Species Status Assessment Report for the Central Texas Mussels:

False spike (*Fusconaia mitchelli*)
Balcones spike (*Fusconaia iheringi*)
Texas fatmucket (*Lampsilis bracteata*)
Texas fawnsfoot (*Truncilla macrodon*)
Texas pimpleback (*Cyclonaias petrina*)
Guadalupe fatmucket (*Lampsilis bergmanni*)
Guadalupe orb (*Cyclonaias necki*)

Version 2.1

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v. 1.5. – revised to include recent scientific publications and recent mussel surveys; this version is the biological background for the proposed listing determination (December 2019)
v. 2.1 – revised reflecting public comments, updated taxonomy, and addition of recent mussel distribution data (September 2022)

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Chapter 1. Introduction

This Species Status Assessment Report (SSA Report; version 2.1 – September 2022) provides a review of the ecological needs and current condition of seven species of freshwater mussels (Family Unionidae) endemic to the Central Texas region in the Brazos, Colorado, Guadalupe, and Trinity River basins. This SSA Report will refer to the species collectively as "Central Texas mussels" and individually by common name and by scientific name (i.e., genus and specific epithet) where appropriate. The U.S. Fish and Wildlife Service (Service) is responsible for identifying those species that are in need of protection under the Endangered Species Act of 1973, as amended (Act).

The Species Status Assessment (SSA) framework supports an in-depth review of the species biology and threats, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability (USFWS 2016a, entire). The intent is for the SSA Report to be easily updated as new information becomes available and to support all functions of the Endangered Species Program from Candidate Assessment to Listing to Consultations to Recovery (if warranted). As such, the SSA Report will be a living document upon which other documents, such as possible listing rules, recovery plans, and 5-year reviews, would be based for those species warranting protections under the Act, should they become listed.

The false spike (*Fusconaia mitchelli*) is a petitioned species with a positive 90-day finding under the Act (USFWS 2009, entire). The Service is required to conduct a status review and complete a 12-month finding to determine whether or not listing under the Act is warranted. The Texas fatmucket (*Lampsilis bracteata*), Texas fawnsfoot (*Truncilla macrodon*), and Texas pimpleback (*Cyclonaias petrina*, formerly classified as *Quadrula petrina*) are all candidate species with warranted 12-month findings under the Act (USFWS 2011, entire). These species have been candidates for listing since 2011. The Guadalupe fatmucket (*Lampsilis bergmanni*) and Guadalupe orb (*Cyclonaias necki*) were described in 2018 and 2019 as separate species distinct from Texas fatmucket (Inoue et al. 2018, pp. 5-6 and Inoue et al. 2019, entire) and Texas pimpleback (Burlakova et al. 2018, entire and Johnson et al. 2018, entire), respectively, and are included as such in this SSA Report. The Balcones spike (*Fusconaia iheringi*) was described in 2020 as a separate species distinct from false spike (Smith et al. 2020, entire) and is included as such in this SSA Report.

Several taxonomic revisions have taken place since the Central Texas Mussels were petitioned for listing in 2008. Several of the species within the genus *Quadrula* were assigned to the genus *Cyclonaias* in 2017 (Williams et al. 2017, p. 37). As mentioned above, the Guadalupe orb was recently described as a separate and distinct species from Texas pimpleback (Burlakova et al. 2018, entire and Johnson et al. 2018, entire). Also, the Guadalupe fatmucket was recently discovered to be a separate species distinct from Texas fatmucket (Inoue et al. 2019, entire). Fawnsfoot (*Truncilla donaciformis*) in the Trinity River is now known to be Texas fawnsfoot (*Truncilla macrodon*; Inoue et al. 2018, p. 6). False spike (*Fusconaia mitchelli*) had previously been assigned as *Quincuncina mitchelli* and *Quadrula mitchelli* (Williams et al. 2017, p. 39). The Balcones spike was recently discovered to be a separate species distinct from false spike (Smith et al. 2020, entire).

The Service is required to make a final determination of whether these species warrant listing under the Act. A candidate is a species for which we have on file sufficient information on biological vulnerability and threats to support a proposal to list as endangered or threatened but is precluded by higher priority listing actions. Previous status reviews indicated that these three freshwater mussel species face threats including impoundments, sedimentation, habitat loss, and riverbank destabilization.

For this assessment, we generally define viability as the ability of the Central Texas mussels to sustain populations in natural river systems over time. Using the SSA framework (Figure 1.1), we consider what the species need to maintain viability by characterizing the status of the species in terms of its **resiliency**, **redundancy**, and **representation** (i.e., the **3Rs**, Smith et al. 2018, entire). The 3Rs are defined as:

Resiliency describes the ability of populations to withstand stochastic disturbance. Populations need abundant individuals within habitat patches of adequate area and quality to maintain survival and reproduction despite disturbance. We can measure resiliency based on metrics of population health, e.g., birth versus death rates and population size. Highly resilient populations are better able to withstand disturbances such as random fluctuations in birth rates (demographic stochasticity), variations in rainfall (environmental stochasticity), or the effects of anthropogenic activities.

Redundancy describes the ability of a species to withstand catastrophic events. Measured by the number of populations, their resiliency, and their distribution (and connectivity), redundancy gauges the probability that the species has a margin of safety to withstand or can bounce back from catastrophic events (such as a rare destructive natural event or episode involving many populations).

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

To evaluate the biological status of the Central Texas mussels both currently and into the future, we assessed a range of conditions to allow us to consider the species' resiliency, redundancy, and representation (together, the 3Rs). This SSA Report provides a thorough assessment of biology and natural history of these species and assesses demographic risks, stressors, and limiting factors in the context of determining the viability and risks of extinction for the species.

The format for this SSA Report includes: the resource needs of individuals (Chapter 2), populations and species (Chapter 3); the Central Texas mussels' historical distribution and a framework for determining the distribution of resilient populations across its range for species viability (Chapter 3); a review of the current, and past management of water resources in Texas generally, and specifically, for each river basin (Chapter 4); determining which of the risk factors affect the species' viability and to what degree (Chapter 5); reviewing the likely causes of the current and future status of the species (Chapter 6); and concluding with a description of the viability in terms of resiliency, redundancy, and representation (Chapter 7). This document is a compilation of the best available scientific and commercial information and a description of past, present, and likely future risk factors to the Central Texas mussels.

Appendix A includes all references cited, which are available upon request, in portable document format (pdf), from the Austin, Texas Ecological Services Field Office[1]. Appendix B contains Cause and Effects Tables, which evaluate the stressors to the species historically and into the future. Appendix C contains detailed tables of the results of our analysis, and Appendix D describes the results by population. Finally, Appendix E contains a glossary of terms used in this SSA Report; these terms are indicated in bold text

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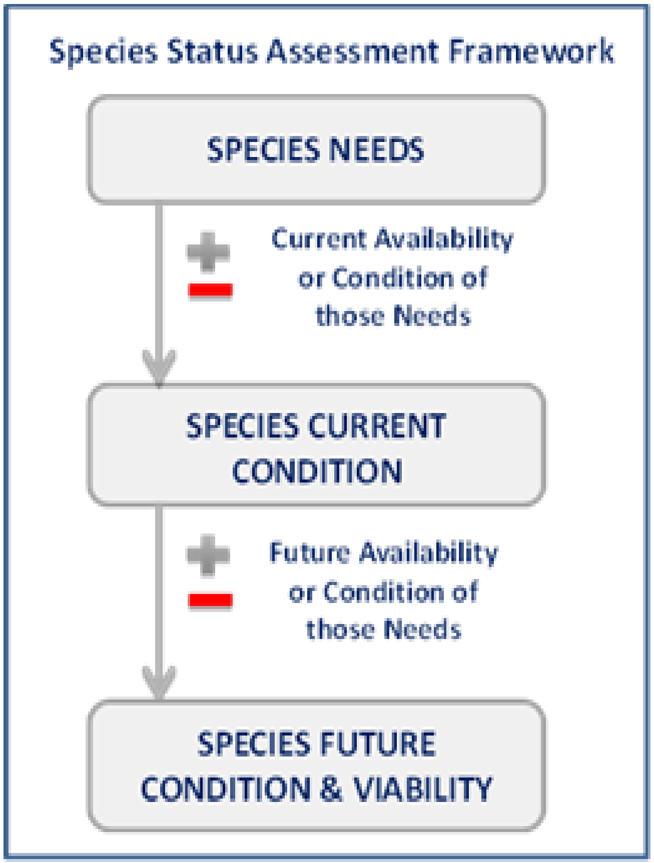

Figure 1.1. Species Status Assessment Framework (USFWS, 2016a).

Chapter 2 - Individual Needs

This chapter reviews the basic biological and ecological information about the seven species of Central Texas mussels. This information includes taxonomy, phylogenetic relationships, morphology, and a description of known life history traits, with an emphasis on those life history traits that are important to this analysis. We then outline the resource needs at the level of the individual. Basic information is included about freshwater mussels in general, to the Central Texas mussels, and to individual species where appropriate.

2.A. Central Texas Mussels – General Individual Needs

2.A.1 Taxonomy of Central Texas Mussels

Each of the seven species of Central Texas mussels belong to Family Unionidae, also known as the naiads and pearly mussels, a group of bivalve mollusks known to have been in existence for over 400 million years (Howells et al. 1996, p.1) and now representing over 600 species worldwide and over 250 species in North America (Strayer et al. 2004, p. 429; Lopes-Lima et al. 2018, pp. 23).

This report follows the most recently published and accepted taxonomic treatment of North American freshwater mussel as provided by Williams et al. (2017, entire) and applies in common to each of the seven species of Central Texas mussels assessed in this report.

PHYLUM	**Mollusca Linnaeus, 1758**
CLASS	**Bivalvia Linnaeus, 1758**
ORDER	**Unionida Gray, 1854**
FAMILY	**Unionidae Rafinesque, 1820**
SUBFAMILY	**Ambleminae Rafinesque, 1820**

Each of the seven species of Central Texas mussels, along with approximately 85% of North American mussel species, belongs to the subfamily Ambleminae, and while notable exceptions apply (i.e., Texas fatmucket), members of this group generally share the following common characteristics: (1) are typically slow-growing and commonly live for more than twenty years, with growth rates typically between 1–5mm/year, depending on conditions (Howells et al. 1996, p.17), (2) are frequently summer breeders (Howells et al. 1996, p. 9) although the Lampsilini (e.g., Texas fatmucket) typically spawn in fall and brood through the winter, (3) possess either unhooked or axe-head-type **glochidia**; may brood larvae in either all six or the outer two (lateral) **demibranchs** (McMahon and Bogan 2001, p. 342), (4) glochidia attach primarily to gills (Barnhart et al. 2008, p. 375), (5) produce and store **conglutinates** in their mantle to facilitate rapid discharge of glochidia when fish attempt to feed (Barnhart et al. 2008, p. 375) and (6) free glochidia (not attached) may appear in drift, i.e., are exposed to free water prior to host infestation, for hours to weeks (Barnhart et al. 2008, p. 375).

2.A.2 Life History of Central Texas Mussels

Freshwater mussels, including the Central Texas mussels, have a complex life history (Figure 2.1) involving an obligate parasitic larval life stage, called **glochidia**, which are wholly dependent on host fish. As freshwater mussels are generally sessile, dispersal is accomplished primarily through the behavior of host fish and their tendencies to travel upstream and against the current (**positive rheotaxis**) in rivers and streams. Mussels are broadcast spawners; males release sperm into the water column, which is taken in by the female through the **incurrent siphon** (the tubular structure used to draw water into the body of the mussel). The sperm fertilizes the eggs, which are held during maturation in an area of the gills called the

marsupial chamber. The developing larvae remain in the marsupial chamber until they mature and are ready for release as glochidia, to attach on the gills, head, or fins of fishes (Vaughn and Taylor 1999, p. 913; Barnhart et al. 2008, pp. 371-373). Glochidia die if they fail to find a host fish, attach to the wrong species of host fish, attach to a fish that has developed immunity from prior infestations, or attach to the wrong location on a host fish (Neves 1991, p. 254; Bogan 1993, p. 599). Glochidia encyst (enclose in a cyst-like structure) on the host's tissue, draw nutrients from the fish, and develop into juvenile mussels weeks or months after attachment (Arey 1932, pp. 214-215). The glochidia will remain encysted for about a month through a transformation to the juvenile stage. Once transformed, the juveniles will excyst from the fish and drop to the substrate. Freshwater mussel species vary in both onset and duration of spawning, how long developing larvae are held in the marsupial gill chambers (gills utilized for holding eggs and glochidia), and which fish species serve as hosts. The mechanisms employed by mussel species to increase the likelihood of interaction between host fish and glochidia vary by species.

Mussels are generally immobile but experience their primary opportunity for dispersal and movement within the stream as glochidia attached to a mobile host fish (Smith 1985, p. 105). Upon release from the host, newly transformed juveniles drop to the substrate on the bottom of the stream. Those juveniles that drop in unsuitable substrates die because their immobility prevents them from relocating to more favorable habitat. Juvenile freshwater mussels burrow into interstitial substrates and grow to a larger size that is less susceptible to predation and displacement from high flow events (Yeager et al. 1994, p. 220). Adult mussels typically remain within the same general location where they dropped off (excysted) their host fish as juveniles.

Host specificity can vary across mussel species, which may have specialized or generalized relationships with one or more taxa of fish. Mussels have evolved a wide variety of adaptations to facilitate transmission of glochidia to host fish, including display/mantle lures mimicking fish or invertebrates, packages of glochidia (conglutinates) that mimic worms, insect larvae, larval fish, or fish eggs, and release of glochidia in mucous webs that entangle fish (Strayer et al. 2004, p. 431). Polymorphism of mantle lures and conglutinates frequently exists within mussel populations (Barnhart et al. 2008, p. 383), representing important adaptive capacity in terms of genetic diversity and ecological representation.

Freshwater mussels can be long-lived and slow-growing (but see Haag and Rypel 2010, p. 2), and individuals have been estimated to have been decades to centuries old (Strayer et al. 2014, p. 433). In part, because of their long lifespans, **recruitment** is episodic, and populations may be slow to recover from disturbance. Thin-shelled mussels (like *Truncilla* spp.) often live 4–10 years while thick-shelled mussels (like *Quadrula spp.* or *Cyclonaias* spp.) can live for 20–40 years, or longer (Howells et al. 1996, p.17).

Fast-growing species (like *Lampsilis* spp.) may mature as early as their first year, while slow-growing species (like *Quadrula* spp. or *Cyclonaias spp.*) may take as long as 5–20 years to mature (Haag and Rypel 2010, p. 19), and fast-growing short-lived species may be better adapted to more variable environments and better suited to recovering from high-mortality events than slower-growing longer-lived species that may be better adapted to more stable environments (Haag and Rypel 2010, p. 20). With that said, growth rates and longevity can be expected to vary somewhat within and among populations.

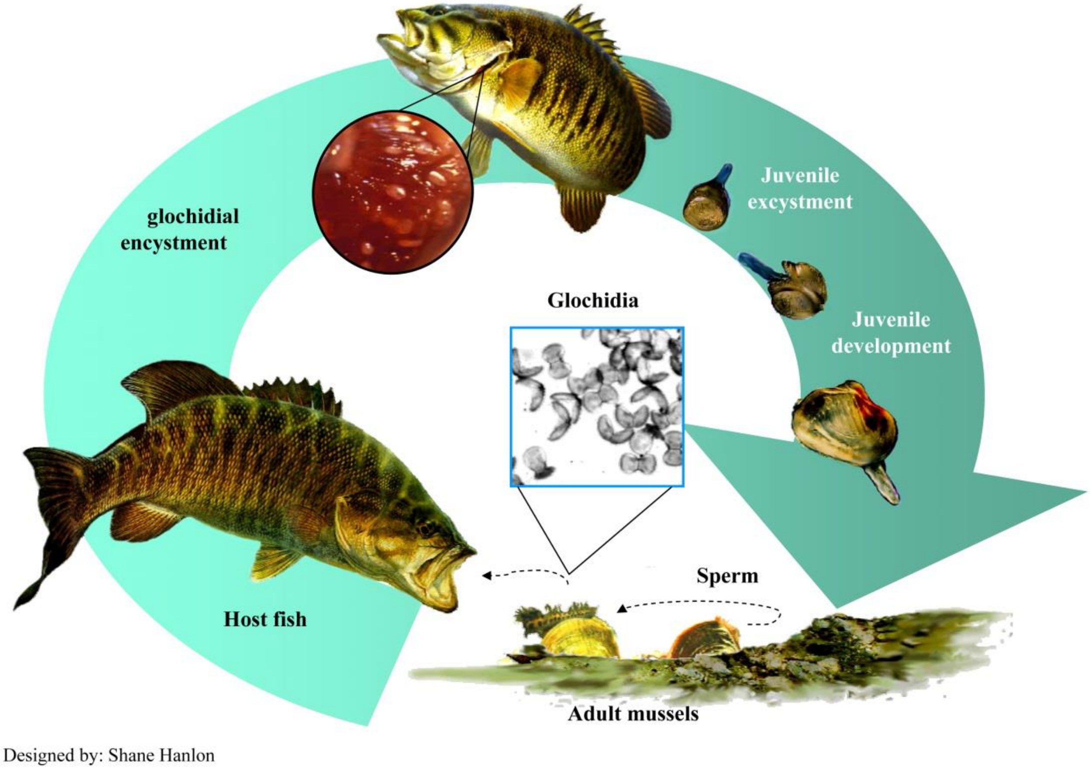

Figure 2.1. Generalized freshwater mussel life cycle. Freshwater mussels, including the Central Texas mussels, have a complex life history involving an obligate parasitic larval life stage, called glochidia, which are wholly dependent on host fish. (Image courtesy Shane Hanlon, USFWS.)

2.A.3. Resource (Habitat) Needs of Individuals

Here we describe general habitat needs common to each of the seven Central Texas mussel species. We describe the specific needs of each species in section 2.B (Species-Specific Needs of Central Texas Mussels).

The seven species of Central Texas mussels generally occur in medium to large streams and rivers and require adequate amounts of flowing water, free of contaminants and water quality degradations and having adequate food supply, with refugia from both high- and low-flow events, appropriate substrate that is generally characterized as stable and free of excessive fine sediment, access to appropriate fish hosts, and habitat connectivity (i.e., lack of excessive impoundments and barriers to fish passage) (Figure 2.2).

