Support for Maintaining Endangered Status
For the Bone Cave Harvestman (*Texella reyesi*)

Submitted to the U.S. Fish and Wildlife Service
By City of Austin and Travis County
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Texella reyesi, photo: Colin Strickland

The purpose of this document is to provide an independent assessment of the threats to the Bone Cave harvestman (*Texella reyesi*) and provide supplemental data collected at sites monitored by the City of Austin and Travis County. Our data are intended to supplement a thorough review of the species status conducted by the U.S. Fish and Wildlife Service (USFWS) in 2018 and to inform the current status review, initiated after a positive 90-day finding was made on a petition to delist *T. reyesi*.

Below is our summary for each of the five factors used to determine whether listing as endangered or threatened is warranted under Section 4 of the Endangered Species Act. More detailed analyses are provided in attachments A-C. Given *T. reyesi*'s limited range and magnitude of threats to its habitat, we conclude that delisting this species is not warranted, and that *T. reyesi* should continue to be protected as an endangered species.

Factor A – Present or threatened destruction, modification, or curtailment of its habitat or range.

The Bone Cave Harvestman (*T. reyesi*) was listed as endangered due to habitat loss from urban development. Described as *T. reddelli* at the time of listing (USFWS 1988), its taxonomy has been refined (USFWS 1993, 1994; Hedin and Derkarabetian 2020). Its entire range occurs in portions of only two counties, Travis and Williamson. Both counties continue to experience rapid loss of karst habitat due to urban expansion. The human population of Travis County has increased from 557,219 in 1988 to 1,273,954 in 2019, an increase of 129%. The Williamson County population has increased from 129,602 in 1988 to 590,551 in 2019, an increase of 356%. The Texas Demography Center projects that in 2050 the population in Travis County will increase to 1,970,000 and the population of Williamson County will be 1,640,000, an increase of 55% and 178% since 2019 for Travis and Williamson counties, respectively. The increased human population and concomitant loss of surface and subsurface habitat further threatened the continued survival of *T. reyesi*.

Subsurface and surface habitats are integrally connected in karst ecosystems. As a troglobitic species, *T. reyesi* is uniquely adapted to live solely in the karst subsurface. This underground ecosystem depends on native surface plant and animal communities to maintain stable temperatures, humidity, and nutrient supplies. Historically, the vegetation along the eastern edge of the Edwards Plateau, which includes the range of *T. reyesi*, was predominantly Ashe juniper (*Juniperus ashei)*-oak (*Quercus* sp.) woodlands and forests (O'Donnell 2019). Taylor et al. (2007) reported the most abundant plants near nine caves in Bexar, Hays, and Travis counties were Texas persimmon (*Diospyros texana*), plateau live oak (*Quercus fusiformis*), agarita (*Mahonia trifoliolata*), *J. ashei*, and cedar sedge (*Carex planostachys*). These plant communities and soils provide water, leaf litter and woody debris, fungi, and other nutrients to the subsurface (see examples in figures 1 and 2). Tree canopies reduce evaporation (Nagra et al. 2016), flooding, and air and soil temperatures. Removal of native canopy leads to hotter, drier conditions (Ellison et al. 2017), less water infiltration (Slaughter 1997, Lindley 2005, Dasgupta et al. 2006), loss of nutrients, erosion and sedimentation, and invasion of non-native species such as the red-imported fire ant (*Solenopsis invicta*) that prey on karst fauna. These surface plant and animal communities are a critical component of karst ecosystems, including humanly-accessible caves and interstitial space or mesocaverns.

Keystone taxa in Central Texas karst ecosystems include cave crickets (*Ceuthophilus* spp.) and cave-adapted springtails (Taylor et al. 2003). Cave cricket species include *Ceuthophilus secretus* and other undescribed *Ceuthophilus* species that roost in the cave during the day and forage on the surface at night; they have been found over 100 meters from the cave entrance and occasionally between caves. These trogloxenes are known to feed on saprophytic mushrooms (Zara Environmental 2014), Texas persimmon fruit, and dead insects (Taylor et al. 2005). The species *Ceuthophilus cunicularis* rarely forages outside the cave. Cave cricket feces, carcasses, and eggs provide an important source of nutrients to the karst ecosystem. Cave cricket guano forms layers of energy rich substrate that support healthy populations of springtails (Taylor et al. 2005, 2007). Studies have shown that species of spiders and harvestman, both in the Class Arachnida, have improved rates of survival and reproduction when fed springtails (Toft and Wise 1999, Allard and Yeargen 2005). Opportunistic feeders, like *T. reyesi*, may also depend on rich food resources, like springtails, for survival and reproduction.

Conversion of native tree and shrub canopy to urban development removes the native vegetation needed to support the karst ecosystem. Additional habitat loss occurs with excavation, trenching, fill material, impervious cover, alteration of natural drainage patterns, introduction of non-native vegetation, application of pesticides, herbicides, and fertilizers, and exposure to urban runoff and other pollutants. Taylor et al. (2007) found that the number of individuals of cave taxa, including cave crickets, "are correlated with the level of human impact. As the percentage of impervious cover and percentage of impacted area increased, the total number of cave taxa decreased. This trend held true when either 11.2 or 90 acres around the cave entrance were considered in scoring the level of impact. Additionally, the total number of individuals of other taxa recorded from the caves was strongly correlated with the total number of cave crickets. Maintaining land in a natural state within the foraging range of cave crickets (*C. secretus* and *C*. species B), and controlling the fire ant, *S. invicta*, are therefore important considerations in the management of Texas' federally listed endangered cave invertebrates." They further state that, "a preserve size of 11.2 acres is not sufficient to maintain a fully functioning cave ecosystem in Central Texas."

Yearwood et al. (2014) provided a list of section 7 consultations and section 10 permits that they state protect known *T. reyesi* localities. However, we did not see supporting documentation to evaluate the adequacy of the preserves, and at least two of the permits (Comanche Canyon, Russell Park Estates) apparently have no *T. reyesi* protections (Appendix B in Yearwood et al. 2014). To our knowledge, Lakeline Cave is the only developed site with a long-term cave fauna dataset that includes pre- and post-development data. This cave is located in a 2.3-acre preserve surrounded by a shopping mall (USFWS 1992). Zara Environmental (2009) reported a significant decline in counts of cave crickets and the endangered Tooth Cave ground beetle (*Rhadine persephone*), and a decline in *T. reyesi* counts (not significant due to very low numbers) from 1992-2009 following development of the mall, despite efforts to control *S. invicta*. While Yearwood et al. (2014) state that Weldon Cave provides an example of how development has not resulted in a decrease in *T. reyesi* abundance, we note that little development has occurred near this cave, likely because it is a known endangered species cave. The nearest development is a parking lot, which is approximately 450 feet east of the cave entrance. Further, few *T. reyesi* have been observed in Weldon Cave over the past decade (0-4 individuals observed on 26 visits from 2011-2019), indicating a highly vulnerable population at this site. Without long-term trend data, we caution that presence is not indicative of a viable population, healthy ecosystem, or adaptations to human activities.

While northern Travis County has a large amount of preserve land within *T. reyesi*'s approximate range, most of these preserves are in valleys that are at a lower elevation than the cave-forming geologic layers. It is common practice for developers to build on the desirable upland flat areas and set aside as preserves the canyons and valleys that are harder to build on. As a result, most development in the Jollyville karst fauna region takes place on the flat upland areas that have a higher probability of having *T. reyesi* present, while the majority of the preserve lands are in areas with extremely low probabilities of presence.

Other threats to *T. reyesi* habitat include quarrying and mining. Based on an analysis of recent aerial photography, approximately 3,860 acres (6 square miles) of land within *T. reyesi*'s range has been destroyed by limestone quarries. The type locality is surrounded by quarries (Figure 3).

Attachment A provides an analysis of land cover changes in the immediate vicinity of known *T. reyesi* sites from 2001 to 2016, and documents the increasing loss of natural cover to development. Attachment B presents an analysis of voids encountered during construction within *T. reyesi*'s range. Attachment C presents analyses of *T. reyesi* and cave cricket count data for caves within the Balcones Canyonlands Preserve.

(a) (b) (c)

Figure 1. (a) Ashe juniper and shin oak tree roots (photo by City of Austin); (b) tree roots (photo by Brian Pickles); (c) *Ceuthophilus secretus* on tree roots (photo by Colin Strickland), from caves within the Balcones Canyonlands Preserve, Austin, Texas.

Figure 2. Fungi in caves near Austin, Texas (photos by Colin Strickland).

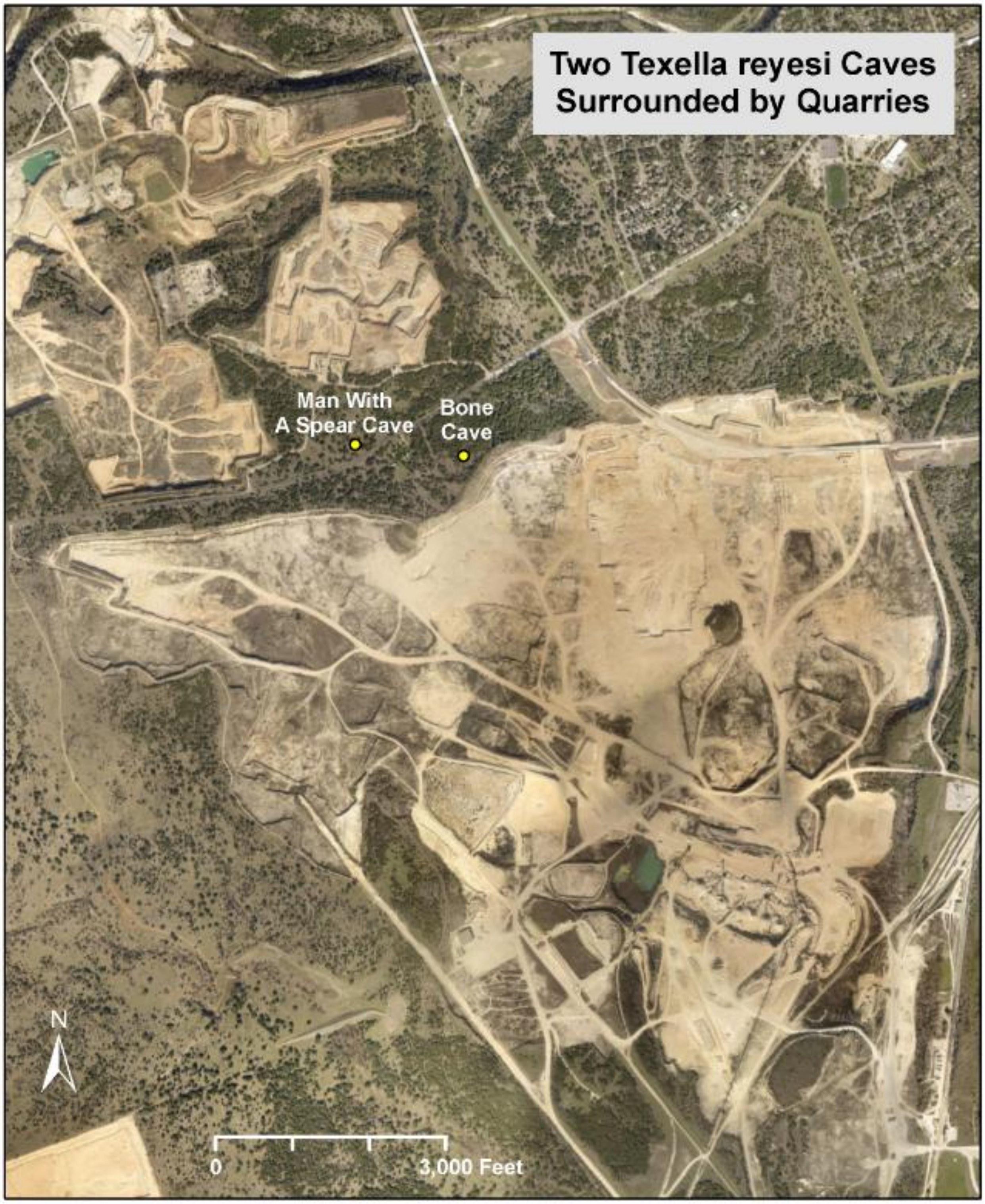

Figure 3. *Texella reyesi* type locality surrounded by quarries.

Factor B – Overutilization of the species for commercial, recreational, scientific, or educational purposes.

We are unaware of any major threats from these activities.

Factor C – Disease or predation.

Solenopsis invicta is considered one of the 14 worst invasive alien insect species in the world (Lowe et al. 2004). The prevalence and impact of *S. invicta* in karst ecosystems has been well-established. *S. invicta* is "the most important cave-associated ant in Texas" (Reddell and Cokendolpher 2001) and one of two ant species known to forage deep inside Central Texas caves (Wojcik et al. 2001, Cokendolpher et al. 2009). *S. invicta* has been known to access karst ecosystems through cave entrances and smaller spaces (mesocaverns) not accessible to humans (Taylor et al. 2003). An aggressive and opportunistic omnivore, *S. invicta* has had a "devastating effect on cave fauna in all areas within its range" (Reddell and Cokendolpher 2001), and is one of "the most critical management problems facing the rare and endangered endemic cave fauna" (Taylor et al. 2005). Impacts are primarily on food sources such as the cave cricket, but can also be direct. Where *S. invicta* can access areas inhabited by *T. reyesi* and other species of concern, direct impacts can be "catastrophic" due to their "low population levels, low reproductive rates, and longer life spans" (Taylor et al. 2003).

The degree to which *S. invicta* impacts native ant and arthropod communities depends on multiple factors, including local habitat conditions (*S. invicta* is rare in forested areas and prefers sunny sites with little/no canopy, disturbed soils, riparian areas, and periodic flooding; LeBrun et al. 2012), disturbance history, and whether the colonies are monogyne or polygyne. Intensity of impacts are to scale with intensity of disturbance. For example, Morrison (2002) replicated an earlier study by Porter and Savignano (1990) on a single, predominately forested site (University of Texas at Austin's Brackenridge Field Laboratory, or BFL) with development pre-dating the *S. invicta* invasion in the 1980s. He found that *S. invicta* declined and native ant populations rebounded within 12 years. A crucial biological mechanism for the recovery was that BFL was a mildly disturbed natural area that contained a diverse and healthy population of native ants before the *S. invicta* invasion, and many native ant species persisted by competing for resources. Furthermore, studies in the use of successful biological controls to combat *S. invicta*, such as the microsporidian *Thelohania solenopsae* (Williams et al. 1998) and *Pseudacteon* phorid flies (Gilbert and Morrison 1997), were already underway at BFL during the period of recovery. Morrison (2002) concludes that "The results of this study should not be interpreted as an indication that detrimental effects of invasive ants will simply disappear with time. *Solenopsis invicta* is a serious pest throughout much of its introduced range in the United States and is spreading….My findings may not be representative of other, more disturbed areas invaded by *S. invicta*." Dr. Rob Plowes (BFL, pers. communication, 2020) noted that *S. invicta* at BFL declines as forest cover increases, but "are back in full force" with soil disturbance or loss of canopy cover. In an expanded study of central Austin, Plowes et al. (2007) found that "some residential areas of Austin form unexpected refuges for native fire ants." Similar to BFL, they attributed the resistance to "low levels of disturbance and continuous plant cover in older residential areas" that were constructed prior to 1980. Conversely, more recent construction has allowed establishment by *S. invicta* through soil disturbance and loss of plant cover, resulting in loss of native ant communities.

S. invicta is not ecologically equivalent to native fire ants, particularly *S. geminata*, which feeds on seeds and impacts the soil seed bank; whereas *S. invicta* is an aggressive predator and thus impacts the entire arthropod community (Tennant & Porter 1991, LeBrun et al. 2012). In Central Texas, *S. invicta* colonies are usually polygyne, while *S. geminata* colonies tend to be monogyne, which allows *S. invicta* to form large interconnected colonies. *S. geminata* is now rare in rural Travis County due to habitat loss and displacement by *S. invicta* (Plowes et al. 2007).

S. invicta is a concern especially for cave crickets, because both species forage on the surface at night, *S. invicta* is known to feed on cave crickets, and the cave cricket plays a critical role in provision of nutrients into the karst ecosystem (Taylor et al. 2007). Taylor et al. (2007) found that when cave cricket numbers decrease, in-cave fauna decrease. Peterson et al. (2009) modeled *S. invicta* impacts on cave cricket populations in which some scenarios resulted in complete cave loss, and vulnerability increased with decreasing cave size. They concluded that while even the largest caves are at risk, small caves (K $\leq$500 cave crickets) are especially vulnerable to extirpation (Peterson et al. 2009).

Zara Environmental (2009) found that cave crickets experienced a significant decline in Temples of Thor Cave (within a 105-acre preserve) from 1992-2009, but in-cave counts remained above 500 in spring 2009. *T. reyesi* counts increased significantly after initiating treatments to control *S. invicta* in 1998, which suggests other sources of nutrients increased during this time period that more directly benefited *T. reyesi*. Zara Environmental (2009) noted an increase in mammal scat following *S. invicta* treatments, which may have increased the number of springtails, mites, and/or other prey that *T. reyesi* feeds on. “In addition to the presence of scat, a high number of carcasses at varying states of decay were noted at Temples of Thor Cave. These carcasses provide a veritable feast for multiple cave organisms including springtails, mites, fungus gnats, beetles, and provide a nutrient rich nest for eggs and larvae of various invertebrates.”

The tawny crazy ant (*Nylanderia fulva*) is an invasive ant species from South America that was first reported near Houston, Texas in 2002. Similar to *S. invicta*, *N. fulva* invasions reduce the diversity of native ants and other arthropods, including karst fauna (Figure 4). Where *N. fulva* has invaded karst ecosystems, it tends to be present in high numbers inside caves during hot, dry summers and low density in winter, so is likely to have the greatest impact in the summer months (LeBrun 2017), when *T. reyesi* densities tend to be at their highest. In a study of a single cave (No Rent Cave) in northern Travis County with moderate *N. fulva* density, LeBrun (2017) found that the abundance of four karst invertebrate species, including *T. reyesi*, declined in association with *N. fulva* presence, but was only significant for the troglophilic spider *Cicurina varians*. “However, because this level of impact arises from only a very limited invasion of the cave by TCA [*N.* fulva] over a very short period of time, we expect that it is also not generalizable to TCA invasions of other caves. Had the invasion at No Rent Cave been of similar magnitude as that at Whirlpool Cave, impacts upon karst invertebrates would have been substantially larger.” LeBrun expects that other cave floor-dwelling species similar to *C. varians*, including *T. reyesi*, are likely to show significant declines in response to higher densities and/or more prolonged *N. fulva* invasions.

Figure 4. *Nylanderia fulva* attacking *Ceuthophilus* spp., Whirlpool Cave (photo by City of Austin), Austin, Texas.

N. fulva colonies have been showing up throughout the Austin area and Travis County for the last nine years (LeBrun, pers. comm. 2020). The most notable of these have been found at Briarcliff by Pace Bend Park, the MetCenter, Convict Hill, McNeil High School, Anderson Mill, Emma Long Park, Walnut Creek, and Roy G. Guerrerro Park (Figure 5). The Convict Hill and McNeil populations were found to temporarily impact two Balcones Canyonlands Preserve caves, Whirlpool and No Rent, respectively (LeBrun 2017).

The *N. fulva* colony at Anderson Mill was discovered west of the FM 620 N and Anderson Mill Rd intersection in the summer of 2017. Travis County and the City of Austin have since partnered with Dr. Ed LeBrun and BFL to monitor and inoculate this population with a biological control agent (a microsporidian parasite, *Myrmecomorba nylanderiae*) due to its close proximity to golden-cheeked warbler habitat and sensitive karst environments of the BCP. During this time, the *N. fulva* population has been observed foraging in high densities within the tree canopy and in Bomb Shelter Cave (Travis Clark, pers. comm. 2020) as it continues a southward progression along the developed interface of FM 620 N (Figure 6).

LeBrun et al. (2013) observed that *N. fulva* populations can expand an average of 180 m per year in high density sites and 175 m per year when they are found in moderate densities. Other studies have found in extreme cases they can reach an expansion rate of 100 m a month or 1 km a year (Zenner-Polania 1990). In fact, the Briarcliff population was first reported in December of 2011 and has expanded roughly 2,030 m over 7.5 years at ~270 m a year (LeBrun, per. comm. 2020). It is obvious that the Anderson Mill colony is spreading, but the rate at which it is doing so seems to be governed by the habitats they encounter. Data shows that they tend to slow down in areas where they are presented with an assortment of three-dimensional options, such as an extensive intact forest community or an underground karst system; only progressing 0 – 20 m per year. This implies that the population is potentially exploiting resources above and below ground. The fastest expansion of this colony has been observed in the open landscapes and developed areas on the northern and western sides of FM 620 N; progressing at a rate of 50 – 180 m per year. At this time, the leading edge of the invasion is approximately 3 – 4 km from a particularly dense assemblage of Balcones Canyonlands Preserve caves managed by Travis County and the City of Austin harboring *T. reyesi*.

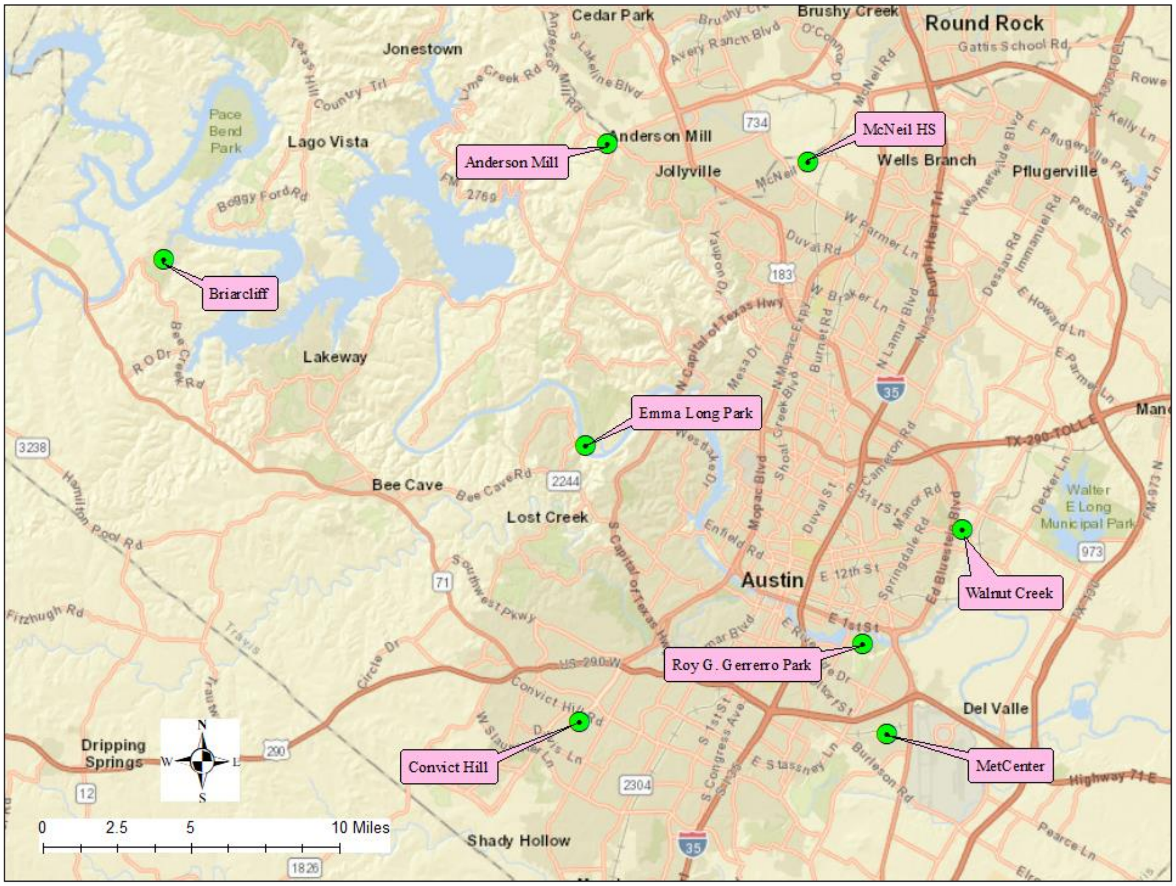

Figure 5: *Nylanderia fulva* colony locations found throughout Travis County since 2011.

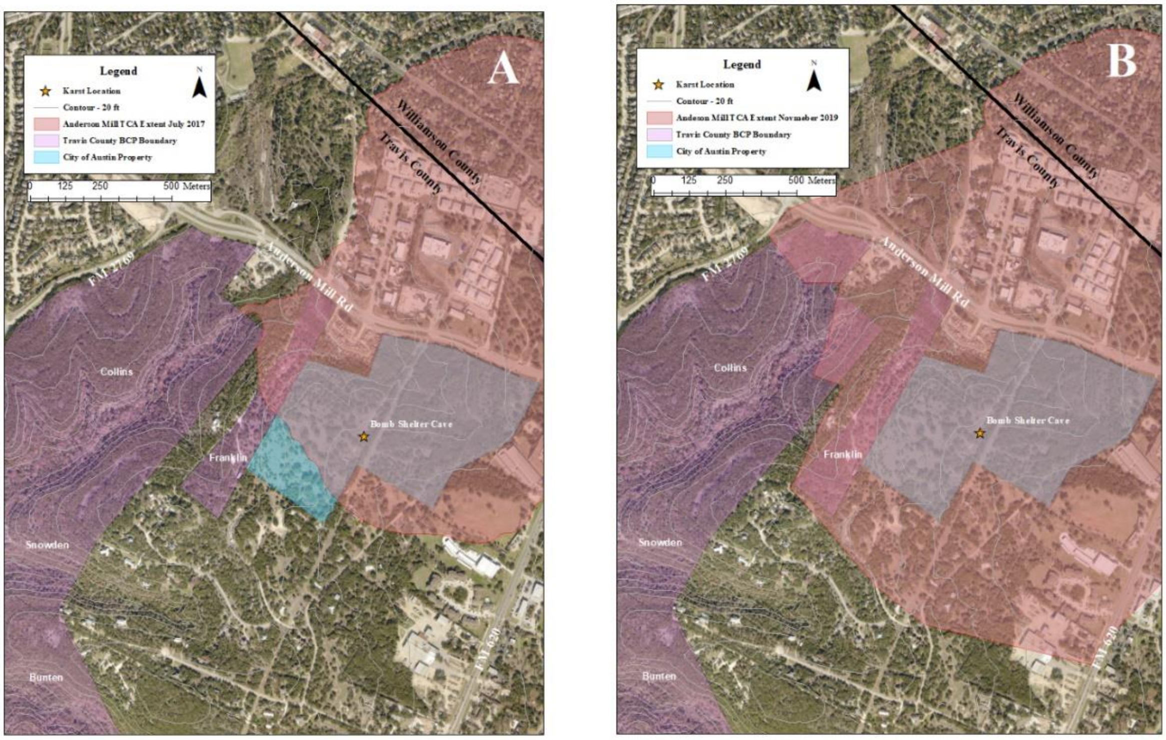

Figure 6. Maps depicting the extent of the Anderson Mill *Nylanderia fulva* population upon detection in (A) July 2017 to (B) November 2019.

The fungal pathogen white-nose syndrome (*Pseudogymnoascus destructans*) poses another threat to karst ecosystems. Two of the most common bats found in Central Texas caves are the tri-colored bat (*Perimyotis subflavus*) and the cave myotis bat (*Myotis velifer*). These bats can become infected with the white-nose syndrome and suffer mass mortality (O'Keefe et al 2019, Powers et al 2015). In 2018, the fungus was detected in Central Texas caves and by 2019, biologists reported finding high levels of the fungus on *M. velifer* at several Central Texas locations. It has now been found in 21 counties across the state, and on February 23, 2020, the first infected bat (*M. velifer*) was found dead in Central Texas (TPWD 2020). This new, deadly pathogen could greatly reduce the number of bats inhabiting caves, and therefore reduce vital nutrients for cave-obligate species. According to TexBio Fauna Records (TSS 2020) for Williamson County, *P. subflavus* has been documented in 26 *T. reyesi* caves, and *M. velifer* has been confirmed in 19 *T. reyesi* caves. For Travis County, *P. subflavus* has been confirmed for three *T. reyesi* caves, and *M. velifer* has been confirmed for three caves including the large maternity colony in McNeil Bat Cave. Bat guano is an important resource for springtails (Santos et al. 2013). The subsequent loss of bat guano as a food resource will likely negatively affect populations of smaller taxa, like springtails, on which *T. reyesi* may depend.

Factor D – Inadequacy of existing regulatory mechanisms.

The adequacy of existing regulations for the protection of *T. reyesi* is limited by the emphasis on water quality protection rather than karst species habitat protection. The City of Austin, Travis County, Williamson County, and TCEQ Edwards Rules (30 Texas Administrative Code, Chapter 213) implemented cave/karst feature protection in the mid-1990s with an emphasis on protection of the Edwards Aquifer. Reliance on existing municipal and state regulations that do not specifically address protection of karst ecosystems are inadequate to protect *T. reyesi*, much less ensure its continued survival. Below is a brief summary of some of the current deficiencies.

Texas Commission on Environmental Quality (TCEQ) Regulations (Geological Assessment Standards) - TCEQ (2004) standards for geologic assessment include:

> *"Geologists doing the assessment are not asked to express a high degree of certainty about flow characteristics and communication to the subsurface to rank features as sensitive, as uncertainty is already expressed in the language of the Edwards Aquifer rules."*
>
> *"The Edwards Aquifer rules require that this report is to be prepared by a geologist. The rules specify that the qualifications of the geologist are that he or she "has received a baccalaureate or post-graduate degree in the natural science of geology from an accredited university and has training and experience in groundwater hydrology and related fields, or has demonstrated such qualifications by registration or licensing by state, professional certification, or has completed an accredited university program that enables that individual to make sound professional judgments regarding the identification of sensitive features located in the recharge zone or the transition zone." After September 1, 2003, geologists conducting assessments are expected to be licensed according to the provisions of Texas Geoscience Practice Act. In addition, the geologist should be familiar with standard karst, hydrology, and Edwards recharge zone literature."*
>
> *"Tests such as excavation, cave mapping, infiltrometer tests, geophysical studies, or tracer studies are not required for the geologic assessment of any feature."*

Geologic assessments submitted for proposed development sites typically do not identify caves that are present. For example, Hauwert and Johns (2016) discussed a case where intensive development and wastewater irrigation associated with a subdivision development were proposed on a 608-acre tract. The geologic assessment submitted to the TCEQ did not report caves and only identified 31 karst features. An independent survey conducted on the same property by the City of Austin and Barton Springs/Edwards Aquifer Conservation District found 140 sensitive features; seven of which were caves, three were large sinkholes with likely cave drains, and five were additional features that appeared to be filled caves. An additional cave was later reported by a geologist representing the property owners. The geologic assessment is the initial step for protection of caves in much of the *T. reyesi* karst faunal areas. This example demonstrates that species protection may be inadequate if the geologic assessment for a site is inaccurate. Geologic assessments of other caves (for example, HQ Flat Cave and Flint Ridge Cave) have also undervalued their significance (Hauwert 2009). These examples are all from the Barton Springs segment of the Edwards Aquifer. However, the northern segment that encompasses *T. reyesi*'s range does not have a groundwater district, so these problems are likely even worse.

The loss of Ballenton Cave is another example of the inadequacy of TCEQ rules to protect karst ecosystems. On September 18, 1993, Barton Springs/Edwards Aquifer Conservation District hydrogeologist Nico Hauwert and Texas Speleological Association member William Russell found filled Ballenton Cave which they excavated, mapped, and reported to TCEQ on January 4, 1994, in a comment letter copied to the applicants. Ballenton Cave was briefly opened of fill in the entrance to reveal a cave 30 feet long and 15 feet deep and continued in sediment-filled passages. On February 7, 1994, the applicant amended their Water Pollution Abatement Plan to note:

> "*Two recently discovered features are 165A and 165B (Ballenton Cave). Though not considered significant due to drainage areas less than 0.25 acre, they merit discussion. Feature 165A, when discovered was dirt and rock filled. Subsequent opening of the feature by unknown person or persons left the sink exposed without the natural filtration it previously had. With TNRCC concurrence, the sink has been refilled with rock and dirt to return it to the previous natural ground elevation. During construction silt fence is to be placed around the feature for further protection. Feature 165C is located in Ballenton Lane. The only current recharge is the rain that falls directly on the feature. If the feature leads to more substantial subsurface cavities discovered during excavation or trenching, then appropriate measures will be taken at such time.*"

Neither Ballenton Cave, Salamander Mountain Cave, Grassy Cove Cave, La Crosse Cave, or Wildflower Cave nor many other sinks encountered were reported on the Geologic Assessments that were submitted to the TCEQ with the Water Pollution Abatement Plan (WPAP) applications. Both Ballenton Cave and Salamander Mountain Cave were subsequently covered with residential lots and homes. Many other well-known caves have also been built over, including 250-foot long Spyglass Cave (east of Mopac South and Spyglass Drive) and Dead Dog Cave west of Mopac at Steck Avenue. These examples point to the possibility for loss of potential *T. reyesi* habitat due to inaccurate Geologic Assessments.

<u>State and Local Regulations (Buffers and Void Mitigation)</u> - State and local regulations may establish buffers around the relatively few caves that are identified prior to development. However, these buffers are based solely on protecting water quality and are not adequate for endangered species protection. TCEQ (2005) notes:

> *"Sensitive features should be identified before the tract is subdivided and proposed locations for roads or structures defined so that they may be avoided. The sensitive features identified in the Geological Assessment should not be sealed, but instead protected from the potential impacts of stormwater runoff from any new development in the area. These features are analogous to icebergs in that the surface expression represents only a fraction of the spatial extent of the feature that exists just below the soil profile. Because these features can accept recharge over a substantial area, providing treatment of runoff only within the depression may lead to degradation of water quality in the aquifer…Consequently, the best protection of these features is provided by a natural buffer area sized based on the drainage area for the feature."*

"The natural buffer around a feature should extend a minimum of 50 feet in all directions. Where the boundary of the drainage area to the feature lies more than 50 feet from the feature, the buffer should extend to the boundary of the drainage area or 200 feet, whichever is less."

"Where extenuating circumstances exist and development over a significant point recharge feature and its catchment is proposed, the developer can consider demonstrating that no feasible alternatives to construction over the sensitive feature exist. Feasibility of alternatives should be based primarily on technical, engineering and environmental criteria. Feasibility should not be based predominantly on marketing or economic considerations or special or unique conditions which are created as a result of the method by which a person voluntarily subdivides or develops land. Where extenuating circumstances are approved by the TCEQ, the developer should provide alternatives to make up for the loss of recharge to the aquifer."

Mitigation of karst features, also termed voids, encountered during construction is regulated in the Edwards Aquifer Recharge and Transition Zones by the TCEQ Austin and San Antonio regional offices. The terms used are "encountered feature" and "solution feature." Neither the Edwards Rules, nor the Technical Guidance Manual for Compliance with the Edwards Rules (TCEQ 2005), nor the Edwards Aquifer Protection Program (EAPP) guidance for inspection and evaluation of encountered features includes a requirement to observe or identify invertebrate species. As a result, TCEQ staff does not consider species protective measures when reviewing descriptions of encountered features or the proposed mitigation plans to protect infrastructure and prevent pollution of the Edwards Aquifer. Protective measures require that encountered features be sealed with concrete at the plane of interception. This action results in altered and bisected subsurface void interiors, and possibly interrupts mesocavern connectivity to nearby occupied caves. The existence of these regulations should not be relied upon as a protective strategy for *T. reyesi*.

The City of Austin and Travis County's subdivision environmental regulations are stipulated in the City of Austin's Code of Ordinances, Land Development Code (LDC) Sections 25-8-121, 25-8-151, 25-8-281, 25-8-282, 30-5-151, 30-5-281 and 30-5-282. Section 25-8, applicable to the City of Austin, and Section 30-5, Travis County's subdivision regulations, have the same content and criteria related to cave protection (City of Austin, 2020). The City of Austin (2020) regulations for cave protection are explained in the Environmental Criteria Manual:

"1.10.0 - CRITICAL ENVIRONMENTAL FEATURE IDENTIFICATION AND PROTECTION
1.10.1 - Statement of Intent
The intent of these guidelines is to assist applicants in complying with the Land Development Code (LDC) Sections 25-8-121, 25-8-151, 25-8-281, 25-8-282, 30-5-151, 30-5-281 and 30-5-282. The guidelines specify and outline the decision-making process for the identification, evaluation and determination of protective buffers for critical environmental features (CEFs) for the Environmental Resource Inventory (ERI) Report. Source: Rule No. R161-14.25, 12-30-2014 .

1.10.2 – Background
A. In adopting the Land Development Code, the Austin City Council found that:
1. Protection of critical environmental features such as caves, sinkholes, springs, canyon rimrocks and bluffs is necessary to protect water quality in those areas most susceptible to pollution;
2. Minimum standards should be adopted and applied as general principles for the conservation and development of land. The purpose of the standards are:
(a) To prevent loss of recharge to localized aquifers supplying local seeps and springs essential to the maintenance of the ecosystem and the baseflow and water quality of many of Austin's creeks; and
(b) To maintain or enhance the water quality of the Edwards Aquifer by protection the water quality of surface water recharging the Edwards Aquifer.
B. Thus, the underlying principles and objectives of the watershed regulations with respect to critical environmental features are the:
1. Protection of the natural character and function of CEFs;
2. Protection of groundwater quality and quantity through protecting and maintaining recharge; and,
3. Protection of surface water quality and quantity through maintaining the quality and quantity of surface water runoff and overland flow."

