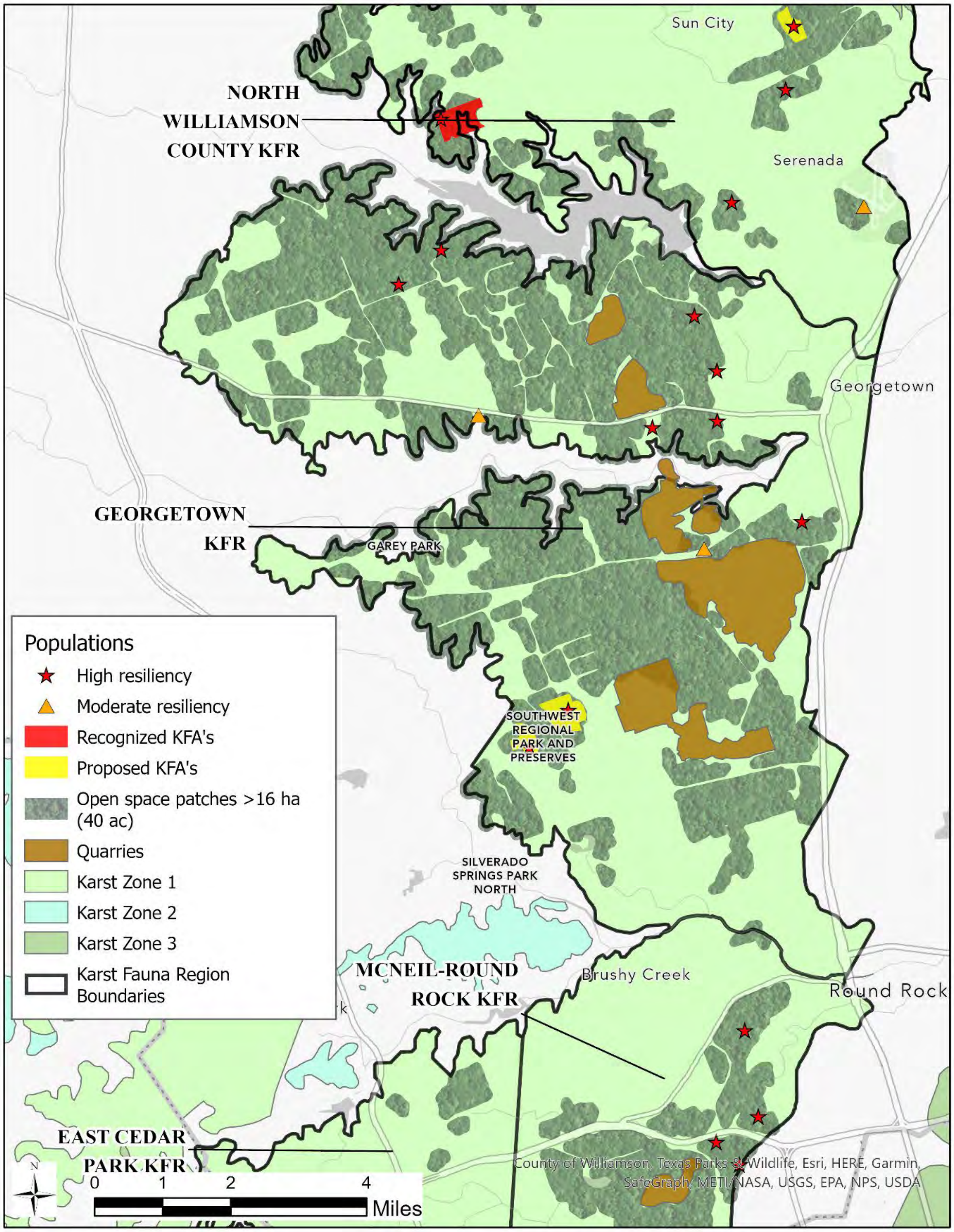


Figure 26. Proposed and recognized karst fauna areas and patches of unimpacted habitat greater than 16 ha (40 ac) within the range of the Bone Cave harvestman in the Georgetown Karst Fauna Region.

10.4 McNeil/Round Rock Karst Fauna Region

The McNeil/Round Rock Karst Fauna Region encompasses 8,204 ha (20,272 ac) generally west of State Highway Loop 1 from Brushy Creek in the north, southward to Bull Creek (Figure 27). Karst Zones 1 and 2 cover all but approximately 283 ha (699 ac) of this region and the modeled range of the Bone Cave harvestman includes all but 31 ha (77 ac) of Karst Zone 2 in the southwest part of the KFR (Veni and Jones 2021, p. 24). More than 60% of the Bone Cave harvestman's range (5,225 ha [12,911 ac]) has been impacted by some form of human development. Of the remaining area, approximately 24% (1,940 ha (4,793 ac) occurs in patches 40 acres or more (Figure 28). Given the smaller area of large parcels, previously undocumented caves may be in close proximity to existing occupied caves and may represent extensions of already known populations. Quarrying activities are also impacting some large parcels in this region.

A total of seven cave clusters and eight individual extant caves occupied by the Bone Cave harvestman are located in the McNeil/Round Rock Karst Fauna Region (Appendix B, Table 9). Based on our review of habitat elements, three cave clusters are high resiliency, one is moderate resiliency, two are low, and one is impaired. Karst fauna areas have not been established or proposed in the McNeil/Round Rock Karst Fauna Region. Most sites in this region lack sufficient protections from land conversion.

One high resiliency site, Chaos Cave Cluster, receives some level of protection through an existing preserve (i.e., Chaos Karst Preserve). The preserve, however, does not constitute a karst fauna area as only portions of the cave cricket foraging areas and drainage basins are protected. Travis County officials are cooperating with the Round Rock Independent School District to protect an area surrounding two caves at the McNeil Cave Cluster, another high resiliency site. To qualify as a karst fauna area, the protected area would need to be enlarged to include the entire cave cricket foraging area and drainage basins for Weldon Cave. The remaining high resiliency site is the Wyoming Springs Cave Cluster.

Cold Cave and Hole-in-the-Road Cave Cluster is currently of moderate resiliency based on this review, however, both caves in the cluster are near development and it is likely that their surface and subsurface drainage basins are being impacted. Beck Cave Cluster consists of 34 individual caves but surface habitat is discontinuous and highly fragmented by development. Beck Cave Preserve, a 16 ha (40 ac) protected area, lies within the cluster. However, all cave openings in this preserve have insufficient distance from cave entrance to edge and all cave cricket foraging areas have experienced human impacts. All of the caves within the Beck Cave Cluster are low resiliency, impaired, or destroyed. The remaining clusters, Lineament Cave Cluster and Fern Bluff Cave Cluster are low resiliency and impaired respectively.

Raccon Lounge and Six Meter Sink are the only high resiliency individual caves in this karst fauna region. One cave, Beer Bottle Cave, is of moderate resiliency The remaining five individual caves in this KFR are impaired.

In summary, three cave clusters and two individual caves in the McNeil/Round Rock Karst Fauna Region have the potential to support high resiliency Bone Cave harvestman populations given maintenance of current ecological conditions. Only one cave cluster and one individual cave have a moderate potential to support resilient populations of this species. However, several of these sites are adjacent to development and subject to land conversion. Three Bone Cave harvestman-occupied cave clusters and five of the eight extant individual caves are significantly impacted by human disturbance.

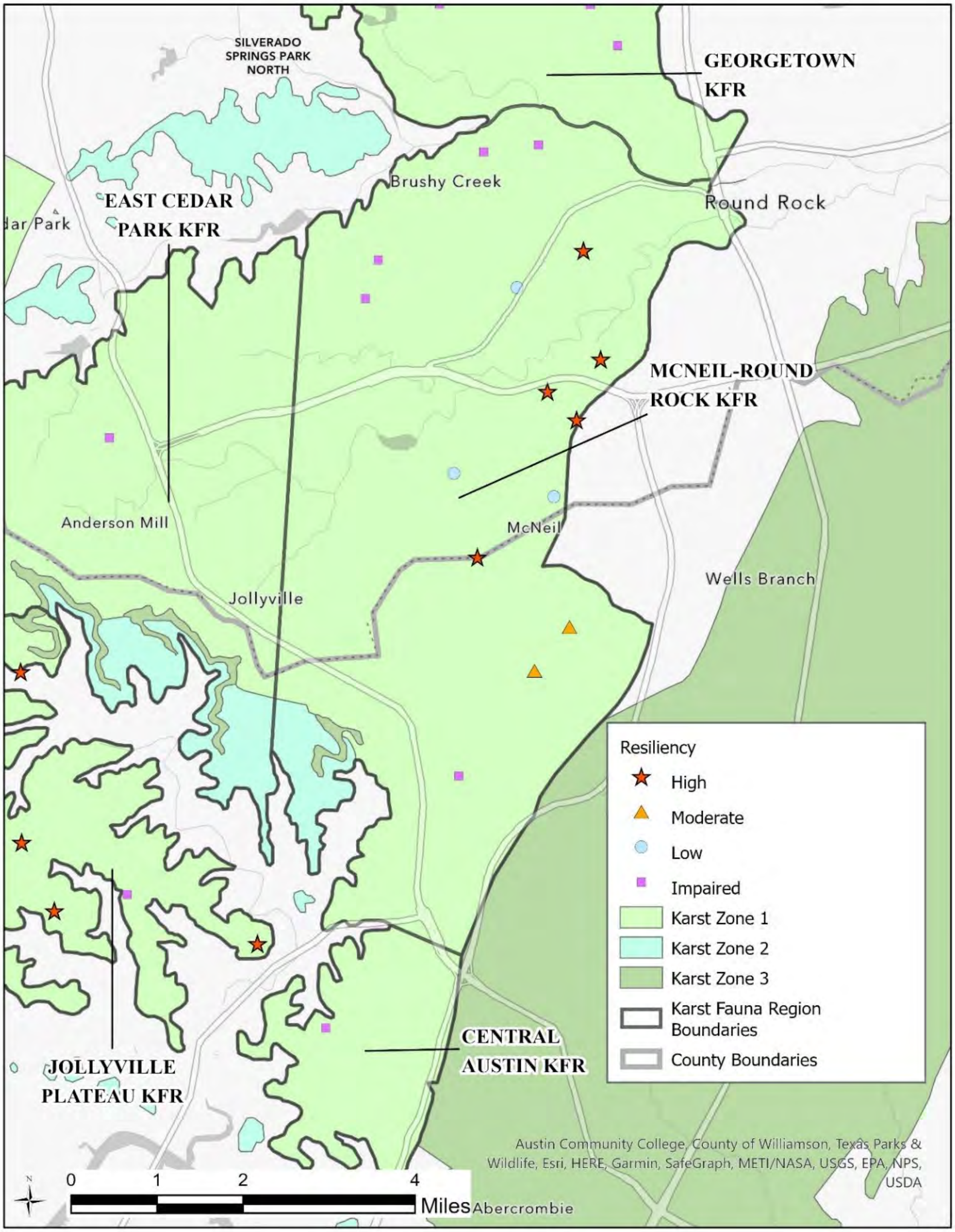


Figure 27. Current resiliency of Bone Cave harvestman caves and cave clusters in the McNeil/Round Rock Karst Fauna Region.

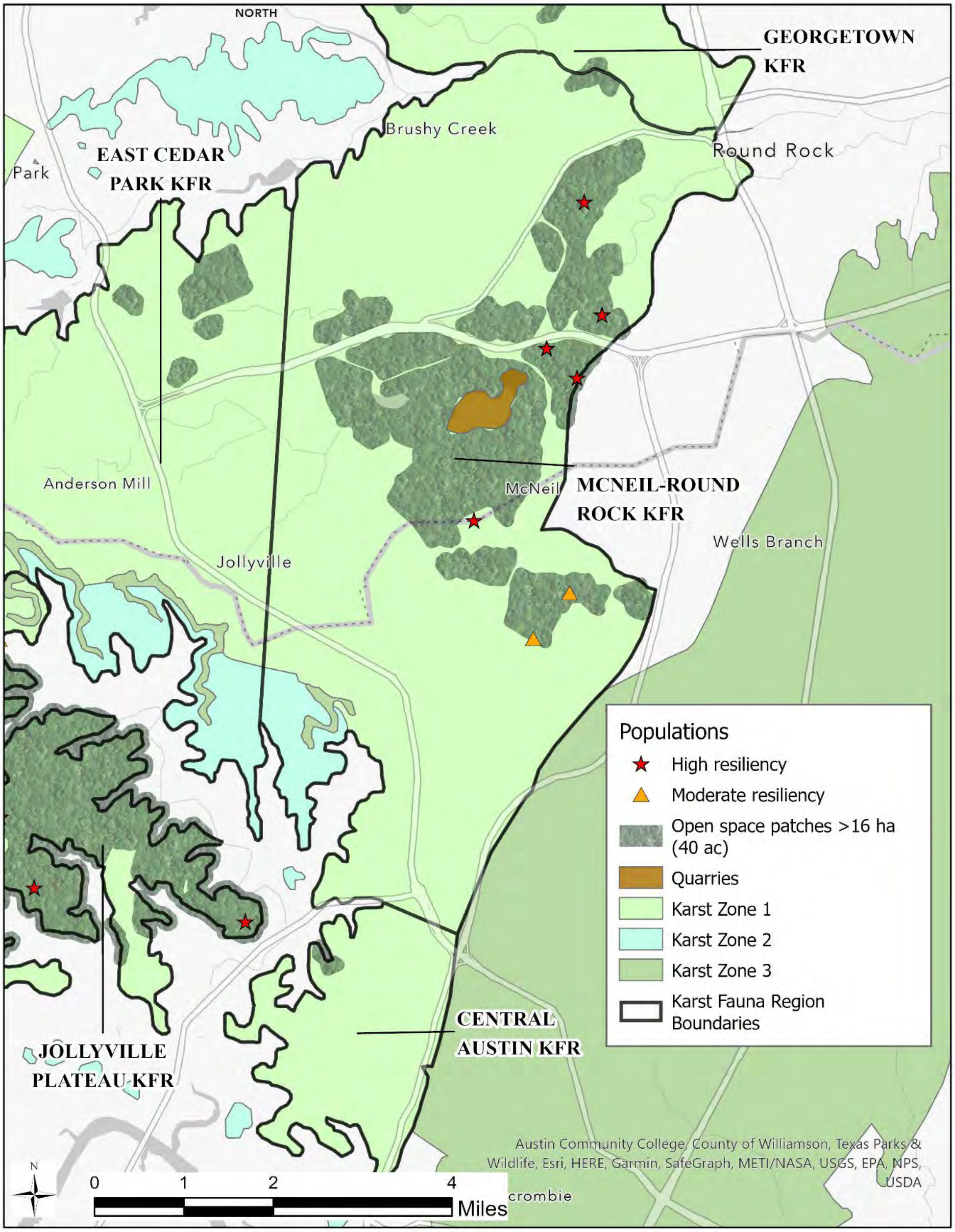


Figure 28. Patches of unimpacted habitat greater than 16 ha (40 ac) within the range of the Bone Cave harvestman in the McNeil-Round Rock Karst Fauna Region.

10.5 Jollyville Plateau Karst Fauna Region

The Jollyville Plateau Karst Fauna Region encompasses 3,705 ha (9,156 ac) east of Lake Travis and to the southwest of Anderson Mill Road (Figure 29). Karst Zone 1 as well and the modeled range of the Bone Cave harvestman cover all but approximately 30 ha (73 ac) of this karst fauna region. Approximately 30 % of this region has been impacted by development (U.S. Geological Survey 2016). Of the remaining unimpacted habitat, approximately 64% of this region (2,351 ha [5,810 ac]) occurs in patches of 40 acres or more (Figure 30). A preserve system provides protection for most of the remaining large parcels in this region.

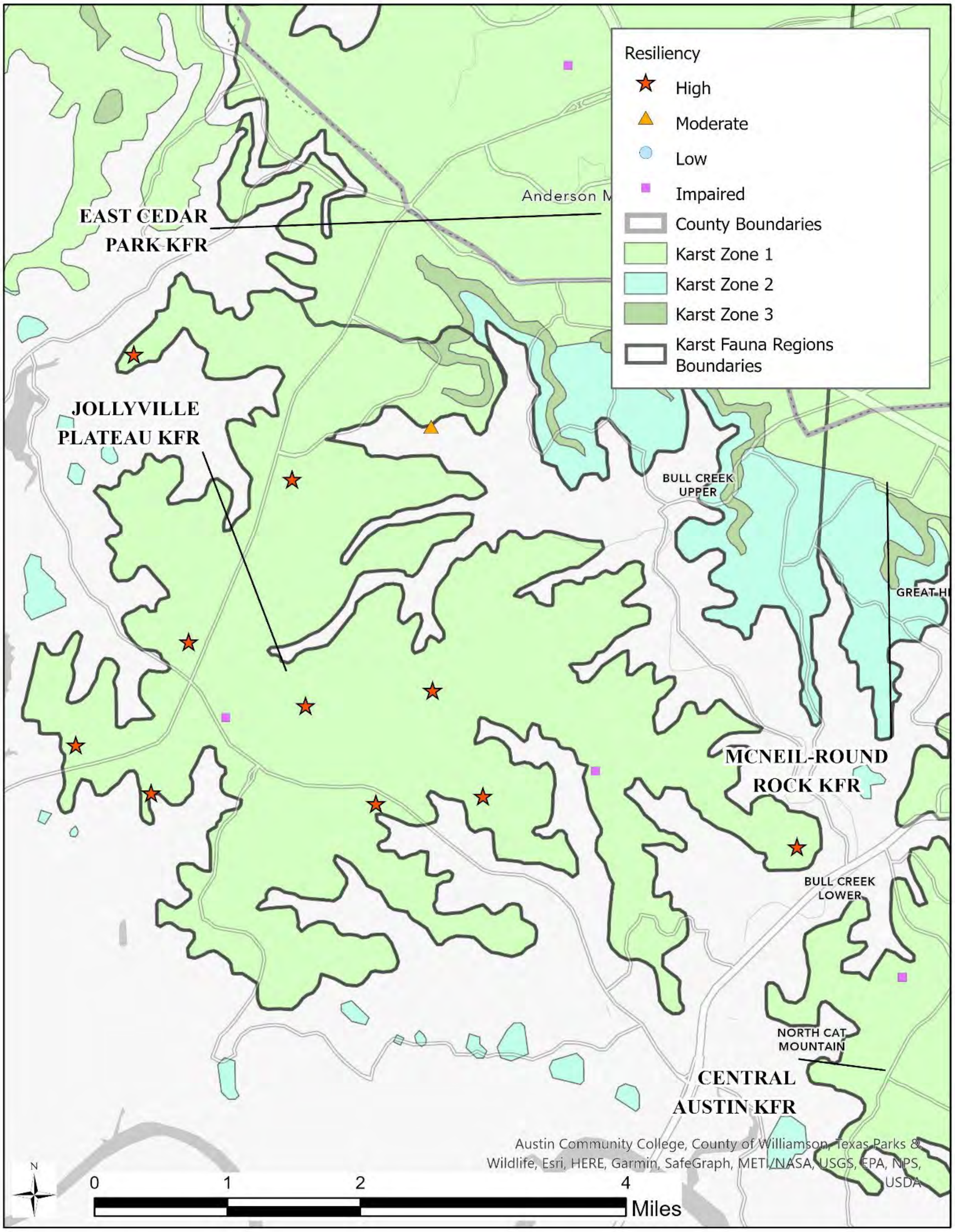
A Habitat Conservation Plan (i.e., 10(a)(1)(B) permit) was issued to the City of Austin and Travis County in 1996 for incidental take of two listed bird species and six listed karst invertebrates. The Habitat Conservation Plan required the establishment of a preserve system to protect habitat for the covered species. That preserve, the Balcones Canyonlands Preserve, encompasses over 12,545 ha (31,000 ac) in Travis and Williamson counties and includes several tracts in the Jollyville Plateau Karst Fauna Region that host the Bone Cave harvestman. Along with the City of Austin and Travis County, a number of other entities are responsible for ownership and/or management of the parcels of land that compose the preserve including the Lower Colorado River Authority, Travis Audubon Society, The Nature Conservancy, and private landowners. All sites protected within the Balcones Canyonlands Preserve may not provide protections equivelant to karst fauna area criteria and guidelines.