The seven species of Central Texas mussels are generally not adapted to **lentic** environments (such as ponds, reservoirs, and impoundments) and, with few exceptions, do not persist and thrive in habitats that are not free-flowing (**lotic**, such as unimpeded stream and river reaches). Therefore, the seven species of freshwater mussels in this report are considered lotic-habitat specialists. Freshwater mussel communities in Central Texas have generally shifted to become dominated by habitat generalists (tolerant of lentic conditions) following conversion to lentic habitats by impoundment, and other environmental changes (Randklev et al. 2013, pp. 1, 2, 10, 12). Following are the broad categories of habitat needs of the species, which are also summarized in Table 2.1.

Flowing water and protection from low-flow (dewatering) events. The seven species of Central Texas mussels are adapted to free-flowing rivers and streams (lotic environments). As such, they require unaltered rivers and streams, free from major impoundments and other structures that create a non-flowing (lentic) environment. Free-flowing water provides appropriate oxygenation, nutrition, thermal buffering, and access to fish hosts for reproduction and dispersal. Central Texas mussels require adequate, but not excessive flows that may lead to scouring of suitable substrates.

Central Texas mussels generally do not tolerate exposure to a non-watered environment (i.e., a lack of water and increased water and air temperature approaching or exceeding lethal thresholds) and dewatering can lead to reduced reproduction, health, body condition, fitness, and can result in eventual death of stranded mussels, and exposure to predation. As such, Central Texas mussels require habitats and meso-habitats that provide some minimum flows and protections from dewatering throughout the year. While some species are more tolerant of dewatering than others or have adaptations to avoid stranding (i.e., Texas fatmucket and Texas pimpleback; Bonner et al 2018, p. 196), in general Central Texas mussels are not well adapted to persist in habitats subject to rapid and frequent dewatering (Mitchell et al. 2018, p. 16).

The observed differences in Central Texas mussels' behavioral responses to dewatering and tolerance of desiccation are likely explained by differences in life history strategies and habitat adaptations (Mitchell et al. 2018, pp. 14). Mussels tolerant of **emersion** (exposure; Texas pimpleback; which is often found in shallow runs and riffle habitats) had little horizontal movement in response to dewatering and became easily stranded, while mussels that were intolerant to emersion (Texas fatmucket; which is often found in run of the river pools) did exhibit horizontal movement and were able to avoid stranding during slow dewatering (Mitchell et al. 2018, pp. 14-16).

Water quality. The seven species of Central Texas mussels are sensitive to contaminants and water quality degradations and require clean water free from contaminants and water quality degradation. Water quality degradations include the presence of excessive nutrients such as ammonia (NH_3), which is highly toxic to aquatic organisms, other chemicals including chlorine (Cl), pollutants including heavy metals (Cu, Cd, Hg), dissolved salts (salinity), and organic contaminants like pesticides and herbicides, and may affect each life stage of freshwater mussels (Cope et al. 2008, p. 452). Augsperger et al. (2003) estimated a safe range of ammonia concentrations for all mussel life stages of 0.3-0.7 mg/L total ammonia a N at pH 8 (p. 2574) and noted that "sediment pore-water concentrations of ammonia typically exceed those of overlying surface water" (p. 2574). In a laboratory setting, a subset of Central Texas mussels species exhibited behavioral responses when exposed to salinity [as NaCl] concentrations, resulting in partial valve closure at 2.0 ppt and complete valve closure at 4.0 ppt and "high frequency of valve closure raises the possibility of negative impacts on filtration, respiration, and fertilization efficiency during long-term exposure" (Bonner et al. 2018, pp. 7, 154). Because laboratory trials have investigated salinity tolerance for all the Central Texas mussels, and many species in the group are sympatric (overlapping in distribution), we determine that an optimal salinity range of < 2 ppt is generally suitable for all species in the Central Texas mussels group.

High-quality water has appropriate oxygenation (expressed as dissolved oxygen, DO), and provides appropriate thermal requirements for the Central Texas Mussels; both elevated and depressed water temperatures also represent water quality degradations. Some species (i.e., Texas pimpleback) may be tolerant to low DO and high temperatures (< 40 °C) at least over the short-term (Bonner et al. 2018, pp. 6, 140; Mitchell et al. 2018, p. 17). Optimal temperatures for the Central Texas mussels range from 28–

35°C while lethal effects due to thermal stress begin to be realized at approximately 39°C for Texas pimpleback and 31°C for false spike (Bonner et al. 2018, pp. 6, 140). Sublethal effects of increased water temperatures are evident as "results [from laboratory studies on Central Texas mussels] suggest that the main impact of increasing temperatures to a maximum of 36°C is to increase metabolic demand for basic maintenance. Thus, mussels of [Texas pimpleback and false spike] require more food and are likely to become more susceptible to food limitation, at warm temperatures" (Bonner et al 2018, pp. 130-131). Because the Central Texas mussels exhibit variable thermal tolerance, and are sympatric, we determine that an optimal environmental thermal range for all species (at or below 29 ºC) is suitable for all seven species in the Central Texas mussels group. Elevated suspended solids and sediments (expressed as TSS or as turbidity) can degrade water quality with adverse effects to freshwater mussels (Gascho-Landis and Stoeckel 2015, p. 8). However, in a laboratory setting, behavioral responses of Central Texas mussels to high levels of TSS were either not detected or only small responses were detected, depending on the species (Bonner et al. 2018, pp. 7, 146).

Protection from high-flow (scour) events. The seven species of Central Texas mussels live in the substrate of the benthic environment (stream bed and bank habitats) and these sediments and cobble are subject to periodic disturbance as the substrate (and any mussels) is scoured and transported downstream to locations that may or may not be suitable. As such, Central Texas mussels require microhabitats (flow refugia) that are naturally protected from scouring high-flow events that may occur during flood conditions. Some examples of flow refugia include boulders, crevices, and bedrock shelves, bends, meanders, undercut banks, eddies, riffles, and living or dead vegetation (i.e., tree roots and coarse woody debris). Central Texas mussels require adequate flows. Excessive flows can result in scouring of substrate, degrading or destroying habitats. For example, a single mussel bed containing an estimated 127 Texas pimpleback at a site in the Lower Colorado River known locally as the "Altair Riffle" was reduced to 8 following flooding, excessive flows, scour, and substrate mobilization associated with Hurricane Harvey in 2017 (Bonner et al. 2018, p. 7).

Firm and stable substrate. Central Texas mussels live in the substrate of the benthic environment (stream bed and bank habitats) and these sediments and cobble are subject to periodic disturbance as the substrate (and any mussels) are scoured and transported downstream to a location that may or may not be suitable. Sediments including shifting sands and unconsolidated silts generally do not provide appropriate anchoring substrate, and thus appropriate habitat, for Central Texas mussels.

Nutrition and food supply. Adult freshwater mussels, including Central Texas mussels, are filter-feeders, siphoning suspended phytoplankton, zooplankton, rotifers, protozoans, detritus and dissolved organic matter from the water column (Strayer et al. 2004, p. 430) and from sediment; juvenile mussels can use their feet to collect food items from sediments (pedal feeding; Vaughn et al. 2008, pp. 409-411). Glochidia derive what little nutrition they need from their obligate fish hosts (Barnhart et al. 2008, p. 372). Stable isotope studies suggest some Central Texas mussels (e.g., Texas pimpleback and Texas fatmucket) are feeding on coarse particulate organic matter (CPOM), or bacteria and fungi adhered to and decomposing CPOM (Bonner et al. 2018, pp. 7, 215). Freshwater mussels must keep their shells open (gaped) to obtain food and facilitate gas exchange, but they often respond to water quality degradations by closing their shells (Bonner et al. 2018, p. 141). Food supply is not generally considered limiting in those environments inhabited by Central Texas mussels. However, food limitation may be important during times of elevated water temperature, as both metabolic demand and incidence of valve closure increases concomitantly, resulting in reduced growth and reproduction (Bonner et al. 2018, p. 6).

Fish hosts. Central Texas mussels have an obligate parasitic relationship with their respective host fishes. Nearly all freshwater mussels including Central Texas mussels cannot successfully reproduce or disperse in the absence of appropriate host fish. Host fish are necessary to facilitate downstream dispersal and represent the only mechanism to achieve upstream dispersal in a free-flowing environment. Both large and small run of river impoundments act as barriers to fish passage and mussel dispersal and recolonization. Freshwater mussels may be more tolerant of water quality degradation than their host fish. For example, dissolved oxygen (DO) concentrations below 5 mg/L is generally considered to be harmful to many fish species, and fish mortality is almost certain below 2 mg/L (Francis-Floyd 2011, p. 1).

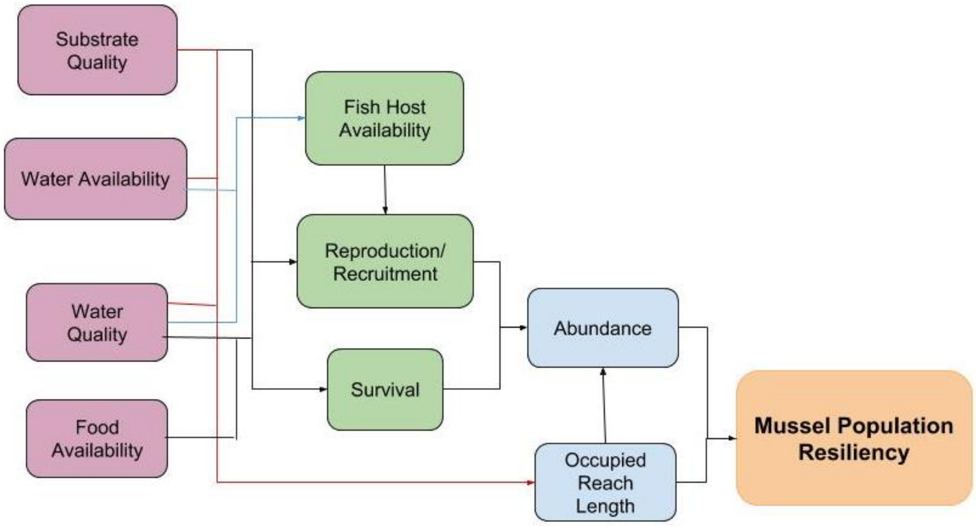

Figure 2.2. Influence diagram representing the general population needs of the Central Texas mussels. Habitat factors (red boxes) influence demographic factors (green boxes) that affect population attributes (blue boxes) which influence resiliency of Central Texas mussel populations.

Table 2.1. Generalized life history and resource needs of Central Texas mussels.

Life Stage	Resource Need(s) - Habitat Requirements	Reference(s)
Gamete (broadcast sperm, egg development, to fertilization)	• High-quality water having an absence of a high total suspended solids (TSS) load (i.e., sediment and algae) and without toxicants • Appropriate water temperature and food availability (for gravid adult mussels) • Appropriate water temperatures for brooding – high temperatures can lead to premature expulsion of glochidia	Gascho-Landis and Stoeckel 2015, p. 8 Gascho-Landis et al. 2013, pp. 76, 79 Cope et al. 2008, p. 454 Galbraith and Vaughn 2009, p. 12
Glochidium (attachment through excystment)	• Presence of appropriate host fish (for attachment, encystment and upstream dispersal) • High water quality and lack of contaminants (including chlorides), for mussels and host fish (thresholds could differ) – can be up to four times more sensitive than juveniles	Barnhart et al. 2008, p. 372 Augspurger et al. 2003, p. 2571 Wang et al. 2018, p. 3041

Table 2.1 continued. Generalized life history and resource needs of Central Texas mussels.

Life Stage	Resource Need(s) - Habitat Requirements	Reference(s)
Juvenile and sub-adult (excystment through maturity)	• Flow refuges • Appropriate substrate (for burrowing) • Low salinity • Low ammonia levels (below 0.3–0.7 mg/L NH_3-N at pH 8 and 25°C) • Low levels of copper (and other metals) and other contaminants (chlorine) • Dissolved oxygen (DO) > 2 parts per million (ppm) • Flowing water	Augspurger et al. 2003, pp. 2571, 2574 Augspurger et al. 2003, p. 2569 Cope et al. 2008, p. 456 Wang et al. 2007, p. 2055 Wang et al. 2017, p. 791, 795
Adult (maturity)	• Flow refuges • Appropriate substrate (for burrowing) • Dissolved oxygen (DO) >2 mg/L [respiratory distress begins around 2–3 mg/L] • Low salinity (< 2 ppt) • Appropriate food source • Water temperature < 29 ° C (84 ° F) [see species specific tables that follow] generally below 29°C would be suitable for the Central Texas species, based on thermal tolerance studies of the Central Texas mussels and sympatric species • Flowing water • Adequate dissolved minerals (Ca) to support shell growth	Bonner et al. 2018, pp. 6,7,130-1,140, 161-2, 164

2.B Species-Specific Needs of Central Texas Mussels

2.B.1 False spike, *Fusconaia mitchelli* (Simpson, 1895)

2.B.1.a Taxonomic and Morphological Descriptions

The false spike was originally described as the species *Unio mitchelli* by Charles T. Simpson in 1895 from the Guadalupe River in Victoria County, Texas (Dall 1896, pp. 5-6). A similar species, *Unio iheringi* was described as a new species by Berlin H. Wright in 1898 from the San Saba River (a tributary of the Colorado) in Menard County, Texas (Wright 1898, p. 93). This taxon was recognized as a form of *Unio mitchelli* var. *iheringi* by Simpson in 1914 (pp. 622-3).

Strecker (1931) synonymized *Unio mitchelli* (from the Guadalupe River) and *Unio iheringii* (from the

San Saba River) and treated false spike as *Elliptio tamaulipasensis*[2] and noted it "a variable species with long and short, compressed and inflated forms living in the same stream" and found in the Brazos, Colorado, and Guadalupe systems from locations including the Leon River in Bell and Coryell Counties, Guadalupe River in Comal, Kendall, Kerr and Victoria Counties, Llano River in Mason County, and the San Saba River in Menard County (Strecker 1931, pp. 18-19).

The false spike has been assigned as *Quincuncina mitchelli* by Turgeon et al. (1988, p. 33) as it was recognized by Howells et al. (1996, p. 127) as *Quadrula mitchelli* by Haag (2012, p. 71), and as *Fusconaia mitchelli* by Pfeiffer et al. where it was reported as "an endemic to the Guadalupe, Colorado, and Brazos drainages of Central Texas" (2016, p. 289). However, Smith et al. (2020, entire) recently described the Balcones spike (*Fusconaia iheringi*) from the Brazos and Colorado River basins as a species separate from false spike (*Fusconaia mitchelli*). The false spike (*Fusconaia mitchelli*) is now recognized to only occur in the Guadalupe basin, while the Balcones spike (*Fusconaia iheringi*) occurs in the Brazos and Colorado River basins. Both species are included in this SSA report and are expected to have similar habitat and fish host needs. False spike has been characterized as a very rare Texas endemic (Burlakova et al. 2011a, p. 158).

The current recognized scientific name for false spike is *Fusconaia mitchelli*, and this report refers to it as such. The following taxonomic treatment follows Williams et al. (2017, pp. 35, 39).

CLASS	**Bivalvia Linnaeus, 1758**
ORDER	**Unionida Gray, 1854**
FAMILY	**Unionidae Rafinesque, 1820**
SUBFAMILY	**Ambleminae Rafinesque, 1820**
TRIBE	**Pleurobemini Hannibal, 1912**
GENUS	***Fusconaia* Simpson, 1900**
SPECIES	***Fusconaia mitchelli* Simpson, 1895 (reassigned from *Quincuncina*)**

The false spike is a medium-sized freshwater mussel (to 132 mm) with a yellow-green to brown, to black, elongate shell, sometimes with greenish rays (Figure 2.3). For a detailed description see Howells et al. 1996 (pp. 127-8) and Howells 2014 (p. 85).

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[2] Howells et al. (1996, pp. 127-8) and Howells (2014, pp. 85-86) treated *Sphenonaias taumilpana* as a synonym of false spike and included the Rio Grande basin of Texas and New Mexico within the historic range of false spike. However, Pfeiffer et al. (2016, p. 285, 289) reject that treatment and instead follow Graf and Cummings (2007, p. 309), who treat *Sphenonaias taumilapana* is a separate species endemic to the Rio Grande drainage (and distinct from *F. mitchelli*), "known only from fossil specimens" and having "much larger" shells than *F. mitchelli* in Central Texas. As such, this report does not include the Rio Grande drainage as part of the historical range of the false spike, *Fusconaia mitchelli*.

Figure 2.3. False spike from the Guadalupe River, Gonzales County, Texas. (Photo courtesy: Dr. Charles Randklev, Texas A&M University.)

2.B.1.b Genetic Diversity

Pfeiffer et al. (2016, pp. 287-288; Fig.2, p. 284) presented preliminary information that false spike may be endemic just to the Guadalupe River basin, while false spike from the Colorado and Brazos River basins may be a new species (*Fusconaia iheringi*), but he stopped short of concluding that *F. iheringi* should be recognized as a separate species. However, Smith et al. (2020, entire) concluded that false spike from the Colorado and Brazos River basins are a separate and distinct species called the Balcones spike, *F. iheringi*.

2.B.1.c Reproduction and Fish Host Interactions

Dudding et al. (2019, p. 16) conducted laboratory studies that tested eight potential species of host fish and reported that false spike glochidia successfully transformed on red shiner (*Cyprinella lutrensis*) and blacktail shiner (*Cyprinella lutrensis*). Dudding et al. (2019, p. 16) also reported encountering gravid females during March through April in the Guadalupe River population, and that only 10 of 34 collected gravid females produced viable glochidia that could be infected on possible host fish during the study. Dudding et al. (2019) caution that the patchy distribution of false spike could be related to host fish relationships; that is, because their host fish have a small home range, limited dispersal ability, and are sensitive to human impacts, distribution of false spike could be limited by access to, and movement of host fish (pp. 16-7).

Pfeiffer et al. (2016, p. 287) suggested that, based on closely related species, false spike likely brood eggs and larvae from early spring to late summer and that host fish are expected to be minnows (family Cyprinidae). Howells et al. (1996, pp. 127-8) and Howells (2014, p. 85) report the fish hosts as unknown.

Members of the tribe Pleurobemini produce conglutinates (Barnhart et al. 2008, p. 376) and tend to exhibit short-term brooding (**tachytictia**), that is, they release glochidia soon after the larvae mature (Barnhart et al. 2008, p. 384). Conglutinates may be important in protecting glochidia from some water quality contaminants (Barnhart et al. 2008, p. 375), serving as barriers as glochidia physically encased in conglutinates, rather than free-floating, are not directly exposed to waterborne contaminants (including metals such as copper; Gillis et al. 2008, pp.138, 144). Similar physical protection is also afforded to glochidia when they encyst on host fish.