Void mitigation regulations of the City of Austin require protection of karst features that are intercepted during construction activities, typically during trenching. The City of Austin Land Development Code, Chapter 25-8, Section 25-8-281 (D) requires compliance with the Void and Water Flow Mitigation Rule in Section 1.12.0 of the Environmental Criteria Manual and Item No. 658S of the Standard Specifications Manual (City of Austin 2020). These requirements emphasize water quality protection, rather than karst species habitat protection. In particular, the necessity to seal off the intercepted void with concrete along the wall or floor of a trench may result in the disruption of *T. reyesi* habitat or connectivity to sources of nutrients. Attachment B has additional information on the lack of sufficient karst ecosystem protection from void mitigation.

Both TCEQ and City of Austin protection measures for caves are based on protecting the Edwards Aquifer from water-born contamination rather than protecting cave ecosystems. The recommended buffer sizes are significantly smaller than the USFWS (2012) standards for karst preserves and should not be relied upon for long-term sustenance. These regulations also lack oversight after development construction is complete. Once karst buffers are established at the time of permitting, very few cave or karst buffers have follow-up inspections to ensure that the buffer is maintained and is not encroached by land disturbances such as trash dumping, vegetation clearing or other alterations. The City of Austin implemented Critical Environmental Feature Buffer Maintenance and Inspection requirements as Section 1.10.5 of the Environmental Criteria Manual. This rule, effective December 30, 2014, is enforced by City of Austin Watershed Protection Department staff. Landowners of buffers must conduct inspections every 6 months and retain records for 3 years for City of Austin review. There is not a program for routine reporting requirements or inspections by City of Austin staff, at this time. If a cave is not routinely monitored due to other regulatory entity requirements, then preservation of surface habitat and ecological support services for the benefit of *T. reyesi* may not be assumed.

<u>Balcones Canyonlands Preserve</u> - The federal section 10 permit that established the Balcones Canyonlands Preserve in 1996 requires a minimum of 62 caves be protected as mitigation for loss of karst habitat in western Travis County. Of these 62 caves, *T. reyesi* has been documented in 22 (updated to reflect recent taxonomic revisions for *Texella* in Jester Estates Cave and Spider Cave). Based on information provided in Travis County and City of Austin (2019) and by Balcones Canyonlands Preserve staff, the following is a brief overview of the status of these 22 caves:

- Seven caves have had robust hydrogeological studies as described by Hauwert and Cowan (2013) that utilize direct tracing, site geology, drip chemistry and elevation of drip horizons to map the subsurface; four of these caves are in the Jollyville Plateau karst fauna region (KFR), and three are in the McNeil/Round Rock KFR.

- Three caves are on City of Austin or Travis County tracts and meet the USFWS (2012) karst preserve guidelines, in that all three have at least 100 acres protected around the cave entrance; these caves are in the Jollyville Plateau KFR.

- Twelve caves are owned by the City of Austin or Travis County, but due to historic or recently permitted development, less than 40 acres are protected around the cave entrance. Because these 12 caves do not have sufficient surface and subsurface habitat necessary for long-term sustenance of the karst fauna ecosystems, active management is required to maintain them. One of these caves is in the Central Austin KFR, eight are in the Jollyville Plateau KFR, and three are in McNeil/Round Rock KFR. Below are a few examples of management challenges for these caves:

    - Two caves owned by the City of Austin are not formally managed as part of the Balcones Canyonlands Preserve (one in Central Austin KFR, one in McNeil/Round Rock KFR); the McNeil/Round Rock cave was filled historically, and its location is unknown. Many caves were historically filled across Central Texas for reasons including keeping runoff at the surface for water supply to mills, stock ponds for livestock, trash disposal, eliminating fall hazards for livestock and encroaching urbanization, and as an investment strategy to facilitate future development (Hauwert, 2009; Veni and Hauwert 2015). Removing this cave fill is much more difficult an effort than filling them was, generally by hand excavation, one bucket at a time.

    - No Rent Cave entrance is located 20 feet from the edge of its preserve.

    - The entrance of Weldon Cave is only 40 feet from the edge of its established preserve, and its cave footprint extends off of its preserve.

    - Root and North Root Caves are located less than 50 to 30 feet from the edge of their preserve and a recently developed shopping mall.

    - Tooth Cave is located about 200 feet from a major highway and about 250 feet from the same recent shopping mall.

- Three caves are on private property and covered under a separate 10(a) permit or section 7 consultation, and whether these caves are being actively managed or if the caves are still viable karst ecosystems is unknown; all three are in the Jollyville Plateau KFR.

- Four caves have no formal protection and are in the McNeil/Round Rock KFR. Within this KFR, McNeil High School expansion has encountered several sizable caves during construction, including "Cave 19" intercepted in July 2018 (Austin American Statesman, 15 July 2018). The significant number and size of caves intercepted during construction is indicative of the challenge of supporting the viability of this KFR due to the dissection of subsurface habitat by utility pipes and concrete seals to separate the pipes from karst feature openings.

T. reyesi's range encompasses a total of 213,415 acres, of which 138,443 acres are known or have a high probability of suitable habitat (USFWS 2018). The Balcones Canyonlands Preserve encompasses approximately 7,632 acres, but only 2,586 acres are in the high probability of suitable habitat zones (<2% of *T. reyesi*'s range). The other 5,046 acres are in valleys and canyons that are below the cave-forming geologic layers, so the presence of *T. reyesi* in those areas is very unlikely. Karst preserve sizes range from a few acres to over 1,000 acres. Travis County contains approximately 27% of *T. reyesi*'s range and approximately 90% the collective preserve lands within its range.

<u>Williamson County Regional Habitat Conservation Plan (RHCP)</u> - Williamson County development activities that may impact *T. reyesi* may apply to participate in the Regional Habitat Conservation Plan (SWCA, 2008) or seek an individual permit from the U.S. Fish and Wildlife Service. Incidental take of covered species is listed in the RHCP for the following activities: "road construction, maintenance, and improvement projects; utility installation and maintenance, including but not limited to power and cable lines; water, sewer, and natural gas pipelines; construction of plants and other facilities; school development or improvement projects; public of private construction and development; and land clearing."

The level of take of species-occupied caves is considered within either an Impact Zone A, described as 50 to 345 feet (ft) from cave footprint, or within an Impact Zone B, described as within 50 ft of a cave footprint. RHCP participants pay fees of $10,000 per acre to conduct development activities within Impact Zone A, or a $400,000 flat fee to disturb the area within Impact Zone B. If previously undetected species-occupied voids are disturbed outside of Impact Zones A and B and within the Karst Zone, then a $100 per acre fee is required. Fees are intended to support the Williamson County Conservation Foundation (WCCF) efforts to purchase and manage Karst Faunal Areas (KFAs) to offset the species take in individual caves and karst features that are impacted by development. In rapidly urbanizing areas, the strategy is likely to result in reduced protection of the surface and subsurface habitat of individual caves. Void interception during trenching or subsurface utility construction, even if species-occupied, does not require specific protective measures as part of the mitigation or closure of the void. Therefore, subsurface habitat loss for *T. reyesi* may occur when species-occupied mesocaverns are intercepted and subsequently partially or completely filled with concrete as part of void mitigation for water quality protection.

T. reyesi's range encompasses a total of 213,415 acres, of which 138,443 acres are known or have a high probability of suitable habitat (USFWS 2018). The WCCF preserves encompass approximately 886 acres, less than 1% of *T. reyesi*'s range. Preserve sizes range from 3 to 173 acres and average 32 acres, less than the 40 acres recommended for a medium-quality preserve (USFWS 2012). While Williamson County contains approximately 73% of *T. reyesi's* range, it contributes approximately 10% to the preserve land within the range.

Summary - Existing state regulations, namely the Edwards Rules administered by the TCEQ, for karst feature protection within *T. reyesi*'s range, do not address endangered species habitat or karst ecosystem protection. The City of Austin and Travis County have karst feature regulations that also emphasize water quality, but not endangered species or karst ecosystem, protection. Thus, reliance on these regulations for long term viability of *T. reyesi* will not ensure its long-term survival. The Balcones Canyonlands Preserve and Williamson County RHCP are the most notable municipal programs for *T. reyesi* habitat protection and collectively protect less than 5% of karst habitat within *T. reyesi*'s range. While it continues to be a struggle to establish proper cave preserves and management while karst species are listed as endangered, much less effort would be justified and garnered if *T. reyesi* were delisted.

Factor E – Other natural or manmade factors affecting its continued existence.

Recent scientific evidence demonstrates increases in average air temperatures in the last 50 years, coupled with an increase in heat waves and more erratic, heavy precipitation events (IPCC 2007). These trends are projected to continue and increase in the next century with the southwest being the most impacted of the continental United States (IPCC 2007). Due to their restricted distribution and sensitivity to fire and drought, Ashe juniper-oak forests are particularly vulnerable (Galbraith and Price 2009). Climate change impacts may include increased drought and heat stress, flooding, wind damage, invasive plants and animals, insect damage, and pathogens (Brandt et al. 2020). Following an extreme drought in 2011, Crouchet et al. (2019) reported 20% crown mortality for Ashe juniper and 23% for live oak across the Edwards Plateau, with tree mortality decreasing with increasing tree size. If these trends continue, further tree mortality and shifts toward more xeric (drier) conditions and drought-tolerant species is expected, with a concomitant decline in forest ecosystem services (Brandt et al. 2020).

As stated under Factor A, these native Ashe juniper-oak forests provide stable temperatures, humidity, and nutrients that karst ecosystems depend on, so loss of canopy cover will result in hotter, drier, and more extreme conditions of both the surface and subsurface karst environment. Shallow caves (generally 20 to 30 feet in depth) occupied by *T. reyesi* will be especially vulnerable to global warming. Rainfall regime changes and more extreme rain events may also impact the cave environments by flooding, filling in with debris, and/or adversely affecting nutrient inputs.

Yearwood et al. (2014) mention "minor signs of decline" in Holler Hole Cave in the Sun City development that they attributed to "a prolonged period of drought and presence of an Ashe juniper above the cave." While they acknowledge the impact of climate on karst ecosystems and that the species retreat deeper into caves under dry surface conditions, they do not report whether the decline was of *T. reyesi* counts or other cave fauna, or provide supporting data. Since Ashe juniper is a key component of Central Texas karst ecosystems, their rationale for a native tree contributing to the decline is unclear. Their statement that Ashe juniper is an example of "excessive drying vegetation" is also unsupported (for example, see O'Donnell 2019 and O'Donnell et al. 2020) and can encourage removal of native vegetation that are an integral part of these karst ecosystems.

Millipede Cave is an example of what can happen when a cave has inadequate setbacks from adjacent development. When Millipede Cave was mapped in October 1992, the cave and the adjacent Millipede Annex Cave were named after millipedes (*Speodesmus* sp.) due to the large numbers of *Speodesmus* sp. in the cave at that time (Mike Warton, pers. comm.). Both caves are in a courtyard surrounded by a high school, which opened in August 1992. When Balcones Canyonlands Preserve staff first surveyed Millipede Cave in 2010, they observed 6 to 12 *Speodesmus* sp. and 0 to 10 *Texella*. In the fall of 2015, BCP staff initiated faunal surveys twice a year (spring/fall) and to date, rarely observe *Speodesmus* sp. in Millipede Cave, and only a few *Texella*. The lower level of the cave, which is closest to the school's courtyard wall, is damp with many active speleothems, where *Speodesmus* sp. and *T. reyesi* should be abundant; however, this area is now mostly devoid of life. This may be due to pesticide application along the wall of the courtyard seeping into this zone; the drier portion of the cave still has karst fauna including listed species. In December 2018, Balcones Canyonlands Preserve staff discovered a non-native arachnid in Millipede Cave, the short-tailed whipscorpion (*Stenochrus portoricensis*). *S. portoricensis* is native to the Yucatan Peninsula and is believed to survive in greenhouses, so it may have been accidentally introduced when rose bushes from a local nursery were planted near the cave. Since there are so few *Texella* in this cave, Balcones Canyonlands Preserve staff has not observed any interactions between *S. portoricensis* and *T. reyesi*; however, they have observed *S. portoricensis* apparently chasing the endangered Tooth Cave spider (*Tayshaneta myopica*), so one could infer that this newly introduced, fast moving predator could negatively impact *T. reyesi*.

With rapidly increasing urban development in *T. reyesi*'s range (see Attachment A), increased impacts from exotic species are expected. Millipede Cave provides a prime example of a species introduction from the landscaping industry, with yet unknown impacts. One species we may already be seeing competitive exclusion impacts from is the greenhouse millipede (*Oxidus gracilis*). *O. gracilis* is native to Japan and has spread globally, likely aided by the landscaping industry (Hoffman 1999). *O. gracilis* is now commonly found in Central Texas caves and are thought to "both compete with native species and harbor potential diseases" (Reeves 1999). Balcones Canyonlands Preserve staff routinely see them in caves, usually associated with organic matter that has washed into caves. By consuming this organic matter, they likely disrupt the natural food chain, removing the food source for *T. reyesi* prey. Also, this idea of non-native species harboring diseases is one that we have not seen documented as a potential danger to *T. reyesi*, but should be considered. Additionally, Lewis and Lewis (2015) documented large numbers of *O. gracilis* in an endangered species cave and expressed concern about their toxic secretions which contain phenol, hydrogen cyanide, and benzaldehyde.

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Land Cover Change in Proximity to Confirmed *Texella reyesi* Sites

by Colin Strickland

Introduction

The Bone Cave Harvestman (*Texella reyesi*) was listed as endangered due to habitat loss from increasing urbanization. The full list of threats cited can be found in the Appendix. Both Travis and Williamson counties continue to have high population growth and the development that goes with it. The population of Travis County has increased from 557,219 in 1988 to 1,273,954 in 2019, an increase of 128.63%. The population of Williamson County has increased from 129,602 in 1988 to 590,551 in 2019, an increase of 355.67% (Resident Population in Travis/Williamson County, TX). The Texas Demography Center projects that in 2050 the population of Travis County will be 1,970,000 and the population of Williamson County will be 1,640,000. That is an increase of 54.64% for Travis County from 2019 and an increase of 177.71% for Williamson County from 2019 (Center for Austin's Future).

Methods

This analysis looks at land cover change around confirmed *T. reyesi* sites. The land cover data is from the National Land Cover Database (NLCD) which is produced every 5 years by the Multi-Resolution Land Characteristics Consortium (MRLC) a partnership of federal agencies (National Land Cover Database). The NLCD has 30 meter resolution with 16 classes of land cover (Figure 1) (National Land Cover Database 2016 Legend). Full Descriptions of each class can be found in the Appendix.

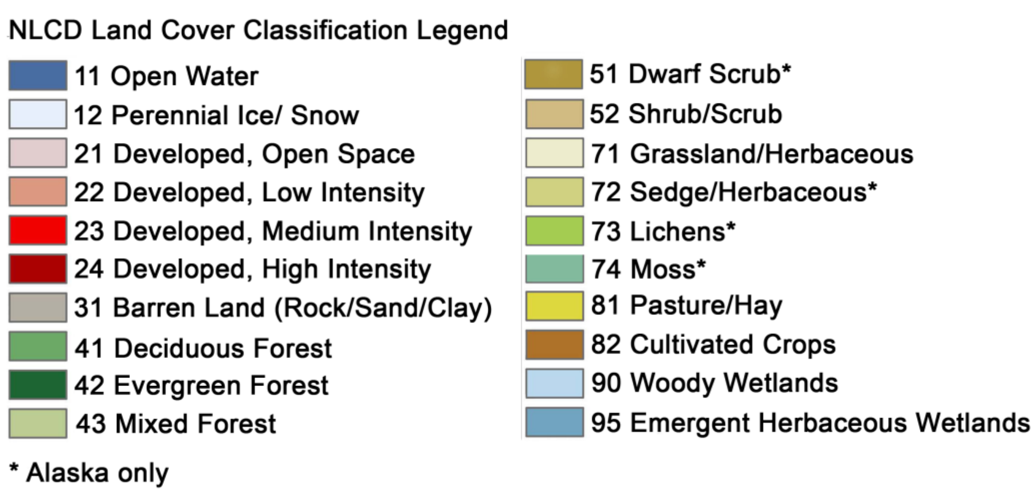

Figure 1. National Land Cover Database Classes

In this analysis I only used NLCD from 2001, 2006, 2011, and 2016. The data sets from 1992 and 1996 had a slightly different classification system which makes it difficult to compare with the new system that started in 2001. The 2020 NLCD is not yet available.

When using all the classes the graphs can get a bit busy so in addition to graphing changes in all land cover classes present, I also made a simplified classification by spitting the classes into two categories: Natural and Developed. Natural includes Deciduous Forest, Evergreen Forest, and Grassland/Herbaceous. Developed includes Developed Open Space, Developed Low Intensity, Developed Medium Intensity, and Developed High Intensity.

I am using a subset of *T. reyesi* sites for several reasons. Due to the sensitive nature of cave locations, especially those containing endangered species, I only had the locations of 156 of the 225 on the USFWS list. I removed duplicates and added two sites missing from the Balcones Canyonlands Preserve. Next, I only include the sites in which USFWS had a high degree of confidence of the presence of *T. reyesi*. The confidence levels in descending order are Confirmed, C, UID, Sight Record and Unverified Reference. I only used the sites classified as Confirmed and C. These are the sites in which USFWS has a high degree of confidence in *T. reyesi*'s presence. The full list of confidence class descriptions can be found in the Appendix at the end of this document. For the remainder of this document I will refer to both Confirmed and C classes together as just confirmed sites.

After excluding the UID , Sight Records and Unverified References, that left 72 Confirmed locations and 76 C locations, for a total of 148. To analyze the land cover change in proximity to these sites, I created two sizes of buffers: a 105 meter buffer, which is the estimated cave cricket foraging area, and a 227 meter buffer, which is an approximately 40 acre circle. Forty acres is the minimum size for a medium quality preserve according to USFWS guidelines (Bone Cave Harvestman (*Texella reyesi*) 5-Year Review 2018). The NLCD from 2001, 2006, 2011, and 2016 were clipped to these buffers and then the counts of cells of each land cover class were exported as tables. With this I could track the changes in land cover by both number of acres as well as by the percent increase or decrease of each class. I first looked at all the confirmed sites together and then I looked at each Karst Faunal Region (KFR) individually. The KFR descriptions can be found in the Appendix (Veni & Martinez 2007).

Results

In the 40 acre circles surrounding all confirmed *T. reyesi* sites, 685.6 acres of natural land cover was converted into developed land cover between 2001 and 2016. In the 40 acres surrounding all confirmed *T. reyesi* sites, natural land cover decreased by 23.0%, dropping from 2980.9 acres to 2295.3 acres. Developed land cover increased by 45.6%, rising from 1502.2 acres to 2187.8 acres between 2001 and 2016 (Figure 2).

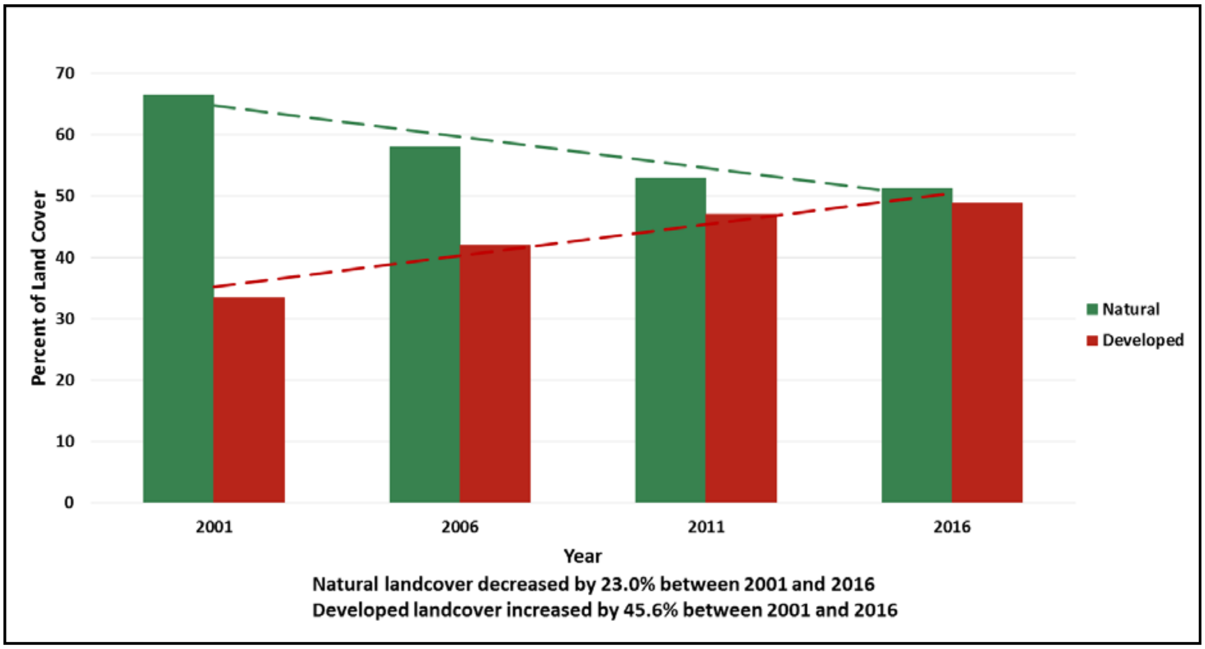

Figure 2. Percent Change of Natural and Developed Land Cover Within 40 Acre Circles Around Confirmed *Texella reyesi* Locations From 2001 to 2016

In the 40 acres surrounding all confirmed *T. reyesi* sites, the percent of land cover of all three natural classes fell. Deciduous Forest fell 29.2% from 694.3 acres down to 491.5 acres. Evergreen Forest fell 14.4% from 1031.0 acres down to 882.9 acres. Grassland/Herbaceous fell 27.7% from 1208.2 acres down to 873.3 acres (Figure 3).

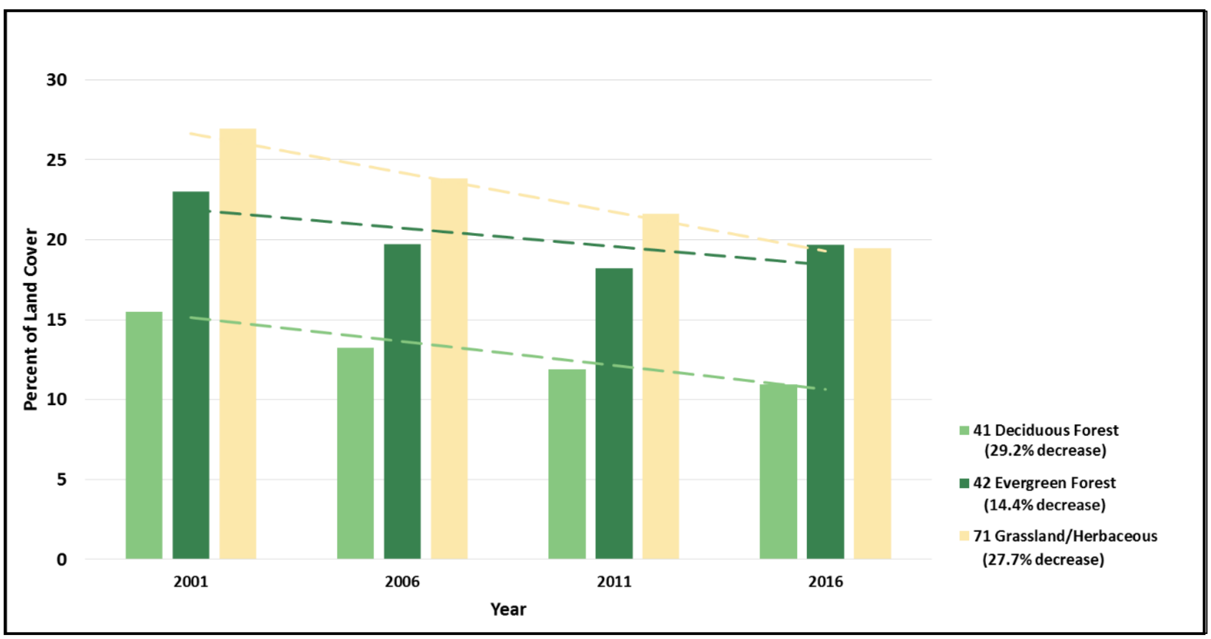

Figure 3. Changes in Natural Land Cover Percentages Within 40 Acre Circles Surrounding Confirmed *Texella reyesi* Locations From 2001 to 2016

In the 40 acres surrounding all confirmed *T. reyesi* sites, the percent of land cover of three out of four of the developed classes rose. Developed Open Space fell 12.6% from 710.5 acres down to 621.1 acres. Developed Low Intensity rose 59.8% from 395.9 acres up to 632.7 acres. Developed Medium Intensity rose 138.2% from 319.1 acres up to 760.1 acres. Developed High Intensity rose 112.2% from 76.7 acres up to 162.8 acres (Figure 4). The drop in Developed Open Space was likely due to its conversion into higher development classes rather than into grassland or forest classes.

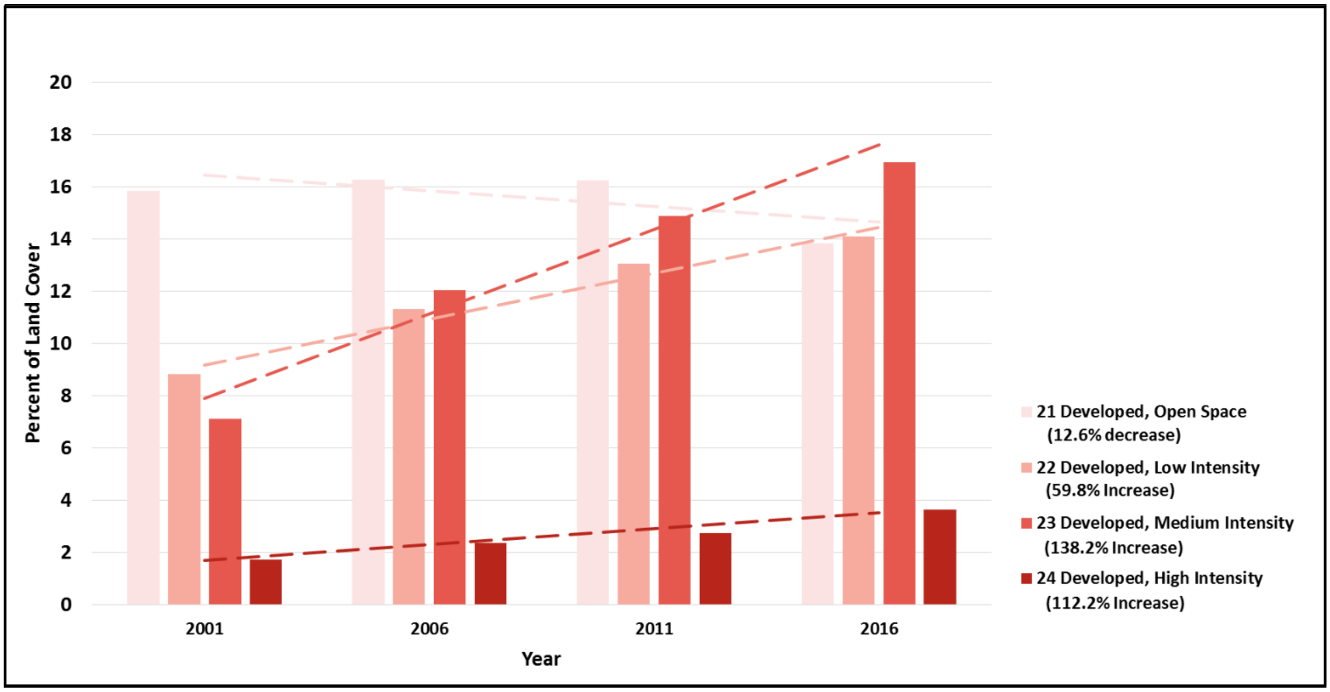

Figure 4. Changes in Developed Land Cover Percentages Within 40 Acre Circles Surrounding Confirmed *Texella reyesi* Locations From 2001 to 2016

In the 105m buffers (8.6 acre circles) surrounding all confirmed *T. reyesi* sites, 165.2 acres of natural land cover was converted into developed land cover between 2001 and 2016. In the 105m buffers surrounding all confirmed *T. reyesi* sites, natural land cover decreased by 19.9% from 831.3 acres to 666.0 acres. Developed land cover increased by 50.6% from 326.7 acres to 491.9 acres between 2001 and 2016 (Figure 5).

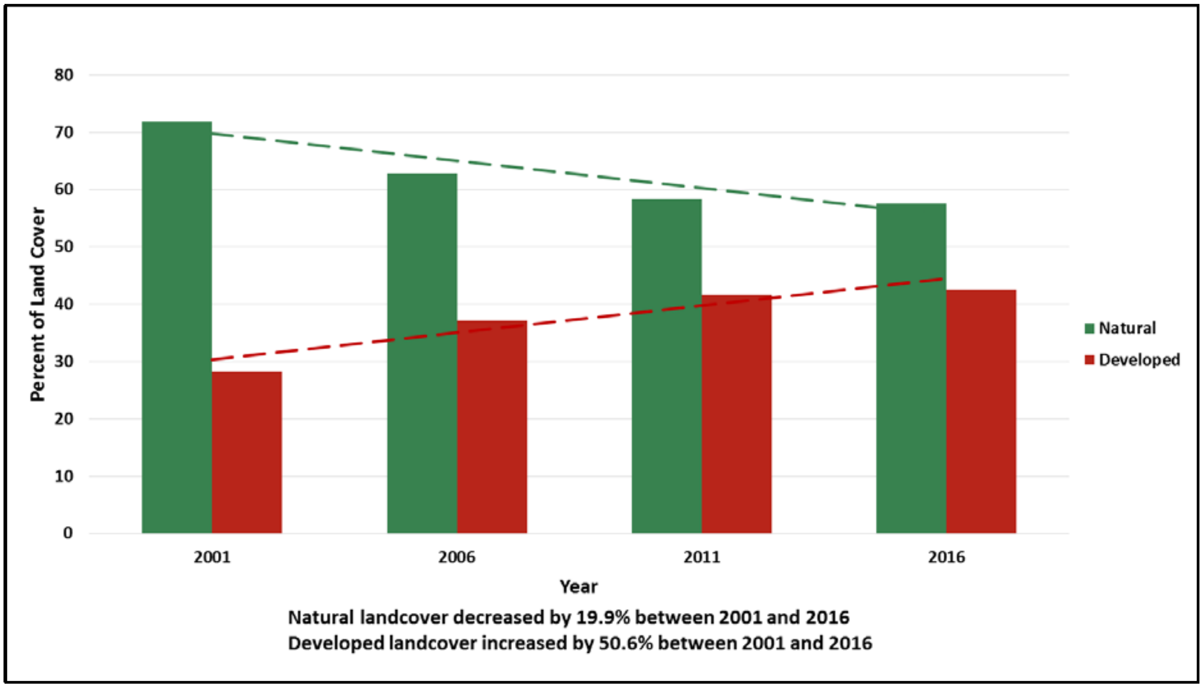

Figure 5. Change in Land Cover Percentages Within 105 Meter Buffers of Confirmed *Texella reyesi* Locations From 2001 to 2016

In the 105 meter buffers surrounding all confirmed *T. reyesi* sites, the percent of land cover of all three natural classes fell. Deciduous Forest fell 23.3% from 199.7 acres down to 153.2 acres. Evergreen Forest fell 9.7% from 295.3 acres down to 266.6 acres. Grassland/Herbaceous fell 28.7% from 330.2 acres down to 235.5 acres (Figure 6).

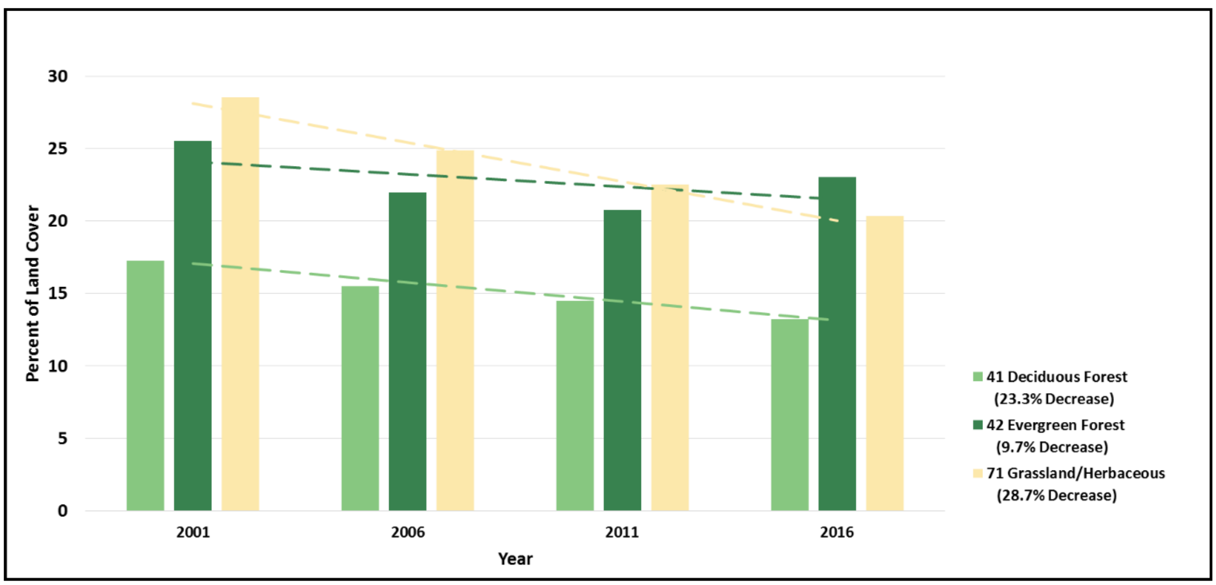

Figure 6. Changes in Land Cover Percentages Within 105 Meter Buffers of Confirmed *Texella reyesi* Locations From 2001 to 2016

In the 105 meter buffers surrounding all confirmed *T. reyesi* sites, the percent of land cover of three out of four of the developed classes rose. Developed Open Space fell 15.3% from 188.8 acres down to 159.9 acres. Developed Low Intensity rose 92.2% from 68.7 acres up to 132.1 acres. Developed Medium Intensity rose 185.5% from 56.9 acres up to 162.6 acres. Developed High Intensity rose 196.4% from 12.2 acres up to 36.2 acres (Figure 7). The drop in Developed Open Space was likely due to its conversion into higher development classes rather than into grassland or forest classes.

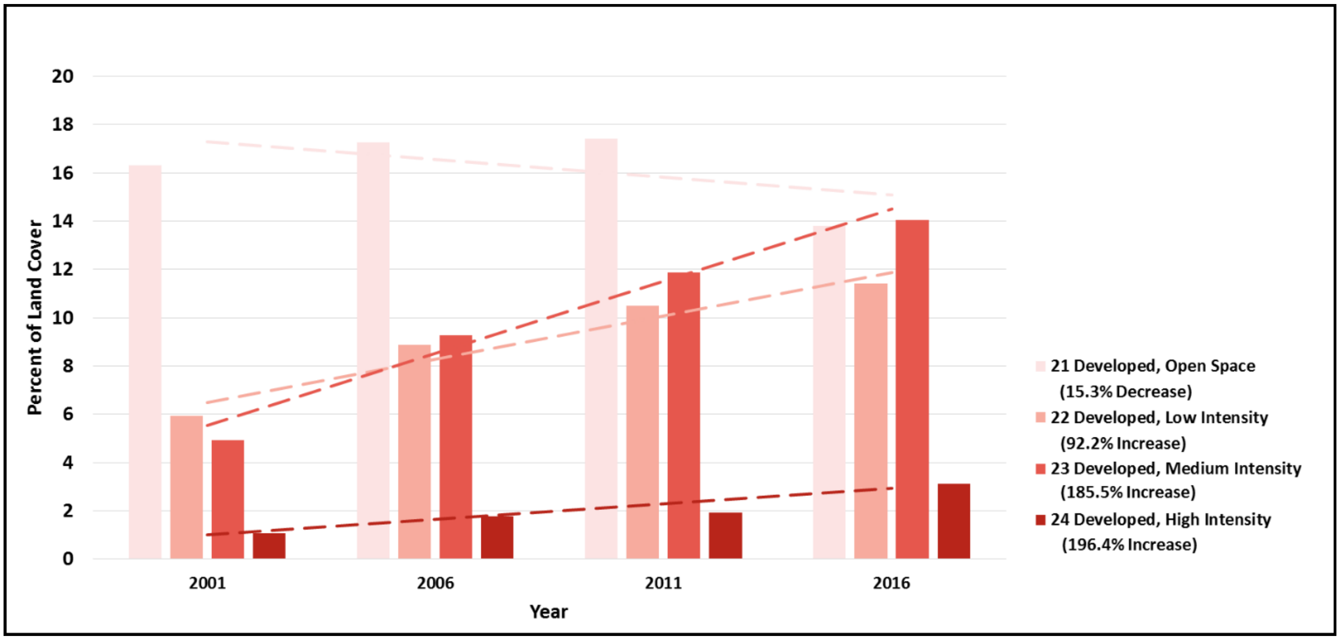

Figure 7. Changes in Land Cover Percentages Within 105 Meter Buffers of Confirmed *Texella reyesi* Locations From 2001 to 2016

There are confirmed *Texella reyesi* locations in six KFRs (Figure 8). A visual overview of land cover change between 2001 and 2016 can be seen in Figure 9. From North to South there are 45 confirmed sites in the North Williamson County KFR, 28 in the Georgetown KFR, 53 in the McNeil/Round Rock KFR, 3 in the Cedar Park KFR, 17 in the Jollyville KFR, and 2 in the Central Austin KFR (Figure 10). A list with the names of each cave and its *T. reyesi* presence confidence level can be found in the Appendix.