A total of six cave clusters and seven individual caves, occupied by the Bone Cave harvestman, are located in the Jollyville Plateau Karst Fauna Region (Appendix B, Table 10). Based on our review of habitat elements, four of the six cave clusters in this region are high resiliency with more than 40 ha (100 ac) of open space, sufficient distances from cave entrance to edge for most caves, and majority of caves with unaltered cave cricket foraging areas. One cave cluster is of moderate resiliency (i.e., Plethodon Cave and Stovepipe Cave Cluster) and one cave cluster is impaired (i.e., Puzzle Pits Cave and Twisted Elm Cave Cluster).

The Balcones Canyonlands Preserve provides protection to the four high resiliency cave clusters, Four Points, Kent Butler Ecological Reserve, New Comanche Trail, and Tooth Cave Cave Clusters and a portion of the Plethodon Cave and Stovepipe Cave Cluster (Balcones Canyonlands Preserve 2014, pp. 11-14). These sites may approximate karst fauna areas but will require further assessment to determine if all needed criteria (e.g., drainage basin delineations, legally binding agreement for perpetual protection, and confirmation of species presence) are in place for that recognition.

Of the seven individual caves in this karst fauna region five (i.e., RI-1, and Cortana, Jest John, McDonald and Spider Caves), currently have the potential to support high resiliency populations and one (Pickle Pit) moderate. One cave (Jester Estates Cave) is impaired. All of the seven caves are on parcels protected by the BCP. The high resiliency sites will require further assessment to determine if all needed criteria (e.g., drainage basin delineations, legally binding agreement for perpetual protection, and confirmation of species presence) are in place for recognition as karst fauna areas.

In summary, five cave clusters and six individual caves in the Jollyville Plateau Karst Fauna Region have the potential to support high or moderate resiliency Bone Cave harvestman populations given maintenance of current ecological conditions. The Balcones Canyonlands Preserve afford these sites some level of protection. Additional information is needed regarding those sites to determine if they qualify as karst fauna areas.



Austin Community College, County of Williamson, Texas Parks & Wildlife, Esri, HERE, Garmin, SafeGraph, METI/NASA, USGS, EPA, NPS, USDA

Figure 29. Current resiliency of Bone Cave harvestman caves and cave clusters in the Jollyville Plateau Karst Fauna Region.

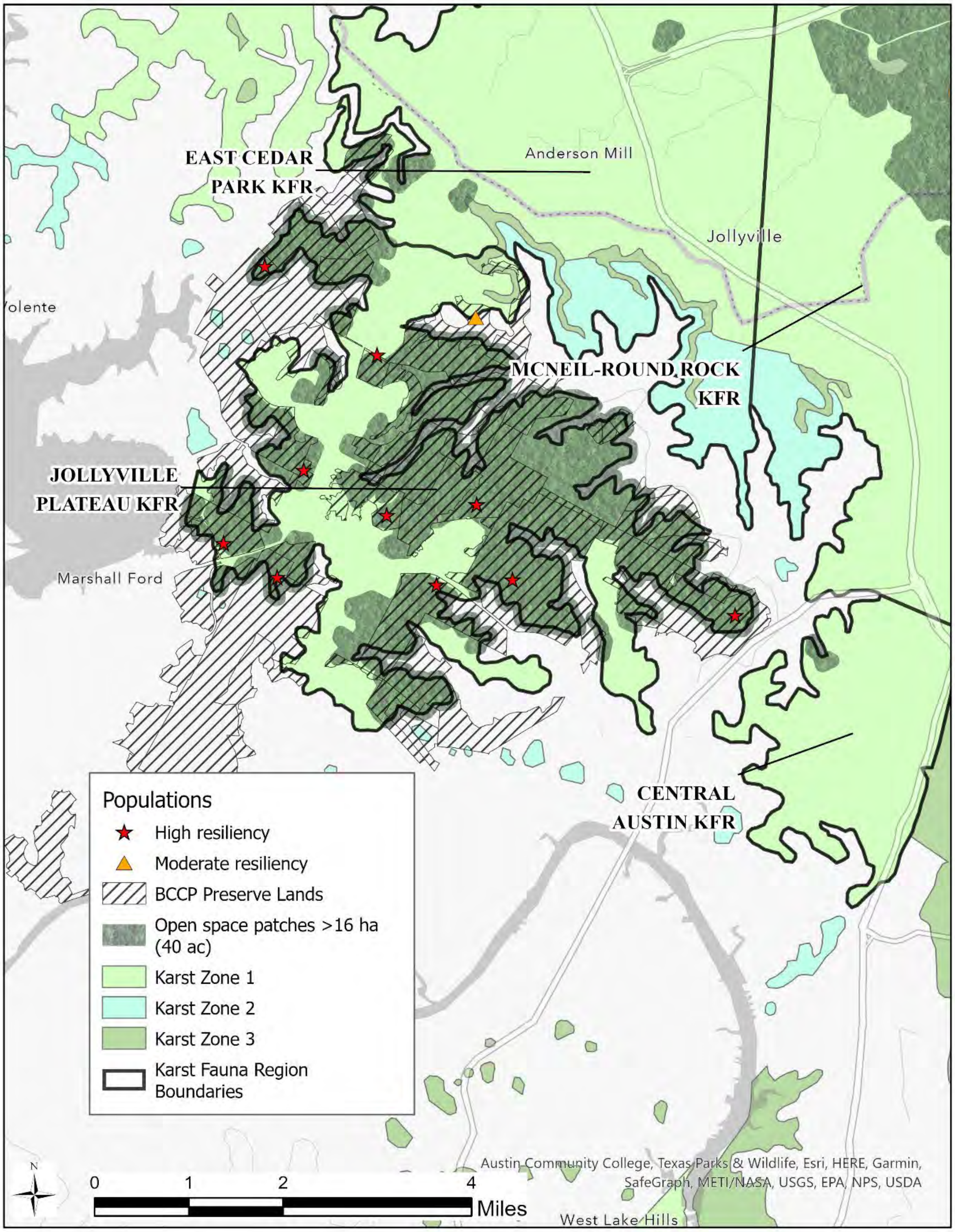


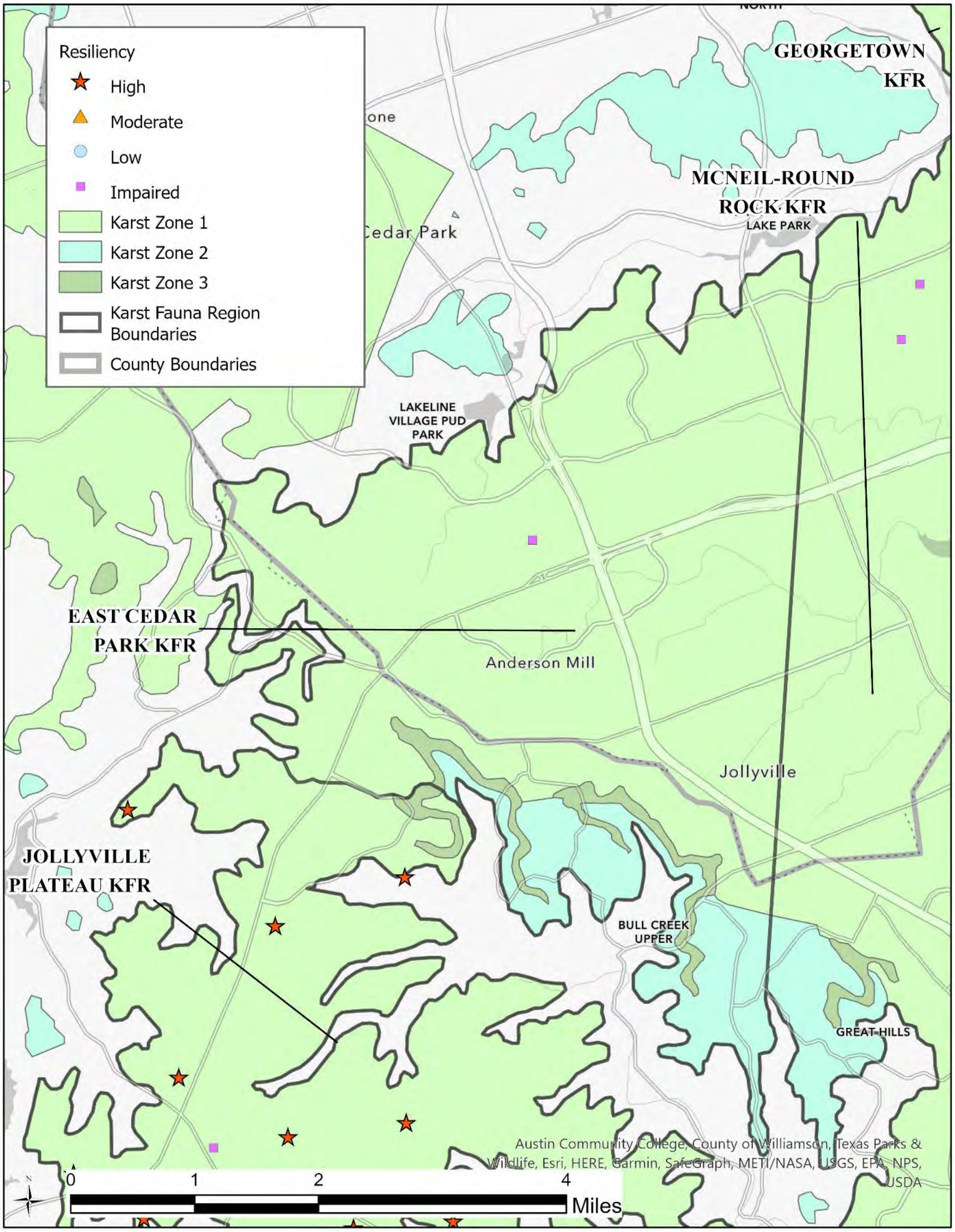
Figure 30. Areas protected through the Balcones Canyonlands Conservation Plan and patches of unimpacted habitat greater than 16 ha (40 ac) within the range of the Bone Cave harvestman in the Jollyville Plateau Karst Fauna Region.

10.6 Cedar Park and Central Austin Karst Fauna Regions

The East Cedar Park Karst Fauna Region encompasses 4,499 ha (11,118 ac) generally west of Parmer Lane and south of Brushy Creek Road in the City of Cedar Park (Figure 31). Karst Zones 1 and 2 cover all but 126 ha (312 ac) of this region. Approximately 4,211 ha (10,406 ac) of this area is within the modeled range for the Bone Cave harvestman. Over 80% of the Bone Cave harvestman range has been impacted by development (U.S. Geological Survey 2016). Of the remaining area, less than 10% (261 ha [646 ac]) occurs in patches greater than 16 ha (40 ac) (Figure 32). The Balcones Canyonlands Preserve provides protection for several large parcels in this region.

The Central Austin Karst Fauna Region encompasses 1,195 ha (2,952 ac) north of the Colorado River between North Capitol of Texas Highway and State Interstate Loop 1 in the City of Austin (Figure 33). This region represents the southern extent of the Bone Cave harvestman's range. The entire region is classified as Karst Zone 1 and within the modeled range of the Bone Cave harvestman (Veni and Jones 2021). Over 80 percent of this area has been impacted by human development and less than one percent occurs in patches greater than 16 ha (40 ac) (Figure 34). The Central Austin Karst Fauna Region is the most intensively urbanized of the six regions that contain the Bone Cave harvestman.

Only one impaired cave cluster exists in the Cedar Park Karst Fauna Region (i.e., Lakeline Cave and Underline Cave Cluster). Of the two caves that comprise this cluster, Lakeline Cave is impaired and Underline Cave was destroyed (Appendix B, Table 11). The Central Austin Karst Fauna Region also contains only one impaired cave cluster (i.e., Cotterell Cave and West Rim Cave Cluster). Human activities have affected the cave sites within that cluster resulting in their impaired status (Appendix B, Table 12). Cotterell Cave occurs on an 8 ha (20 ac) tract owned by the City of Austin but the cave is located near the southern edge of the property decreasing the distance of the cave entrance to edge. An adjacent residential development overlays a portion of the cave's subsurface drainage basin and has altered the cave cricket foraging area. West Rim Cave lays approximately 305 m (1,000 ft) to the northwest of Cotterell Cave on a 0.8 ha (2 ac) tract surrounded by development. A residential subdivision there impacts a significant portion of the cave cricket foraging area.



Austin Community College, County of Williamson, Texas Parks & Wildlife, Esri, HERE, Garmin, SafeGraph, METI/NASA, USGS, EPA, NPS, USDA

Figure 31. Current resiliency of Bone Cave harvestman caves and cave clusters in the East Cedar Park Karst Fauna Region.

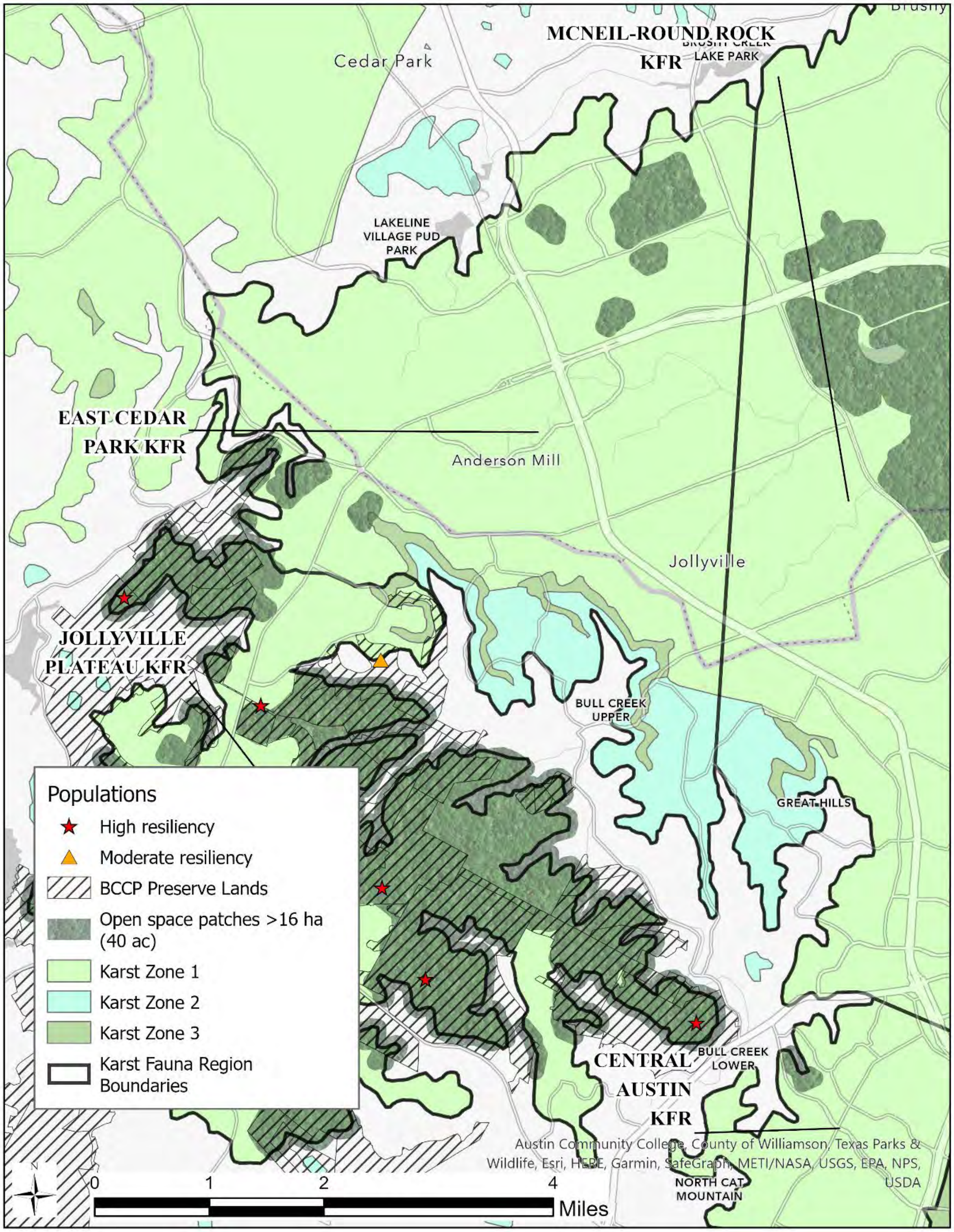


Figure 32. Areas protected through the Balcones Canyonlands Conservation Plan and patches of unimpacted habitat greater than 16 ha (40 ac) within the range of the Bone Cave harvestman in the East Cedar Park Karst Fauna Region.