2.B.1.d Age and Growth

Congeners (*Fusconaia* spp.) from the southeast United States are reported by Haag and Rypel (2010) to reach a maximum age of 15–51 years (Table 1, pp. 4-6) and members of tribe Pleurobemini ranged from 14–57 years (p. 10). No age at maturity information exists for this species (Howells 2010d, p. 3). However, preliminary and ongoing shell sectioning studies suggest that the species has a maximum life span of about 17 years and frequently lives only for about 10 years (Dudding et al. 2018, in prep).

2.B.1.e Habitat

False spike occurs in larger creeks and rivers with sand, gravel, or cobble substrates, and with slow to moderate flows, and is not known from impoundments, nor from deep waters (Howells 2014, p. 85) (Table 2.2).

Table 2.2. False spike life history and resource needs.

Life Stage	Resource Needs	Reference
Glochidia through host fish attachment	• Obligate ectoparasite of fish gills. • red shiner and blacktail shiner	Morton et al. 2016, p. 4 Haag 2012, p. 41 Dudding et al. 2019, p. 16
Juveniles -Excystment through sexual maturity	• Habitat associations remain undescribed, although likely similar to adult needs.	Morton et al. 2016, p. 4 Howells et al. 2010, p. 8 of 122
Adults	• Large rivers and creeks in moderate to slowly flowing water with gravel-cobble substrates, mainly riffle and run mesohabitats. Not known to occur in impoundments or reservoirs. • Phytoplankton, algae, and detritus for food. • Dissolved Oxygen (DO) > 2 mg/L • Water temperature < 29 º Celsius (84º Fahrenheit). Recent 12-hour trials determined a lethal temperature for 50% of the population (LT_{50}) of 36 ºC. • Total ammonia nitrogen (TAN) < 0.77 mg/L • Salinity < 2 ppt	Morton et al. 2016, p. 4 Howells 2014, p. 85 Randklev et al. 2013, p.18–19 Randklev et al. 2012, p. 1 Bonner et al. 2018, pp. 11, 161-, 164, 175 Stoeckel 2018, entire Khan et al. 2018, pp. 32-41

2.B.2 Balcones spike, *Fusconaia iheringi* (Wright, 1898)

2.B.2.a Taxonomic and Morphological Descriptions

The Balcones spike (*Fusconaia iheringi)* was recently described as a separate and distinct species from false spike (*Fusconaia mitchelli)*; Smith et al. 2020, entire). The Service now recognizes *Fusconaia mitchelli* to only occur in the Guadalupe River basin while *Fusconaia iheringi* is now recognized to only occur in the Brazos and Colorado River basins. The two species are assumed to have similar habitat and host fish needs.

The current recognized scientific name for Balcones spike is *Fusconaia iheringi* and this report refers to it as such. The following taxonomic treatment follows Williams et al. (2017, pp. 35, 39).

CLASS	**Bivalvia Linnaeus, 1758**
ORDER	**Unionida Gray, 1854**
FAMILY	**Unionidae Rafinesque, 1820**
SUBFAMILY	**Ambleminae Rafinesque, 1820**
TRIBE	**Pleurobemini Hannibal, 1912**
GENUS	***Fusconaia* Simpson, 1900**
SPECIES	***Fusconaia mitchelli* Simpson, 1895 (reassigned from *Quincuncina*)** ***Fusconaia iheringi* Smith et al., 2020 (new species)**

The Balcones spike is a medium-sized freshwater mussel (to 96 mm) with a yellow-green to brown, elongate shell, sometimes with greenish rays. For a detailed description, see Smith et al. 2020 (entire).

Figure 2.4. Balcones spike from the Brushy Creek, Milam County, Texas. (Photo courtesy Brad Littrell, Bio-West, Inc.)

2.B.2.b Genetic Diversity

The Balcones spike (*Fusconaia iheringi*) was recently proposed as a separate and distinct species from false spike (*Fusconaia mitchelli*; Smith et al. 2020, entire).

2.B.2.c Reproduction and Fish Host Interactions

Members of the tribe Pleurobemini produce conglutinates (Barnhart et al. 2008, p. 376) and tend to exhibit short-term brooding (**tachytictia**), that is, they release glochidia soon after the larvae mature (Barnhart et al. 2008, p. 384). Conglutinates may be important in protecting glochidia from some water quality contaminants (Barnhart et al. 2008, p. 375), serving as barriers as glochidia physically encased in conglutinates, rather than free-floating, are not directly exposed to waterborne contaminants (including metals such as copper; Gillis et al. 2008, pp.138, 144). Similar physical protection is also afforded to glochidia when they encyst on host fish.

Like the false spike, Balcones spike likely brood eggs and larvae from early spring to late summer and their host fish are expected to be minnows (family Cyprinidae). The host fish for Balcones spike are expected to include red shiner (*Cyprinella lutrensis*) and blacktail shiner (*Cyprinella venusta*). For false spike, Dudding et al. (2019) cautioned that the patchy distribution of false spike could be related to host fish relationships; thus, due to their similarities, it is expected that the patchy distribution of Balcones spike could be related to its host fish relationship. Because Balcones spike potentially has similar host fish that have small home ranges, limited dispersal ability, and are sensitive to human impacts, distribution of Balcones spike could be limited by access to, and movement of, host fish (pp. 16-7).

2.B.2.d Age and Growth

Congeners (*Fusconaia* spp.) from the southeast United States are reported by Haag and Rypel (2010) to reach a maximum age of 15–51 years (Table 1, pp. 4-6) and members of tribe Pleurobemini ranged from

14–57 years (p. 10). No age at maturity information exists for this species (Howells 2010d, p. 3). However, Dudding et al. (2018, in prep) preliminary and ongoing shell sectioning studies done for the false spike suggest that the species has a maximum life span of about 17 years and frequently lives only for about 10 years. Due to their similarities, it is expected Balcones spike has a similar life span to false spike.

2.B.2.e Habitat

Like the false spike, Balcones spike is expected to utilize larger creeks and rivers with sand, gravel, or cobble substrates, and with slow to moderate flows, and is not known from impoundments, nor from deep waters (Howells 2014, p. 85) (Table 2.3).

Table 2.3. Presumed Balcones spike life history and resource needs.

Life Stage	Resource Needs	Reference
Glochidia through host fish attachment	• Obligate ectoparasite of fish gills. • red shiner and blacktail shiner	Morton et al. 2016, p. 4 Haag 2012, p. 41 Dudding et al. 2019, p. 16
Juveniles -Excystment through sexual maturity	• Habitat associations remain undescribed, although likely similar to adult needs.	Morton et al. 2016, p. 4 Howells et al. 2010, p. 8 of 122
Adults	• Large rivers and creeks in moderate to slowly flowing water with gravel-cobble substrates, mainly riffle and run mesohabitats. Not known to occur in impoundments or reservoirs. • Phytoplankton, algae, and detritus for food. • Dissolved Oxygen (DO) > 2 mg/L • Water temperature < 29 º Celsius (84º Fahrenheit). Recent 12-hour trials determined a lethal temperature for 50% of the population (LT_{50}) of 36 ºC. • Total ammonia nitrogen (TAN) < 0.77 mg/L • Salinity < 2 ppt	Morton et al. 2016, p. 4 Howells 2014, p. 85 Randklev et al. 2013, p.18–19 Randklev et al. 2012, p. 1 Bonner et al. 2018, pp. 11, 161-, 164, 175 Stoeckel 2018, entire Khan et al. 2018, pp. 32-41

2.B.3 Texas fatmucket, *Lampsilis bracteata* (Gould 1855)

2.B.3.a Taxonomic and Morphological Description

The Texas fatmucket was originally described as the species *Unio bracteatus* by A.A. Gould in 1855 from the "Llanos River" in "Upper" Texas (p. 228). Simpson (1900, p. 543) placed the species in the genus *Lampsilis* and noted the species occurred in the Llanos (sic), Guadalupe, and Colorado rivers of Texas. Simpson later recognized the species as *Lampsilis bracteata* (1914, pp. 73-74). Strecker (1931, p.39) recognized Texas fatmucket as *Lampsilis bracteata*, and that it was "characteristic of the Guadalupe and Colorado river systems." Texas fatmucket has been characterized as a rare Texas endemic (Burlakova et al. 2011a, p. 158).

The recognized scientific name for Texas fatmucket is *Lampsilis bracteata*, and this report refers to it as such. The following taxonomic treatment follows Williams et al. (2017, pp. 35, 39).

CLASS	**Bivalvia Linnaeus, 1758**

ORDER	**Unionida Gray, 1854**
FAMILY	**Unionidae Rafinesque, 1820**
SUBFAMILY	**Ambleminae Rafinesque, 1820**
TRIBE	**Lampsilini Ihering, 1901**
GENUS	***Lampsilis* Rafinesque, 1820**
SPECIES	***Lampsilis bracteata* Gould, 1855**

The Texas fatmucket is a small to medium-sized freshwater mussel (to 100 mm) that exhibits **sexual dimorphism** and has a yellow-green-tan elliptical to subrhomboidal shell with “black or brown rays that broaden near the margin and are often broken.” Females have variable mantle flaps that are used as lures (Howells et al. 2011, pp. 14-16). For a detailed morphological description see Howells et al. 1996 (p. 61) and Howells 2014 (p. 41) (Figure 2.5).

Figure 2.5. Male (left) and female (right) Texas fatmucket from the San Saba River, Menard County, Texas. (Photo courtesy Gary Pandolfi, USFWS.)

2.B.3.b Genetic Diversity

Hannes (2017) investigated species relationships in the genus Lampsilis and found that *L. bracteata* was a separate and distinct species from *L. hydiana* (Louisiana fatmucket), a species having a similar appearance but little overlap in range (p. 18). Hannes (2017, pp. 8-18) analyzed four *L. bracteata* specimens (collected from the Llano River in Kimble County and the San Saba River in Menard County - p.8) and found that they shared the same **haplotype** (p. 18) but acknowledges that some genetic diversity may exist and is expressed as “ecophenotypes” (p. 18) with some having more elongate shells, and with variation in mantle lures as described by Howells et al. (2011, pp. 1-3), with individuals from different parts of the Colorado River basin having noticeably different mantle flaps/lures. Given the importance of glochidia attachment in the mussel life cycle, mantle lure polymorphism is an important component of genetic/environmental diversity, adaptive potential, and thus, representation for the Texas fatmucket.

Recently, Inoue et al. (2019, entire) found that Texas fatmucket in the Guadalupe River basin are more closely related to *L. hydiana* than to *L. bracteata* and are likely a new species. In this report, we recognize these Guadalupe River basin populations to be a distinct species, the Guadalupe fatmucket (*Lampsilis bergmanni*), separate from the Texas fatmucket. Both species are included in this SSA and are expected to have similar habitat and fish host needs.

2.B.3.c Reproduction and Fish Host Interactions

Host fishes are known to be members of the Family Centrarchidae (sunfishes), including bluegill (*Lepomis macrochirus*), green sunfish (*Lepomis cyanellus*), Guadalupe bass (*Micropterus treculii*), and largemouth bass (*Micropterus salmoides*) (Howells 1997, p. 257; Johnson et al. 2012, p. 148; Howells 2014, p. 41; Ford and Oliver 2015, p. 4; Bonner et al. 2018, p. 9).

Members of the Lampsilini tribe can expel conglutinates and are known to use mantle lures (Barnhart et al. 2008, p. 377) to attract sight feeding fishes that attack and rupture the marsupium, becoming infested by glochidia (p. 380). These species are long-term brooders (**bradytictic**) (p. 384).

2.B.3.d Age and Growth

Congeners (*Lampsilis* spp.) from the southeast United States are reported by Haag and Rypel (2010) to reach a maximum age of 13–25 years (Table 1, p. 4-6) and members of tribe Lampsilini ranged from 4–50 years (p. 10) with a higher growth rate compared to other tribes (p. 15). Louisiana fatmucket (*Lampsilis hydinia*) has been reported mature at 36.4 mm, and presumably, Texas fatmucket is similar, (Howells 2010, p. 68). No age at maturity information exists for this species (Howells 2010c, p. 3).

In the Llano River, recent studies indicate that population structure is 0.5 males to every female (of n=72 sampled), at one sampling location (Seagroves and Schwalb 2017, p. 11). Additionally, from one sampling location in the San Saba River the sex ratio was 1.3 males per female mussel (of n=87 sampled) (Seagroves and Schwalb 2017, p. 11). During peak reproduction months (February through July) the Llano River showed glochidia viability averaging 80% whereas the San Saba River glochidia viability averaged 81% (Seagroves and Schwalb 2017, p. 12). One reviewer noted that 80% viability is low compared with typically 95% for healthy mussel populations and that because the Llano River and San Saba River populations receive high sampling pressure by multiple researchers and reduced glochidia viability could result from stress associated with repeated handlings and removals.

2.B.3.e Habitat

The Texas fatmucket occurs in flowing streams and rivers of the Edwards Plateau with substrates of "firm mud, stable sand, and gravel bottoms, in shallower waters" sometimes in bedrock fissures or among roots of bald cypress (*Taxodium distichum*) and other aquatic vegetation (Howells 2014, p. 41) (Table 2.4). The Texas fatmucket has been described as more vulnerable to extreme low flows and positively associated with spring outflows of the Edwards Plateau (Bonner et al. 2018, p. 9). In a laboratory dewatering experiment, the median Lethal Time (LT_{50}) was 2.86 days and Texas fatmucket did not exhibit a behavioral movement response to the dewatering (Bonner et al. 2018, pp. 8-9, 196). Recent thermal tolerance studies on Texas fatmucket found a lethal temperature for 50% of the population (LT_{50}) during a 24-hour period of 34.7°C (Khan et al. 2018, p. 32).

Table 2.4. Texas fatmucket life history and resource needs.

Life Stage	Resource Needs	Reference
Glochidia through host fish attachment	• Known host fishes include bluegill, green sunfish, largemouth bass, and Guadalupe bass, while other hosts in the family Centrarchidae possible.	Johnson et al. 2012, p. 1
Juveniles -Excystment through ~36 mm	• Habitat associations remain undescribed, although likely similar to the needs of adults.	Howells 2010a, p. 3
Adults	• Bank and pool habitat in moderate to small sized streams in flowing waters. Typically occur in finer substrates of mud, sand, and gravel in relatively shallow waters. • Occasionally known to occur in sediment-filled bedrock crevices and fissures. Individuals also documented from aquatic macrophytes (in beds of submerged vegetation) that retain and stabilize suitable substrates. • Flowing water, positively associated with spring outfalls • Dissolved oxygen (DO) > 2 mg/L • Water temperature optimally < 29 °C (84° F) (presumed from thermal studies). [LT_{50} described as 34°C and LT_{05} at 29°C]. • Salinity < 2 ppt (higher levels result in valve closure) • Total ammonia nitrogen (TAN) < 0.77 mg/L	Randklev et al. 2017c, p. 40 Howells 2010a, p. 3 Bonner et al. 2018, pp. 8-9, 161-2 Stoeckel 2018, entire. Mitchell et al. 2018, entire Khan et al. 2018, pp. 32-41

2.B.4 Texas fawnsfoot, *Truncilla macrodon* (Lea 1859)

2.B.4.a Taxonomic and Morphological Descriptions

The Texas fawnsfoot was originally described as the species *Unio macrodon* by Isaac Lea in 1859 from a location near Rutersville, Fayette County, Texas (pp. 154-5); with shell morphology described by Lea (1862, pp. 192-3). Strecker (1931, p. 48) recognized Texas fawnsfoot as *Truncilla macrodon* and noted "is an abundant shell in the Colorado and Brazos rivers" with "largest examples from Austin and Waco" and that "adult shells from many of the tributary streams average much smaller" and provided locations in the Brazos River in Brazos and Robertson Counties, Colorado River in Burnet, Colorado, Travis (at Austin) and Wharton Counties, Leon River in Coryell County, Aquilla Creek in McLennan County, Bosque River in McLennan County, North Bosque River in McLennan County, and Llano River in Mason County. Texas fawnsfoot has been characterized as a rare Texas endemic (Burlakova et al. 2011a, p. 158).

Howells et al. (1996) included the Trinity River drainage within the range of *Truncilla macrodon* (p. 143) and Johnson (1999), in an attempt to revise the genus *Truncilla*, presented *T. macrodon* as a synonym of fawnsfoot (*T. donaciformis*) (p. 6) and described difficulty in distinguishing between the two based on shell morphology (pp. 38-41, 64-65). The combining of the two species was not widely accepted, and recent information suggests that *Truncilla macrodon* may occur in the Trinity River (Randklev et al. 2017a, p. 11). Recent evidence indicates that individuals identified as *Truncilla donaciformis* in the Trinity River are actually *Truncilla macrodon*, with the largest Trinity River population occurring in the middle sections near Oakwood, Texas (Randklev et al. 2017a, p. 11; Inoue et al. 2018, p. 6). Thus, this analysis will include Trinity River populations of *T. macrodon.*

The recognized scientific name for Texas fawnsfoot is *Truncilla macrodon*, and this report refers to it as such. The following taxonomic treatment follows Williams et al. (2017, pp. 35, 44).

CLASS	**Bivalvia Linnaeus, 1758**
ORDER	**Unionida Gray, 1854**
FAMILY	**Unionidae Rafinesque, 1820**
SUBFAMILY	**Ambleminae Rafinesque, 1820**
TRIBE	**Lampsilini Ihering, 1901**
GENUS	***Truncilla* Rafinesque, 1819**
SPECIES	***Truncilla macrodon* Lea, 1859**

Texas fawnsfoot is a small- to medium-sized (60 mm) mussel with a compressed, elongate oval shell that is “dull green, tan, yellow-brown, reddish-brown with patterns of broken rays, often with irregular blotches, inverted [chevrons] or zig-zag markings, sometimes between rays” (Howells 2014, p. 111) (Figure 2.6); for a more detailed description see Howells et al. 1996 (p. 143) and Howells 2014 (p. 111).

Figure 2.6. Multiple size individuals of Texas fawnsfoot, Truncilla macrodon, from the Brazos River, Falls County, Texas. (Photo courtesy Mark Fisher, Texas Department of Transportation).

2.B.4.b Genetic Diversity

Genetic analysis of haplotype networks of *Truncilla* species in Texas indicates that there is no gene flow between Texas fawnsfoot populations in the three major river basins in which it occurs: the Colorado, Brazos, and Trinity rivers (Inoue et al. 2018, p. 4). Each of the three basins likely represents ecologically significant units, of a single species. Therefore, this report recognizes Texas fawnsfoot (*Truncilla macrodon*) as occurring in the Brazos, Colorado, and Trinity River basins of Texas.