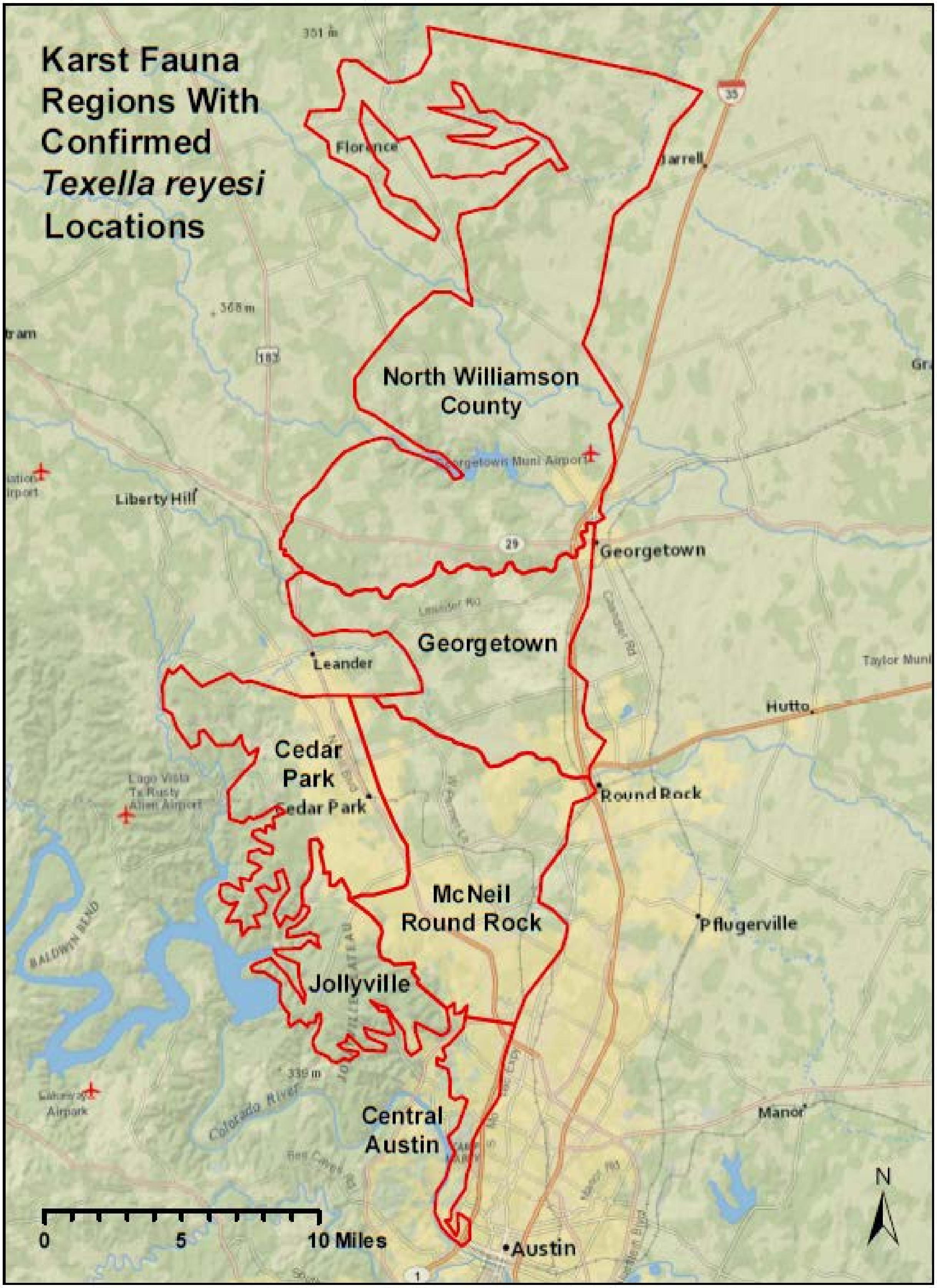

Figure 8. Karst Fauna Regions with Confirmed *Texella reyesi* Sites

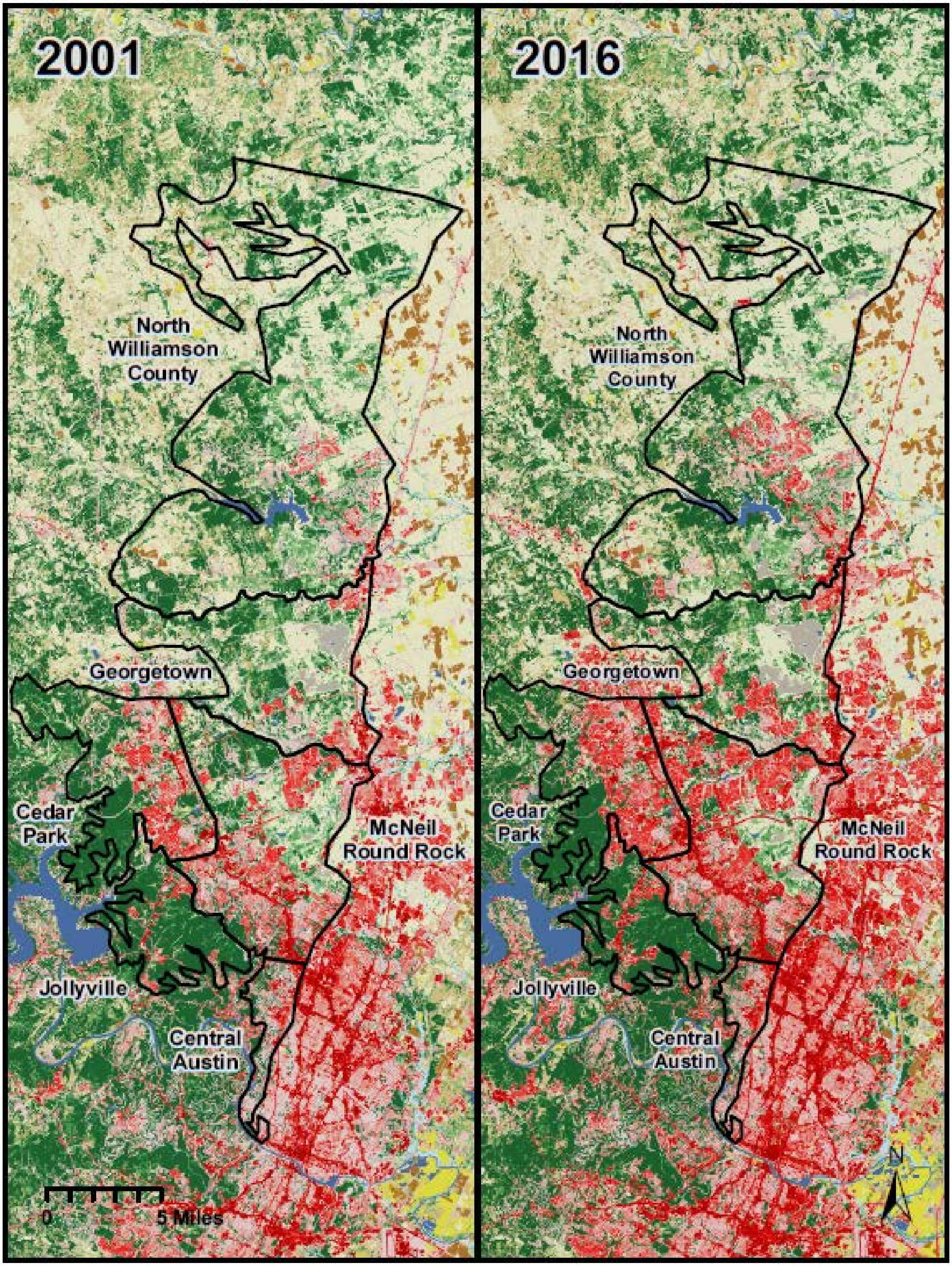

Figure 9. Land Cover Change in *Texella reyesi* KFRs from 2001 to 2016

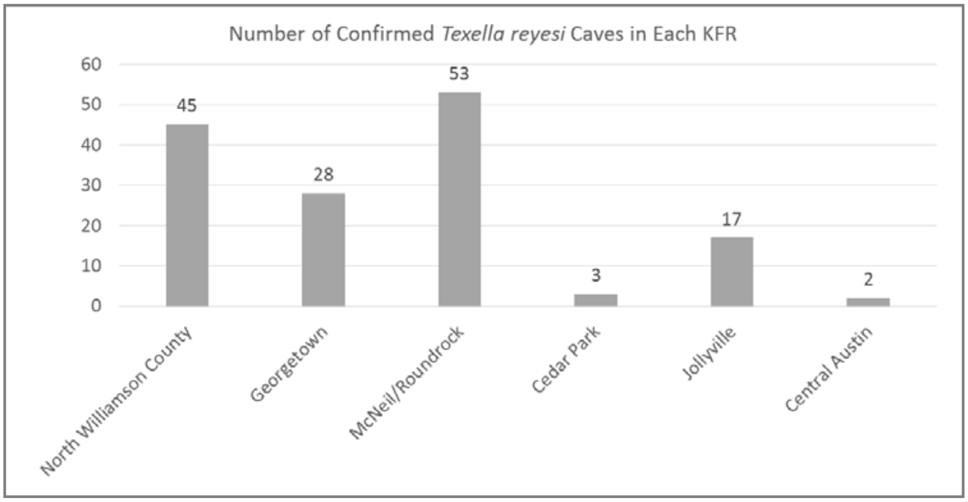

Figure 10. Number of Confirmed *Texella reyesi* Caves in Each Karst Fauna Region

The North Williamson County KFR had by far the largest increase in acreage of developed land covers in 40 acre circles surrounding confirmed *T. reyesi* locations between 2001 and 2016. Developed Open Space increased by 14.5 acres, Developed Low Intensity increased by 76.1 acres, Developed Medium Intensity increased by 91.0 acres and Developed High Intensity increased by 3.3 acres (Figure 11).

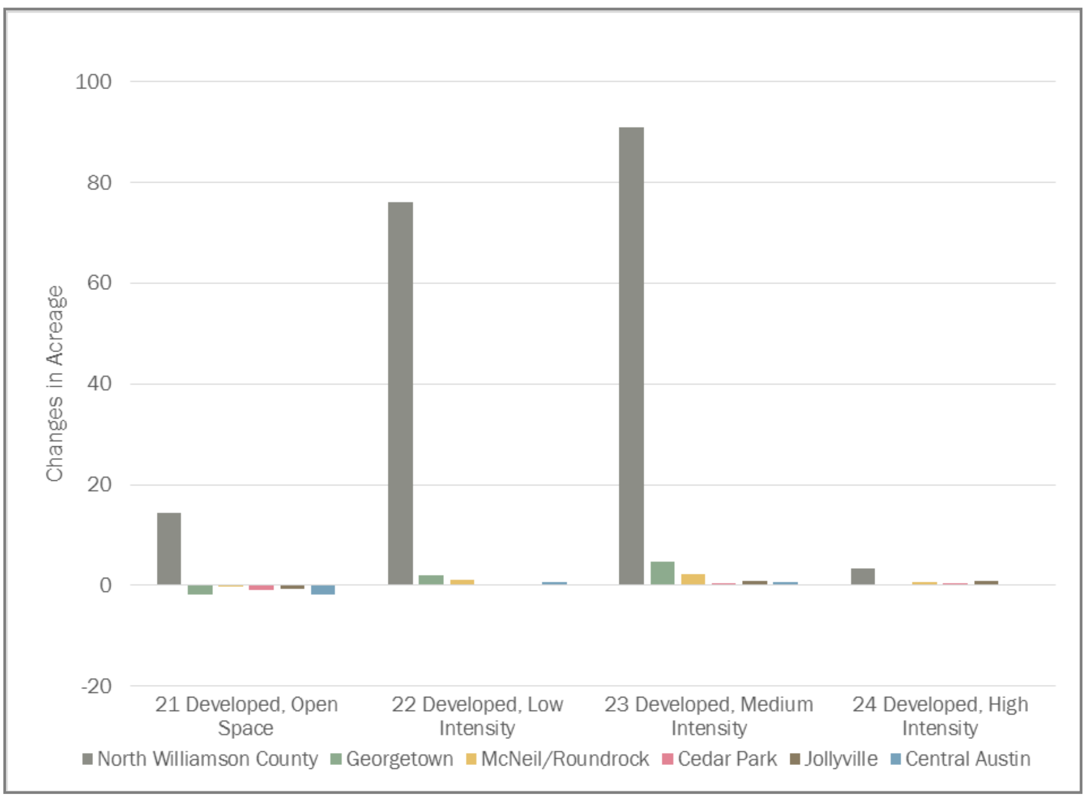

Figure 11. Developed Land Cover Changes in Acreage Within 40 Acre Circles Around Confirmed *T. reyesi* Locations in Six KFRs.

As a result of the large increases in developed land covers in the North Williamson County KFR, it also had the largest losses of natural land covers in 40 acre circles surrounding confirmed *T. reyesi* locations between 2001 and 2016. Deciduous Forest fell 85.4 acres, Evergreen Forest fell 18.2 acres, and Grassland/Herbaceous fell 91.8 acres (Figure 12).

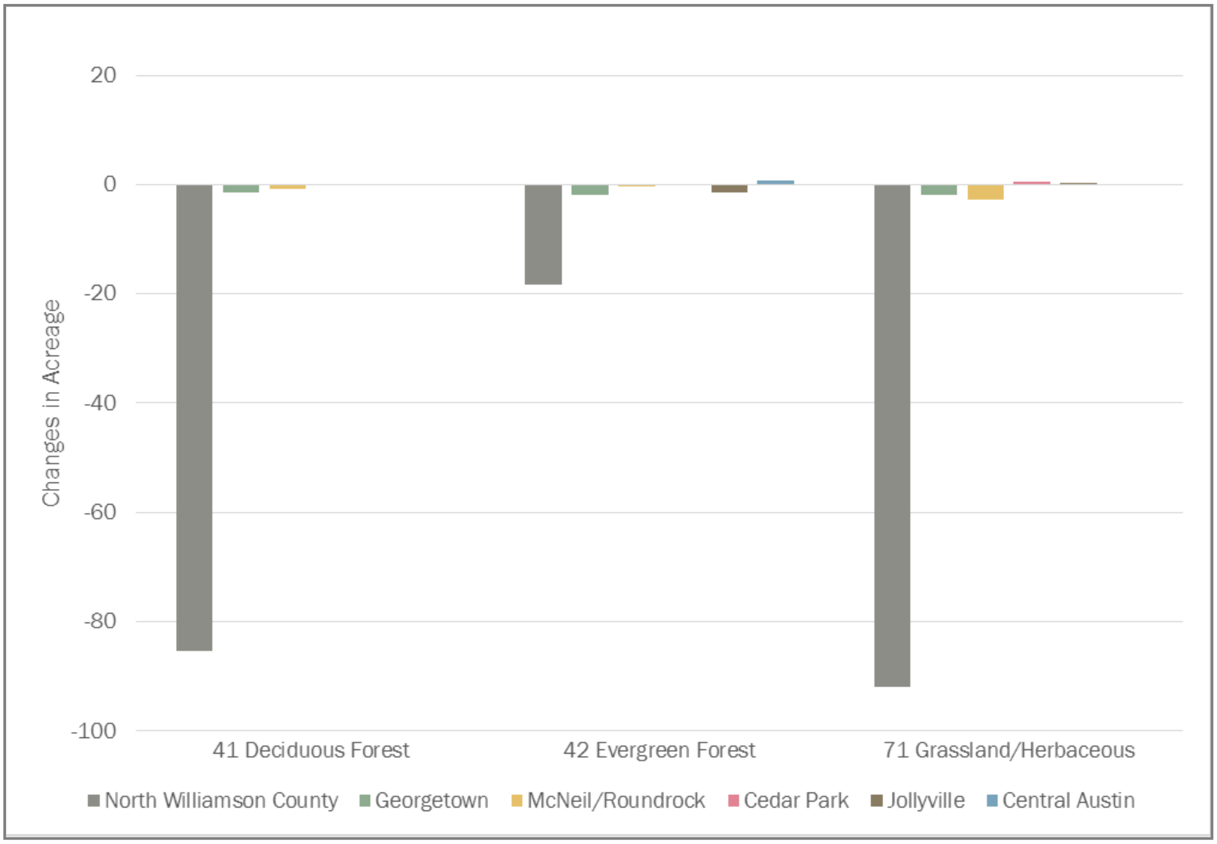

Figure 12. Natural Land Cover Changes in Acreage in the Six KFRs
Within 40 Acre Circles Around Confirmed *T. reyesi* Locations

The large amount of acreage converted from natural to developed land covers in the North Williamson County KFR is partly due to it having the second highest number of confirmed sites, but if you divide the acreages lost or gained by the number of caves in each KFR you still find that North Williamson County had the largest losses of natural land cover and gains in developed land cover (Figures 13 & 14).

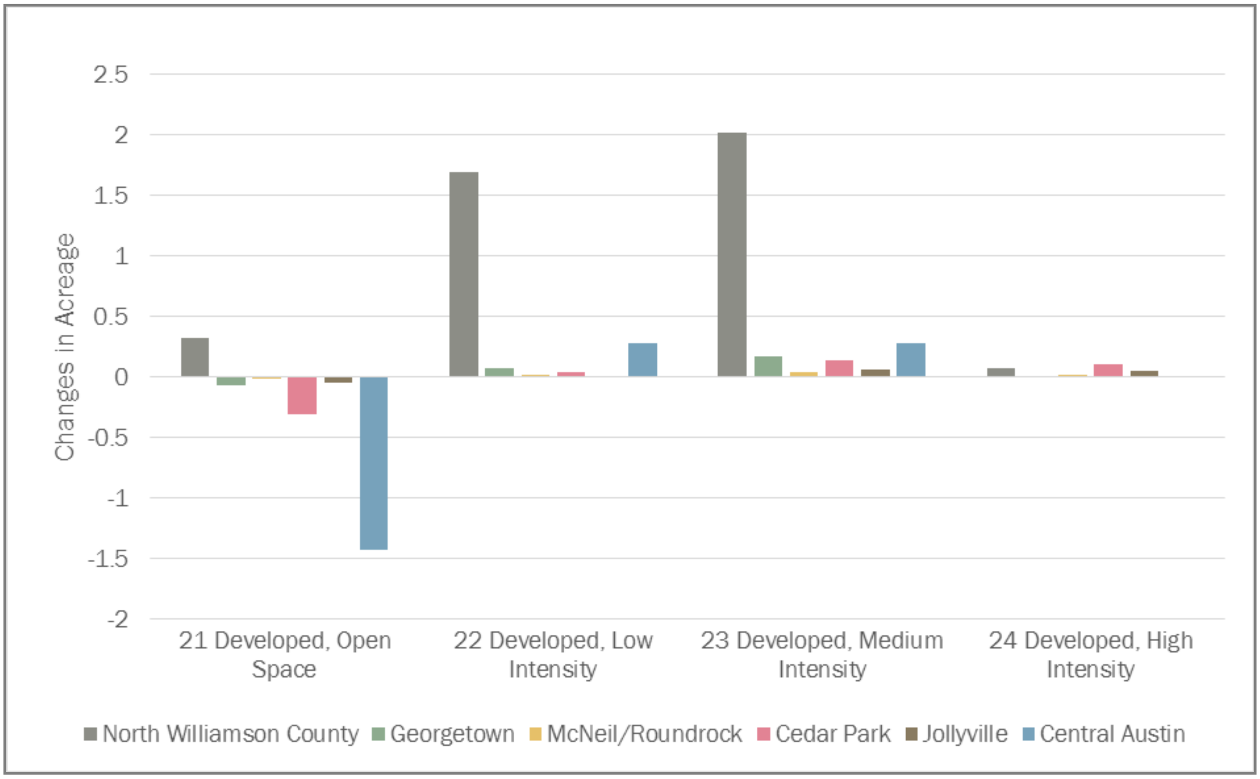

Figure 13. Average Acreage Change per Cave of Developed Land Cover Within 40 acre circles Around Confirmed *T. reyesi* Locations

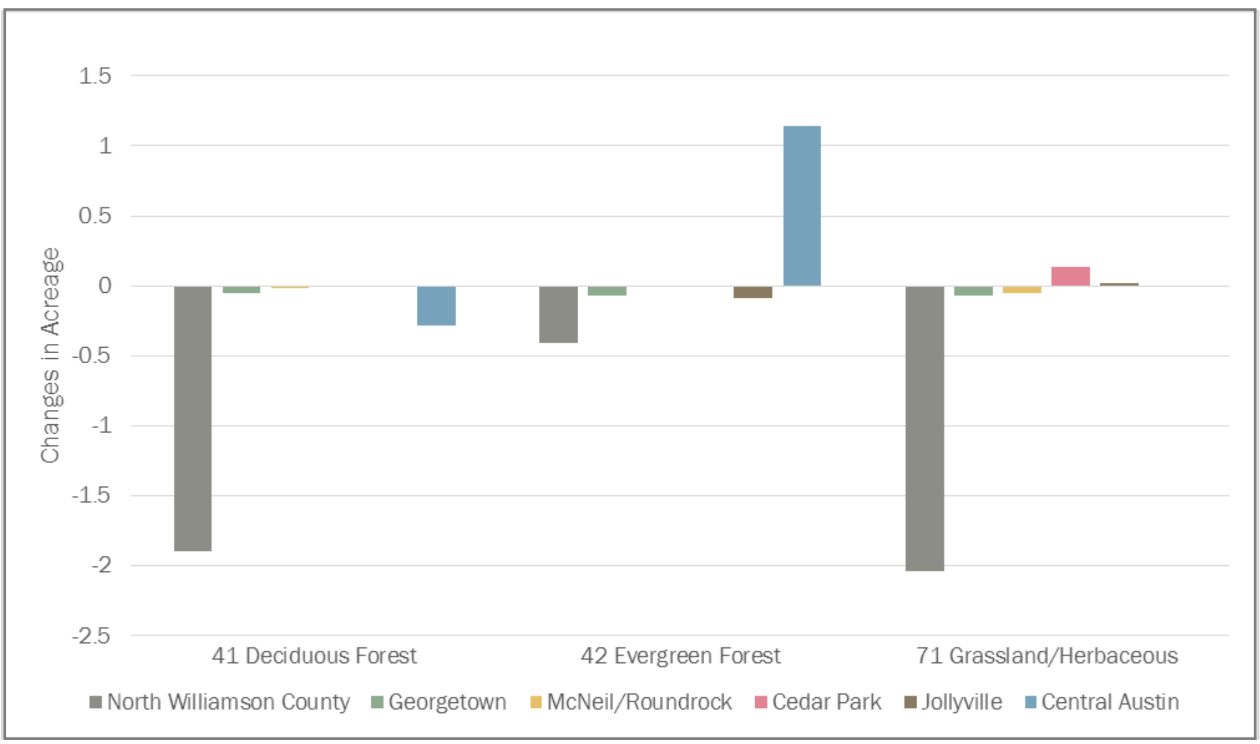

Figure 14. Average Acreage Change per Cave of Natural Land Cover Within 40 acre circles Around Confirmed *T. reyesi* Locations

When looking at the KFRs other than North Williamson County, the next largest gains in developed land cover and losses of natural land cover are in the Georgetown KFR and McNeil/Roundrock KFR (Figures 15 & 16). Between 2001 and 2016 in 40 acre circles surrounding confirmed *T. reyesi* locations the Georgetown KFR lost 1.8 acres of Developed Open Space, gained 2.0 acres of Developed Low intensity, gained 4.7 acres of developed Medium Intensity, and gained 0.3 acres of Developed High intensity. Between 2001 and 2016 in 40 acre circles surrounding confirmed T. reyesi locations the McNeil/Roundrock KFR lost 0.1 acres of Developed Open Space, gained 1.2 acres of Developed Low intensity, gained 2.2 acres of developed Medium Intensity, and gained 0.7 acres of Developed High intensity. Between 2001 and 2016 in 40 acre circles surrounding confirmed T. reyesi locations the Georgetown KFR lost 1.5 acres of Deciduous Forest, 1.8 acres of Evergreen Forest, and 1.9 acres of Grassland/Herbaceous. Between 2001 and 2016 in 40 acre circles surrounding confirmed T. reyesi locations the McNeil/Roundrock KFR lost 0.9 acres of Deciduous Forest, 0.4 acres of Evergreen Forest, and 2.7 acres of Grassland/Herbaceous.

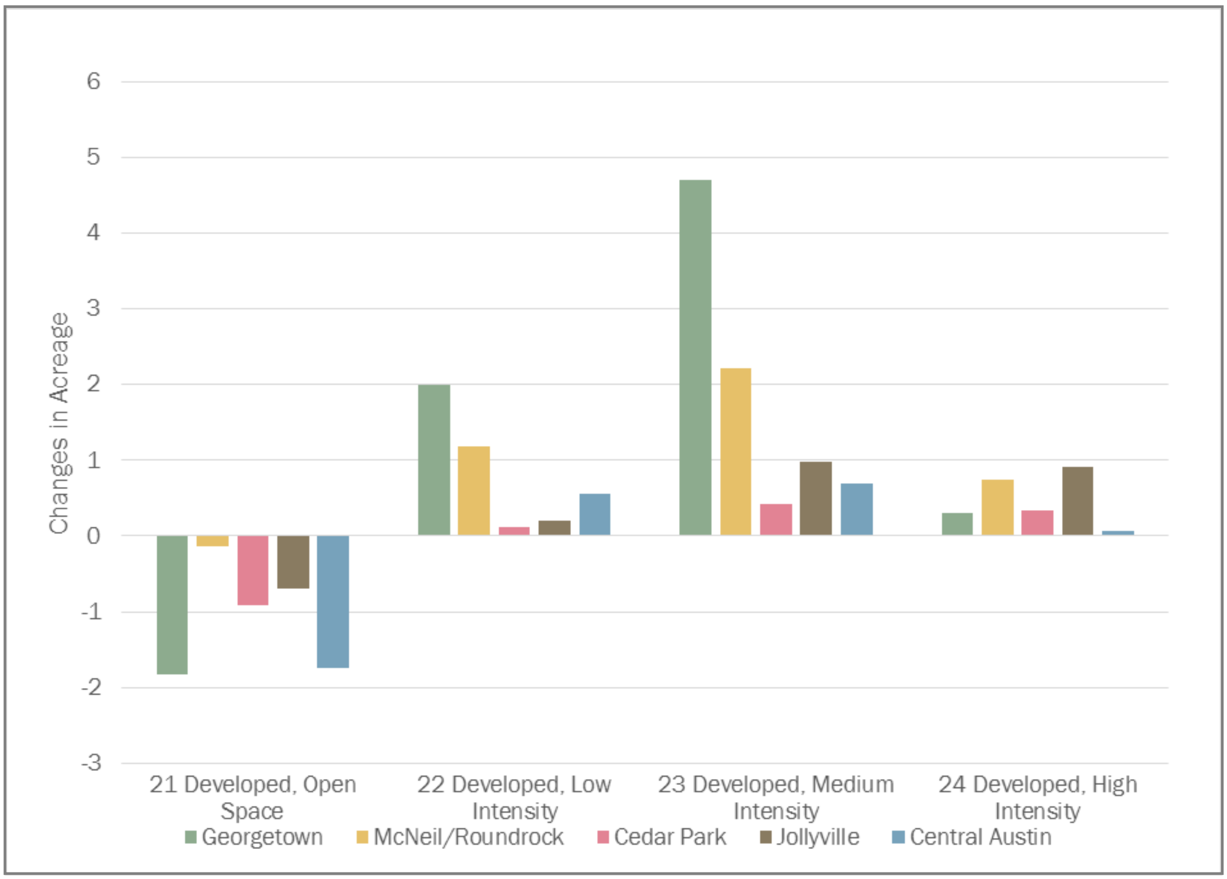

Figure 15. Developed Land Cover Changes in Acreage in KFRs Other Than North Williamson County Within 40 Acre Circles Around Confirmed *T. reyesi* Locations

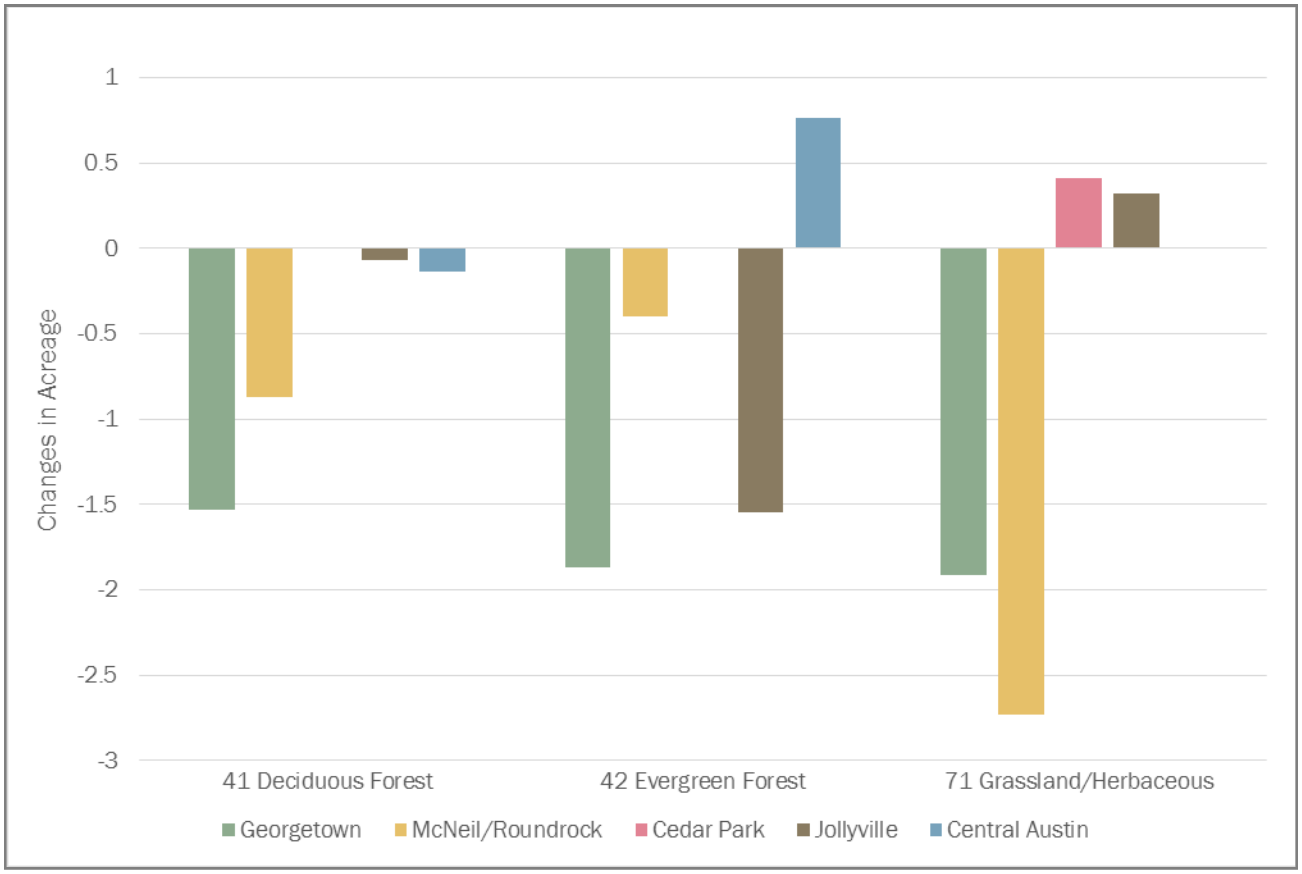

Figure 16. Natural Land Cover Changes in Acreage in KFRs Other Than North Williamson County Within 40 Acre Circles Around Confirmed *T. reyesi* Locations

Dividing each KFR by the number of caves, it becomes apparent that in 40 acre circles surrounding confirmed *T. reyesi* sites the Central Austin KFR had the largest average increase per cave of Developed Low Intensity and Developed High Intensity between 2001 and 2016. Developed Low Intensity increased on average by 0.3 acres per cave and Developed Medium Intensity increased on average by 0.3 acres per cave. Interestingly, it appears that in the 40 acre circles surrounding confirmed *T. reyesi* locations in the Central Austin KFR, some Developed Open Space was converted into Evergreen Forest between 2001 and 2016. Developed Open Space dropped by an average of 0.9 acres per cave while Evergreen Forest increased by an average of 0.4 acres per cave (Figures 17 & 18).

Figure 17. Average Acreage Change per Cave of Developed Land Cover Within 40 acre circles Around Confirmed *T. reyesi* Locations in KFRs Other Than North Williamson County

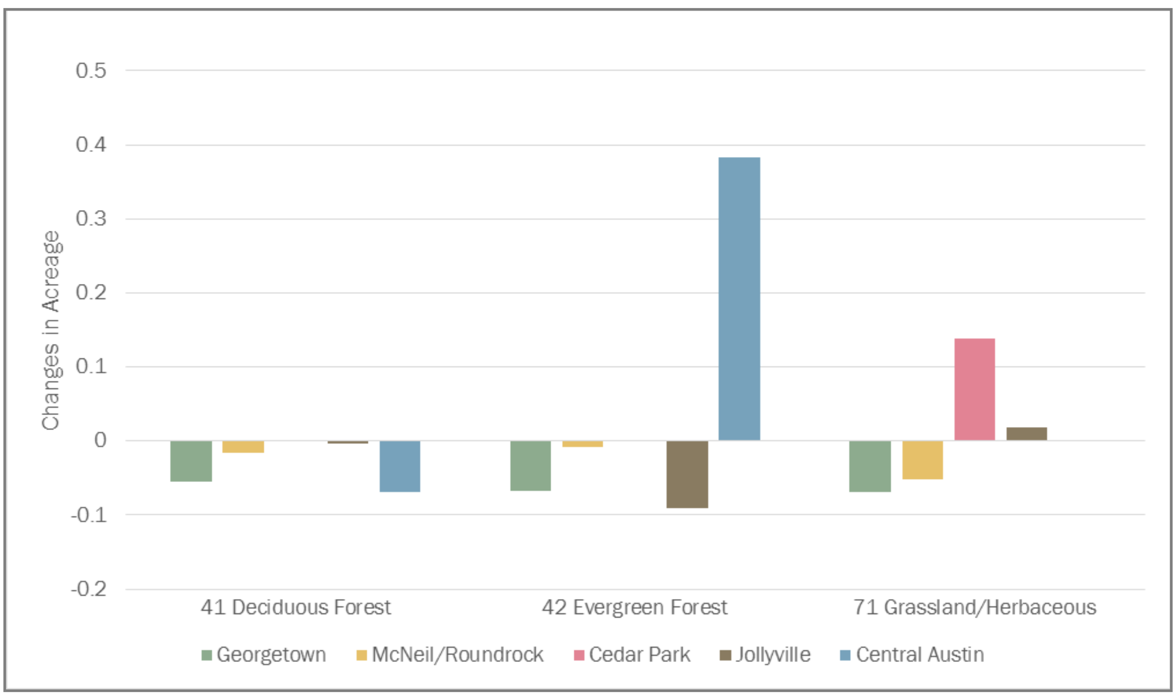

Figure 18. Average Acreage Change per Cave of Natural Land Cover Within 40 acre circles Around Confirmed *T. reyesi* Locations in KFRs Other Than North Williamson County

Now we will look closer at the North Williamson County, Georgetown and Mcneil/Roundrock KFRs, which were the three with the largest conversions of acreage from natural to developed land covers.

North Williamson County KFR

All three natural land covers decreased their percentages of the land cover in the 40 acre circles surrounding confirmed *T. reyesi* sites in the North Williamson County KFR. Two out of three natural land covers decreased their percentages of the land cover in the 105 meter buffers surrounding confirmed *T. reyesi* sites in the North Williamson County KFR (Figures 19 & 20). All four developed land covers increased their percentages of the land cover in both the 40 acres circles and the 105 meter buffers surrounding confirmed *T. reyesi* sites in the North Williamson County KFR (Figures 21 & 22). The number of acres gained or lost can be found in Tables 1 and 2. The change between 2001 and 2016 can be seen visually in Figure 23.