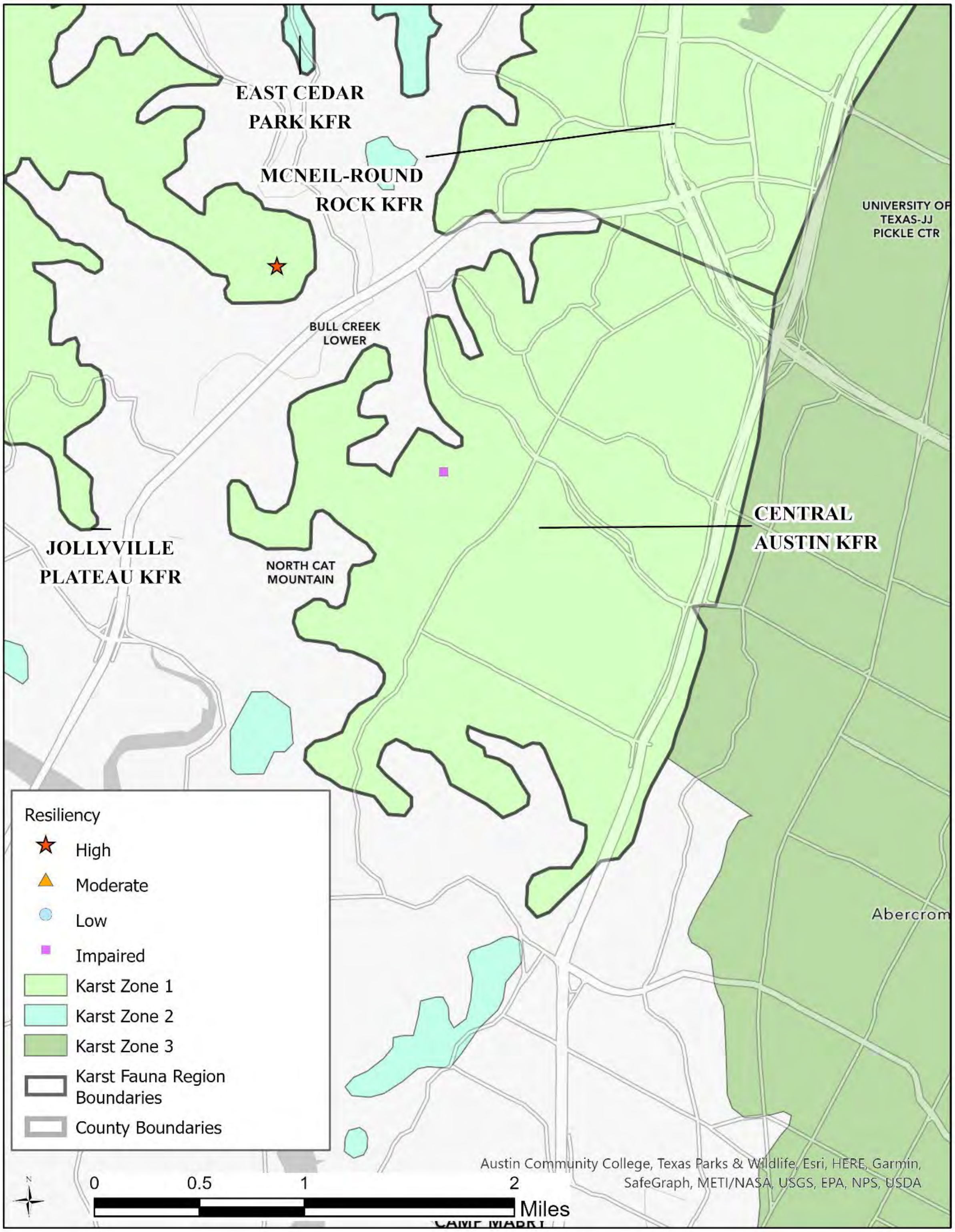


Figure 33. Current resiliency of Bone Cave harvestman caves and cave clusters in the Central Austin Karst Fauna Region.

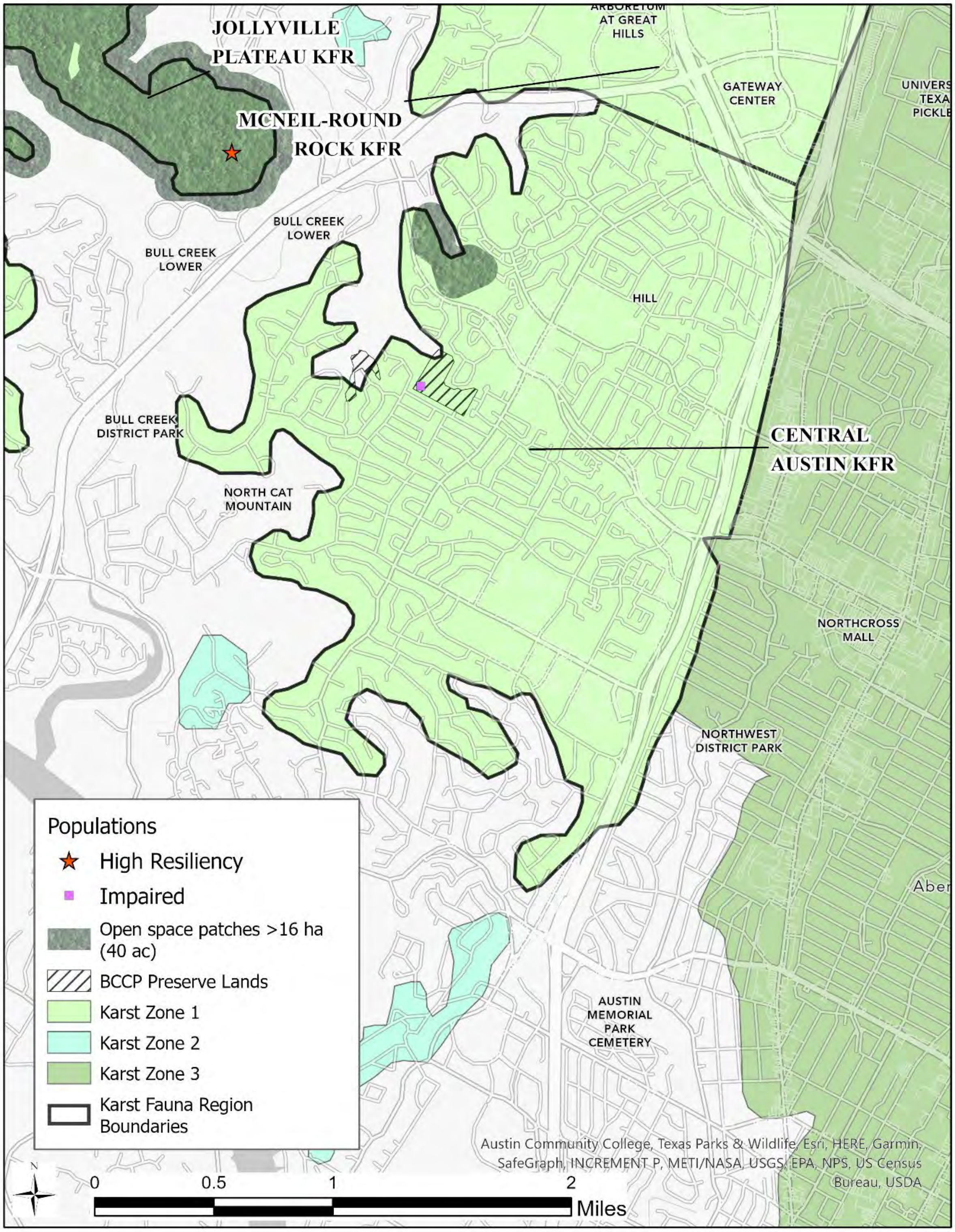


Figure 34. Areas protected through the Balcones Canyonlands Conservation Plan and patches of unimpacted habitat greater than 16 ha (40 ac) within the range of the Bone Cave harvestman in the East Cedar Park Karst Fauna Region.

10.7 Summary of Current Conditions

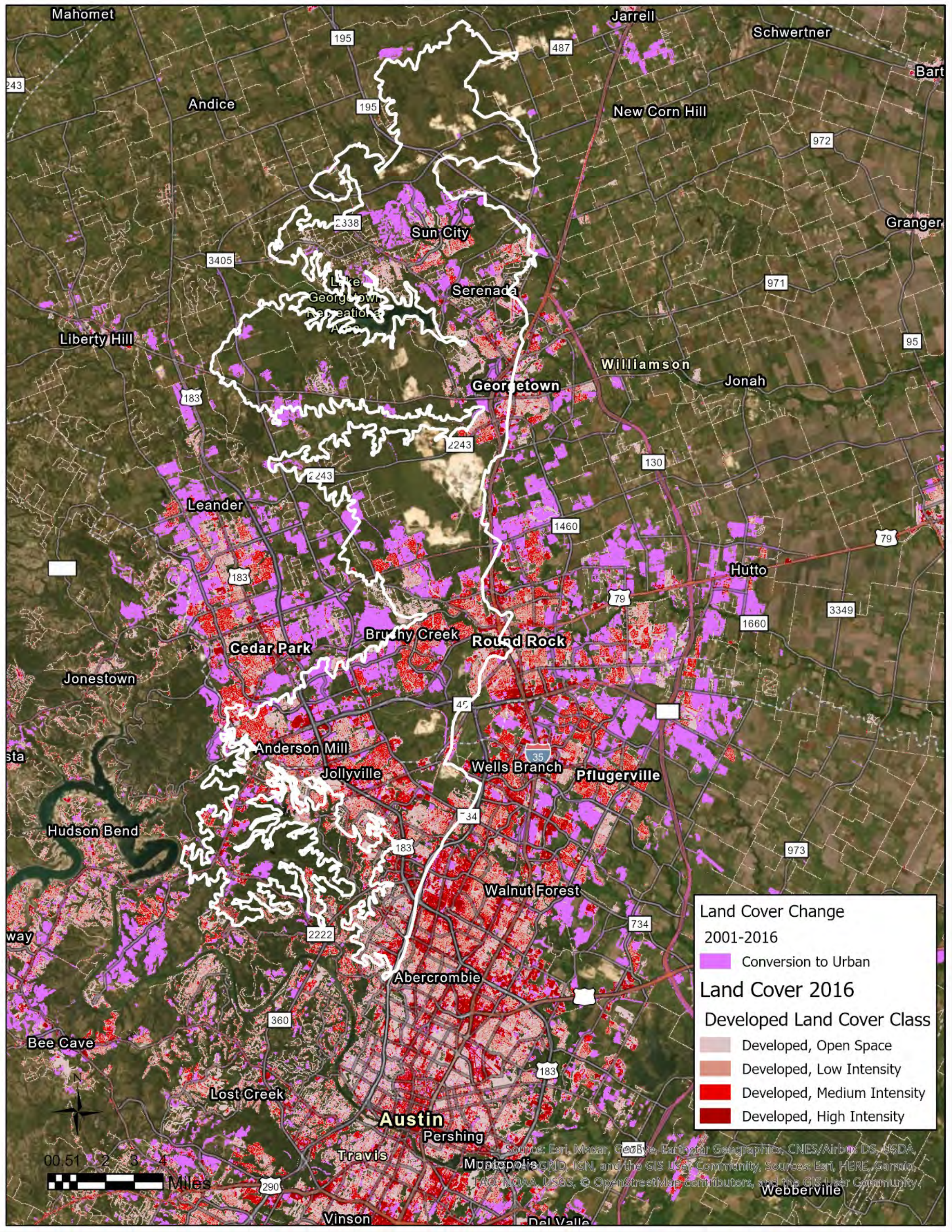
Our analyses (Table 5) indicate that 32 of the 77 extant Bone Cave harvestman cave clusters and individual cave sites are impaired. The majority of those 32 impaired sites fall below 3.6 ha (9 ac) in size and, due to degraded cave cricket foraging area, potential edge effects, and isolation from other 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 into the future. These sites are adjacent to commercial development, single and multi-family housing, and roadways that are unlikely to be restored to natural or semi-natural habitats. Six sites are 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, 38 of the 77 extant occupied sites range-wide have reduced potential for species persistence.

Based on our review, 39 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 on larger tracts of open space and have relatively unaltered cave cricket foraging areas. Four of these sites have permanent protection as karst fauna areas and three additional sites may be recognized as karst fauna areas as more information becomes available. Eleven sites within the Balcones Canyonlands Preserve may approximate karst fauna areas given further assessment. The remaining 21 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.

In the absence of perpetual protection, it is unlikely that the current resiliency of those unprotected sites can be maintained over the long-term given rapid human population growth and increasing development pressures. Urban, surburban, and exurban development is occurring at a rapid rate. Even over the short term (i.e., 2001-2016), sizeable areas of natural surface habitat have been converted to commercial and/or residential development (Figure 35). This development also continues to encroach on unprotected high to high to moderate resiliency sites.

Table 5. Current resiliency of Bone Cave harvestman sites (cave clusters and individual caves) by karst fauna region.

Karst Fauna Region	High	Moderate	Low	Impaired	Destroyed
North Williamson County	8	2	2	13	2
Georgetown	9	2	2	9	0
McNeil/Round Rock	5	2	2	6	0
Jollyville Plateau	9	2	0	2	0
Cedar Park	0	0	0	1	0
Central Austin	0	0	0	1	0
Total	31	8	6	32	2



Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community, Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community

Figure 35. Developed land cover in the Ausitn-Round Rock-Georgetown Metropolitan Area. Karst Zones 1 and 2 outlined in white.. Light purple indictes those areas converted to developed land cover between 2001-2016.

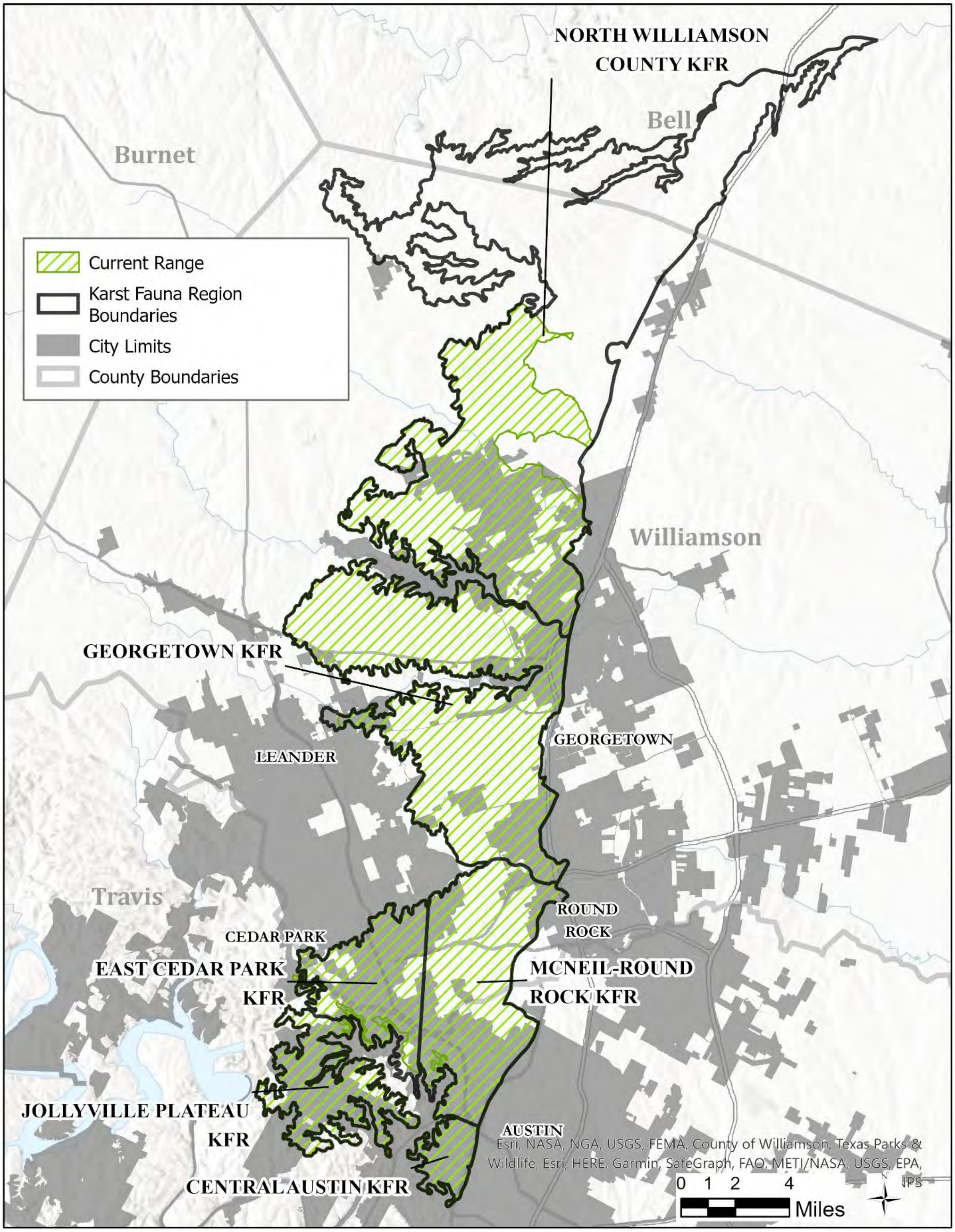
11.0 Projected Future Conditions

Almost 40% of the range of the Bone Cave harvestman occurs within the city limits of five central Texas cities (i.e. Austin, Cedar Park, Georgetown, Leander and Round Rock). Few of these sites have sufficient perpetual protections to shield them from stressors, particularly those associated with rapid urban, suburban, and exurban development (Figure 36). In addition, U.S. Census Bureau (2019a) estimates place the Austin-Round Rock-Georgetown, TX metropolitan area in the top 10 in the nation in numeric growth from 2010 to 2019 and the top five in percentage growth for the same period.

Projected human population growth estimates for both Travis and Williamson counties indicate substantial increases will continue over the next several decades. Population projections from the Texas Demographic Center (2018) estimate that Travis County, which was in the top ten counties in the U.S. in numeric growth from 2010 to 2019 according to the U.S. Census Bureau (2019b), will increase in population from a projected 1,317,306 people in 2021 to 1,980,918 people in 2050 (a 50% increase over the next 29 years). The City of Austin's population is expected to reach 1,372,843 people by 2050 (City of Austin 2020a), an increase of 34% over 29 years.

The Texas Demographic Center (2018) projects Williamson County to increase in population from 609,818 people in 2021 to 1,645,982 people in 2050 (a 169% increase over the next 29 years). The City of Georgetown's population is estimated to grow from a population of 77,436 in 2021 to between 89,006 and 110,064 people by 2030 (City of Georgetown 2021), an increase of between 15 and 42% over 11 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 31% over 9 years. Cedar Park is expected to reach 94,094 people by 2030 (City of Cedar Park 2017), an increase 11% of over 9 years.