2.B.4.c Reproduction and Fish Host Interactions

Host fishes are unknown for the Texas fawnsfoot but assumed to be freshwater drum (*Aplodinotus grunniens;* Howells 2014, p. 111). Other *Truncilla* species occurring in Texas, and elsewhere, are known to use freshwater drum and sauger (*Sander canadensis*, Percidae; which does not occur in Texas) where they co-occur (Ford and Oliver 2015, p. 8 and Haag 2012, pp. 177-178).

Mussels in the genus *Truncilla* have miniature glochidia and "use **molluscivorous** freshwater drum as hosts" (Barnhart et al. 2008, p. 373); that is, freshwater drum are infested with glochidia when they consume female mussels with mature glochidia. Freshwater drum is just one of many fish species known to consume freshwater mussels; other species include: American shad, common carp, black carp, smallmouth buffalo, black buffalo, spotted sucker, river redhorse, striped bass, blue catfish, channel catfish, warmouth, bluegill, red-ear sunfish, and lake sturgeon (McMahon and Bogan 2001, p. 385). Most of these species eat adults of smaller mussel species or juveniles of larger mussel species. However, freshwater drum are specially adapted for feeding on larger mussels with large muscular pharyngeal plates that are capable of crushing shells (McMahon and Bogan 2001, p. 385) and can eat adult mussels, including gravid females. Females of *Truncilla* species are generally small enough to be eaten by molluscivorus fish like freshwater drum (Haag 2012, p. 178) and this strategy of host infestation may limit population size, as reproductively successful females are sacrificed, explaining sex ratios apparently skewed toward males.

While this evolutionary strategy seems likely for Texas fawnsfoot, female self-sacrifice and male-skewed sex ratios have not yet been directly observed in this species. Freshwater drum are benthic generalists and are known to consume various insects, worms, and snails, with larger individuals also consuming crayfish and freshwater mussels (Jacquemin et al. 2014, p. 133). Members of the tribe Lampsilini tend to exhibit long-term brooding (bradytictia), that is, they brood larvae over the winter instead of releasing them immediately (Barnhart et al. 2008, p. 384).

2.B.4.d Age and Growth

Congeners (*Truncilla* spp.) from the southeast and the Midwest United States are reported by Haag and Rypel (2010) to reach a maximum age of 8–18 years (Table 1, pp. 4-6) and members of the tribe Lampsilini ranged from 4–50 years (p. 10) with a higher growth rate compared to other tribes (p. 15). No age at maturity information exists for this species (Howells 2010c, p. 3). However, in 2017, Service and TxDOT biologists made note of Texas fawnsfoot in the middle Brazos River (Falls County, Texas) measuring between 17.8mm and 49.6mm (total shell length) (USFWS 2018, entire). In the Lower Colorado River (near Altair, Texas) Texas fawnsfoot ranged from 32–58 mm in length (Bonner et al. 2018, p. 265).

2.B.4.e Habitat

Texas fawnsfoot are found in medium- to large-sized streams and rivers with flowing waters and mud, sand, and gravel substrates (Howells 2014, p. 111), and adults are most often found in bank habitats and occasionally in backwater, riffle, and point bar habitats with low to moderate velocities that appear to function as flow refuges during high flow events (Randklev et al. 2017c, p. 137). Texas fawnsfoot are also reported from run edge, pool edge, and backwater habitats (Bonner et al. 2018, p. 10). Texas fawnsfoot is relatively small bodied and mobile, with reported observed movement ranging between 1 and 20m (Bonner et al. 2018, pp. 10-11). Habitat suitability for Texas fawnsfoot in the Lower Colorado River (near Altair, Texas) was reported to be highest at water depths of 0.6 to 0.9 m, with mean column velocities below 0.5 m/s (Bonner et al. 2018, pp. 243, 253).

Table 2.5. Texas fawnsfoot life history and resource needs.

Life Stage	Resource Needs	Reference
Glochidia through host fish attachment	• Assumed fish host is freshwater drum.	Dudding et al. 2016, p.3
Juveniles -Excystment through sexual maturity	• Habitat requirements presumed to be similar to adults.	
Adults	• Like other *Truncilla* species, often found in bank habitats with fine and coarse sediment, also run edge and pool edge. • Occasionally found in backwater or riffle habitats. • Dissolved Oxygen (DO) > 2 mg/L • Salinity < 2 ppt • Total ammonia nitrogen (TAN) < 0.77 mg/L • Water temperature < 29 º Celsius (84 º Fahrenheit); currently no laboratory testing of thermal tolerances of this species or within the *Truncilla* spp. genus; 29º C is suitable for other (sympatric) species.	Dudding et al. 2016, pp.1-3 Howells 2010c, pp. 3-5 Bonner et al. 2018, p. 10 Stoeckel 2018, entire.

2.B.5 Texas pimpleback, *Cyclonaias petrina* (Gould 1855)

2.B.5.a Taxonomic and Morphological Descriptions

Texas pimpleback has been characterized as a very rare Texas endemic (Burlakova et al. 2011a, p. 158). The Texas pimpleback was originally described as the species *Unio petrinus* by A.A. Gould in 1855 from the "Llanos River" in Texas (p. 228). Strecker (1931) recognized the species as *Quadrula petrina* and noted it as "variable in shape and coloration" and being able to "identify even extreme forms by the plications on the posterior slope of the shell" and included locations from the Colorado River and Onion Creek at Austin (Travis County), the Llano River in Llano and Mason Counties, the San Saba River in Runnels County, and the South Concho River in Tom Green County.

The Texas pimpleback was recently reassigned from *Quadrula* to *Cyclonaias*, and the Service recognizes the Texas pimpleback as *Cyclonaias petrina* in Randklev et al. (2017, p. 280). The following taxonomic treatment follows Williams et al. (2017, pp. 35, 37). Burlakova et al. (2018, entire) recently described the Guadalupe orb (*Cyclonaias necki*) from the San Marcos River and the Guadalupe River basin as a species separate from Texas pimpleback (*Cyclonaias petrina*). The Texas pimpleback (*Cyclonaias petrina*) is now recognized to only occur in the Colorado basin, while the Guadalupe orb (*Cyclonaias necki)* occurs only in the Guadalupe basin. Both species are included in this SSA report and are expected to have similar habitat and fish host needs.

The following taxonomic treatment follows Williams et al. (2017, pp. 35, 39).

CLASS	**Bivalvia Linnaeus, 1758**
ORDER	**Unionida Gray, 1854**

FAMILY	**Unionidae Rafinesque, 1820**
SUBFAMILY	**Ambleminae Rafinesque, 1820**
TRIBE	**Quadrulini**
GENUS	***Cyclonaias* Pilsbry in Ortmann and Walker, 1922**
SPECIES	***Cyclonaias petrina* Gould, 1855 (reassigned from *Quadrula*)**
	***Cyclonaias necki* Burlakova et al., 2018 (new species)**

The Texas pimpleback is a small- to medium-sized (to 103 mm) mussel with a subquadrate to sub-oval and moderately inflated "yellow to tan, brown to black, occasionally with vague green rays or concentric blotches" (Figure 2.7); for a more detailed description refer to Howells (2014, p. 93).

Figure 2.7. Texas pimpleback from the Colorado River, Lampasas County, Texas. (Photo courtesy: Gary Pandolfi, USFWS)

2.B.5.b Genetic Diversity

Recent phylogenetic analyses provided sufficient information to warrant taxonomic splitting Texas pimpleback between the Colorado River basin and Guadalupe River basin. The species in the Colorado River basin remained Texas pimpleback (*Cyclonaias petrina*) but the Guadalupe River basin portion of the range was formally described as Guadalupe orb (*Cyclonaias necki*) (Burlakova et al. 2018, entire). Both species are included in this SSA report and are expected to have similar habitat and fish host needs.

Randklev et al. (2017c) suggested that the Colorado River and Guadalupe River clades of *Cyclonaias petrina* may be divergent enough to warrant the recognition of a new species (*Cyclonaias howmanni*), a Guadalupe River endemic (pp. 282, 290) based on both genetic and morphological characteristics, and provide a haplotype network with significant intraspecific diversity for each clade in the *Cyclonaias petrina* species complex (p. 294).

2.B.5.c Reproduction and Fish Host Interactions

Several species of native catfishes overlap in range with the Texas pimpleback including black bullhead

(*Ameiurus melas*), yellow bullhead (*Ameiurus natalis*), blue catfish (*Ictalurus furcatus*), channel catfish (*Ictalurus punctatus*), tadpole madtom (*Noturus gyrinus*), freckled madtom (*Noturus nocturnus*), and flathead catfish (*Pylodictis olivaris*) (Thomas et al. 2007, pp. 93-100). Attachment of Texas pimpleback glochidia was reported on yellow bullhead, flathead catfish, and bluegill but metamorphosis was not observed (Howells 2010, p.108). Other species of "*Quadrula*" that occur in Texas are known to have multiple fish hosts in the Centrarchidae, Clupeidae, Ictaluridae, Percidae, and Poecilidae fish families (Ford and Oliver 2015, p. 7). Recent laboratory studies on the closely related Guadalupe orb (*Cyclonaias* necki) confirmed channel catfish (*Ictalurus punctatus*), flathead catfish (*Pylodictus olivarus*) and tadpole madtom (*Noturus gyrinus*) are host fishes (Dudding et al. 2019, p. 15). Given their close phylogenetic relationship, we expect host fish requirements be similar between the Guadalupe orb and Texas pimpleback.

Members of the *Quadrula quadrula* species complex, like Texas pimpleback, have miniature glochidia and "use molluscivorous catfish hosts" and mantle magazines that allow "storage of a bolus of glochidia for reflexive release" (Barnhart et al. 2008, pp. 373, 379). Additionally, members of the tribe Quadrulini can produce conglutinates (Barnhart et al. 2008, p. 376) and tend to exhibit short-term brooding (tachytictia), that is, they release glochidia soon after the larvae mature (p. 384).

Texas pimpleback is reported to be reproductively active between April and August (Randklev et al. 2017c, p. 110).

2.B.5.d Age and Growth

Congeners (Quadrula spp.; now Cyclonaias) from the southeast United States are reported by Haag and Rypel (2010) to reach a maximum age of 15–72 years (Table 1) and members of tribe Quadrulini ranged from 15–91 years (p. 10). No age at maturity information exists for this species (Howells 2010c, p. 3). Texas pimpleback collected from the Lower Colorado River (near Altair, Texas) averaged 65.90 mm in length (Bonner et al. 2018, p. 221). Texas pimpleback from the Lower Colorado River (near Altair, Texas) ranged from 32–58 mm in length and grew, on average, 2.25 mm/month between April and August 2017 (Bonner et al. 2018, pp. 265, 270). Texas pimpleback from the Middle Colorado River (near San Saba, Texas) ranged from 30–94 mm and grew, on average, 0.75 mm/month between April and August 2017, and this population was noted as being "dominated by large individuals, which are assumed to have slower growth rates, than smaller individuals" (Bonner et al. 2018, pp. 265-7, 271). Texas pimpleback appear to be feeding on coarse particulate organic matter (CPOM) and bacteria and fungi associated with these particles (Bonner et al. 2018, p. 215).

2.B.5.e Habitat

Texas pimpleback occurs in medium- to large-sized streams and rivers in flowing waters with "mud, sand, or gravel bottoms, or sometimes in gravel-filled cracks in the bedrock, often at depths less than 2 m" and are "not known from impoundments" (Howells 2014, p. 93). They are also found in riffle and run mesohabitats with flowing water (Randklev et al. 2017c, p. 110) (Table 2.6) and have a particular affinity for riffles compared with other mussel species in the Lower Colorado River (Bonner et al. 2018, p. 244). Habitat suitability for Texas pimpleback in the Lower Colorado River (near Altair, Texas) was reported to be highest at water depths of 0.6 to 0.9 m, with mean column velocities below 0.2 m/s (Bonner et al. 2018, pp. 243, 251). Texas pimpleback is reported to be more tolerant than other Central Texas mussels of dewatering (LT50 at 32 days) and exhibits a behavioral response (movement) to dewatering, which makes it somewhat more resilient to stranding during lower flows events (Bonner et al. 2018, pp. 196-197).

Table 2.6 Texas pimpleback life history and resource needs.

Life Stage	Resource Needs	Reference

Glochidia through host fish attachment	• Presence of host fish, including tadpole madtom, flathead catfish and channel catfish	Randklev et al. 2017c, p. 110 Dudding et al. 2019, p. 15
Juveniles -Excystment through ~45 mm	• Habitat requirements presumed to be similar to adults.	
Adults	• Flowing waters, primarily pools, and runs, in streams of moderate size with substrates of mud, sand, gravel, and cobble. Primarily found in riffles. Occasionally found in fine sediment deposited in bedrock crevices and fissures. • Access to different elevations of habitat, to provide escape during lower flows, with depths between 0.5 and 1.0 m available at multiple flow ranges. Has a particular affinity for riffles. • DO > 2 mg/L [sublethal effects, valve closure] • Salinity < 2 ppt [sublethal effects, valve closure] • Total Ammonia Nitrogen (TAN) < 0.77 mg/L [sublethal effects, valve closure] • Not reported or known to occur in large impoundments. • Water temperature: Based on recent research the optimal temperature range is < 29°C. For the Guadalupe orb the LT_{50} effects were observed during 12-hour trails at 36°C in laboratory experiments. The LT_{05} for the same species was reported at 27°C. • Nutrition: CPOM and associated bacteria and fungi	Randklev et al. 2017c, p. 110 Howells 2010b, pp. 3-5 Bonner et al. 2018, pp. 161-2, 175, 196, 215, 240, 244. Stoeckel 2018, entire Mitchell et al. 2018, entire Khan et al. 2018, p. 33

2.B.6 Guadalupe fatmucket, *Lampsilis bergmanni* (Inoue 2019)

2.B.6.a Taxonomic and Morphological Descriptions

The Guadalupe fatmucket (*Lampsilis bergmanni*) was recently described as a separate and distinct species from Texas fatmucket (*Lampsilis bracteata*; Inoue et al. 2019, entire). The Service now recognizes *Lampsilis bracteata* to only occur in the Colorado River basin while *Lampsilis bergmanni* is now recognized to only occur in the Guadalupe river basin. The two species are assumed to have similar habitat and host fish needs.

The following taxonomic treatment follows Williams et al. (2017, pp. 35, 39).

CLASS	**Bivalvia Linnaeus, 1758**
ORDER	**Unionida Gray, 1854**
FAMILY	**Unionidae Rafinesque, 1820**
SUBFAMILY	**Ambleminae Rafinesque, 1820**
TRIBE	**Lampsilini Ihering, 1901**
GENUS	***Lampsilis* Rafinesque, 1820**

SPECIES *Lampsilis bracteata* **Gould, 1855**
Lampsilis bergmanni **Inoue et al. 2019**

At this time the morphological variation (shell and soft tissue anatomy) remains undescribed. Aside from genetic confirmation the current distinguishing feature between Guadalupe fatmucket and Texas fatmucket is the location in which the specimen is found; being either the Guadalupe River basin or the Colorado River basin, respectively.

Figure 2.8. Guadalupe fatmucket collected from Johnson Creek, Kerr County, Texas. (Photo courtesy Gary Pandolfi, USFWS)

2.B.6.b Genetic Diversity

The Guadalupe fatmucket (*Lampsilis bergmanni*) was recently proposed as a separate and distinct species from Texas fatmucket (*Lampsilis bracteata*; Inoue et al. 2019, entire). At this time little is known about the inter-species genetic variation across the populations in the Upper Guadalupe River basin. Genetic information suggests any *Lampsilis spp.* downstream of Canyon Lake Reservoir and the confluence of the San Marcos River are Louisiana fatmucket (*Lampsilis hydiana*).

2.B.6.c Reproduction and Fish Host Interactions

Reproduction and fish host interaction information for the Guadalupe fatmucket is assumed to be like that of the Texas fatmucket provided above (section 2.B.2.c).

2.B.6.d Age and Growth

Guadalupe fatmucket collected from the Upper Guadalupe River (near Comfort, Texas) averaged 50.69 mm (Bonner et al. 2018, p. 223).

Age and growth information for the Guadalupe fatmucket is assumed to be like that of the Texas fatmucket provided above (section 2.B.2.d).

2.B.6.e Habitat

The Guadalupe fatmucket habitat requirements are assumed to be similar to that of the Texas fatmucket, as described above (2.B.3.e, Table 2.4) (Table 2.7).

Table 2.7. Presumed Guadalupe fatmucket life history and resource needs.

Life Stage	Resource Needs	Reference
Glochidia through host fish attachment	• Known host fishes include bluegill, green sunfish, largemouth bass, and Guadalupe bass, while other hosts in the family Centrarchidae possible.	Johnson et al. 2012, p. 1
Juveniles -Excystment through ~36 mm	• Habitat associations remain undescribed, although likely similar to the needs of adults.	Howells 2010a, p. 3
Adults	• Bank and pool habitat in moderate to small sized streams in flowing waters. Typically occur in finer substrates of mud, sand, and gravel in relatively shallow waters. • Occasionally known to occur in sediment-filled bedrock crevices and fissures. Individuals also documented from aquatic macrophytes (in beds of submerged vegetation) that retain and stabilize suitable substrates. • Flowing water, positively associated with spring outfalls • Dissolved oxygen (DO) > 2 mg/L • Water temperature optimally < 29 °C (84° F) (presumed from thermal studies). [LT_{50} described as 34°C and LT_{05} at 29°C]. • Salinity < 2 ppt (higher levels result in valve closure) • Total ammonia nitrogen (TAN) < 0.77 mg/L	Randklev et al. 2017c, p. 40 Howells 2010a, p. 3 Bonner et al. 2018, pp. 8-9, 161-2 Stoeckel 2018, entire Mitchell et al. 2018, entire Khan et al. 2018, pp. 32-41

2.B.7 Guadalupe orb, *Cyclonaias necki* (Burlakova 2018)

2.B.7.a Taxonomic and Morphological Descriptions

Burlakova et al. (2018, entire) recently described the Guadalupe orb (*Cyclonaias necki*) from the San Marcos River and the Guadalupe River basin as a species separate from Texas pimpleback (*Cyclonaias petrina*). The Guadalupe orb (*Cyclonaias necki)* occurs only in the Guadalupe basin. Strecker (1931) recognized the species as a small variety of *Quadrula petrina* and included locations from the Guadalupe River at New Braunfels (Comal County) and in Kendall, Kerr (at Kerrville) Counties and the Guadalupe River in Victoria County (pp. 27-8).