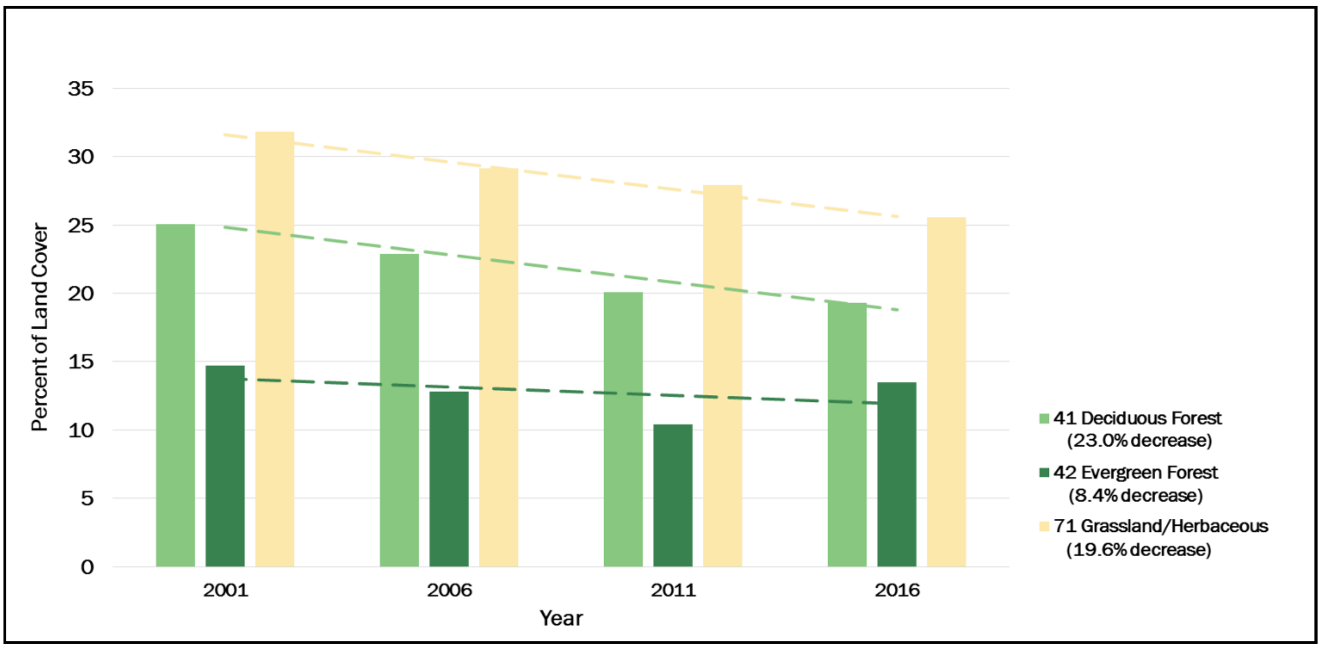

Figure 19. North Williamson County Karst Fauna Region Changes in Land Cover Percentages Within 40 Acre Circles Surrounding Confirmed *Texella reyesi* Locations From 2001 to 2016

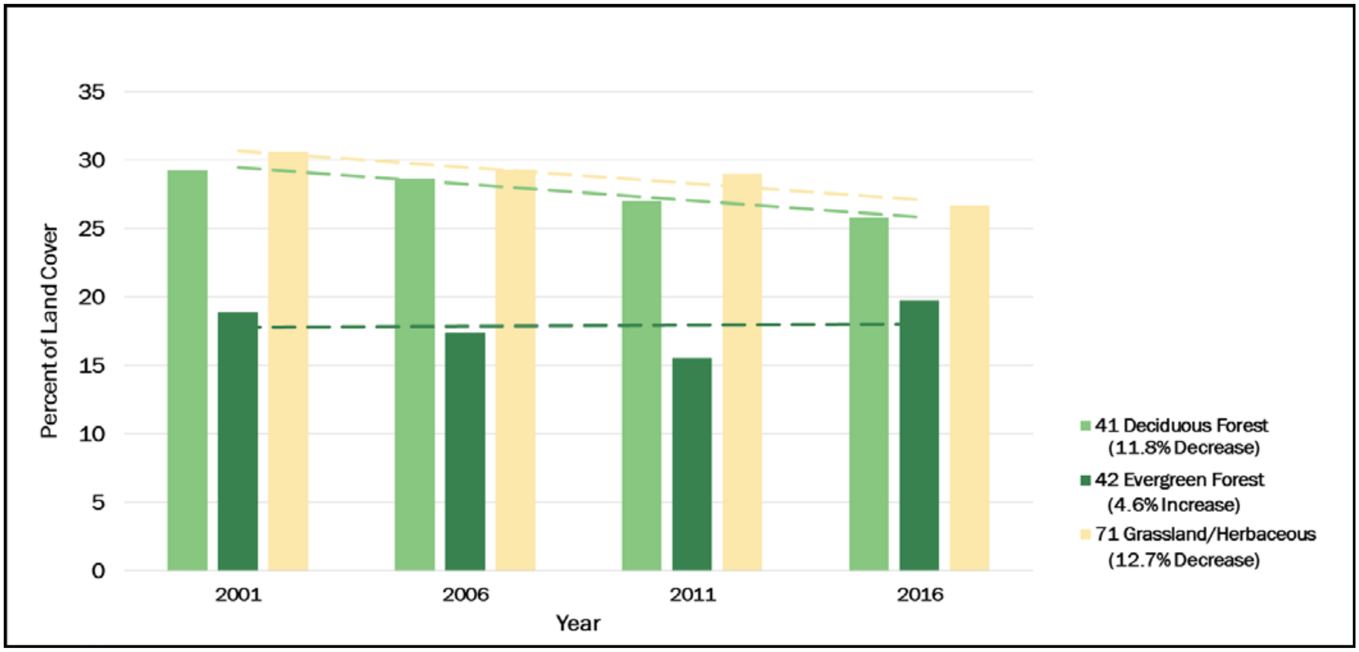

Figure 20. North Williamson County Karst Fauna Region Changes in Land Cover Percentages Within 105 Meter Buffers of Confirmed *Texella reyesi* Locations From 2001 to 2016

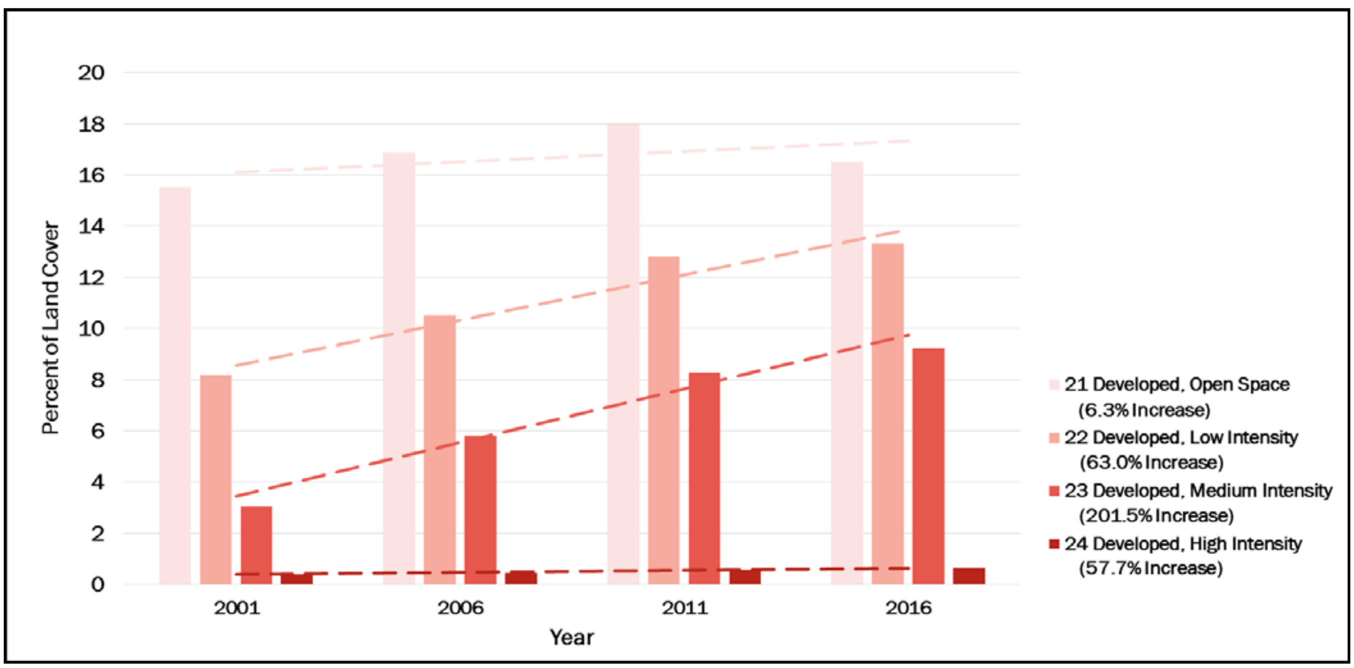

Figure 21. North Williamson County Karst Fauna Region Changes in Land Cover Percentages Within 40 Acre Circles Surrounding Confirmed *Texella reyesi* Locations From 2001 to 2016

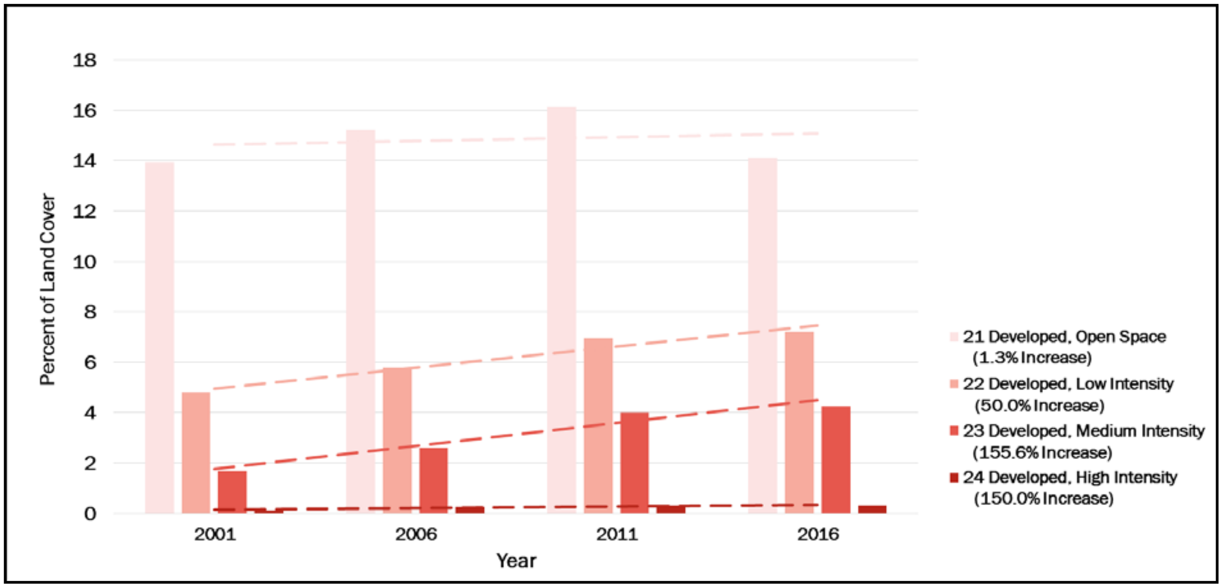

Figure 22. North Williamson County Karst Fauna Region Changes in Land Cover Percentages Within 105 Meter Buffers of Confirmed *Texella reyesi* Locations From 2001 to 2016

Land Cover Class	Change in Acreage
Developed, Open Space	14.5
Developed, Low Intensity	76.1
Developed, Medium Intensity	91.0
Developed, High Intensity	3.3
Deciduous Forest	-85.4
Evergreen Forest	-18.2
Grassland/Herbaceous	-91.8

Table 1. Changes in Acreage in 40 Acre Circles Surrounding Confirmed *Texella reyesi* Sites in the North Williamson County KFR Between 2001 and 2016

Land Cover Class	Changes in Acreage
Developed, Open Space	0.7
Developed, Low Intensity	8.7
Developed, Medium Intensity	9.3
Developed, High Intensity	0.7
Deciduous Forest	-12.5
Evergreen Forest	3.1
Grassland/Herbaceous	-14.0

Table 2. Changes in Acreage in 105 Meter Buffers Surrounding Confirmed *Texella reyesi* Sites in the North Williamson County KFR Between 2001 and 2016

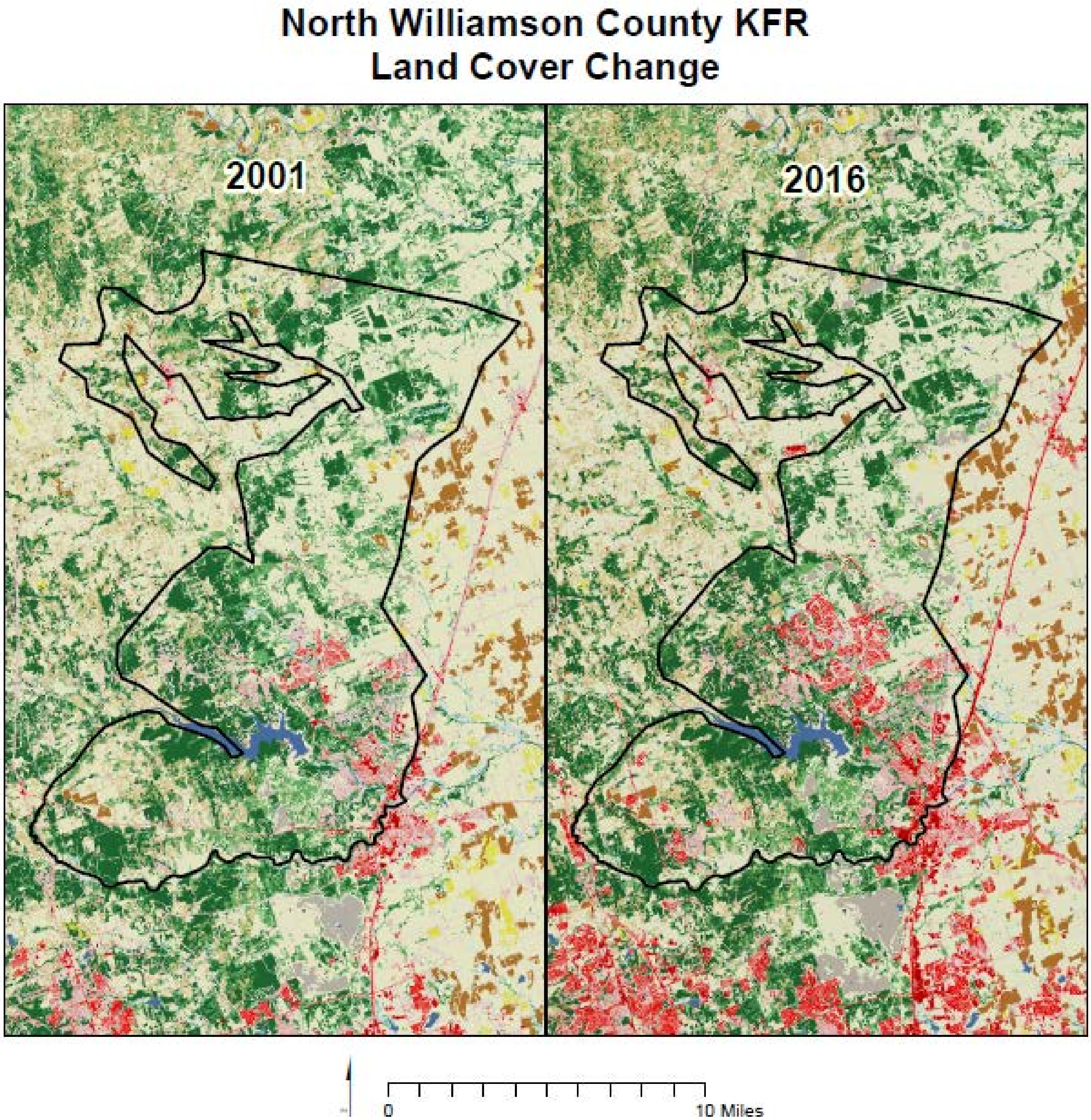

Figure 23. Land Cover Change in the North Williamson County KFR between 2001 and 2016

McNeil/Roundrock KFR

All three natural land covers decreased their percentages of the land cover in both the 40 acre circles and the 105 meter buffers surrounding confirmed *T. reyesi* sites in the McNeil/Roundrock KFR (Figures 24 & 25). Three out of four developed land covers increased their percentages of the land cover in both the 40 acres circles and the 105 meter buffers surrounding confirmed *T. reyesi* sites in the McNeil/Roundrock KFR (Figures 26 & 27). The number of acres gained or lost can be found in Tables 3 and 4. The change between 2001 and 2016 can be seen visually in Figure 28.

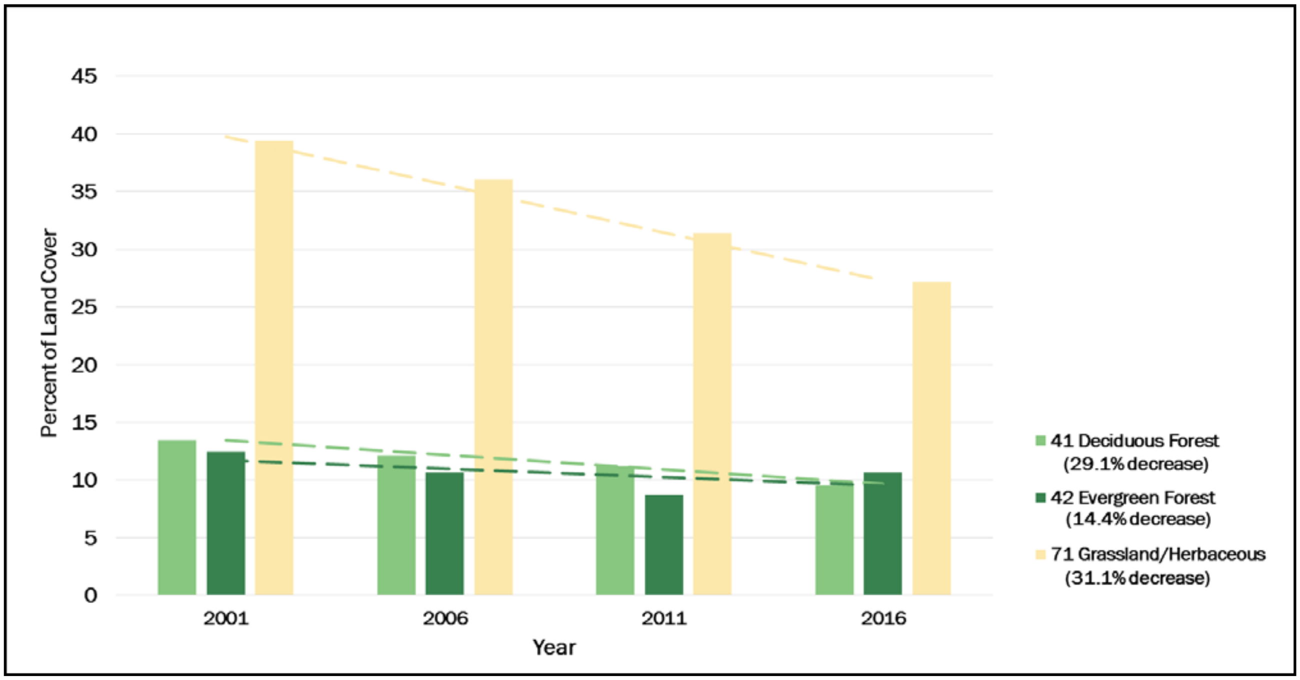

Figure 24. McNeil/Roundrock Karst Fauna Region Changes in Land cover Percentages Within 40 Acre Circles Surrounding Confirmed *Texella reyes*i Locations From 2001 to 2016

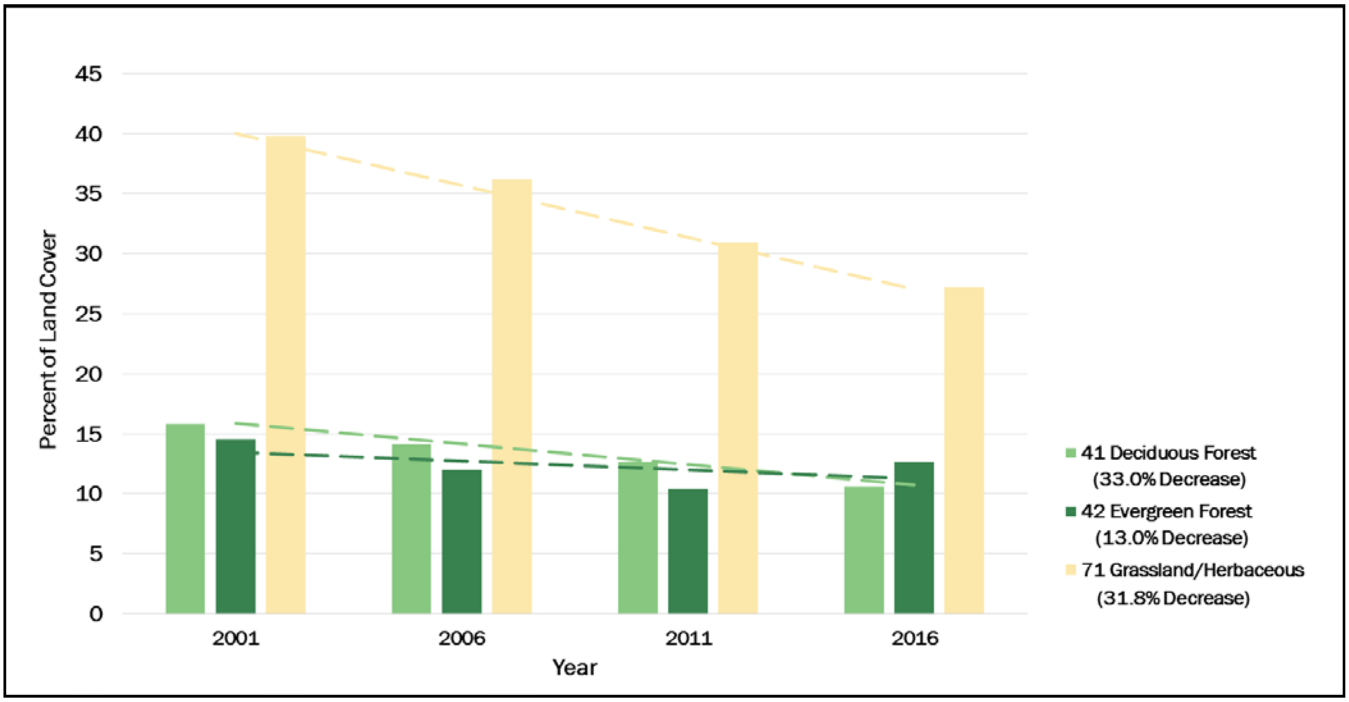

Figure 25. McNeil/Roundrock Karst Fauna Region Changes in Land Cover Percentages Within 105 Meter Buffers of Confirmed *Texella reyesi* Locations From 2001 to 2016

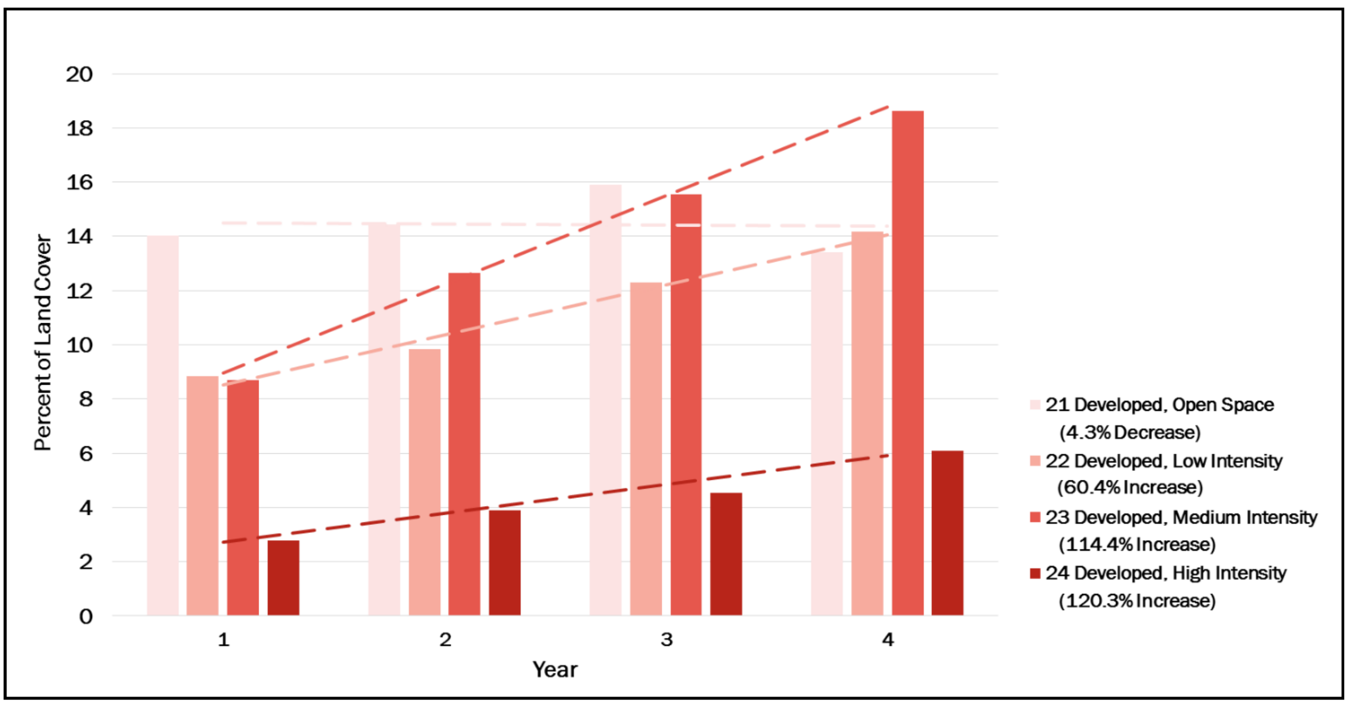

Figure 26. McNeil/Roundrock Karst Fauna Region Changes in Land Cover Percentages Within 40 Acre Circles Surrounding Confirmed *Texella reyesi* Locations From 2001 to 2016

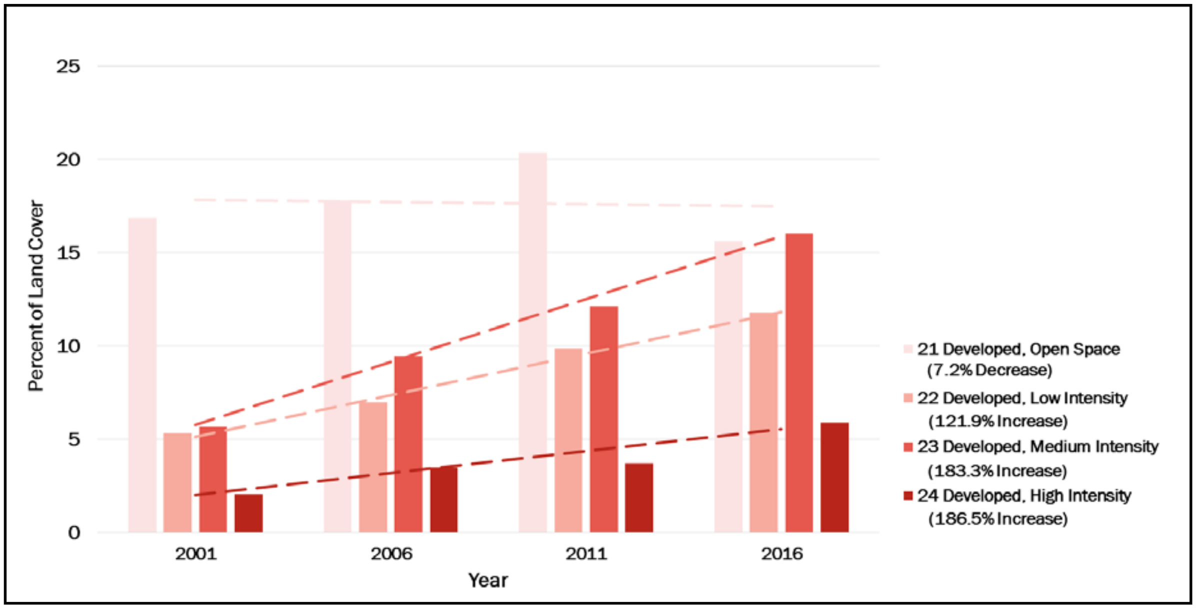

Figure 27. McNeil/Roundrock Karst Fauna Region Changes in Land Cover Percentages Within 105 Meter Buffers of Confirmed *Texella reyesi* Locations From 2001 to 2016

Land Cover Class	Change in Acreage
Developed, Open Space	-8.9
Developed, Low Intensity	78.1
Developed, Medium Intensity	145.2
Developed, High Intensity	48.7
Deciduous Forest	-57.2
Evergreen Forest	-26.2
Grassland/Herbaceous	-179.5

Table 3. Changes in Acreage in 40 Acre Circles Surrounding Confirmed *Texella reyesi* Sites in the McNeil/Roundrock KFR Between 2001 and 2016

Land Cover Class	Change in Acreage
Developed, Open Space	-4.9
Developed, Low Intensity	26.0
Developed, Medium Intensity	41.6
Developed, High Intensity	15.3
Deciduous Forest	-20.9
Evergreen Forest	-7.6
Grassland/Herbaceous	-50.9

Table 4. Changes in Acreage in 105 Meter Buffers Surrounding Confirmed *Texella reyesi* Sites in the McNeil/Roundrock KFR Between 2001 and 2016

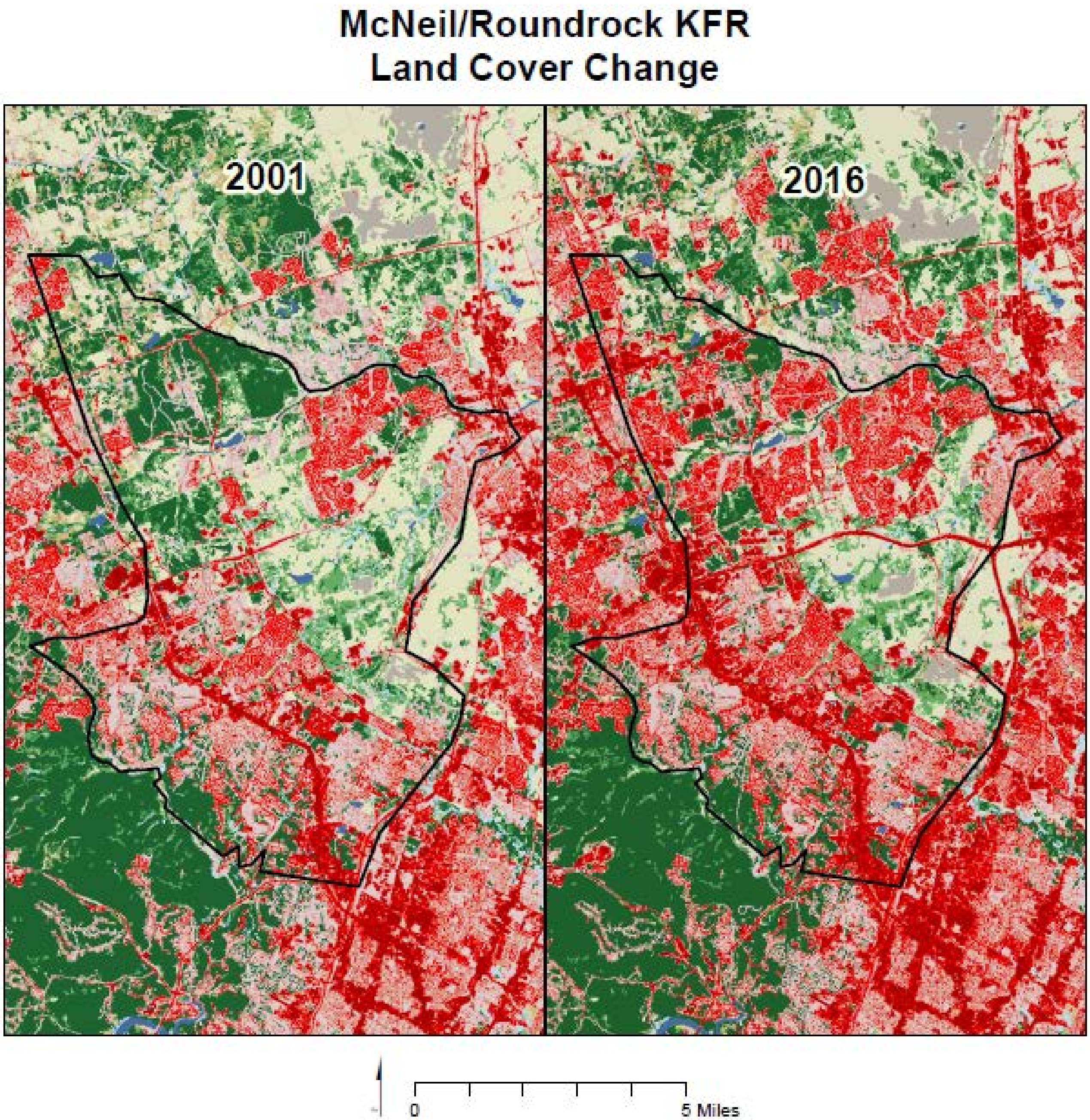

Figure 28. Land Cover Change in the McNeil/Roundrock KFR between 2001 and 2016

Georgetown KFR

All three natural land covers decreased their percentages of the land cover in both the 40 acre circles and the 105 meter buffers surrounding confirmed T. reyesi sites in the Georgetown KFR (Figures 29 & 30). Three out of four developed land covers increased their percentages of the land cover in both the 40 acres circles and the 105 meter buffers surrounding confirmed *T.*

reyesi sites in the Georgetown KFR (Figures 31 & 32). The number of acres gained or lost can be found in Tables 5 and 6. The change between 2001 and 2016 can be seen visually in Figure 33.