Conversion of natural habitat to urban, suburban, and/or exurban development will accompany population growth. 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). Rapid population growth and development have already reduced surface habitats surrounding karst features occupied by the Bone Cave harvestman (City of Austin 2020c, pp. A-2-A-28). The Cedar Park and Central Austin Karst Fauna Regions exemplify this process, where construction and development has resulted in the destruction and degradation of surface habitats surrounding karst features. Without adequate planning and protection, this same process will likely occur in other portions of the species range as development efforts intensify in the McNeil/Round Rock, Georgetown, Jollyville Plateau, and North Williamson County Karst Fauna Regions.



Esri, NASA, NGA, USGS, FEMA, County of Williamson, Texas Parks & Wildlife, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS

Figure 36. Central Texas cities within Bone Cave harvestman current range.

We forecasted future resiliency, redundancy, and representation for the Bone Cave harvestman in each occupied karst fauna region under two potential scenarios. The scenarios evaluated two levels of conservation effort with Scenario 1 exploring a status quo conservation effort and Scenario 2 no additional conservation effort. These scenarios forecast viability of the species from the present to the year 2050 (Table 6; Figures 37-43), the end date for Travis and Williamson counties human population projections.

To predict potential future changes to open space patches related to urban growth, we added preliminary and platted roads from the City of Georgetown's streets layer into our neighborhood analysis. In addition, we used layers from the U.S. Geological Survey (2019) SLEUTH Urbanization 2020-2100 dataset to map future predicted changes in urbanization with an 80% probability by the year 2050.

In order to forecast future resiliency, we evaluated the extent of existing or in-progress residential and/or commercial development surrounding patches of open space using aerial imagery of each cave cluster and individual cave site. We also noted the proximity of existing roadways or in-progress roadway construction. Finally, we 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/exurban land uses.

While the potential exists for the discovery of additional Bone Cave harvestman populations in some karst fauna regions, we did not include projections for new populations in the development of scenarios. Identification of new populations is dependent on a number of variables including future survey effort, quantity and quality of available surface and subsurface habitat, and geological connectivity among others. Because we lack detailed information for most of those variables, estimates of new population discovery into the near future would be very uncertain. We based scenarios for the Bone Cave harvestman on known populations only.

We assumed perpetual protection of a site by an external party would take the form of a karst fauna area or other mechanisms with comparable levels of protection. Potential targets for protection under the 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 hinges on external parties implementing adequate permanent protections that maintain high and moderate resiliency sites. Assumptions for each scenario are as follows:

Scenario 1

- Human population growth continues to increase and development expands across the species' range.
- Future conservation efforts to protect and manage currently known, unprotected cave clusters and individual caves continues as in the past.
- Some additional protected areas are established. Open space surrounding most unprotected high and moderate resiliency cave cluster and individual caves converts to development and degrades in quality.

- Management and protection of current and proposed karst fauna areas is adequate and perpetual.
- Open space surrounding karst fauna areas converts to development, with some sites declining in resiliency.

Scenario 2

- Human population growth continues to increase and development expands across the species' range.
- There is no additional conservation effort to protect and manage currently known, unprotected cave clusters and individual caves for Bone Cave harvestman.
- No additional protected areas are established. Open space surrounding most unprotected high and moderate resiliency cave clusters and individual caves converts to development and degrades in quality.
- Management and protection of current karst fauna areas is adequate and perpetual.
- Open space surrounding karst fauna areas converts to development, with some sites declining in resiliency.

Table 6. Number of high and moderate resiliency sites by scenario for each karst fauna region by 2050.

			Scenario 1 Status Quo Effort		Scenario 2 No Effort	
Karst Fauna Region	**Current Number of Sites[a] H/M (Total)**	**Current Karst Fauna Areas[b]**	**High Resiliency**	**Moderate Resiliency**	**High Resiliency**	**Moderate Resiliency**
North Williamson County	10 (25)	4	3	3	2	4
Georgetown	11 (22)	0	1	3	1	1
McNeil/ Round Rock	7 (15)	0	1	2	0	0
Jollyville Plateau	11 (13)	1	7	2	7	2
Cedar Park	0 (1)	0	0	0	0	0
Central Austin	0 (1)	0	0	0	0	0

[a] Total number of high and moderate sites (H/M) and total number (Total) of high, moderate, low resiliency, and impaired sites.

[b] Number of Service recognized karst fauna areas in perpetual protection.

11.1 Scenario 1

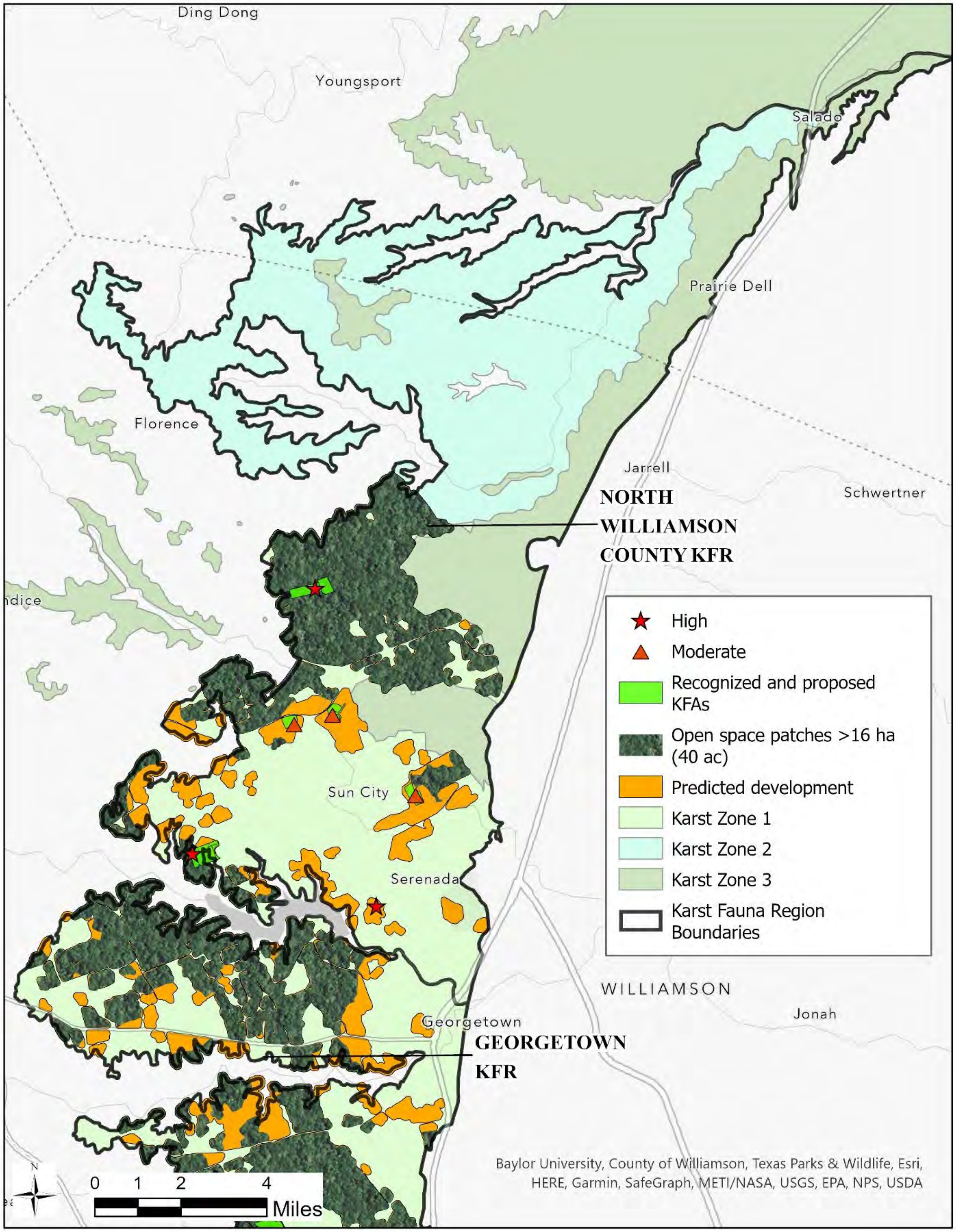
North Williamson County Karst Fauna Region: The four currently recognized karst fauna areas established in the North Williamson County Karst Fauna Region continue to provide permanent protection for the Bone Cave harvestman and a fifth proposed karst fauna area is protected (Figure 37). No other karst fauna areas are established in the region. Perpetual protection of these karst fauna areas provides stable surface and subsurface habitats the species requires for survival and persistence. As development proceeds, three karst fauna areas decline in resiliency from high to moderate. Four of the five remaining unprotected sites degrade to low resiliency or become impaired due to development activities. Ultimately, three high resiliency and three moderate resiliency sites persist in this region.

Georgetown Karst Fauna Region: Two currently proposed karst fauna areas are recognized and permanently protected in the Georgetown Karst Fauna Region; however, one declines in resiliency from high to moderate as development proceeds nearby (Figure 38). In addition, one moderate resiliency population is protected through Habitat Conservation Plans or other mechanisms leading to a third karst fauna area being protected. One site remains undeveloped through 2050 but declines in resiliency. The remaining unprotected high and moderate resiliency sites degrade in quality to low or impaired due to development activities. One high resiliency and three moderate resiliency sites persist in this region.

McNeil/Round Rock Karst Fauna Region: Three sites are proposed and permanently protected as karst fauna areas in the McNeil/Round Rock Karst Fauna Region as a result of Habitat Conservation Plans or other mechanisms (Figure 39). Perpetual protection of these karst fauna areas provides stable surface and subsurface habitats the species requires for survival and persistence. However, encroaching development may lead to these karst fauna areas declining from high to moderate resiliency. The remaining four unprotected high to moderate resiliency sites degrade in quality to impaired or are destroyed due to development activities. Ultimately, one high and two moderate resiliency sites persist in this region.

Jollyville Plateau Karst Fauna Region: Eight high to moderate resiliency cave cluster and cave sites protected within the Balcones Canyonlands Preserve meet the requirements for recognition as karst fauna areas (Figure 40). Perpetual protection of these eight sites as karst fauna areas provides stable surface and subsurface habitats the species requires for survival and persistence although three cave cluster or individual cave sites may decline in resiliency due to development activities nearby. Two high and one moderate resiliency sites are also protected from development pressure within the preserves. As a result, seven high resiliency and four moderate resiliency sites persist in this region.

Cedar Park and Central Austin Karst Fauna Regions: There are no high or moderate resiliency sites in either the Cedar Park or Central Austin Karst Fauna Regions. Only two impaired sites are known to contain Bone Cave harvestmen in these regions. We anticipate that the effects of urbanization, habitat fragmentation, and other stressors will continue to degrade these sites.



Baylor University, County of Williamson, Texas Parks & Wildlife, Esri, HERE, Garmin, SafeGraph, METI/NASA, USGS, EPA, NPS, USDA

Figure 37. Scenario 1 for Bone Cave harvestman caves and cave clusters in the North Williamson County Karst Fauna Region.

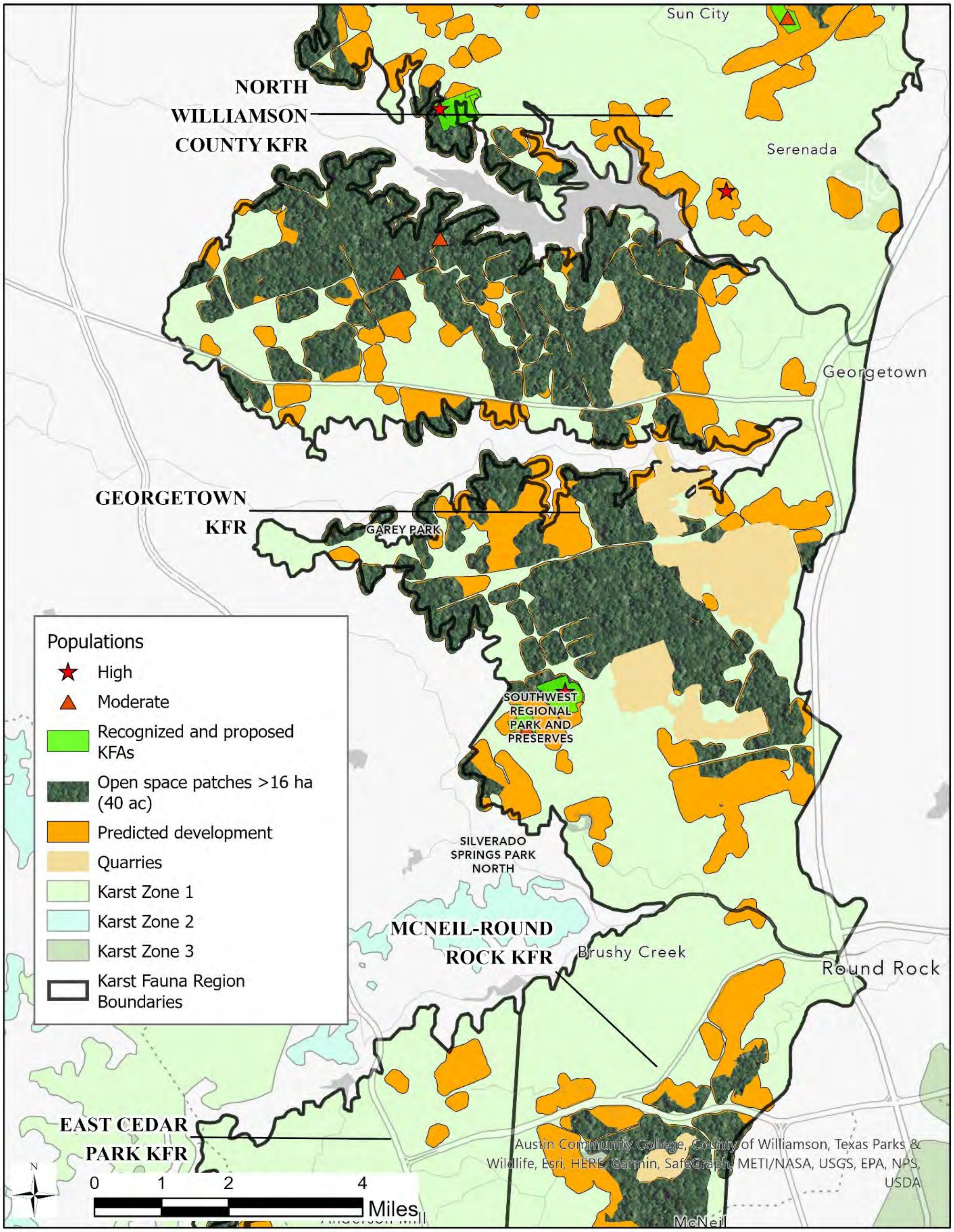


Figure 38. Scenario 1 for Bone Cave harvestman caves and cave clusters in the Georgetown Karst Fauna Region.

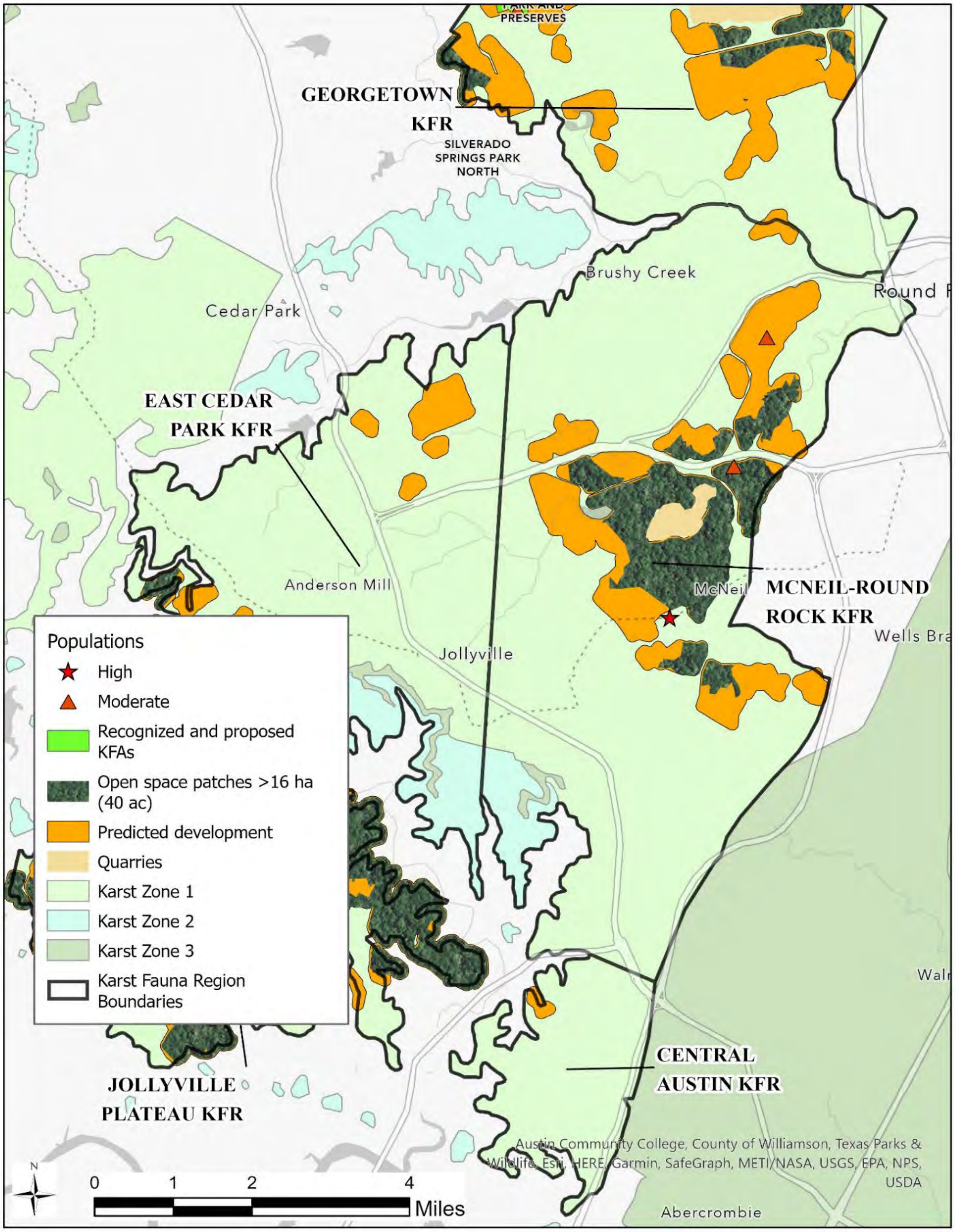
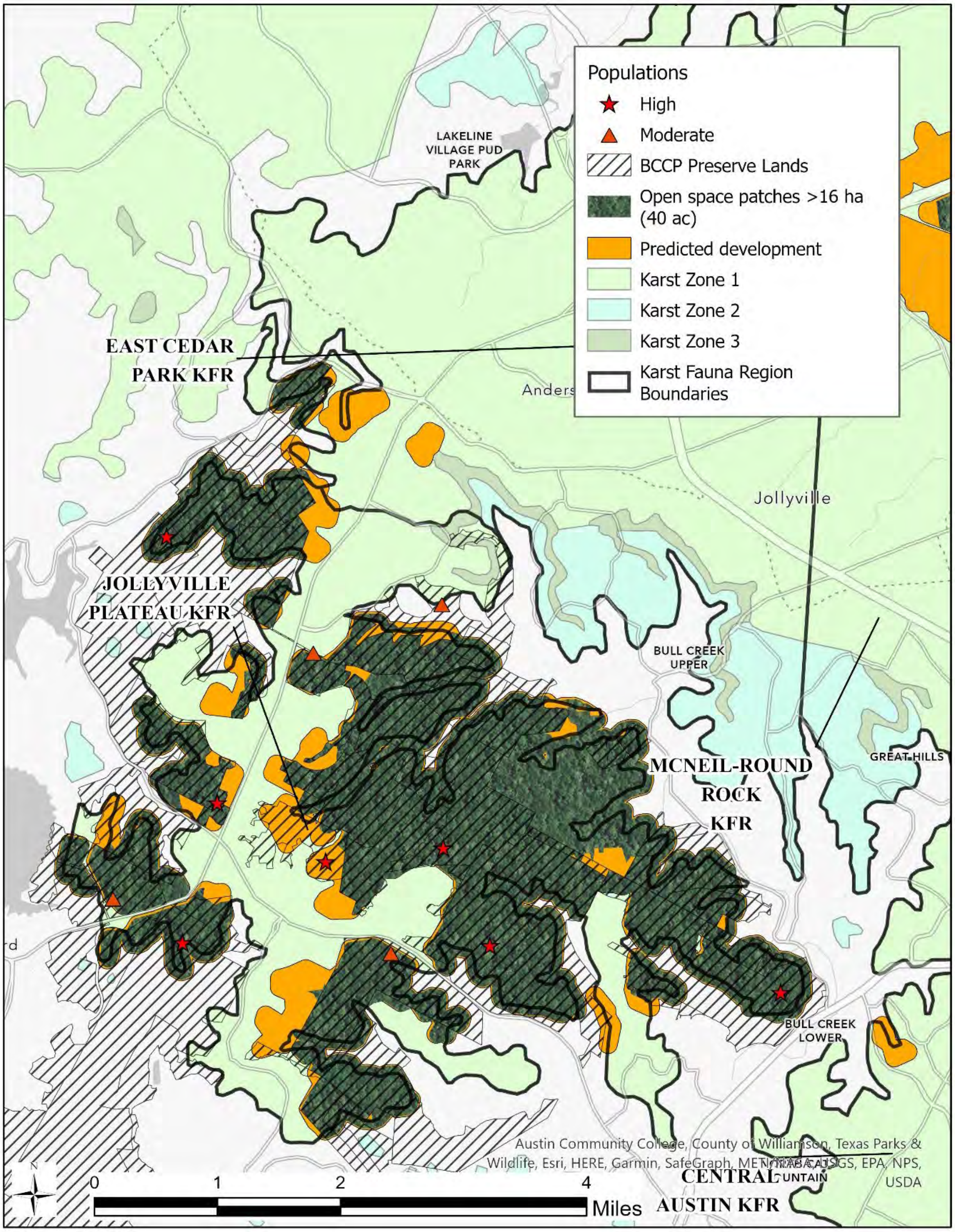