The following taxonomic treatment follows Burlakova et al. (2018, entire) and Williams et al. (2017, pp. 35, 39).

CLASS	**Bivalvia Linnaeus, 1758**
ORDER	**Unionida Gray, 1854**
FAMILY	**Unionidae Rafinesque, 1820**
SUBFAMILY	**Ambleminae Rafinesque, 1820**
TRIBE	**Quadrulini**
GENUS	***Cyclonaias* Pilsbry in Ortmann and Walker, 1922**
SPECIES	***Cyclonaias petrina* Gould, 1855 (reassigned from *Quadrula*)** ***Cyclonaias necki* Burlakova et al., 2018 (new species)**

The Guadalupe orb is a small-sized mussel with a shell length that reaches up to 63 mm (Burlakova et al. 2018, p. 48). It has thinner, more compressed and rectangular shells as compared to the Texas pimpleback. The posterior ridge is also more distinct and prominent, and the umbo is more compressed than the Texas pimpleback (Burlakova et al. 2018, p. 48).

Figure 2.9. Guadalupe orb collected from the South Fork Guadalupe River, Kerr County, Texas. (Photo courtesy Gary Pandolfi, USFWS).

2.B.7.b Genetic Diversity

Recent molecular analyses identified four haplotypes from the Guadalupe orb's eight-county range within the Guadalupe River-San Antonio River drainage (Burlakova et al. 2018, p. 49). Note that the Guadalupe-San Antonio River basin is sometimes referred to together as a single basin because the two rivers converge about nine miles inland of San Antonio Bay (see Chapter 4.D, pp. 58). However, to date there are no records to indicate that the Guadalupe orb or any of the other five species of Central Texas mussels ever occurred in the San Antonio River basin or its tributaries.

2.B.7.c Reproduction and Fish Host Interactions

Reproduction and fish host interaction information for the Guadalupe orb is assumed to be similar to that of the Texas pimpleback provided above (section 2.B.5.c). Recent laboratory studies conclude that channel catfish (*Ictalurus punctatus*), flathead catfish (*Pylodictis olivaris*), Yellow bullhead (*Amerius natalis*), and tadpole madtom (*Noturus gyrinus*) are suitable host fishes for Guadalupe orb from a total of 12 species tested (Dudding et al. 2019, p. 15). Dudding et al. (2019) cautioned that the apparent clumped distribution of Guadalupe orb (and congeners) in “strongholds” could be related to observed ongoing declines in native catfishes, including the small and rare tadpole madtom, a riffle-specialist (p. 16).

2.B.7.d Age and Growth

Individuals collected from the Upper Guadalupe River (near Comfort, Texas) averaged 48.12 mm (Bonner et al. 2018, p. 221). Although studies investigating age and growth of this species have yet to be performed, we expect that age and growth of Guadalupe orb like that of the Texas pimpleback (*Cyclonaias petrina*), as described above (section 2.B.5.D).

2.B.7.e Habitat

The Guadalupe orb habitat requirements are assumed to be similar to that of the Texas pimpleback, as described above (section 2.B.5.e, Table 2.6) (Table 2.8).

Table 2.8. Presumed Guadalupe orb life history and resource needs.

Life Stage	Resource Needs	Reference
Glochidia through host fish attachment	• Presence of host fish, including tadpole madtom, flathead catfish and channel catfish	Randklev et al. 2017c, p. 110 Dudding et al. 2019, p. 15
Juveniles -Excystment through ~45 mm	• Habitat requirements presumed to be similar to adults.	
Adults	• Flowing waters, primarily pools, and runs, in streams of moderate size with substrates of mud, sand, gravel, and cobble. Primarily found in riffles. Occasionally found in fine sediment deposited in bedrock crevices and fissures. • Access to different elevations of habitat, to provide escape during lower flows, with depths between 0.5 and 1.0 m available at multiple flow ranges. Has a particular affinity for riffles. • DO > 2 mg/L [sublethal effects, valve closure] • Salinity < 2 ppt [sublethal effects, valve closure] • Total Ammonia Nitrogen (TAN) < 0.77 mg/L [sublethal effects, valve closure] • Not reported or known to occur in large impoundments.	Randklev et al. 2017c, p. 110 Howells 2010b, pp. 3-5 Bonner et al. 2018, pp. 161-2, 175, 196, 215, 240, 244. Stoeckel 2018, entire Mitchell et al. 2018, entire Khan et al. 2018, p. 33

Table 2.8 continued. Presumed Guadalupe orb life history and resource needs.

Life Stage	• Resource Needs	Reference

Adults	• Water temperature: Based on recent research the optimal temperature range is < 29°C. For the Guadalupe orb the LT_{50} effects were observed during 12-hour trails at 36°C in laboratory experiments. The LT_{05} for the same species was reported at 27°C. • Nutrition: CPOM and associated bacteria and fungi	

2.C Summary

This report considers seven species of Central Texas mussels, false spike, Balcones spike, Texas fatmucket, Texas pimpleback, Texas fawnsfoot, Guadalupe fatmucket, and Guadalupe orb, all of which belong to the subfamily Ambleminae of the family Unionidae. The seven species occur in one or more of the following basins in Texas: Brazos River, Colorado River, Guadalupe River, and Trinity River. The false spike, Texas fatmucket, Texas pimpleback, and Texas fawnsfoot are among the fifteen mussel species added to the list of Texas state threatened species by the Texas Parks and Wildlife Department (TPWD) in 2009 (TPWD 2021, entire).

Species needs for each of the seven Central Texas mussels generally include a suitable substrate, adequate but not scouring flows, high-quality water (within optimal thermal and DO limits, and without exceedingly high TSS, and without contaminants), refuge from high and low flow events, access to appropriate host fishes, and appropriate nutrition (adequate but not excessive levels of CPOM and associated bacteria and fungi, or suspended phytoplankton).

Chapter 3 - Population and Species Needs

This chapter considers the historical distribution and those parameters that are important in assessing the viability of each of the seven Central Texas mussel species. First, historical range and species distribution are discussed. Then, the conceptual needs of the species are considered, including population resiliency, redundancy, and representation to support viability and reduce the likelihood of extinction, for each of the Central Texas mussel species.

For the purposes of this assessment, **viability** is defined as the ability of the species to sustain populations in the wild over time, which in this case is considered to be 50 years. Fifty years represents at least three generations for any of the Central Texas mussels and reflects the approximate forecasting time horizon for water supply planning and human population projections for the State of Texas. This assessment further considers viability for each species following the species status assessment framework based on "the conservation biology principles of representation, resiliency, and redundancy (**the 3Rs**) to evaluate the current and future conditions of a species" and described by Smith et al. (2018, p. 7).

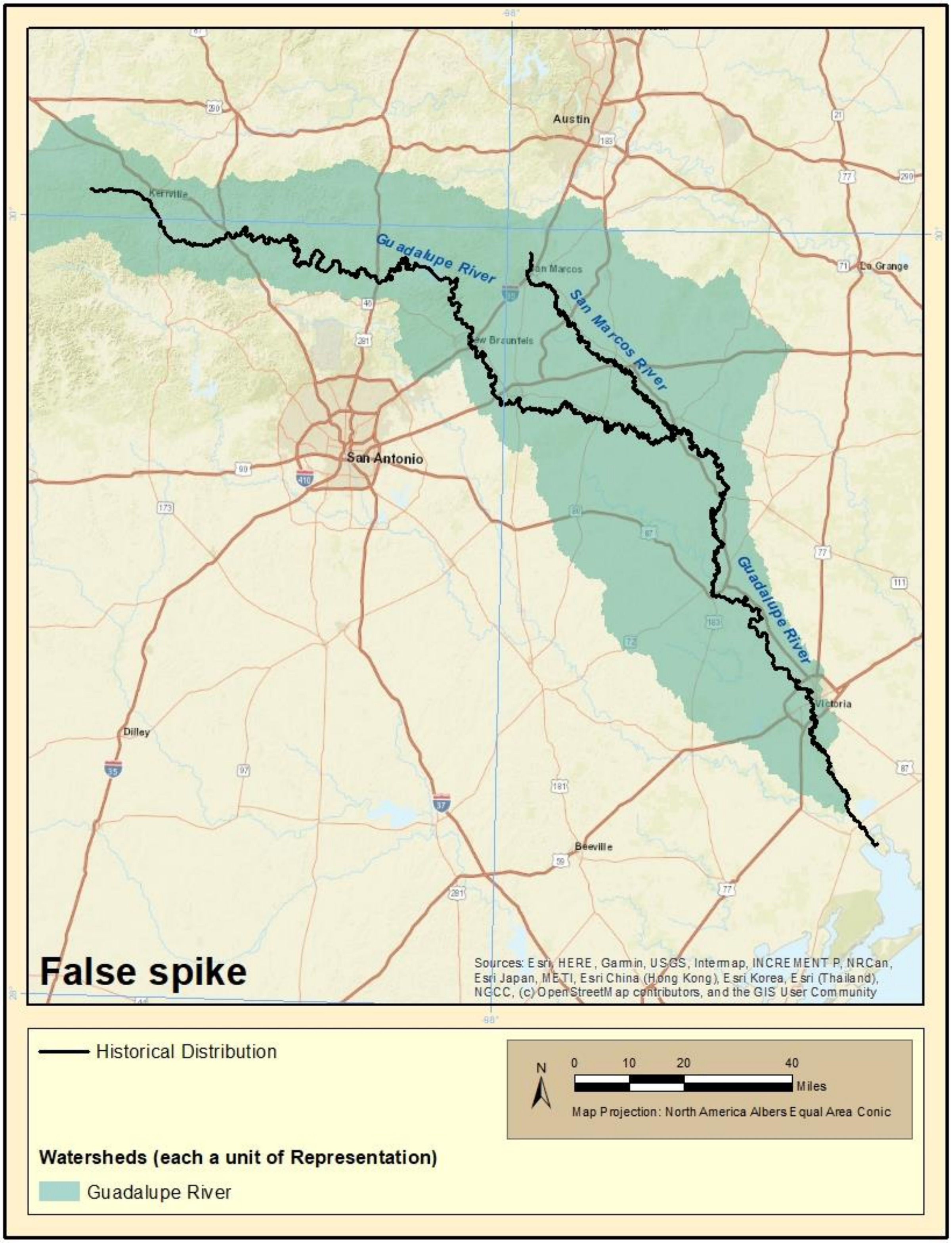
3.A. Historical Range and Distribution

3.A.1 False spike

The false spike was previously believed to occur in the Brazos, Colorado, and Guadalupe drainages in Central Texas (Howells 2010, p. 4; Randklev et al. 2017c, p. 12; Figure 3.1). However, following genetic analyses by Smith et al. (2020, entire), populations of the false spike from the Guadalupe River basin are now considered a separate and distinct species from the populations in the Colorado and Brazos River basins, which are now known as the Balcones spike (*Fusconaia iheringi*).

The false spike was, in the past, thought to have historically occurred in the Rio Grande based on fossil and subfossil shells (Howells 2010, p. 4), but those specimens have now been attributed to *Sphenonaias taumilapana* Conrad 1855 (no common name; Randklev et al. 2017c, p. 12; Graf and Cummings 2007, p. 309).

False spike was once considered common wherever it was found; however, beginning in the early 1970s, the species began to be regarded as rare throughout its range, based on collection information (Strecker 1931, pp. 18-19; Randklev et al. 2017c, p. 13). Williams et al. (1993, p.14) noted that false spike was rare throughout its range and ranked it threatened, and Nature Serve (2016, p.1) ranked the species as critically imperiled. Howells (2010, p. 4) indicated that no living populations were known in the previous 30 years. However, in 2011, the discovery of 7 live false spike in the Guadalupe River, near Gonzales, Texas, was the first report of living individuals in nearly four decades (Randklev et al. 2011, p. 17).



False spike

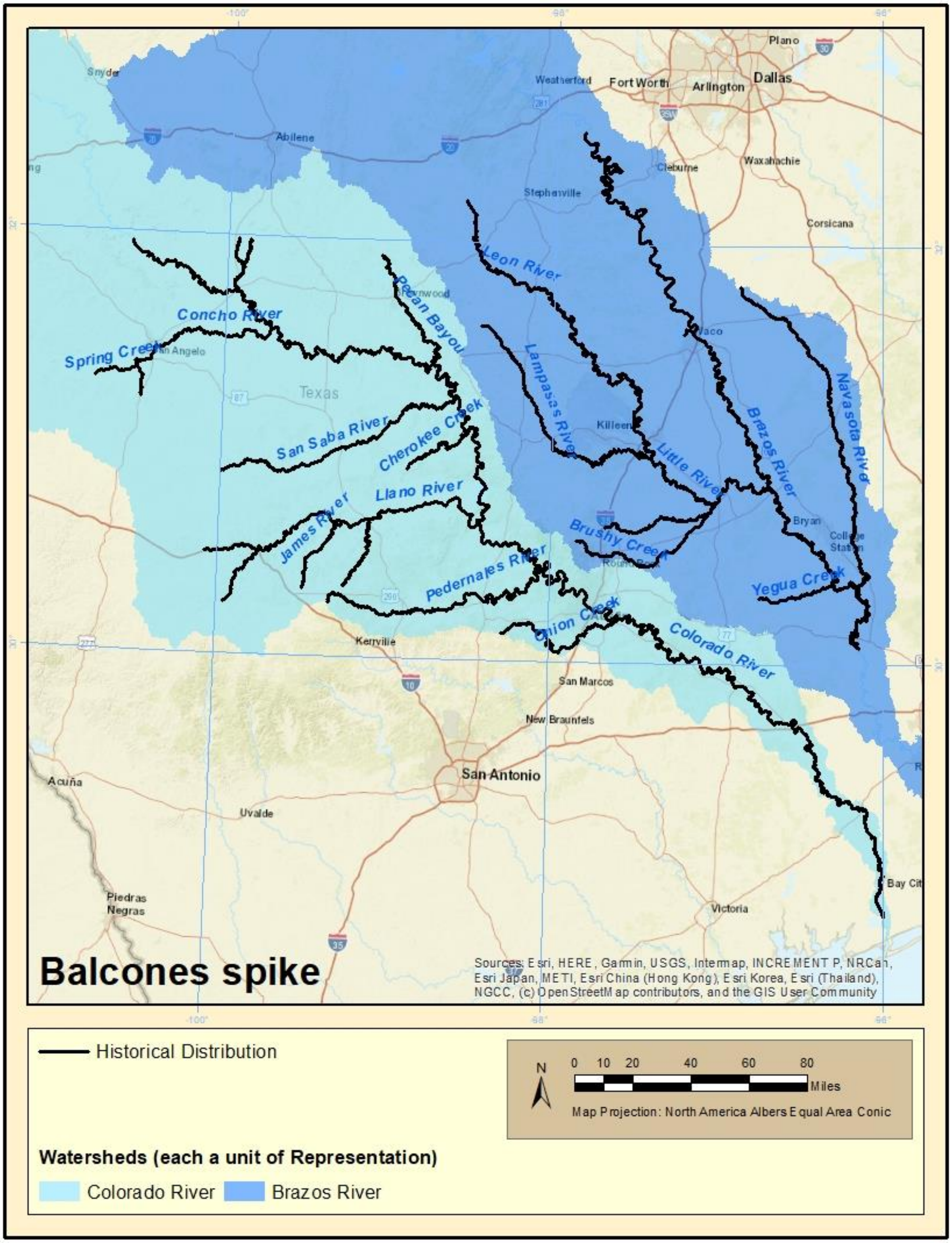
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

Figure 3.1 Presumed historical distribution of false spike in the Guadalupe River basin of Texas.

3.A.2. Balcones spike

The Balcones spike was previously assigned to the same species as the false spike (*Fusconaia mitchelli*). However, following the morphological and genetic analyses by Smith et al. (2020, entire), it is now recognized as a separate and distinct species occurring in the Brazos and Colorado drainages. For this reason, what are now considered Balcones spike populations are referred to as false spike in the literature documenting its occurrences prior to 2020.

In the Brazos River basin, historical records document the occurrence of Balcones spike in the Little River system and the Brazos River (Figure 3.2). The species has also been historically collected from the Leon River, a tributary of the Little River, in Bell County and Coryell Counties (Strecker 1931 pp. 18-19; Randklev et al. 2017c, p. 12) and from the Lampasas River, another tributary of the Little River (Randklev et al. 2017c, p. 12). In the Brazos River, the species has been collected from the boundary of Brazos and Burleson Counties (Randklev et al. 2017c, p. 12).



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

Figure 3.2. Presumed historical distribution of Balcones spike in the Brazos and Colorado River Basins of Texas.

3.A.3 Texas fatmucket

The Texas fatmucket was previously believed to occur in both the Colorado and Guadalupe River basins of the east-central portions of the Edwards Plateau ecoregion, known as the "Hill Country" of Central Texas (Figure 3.3). However, following genetic analyses by Inoue et al. (2019, entire), populations of the Texas fatmucket from the Colorado River basin are now considered a separate and distinct species from the populations in the Guadalupe River basin, which are now known as the Guadalupe fatmucket (*Lampsilis bergmanni*).

The Texas fatmucket once existed with historical populations in at least 14 rivers in the upper Colorado River basin of the east-central portions of the Edwards Plateau ecoregion, known as the "Hill Country" of Central Texas (Figure 3.3). In the Colorado River, it ranged from Travis County upstream approximately 320 kilometers (km) ((200 miles (mi)) to Runnels County. It was also found in many tributaries including the Pedernales, Llano, San Saba, and Concho Rivers, and Jim Ned, Elm, and Onion Creeks (Howells et al. 1996, p. 61). Howells (2004, p. 7) noted that no live **unionids** (native freshwater mussels) were reported from Elm Creek or from the Colorado River near Ballinger, Texas, in August 2003.

Strecker (1931, p. 39) described Texas fatmucket as being "especially common in the San Saba and Llano rivers" and attaining high densities in the Concho River and notes locations on Cypress Creek (Blanco County), San Saba River in Menard and McCulloch Counties, Llano River in Mason County, Colorado River in Runnels County, and South Concho River in Tom Green County.

A Salado Creek record from Bell County (Strecker 1931, pp. 62-3) is also probably a misidentified Louisiana fatmucket because Texas fatmucket is not known to occur in the Brazos River basin or its tributaries (Howells et al. 1996, p. 61; Howells 2010c, p. 6).