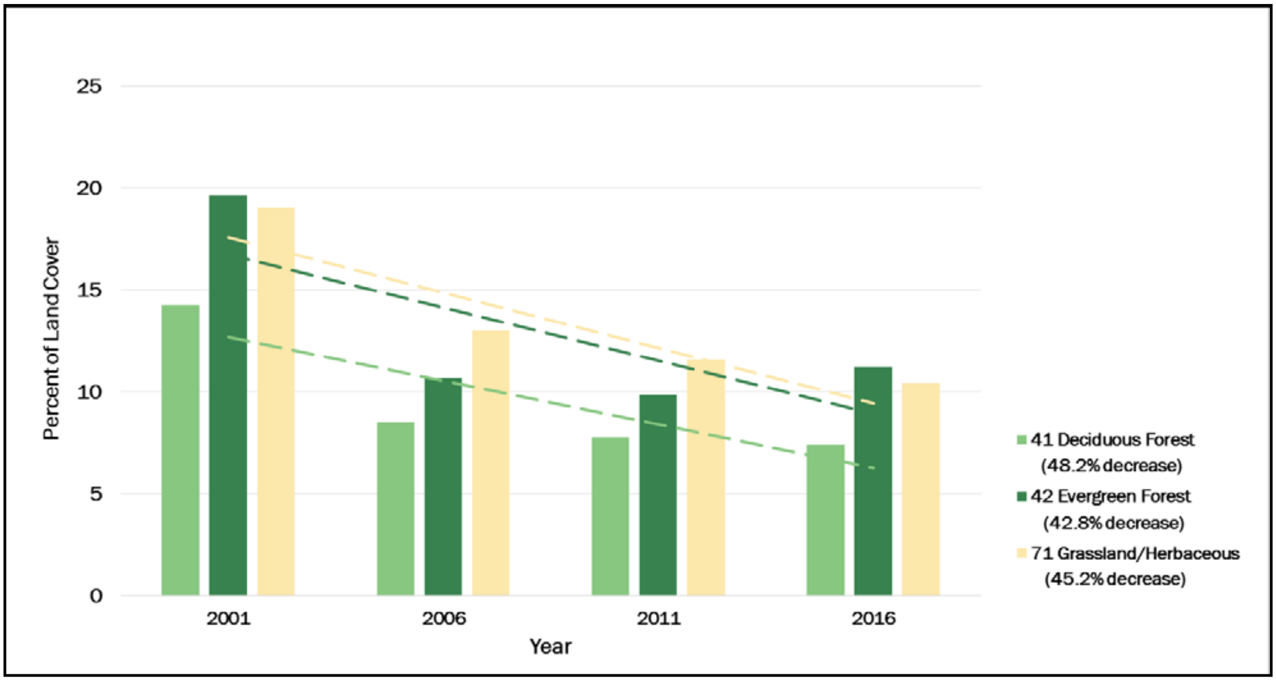

Figure 29. Georgetown Karst Fauna Region Changes in Land Cover Percentages Within 40 Acre Circles Surrounding Confirmed Texella reyesi Locations From 2001 to 2016

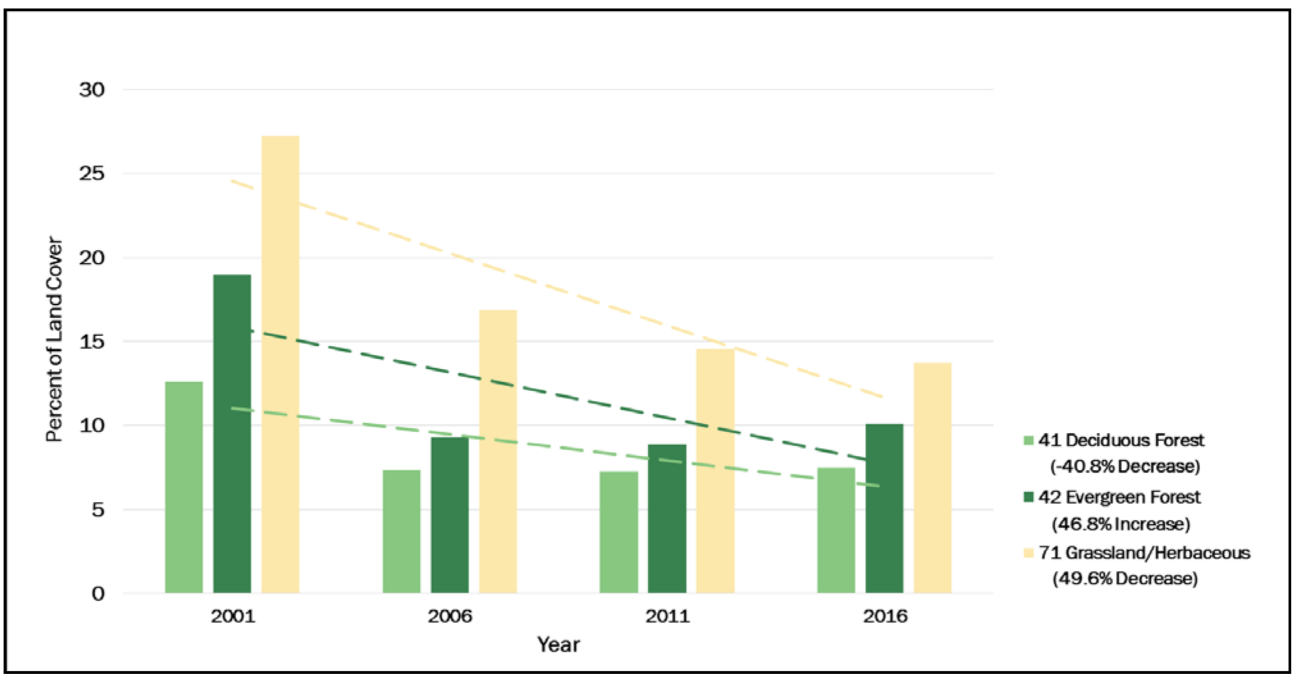

Figure 30. Georgetown Karst Fauna Region Changes in Land Cover Percentages Within 105 Meter Buffers of Confirmed Texella reyesi Locations From 2001 to 2016

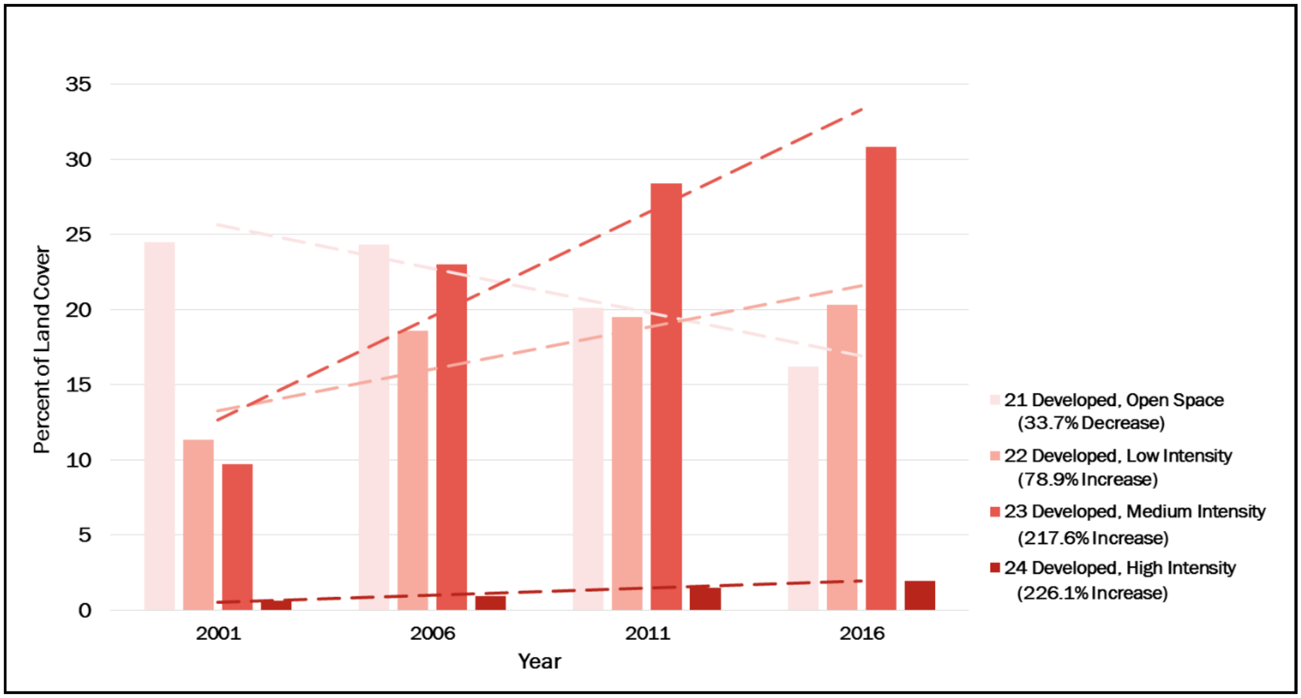

Figure 31. Georgetown Karst Fauna Region Changes in Land Cover Percentages Within 40 Acre Circles Surrounding Confirmed Texella reyesi Locations From 2001 to 2016

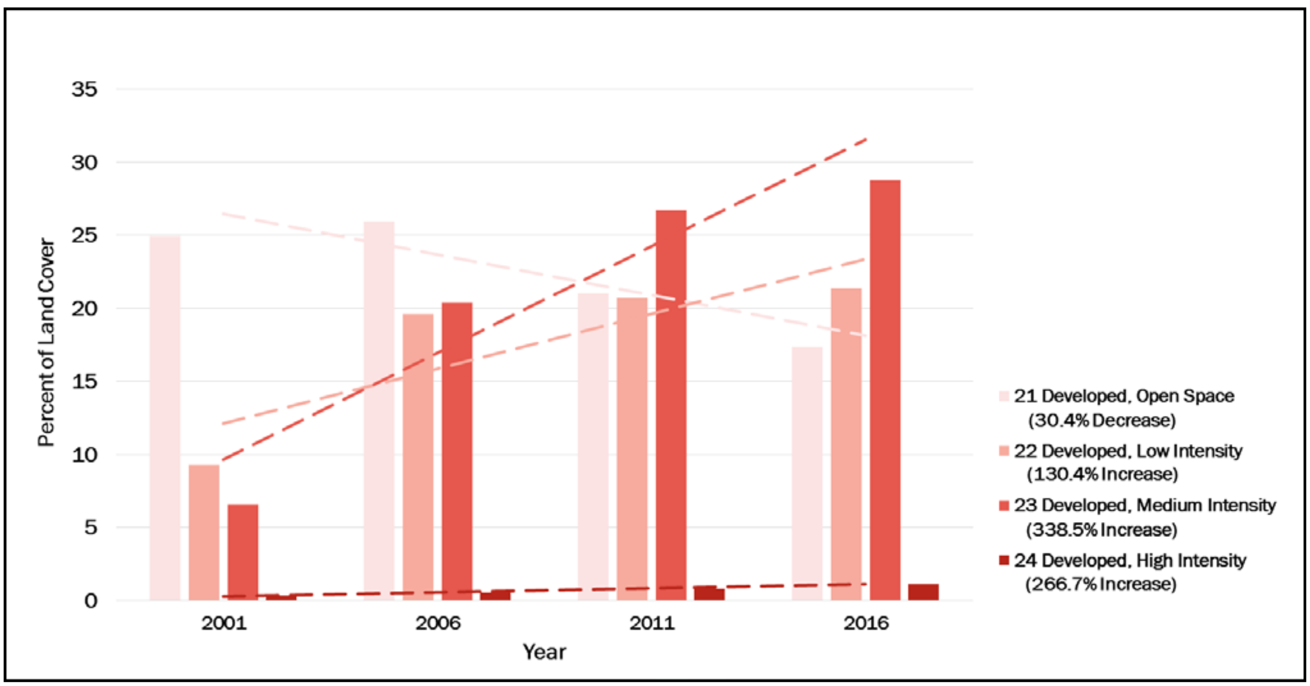

Figure 32. Georgetown Karst Fauna Region Changes in Land Cover Percentages Within 105 Meter Buffers of Confirmed *Texella reyesi* Locations From 2001 to 2016

Land Cover Class	Acre Change
21 Developed, Open Space	-69.8
22 Developed, Low Intensity	75.8
23 Developed, Medium Intensity	178.6
24 Developed, High Intensity	11.6
41 Deciduous Forest	-58.3
42 Evergreen Forest	-71.2
71 Grassland/Herbaceous	-72.7

Table 5. Acres Gained or Lost in 40 Acre Circles Surrounding Confirmed *Texella reyesi* Sites in the Georgetown KFR Between 2001 and 2016

Land Cover Class	Acre Change
21 Developed, Open Space	-16.7
22 Developed, Low Intensity	26.7
23 Developed, Medium Intensity	48.9
24 Developed, High Intensity	1.8
41 Deciduous Forest	-11.3
42 Evergreen Forest	-19.6
71 Grassland/Herbaceous	-29.8

Table 6. Acres Gained or Lost in 105 Meter Buffers Surrounding Confirmed *Texella reyesi* Sites in the McNeil/Roundrock KFR Between 2001 and 2016

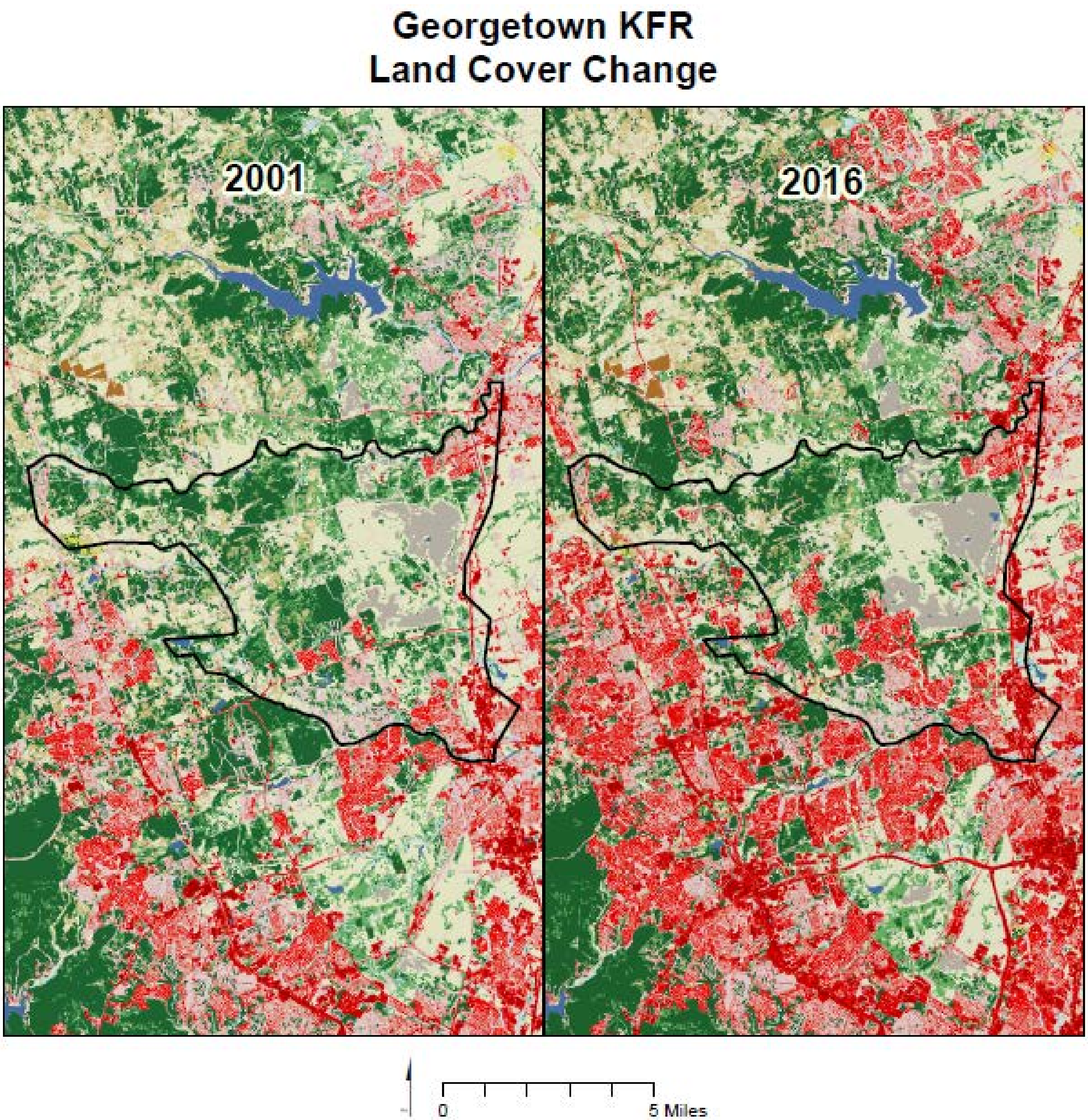

Figure 33. Land Cover Change in the Georgetown KFR between 2001 and 2016

The conversion of natural areas to developed land around confirmed *T.* reyesi locations between 2001 and 2016 has been substantial throughout its range. The North Williamson County KFR has had the largest increase in developed land covers, which is especially concerning since with 48 confirmed locations, it has 30.4% of the total confirmed locations within *T. reyesi*'s range. Development has continued at a rapid rate since 2016. From 2016 to 2019, the population of Travis County increased from 1,206,110 to 1,273,954 a 5.6% increase, and the population of Williamson County has increased from 527,622 to 590,551 an 11.9% increase (Resident Population in Travis/Williamson County, TX). For example, Figure 34 shows recent development adjacent to Tooth Cave Preserve. While the caves on the preserve have been omitted to keep their locations secure, the figure includes those that have been heavily impacted by development. None of these caves are confirmed *T. reyesi* locations, but they are close to Tooth Cave, a confirmed location, and may not have had sufficient surveys for *T. reyesi* detection. Tooth cave is not shown on the map, but it is approximately 80m from the edge of the construction zone.

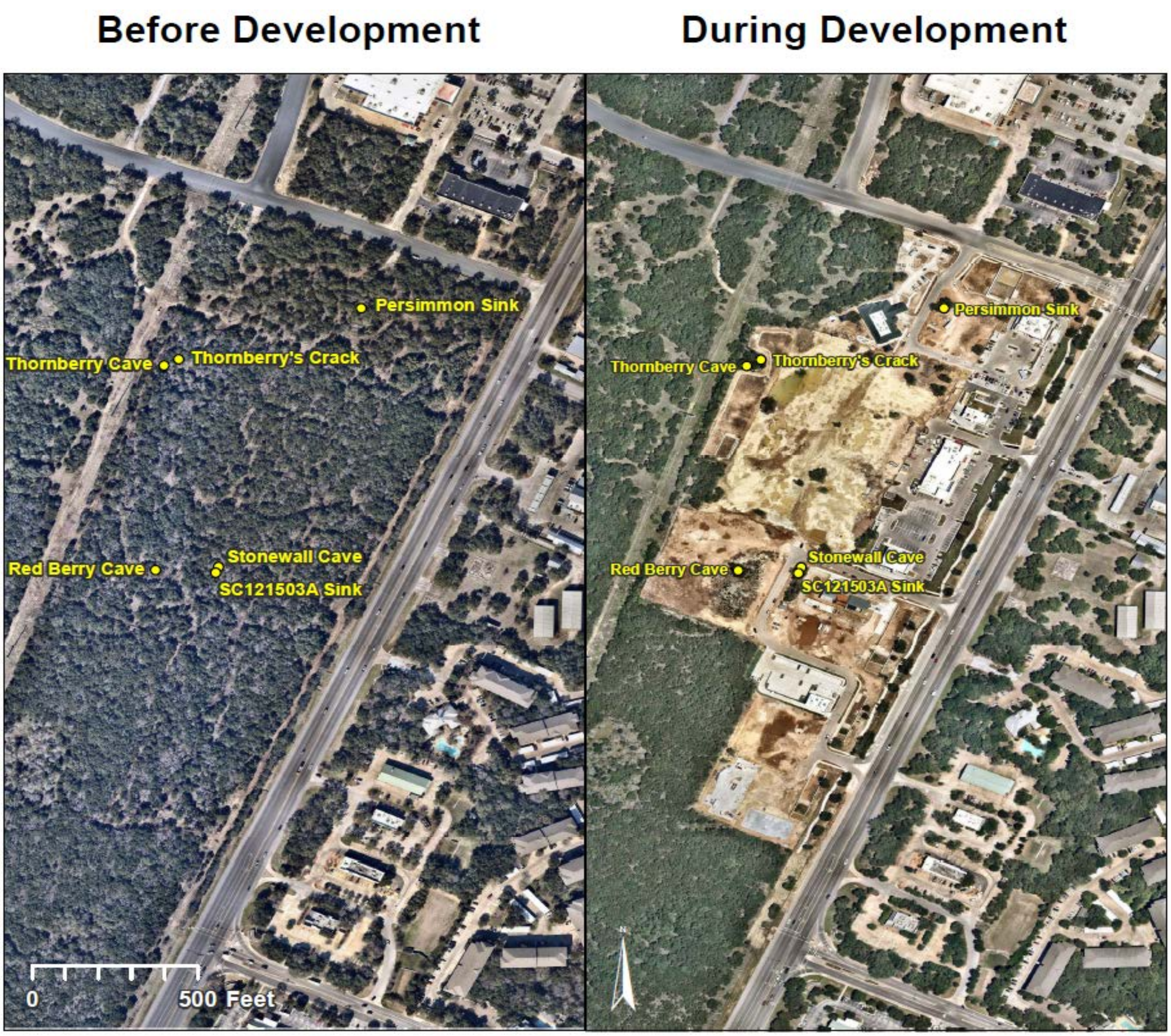

Figure 34. Before and During Development of Site Adjacent to Tooth Cave

The increasing number of known *T. reyesi* locations has been cited as evidence that the species is doing well and is not under threat. However, there are several issues with that number. Whenever a cave is surveyed and *T. reyesi* is confirmed as present, USFWS adds it to the list of known locations. Many of these caves are only surveyed once and never visited again. Without monitoring, there is no way of knowing if they persist. Most surveys were performed prior to development, when the caves were surrounded by natural habitat. After development, few of the confirmed locations have had continuous monitoring or any follow-up surveys. Also, when a confirmed location has been destroyed, USFWS will take it off the list; however, USFWS does not have the resources to conduct routine inspections to determine the status of each cave. Thus, some of these "confirmed locations" may have been destroyed, but this was not reported. As an example, although the accuracy of cave locations is notoriously questionable, if the cave locations in Figure 35 are correct, then many of the caves shown have been destroyed. And if the locations are only slightly inaccurate, then they have been at least severely degraded.

While it is possible that there may be many more *T. reyesi* locations that are inaccessible to humans, these unknown and unprotected locations are also vulnerable to loss of surface and subsurface habitat, especially with the rate of continued development in the region. Since these locations are unable to be detected, they are unlikely to receive protection from development. Not only is surface habitat removed, the subsurface is then subject to excavation, leveling, and trenching. Figures 36 and 37 show the depth of leveling that has been done prior to construction at the development adjacent to Tooth Cave Preserve. It should be noted that caves in this area are very shallow, generally around 10 or 15 ft. deep, with the deepest in the area around 25 ft. deep. After leveling, trenches are cut through the whole area for water, wastewater, drainage and electric lines (Figure 38). The larger karst features that are noticeable from the surface may be spared complete destruction, but the setbacks are inadequate to sustain karst ecosystems. Figures 39 and 40 show Persimmon Sink and Stonewall Cave. Once the parking lots are installed, the habitat around these caves will be tiny islands in a sea of pavement.

Finally, climate change is making prolonged droughts in our region a more common occurrence. Areas with natural land cover will be far more resistant to cave desiccation than developed areas with no tree cover. *T. reyesi* may be able to retreat farther down in search of higher humidity levels. However, in areas such as the Jollyville KFR, the soluble zone filled with voids is very shallow and could be completely desiccated in a prolonged drought, especially if all the vegetation and soil has been removed and replaced by pavement.

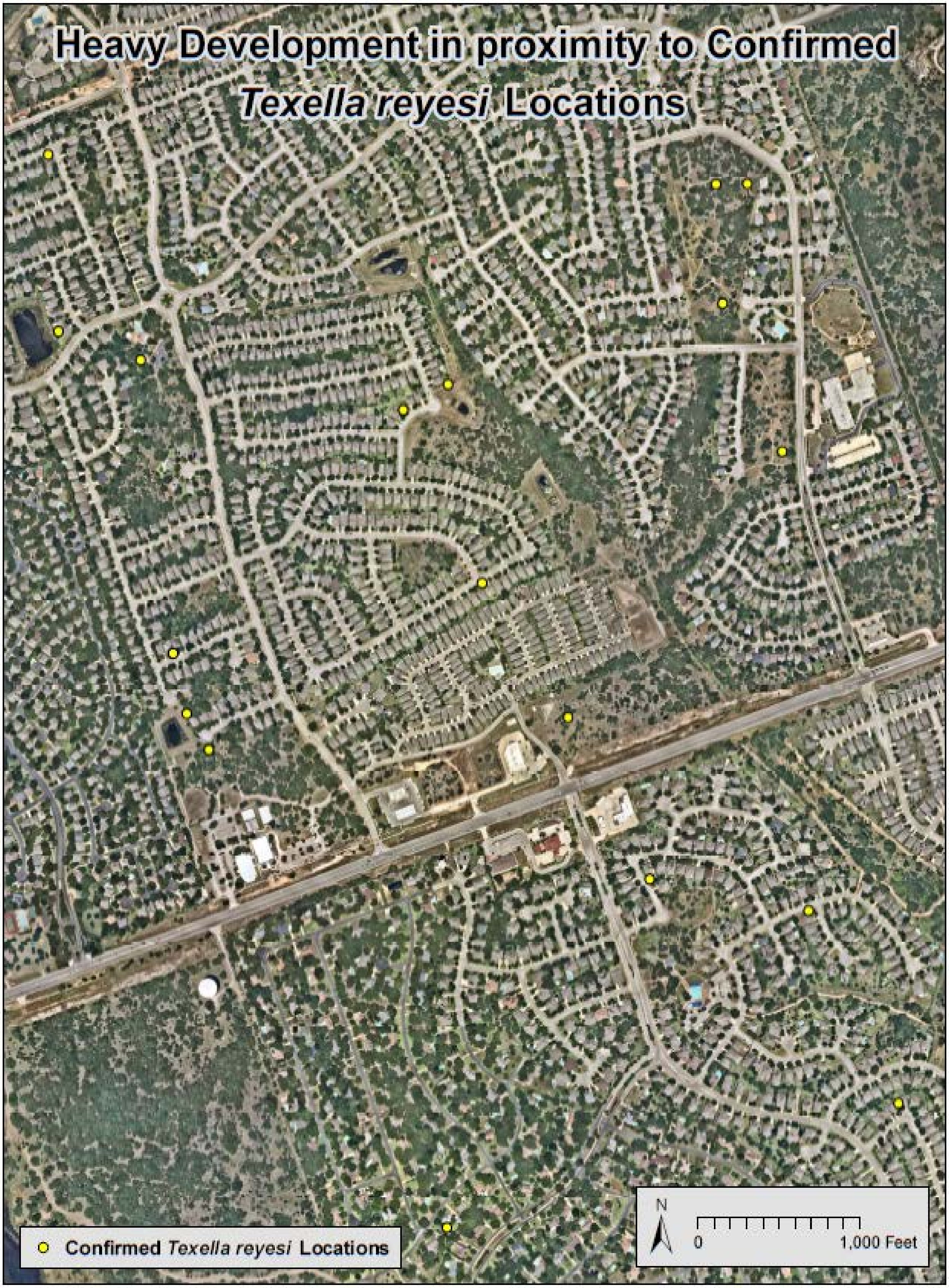

Figure 35. Heavy Development in Proximity to Confirmed *Texella reyesi* Locations

Figure 36. Down Cutting to Level Development Site Adjacent to Tooth Cave, June 2020

Figure 37. Down Cutting to Level Development Site Adjacent to Tooth Cave, June 2020

Figure 38. Leveling and Trenching of Development Site Adjacent to Tooth Cave, June 2020

Figure 39. Persimmon Sink in Development Site Adjacent to Tooth Cave, June 2020

Figure 40. Red Berry Cave in Development Site Adjacent to Tooth Cave, June 2020

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Appendix

A1 - List of threats cited in:
Bone Cave Harvestman (*Texella reyesi*) 5-Year Review: Summary and Evaluation (2009)

Texella reyesi was listed as endangered based on the threats of: 1) habitat loss to development; 2) cave collapse or filling; 3) alteration of drainage patterns; 4) alteration of surface plant and animal communities, including the invasion of exotic plants and predators (i.e. the red-imported fire ant (RIFA), *Solenopsis invicta*), changes in competition for limited resources and resulting nutrient depletion, and the loss of native vegetative cover leading to changes in surface microclimates and erosion; 5) contamination of the habitat, including groundwater, from nearby agricultural disturbance, pesticides, and fertilizers; 6) leakages and spills of hazardous materials from vehicles, tanks, pipelines, and other urban or industrial runoff; and 7) human visitation, vandalism, and dumping; mining; quarrying (limestone); or, blasting above or in caves.

A2 - National Land Cover Database Classification Descriptions

Class\ Value		Classification Description
Water		
	11	**Open Water-** areas of open water, generally with less than 25% cover of vegetation or soil.
	12	**Perennial Ice/Snow-** areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover.
Developed		
	21	**Developed, Open Space-** areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
	22	**Developed, Low Intensity-** areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.
	23	**Developed, Medium Intensity** -areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.
	24	**Developed High Intensity**-highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.
Barren		

	31**Barren Land (Rock/Sand/Clay)** - areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
Forest	
	41**Deciduous Forest**- areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.
	42**Evergreen Forest**- areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.
	43**Mixed Forest**- areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.
Shrubland	
	51**Dwarf Scrub**- Alaska only areas dominated by shrubs less than 20 centimeters tall with shrub canopy typically greater than 20% of total vegetation. This type is often co-associated with grasses, sedges, herbs, and non-vascular vegetation.
	52**Shrub/Scrub**- areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.
Herbaceous	
	71**Grassland/Herbaceous**- areas dominated by gramanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
	72**Sedge/Herbaceous**- Alaska only areas dominated by sedges and forbs, generally greater than 80% of total vegetation. This type can occur with significant other grasses or other grass like plants, and includes sedge tundra, and sedge tussock tundra.
	73**Lichens**- Alaska only areas dominated by fruticose or foliose lichens generally greater than 80% of total vegetation.
	74**Moss**- Alaska only areas dominated by mosses, generally greater than 80% of total vegetation.
Planted/Cultivated	
	81**Pasture/Hay**-areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.
	82**Cultivated Crops** -areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.
Wetlands	
	90**Woody Wetlands**- areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
	95**Emergent Herbaceous Wetlands**- Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

A3 - USFWS *Texella reyesi* Location Confidence Classes

Confirmed: Records based on identifications of vouchered adult males, which are the highest confidence taxonomically.

C: Records that may be based on females or juveniles, or for which the historical confirmation needs to be further documented. These are usually within the range of the species or near other caves that are confirmed and thus remain a higher level of confidence.

UID: This stands for unconfirmed identification and is a placeholder. At any point in time, a specimen may not have been examined taxonomically yet, there may be a question about the taxonomy, or the documentation regarding the taxonomy may not have been transmitted to the Service for a specimen.

Sight Record: Living individuals were noted in a cave but no voucher specimen has been collected.

Unverified Reference: References for caves that have been associated with the species historically, but further research is necessary to either confirm the reference or to remove it from our list of occupied caves. These caves are not included in an analysis of the species status.

A4 - Karst Zone Delineation

Karst Zone Delineation Veni (1992) divided the Austin area karst into 11 karst fauna regions within the outcrop of the Edwards Limestone Group that were defined in south to north order as:

North Hays County. Bounded to the north by Bear Creek, southern boundary undetermined; possibly drainage divide of the San Antonio and Barton Springs segments of the Edwards Aquifer. Limestone thinning due to erosion on San Marcos Arch. Intensely faulted.

South Travis County. Bounded to the south by Bear Creek and to the north by Barton Creek. Intensely faulted area.

Rollingwood. Bounded to the south by Barton Creek and to the north by the Colorado River. Intense faulting. Area of discharge from Barton Creek Segment of aquifer.

Central Austin. Bounded to the south by the Colorado River and to the north by thin section of Edwards Limestone near the McNeil area. Intense to moderate faulting.

McNeil. Bounded by narrow exposure of Edwards Limestone near east end of Travis Williamson County line along Edwards outcrop. Moderate to intense faulting. Round Rock. Bounded to the north by Brushy Creek and to the south and west near the Brushy Creek drainage divide. Moderate faulting.

Georgetown. Bounded to the south by Brushy Creek and to the north by the San Gabriel River. Moderate faulting. Groundwater discharge area along San Gabriel River.

Cedar Park. Bounded by area of complex stratigraphy. Little faulting. Jollyville Plateau. Bounded by connection of plateau to other Edwards outcrops along Travis-Williamson County line. Little faulting.

North Williamson County. Area north of San Gabriel River; northern boundary undetermined, probably near Williamson-Bell County line where limestone thins and becomes marly. Little to moderate faulting.

Post Oak Ridge. Isolated exposure of Whitestone Lentil of Walnut Formation along ridgetop. Little faulting.

Based on more recent geologic studies and mapping, some of these definitions could be refined but remain generally adequate.

https://www.fws.gov/southwest/es/Documents/R2ES/TX_Karst_Veni_2007_Austin_area_karst_zones.pdf

A5 - List of Confirmed Locations Divided up by KFR

North Williamson County	Status
Apache Cave	C
Buzzard Feather Cave	Confirmed
Cassidy Cave	Confirmed
Cat Cave	Confirmed
Choctaw Cave	C
Deliverance Cave No. 1	Confirmed
Deliverance Cave No. 2	C
Double Dog Hole Cave	C
Dragonfly Cave	Confirmed
Duckworth Bat Cave	C
Electro-Mag Cave	C
Flat Rock Cave	Confirmed
Heritage Oaks Cave No. 2	Confirmed
Holler Hole	Confirmed
Hourglass Cave	Confirmed
Karankawa Cave	C
Kiva Cave No.1	C
Little Surprise Cave	Confirmed
Lobo's Lair	Confirmed
Medicine Man Cave	Confirmed
Polaris Cave	C
Pow Wow Cave	C
Priscilla's Cave	C
Priscilla's Well Cave	C
Pussy Cat Cave	C
Rattlesnake Inn Cave	C
Red Crevice Cave	C
Shaman Cave	Confirmed
Sore-ped Cave	Confirmed
Stalagroot Cave	C
Temples of Thor Cave	Confirmed
Texella Cave	C
Turner Goat Cave	C

Unearthed Cave	C
Ute Cave	C
Venom Cave	Confirmed
War Party Cave	C
Waterfall Canyon Cave	Confirmed
Williams Cave No. 1	C
Wolfs Rattlesnake Cave	C
Woodruffs Well Cave	C
Yellow Hand Cave	C
You-Dig-It Cave	C
Abused Cave	C
Do-Drop-In Cave	Confirmed

McNeil/Roundrock	**Status**
Beer Bottle Cave	Confirmed
Cold Cave	Confirmed
Fossil Cave	C
Fossil Garden Cave	Confirmed
Hole-in-the-Road Cave	C
McNeil Bat Cave	C
Millipede Annex Cave	Confirmed
Millipede Cave	Confirmed
No Rent Cave	C
Pecan Gap Cave No. 1	Confirmed
Weldon Cave	Confirmed
Backhoe Surprise Cave	Confirmed
Beck Bat Cave	Confirmed
Beck Blowing Well	Confirmed
Beck Bridge Cave	C
Beck Horse Cave	C
Beck Pride Cave	C
Beck Ranch Cave	Confirmed
Beck Rattlesnake Cave	Confirmed
Beck Sewer Cave	Confirmed
Beck Tex-2 Cave	C
Black Cat Cave	C
Broken Zipper Cave	C
Cat Hollow Bat Cave	C
Cat Hollow Cave #1	Confirmed
Cat Hollow Cave #2	C
Cave Coral Cave	Confirmed
Chaos Cave	Confirmed
Crescent Cave	Confirmed
El Tigre Cave	C

Ensor Cave	C
Eulogy Cave	C
Flint Wash Cave	C
Hollow Oak Cave	Confirmed
Joint Effort Cave	C
Leachate Cave	C
Lineament Cave	Confirmed
Mustard Cave	C
Near Miss Cave	Confirmed
O'Connor Road Cave	Confirmed
Pencil Cactus Cave	C
Raccoon Lounge Cave	C
Sam Bass Hideaway Cave	Confirmed
Scoot Over Cave	C
Serta Cave	C
Stepstone Cave	C
Swarm Cave	C
Under-the-Fence Cave	Confirmed
Underdeveloped Cave	C
Undertaker Cave	Confirmed
Varicose Cave	C
Wild Card Cave	C
Rock Fall Cave	C

Jollyville	**Status**
Beard Ranch Cave	C
Eluvial Cave	C
Gallifer Cave	Confirmed
Geode Cave	Confirmed
Jest John Cave	Confirmed
Jollyville Plateau Cave	Confirmed
M.W.A. Cave	Confirmed
McDonald Cave	Confirmed
New Comanche Trail Cave	C
Puzzle Pits Cave	Confirmed
Root Cave	Confirmed
Stovepipe Cave	Confirmed
Tooth Cave	Confirmed
Twisted Elm Cave	Confirmed
Cortana Cave	Confirmed
Pickle Pit	Confirmed
Pond Party Pit	Confirmed

Georgetown	Status
Abyss Cave	Confirmed
Bone Cave	Confirmed
Brown's Cave	C
Elm Cave	C
Fence-Line Sink	Confirmed
Flowstone Rift Cave	C
Formation Forest Cave	Confirmed
Fortune 500 Cave	C
Inner Space Cavern	Confirmed
Man-With-A-Spear Cave	Confirmed
Mayfield Cave	C
Mayor Elliott Cave	Confirmed
Mosquito Cave	C
Off Campus Cave	Confirmed
Ominous Entrance Cave	C
On Campus Cave	Confirmed
Onion Branch Cave	C
Posh Cave	C
Price Is Right Cave	C
Rootin Tootin Cave	C
Round Rock Breathing Cave	Confirmed
Short Stack Cave	C
Steam Cave	C
Thin Top Cave	C
Tres Amigos Cave	Confirmed
Venturi Cave	Confirmed
Yamas Cave	C
Zapata Cave	Confirmed

Central Austin	Status
Cotterell Cave	Confirmed
West Rim Cave	C

Cedar Park	Status
Hatch Cave	C
Lakeline Cave	Confirmed
Underline Cave	Confirmed

Voids Encountered During Construction

By Colin Strickland

Many of the karst zones in Central Texas are very shallow with the deepest caves around 25 ft. deep. When preparing work sites for construction often the whole site is leveled which means areas at higher grade are cut down by sometimes 10 or more feet. (Figure 1). Trenches for utilities are then cut even deeper (Figure 2).

Figure 1. Down Cutting at Construction Site in Travis County Within Several Hundred Feet of Multiple *Texella reyesi* Caves

Figure 2. Utility Trench at Construction Site in Travis County

These trenches often encounter smaller voids sometimes referred to as mesocaverns or interstitial cavities and larger caves. Voids and caves are numerous in karstic limestone and can occur as interstitial cavities, solution enlarged bedding plane cavities, solution enlarged fractures and caves (Pope, 2011). We acquired the void database from City of Austin Watershed Protection Department, to determine how many voids are being encountered during construction. The void database was created in 2015 and thus currently has incomplete data coverage, with 325 voids encountered to date, of which more than half (218) are in just one development. Table 1 and Figure 3 show the type of utility being put in when the voids were encountered.