Figure 39. Scenario 1 for Bone Cave harvestman caves and cave clusters in the McNeil-Round Rock Karst Fauna Region.



Austin Community College, County of Williamson, Texas Parks & Wildlife, Esri, HERE, Garmin, SafeGraph, METI/NASA, USGS, EPA, NPS, USDA

Figure 40. Scenario 1 for Bone Cave harvestman caves and cave clusters in the Jollyville Plateau Karst Fauna Region.

11.2 Scenario 2

North Williamson County Karst Fauna Region: The four currently recognized karst fauna areas established in the North Williamson County Karst Fauna Region continue to provide permanent protection for the Bone Cave harvestman. No other karst fauna areas are established in the region. Perpetual protection of these karst fauna areas provides stable surface and subsurface habitats the species requires for survival and persistence. As development proceeds, four karst fauna areas decline in resiliency from high to moderate. Four of the five remaining unprotected sites degrade to low resiliency, become impaired, or are destroyed due to development activities. One remaining site is within a protected preserve established as mitigation for a habitat conservation plan. No further effort is expended to designate that site as a karst fauna area. Ultimately, two high resiliency and four moderate resiliency sites may persist in this region (Figure 41).

Georgetown Karst Fauna Region: Two currently proposed karst fauna areas are recognized and permanently protected in the Georgetown Karst Fauna Region; however, one declines in resiliency from high to moderate as development proceeds nearby (Figure 42). The remaining unprotected high and moderate resiliency sites degrade in quality to impaired due to development activities.

McNeil/Round Rock Karst Fauna Region: High to moderate resiliency cave cluster and individual cave sites in this region lack protection from development or land conversion. Most sites are located in areas with development and are susceptible to destruction or the ecological impacts of surrounding urbanization. Development activities degrade or impair habitat quality of these unprotected sites to the point that overall resiliency is reduced or lost. No high or moderate resiliency sites persist in this region.

Jollyville Plateau Karst Fauna Region: Eight high to moderate resiliency cave cluster and cave sites protected within the Balcones Canyonlands Preserve meet the requirements for recognition as karst fauna areas (Figure 43). Perpetual protection of these eight sites as karst fauna areas provides stable surface and subsurface habitats the species requires for survival and persistence although three cave cluster or individual cave sites may decline in resiliency due to development activities nearby. Two high and one moderate resiliency sites are also protected from development pressure within the preserves. As a result, seven high resiliency and four moderate resiliency sites persist in this region.

Cedar Park and Central Austin Karst Fauna Regions: There are no high or moderate resiliency sites in either the Cedar Park or Central Austin Karst Fauna Regions. Only two impaired sites are known to contain Bone Cave harvestmen in these regions. We anticipate that the effects of urbanization, habitat fragmentation, and other stressors will continue to degrade these sites.

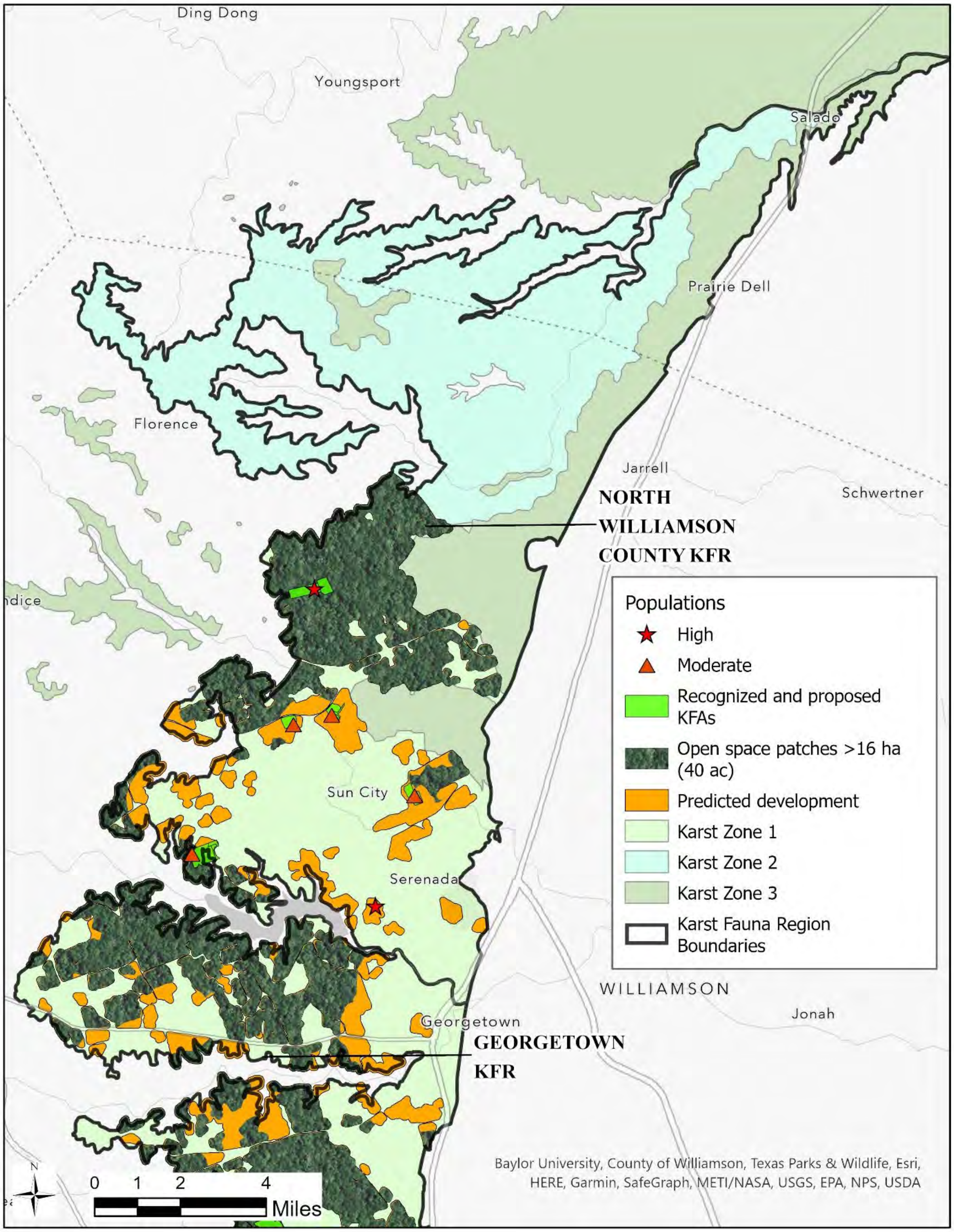


Figure 41. Scenario 2 for Bone Cave harvestman caves and cave clusters in the North Williamson County Karst Fauna Region.

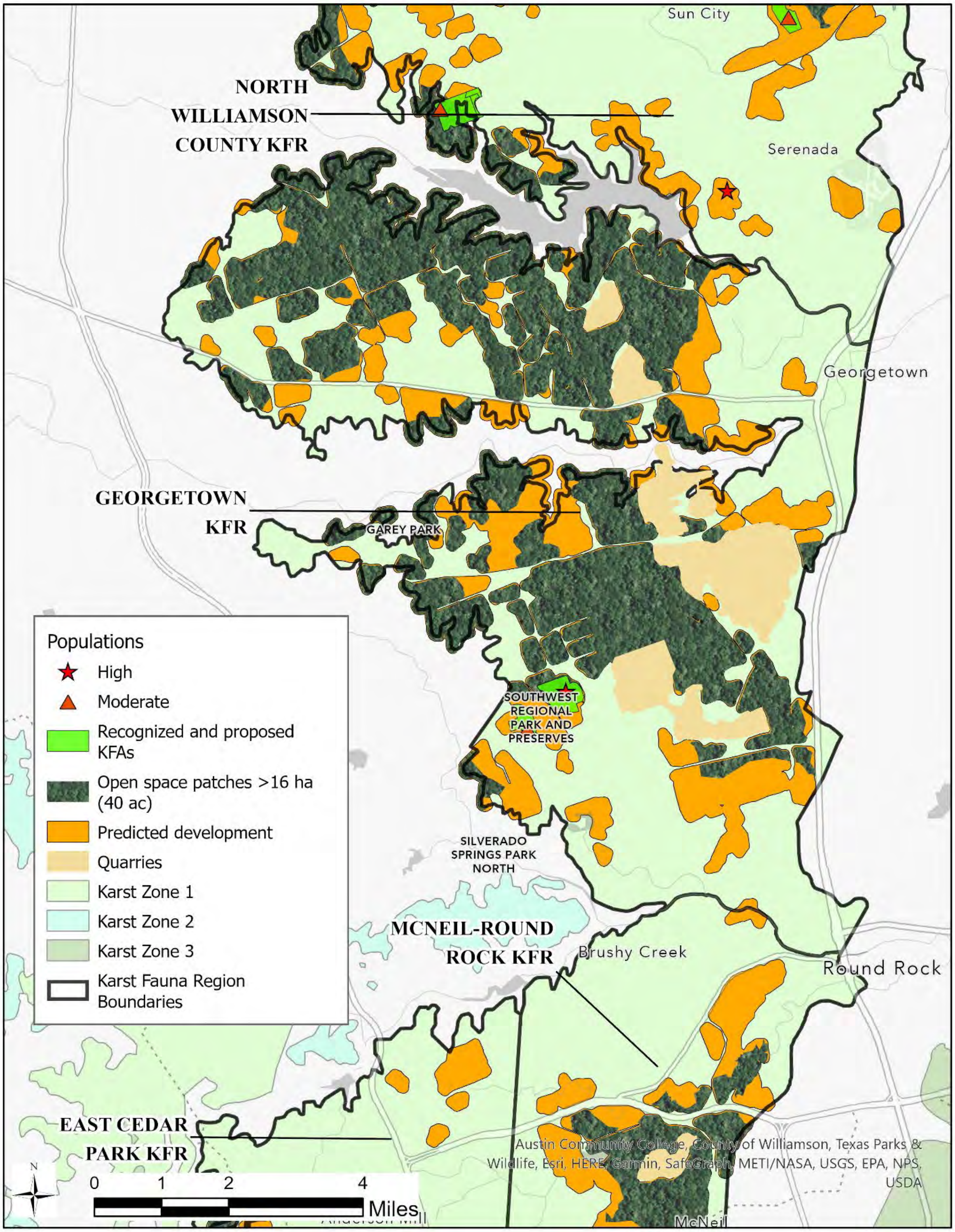


Figure 42. Scenario 2 for Bone Cave harvestman caves and cave clusters in the Georgetown Karst Fauna Region.

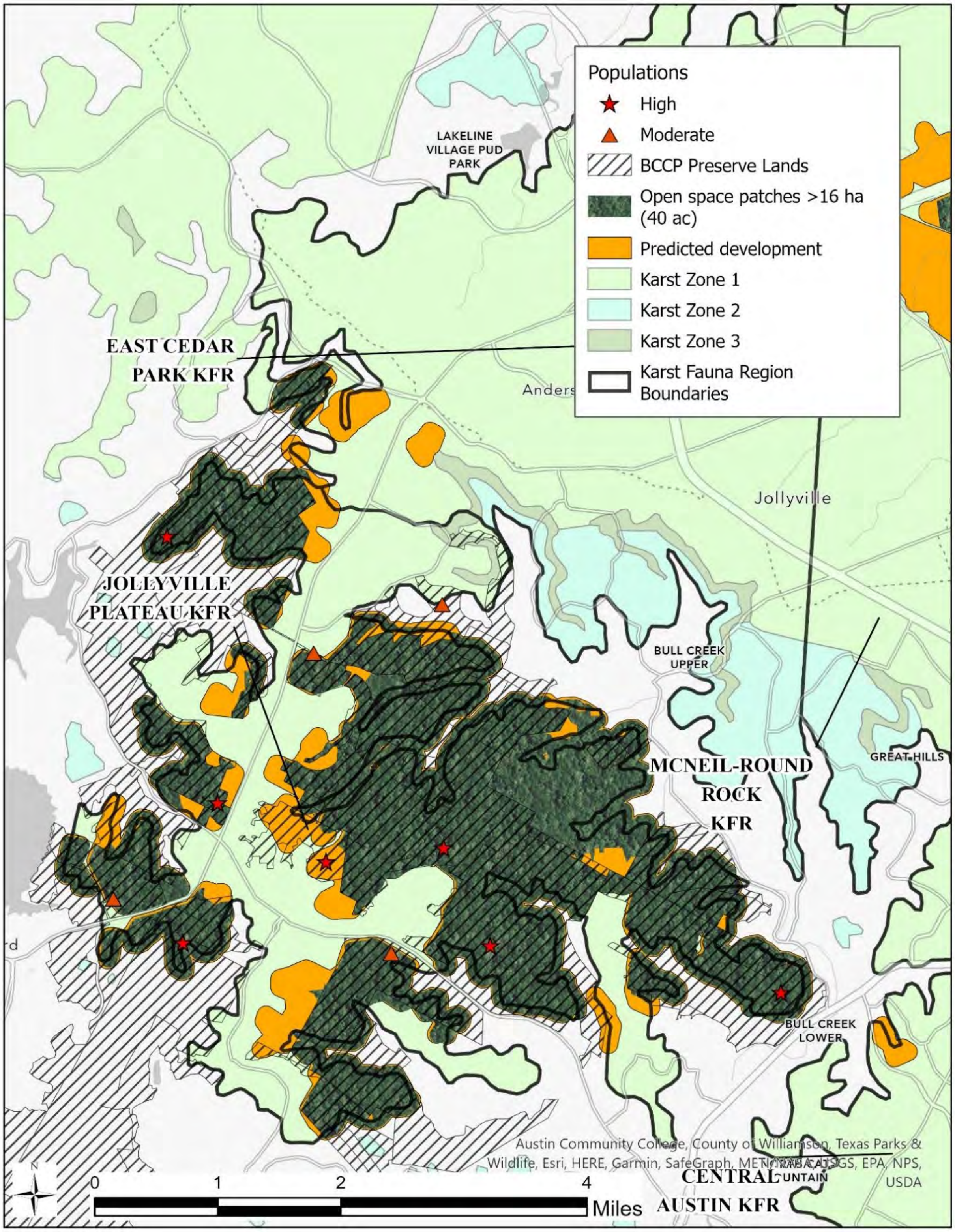


Figure 43. Scenario 2 for Bone Cave harvestman caves and cave clusters in the Jollyville Plateau Karst Fauna Region.

Summary

The Bone Cave harvestman occurs at 77 cave clusters and individual caves in Travis and Williamson counties. Of that total, 38 sites are low resiliency or impaired. Urban, suburban, and exurban development in the rapidly growing Austin-Round Rock metropolitan area has resulted in significant loss and degradation of surface and subsurface habitats and is an ongoing stressor for the species. Open space with native vegetation has been reduced at low resiliency and impaired sites with tracts fragmented and isolated from one another. These sites may be unable to support viable populations of the Bone Cave harvestman over the long-term. Human activity has destroyed 13 caves that contained the Bone Cave harvestman.

There are currently 39 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.