In the San Antonio River basin, questionable records exist from the Medina River in Bexar County upstream to the City of San Antonio, as well as in the Medina River and Cibolo Creek (Howells et al. 1996, p. 61; Howells 2010c, p. 6). San Antonio River accounts of Texas fatmucket are most likely misidentified Louisiana fatmucket (*Lampsilis hydiana*). Given extensive mussel survey efforts in the San Antonio River basin over the last 30 years (San Antonio River Authority 2017, p. 1), it is likely that additional records would exist if Texas fatmucket were present in the San Antonio River or its tributaries (Randklev 2018, entire). Therefore, this report does not consider the Texas fatmucket or the Guadalupe fatmucket to have historically occurred in the San Antonio River basin.

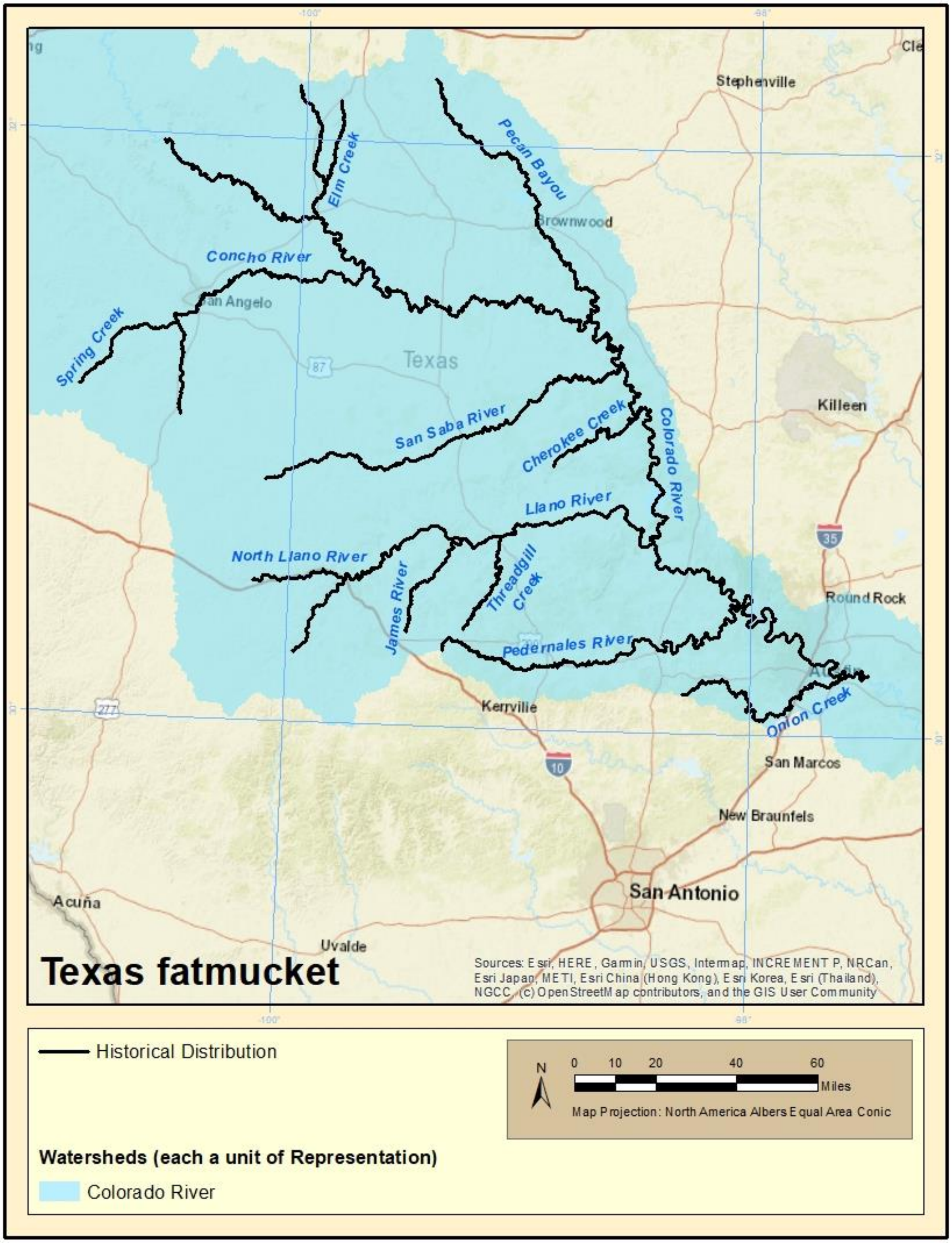


Figure 3.3. Presumed historical distribution of Texas fatmucket in the Colorado River basin of Texas.

3.A.4 Texas fawnsfoot

Strecker (1931, p. 48) noted that the Texas fawnsfoot was abundant in both the Brazos and Colorado Rivers, based on the presence of shell material. The Texas fawnsfoot is endemic to the Brazos and Colorado River basins of Central Texas (Howells et al. 1996, p. 143; Randklev et al. 2010a, p. 297; Figure 3.4) and was recently reported from the Trinity River (Randklev et al. 2017b, pp. 9-10). Texas fawnsfoot was presumed to have been extirpated from most of its range until recently (Randklev et al. 2017, p. 137) because **malacologists** working in Central Texas from the 1960s-90s found few individuals in few new locations (Howells 2010d, p. 6). Historical records suggest the Texas fawnsfoot inhabited much of the Colorado River basin, from the mainstem Colorado River in Wharton County upstream to the North Fork of the Concho River in Sterling County, and throughout the Concho, San Saba, Llano Rivers and Onion Creek (Howells 2010d, p. 4; Randklev et al. 2010b, p. 24). In the Brazos River, the species occurred from Fort Bend County upstream to the lower reaches of the Clear Fork of the Brazos River in Shackelford County, as well as in the Leon, Little, Navasota, and San Gabriel Rivers, as well as Deer and Yegua Creeks (Howells 2010d, pp. 4-5; Randklev et al. 2010b, p. 24).

Early reports and accounts of Texas fawnsfoot (*Truncilla macrodon*) from the Trinity River and other East Texas waters were until recently considered to be misidentified fawnsfoot (*Truncilla donaciformis*; Howells 2010d, p. 4, Howells 2014, pp. 111-2). However, a recent investigation of the Trinity River mussels (Randklev et al. 2017b, pp. 9-11) suggests that the fawnsfoot collected from the Trinity River may actually be *Truncilla macrodon* (Texas fawnsfoot) rather than *Truncilla donaciformis* (fawnsfoot) and that the species still occurs in the East Fork of the Trinity River and in middle sections of the mainstem of the Trinity River, generally near Oakwood, Texas. Preliminary **phylogenetic** studies appear to support the conclusion that *Truncilla macrodon*, rather than *Truncilla donaciformis*, is the species that actually occurs in the Trinity River (Inoue et al. 2018, pp. 4-13).

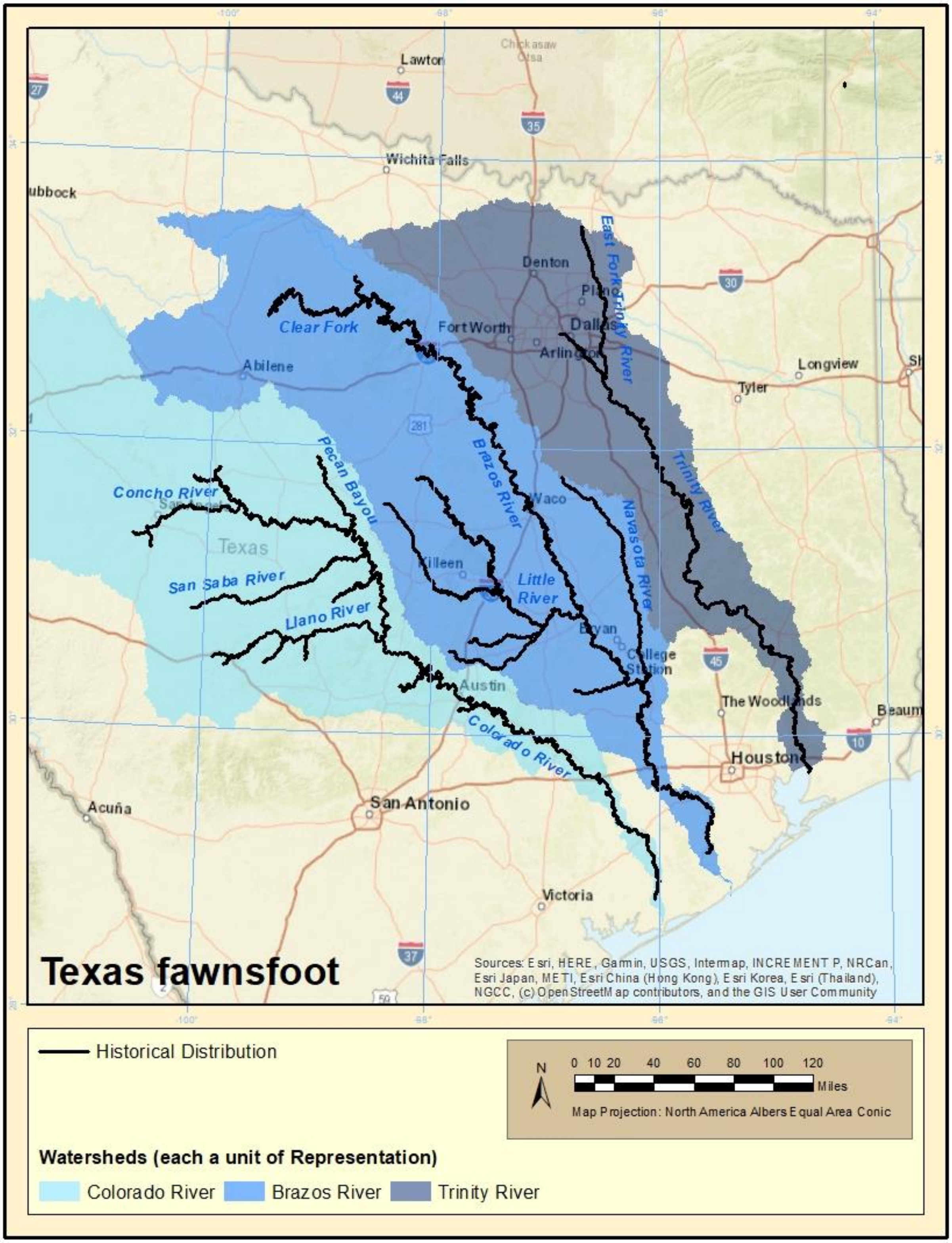


Figure 3.4. Presumed historical distribution of Texas fawnsfoot in the Trinity, Brazos, and Colorado River basins of Texas.

3.A.5 Texas pimpleback

The Texas pimpleback was previously believed to occur in both the Colorado and Guadalupe River basins of Central Texas (Howells 2010, pp 108-11; Figure 3.4). However, following the morphological and genetic analyses of Burlakova et al. (2018, entire), this species is now recognized as a distinct species, separate from the recently described Guadalupe orb (*Cyclonaias necki*) and endemic only to the Colorado River basin of Central Texas. In the Colorado River basin, Texas pimpleback historically occurred throughout nearly the entire mainstem, as well as numerous tributaries, including the Concho, North and South Concho, San Saba, Llano, and Pedernales Rivers, and Elm and Onion Creeks (Howells 2010e, p. 5; Randklev et al. 2010c, p. 4; OSUM 2011d, p. 1; Randklev et al. 2017b, p. 109). Historical reports of the species in the Brazos and Trinity River basins are misidentified smooth pimpleback (*Cyclonaias houstonensis*) and western pimpleback (*Cyclonaias mortoni*; Randklev et al. 2017b, p. 109).

Several specimens of what was thought to be Texas pimpleback have been reported from the San Antonio River basin (Salado, San Antonio, and Medina Rivers) (San Antonio River Authority 2017a, p. 1; San Antonio River Authority 2017b, pp. 32-4; TIFP and SARA 2017, pp.42-5). However, because those specimens are most likely misidentified golden orb (*Cyclonaias aurea*) and no recent collections of Texas pimpleback have been made from the San Antonio River basin despite significant effort (Randklev et al. 2017c, p. 109, Randklev 2018, SARA 2017a, p. 1), this report does not consider the San Antonio River basin part of the historical distribution of Texas pimpleback or the Guadalupe orb.

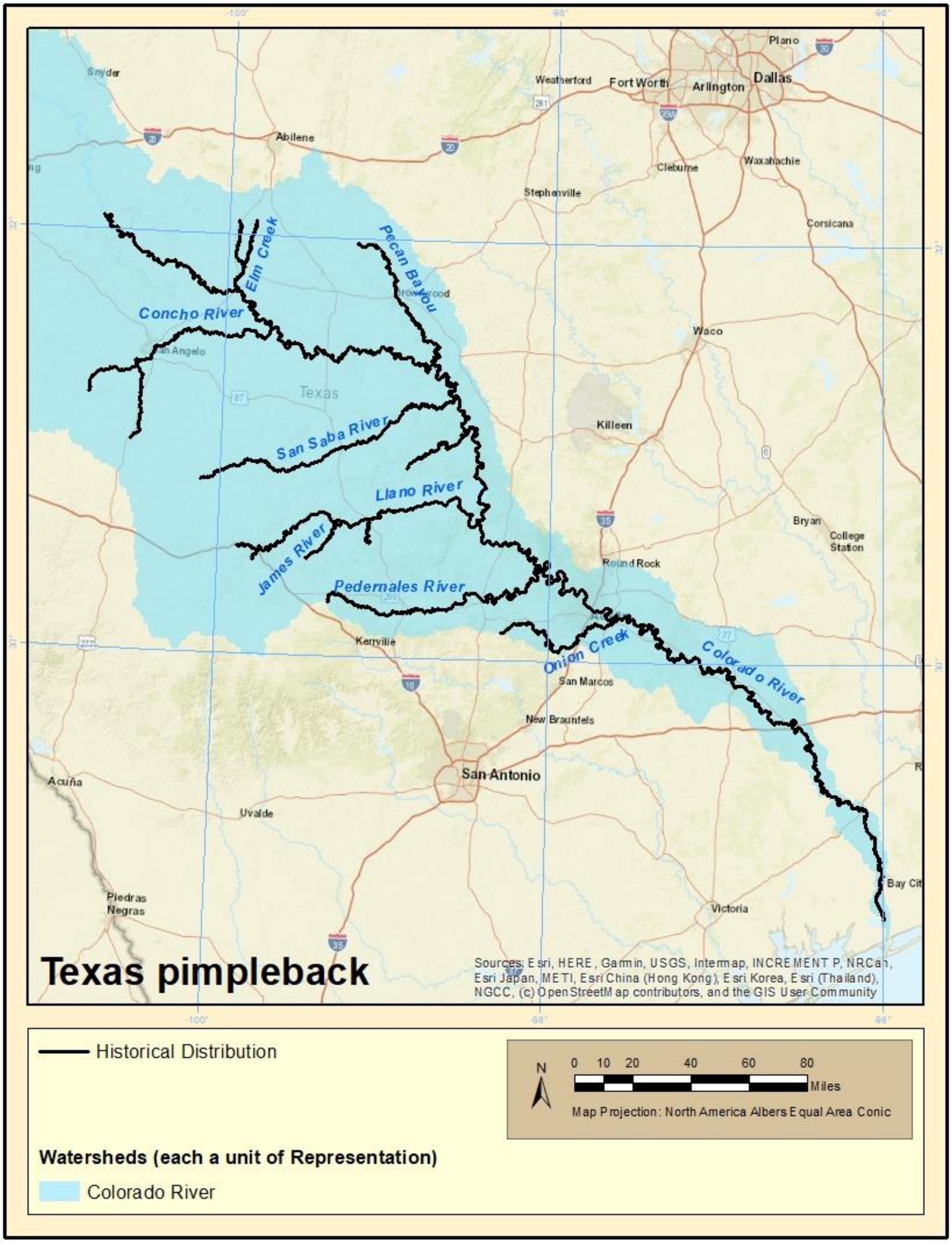


Figure 3.5. Presumed historical distribution of Texas pimpleback in the Colorado River basin of Texas.

3.A.6 Guadalupe fatmucket

The Guadalupe fatmucket (*Lampsilis bergmanni*) was previously assigned to the same species as the Texas fatmucket (*Lampsilis bracteata*). However, following genetic analyses (Inoue et. al. 2019, entire), it is now recognized as a separate and distinct species occurring within the Guadalupe River. For this reason, what we now consider Guadalupe fatmucket populations are referred to as the Texas fatmucket in the literature documenting its occurrences prior to 2018.

In the Guadalupe River basin, the Guadalupe fatmucket occupied approximately 240 km (150 mi) of the Guadalupe River, from Gonzalez County upstream to Kerr County, including the North Guadalupe River, Johnson Creek, and the Blanco River. Strecker (1931, pp. 66-8) reported what would now be considered a Guadalupe fatmucket from a lake in Victoria County in the lower Guadalupe River drainage, but this is probably a misidentified Louisiana fatmucket (*L. hydiana*), which is known to occur in lakes and impoundments (Howells, 2010c. p. 6).