Utility Type	Count
Basin	10
No Data	8
Other	35
Storm	53
Wastewater	148
Water	71
Total	325

Table 1. Utility Types when Voids were Encountered

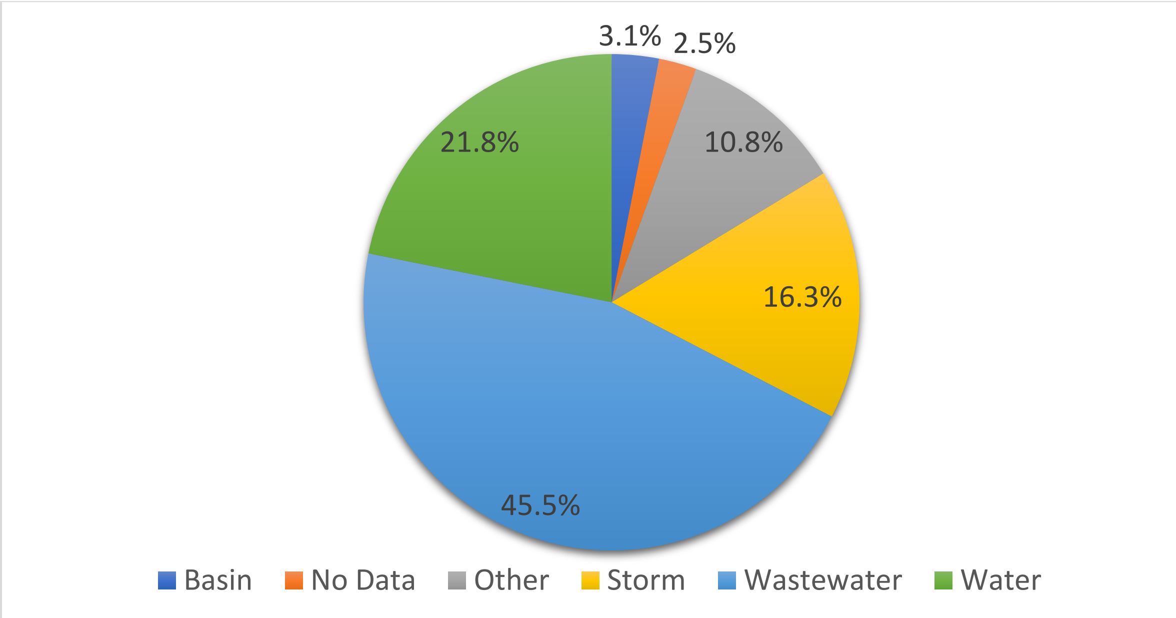

Figure 3. Utility Types when Voids were Encountered

There are different sizes of voids from Grade 1 to Grade 3. The following are the Grade definitions from the Void and Waterflow Mitigation section (1.12.0) of the City of Austin Environmental Criteria Manual (City of Austin, 2020).

- Grade 1: An opening in rock measuring more than 1 cubic foot (.028 cubic meters) (e.g., 1 foot by 1 foot by 1 foot), but less than 18 cubic feet (.504 cubic meters) (e.g., 2 feet by 3 feet by 3 feet).
- Grade 2: An opening in rock measuring 18 cubic feet or more (.504 cubic meters) but less than 160 cubic feet (4.48 cubic meters) (e.g., 4 feet by 4 feet by 10 feet or 2 feet by 2 feet by 20 feet).
- Grade 3: An opening in rock measuring 160 cubic feet or more (4.48 cubic meters). A specifically designed mitigation measure will typically be required for this size void. A licensed geotechnical or structural engineer must provide a cave-roof stability analysis that demonstrates that the proposed mitigation measures will minimize the risk of infrastructure or cave collapse.

Table 2 and Figure 4 show the number of each grade of voids encountered.

Grade Class	Count
Grade 1	81
Grade 2	124
Grade 3	120

Table 2. Number of Voids in Each Size Class

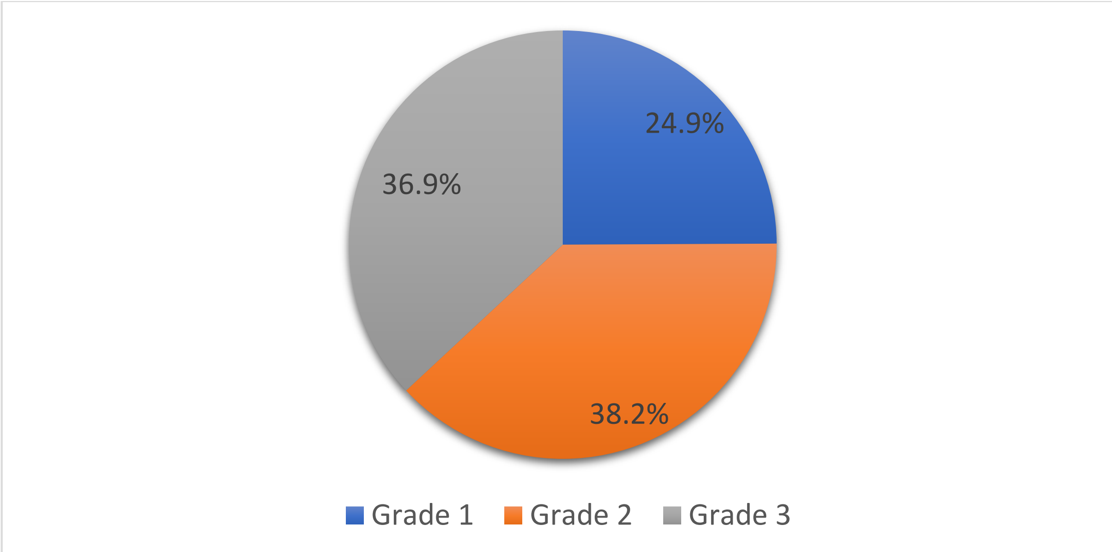

Figure 4. Percent of Voids in Each Size Class

Grades 2 and 3 includes voids that qualify as caves. The definition of void, “a completely empty space,” tends to minimize the importance of these geologic features. A cave is far more than an empty space. Figure 5 from the City of Austin Void and Water Mitigation Summary shows an example of an encountered “void” that is a cave (City of Austin, 2020).

Figure 5. Cave "Void" Encountered by Trench in Austin Texas

Unfortunately, the void data covers a very small amount of the construction that has happened in the last three decades in Central Texas. The large numbers of voids found in the example shown in Figure 6 are probably typical for the karst areas in northern Travis County and southern Williamson County.

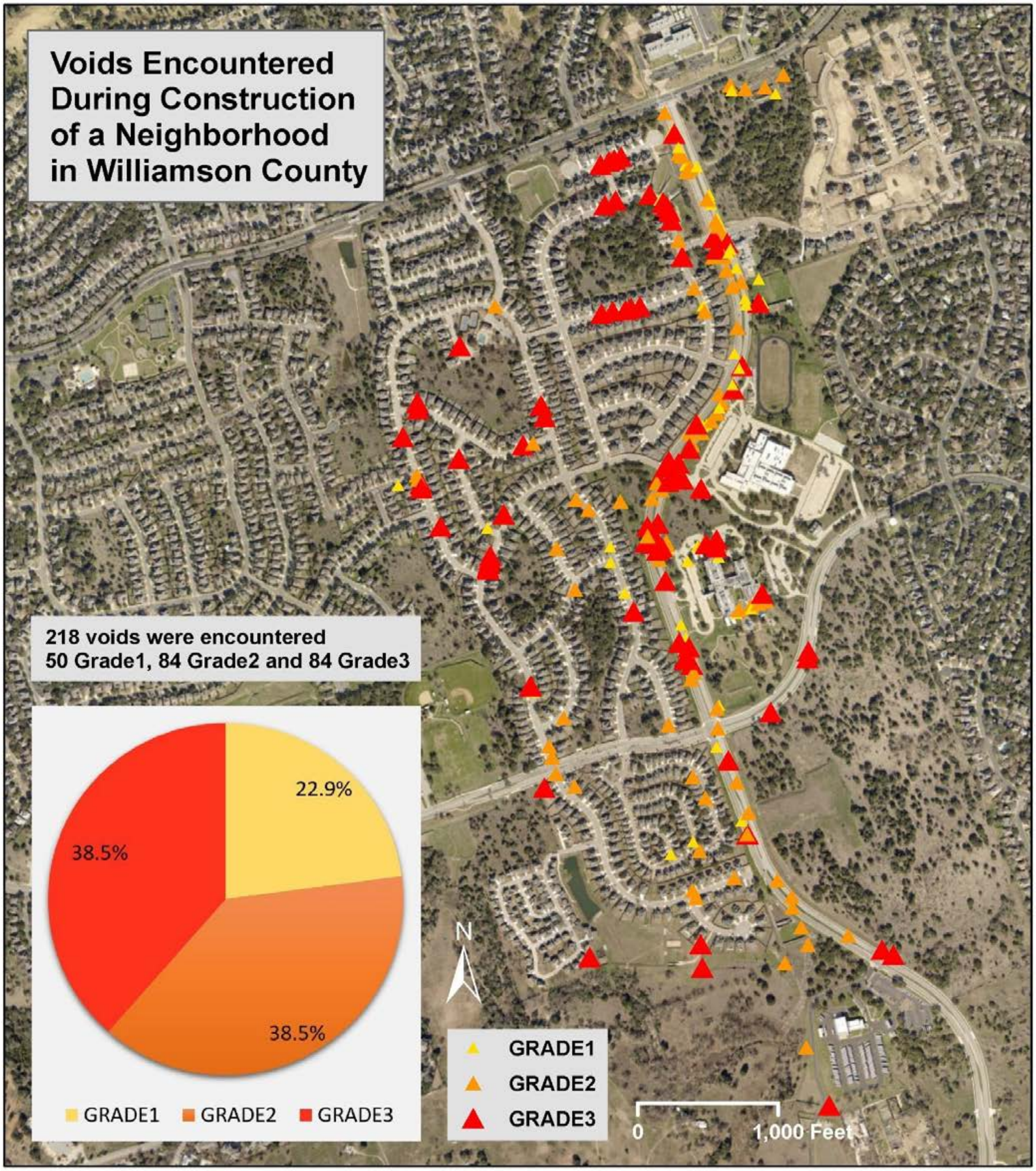

Figure 6. Voids Encountered during the Construction of a Neighborhood in Williamson County

Figure 7 shows *T. reyesi* caves and other caves in the area, which likely have similar concentrations of voids as those reported for this subdivision.

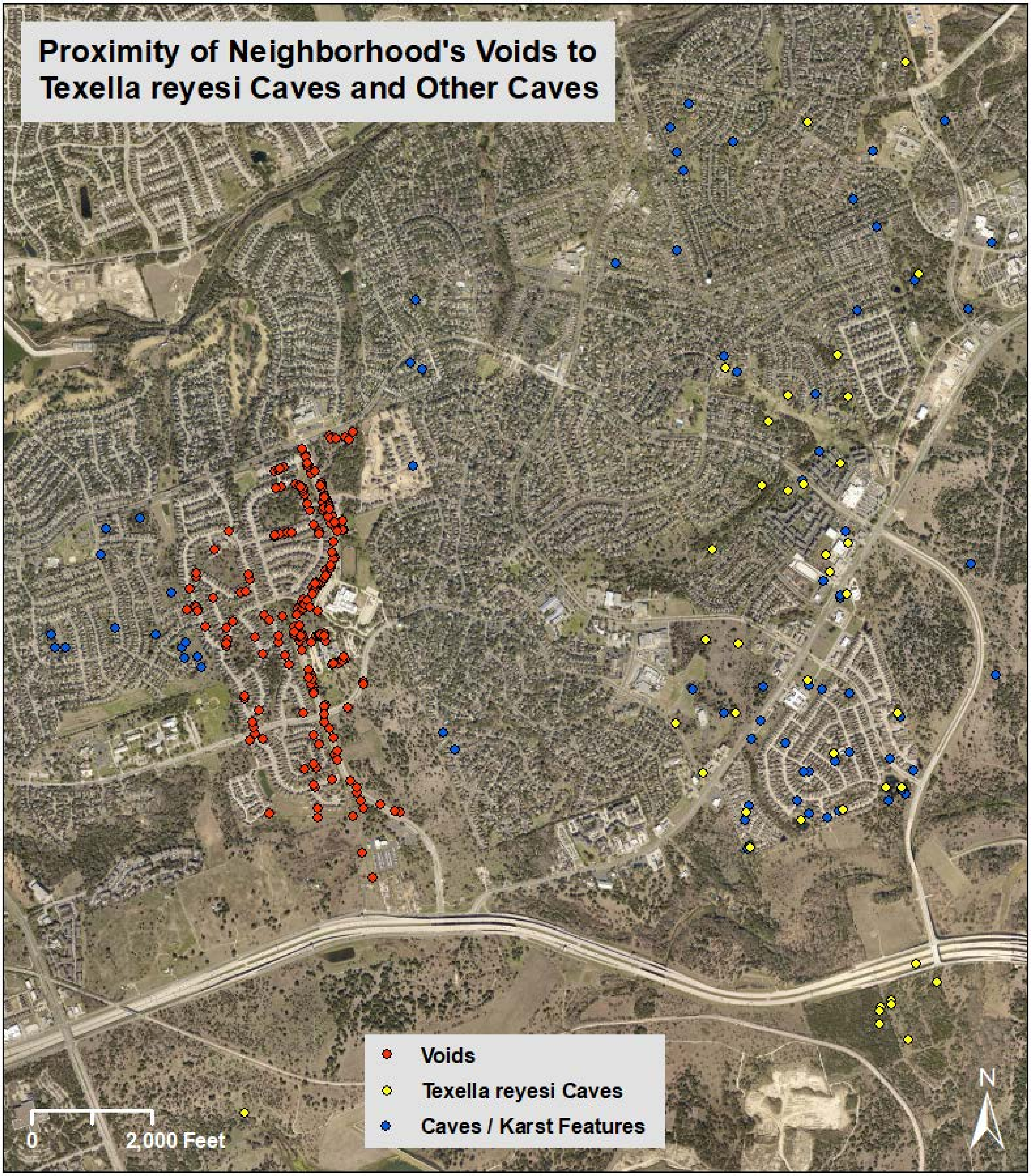

Figure 7. Proximity of Neighborhood's Voids to *Texella reyesi* Caves and Other Caves

Note: Void data were not collected when the surrounding neighborhoods were constructed. Void concentrations in those areas are likely similar to those in this neighborhood. There are likely many more caves and karst features in this area, but only available data was mapped.

City of Austin (2020) includes mitigation of voids. Unlike the Balcones Canyonlands Preserve, which was established to mitigate for habitat loss due to development by protecting karst ecosystems, void mitigation is intended solely to protect water supplies from contaminants primarily by filling them with concrete. The goal of most mitigations is to seal the caves and voids from the trench to prevent infiltration of wastewater or other contaminants if a leak should occur. An example of mitigation measures for a trench that bisects a void is shown in Figure 8 (Pope, 2011). In large developments trenches are numerous and replace limestone filled with interconnected interstitial spaces with fill that is not easily traversed by karst fauna. Sometimes PVC pipes are added connecting voids to allow flow of water and movement of fauna, but this is the exception rather than the rule, and still results in a drastic reduction in interconnectivity. An example of connecting PVC pipes is shown in Figure 9 (Pope, 2011).

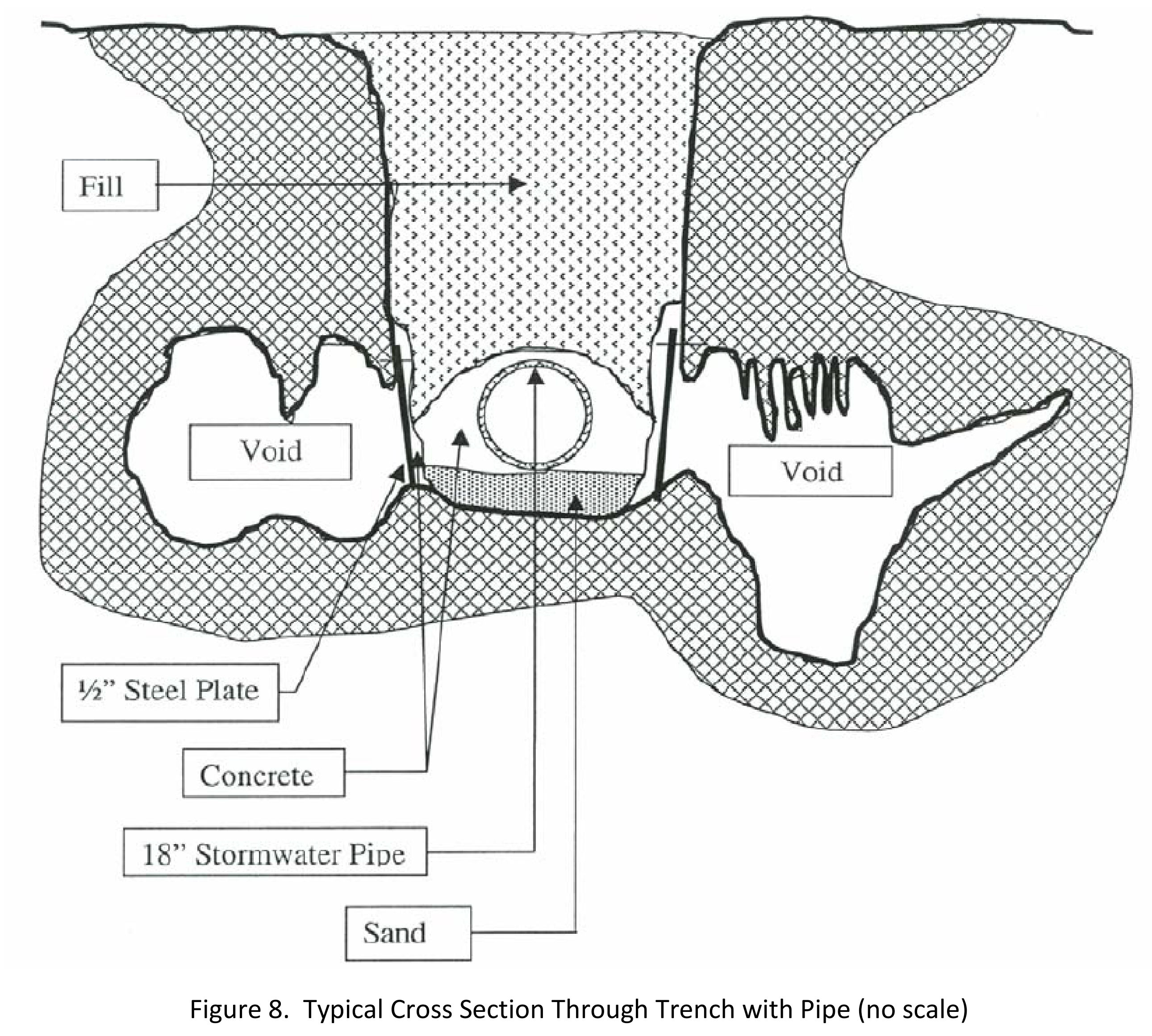

Figure 8. Typical Cross Section Through Trench with Pipe (no scale)

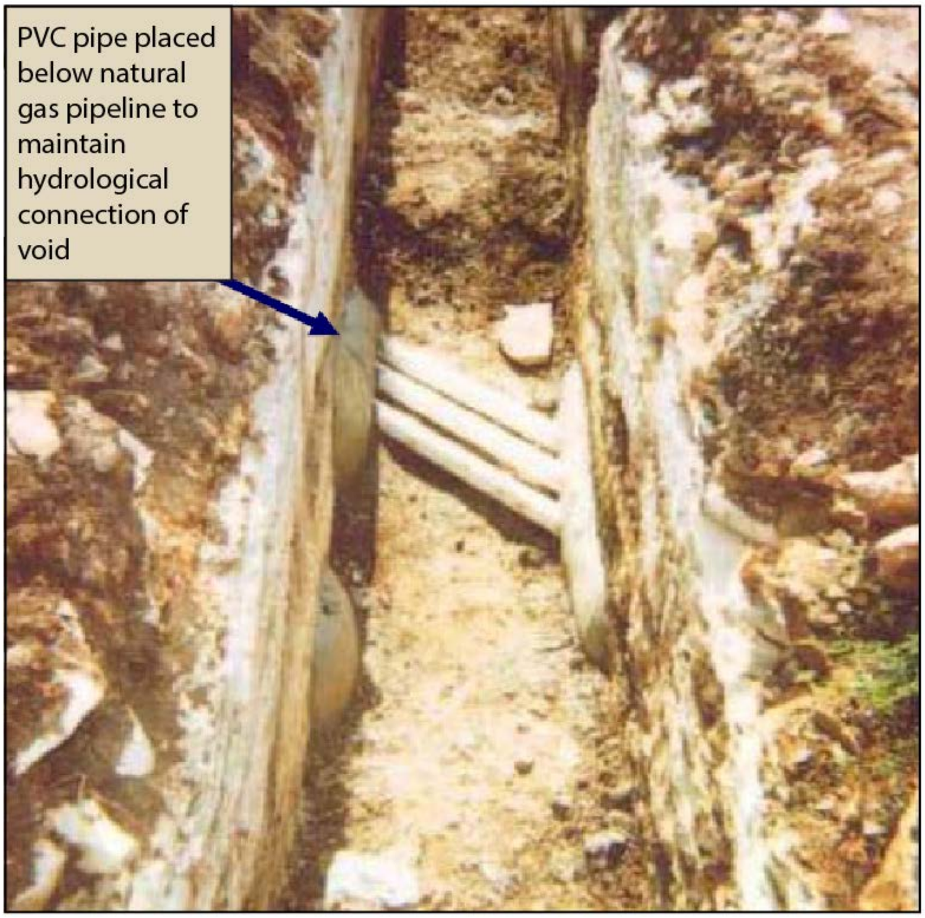

Figure 9. PVC Connecting Two Voids in Trench for Natural Gas Line

Many times, if the void or even a cave is in an inconvenient location it will be completely filled with concrete to ensure structural integrity for the construction above. There were many comments of features being filled with concrete in the void database. When describing mitigation for large features, the Environmental Criteria Manual states that "A normal strength concrete is required for structural 'wall' elements; however, any approved flowable fill is adequate where a large expanse of a void is being completely filled in" (City of Austin, 2020).

For karst fauna to survive in the subsurface environment, there needs to be healthy surface habitat and entrances to allow nutrients to enter caves and mesocaverns. When development replaces surface habitat with pavement, dissects the landscape with trenches, and fills any voids encountered with concrete, it severely impacts the subterranean environment. Nutrient inflow is decreased and interconnectivity between caves and mesocaverns is blocked by the utility trenches. Caves and mesocaverns are only truly protected when the surface habitat is preserved in its natural state.

Literature Cited

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Pope, S. R. (2011). Karst Void Mitigation for Water Quality and Quantity Protection in Austin, Texas. City of Austin Watershed Protection Department.

Bone Cave Harvestman (*Texella reyesi)* Faunal Data and Cave Cricket (*Ceuthophilus spp*.) Exit Count Data Analysis for Caves within the Balcones Canyonlands Preserve

Introduction

The Balcones Canyonlands Preserve (BCP) karst faunal surveys were standardized in 2011 and are described in City of Austin and Travis County (2019). Here we present analyses of the 2011-2019 datasets for 12 caves with Bone Cave Harvestman (*Texella reyesi*) and 17 cave cricket (*Ceuthophilus secretus* and *Ceuthophilus* Sp. B.) exit count caves, of which 7 are inhabited by *T. reyesi* and 10 are outside of the *T. reyesi* range. While development has increased at two cave cricket exit count caves (Flint Ridge, Testudo Tube), little to no increase in development has occurred within 745 feet (40-acre circle, or medium quality habitat based on USFWS 2012) of the surveyed caves. Surface vegetation is predominantly forested, and areas that are still open grassland with red-imported fire ants (*Solenopsis invicta*) are treated with boiling water. With the exception of Flint Ridge Cave and Testudo Tube, the datasets from the protected and managed karst preserves within the BCP allow for evaluation of abundance fluctuations in response to factors other than urban development.

Methods

The protocol for research and monitoring cave fauna involves the use of one to five (depending on size of cave and logistics) predesignated, permanent survey zones per cave in which all living organisms encountered are identified and enumerated, and some species are separated by age or size class (for example, adult vs. juvenile for *Texella spp.*). Survey zones are either transects approximately 5 meters in length that span the width of the cave, or distinct units of the cave such as a small room or an easily discernible section, so that the size and location of the survey area remains constant during the course of the study for trend comparison. Relative humidity (RH) and temperature are also recorded both outside the cave and at each survey zone. All data collected during cave surveys are entered into the BCP Karst Database.

In order to assess population trends for the *T. reyesi*, count data of individuals were totaled for all survey zones per survey. Count data of *T. reyesi* adults, juveniles, and total were graphed for each cave and linear regression analysis was completed to assess general trends in counts for each of the 12 caves. To assess relationships with environmental data like annual rainfall patterns, data from five caves that were surveyed in the same two seasonal periods (winter and summer) consistently from 2011-2019 were compiled, and totaled. We lumped data into two seasonal categories, Summer or Winter (most in this reduced dataset were completed in January and August, though some winter counts were completed in early February and some summer counts were in July or September). These caves were Cotterell, Pond Party Pit, Stovepipe, Gallifer, and Cortaña. Rainfall data and temperature data for this period were downloaded as daily rainfall totals and daily average temperature from NOAA for the nearby Camp Mabry weather station. We correlated rainfall from various time intervals with observed *T. reyesi* numbers, in order to explore at what scale rainfall might be important. Rainfall intervals that were compiled and examined in a correlation matrix included total rainfall during the month of the survey, total 1 month before the survey month, total during month 2 months before the survey month, total from the month 3 months before the survey month, total from 5 months including month of survey, total and average for all months between each survey, total for all months between each survey excluding the month of the survey, total from 6 months before month of survey, and total from 12 months before survey month. Month of survey for all of these rainfall metrics was always August for summer surveys and January for winter surveys. We also assessed the relationship between total number of *T. reyesi* found per cave survey and the average of RH measurements from inside the cave with a linear regression analysis. For this analysis, five outlier RH measurements (1.9% of N = 262) that were below 80% were excluded from the data.

As part of the Karst Survey Plan developed in 2011, cave cricket exit count surveys were to be completed for a portion of the caves that had in-cave surveys. These counts were completed within the same month of the in-cave survey, in order to better monitor each cave's cave cricket population. From 2011-2019, cave cricket exit counts were conducted for 17 caves, including 7 caves with *T. reyesi* and 10 caves outside of *T. reyesi*'s range. Cave cricket exit count surveys are completed by biologists and 1-3 assistants (depending on size of cave opening) using hand-held click counters. Nymph, subadult, and adult crickets are counted as they exit the cave, and data are recorded in ten-minute intervals for two hours, beginning in the first ten-minute interval after sunset. Temperature and humidity are recorded at the start and end of each survey. Red colored headlamps are used by observers to count crickets as they exit. Since crickets can exit in large quantities, it can be difficult to determine species identification between *C. secretus* and *C.* Sp. B, so although some counts have split the adults of the two species, for analysis, values for the two species are combined. Data for each cave are recorded on a field data sheet and later entered into an Excel spreadsheet. For this analysis, totals of each size class were compiled from each survey, as well as the sum of all crickets that were observed in each survey. The total cricket nymph, subadult, and adult numbers were graphed for each cave, and linear regression analysis was completed on total crickets to assess trend direction. A correlation matrix was created using Microsoft Excel to examine the relationship between total cricket exit count numbers and the observed *T. reyesi* numbers for the 2011-2019 period in Cotterell Cave, Cortaña Cave, Pond Party Pit Cave, and Stovepipe Cave. Additionally, we completed similar analyses for crickets in New Comanche Trail Cave from surveys inside the cave, as cricket exit counts were not completed for this cave.

Results

The average of all *T. reyesi* counts from 2011-2019 for the narrowed dataset of five caves (Cotterell, Pond Party Pit, Stovepipe, Gallifer, and Cortaña) was 17.4 among winter surveys and 22.2 for summer surveys. The trend data suggest generally higher numbers in summer surveys compared to previous and following winter surveys, although summer 2013 was anomalous, where an average of only 12.6 *T. reyesi* were observed. The general linear regressions for 12 caves analyzed show very few caves had statistically significant trends (see Table 1). Of those, Gallifer and Cortaña saw significant increasing trends for adults, juveniles, and totals, McDonald and No Rent for adults, and Tooth Cave for juveniles and total.

The correlation analysis for temperature and rainfall metrics from various time intervals shows that total rainfall between surveys has the strongest relationship with the total and average numbers of *T. reyesi* between survey periods (0.69 correlation coefficient), followed closely by the total rainfall between surveys including the month the survey was completed (0.68). Total rainfall from the 12 months before the survey also had a strong correlation (0.63 correlation coefficient). This relationship does not hold when looking at caves individually. We also ran correlations for just the data from summer and winter months separately. For data from summer months, average rainfall between surveys had the strongest correlation (0.86) with *T. reyesi* numbers. *T. reyesi* numbers from winter surveys were most strongly correlated (0.65) with total rainfall from 12 months before survey. Linear regression analysis of average RH among survey zones compared to total *T. reyesi* revealed a significant positive relationship ($R^2 = 0.0359$, $t = 3.09$, $p = 0.002$).

Cave cricket trends show some caves increasing and some decreasing. Cotterell was the only cave to have a statistically significant trend ($R^2 = 0.487$, $t = 4.143$, $p = 0.001$, Table 3). Many caves saw large spikes in cave crickets during 2015 and 2016 counts. Additionally, we compared cricket exit count data from four caves (Cotterell, Cortaña, Pond Party Pit, and Stovepipe) to the *T. reyesi* counts from corresponding periods and did not find strong correlation for three of the caves, though Cortaña Cave alone saw a slightly strong correlation (0.59). Total *T. reyesi* and total crickets for these four caves were also not strongly correlated (0.15). Cricket numbers at these four caves combined were more strongly correlated to mean monthly temperature during month surveyed (correlation value 0.45) than any of the rainfall periods analyzed. Of all rainfall periods examined, total rainfall from month of survey had the strongest correlation to cricket numbers (0.30).

Discussion

All populations of *T. reyesi* in this analysis are located in caves on protected BCP lands, which are managed for closed-canopy juniper-oak woodlands, specifically for endangered avian and karst species. Despite active management and protections, our data indicate that *T. reyesi* populations are fluctuating. Fluctuations are expected amongst invertebrate populations, even those in equilibrium (Hanski 1990). Five of twelve surveyed caves (42%) show a significant increase in adult or total population between 2011-2019 (Table 1). Increasing trends of *T. reyesi* are likely responding to increasing canopy cover and management activities. Of these five caves, four are treated for *S. invicta*, three have most of the area within a 40-acre buffer under protection (range 88% - 100%), and three have 100% forested land cover. All five of these caves had limited change in land development between 2011-2016 (range 0% -20%).

T. reyesi populations are vulnerable to extreme weather events and stochasticity. The year 2011 was the driest ever recorded in Texas (Neilson-Gammon 2011). Six of eleven caves (55%) showed very low numbers of adults (range 0 - 10) in 2011-2012, with populations not recovering until two to four years later in 2014-2016. In 2018, eight of twelve caves (67%) showed a crash in adult population size. Although the reason for the 2018 crash is unknown, on 28 August 2017, Hurricane Harvey dropped 10 inches of rain in two days while daily temperatures averaged ninety degrees. Pathogen reproduction and survival are influenced by temperature and humidity (Velasquez et al. 2018). Regardless of whether Harvey increased pathogen abundance, our data suggest that a combination of biotic and/or abiotic stressors could mount an additive population response resulting in local extirpations of *T. reyesi*. Two caves – McDonald and Tooth – showed only minimal decline, which emphasizes the importance of conserving multiple caves within each karst faunal region to increase the chance of some meta-populations surviving extreme weather events.

Despite potential negative impacts from extreme rainfall events, we see a positive relationship between *T. reyesi* numbers and rainfall abundance (Fig. 2b). Matrix correlation was highest for average rainfall prior to summer survey counts (0.86). Rainfall in central Texas tends to occur year round with peaks in May-June and September-October (Climate-Data.org, Fig. 2a), so extreme rainfall events or lack of rainfall during drought may account for the majority of correlation. These data support USFWS' contention that populations of *T. reyesi*, especially small populations, are vulnerable to climate change as extreme weather events increase in frequency (Neilson-Gammon 2020)

T. reyesi populations of adults and juveniles appear to be fluctuating asynchronously with high adult numbers producing high juvenile numbers and vice versa. In four caves (Pond Party Pit, Stovepipe, Gallifer, and Tooth), a spike in juvenile numbers is followed by a marked increase in adults 6 to 12 months later. *T. reyesi* are likely opportunistic feeders, but they may be dependent upon secondary food resources, like Collembola feeding on guano (Taylor et al. 2005, Allard and Yeargen 2005) or invertebrates scavenging on carcasses (Zara Environmental 2009), for nutrients essential to reproduction (Toft and Wise 1999). Time to population recovery and recruitment of juveniles to adults may be slower in caves with an insufficient cave food web. A healthy, diverse Ashe juniper-oak woodland community is critical to preserving energy flow into the cave, which supports the need for increased buffers and greater surface protections.

Our results show that active control of *S. invicta* supports increased populations of karst invertebrates. For example, at New Comanche Trail Cave, active management of *S. invicta* (pouring boiling water on top of active mounds near the cave entrance) began in 2013. Prior surveys of in-cave counts documented very few *T. reyesi* and cave crickets. Since treatments began, *T. reyesi* counts have increased from 0 to 18 and cave crickets from 0 to over 5000.

The majority of the caves assessed in our analysis had consistent *S. invicta* control. Pond Party Pit and Beard Ranch Cave have not required control. These two nearby caves are surrounded by dense juniper-oak woodland and a lack of disturbance, both of which deter the spread of *S. invicta* (LeBrun et al. 2012). *S. geminata*, a native congener which are competitively replaced by *S. invicta* (Plowes et al. 2007), are often detected in Pond Party Pit, further indicating that *S. invicta* are not established in the vicinity of these caves. Our data suggest that active control of *S. invicta* is a successful management strategy where they are currently invasive, and that expanded setbacks to promote contiguous forest canopy cover and reduce disturbance is a proactive management strategy to maintain healthy populations of karst fauna, including *T. reyesi*.

Our data show a positive correlation between RH and numbers of *T. reyesi* (Figure 2c). *T. reyesi* typically inhabit the deeper reaches of caves, where RH approaches saturation and temperature fluctuations are buffered from seasonal shifts on the surface (Ubick and Briggs 1992). We observed that deeper caves had larger numbers of *T. reyesi* and that no cave less than 5m deep contained more than 18 *T. reyesi* during one survey. The largest counts of *T. reyesi* were 91 in Tooth Cave (5.6m deep) and 89 in Gallifer Cave (7.3m deep). Caves deeper than 5m are relatively rare in the range of *T. reyesi* (N. Hauwert, pers. comm.). The conservation of multiple caves with maximum surface protections can improve population resiliency in response to stochastic events.

Cave cricket populations are also fluctuating. Cave cricket populations that we compared to *T. reyesi* caves (N = 4, range: 398-3712) were only mildly correlated with mean monthly temperature and weakly correlated with rainfall metrics. Except for extreme weather events, cave cricket populations appear to be fluctuating independently of external abiotic variables. In contrast to *T. reyesi*, adult and juvenile cave cricket populations appear to be fluctuating in tandem. Maple Run, Broken Arrow, and District Park Caves show remarkable synchrony between populations of nymphs, subadults, and adults. Cave crickets may have a density-dependent population response to resource availability and/or predation. In other words, if resource availability is high, then all age classes increase until resources become limited, at which point adults and juvenile populations decline synchronously.

Total cave cricket populations and total *T. reyesi* populations are not correlated (0.15, N = 4). As a keystone species, cave crickets contribute significant nutrient inputs which support a diverse community of karst fauna (Taylor et al. 2005). Relationships between trogloxene cave crickets and endangered cave arthropods may be direct or indirect. However, our sample size was small, and we performed limited analyses, which could explain our weak correlation. For example, there may be delays in response between cricket population fluctuations and resulting changes in *T. reyesi* populations. *Rhadine* beetles prey upon the eggs of cave crickets (Taylor et al. 2007), while *Cicurina* spiders feed on the springtails that rely on the guano of roosting cave crickets (Taylor et al. 2003), both of which would have differing delays in response. Although the relationship between *T. reyesi* and cave crickets is unknown, all of the surveyed caves that contain *T. reyesi* also support populations of cave crickets.

Land use change can impact cave cricket populations. By 2015, the neighboring property to Testudo Tube Cave was converted to residential housing, and the cave cricket population declined ($t = -1.183$, $p = 0.254$). In October 2013, extreme flooding caused substantial changes to the entrance of Flint Ridge Cave, and we subsequently documented a steep decline in cave crickets ($t = -2.021$, $p = 0.053$). Changes in the surface flow may have been exacerbated by the construction of State Highway 45. In contrast, Cotterell Cave showed a significant increase in total population between 2011-2019 (Table 3), where development has encroached on parts of the preserve, but other portions are contiguous to an extensive natural area. Large surface foraging areas are required to maintain healthy populations of cave crickets, supporting the need for increased buffers and greater surface protections.

Figures 1a-1l. Adult, Juvenile, and Total *Texella reyesi* Count Data per Cave. These figures show count data as combined among survey zones for each survey. Linear regression trend lines and corresponding R^2 values are included where significant.

Figure 1a. Beard Ranch Cave

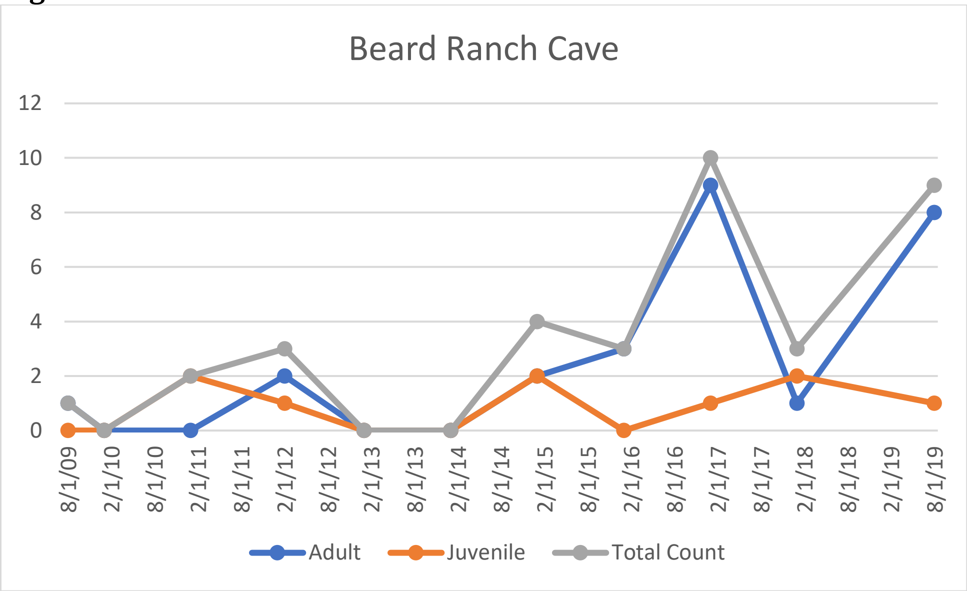


Figure 1b. Cotterell Cave.