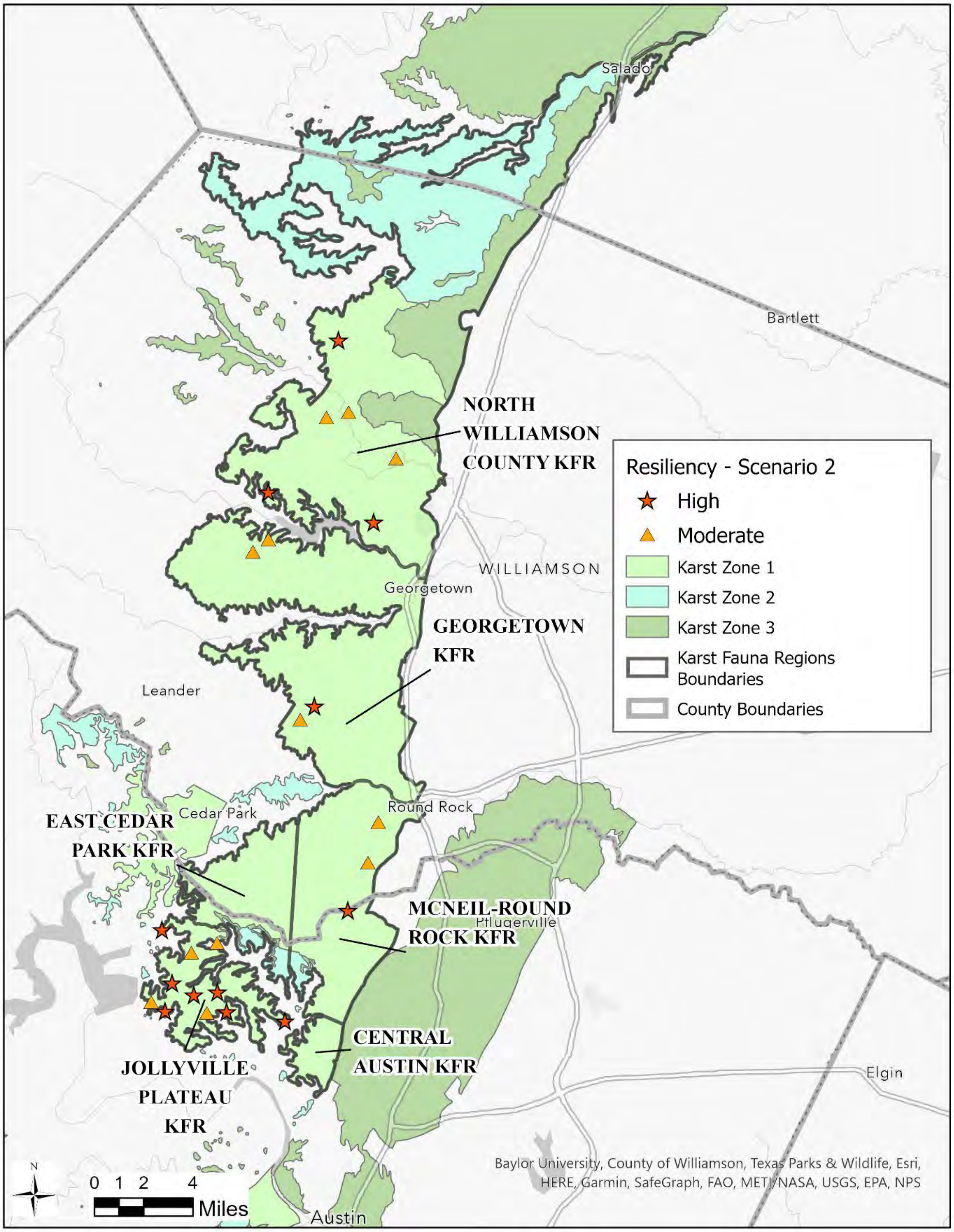
Projections indicate that the combined human population of the Travis and Williamson county area will grow from 1,927,124 people in 2021 to 3,626,900 people in 2050, an increase of 88% over 29 years (Texas Demographic Center 2018). Percentage of urbanized land in Travis County is projected to increase 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). 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 sites over time.

Only a few high to moderate resiliency sites currently have adequate protections in place to shield them from stressors associated with rapid urban, suburban, and exurban development. Of the 39 high to moderate resiliency sites that exist across the Bone Cave harvestman's range, 15 cave clusters or individual caves possess protections as karst fauna areas or as components of the Balcones Canyonlands Preserve. Sites protected within the Balcones Canyonlands Preserve may not provide protections equivelant to karst fauna area criteria and guidelines, however. Three additional sites are also proposed as potential karst fauna areas. Distribution of the 13 currently protected cave clusters and individual caves does not adequately capture Bone Cave harvest representation across the species' range. Protection of representative sites within each occupied karst fauna region is important given the north to south morphological variation in Bone Cave harvestman populations.

Currently, four protected areas are located at the northern extent of the species range in the North Williamson County Karst Fauna Region, with the remaining eleven sites clustered in the southwestern portion of the Bone Cave harvestman's range in the Jollyville Plateau Karst Fauna Region. Two karst fauna areas proposed for the Georgetown Karst Fauna Region would provide redundancy and representation in that region provided they are finalized. Increasing the number of high to moderate resiliency protected sites in the Georgetown Karst Fauna Region would augment Bone Cave Harvestman population redundancy there. The McNeil/Round Rock Karst Fauna Region, roughly in the center of the species range, currently lacks any high to moderate resiliency protected sites that provide representation for that region into the future. Absence of representation and redundancy there reduces the probability of Bone Cave harvestman persistence given the potential for increased development. Widespread urbanization has resulted in the loss of high to moderate resiliency sites in the Cedar Park and Central Austin Karst Fauna Region.

Forecasts of future resiliency, redundancy, and representation underscore the critical role adequate habitat protection will play in securing long-term persistence of Bone Cave harvestman populations. Economic demand for converting natural open space to development is high in the Austin-Round Rock-Georgetown metropolitan area and that demand is only expected to increase in response to a growing human population. Scenarios 1, 2, and 3 forecast persistence of sites occupied by the Bone Cave harvestman into the future. Only high and moderate resiliency sites were considered suitable targets for protection under these scenarios as these areas offer the greatest potential for Bone Cave harvestman long-term persistence.

Under Scenario 1, development activities and lack of protection degrades resiliency in the North Williamson County Karst Fauna Region to three high and three moderate resiliency sites (Figure 44). Most sites in the Jollyville Plateau Karst Fauna Region continue to benefit from protection within the Balcones Canyonlands Preserve, with seven high and four moderate resiliency sites remaining in this region. The Georgetown Karst Fauna Region continues to support one high and three moderate resiliency sites. All but one high and two moderate resiliency sites in the McNeil/Round Rock Karst Fauna Region decline in quality to low resiliency or impaired due to 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 still probable in four of the six karst fauna regions however the likelihood of species persistence is higher in the Jollyville Plateau and North Williamson County Karst Fauna Regions, the southwestern and northern limits of the species range, respectively. Development pressure in the Georgetown Karst Fauna Region reduces resiliency of current populations with one high and three moderate populations persisting, only two of which possess long term protections. Species representation may be maintained in the center part of the range with a potential for one high and two moderate resiliency populations in the McNeil/Round Rock Karst Fauna Area provided protections can be put in place before development affects the remaining sites. No high and moderate resiliency sites exist in either the Cedar Park or Central Austin Karst Fauna Regions.



Baylor University, County of Williamson, Texas Parks & Wildlife, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS

Figure 44. Predicted future resiliency under Scenario 1.

Under Scenario 2, development activities and lack of protection degrades resiliency in the North Williamson County Karst Fauna Region to two high and four moderate resiliency sites by 2050. Most sites in the Jollyville Plateau Karst Fauna Region continue to benefit from protection within the Balcones Canyonlands Preserve, with seven high and four 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, however one high and one moderate resiliency population may be maintained. 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, and McNeil/Round Rock Karst Fauna Regions and significantly reduced in the Georgetown Karst Fauna Region (Figure 45).

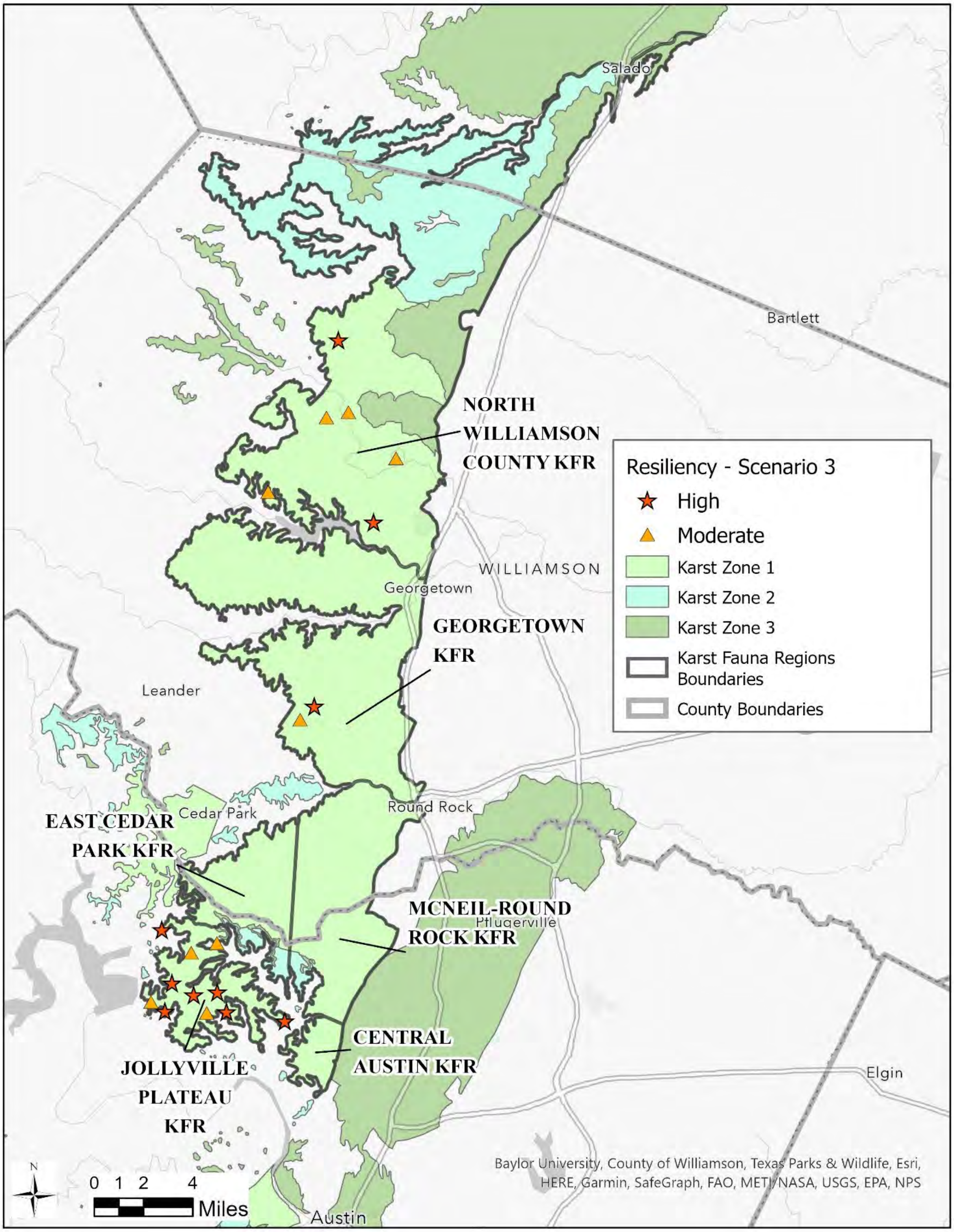


Figure 45. Predicted future resiliency under Scenario 2.

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Appendix: Tables

Table 7. Resiliency of Bone Cave harvestman cave clusters and individual caves in the North Williamson County Karst Fauna Region.

North Williamson County Karst Fauna Region						
Cave Cluster or Individual Cave	**Open Space Area ha (ac)**	**Area Perpetually Protected ha (ac)**	**Distance of Cave Entrance to Nearest Edge m (ft)**	**Percent of Cave Cricket Foraging Area Impacted**	**Current Resiliency**	**Occupancy Confidence**
Cave Clusters						
Georgetown Village Cave Cluster					**High**	
Dewalt's Cave[1]	>40 (>100)	0	>120 (<394)	0%	High	Confirmed (Male)
F-2 (Georgetown Village) [1]	>40 (>100)	0	<120 (<394)	0-25%	Moderate	Confirmed (Male)
Little Surprise Cave[1]	3.6-16 (9-40)	0	<120 (<394)	51-75%	Impaired	Confirmed (Male)
Newman's Own Cave[1]	>40 (>100)	0	<120 (>394)	0-25%	Moderate	Confirmed (Male)
Tanner's Cave[1]	>40 (>100)	0	<120 (<394)	0-25%	Moderate	Confirmed (Male)
Texella Rockslide Cave[1]	>40 (>100)	0	<120 (>394)	0-25%	Moderate	Confirmed (Male)

North Williamson County Karst Fauna Region						
Cave Cluster or Individual Cave	**Open Space Area ha (ac)**	**Area Perpetually Protected ha (ac)**	**Distance of Cave Entrance to Nearest Edge m (ft)**	**Percent of Cave Cricket Foraging Area Impacted**	**Current Resiliency**	**Occupancy Confidence**
Godwin Ranch Cave Cluster					**High**	
Red Crevice Cave	>40 (>100)	106[a]	>120 (>394)	0%	High	Confirmed (Juvenile)
Temples of Thor Cave	>40 (>100)	106[a]	>120 (>394)	0%	High	Confirmed (Male)
Karankawa Cluster					**High**	
Karankawa Cave	>40 (>100)	62	>120 (>394)	0%	High	Confirmed (Male)
Polaris Cave	>40 (>100)	62	>120 (>394)	0%	High	Confirmed (Female)
Prairie Flats Cave[5]	>40 (>100)	0	<120 (<394)	0-25%	Moderate	Sight Record
War Party Cave	>40 (>100)	62	>120 (>394)	0%	High	Confirmed (Female, juvenile)

North Williamson County Karst Fauna Region						
Cave Cluster or Individual Cave	**Open Space Area ha (ac)**	**Area Perpetually Protected ha (ac)**	**Distance of Cave Entrance to Nearest Edge m (ft)**	**Percent of Cave Cricket Foraging Area Impacted**	**Current Resiliency**	**Occupancy Confidence**
Priscilla's Well Cluster					**High**	
Choctaw Cave[3]	>40 (>100)	0	<120 (<394)	26-50%	Low[4]	Confirmed (Juvenile)
Priscilla's Cave	>40 (>100)	51	>120 (<394)	0%	High[4]	Confirmed (Juvenile)
Priscilla's Well Cave	>40 (>100)	51	>120 (>394)	0%	High	Confirmed (Female)
Shaman Karst Preserve					**High**	
Pow Wow Cave	>40 (>100)	75[b]	>120 (>394)	0%	High	Confirmed (Juvenile)
Shaman Cave	>40 (>100)	75[b]	>120 (>394)	0%	High	Confirmed (Male)
Ute Cave Cluster					**Moderate**[6]	
Apache Cave	<3.6 (<9)	5.5[c]	<120 (<394)	26-50%	Impaired	Confirmed (Juvenile)
Deliverance No. 1 Cave	16-40 (40-100)	0	<120 (<394)	0-25%	Low	Confirmed (Male)

North Williamson County Karst Fauna Region

Cave Cluster or Individual Cave	Open Space Area ha (ac)	Area Perpetually Protected ha (ac)	Distance of Cave Entrance to Nearest Edge m (ft)	Percent of Cave Cricket Foraging Area Impacted	Current Resiliency	Occupancy Confidence
Deliverance No. 2 Cave	16-40 (40-100)	0	<120 (<394)	0-25%	Low	Confirmed (Female)
Do Drop In Cave	16-40 (40-100)	0	<120 (>394)	0-25%	Low[4]	Confirmed (Male)
Dragonfly Cave	16-40 (40-100)	0	<120 (<394)	0-25%	Low	Confirmed (Male)
Trail of Tears Cave	16-40 (40-100)	0	<120 (<394)	0-25%	Low	Sight Record
Turner Goat Cave	16-40 (40-100)	0	<120 (<394)	0-25%	Low[4]	Confirmed (Juvenile)
Unearthed Cave	>40 (>100)	0	<120 (>394)	0-25%	Moderate[4]	Confirmed (Female, juvenile)
Ute Cave	>40 (>100)	0	<120 (>394)	0%	Moderate[4]	Confirmed (Female, juvenile)
Venom Cave	>40 (>100)	0	<120 (<394)	0-25%	Moderate[4]	Confirmed (Male)
Woodruff's Well Cave	<3.6 (<9)	0	<120 (<394)	76-100%	Impaired	Confirmed (Juvenile)

North Williamson County Karst Fauna Region

Cave Cluster or Individual Cave	Open Space Area ha (ac)	Area Perpetually Protected ha (ac)	Distance of Cave Entrance to Nearest Edge m (ft)	Percent of Cave Cricket Foraging Area Impacted	Current Resiliency	Occupancy Confidence
You Dig It Cave	16-40 (40-100)	0	<120 (<394)	26-50%	Impaired[7]	Confirmed (Juvenile)
Jack Frost Elementary Cave Cluster					**Impaired**	
Abused Cave	<3.6 (<9)	0	<120 (<394)	76-100%	Impaired	Confirmed (Female)
Williams Cave No. 1	<3.6 (<9)	0	<120 (<394)	26-50%	Impaired	Confirmed (Female)
Kiva Cave No. 1 and Yellow Hand Cave Cluster					**Impaired**	
Kiva Cave No. 1	<3.6 (<9)	0	<120 (<394)	50-75%	Impaired	Confirmed (Female, juvenile)
Yellow Hand Cave	<3.6 (<9)	0	<120 (<394)	51-75%	Impaired	Confirmed (Female, juvenile)
SH 195 Cave Cluster					**Impaired**	
Buzzard Feather Cave	3.6-16 (9-40)	0	<120 (<394)	0-25%	Impaired	Confirmed (Male)
Cobb Drain Cave	3.6-16 (9-40)	0	<120 (<394)	51-75%	Impaired	Confirmed (Juvenile)