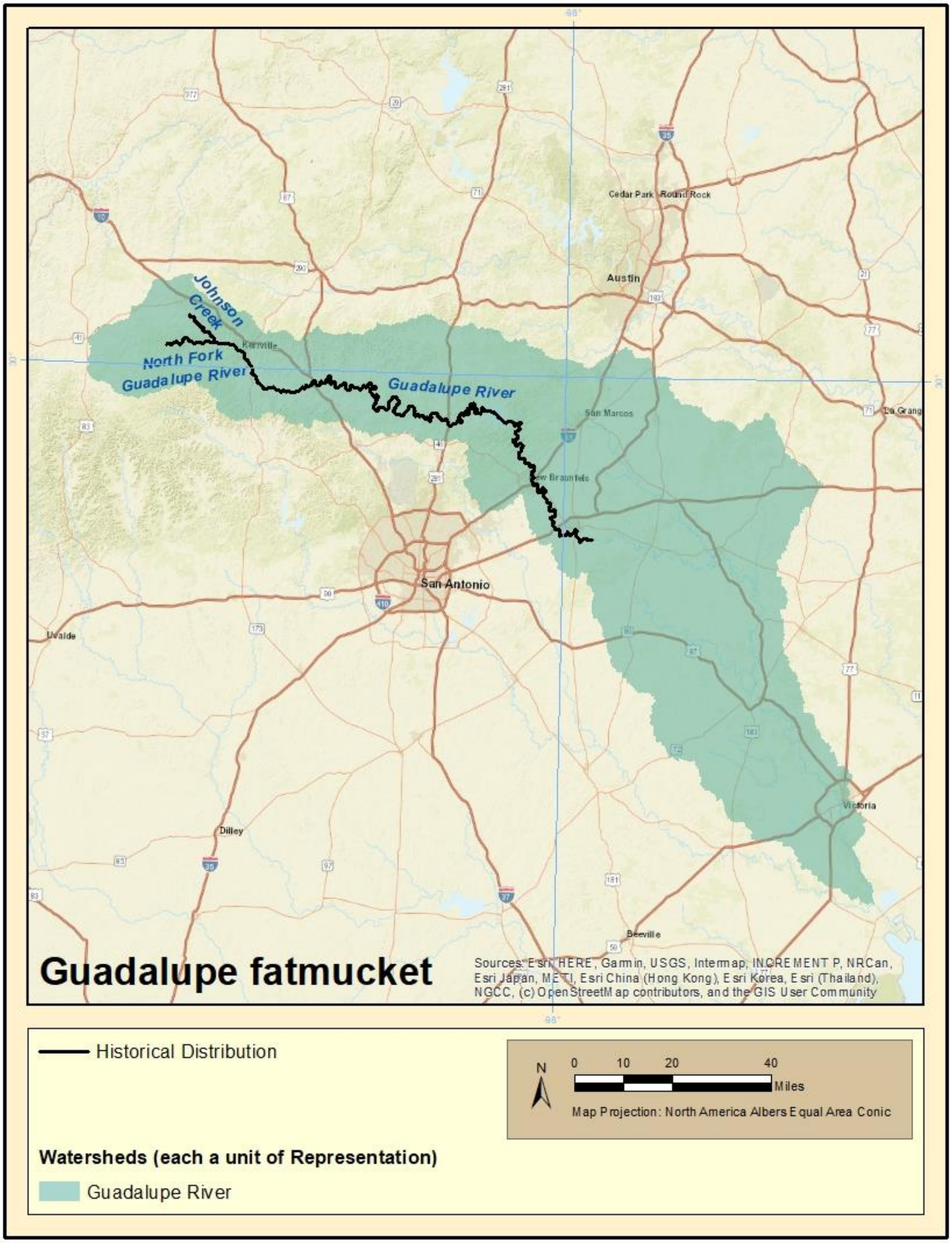


Figure 3.6. Presumed historical distribution of Guadalupe fatmucket in the Guadalupe River basin of Texas.

3.A.7 Guadalupe orb

The Guadalupe orb was previously recognized as the Texas pimpleback (*Cyclonaias petrina*) occurring in the Guadalupe River basin of Central Texas (Howells 2010, pp 108-111) (Figure 3.7). However, following the morphological and genetic analyses by Burlakova et al. (2018, entire), it is now recognized to be a separate species. For this reason, what are now considered Guadalupe orb populations are referred to as Texas pimpleback in the literature prior to 2018.

Although previously identified as Texas pimpleback, Guadalupe orb historically occurred throughout most of the length of the Guadalupe and Blanco Rivers (Horne and McIntosh 1979, p. 122; Howells 2010e, p. 5; OSUM 2011d, p. 1; Randklev et al. 2017c, p. 109) within the Guadalupe River basin. In the Guadalupe River, the species ranged from Comal, Guadalupe, Kendall, Kerr, and Victoria Counties (Randklev et al. 2017b, p. 109).

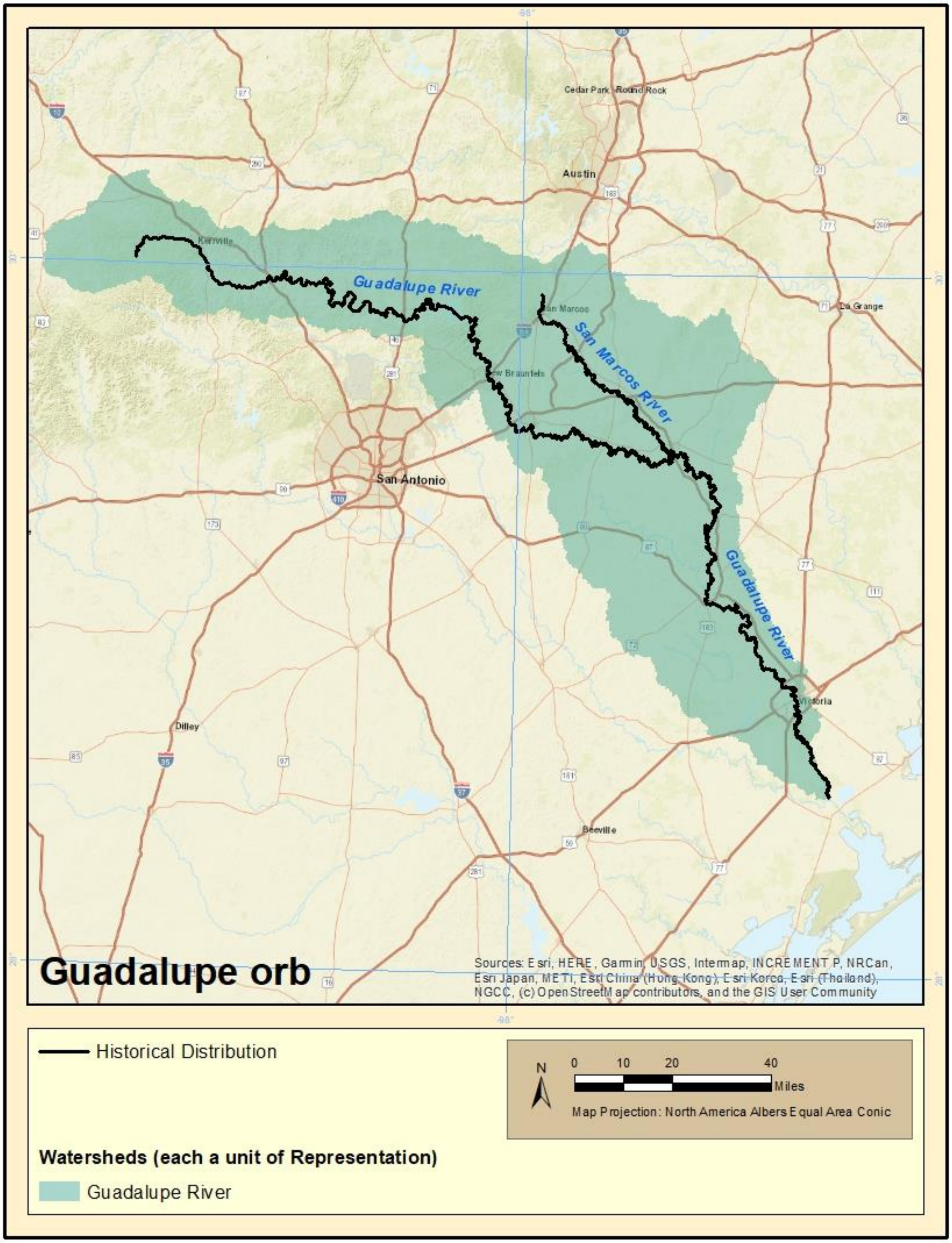


Figure 3.7. Presumed historical distribution of Guadalupe orb in the Guadalupe River basin of Texas.

3.B Needs of Central Texas Mussels

3.B.1 Population Resiliency

For each of the Central Texas mussel species to maintain viability, its populations or some portion thereof must be resilient. Stochastic events that have the potential to affect Central Texas mussel populations include high flow events that result in scour, mobilization of substrates, and burial of mussel beds (these events include flash floods following heavy rains, bank collapse events, etc.), extended droughts and other prolonged dewatering events, pollutant discharge events, large-scale depredation events and disease outbreaks, high water temperature (approaching 40° C) and low dissolved oxygen events (generally below 2–3 ppm), golden algae blooms, and accumulations of large amounts of fine sediment. A number of factors influence the resiliency of populations, including occupied stream length, abundance, and recruitment. While some of the seven species have life history adaptations that help them tolerate dewatering and other stressors to some extent, each of these aforementioned stressors diminishes the resiliency of populations to some degree and especially in combination. Influencing those factors are elements of habitat that determine whether mussel populations can grow to maximize habitat occupancy, thereby increasing the resiliency of populations. These factors and habitat elements are discussed below and in the context of the needs of the individual mussel as presented in Chapter 2 of this report (Tables 2.1-2.8).

Population Factors that Influence Resiliency

Occupied Stream Length – Most freshwater mussels, including the Central Texas mussel species, are found in aggregations, called **mussel beds**, that vary in size from about 50 to >5000 square meters (m^2), separated by stream reaches in which mussels are absent or rare (Vaughn 2012, p. 2). As discussed above, we define a mussel population at a larger scale than a single mussel bed; it is the collection of mussel beds within a stream reach between which infested host fish may travel, allowing for ebbs and flows in mussel bed density and abundance over time throughout the population's occupied reach. Therefore, resilient mussel populations must occupy stream reaches long enough such that stochastic events that affect individual mussel beds do not eliminate the entire population. Repopulation by infested fish from other mussel beds within the reach can allow the population to recover from these events. We consider populations extending more than 50 miles to be highly resilient to stochastic events because a single event is unlikely to affect the entire population. Populations occupying reaches between 20 and 49 river miles have some resiliency to stochastic events, and populations occupying reaches less than 20 miles have little resiliency (Table 3.1). Note that, by definition, an extirpated or functionally extirpated population occupies a stream length of approximately (or approaching) 0.

Table 3.1. Occupied stream length of healthy, moderately healthy, and unhealthy Central Texas mussel populations.

	Occupied Stream Length		
Species	**Healthy**	**Moderately Healthy**	**Unhealthy**
All seven Central Texas mussel species	≥ 50 river miles	49–20 river miles	≤ 19 river miles

Abundance – Mussel abundance in a given stream reach is a product of the number of mussel beds and the density of mussels within those beds. For populations of Central Texas mussel species to be healthy (i.e., resilient), there must be many mussel beds of sufficient density such that local stochastic events do not necessarily eliminate the bed(s), allowing the mussel bed and the overall local population within a stream reach to recover from any one event. We measure mussel abundance by the number of beds within the population, and the estimated density of the species within each bed. Mussel abundance is indicated by the number of individuals found during a sampling event; mussel surveys rarely are a complete census of the population, and instead, density is estimated by the number found during a survey event using various statistical techniques. Because we do not have population estimates for most populations of Central Texas mussels, nor are the techniques directly comparable (i.e., same area size searched, similar search time, etc.), we are using the number of individuals captured as an index over time. While we cannot precisely determine population abundance at the sites using these numbers, we are able to determine if the species is dominant at the site or rare and examine this over time if that data is available. Table 3.2 displays the densities of healthy, moderately healthy, and unhealthy populations of each species.

Table 3.2. Number of mussels per collection event in a single mussel bed of healthy, moderately healthy, unhealthy population, and functionally extirpated populations of Central Texas mussels.

	Number of individuals per sampling event per site			
Species	**Healthy**	**Moderately Healthy**	**Unhealthy**	**Extirpated/ Functionally Extirpated**
All seven Central Texas mussel species	Found in nearly all available habitats surveyed during a reasonable survey effort. More than 100 individuals found per population survey.	Found in approx. 50% of all available habitats surveyed during a reasonable survey effort. Between 26 – 99 individuals found per population survey.	Found in few areas of suitable habitat during a survey reasonable effort. Between 2–25 individuals found per population survey.	Very few or no live individuals documented during a survey exerting reasonable effort (≤ 1).

Reproduction – Resilient Central Texas mussel populations must also be reproducing and recruiting young individuals into the reproducing population. Population size and abundance reflects previous influences on the population and habitat, while reproduction and recruitment reflect population trends that may be stable, increasing, or decreasing. For example, a large, dense mussel population that contains mostly old individuals is not likely to remain large and dense into the future, as there are few young individuals to sustain the population over time (i.e., death rates exceed birth rates and subsequent recruitment of reproductive adults resulting in negative population growth). Conversely, a population that is less dense but has many young and/or gravid individuals may likely grow to a higher density in the future (i.e., birth rates and subsequent recruitment of reproductive adults exceeds death rates resulting in positive population growth). Detection rates of very young juvenile mussels during routine abundance and distribution surveys are extremely low due to sampling bias because sampling for these species involves tactile searches and mussels < 35 mm are very difficult to detect (Strayer and Smith 2003, pp. 47-48).

Evidence of reproduction is demonstrated by repeated captures of small-sized individuals (juveniles and subadults near the low end of the detectable range size ~35 mm; Randklev et al. 2013, p. 9) over time and by observing **gravid** (with eggs in the marsupium, gills, or gill pouches) females during the reproductively active time of year (Table 3.3). While small sized mussels and gravid females can be difficult to detect, it is important to make attempts to detect them as reproduction and subsequent recruitment are especially important demographic parameters that affect growth rates in mussel populations (Berg et al. 2008, pp. 396, 398-9; Matter et al. 2013, pp. 122-3, 134-5).

Table 3.3. Evidence of reproduction in healthy, moderately healthy, unhealthy, and functionally extirpated populations of Central Texas mussels.

	Evidence of Reproduction			
Species	**Healthy**	**Moderately Healthy**	**Unhealthy**	**Extirpated/ Functionally Extirpated**
All seven Central Texas mussel species	50% or more sites having one or more juveniles (< 35 mm) detected and gravid females present during the breeding season and fish hosts present.	25–50% of sites having one or more juveniles (< 35 mm) detected, gravid females present during the breeding season and fish hosts present in moderate abundance.	< 25% of sites having one or more juveniles (< 35 mm) detected, gravid females present during the breeding season, and fish host present in low abundance and/or ability to disperse is reduced.	No evidence suggesting that the juveniles or gravid females are present. Fish host not known to occur.

Habitat Elements that Influence Resiliency

Substrate – Suitable substrate types vary between species of freshwater mussels, including the Central Texas mussels. All species need stable substrate in which to anchor. Three of the Central Texas mussels occur primarily in riffle habitats made up of sand and gravel and occasionally in boulder and bedrock crevices. One species is more tolerant of finer substrates in shallow bank habitats and can occasionally be found in riffles (see Chapter 2). The substrate needs of the Central Texas mussel species are displayed in Table 3.4.

Table 3.4. Substrate conditions of healthy, moderately healthy, unhealthy, and functionally extirpated populations of Central Texas mussels.

	Substrate Conditions			
Species	**Healthy**	**Moderately Healthy**	**Unhealthy**	**Extirpated/ Functionally Extirpated**
false spike	Riffle and run habitats present. Gravel and cobble substrates sufficient to provide lodging habitat. Very low evidence of excessive sediment in the substrate matrix.	Riffle and run habitats present. Gravel and cobble substrates sufficient to provide lodging habitat. Low levels of excess sediment in the substrate matrix.	Riffle and run habitats eroded, unstable, or being buried by mobilized sediments from upstream sources.	No suitable habitat present.

Table 3.4 continued. Substrate conditions of healthy, moderately healthy, unhealthy, and functionally extirpated populations of Central Texas mussels.

	Substrate Conditions			
Species	**Healthy**	**Moderately Healthy**	**Unhealthy**	**Extirpated/ Functionally Extirpated**
Balcones spike	Riffle and run habitats present. Gravel and cobble substrates sufficient to provide lodging habitat. Very low evidence of excessive sediment in the substrate matrix.	Riffle and run habitats present. Gravel and cobble substrates sufficient to provide lodging habitat. Low levels of excess sediment in the substrate matrix.	Riffle and run habitats eroded, unstable, or being buried by mobilized sediments from upstream sources.	No suitable habitat present.
Texas fatmucket	Bedrock fissures and/or vegetative crevices present. Substrate sufficient to provide anchoring within crevices but not filled with sediment.	Bedrock fissures and crevices present. Substrate sufficient in places to provide anchoring while other areas scoured or too heavily filled with sediment.	Fissures and crevices obstructed with excess sediment. Relatively high amount of sedimentation and filling of interstitial spaces.	No suitable habitat present.
Texas fawnsfoot	Clay, mud, and sand banks present. Stream banks stable and without documentation of excessive erosion.	Clay, mud, and sandbanks present. Stream banks mostly stable with some erosion/scouring.	Stream unstable and erosion occurring during high flow. Suitable substrate limited isolated locations.	No suitable habitat present.
Texas pimpleback	Riffle and crevice habitat present. Gravel and cobble substrate sufficient to provide lodging.	Riffle and crevice habitat present. Gravel and cobble substrate sufficient to provide lodging with some deposition of excess sediment.	Riffles eroded or upstream sediments deposited at high enough level to precluded inhabitation.	No suitable habitat present.

Table 3.4 continued. Substrate conditions of healthy, moderately healthy, unhealthy, and functionally extirpated populations of Central Texas mussels.

	Substrate Conditions			
Species	**Healthy**	**Moderately Healthy**	**Unhealthy**	**Extirpated/ Functionally Extirpated**
Guadalupe fatmucket	Bedrock fissures and/or vegetative crevices present. Substrate sufficient to provide anchoring within crevices but not filled with sediment.	Bedrock fissures and crevices present. Substrate sufficient in places to provide anchoring while other areas scoured or too heavily filled with sediment.	Fissures and crevices obstructed with excess sediment. Relatively high amount of sedimentation and filling of interstitial spaces.	No suitable habitat present.
Guadalupe orb	Riffle and crevice habitat present. Gravel and cobble substrate sufficient to provide lodging.	Riffle and crevice habitat present. Gravel and cobble substrate sufficient to provide lodging with some deposition of excess sediment.	Riffles eroded or upstream sediments deposited at high enough level to precluded inhabitation.	No suitable habitat present.

Flowing Water – Freshwater mussels need water for survival. Some of the Central Texas mussels are more resilient to low-velocity water than others (e.g., Texas fatmucket can persist in temporary pools during times of drought). Lentic waters (lakes or other non-flowing systems) are not suitable for any of the seven species. While the Texas pimpleback has adaptations to survive short periods of time out of water (Bonner et al. 2018, p. 196), none of the Central Texas mussel species are found to persist or be tolerant of areas that are regularly dewatered or excessively inundated for long periods of time. A team of Service biologists scored flowing water conditions on a qualitative basis for each mussel population based on a combination of best available information and professional judgement. The flowing water needs of the Central Texas mussel species are displayed in Table 3.5.

Table 3.5. Flowing water conditions of healthy, moderately healthy, unhealthy, and functionally extirpated populations of Central Texas mussels.