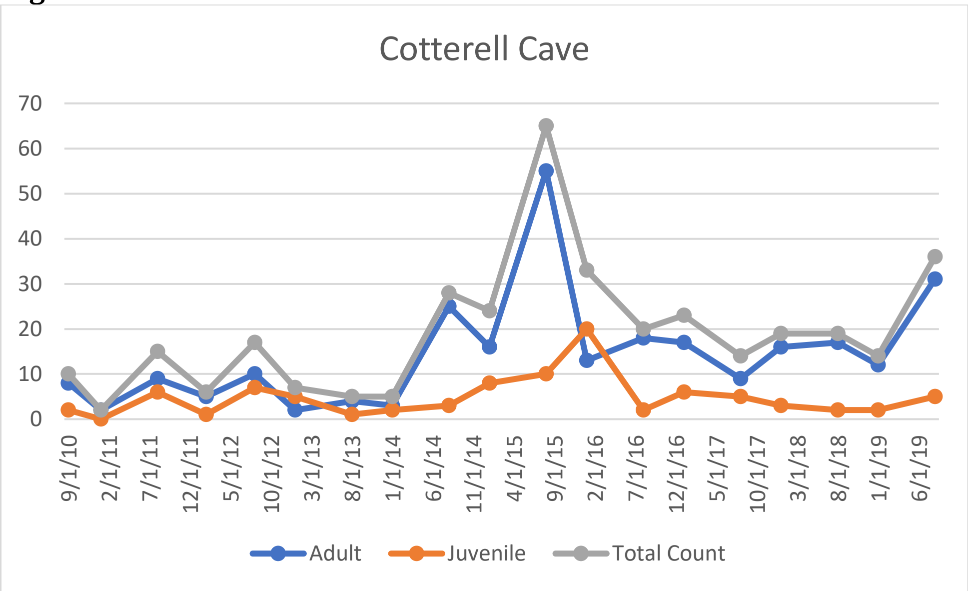


Figure 1c. Pond Party Pit.

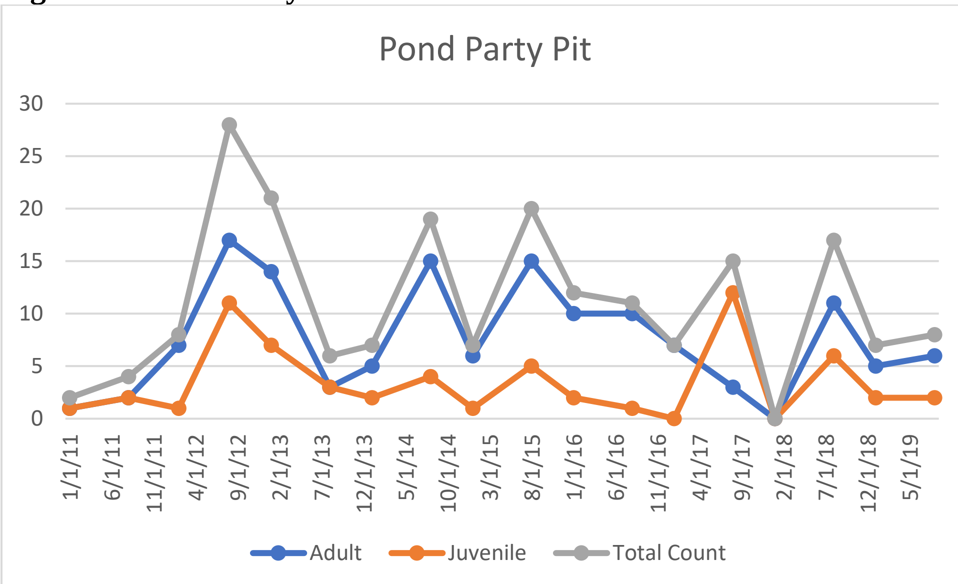


Figure 1d. Stovepipe Cave.

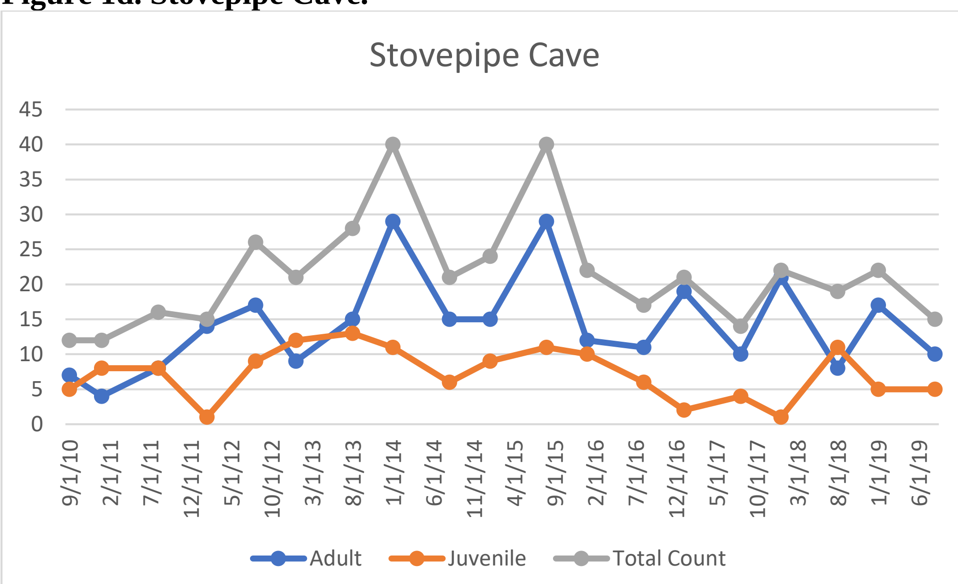


Figure 1e. Gallifer Cave.

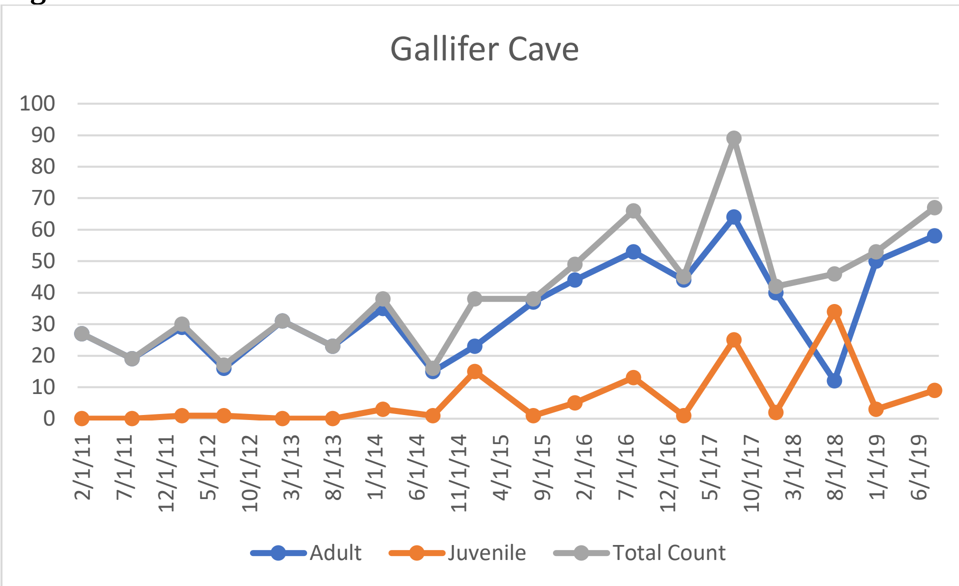


Figure 1f. McDonald Cave. Total not included for McDonald cave, since no juveniles observed.

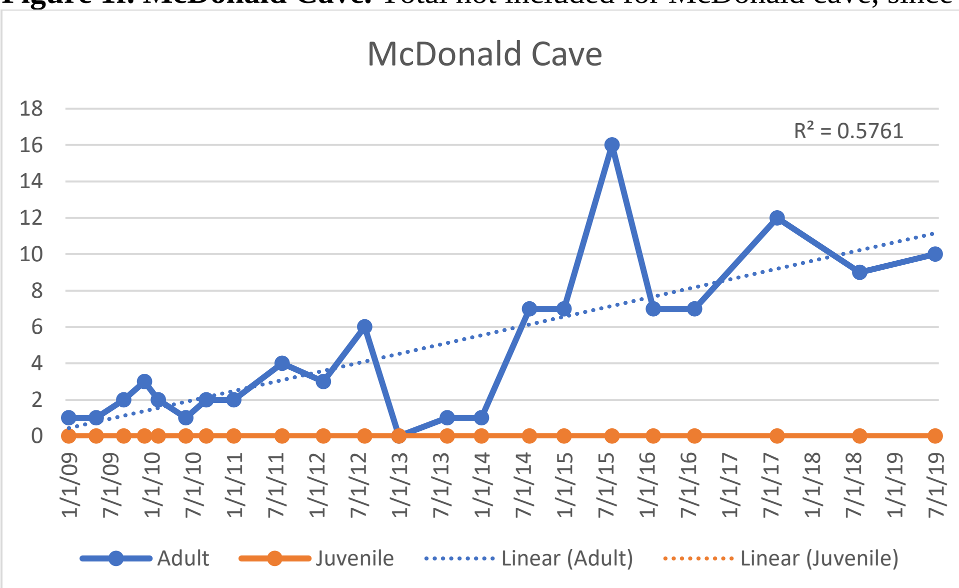


Figure 1g. Tooth Cave.

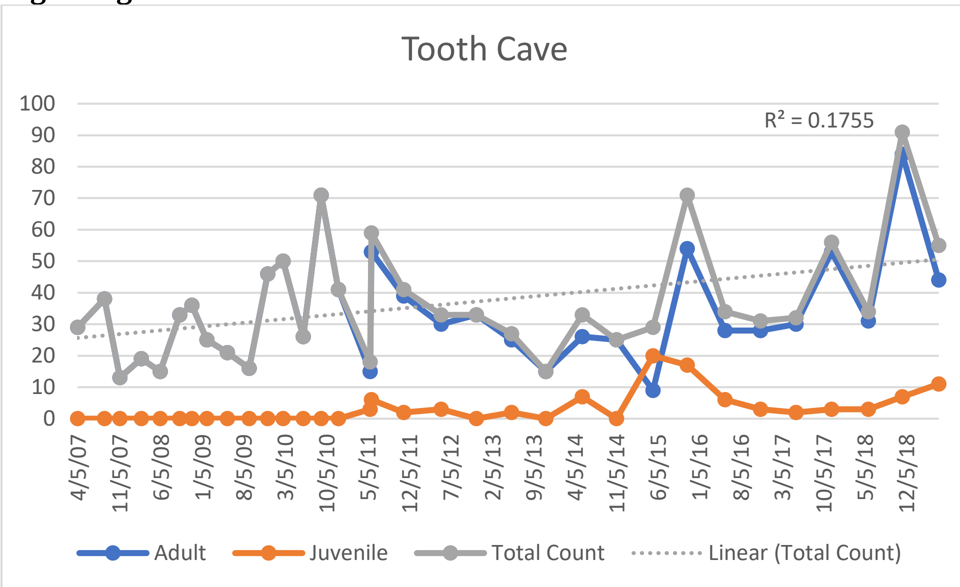


Figure 1h. New Comanche Trail Cave.

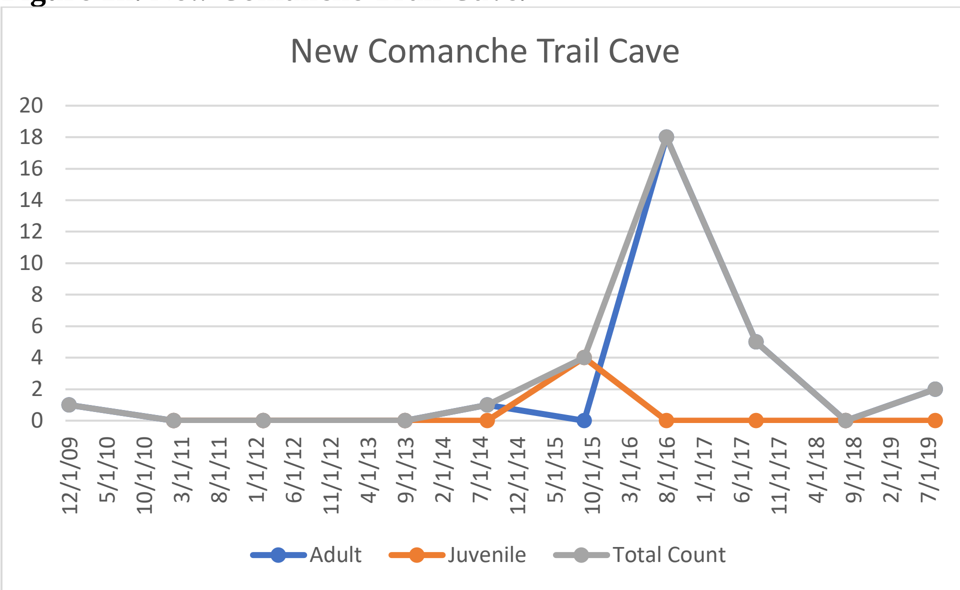


Figure 1i. No Rent Cave.

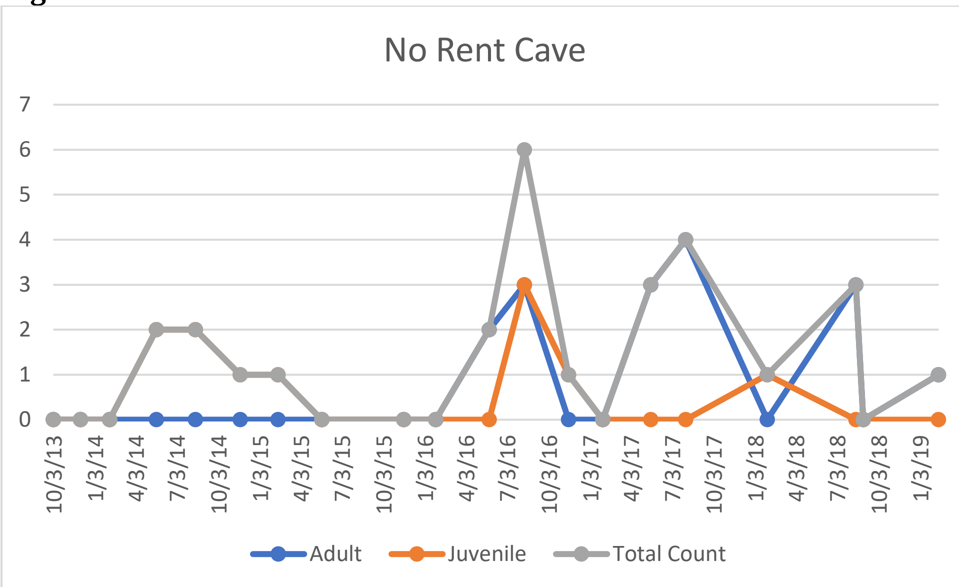


Figure 1j. Weldon Cave.

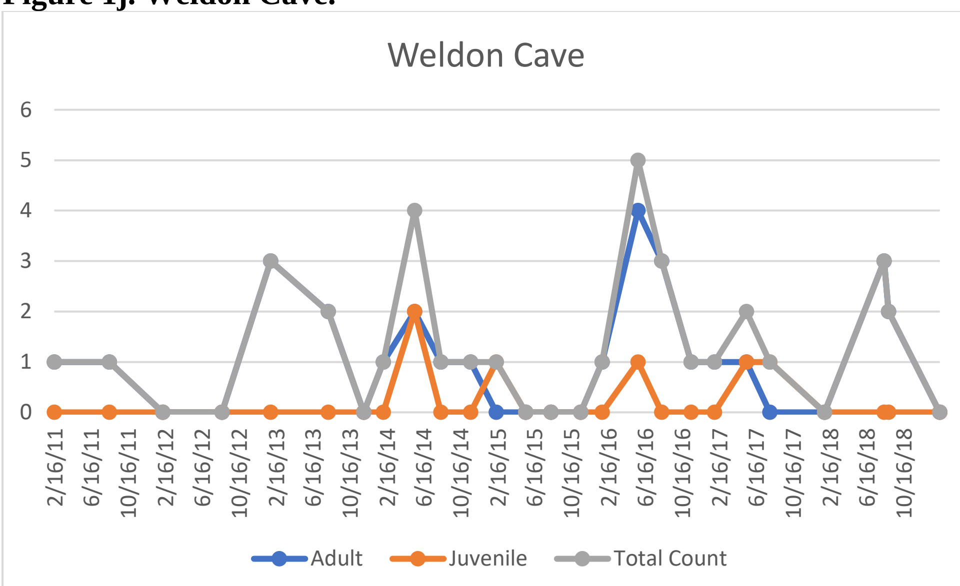


Figure 1k. Cortaña Cave.

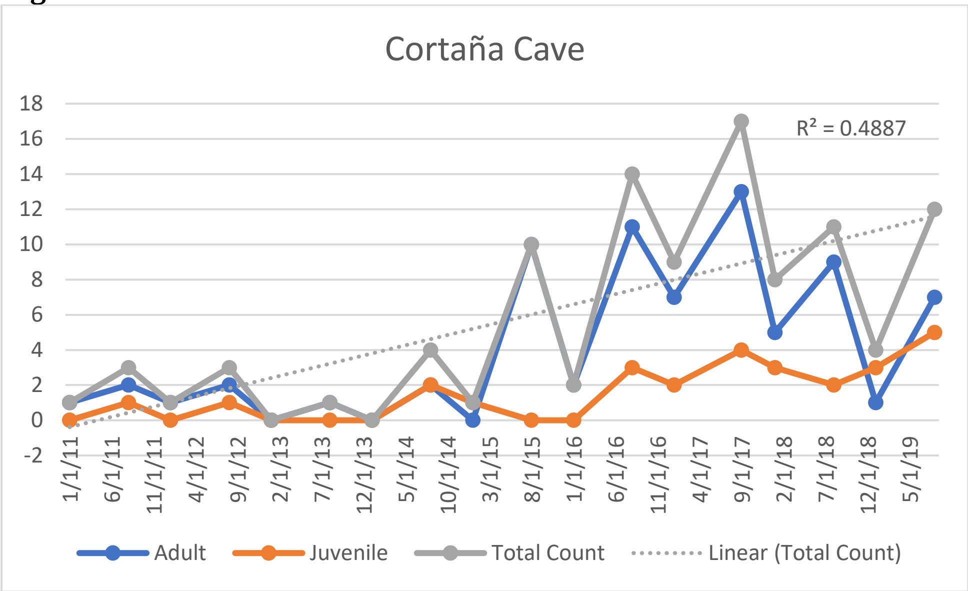


Fig 1l. Geode Cave

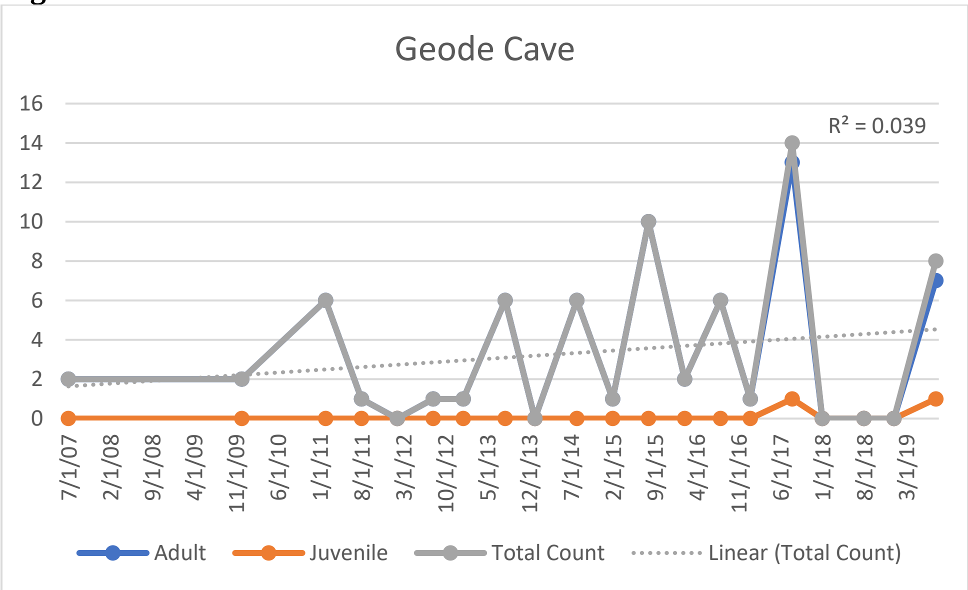


Table 1. Linear Regression Analyses of *Texella reyesi* Trends per Cave.

			Coefficients	*SE*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Beard Ranch Cave	Adult	Intercept	-3.743	6.907	-0.542	0.600	-19.132	11.646
		X Var.	0.000	0.000	0.875	0.402	0.000	0.001
	Juvenile	Intercept	-1.360	1.900	-0.716	0.491	-5.594	2.874
		X Var.	0.000	0.000	1.120	0.289	0.000	0.000
	Total	Intercept	-5.103	7.309	-0.698	0.501	-21.389	11.183
		X Var.	0.000	0.000	1.118	0.290	0.000	0.001
Cotterell Cave	Adult	Intercept	-211.428	111.781	-1.891	0.076	-447.265	24.409
		X Var.	0.005	0.003	2.020	0.059	0.000	0.011
	Juvenile	Intercept	-21.404	44.800	-0.478	0.639	-115.925	73.117
		X Var.	0.001	0.001	0.584	0.567	-0.002	0.003
	Total	Intercept	-232.832	132.146	-1.762	0.096	-511.636	45.972
		X Var.	0.006	0.003	1.907	0.074	-0.001	0.013
Pond Party Pit Cave	Adult	Intercept	20.482	55.829	0.367	0.719	-97.871	138.835
		X Var.	0.000	0.001	-0.231	0.821	-0.003	0.003
	Juvenile	Intercept	8.033	37.961	0.212	0.835	-72.441	88.507
		X Var.	0.000	0.001	-0.121	0.905	-0.002	0.002
	Total	Intercept	28.514	80.359	0.355	0.727	-141.838	198.867
		X Var.	0.000	0.002	-0.217	0.831	-0.004	0.004
Stovepipe Cave	Adult	Intercept	-43.431	66.418	-0.654	0.522	-183.561	96.699
		X Var.	0.001	0.002	0.868	0.397	-0.002	0.005
	Juvenile	Intercept	42.535	35.916	1.184	0.253	-33.240	118.311
		X Var.	-0.001	0.001	-0.984	0.339	-0.003	0.001
	Total	Intercept	-0.896	78.858	-0.011	0.991	-167.271	165.480
		X Var.	0.001	0.002	0.283	0.781	-0.003	0.004
Gallifer Cave	Adult	Intercept	-362.810	133.745	-2.713	0.015	-646.338	-79.282
		X Var.	0.009	0.003	2.971	**0.009**	0.003	0.016
	Juvenile	Intercept	-213.166	88.570	-2.407	0.029	-400.927	-25.405
		X Var.	0.005	0.002	2.479	**0.025**	0.001	0.010
	Total	Intercept	-575.976	139.253	-4.136	0.001	-871.178	-280.774
		X Var.	0.015	0.003	4.430	**0.000**	0.008	0.022
Geode Cave	Adult	Intercept	41711.184	360.871	115.585	0.000	40953.023	42469.344
		X Var.	55.282	73.739	0.750	0.463	-99.638	210.202
	Juvenile	Intercept	41730.556	262.932	158.712	0.000	41178.155	42282.956
		X Var.	1602.944	831.465	1.928	0.070	-143.898	3349.787
	Total	Intercept	41691.047	355.999	117.110	0.000	40943.121	42438.973
		X Var.	59.643	69.750	0.855	0.404	-86.897	206.182
McDonald Cave	Adult	Intercept	-110.243	22.157	-4.976	0.000	-156.462	-64.025
		X Var.	0.003	0.001	5.191	**0.000**	0.002	0.004
	Juvenile	NA	NA	NA	NA	NA	NA	NA
		NA	NA	NA	NA	NA	NA	NA
	Total	Intercept	-110.243	22.157	-4.976	0.000	-156.462	-64.025
		X Var.	0.003	0.001	5.191	**0.000**	0.002	0.004

			Coefficients	*SE*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Tooth Cave	Adult	Intercept	-112.802	88.231	-1.278	0.211	-292.750	67.147
		X Var.	0.004	0.002	1.657	0.108	-0.001	0.008
	Juvenile	Intercept	-81.959	22.149	-3.700	0.001	-127.132	-36.786
		X Var.	0.002	0.001	3.832	**0.001**	0.001	0.003
	Total	Intercept	-194.761	89.970	-2.165	0.038	-378.256	-11.265
		X Var.	0.006	0.002	2.569	**0.015**	0.001	0.010
New Comanche Trail Cave	Adult	Intercept	-53.401	67.040	-0.797	0.449	-207.996	101.195
		X Var.	0.001	0.002	0.837	0.427	-0.002	0.005
	Juvenile	Intercept	-2.992	15.750	-0.190	0.854	-39.313	33.328
		X Var.	0.000	0.000	0.215	0.835	-0.001	0.001
	Total	Intercept	-56.393	65.731	-0.858	0.416	-207.969	95.183
		X Var.	0.001	0.002	0.905	0.392	-0.002	0.005
No Rent Cave	Adult	Intercept	-43.367	19.559	-2.217	0.040	-84.458	-2.276
		X Var.	0.001	0.000	2.258	**0.037**	0.000	0.002
	Juvenile	Intercept	12.863	14.145	0.909	0.375	-16.855	42.581
		X Var.	0.000	0.000	-0.871	0.395	-0.001	0.000
	Total	Intercept	-30.504	25.468	-1.198	0.247	-84.011	23.003
		X Var.	0.001	0.001	1.251	0.227	-0.001	0.002
Weldon Cave	Adult	Intercept	-4.663	12.236	-0.381	0.706	-29.916	20.590
		X Var.	0.000	0.000	0.469	0.643	0.000	0.001
	Juvenile	Intercept	-2.369	5.408	-0.438	0.665	-13.531	8.792
		X Var.	0.000	0.000	0.481	0.635	0.000	0.000
	Total	Intercept	-7.032	14.155	-0.497	0.624	-36.248	22.183
		X Var.	0.000	0.000	0.589	0.561	0.000	0.001
Cortaña Cave	Adult	Intercept	-103.799	37.256	-2.786	0.013	-182.779	-24.819
		X Var.	0.003	0.001	2.897	**0.011**	0.001	0.004
	Juvenile	Intercept	-51.139	10.820	-4.727	0.000	-74.075	-28.203
		X Var.	0.001	0.000	4.866	**0.000**	0.001	0.002
	Total	Intercept	-154.938	41.353	-3.747	0.002	-242.603	-67.273
		X Var.	0.004	0.001	3.883	**0.001**	0.002	0.006

Table 2. Correlation coefficients for Weather Intervals and *Texella reyesi* totals from 5 Caves.

	Summer and Winter Surveys	Summer Surveys	Winter Surveys
Mean temp during month of Survey	0.34	-0.453	0.090
Total rainfall between surveys	0.692	0.690	0.552
Total rainfall between + during	0.68	0.834	0.258
Total rainfall during + 4mos prior	0.574	0.810	0.258
Total rainfall during	0.239	0.453	-0.301
Total rainfall 1mo before	-0.243	-0.448	0.201
Total rainfall 1+2mo before	0.371	0.365	0.441
Total rainfall in mo 3 mo before	0.566	0.564	0.541
Average rainfall between surveys	0.52	0.863	0.191
Average monthly rainfall year before	0.616	0.743	0.581
Total rainfall for 6months before	0.55	0.668	0.490
Total rainfall year prior	0.636	0.748	0.653

Figures 2a-2c. Environmental Data and Relationships to *Texella reyesi.*

Figure 2a. Monthly rainfall totals from Camp Mabry, 2010-2019.

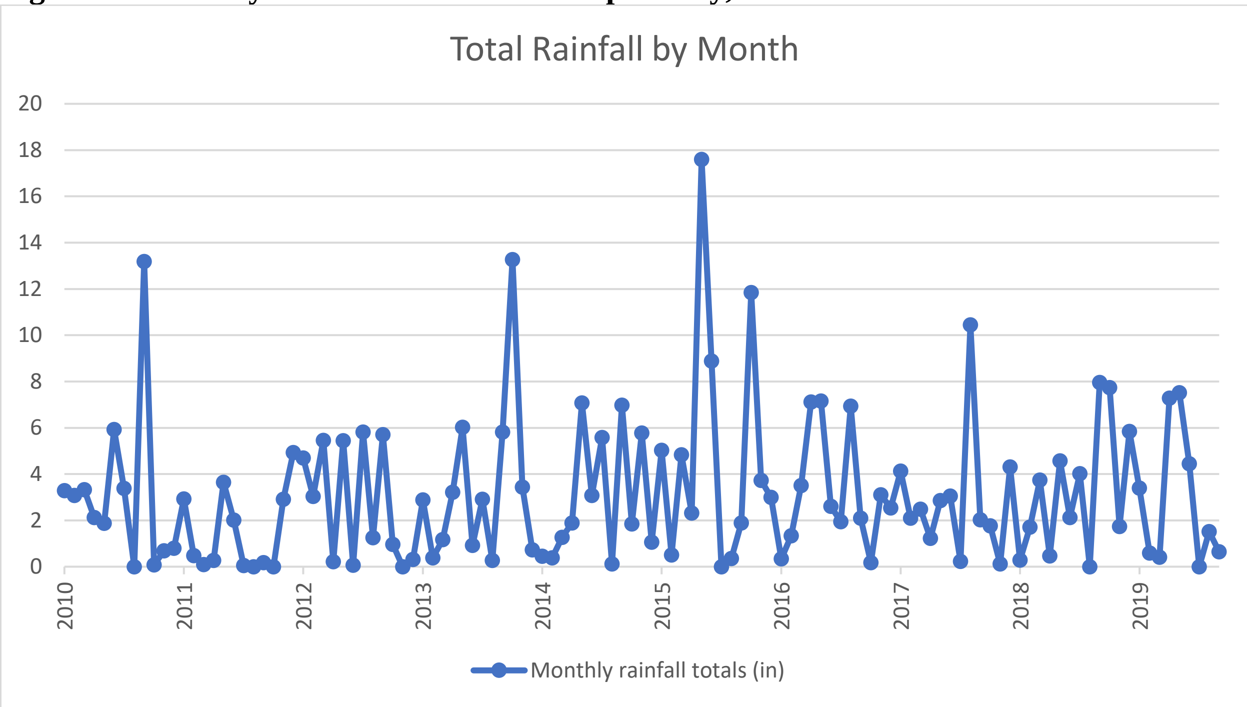


Figure 2b. *Texella reyesi* Total counts vs. Total Rainfall for All Months Between Surveys.

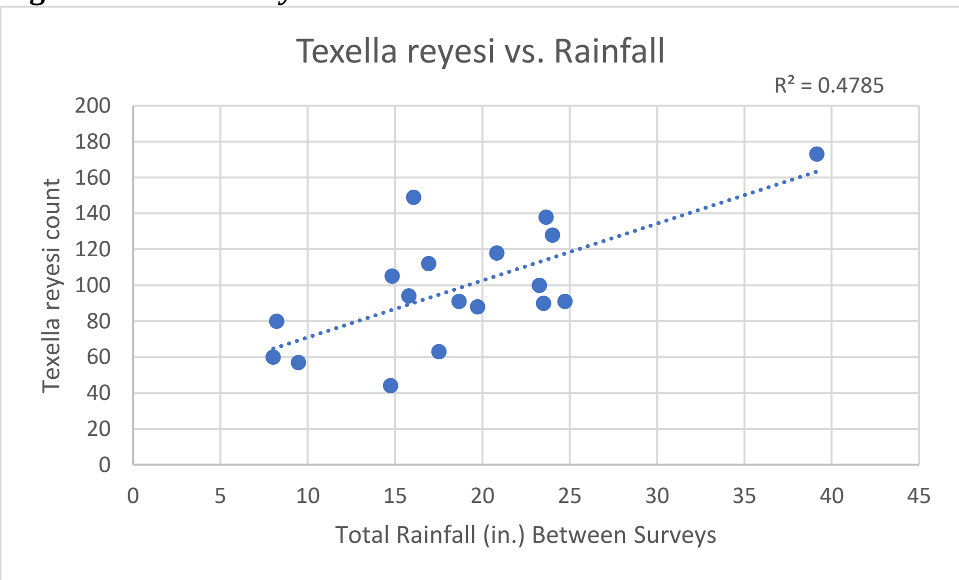
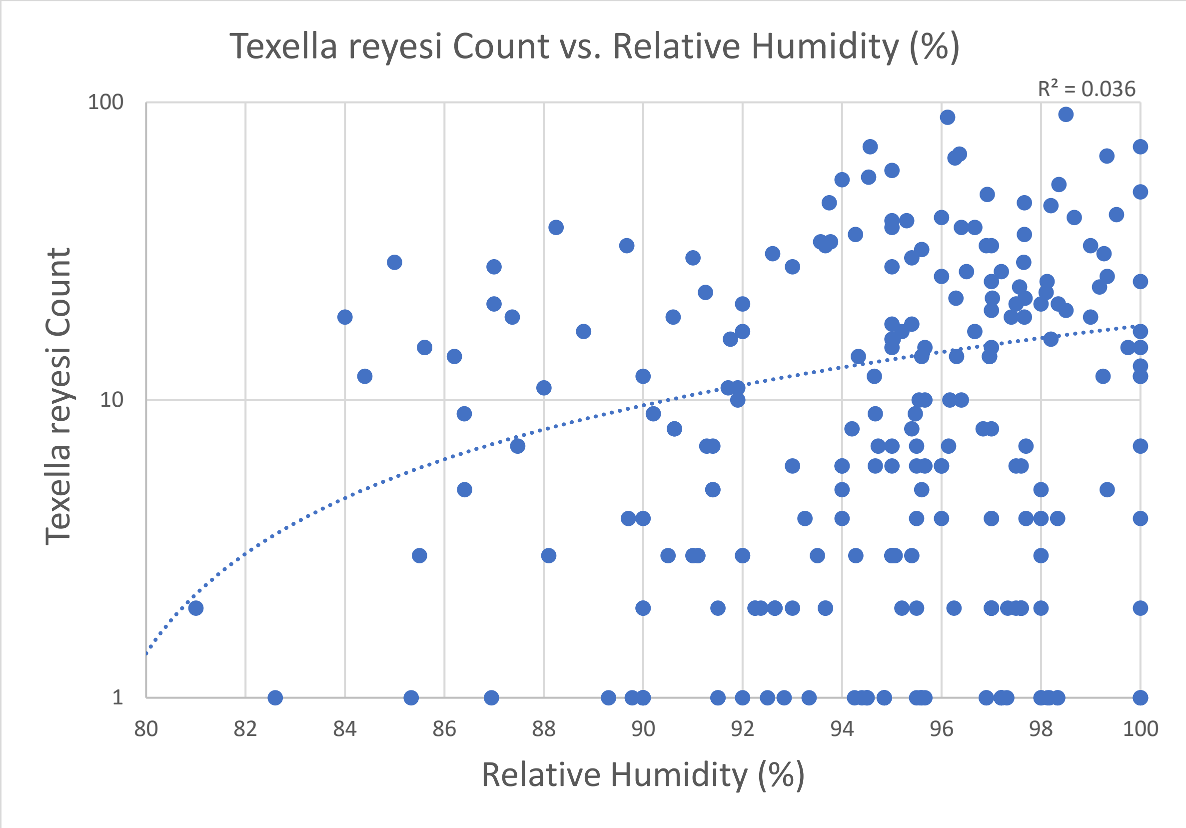


Figure 2c. *Texella reyesi* Total counts vs. Average Relative Humidity Among Survey Zones. Displayed with log scale which cannot include counts of zero.



Figures 3a-3o. Nymph, Subadult, Adult, and Total Cave Cricket Exit Count Data per Cave. These figures show count data for each size class of cave cricket from exit count surveys. Linear regression trend lines and corresponding R^2 values are included where significant.

Figure 3a. Airmen's Cave.