North Williamson County Karst Fauna Region

Cave Cluster or Individual Cave	Open Space Area ha (ac)	Area Perpetually Protected ha (ac)	Distance of Cave Entrance to Nearest Edge m (ft)	Percent of Cave Cricket Foraging Area Impacted	Current Resiliency	Occupancy Confidence
Coke Box Cave	3.6-16 (9-40)	0	<120 (<394)	51-75%	Impaired	Confirmed (Juvenile)
Corn Cobb Cave	<3.6 (<9)	0	<120 (<394)	51-75%	Destroyed[7]	Unconfirmed
Hourglass Cave	3.6-16 (9-40)	0	<120 (<394)	26-50%	Impaired	Confirmed (Male)
Rattlesnake Inn Cave	3.6-16 (9-40)	0	<120 (<394)	0-25%	Impaired	Confirmed (Juvenile)
Individual Caves						
Blowhole Cave[2]	>40 (>100)	0	>120 (>394)	0%	High	Confirmed (Genetics)
Cobbs Cavern	>40 (>100)	163	>120 (>394)	0%	High	Confirmed (Unknown specimen)
Whitney West Cave[5]	>40 (>100)	172	>120 (>394)	0%	High	Confirmed (Unknown specimen)
Willow the Wisp Cave	>40 (>100)	0	<120 (<394)	0-25%	Moderate	Confirmed (Juvenile)

North Williamson County Karst Fauna Region						
Cave Cluster or Individual Cave	**Open Space Area ha (ac)**	**Area Perpetually Protected ha (ac)**	**Distance of Cave Entrance to Nearest Edge m (ft)**	**Percent of Cave Cricket Foraging Area Impacted**	**Current Resiliency**	**Occupancy Confidence**
Pussy Cat Cave	16-40 (40-100)	0	<120 (<394)	0-25%	Low	Confirmed (Female)
Sunless City Cave	>40 (>100)	172	<120 (<394)	26-50%	Low	Confirmed (Unknown specimen)
Cat Cave	<3.6 (<9)	4.5[c]	<120 (<394)	50-75%	Impaired	Confirmed (Male)
Coffin Cave[2]	3.6-16 (9-40)	36	<120 (<394)	0-25%	Impaired	Confirmed (Genetics)
Double Dog Hole Cave	16-40 (40-100)	0	<120 (<394)	25-50%	Impaired	Confirmed (Female, juvenile)
Duckworth Bat Cave[5]	<3.6 (<9)	5.5[c]	<120 (<394)	0-25%	Impaired	Confirmed (Juvenile)
Electro-Mag Cave[5]	3.6-16 (9-40)	0	<120 (<394)	0-25%	Impaired	Confirmed (Female)
Holler Hole Cave	<3.6 (<9)	0	<120 (<394)	26-50%	Impaired[3]	Confirmed (Male)
Medicine Man Cave	3.6-16 (9-40)	0	<120 (<394)	0-25%	Impaired	Confirmed (Male)

North Williamson County Karst Fauna Region

Cave Cluster or Individual Cave	Open Space Area ha (ac)	Area Perpetually Protected ha (ac)	Distance of Cave Entrance to Nearest Edge m (ft)	Percent of Cave Cricket Foraging Area Impacted	Current Resiliency	Occupancy Confidence
Sore-ped Cave	<3.6 (<9)	0	<120 (<394)	76-100%	Impaired	Confirmed (Male)
Texella Cave	16-40 (40-100)	0	<120 (<394)	26-50%	Impaired	Confirmed (Female, juvenile)
Viper Cave	<3.6 (<9)	0	<120 (<394)	26-50%	Impaired	Unconfirmed
F-3 (SH 95)	NA	NA	NA	NA	Destroyed	Confirmed (Unknown specimen)
Heritage Oaks Cave No. 2[2]	<3.6 (<9)	NA	NA	NA	Destroyed[7]	Confirmed (Unknown specimen)

[1] Newly discovered feature added since 2018 Species Status Assessment.

[2] Feature added since 2018 Species Status Assessment due to updated or corrected occupancy status.

[3] Feature resiliency change due to development effects since 2018 Species Status Assessment.

[4] Feature resiliency change due to updated or corrected location information.

[5] Adjustment to feature location resulted in addition to or removal from a cluster.

[6] Population resiliency change due to updated/corrected feature locations.

[7] Corrected value (no change to underlying data).

Table 8. Resiliency of Bone Cave harvestman cave clusters and individual caves in the Georgetown Karst Fauna Region.

Georgetown Karst Fauna Region						
Cave Cluster or Individual Cave	**Open Space Area ha (ac)**	**Area Perpetually Protected ha (ac)**	**Distance of Cave Entrance to Nearest Edge m (ft)**	**Percent of Cave Cricket Foraging Area Impacted**	**Current Resiliency**	**Occupancy Confidence**
Cave Clusters						
Cassidy Cave and Dead Man's Drop Cave					**High**	
Cassidy Cave[5]	<3.6 (<9)	0	<120 (<394)	76-100%	Impaired[4]	Confirmed (Male)
Dead Man's Drop Cave[1]	>40 (>100)	0	<120 (<394)	0-25%	High	Unconfirmed
DB Wood Cave Cluster					**High**	
Brecha Cave[1]	>40 (>100)	0	>120 (>394)	0%	High	Unconfirmed
Curious Calf Cave[1]	>40 (>100)	0	>120 (>394)	0%	High	Unconfirmed
Gray Fox Cave[1]	>40 (>100)	0	>120 (>394)	0%	High	Unconfirmed
Ringtail Cave[1]	>40 (>100)	0	<120 (<394)	0%	High	Unconfirmed

Georgetown Karst Fauna Region						
Cave Cluster or Individual Cave	**Open Space Area ha (ac)**	**Area Perpetually Protected ha (ac)**	**Distance of Cave Entrance to Nearest Edge m (ft)**	**Percent of Cave Cricket Foraging Area Impacted**	**Current Resiliency**	**Occupancy Confidence**
Georgetown Bypass Cave Cluster					**High**	
Algarita Cave	<3.6 (<9)	0	<120 (<394)	76-100%	Impaired[3]	Confirmed (Male)
Avant's Cave	>40 (>100)	0	<120 (<394)	26-50%	Low	Sight Record
Flat Rock Cave	>40 (>100)	0	<120 (<394)	76-100%	Impaired	Confirmed (Male)
Lobo's Lair	>40 (>100)	0	>120 (>394)	0%	High	Confirmed (Male)
Waterfall Canyon Cave	3.6-16 (9-40)	0	<120 (<394)	51-75%	Impaired[4]	Confirmed (Male)
Wolf's Rattlesnake Cave	>40 (>100)	0	>120 (>394)	0%	High	Confirmed (Juvenile)

Georgetown Karst Fauna Region

Cave Cluster or Individual Cave	Open Space Area ha (ac)	Area Perpetually Protected ha (ac)	Distance of Cave Entrance to Nearest Edge m (ft)	Percent of Cave Cricket Foraging Area Impacted	Current Resiliency	Occupancy Confidence
Millennium Cave Cluster					**High**	
Little Demon Cave	>40 (>100)	90[b]	<120 (<394)	0-25%	Moderate[7]	Sight record
Millennium Cave	>40 (>100)	90[b]	<120 (>394)	0%	High	Sight record
Through Trip Cave	>40 (>100)	90[b]	>120 (>394)	0%	High	Unconfirmed
Shadow Canyon Cave Cluster					**High**	
Dwarfs Delight Cave	>40 (>100)	0	>120 (>394)	0%	High	Unconfirmed
Lizard's Lounge Cave	>40 (>100)	0	<120 (>394)	0%	Moderate[3]	Unconfirmed
Salt Lick Cave	3.6-16 (9-40)	2.2 (5.4)	<120 (>394)	0-25%	Impaired[3]	Confirmed (Male)
Three Mile Cave	<3.6 (<9)	0	<120 (<394)	51-75%	Impaired[3]	Sight Record

Georgetown Karst Fauna Region

Cave Cluster or Individual Cave	Open Space Area ha (ac)	Area Perpetually Protected ha (ac)	Distance of Cave Entrance to Nearest Edge m (ft)	Percent of Cave Cricket Foraging Area Impacted	Current Resiliency	Occupancy Confidence
Steam Cave Cluster					**High**	
Coon Scat Cave	<3.6 (<9)	0	<120 (>394)	51-75%	Impaired[4]	Unconfirmed
Fence-line Sink	>40 (>100)	0	>120 (>394)	0%	High	Confirmed (Male)
Mayor Elliot Cave	<3.6 (<9)	0	<120 (<394)	76-100%	Impaired[4]	Confirmed (Male)
Off Campus Cave	<3.6 (<9)	0	<120 (<394)	50-75%	Impaired	Confirmed (Female)
On Campus Cave	<3.6 (<9)	0	<120 (<394)	26-50%	Impaired	Confirmed (Male)
Sierra Vista Cave	<3.6 (<9)	0	<120 (<394)	100%	Impaired (may be destroyed)	Sight Record
Steam Cave	>40 (>100)	0	>120 (>394)	0%	High	Confirmed (Female)
SW Bypass Cave No. 1	>40 (>100)	0	<120 (>394)	0-25%	Moderate[1]	Confirmed (Female)

Georgetown Karst Fauna Region						
Cave Cluster or Individual Cave	**Open Space Area ha (ac)**	**Area Perpetually Protected ha (ac)**	**Distance of Cave Entrance to Nearest Edge m (ft)**	**Percent of Cave Cricket Foraging Area Impacted**	**Current Resiliency**	**Occupancy Confidence**
Wilco Cave Cluster					**High**	
Mongo Cave	>40 (>100)	130[b]	>120 (>394)	0%	High	Confirmed (Juvenile)
Rock Ridge Cave	>40 (>100)	130[b]	>120 (>394)	0%	High	Sight record
Prospectors Cave	>40 (>100)	130[b]	>120 (>394)	0%	High	Sight record
Wilco Cave	>40 (>100)	130[b]	>120 (>394)	0%	High	Sight record
Wild West Cave	>40 (>100)	130[b]	>120 (>394)	0%	High	Sight record
Bone Cave Cluster					**Moderate**	
Bone Cave	>40 (>100)	0	<120 (<394)	0-25%	Moderate	Confirmed (Male)
Klan Cave	16-40 (40-100)	0	<120 (<394)	26-50%	Impaired[2]	Unconfirmed

Georgetown Karst Fauna Region						
Cave Cluster or Individual Cave	**Open Space Area ha (ac)**	**Area Perpetually Protected ha (ac)**	**Distance of Cave Entrance to Nearest Edge m (ft)**	**Percent of Cave Cricket Foraging Area Impacted**	**Current Resiliency**	**Occupancy Confidence**
Man-With-A-Spear Cave	16-40 (40-100)	0	<120 (<394)	0-25%	Low[7]	Confirmed (Unknown specimen)
Cole's Cavern Cluster					**Moderate**	
Cole's Cavern	>40 (>100)	0	<120 (<394)	26-50%	Low[7]	Confirmed (Genetics)
Glenna Mae's Cave	>40 (>100)	0	<120 (<394)	0-25%	Moderate	Confirmed (Male)
Stalagroot Cave[5]	NA	NA	NA	NA	Destroyed	Confirmed (Female, juvenile)
Burled Oak Cave And Four Mile Cave Cluster					**Low[6]**	
Burled Oak Cave	>40 (>100)	0	<120 (<394)	26-50%	Low[3]	Confirmed (Juvenile)
Four Mile Cave	<3.6 (<9)	0	<120 (<394)	76-100%	Impaired	Confirmed (Genetics)

Georgetown Karst Fauna Region						
Cave Cluster or Individual Cave	**Open Space Area ha (ac)**	**Area Perpetually Protected ha (ac)**	**Distance of Cave Entrance to Nearest Edge m (ft)**	**Percent of Cave Cricket Foraging Area Impacted**	**Current Resiliency**	**Occupancy Confidence**
Inner Space Caverns and Shamrock Cave					**Impaired**	
Inner Space Cavern	<3.6 (<9)	0	<120 (<394)	76-100%	Impaired[4]	Confirmed (Male)
Shamrock Cave[1]	3.6-16 (9-40)	0	<120 (<394)	1-25%	Impaired	Unconfirmed ID
Mayfield Cave Cluster					**Impaired**	
Abyss Cave	<3.6 (<9)	0	<120 (<394)	76-100%	Impaired	Confirmed (Male)
Elm Cave	<3.6 (<9)	0	<120 (<394)	76-100%	Impaired	Confirmed (Unknown specimen)
Flowstone Rift Cave	<3.6 (<9)	4[d]	<120 (<394)	51-75%	Impaired	Confirmed (Female)
Formation Forest Cave	<3.6 (<9)	0	<120 (<394)	100%	Impaired	Confirmed (Male)
Fortune 500 Cave	3.6-16 (9-40)	0	<120 (<394)	51-75%	Impaired[4]	Confirmed (Female)

Georgetown Karst Fauna Region

Cave Cluster or Individual Cave	Open Space Area ha (ac)	Area Perpetually Protected ha (ac)	Distance of Cave Entrance to Nearest Edge m (ft)	Percent of Cave Cricket Foraging Area Impacted	Current Resiliency	Occupancy Confidence
Hatchi Cave	<3.6 (<9)	0	<120 (<394)	51-76%	Impaired	Confirmed (Female, juvenile)
Killian Kavern[2]	<3.6 (<9)	0	<120 (<394)	76-100%	Impaired	Confirmed (Male)
Mayfield Cave	<3.6 (<9)	0	<120 (<394)	26-50%	Impaired	Confirmed (Juvenile)
Mosquito Cave	3.6-16 (9-40)	0	<120 (<394)	26-50%	Impaired	Confirmed (Female)
Ominous Entrance Cave	<3.6 (<9)	0	<120 (<394)	75-100%	Impaired	Confirmed (Female)
Onion Branch Cave	3.6-16 (9-40)	0	<120 (<394)	26-50%	Impaired	Confirmed (Male)
Posh Cave	<3.6 (<9)	0	<120 (<394)	76-100%	Impaired	Confirmed (Juvenile)
Price Is Right Cave	<3.6 (<9)	0	<120 (<394)	26-50%	Impaired	Confirmed (Female)
Quarry Fern Cave	<3.6 (<9)	0.3[d]	<120 (<394)	76-100%	Impaired	Sight Record

Georgetown Karst Fauna Region						
Cave Cluster or Individual Cave	**Open Space Area ha (ac)**	**Area Perpetually Protected ha (ac)**	**Distance of Cave Entrance to Nearest Edge m (ft)**	**Percent of Cave Cricket Foraging Area Impacted**	**Current Resiliency**	**Occupancy Confidence**
Rootin Tootin Cave	<3.6 (<9)	0	<120 (<394)	51-75%	Impaired	Confirmed (Female, juvenile)
Round Rock Breathing Cave	3.6-16 (9-40)	0	<120 (<394)	51-75%	Impaired	Confirmed (Male)
Thin TopCave	3.6-16 (9-40)	0	<120 (<394)	26-50%	Impaired	Confirmed (Juvenile)
Venturi Cave	<3.6 (<9)	0	<120 (<394)	51-75%	Impaired	Confirmed (Male)
Yamas Cave	<3.6 (<9)	0	<120 (<394)	76-100%	Impaired	Confirmed (Juvenile)
Zapata Cave	<3.6 (<9)	1[d]	<120 (<394)	75-100%	Impaired	Confirmed (Male)

Georgetown Karst Fauna Region						
Cave Cluster or Individual Cave	**Open Space Area ha (ac)**	**Area Perpetually Protected ha (ac)**	**Distance of Cave Entrance to Nearest Edge m (ft)**	**Percent of Cave Cricket Foraging Area Impacted**	**Current Resiliency**	**Occupancy Confidence**
Individual Caves						
Harrison Cave	>40 (>100)	0	>120 (>394)	0%	High	Confirmed (Male)
Jensen Cave	>40 (>100)	0	>120 (>394)	0%	High	Confirmed (Unknown specimen)
Keyhole Drop Cave[1]	16-40 (40-100)	0	<120 (<394)	26-50%	Low	Unconfirmed
Broken Glass Cave (aka F-18)	<3.6 (<9)	0	<120 (<394)	76-100%	Impaired	Confirmed (Male)
Brown's Cave	<3.6 (<9)	0	<120 (<394)	76-100%	Impaired	Confirmed (Female)
Paradox Cave[2]	<3.6 (<9)	0	<120 (<394)	76-100%	Impaired (may be destroyed)	Sight Record
Short Stack Cave	<3.6 (<9)	0	<120 (<394)	76-100%	Impaired (location uncertain)	Confirmed (Female, juvenile)
Snowmelt Cave	<3.6 (<9)	2[d]	<120 (<394)	76-100%	Impaired	Confirmed (Male)

Georgetown Karst Fauna Region						
Cave Cluster or Individual Cave	**Open Space Area ha (ac)**	**Area Perpetually Protected ha (ac)**	**Distance of Cave Entrance to Nearest Edge m (ft)**	**Percent of Cave Cricket Foraging Area Impacted**	**Current Resiliency**	**Occupancy Confidence**
Tres Amigos Cave	<3.6 (<9)	0	<120 (<394)	26-50%	Impaired	Confirmed (Male)
Waterline Cave	16-40 (40-100)	0	<120 (<394)	26-50%	Impaired	Sight Record

[1] Newly discovered feature added since 2018 Species Status Assessment.

[2] Feature added since 2018 Species Status Assessment due to updated or corrected occupancy status.

[3] Feature resiliency change due to development effects since 2018 Species Status Assessment.

[4] Feature resiliency change due to updated or corrected location information.

[5] Adjustment to feature location resulted in addition to or removal from a cluster.

[6] Population resiliency change due to development impacts on individual features.

[7] Corrected value (no change to underlying data).

Table 9. Resiliency of Bone Cave harvestman cave clusters and individual caves in the McNeil/Round Rock Karst Fauna Region.