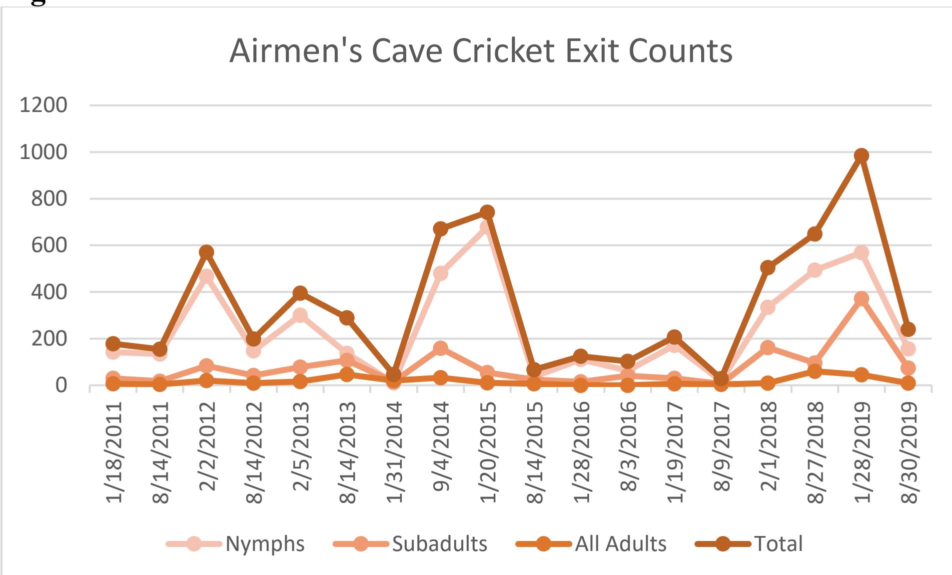


Figure 3b. Broken Arrow Cave.

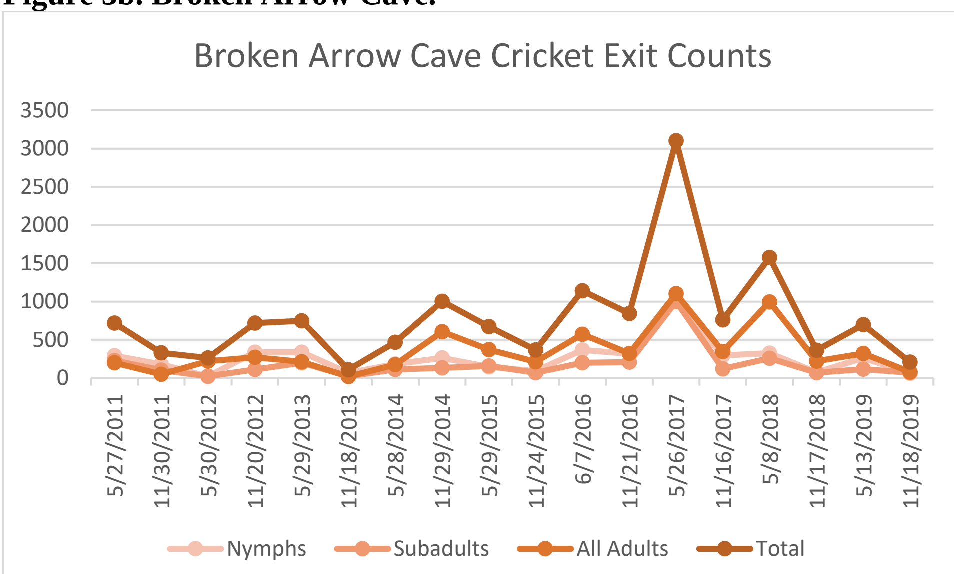


Figure 3c. Cave Y.

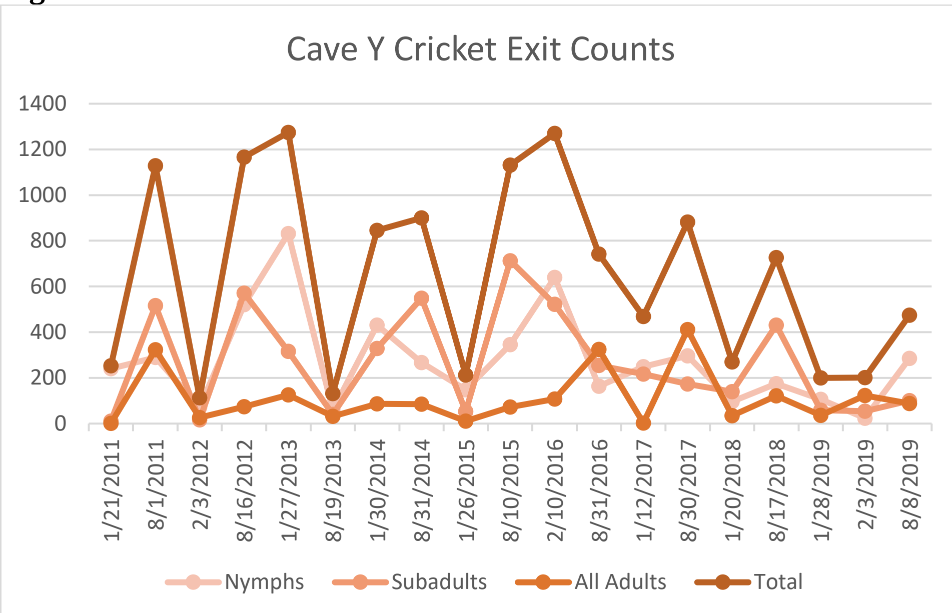


Figure 3d. Cortaña Cave.

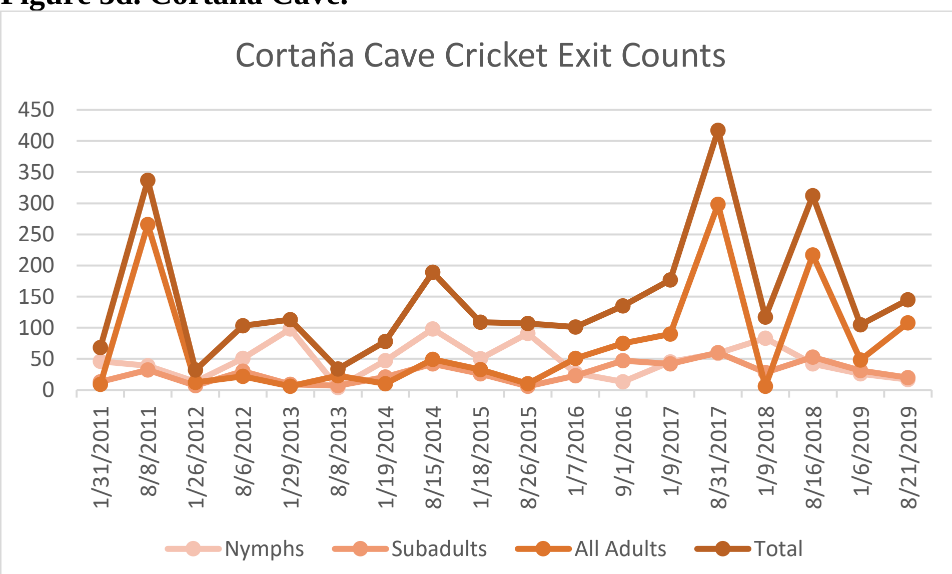


Figure 3e. Cotterell Cave.

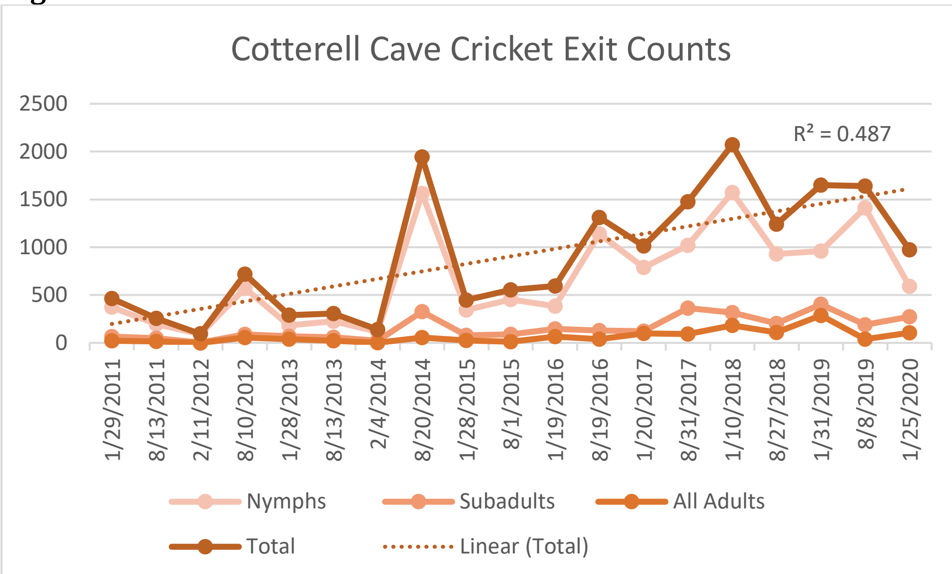


Figure 3f. District Park Cave.

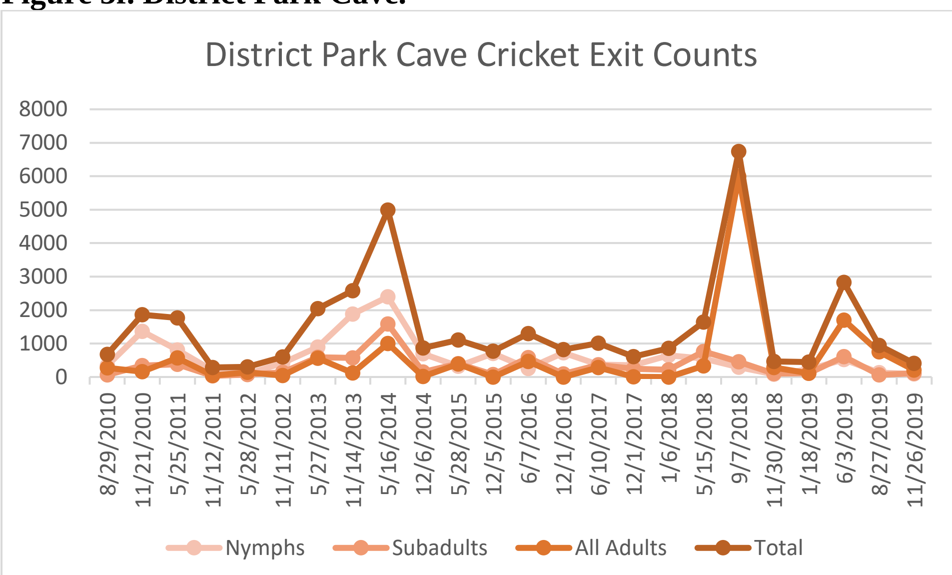


Figure 3g. Flint Ridge Cave.

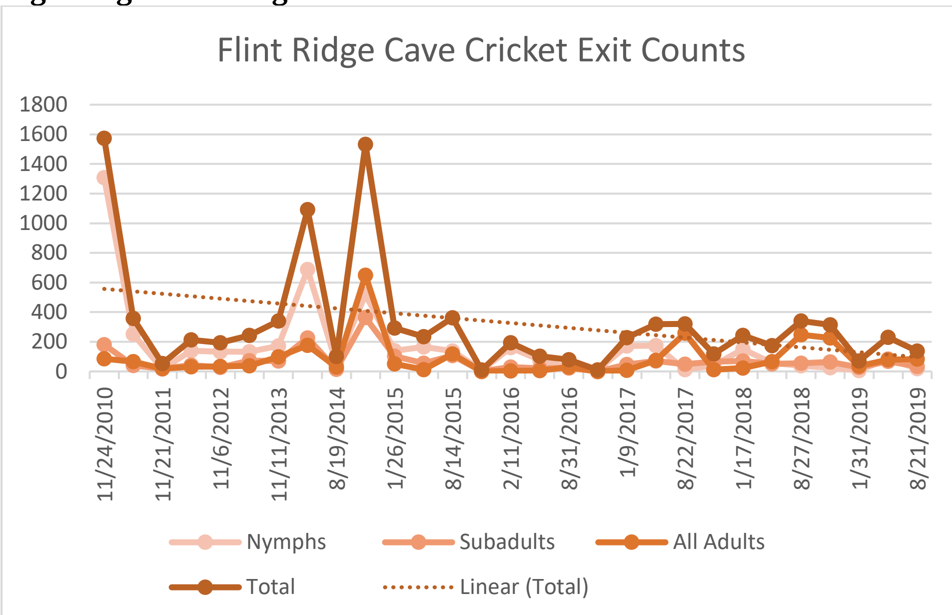


Figure 3h. Jest John Cave.

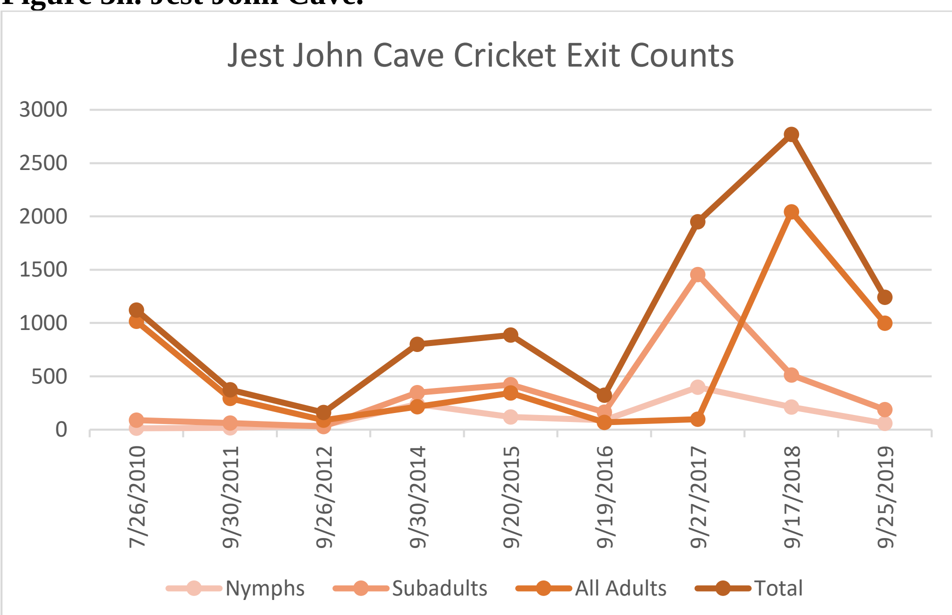


Figure 3i. Jester Estates Cave.

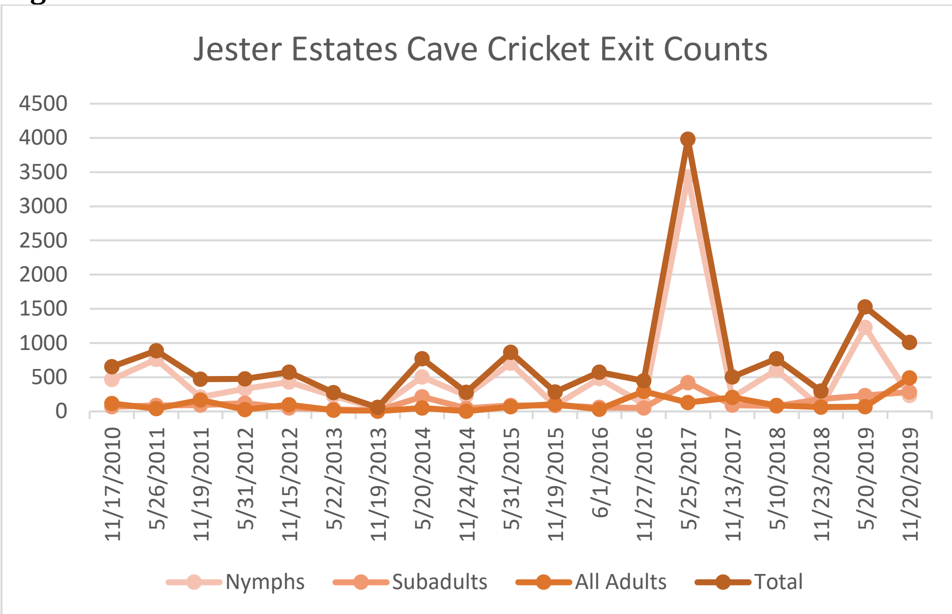


Figure 3j. Little Bee Creek Cave.

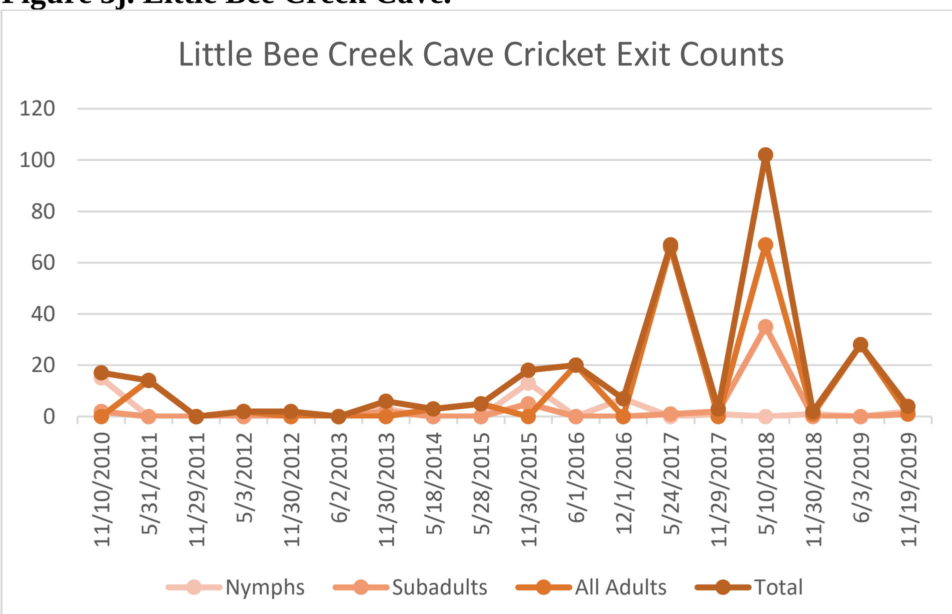


Figure 3k. Maple Run Cave.

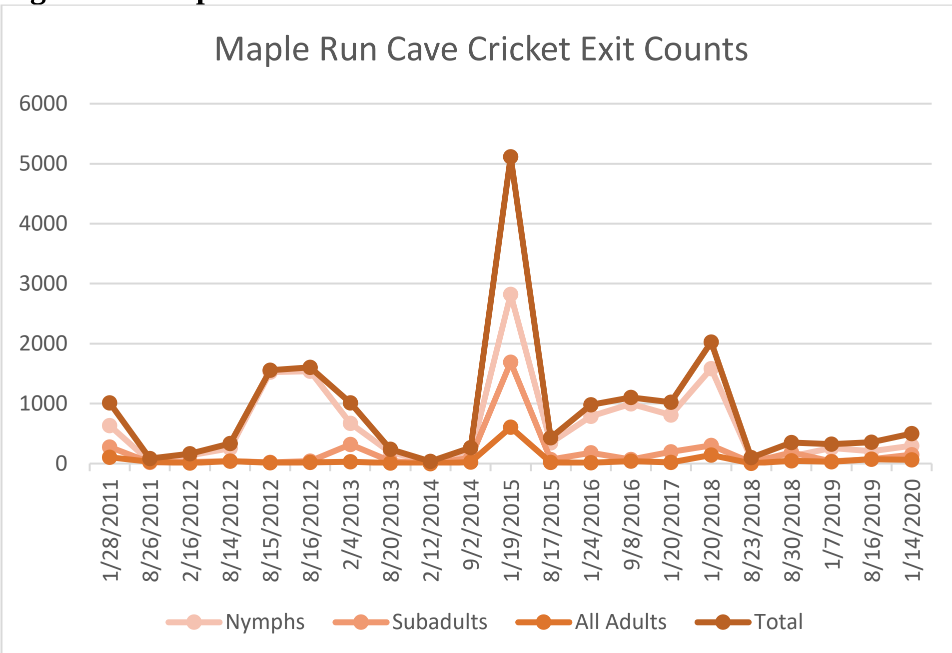


Figure 3l. Midnight Cave.

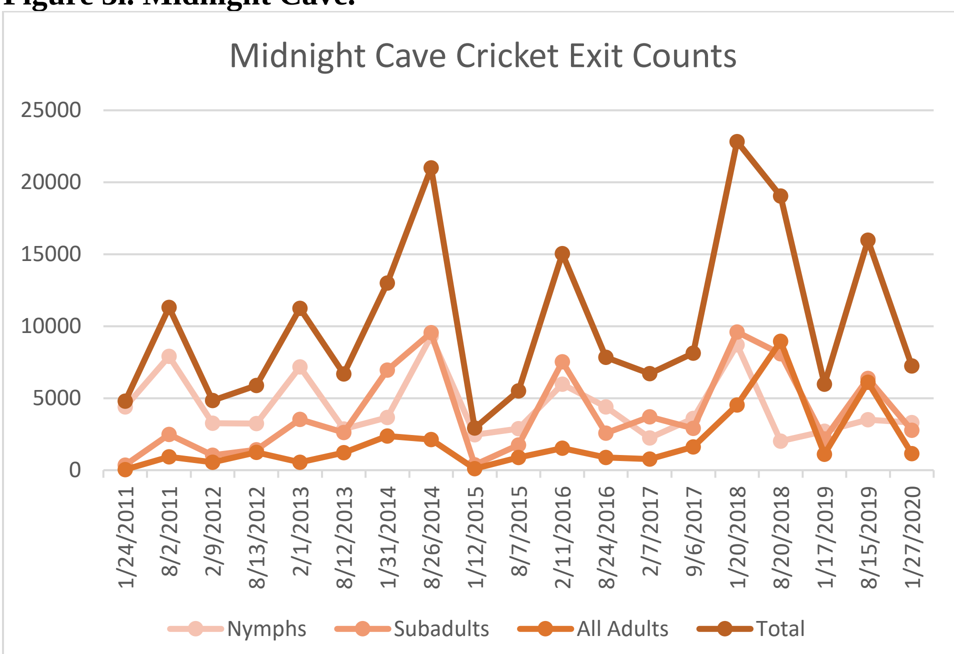


Figure 3j. Pond Party Pit.

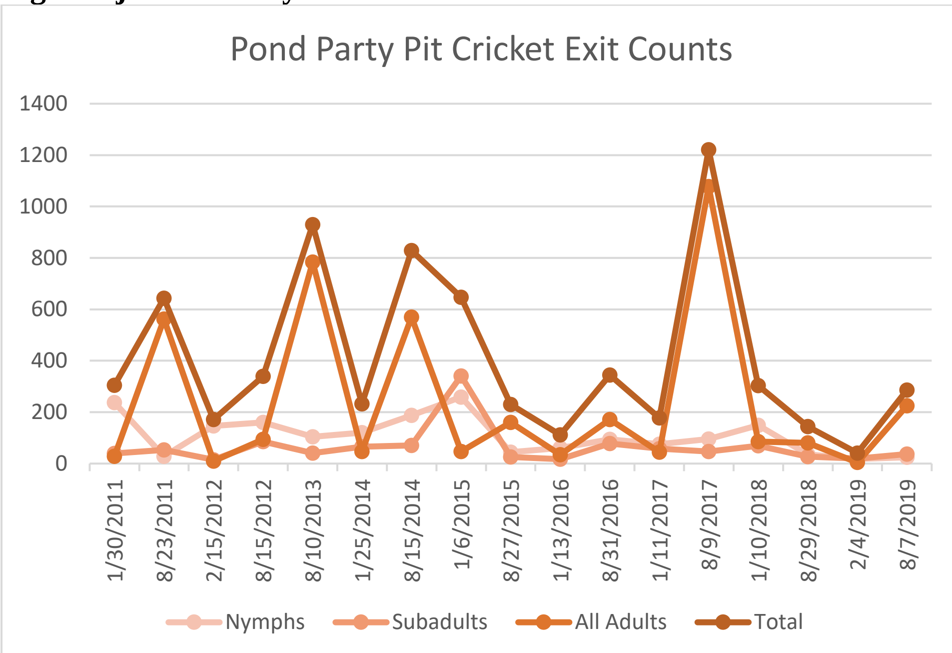


Figure 3k. Seibert Sink Cave.

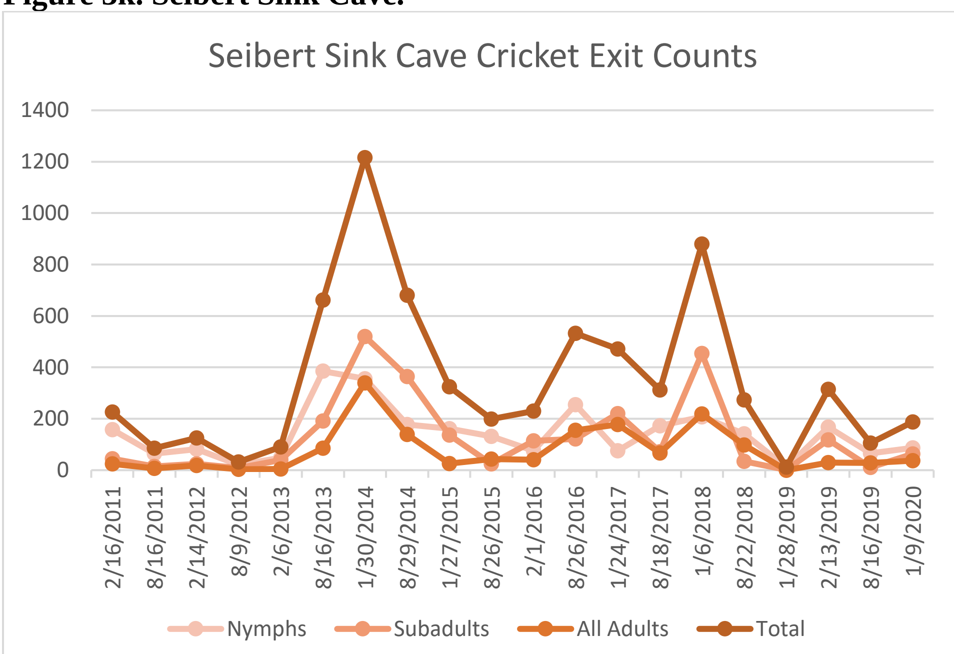


Figure 3l. Spider Cave.

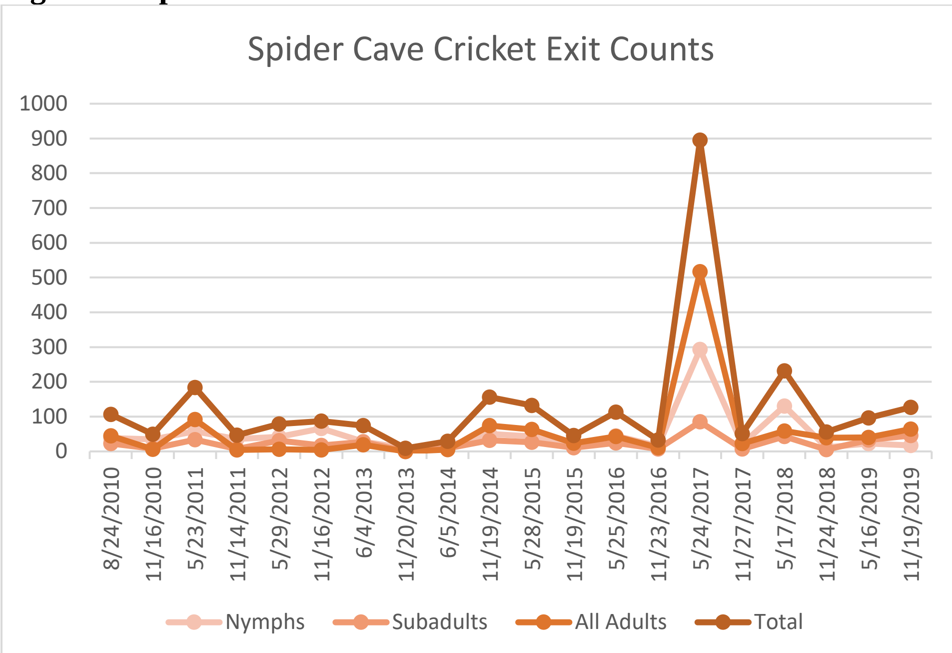


Figure 3m. Stovepipe Cave.

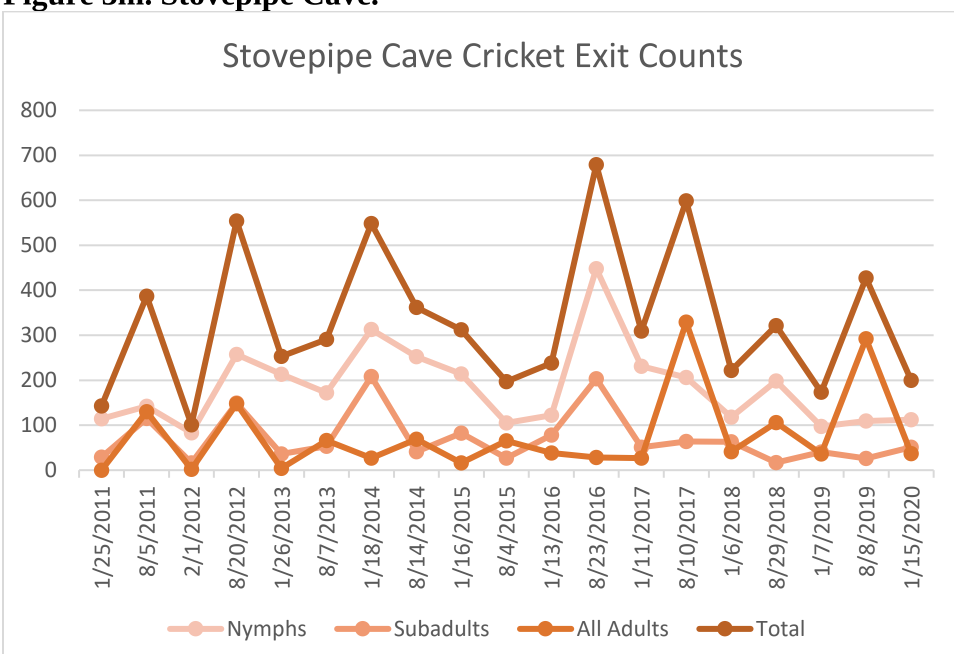


Figure 3n. Testudo Cave.

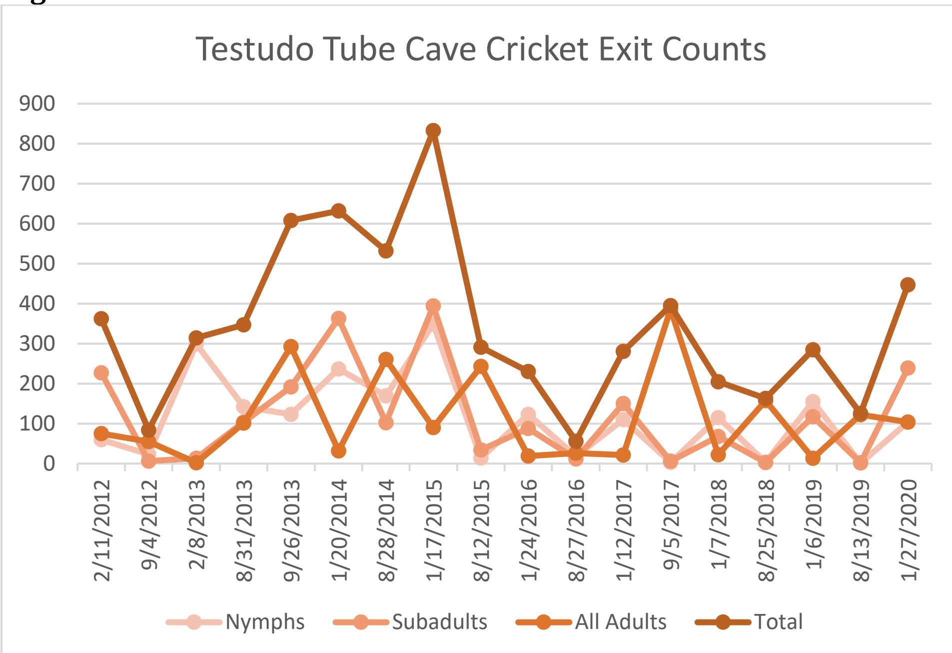


Figure 3o. New Comanche Trail Cave.

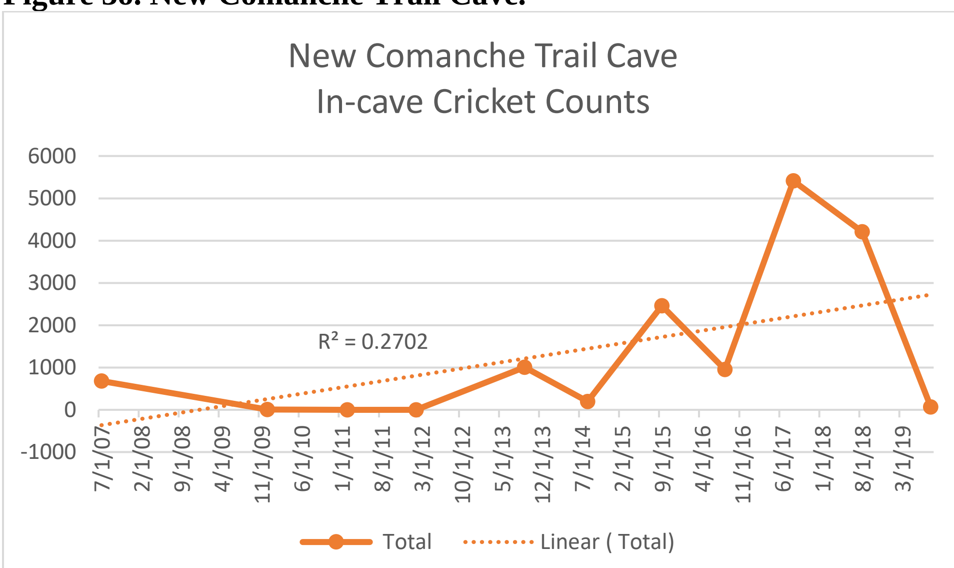


Table 3. Linear Regression Analysis of Cave Cricket Exit Count data.

		Coefficients	*SE*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Airmen's Cave	Intercept	-2504.759	2938.235	-0.852	0.407	-8733.539	3724.022
	X Var.	0.068	0.070	0.969	0.347	-0.080	0.215
Broken Arrow Cave	Intercept	-7683.886	6447.182	-1.192	0.250	-21286.251	5918.480
	X Var.	0.200	0.153	1.309	0.208	-0.123	0.523
Cave Y	Intercept	4528.086	4208.098	1.076	0.297	-4350.223	13406.396
	X Var.	-0.092	0.100	-0.921	0.370	-0.302	0.118
Cortaña Cave	Intercept	-1166.955	1083.597	-1.077	0.297	-3464.077	1130.168
	X Var.	0.031	0.026	1.215	0.242	-0.023	0.086
Cotterell Cave	Intercept	-16154.246	4113.858	-3.927	0.001	-24797.140	-7511.352
	X Var.	0.404	0.098	4.143	**0.001**	0.199	0.609
District Park Cave	Intercept	-2355.729	12456.036	-0.189	0.852	-28187.967	23476.509
	X Var.	0.091	0.294	0.309	0.760	-0.520	0.702
Flint Ridge Cave	Intercept	6902.915	3255.284	2.121	0.043	223.625	13582.206
	X Var.	-0.155	0.077	-2.021	0.053	-0.313	0.002
Jest John Cave	Intercept	-16365.453	9446.034	-1.733	0.127	-38701.774	5970.867
	X Var.	0.414	0.224	1.846	0.107	-0.116	0.944
Jester Estates Cave	Intercept	-9028.054	8069.122	-1.119	0.279	-26052.414	7996.305
	X Var.	0.233	0.191	1.215	0.241	-0.171	0.636
Little Bee Creek Cave	Intercept	-352.580	248.622	-1.418	0.175	-879.634	174.475
	X Var.	0.009	0.006	1.486	0.157	-0.004	0.021
Maple Run Cave	Intercept	3326.443	10378.986	0.320	0.752	-18397.024	25049.909
	X Var.	-0.058	0.246	-0.235	0.817	-0.573	0.457
Midnight Cave	Intercept	-62090.869	56384.829	-1.101	0.286	-181052.460	56870.722
	X Var.	1.715	1.335	1.284	0.216	-1.102	4.531
Pont Party Pit Cave	Intercept	2908.025	3597.982	0.808	0.432	-4760.893	10576.942
	X Var.	-0.059	0.085	-0.695	0.498	-0.241	0.123
Seibert Sink Cave	Intercept	320.152	2993.318	0.107	0.916	-5968.575	6608.879
	X Var.	0.001	0.071	0.009	0.993	-0.148	0.149
Spider Cave	Intercept	-1429.283	1704.088	-0.839	0.413	-5009.439	2150.873
	X Var.	0.037	0.041	0.915	0.372	-0.048	0.122
Stovepipe Cave	Intercept	-72.065	1629.581	-0.044	0.965	-3510.180	3366.050
	X Var.	0.010	0.039	0.248	0.807	-0.072	0.091
Testudo Tube Cave	Intercept	3047.740	2285.841	1.333	0.201	-1798.028	7893.507
	X Var.	-0.064	0.054	-1.183	0.254	-0.178	0.051
New Comanche Trail Cave*	Intercept	-27827.717	15975.152	-1.742	0.115	--63966.021	8310.586
	X Var.	0.699	0.382	1.828	0.101	-0.166	1.564

*data used was from counts inside cave during karst faunal surveys.

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