McNeil/Round Rock Karst Fauna Region						
Cave Cluster or Individual Cave	**Open Space Area ha (ac)**	**Area Perpetually Protected ha (ac)**	**Distance of Cave Entrance to Nearest Edge m (ft)**	**Percent of Cave Cricket Foraging Area Impacted**	**Current Resiliency**	**Occupancy Confidence**
Cave Clusters						
Chaos Cave Cluster					**High**	
Cave Coral Cave	<3.6 (<9)	0	<120 (>394)	0-25%	Moderate[4]	Confirmed (Male)
Chaos Cave	>40 (>100)	30[e]	>120 (>394)	0%	High	Confirmed (Male)
Near Miss Cave	>40 (>100)	0	<120 (>394)	76-100%	Destroyed[4]	Confirmed (Male)
Outcrop Cave	<3.6 (<9)	0	<120 (>394)	76-100%	Impaired[4]	Confirmed (Male)
Poison Ivy Cave	>40 (>100)	30[e]	>120 (>394)	0%	High	Confirmed (Male)
Root Cellar Cave	<3.6 (<9)	0	<120 (>394)	76-100%	Destroyed[4]	Confirmed (Male)
Sam Bass Hideaway Cave	>40 (>100)	0	>120 (<394)	0-25%	High[4]	Confirmed (Male)

McNeil/Round Rock Karst Fauna Region

Cave Cluster or Individual Cave	Open Space Area ha (ac)	Area Perpetually Protected ha (ac)	Distance of Cave Entrance to Nearest Edge m (ft)	Percent of Cave Cricket Foraging Area Impacted	Current Resiliency	Occupancy Confidence
Stepstone Cave	>40 (>100)	0	<120 (>394)	0%	Moderate[4]	Confirmed (Female)
Swarm Cave	>40 (>100)	0	<120 (>394)	0%	Moderate[4]	Confirmed (Female)
Under-the-fence Cave	>40 (>100)	0	>120 (<394)	0%	High[4]	Confirmed (Male)
McNeil Bat Cave Cluster					**High**	
Fossil Garden Cave	>40 (>100)	0	<120 (<394)	0-25%	Low[7]	Confirmed (Male)
McNeil Bat Cave	>40 (>100)	0	<120 (<394)	0-25%	Low[7]	Confirmed (Female, juvenile)
Millipede Annex Cave	<3.6 (<9)	0	<120 (<394)	75-100%	Impaired	Confirmed (Male)
Millipede Cave	<3.6 (<9)	0	<120 (<394)	75-100%	Impaired	Confirmed (Male)
No Rent Cave	>40 (>100)	17[f]	<120 (<394)	0-25%	Low[7]	Confirmed (Female, juvenile)

McNeil/Round Rock Karst Fauna Region						
Cave Cluster or Individual Cave	**Open Space Area ha (ac)**	**Area Perpetually Protected ha (ac)**	**Distance of Cave Entrance to Nearest Edge m (ft)**	**Percent of Cave Cricket Foraging Area Impacted**	**Current Resiliency**	**Occupancy Confidence**
Pencil Cactus Cave	>40 (>100)	0	>120 (>394)	0%	High	Confirmed (juvenile)
Pecan Gap Cave No. 1	>40 (>100)	0	<120 (<394)	0-25%	Moderate[7]	Confirmed (Male)
Weldon Cave	>40 (>100)	17[f]	>120 (>394)	0%	High	Confirmed (Male)
Wyoming Springs Cave Cluster					**High**	
WS-54	>40 (>100)	0	>120 (>394)	0%	High	Confirmed (Unknown specimen)
WS-65	>40 (>100)	0	>120 (>394)	0%	High	Confirmed (Unknown specimen)
WS-71a	>40 (>100)	0	>120 (>394)	0%	High	Confirmed (Unknown specimen)

McNeil/Round Rock Karst Fauna Region

Cave Cluster or Individual Cave	Open Space Area ha (ac)	Area Perpetually Protected ha (ac)	Distance of Cave Entrance to Nearest Edge m (ft)	Percent of Cave Cricket Foraging Area Impacted	Current Resiliency	Occupancy Confidence
Cold Cave and Hole-in-the-Road Cave					**Moderate**	
Cold Cave[5]	>40 (>100)	0	<120 (<394)	0-25%	Moderate	Confirmed (Male)
Hole-In-The-Road Cave[5]	>40 (>100)	0	<120 (<394)	26-50%	Low	Confirmed (Female, juvenile)
Beck Cave Cluster					**Low**	
Beck Bat/Beck Crevice Cave	16-40 (40-100)	40[g]	<120 (<394)	26-50%	Impaired[7]	Confirmed (Male)
Beck Blowing Well Cave	<3.6 (<9)	0	<120 (<394)	51-75%	Impaired	Confirmed (Male)
Beck Bridge Cave	3.6-16 (9-40)	0	<120 (<394)	51-75%	Impaired	Confirmed (Female, juvenile)
Beck Horse Cave	16-40 (40-100)	40[g]	<120 (<394)	0-25%	Low	Confirmed (Female, juvenile)
Beck Pride Cave	16-40 (40-100)	40[g]	<120 (<394)	0-25%	Low	Confirmed (Female, juvenile)
Beck Ranch Cave	3.6-16 (9-40)	0	<120 (<394)	26-50%	Impaired	Confirmed (Male)

McNeil/Round Rock Karst Fauna Region

Cave Cluster or Individual Cave	Open Space Area ha (ac)	Area Perpetually Protected ha (ac)	Distance of Cave Entrance to Nearest Edge m (ft)	Percent of Cave Cricket Foraging Area Impacted	Current Resiliency	Occupancy Confidence
Beck Rattlesnake Cave	<3.6 (<9)	0	<120 (<394)	51-75%	Impaired	Confirmed (Male)
Beck Sewer Cave	<3.6 (<9)	0	<120 (<394)	51-75%	Impaired	Confirmed (Male)
Beck Tex-2 Cave	16-40 (40-100)	40[g]	<120 (<394)	26-50%	Impaired[7]	Confirmed (Female)
Beck Trash Cave	<3.6 (<9)	0	<120 (<394)	51-75%	Impaired	Unconfirmed
Black Cat Cave	NA	NA	NA	100%	Destroyed	Confirmed (Female, juvenile)
Blessed Virgin Cave	16-40 (40-100)	0	<120 (>394)	0%	Low[7]	Confirmed (Male)
Broken Zipper Cave	3.6-16 (9-40)	0	<120 (<394)	0-25%	Impaired	Confirmed (Female)
Cat Hollow Bat Cave	<3.6 (<9)	0	<120 (<394)	51-75%	Impaired	Confirmed (Female)
Cat Hollow Cave #1	<3.6 (<9)	0	<120 (<394)	50-75%	Impaired	Confirmed (Male)

McNeil/Round Rock Karst Fauna Region						
Cave Cluster or Individual Cave	**Open Space Area ha (ac)**	**Area Perpetually Protected ha (ac)**	**Distance of Cave Entrance to Nearest Edge m (ft)**	**Percent of Cave Cricket Foraging Area Impacted**	**Current Resiliency**	**Occupancy Confidence**
Cat Hollow Cave #2	3.6-16 (9-40)	0	<120 (<394)	50-75%	Impaired	Confirmed (Female)
Clark Cave	16-40 (40-100)	0	<120 (<394)	0-25%	Low	Sight Record
Crescent Cave	16-40 (40-100)	0	<120 (<394)	51-75%	Impaired[7]	Confirmed (Male)
El Tigre Cave	<3.6 (<9) 3.6-16 (9-40)	0	<120 (<394)	26-50%	Impaired	Confirmed (Female)
Ensor Cave	<3.6 (<9)	0	<120 (<394)	76-100%	Impaired	Confirmed (Female)
Eulogy Cave	3.6-16 (9-40)	0	<120 (<394)	51-75%	Impaired	Confirmed (Juvenile)
Imprint Cave[2]	<3.6 (<9)	0	<120 (<394)	76-100%	Impaired	Sight Record
Jackhammer Cave	<3.6 (<9)	0	<120 (<394)	76-100%	Destroyed[4]	Confirmed (Male)
Joint Effort Cave	3.6-16 (9-40)	0	<120 (<394)	26-50%	Impaired	Confirmed (Female)

McNeil/Round Rock Karst Fauna Region						
Cave Cluster or Individual Cave	**Open Space Area ha (ac)**	**Area Perpetually Protected ha (ac)**	**Distance of Cave Entrance to Nearest Edge m (ft)**	**Percent of Cave Cricket Foraging Area Impacted**	**Current Resiliency**	**Occupancy Confidence**
Joker Cave[2]	<3.6 (<9)	0	<120 (<394)	76-100%	Impaired	Sight Record
Leachate Cave	3.6-16 (9-40)	0	<120 (<394)	51-75%	Impaired	Confirmed (Juvenile)
O'Connor Cave	<3.6 (<9)	0	<120 (<394)	76-100%	Impaired	Confirmed (Male)
Scoot Over Cave	3.6-16 (9-40)	0	<120 (<394)	26-50%	Impaired	Confirmed (Female, juvenile)
Serta Cave	<3.6 (<9)	0	<120 (<394)	76-100%	Impaired	Confirmed (Female)
Spike’s Goat Cave[2]	16-40 (40-100)	0	<120 (<394)	26-50%	Impaired	Confirmed (Female)
Underdeveloped Cave	<3.6 (<9)	0	<120 (<394)	51-75%	Impaired	Confirmed (Juvenile)
Undertaker Cave	<3.6 (<9)	0	<120 (<394)	76-100%	Impaired	Confirmed (Male)
Vericose Cave	16-40 (40-100)	0	<120 (<394)	76-100%	Impaired[3,4]	Confirmed (Female, juvenile)

McNeil/Round Rock Karst Fauna Region						
Cave Cluster or Individual Cave	**Open Space Area ha (ac)**	**Area Perpetually Protected ha (ac)**	**Distance of Cave Entrance to Nearest Edge m (ft)**	**Percent of Cave Cricket Foraging Area Impacted**	**Current Resiliency**	**Occupancy Confidence**
Wild Card Cave	<3.6 (<9)	0	<120 (<394)	76-100%	Impaired	Confirmed (Female)
Lineament Cave Cluster					**Low[6]**	
Lineament Cave	3.6-16 (9-40)	0	<120 (>394)	0%	Impaired[4]	Confirmed (Male)
Mustard Cave	>40 (>100)	0	<120 (>394)	26-50%	Low[4]	Confirmed (Female, juvenile)
Rock Fall Cave	3.6-16 (9-40)	0	<120 (<394)	76-100%	Impaired	Confirmed (Female)
Fern Bluff Cave Cluster					**Impaired**	
Backhoe Surprise Cave[5]	NA	NA	NA	100%	Destroyed	Confirmed (Male)
Flint Wash Cave	<3.6 (<9)	0	<120 (<394)	51-75%	Impaired	Confirmed (Female)
Hollow Oak Cave	<3.6 (<9)	0	<120 (<394)	76-100%	Impaired	Confirmed (Male)
Monarch Cave[1]	3.6-16 (9-40)	0	<120 (<394)	26-50%	Impaired	Confirmed (Unknown specimen)

McNeil/Round Rock Karst Fauna Region

Cave Cluster or Individual Cave	Open Space Area ha (ac)	Area Perpetually Protected ha (ac)	Distance of Cave Entrance to Nearest Edge m (ft)	Percent of Cave Cricket Foraging Area Impacted	Current Resiliency	Occupancy Confidence
Individual Caves						
Raccoon Lounge Cave[5]	>40 (>100)	0	>120 (>394)	0%	High	Confirmed (Male)
Six Meter Sink	>40 (>100)	0	>120 (<394)	0-25%	High[4]	Confirmed (Juvenile)
Beer Bottle Cave	>40 (>100)	0	<120 (>394)	0%	Moderate[4]	Confirmed (Male)
Fossil Cave	3.6-16 (9-40)	0	<120 (<394)	0-25%	Impaired	Confirmed (Unknown specimen)
Just Kidding Cave	<3.6 (<9)	0	<120 (<394)	26-50%	Impaired	Confirmed (Juvenile)
Oakbrook Cave	<3.6 (<9)	0	<120 (<394)	76-100%	Impaired (may be destroyed)[3]	Unconfirmed
Pearson Palace Cave	<3.6 (<9)	0	<120 (<394)	51-75%	Impaired	Confirmed (Male)
Rocky Horror Cave	16-40 (40-100)	0	<120 (<394)	0-25%	Low[7]	Confirmed (Unknown specimen)

[1] Newly discovered feature added since 2018 Species Status Assessment.

[2] Feature added since 2018 Species Status Assessment due to updated or corrected occupancy status.

[3] Feature resiliency change due to development effects since 2018 Species Status Assessment.
[4] Feature resiliency change due to updated or corrected location information.
[5] Adjustment to feature location resulted in addition to or removal from a cluster.
[6] Population resiliency change due to updated/corrected feature locations.
[7] Corrected value (no change to underlying data).

Table 10. Resiliency of Bone Cave harvestman cave clusters and individual caves in the Jollyville Plateau Karst Fauna Region.

Jollyville Plateau Karst Fauna Region						
Cave Cluster or Individual Cave	**Open Space Area ha (ac)**	**Area Perpetually Protected ha (ac)**	**Distance of Cave Entrance to Nearest Edge m (ft)**	**Percent of Cave Cricket Foraging Area Impacted**	**Current Resiliency**	**Occupancy Confidence**
Cave Clusters						
Four Points Cave Cluster					**High**	
Eluvial Cave	>40 (>100)	160[h]	<120 (<394)	0-25%	Moderate	Confirmed (Unknown specimen)
Jollyville Plateau Cave	>40 (>100)	160[h]	>120 (>394)	0%	High	Confirmed (Penultimate male)
MWA Cave	>40 (>100)	160[h]	>120 (<394)	0%	High[7]	Confirmed (Male)
Kent Butler Ecological Reserve Cluster					**High**	
Beard Ranch Cave	>40 (>100)	942[f]	>120 (>394)	0%	High	Confirmed (Female)
IV-3	>40 (>100)	942[h]	>120 (>394)	0%	High	Confirmed (Male)
Merkin Hole	>40 (>100)	942h	>120 (>394)	0%	High	Preliminary genetics results

Jollyville Plateau Karst Fauna Region

Cave Cluster or Individual Cave	Open Space Area ha (ac)	Area Perpetually Protected ha (ac)	Distance of Cave Entrance to Nearest Edge m (ft)	Percent of Cave Cricket Foraging Area Impacted	Current Resiliency	Occupancy Confidence
						placed specimen with T. reyesi
Pond Party Pit	>40 (>100)	942[h]	>120 (>394)	0%	High	Confirmed (Male)
Tooth Cave Cluster					**High**	
Gallifer Cave	>40 (>100)	169[h]	>120 (>394)	0%	High	Confirmed (Male)
Root/North Root Cave	>40 (>100)	169[h]	<120 (>394)	26-50%	Low[3]	Confirmed (Juvenile)
Tooth Cave	>40 (>100)	169[h]	<120 (<394)	0-25%	Moderate	Confirmed (Male)
New Comanche Trail Cave Cluster					**High**	
CoA-9	>40 (>100)	430[h]	>120 (>394)	0%	High	Sight Record
LU-12 (Lucas tract)	>40 (>100)	430[h]	<120 (<394)	0-25%	Moderate[7]	Confirmed (Unknown specimen)
Geode Cave	>40 (>100)	430[h]	<120 (<394)	25-50%	Low	Confirmed (Unknown specimen)

Jollyville Plateau Karst Fauna Region						
Cave Cluster or Individual Cave	**Open Space Area ha (ac)**	**Area Perpetually Protected ha (ac)**	**Distance of Cave Entrance to Nearest Edge m (ft)**	**Percent of Cave Cricket Foraging Area Impacted**	**Current Resiliency**	**Occupancy Confidence**
New Comanche Trail Cave	>40 (>100)	430[h]	<120 (<394)	0%	Moderate	Confirmed (Juvenile)
Plethodon Cave and Stovepipe Cave					**High[6]**	
Plethodon Cave	<3.6 (<9)	0	<120 (<394)	51-75%	Impaired	Unconfirmed
Stovepipe Cave	16-40 (40-100)	85[h]	>120 (>394)	0-25%	High[7]	Confirmed (Male)
Puzzle Pits Cave and Twisted Elm Cave					**Impaired**	
Puzzle Pits Cave	NA	NA	NA	NA	Destroyed	Confirmed (Male)
Twisted Elm Cave	3.6-16 (9-40)	33[h]	<120 (<394)	76-100%	Impaired	Confirmed (Male)

Jollyville Plateau Karst Fauna Region

Cave Cluster or Individual Cave	Open Space Area ha (ac)	Area Perpetually Protected ha (ac)	Distance of Cave Entrance to Nearest Edge m (ft)	Percent of Cave Cricket Foraging Area Impacted	Current Resiliency	Occupancy Confidence
Individual Caves						
Cortana Cave	>40 (>100)	623[h]	>120 (>394)	0%	High	Confirmed (Male)
Jest John Cave	>40 (>100)	410[h]	>120 (>394)	0%	High	Preliminary genetics results placed specimen with T. reyesi (Male)
McDonald Cave	>40 (>100)	785[h]	>120 (>394)	0%	High	Confirmed (Male)
Spider Cave	>40 (>100)	468[h]	>120 (>394)	0%	High	Preliminary genetics results placed specimen with T. reyesi
Pickle Pit	>40 (>100)	200[h]	<120 (>394)	0-25%	Moderate[6]	Confirmed (Male)
Jester Estates Cave	<3.6 (<9)	3.2[h]	<120 (<394)	51-75%	Impaired	Preliminary genetics results placed specimen with T. reyesi

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[3] Feature resiliency change due to development effects since 2018 Species Status Assessment.

[6] Population resiliency change due to updated/corrected feature locations.

[7] Corrected value (no change to underlying data).

Table 11. Resiliency of Bone Cave harvestman cave clusters and individual caves in the Cedar Park Karst Fauna Region.

Cedar Park Karst Fauna Region						
Cave Cluster or Individual Cave	**Open Space Area ha (ac)**	**Area Perpetually Protected ha (ac)**	**Distance of Cave Entrance to Nearest Edge m (ft)**	**Percent of Cave Cricket Foraging Area Impacted**	**Current Resiliency**	**Occupancy Confidence**
Cave Clusters						
Lakeline Cave and Underline Cave					**Impaired**	
Lakeline Cave	<3.6 (<9)	<3.6 (<9)[h]	<120 (<394)	51-75%	Impaired	Confirmed (Male)
Underline Cave	NA	NA	NA	100%	Destroyed	Confirmed (Male)

Table 12. Resiliency of Bone Cave harvestman cave clusters and individual caves in the Central Austin Karst Fauna Region.

Central Austin Karst Fauna Region						
Cave Cluster or Individual Cave	**Open Space Area ha (ac)**	**Area Perpetually Protected ha (ac)**	**Distance of Cave Entrance to Nearest Edge m (ft)**	**Percent of Cave Cricket Foraging Area Impacted**	**Current Resiliency**	**Occupancy Confidence**
Cave Clusters						
Cotterell Cave and West Rim Cave					**Impaired**	
Cotterell Cave	3.6-16 (9-40)	20[h]	<120 (<394)	25-50%	Impaired	Confirmed (Male)
West Rim Cave	<3.6 (<9)	0	<120 (<394)	75-100%	Impaired	Confirmed (Female)

[a] Godwin Ranch Preserve (Texas Cave Management Association).
[b] Proposed karst fauna area pending recognition.
[c] Sun City Cave Preserves.
[d] Brushy Creek Municipal Utility District.
[e] Chaos Cave Preserve (Williamson County).
[f] Weldon Cave Cluster (Protection pending; Travis County and Round Rock Independent School District).
[g] Beck Cave Preserve (Williamson County).
[h] Balcones Canyonlands Preserve; ownership varies (e.g., City of Austin, Travis County, Private).