Species	**Flowing Water**			
	Healthy	**Moderately Healthy**	**Unhealthy**	**Extirpated/ Functionally Extirpated**
false spike	Flowing water present year-round. Water levels sufficient to keep known habitats constantly submerged. No documented cases of habitat exposure due to low flow events.	Flowing water present year-round, but water levels approaching low levels. No instances of zero flow days and riffle dewatering not documented.	Flowing water not present year-round. Summer records of zero flow days. However, at least some pools stay sufficiently wetted, cool, and oxygenated.	Streambed dry or the number of zero flow days high enough to result in dewatered habitats, precluding survival of mussels.
Balcones spike	Flowing water present year-round. Water levels sufficient to keep known habitats constantly submerged. No documented cases of habitat exposure due to low flow events.	Flowing water present year-round, but water levels approaching low levels. No instances of zero flow days and riffle dewatering not documented.	Flowing water not present year-round. Summer records of zero flow days. However, at least some pools stay sufficiently wetted, cool, and oxygenated.	Streambed dry or the number of zero flow days high enough to result in dewatered habitats, precluding survival of mussels.
Texas fatmucket	Flowing water present year-round. No recorded periods of zero flow days leading to habitat exposure. Water levels sufficient to keep known habitats submerged.	Flowing water present almost year-round. Few instances of zero flow days or minimal exposure of portions of known habitats.	Flowing water does not persist. Summer records of zero flow days while pools stay wetted and sufficiently cool and oxygenated.	Dry stream bed or zero flow days high enough to preclude survival.
Texas fawnsfoot	Flowing water present year-round and sufficient to maintain water quality. No recorded periods of zero flow days. No documented dewatered habitats.	Flowing water present year-round, but water levels approaching low levels. No instance of zero flow days and stream bank drying deviates from appropriate hydrology, with limited habitat desiccation.	Flowing water does not persist annually. Stream banks documented to dry during low flow. Habitat desiccation occurs.	Dry stream bed or zero flow days high enough to preclude survival.

Table 3.5 continued. Flowing water conditions of healthy, moderately healthy, unhealthy, and functionally extirpated populations of Central Texas mussels.

	Flowing Water			
Species	**Healthy**	**Moderately Healthy**	**Unhealthy**	**Extirpated/ Functionally Extirpated**
Texas pimpleback	Flowing water present year-round and sufficient to maintain temperature and dissolved oxygen. No recorded periods of zero flow day and no documented habitat exposure.	Flowing water present year-round, but water levels approaching low levels. No instances of zero flow days and prolonged riffle dewatering not documented.	Prolonged zero flow days or riffle dewatering documented within previous decade.	Dry stream bed or zero flow days high enough to preclude survival.
Guadalupe fatmucket	Flowing water present year-round. No recorded periods of zero flow days leading to habitat exposure. Water levels sufficient to keep known habitats submerged.	Flowing water present almost year-round. Few instances of zero flow days or minimal exposure of portions of known habitats.	Flowing water doesn't persist. Summer records of zero flow days while pools stay wetted and sufficiently cool and oxygenated.	Dry stream bed or zero flow days high enough to preclude survival.
Guadalupe orb	Flowing water present year-round and sufficient to maintain temperature and dissolved oxygen. No recorded periods of zero flow day and no documented habitat exposure.	Flowing water present year-round, but water levels approaching low levels. No instances of zero flow days and prolonged riffle dewatering not documented.	Prolonged zero flow days or riffle dewatering documented within previous decade.	Dry stream bed or zero flow days high enough to preclude survival.

Water Quality – Freshwater mussels, as a group, are very sensitive to changes in water quality parameters such as dissolved oxygen (generally below 2–3 ppm), salinity (generally above 2–4 ppt), ammonia (generally above 0.5 ppm TAN), elevated temperature (generally above 30° C and approaching 40° C), excessive TSS, and other pollutants (Chapter 6). One source of water quality degradation is from wastewater effluent. Habitats with appropriate levels of these parameters are considered suitable, while those habitats with levels outside of the appropriate ranges are considered less than suitable. A team of Service biologists scored water quality conditions on a qualitative basis for each mussel population based on a combination of professional judgement and best available information including, but not limited to, the Texas Integrated Report of Surface Water Quality (TCEQ 2014a, entire; TCEQ 2014b, entire; TCEQ 2014c, entire) and Clean River Program (CRP) Basin Summary Reports (BRA 2017, entire; GBRA 2018f, entire; LCRA 2017, entire; TRA 2018a, entire). The water quality needs of Central Texas mussels are displayed in Table 3.6.

Table 3.6. Water quality conditions of healthy, moderately healthy, unhealthy, and functionally extirpated populations of Central Texas mussels.

	Water Quality			
Species	**Healthy**	**Moderately Healthy**	**Unhealthy**	**Extirpated/ Functionally Extirpated**
All seven Central Texas mussel species	No known incidence of contaminant spills, low dissolved oxygen, or evidence of exposure extreme high or low temperatures, or other water quality degradations. No measured constituents reported to be of concern.	Contaminants known, low dissolved oxygen and temperature extremes documented. No measured constituents reported to be of concern. Levels not high enough to risk extirpation.	Known exposure to contaminants, low dissolved oxygen, and documented cases of excessive water temperatures extremes. Measured constituents reported to be of concern. Water quality parameters diminished such that exposure threatens mussel survival.	Water quality degradation such that occupancy of otherwise suitable habitat is precluded.

Chapter 4 - River Basins and Sections of Interest

4.A. Major Central Texas Watersheds - General Current Conditions

Texas has over 191,000 miles of rivers and streams, seven major estuaries, over one thousand public water bodies, and approximately 200 major streams, all of which provide important services to nearly 270 species of freshwater fish, resident and migratory wildlife, plants, and to over 25 million people throughout the State of Texas (Loeffler 2015, p.1). Texas has only one natural lake, Caddo Lake, in the Cypress Creek Basin of East Texas, which is believed to have been formed by an ancient logjam known as the "Great Raft of the Red River" more than two hundred years ago; that logjam was removed by 1873 and a dam was completed in 1914 (Winemiller et al. 2005, pp. 1-5). Over one hundred (138) major reservoirs had been constructed on Texas rivers before 1960 (Dowell 1964, pp.3-8) and Texas now has 188 major reservoirs and numerous river diversions (TWDB 2017, p. 62). The construction of new reservoirs has slowed, partly because few viable sites remain for major reservoirs, environmental permitting, and construction costs (TWDB 2018d, p. 1). That said, 26 new major reservoirs have been recommended, along with additional strategies, by the regional water planning groups to provide additional surface water supplies (TWDB 2017, p.87), and additional strategies to enhance water supply in the State include: demand management (water conservation), reuse (of treated wastewater), groundwater development (and aquifer storage and recovery), and seawater (desalination; TWDB 2017, p. 90). Many of the proposed new reservoirs are off-channel reservoirs (OCR) that will not be built on the main stem of the rivers but may rely on flows from the main stem, through pumping, or "scalping" during high flow events (TWDB 2017, p. 95). The National Inventory of Dams includes 7,395 total dams in the state of Texas, with the top four primary purposes reported as for flood control, recreation, irrigation, and water supply (USACE 2018b, entire). Most of these dams (5,279 of them) were constructed between 1950 and 1990 (USACE 2018b, entire).

According to the 2017 State Water Plan, prepared by the Texas Water Development Board (2017, p. 30):

> The human population of the State of Texas is expected to increase more than 70% over the next fifty (50) years, from 2020 to 2070, from 29.5 million to 51 million. During that same time, water demands are projected to increase by 17%, from 18.4 million to 21.6 million acre-feet per year. Existing water supplies in the State of Texas is expected to decline from 15.2 million to 13.6 million acre-feet per year, representing an 11% decrease, and water user groups face a potential water shortage of 4.8 million acre-feet per year in 2020 and 8.9 million acre-feet per year in 2070, assuming drought of record conditions.

Texas is one of six states in the United States to have a mixed water law between riparian rights and prior appropriation. Only permitted surface water rights in Texas are subject to prior appropriation (Texas Water Code § 11.027). Texas permitted surface water rights are regulated using a "first-in-time, first-in-right" priority framework by the Texas Commission on Environmental Quality, the state's environmental agency (30 Texas Administrative Code 297.21). Most Texas river basins are considered to be fully appropriated through this process. However, some uses are exempt from permitting requirements (e.g., for domestic and livestock purposes; Texas Water Code § 11.142). River Authorities are quasi-governmental agencies or divisions of the State of Texas, with boards usually being appointed by the Governor. Seventeen river authorities and numerous other special law districts have been established to manage surface water resources throughout the state (TWDB 2014, p. 1).

Groundwater, on the other hand, belongs to the owners of the land above it and is governed by the "Rule of Capture" which allows landowners to withdraw water under their property. Groundwater Districts have been established in most, but not all, areas to manage groundwater (Kaiser 2002, p. 32). Ninety-eight Groundwater Conservation Districts (GCDs) have been created across Texas and can be given authority to regulate the spacing and production of water wells (TWDB 2018a, p. 1). Groundwater is important to freshwater mussels, given that spring flows and other groundwater inputs contribute substantially to base flows in many Central Texas rivers (Wolaver et al. 2014, p. 16).

Given the continental climate and influence of the Gulf of Mexico, Central Texas climate is characterized by prolonged droughts punctuated by major rainfall events leading to significant runoff and flooding. Evaporative demand is high. For example, in southern Central Texas, potential evapotranspiration (ET) can range from 75% (during relatively wet years) to 121% (during very dry years) of available rainfall on an annual basis, such that residual soil moisture from a previous year can be depleted during a subsequent dry year (USGS 2010, pp. 34-5). Central Texas is considered by many as "Flash Flood Alley" because of a combination of factors including landforms and the frequency and severity of rainfall intensities that are commonly experienced throughout the region (TWRI 2016, pp. 6-10). Notable events include: the 2015 Memorial Day storms; 1978 flooding of the Guadalupe River at Comfort, Texas associated with Hurricane Amelia; and most recently flooding associated with Hurricane Harvey in August 2017. Given the widespread scale and extent of flooding and impacts to human lives and property in Texas, the Texas Water Development Board (TWDB) is currently developing a statewide flood plan (Texas Tribune 2017, p. 2). Furthermore, drought and flood events in Texas tend to follow each other, and historically many Texas droughts have been broken by intense rainfall leading to flooding (TWRI 2016, p. 3). The most recent drought, the record-setting 2011 Texas drought, from October 2010 to September 2011 was Texas's driest 12-month period on record and has been attributed to a combination of antecedent severe rainfall deficit combined with anomalous sea surface temperatures (SSTs) associated with a La Nina event (Hoerling et al. 2013, p. 2811). Climate scientists are beginning to be able to attribute extreme events, like the 2011 Texas drought, to anthropogenic warming over the past 50 years (Rupp et al. 2012, pp. 1053-4). Widespread flooding occurred in August and September 2017, associated with Hurricane Harvey and affected the lower portions of the Brazos, Colorado, and Trinity Rivers, among others (Watson et al. 2018, entire). During the months of July and August 2018, the Clear Fork Brazos, Concho, San Saba, Llano, Pedernales, and upper Colorado and upper Guadalupe Rivers all had very low flows (USGS 2019, entire). Widespread flooding was reported in the Colorado and Guadalupe River basins of Central Texas in October 2018.

Water and Environmental Flows in Texas

The 77th Texas Legislature passed Senate Bill 2 (SB2) in 2001 and established the Texas Instream Flow Program (TIFP) to "perform scientific studies to determine flow conditions necessary to support a sound ecological environment in the rivers and streams of Texas" (TIFP-BRA 2010, p. 5). The TIFP has provided funding for multiple studies on various aspects of "how water flow affects river characteristics including aquatic life and habitat, water quality, movement of nutrients and organisms, stream channel formation, and relationships between rivers and surrounding habitat" (TWDB 2018b, p. 1). The TIFP is authorized and described by Texas Water Code § 16.059.

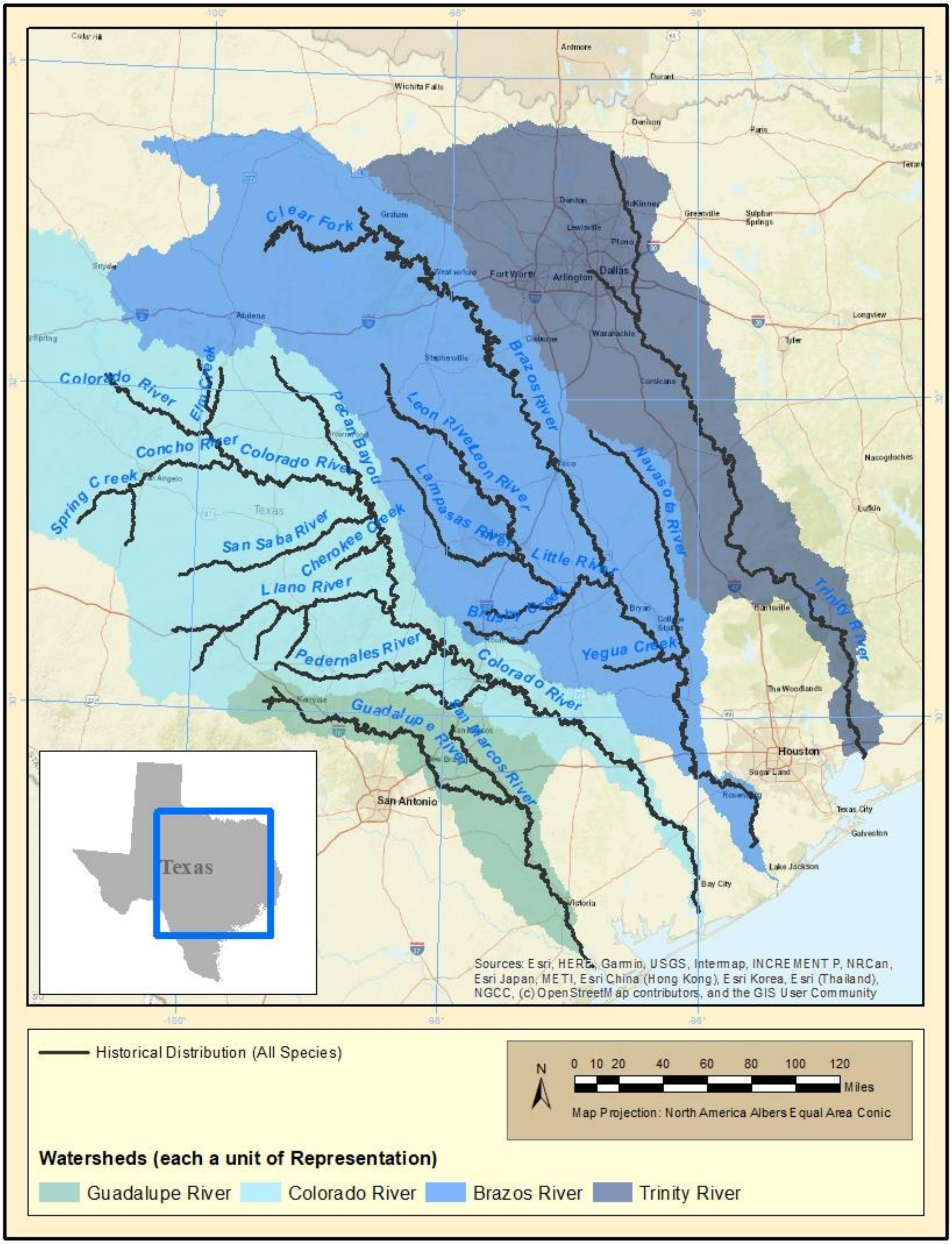
The 80th Texas Legislature passed Senate Bill 3 (SB3) in 2007 to establish a "comprehensive, statewide process to protect environmental flows"; it represents a collaboration between the TPWD, the Texas Commission on Environmental Quality (TCEQ), and the Texas Water Development Board (TWDB), and others. SB3 applies to new appropriations of water issued after 2007 in basins with adopted standards. This legislation instructed TCEQ to establish environmental flow standards for all river basins in Texas. For river basins not specifically named in SB3 (e.g., Red, Canadian, Cypress, and Sulphur Basins), SB3 directs the Environmental Flows Advisory Group (EFAG) to develop a schedule for development of environmental flow regime recommendations and the adoption of environmental flow standards. However, no deadline was given for these actions and to do date the EFAG has not developed such schedules. SB3 also allows for other groups to develop information on environmental flow needs and ways in which those needs can be met for basins for which the EFAG has not yet established environmental flow standard schedules (Loeffler 2015, entire). Environmental Flow Regime Recommendations Reports were provided to TCEQ by the Basin and Bay Expert Science Team (BBEST) for each major basin described in this report. The Hydrology-based Environmental Flow Regime (HEFR; Opdyke et al. 2014, entire) tool was developed during the SB3 process and describes flow regimes in terms of subsistence flows, base flows, pulse flows, and overbank floods and applies the Indicators of Hydrologic Assessment (IHA; TNC 2009, entire) to determine hydrologic separation and then inform an environmental flow recommendation. Environmental Flow Standards (TCEQ 2011a, entire) exist for each of the major river basins considered in this report, the Brazos (TCEQ 2011b, entire), Colorado (TCEQ 2011c, entire), Guadalupe (TCEQ 2011d, entire), and Trinity (TCEQ 2011e, entire). Each of these major river basins was found to be "healthy and sound ecological environments" and minimum flow recommendations were made in Environmental Flows Recommendations Reports, by the BBEST, for each basin.

A Water Availability Model (WAM) "simulates how much water is available under different or alternative management scenarios through a repeated period of hydrology...[and uses] historic streamflow and evaporation data to calculate the supply of available surface water" (LCRA 2014a, p. ES-6). Usually, a WAM is used to determine water availability on a dependable basis based on the Drought of Record under alternative scenarios of water use. In such cases, Firm Water rights are protected over Interruptible Stored Water (LCRA 2014a, p. ES-7). WAMs are used by TCEQ and others to evaluate water rights permit applications and by TWDB for regional water planning (LCRA 2014b, p. 12) and are described in detail by Wurbs (2012, entire).

The Texas Legislature passed the Texas Clean Rivers Act in 1991 (Texas Water Code, Section 26.0135), establishing the Clean Rivers Program (CRP). The CRP collects data on surface water quality across the State and produces Basin Summary Reports approximately every five years. The Basin Summary Reports summarize data available in the TCEQ Integrated Report and identify waterbodies that do not meet established water quality standards as "**impaired**", "not supporting", or "NS" on the 303(d) list. The Reports also identify waterbodies that are close to violating water quality standards as of "**concern** for near non-attainment of standards", or "CN" (BRA 2017, p. 25).

The Texas Water Resources Institute (TWRI) reports that 2011 was the driest year recorded in Texas, and 2015 was the wettest year on record, and May 2015 was the wettest month ever in the recorded history of Texas (TWRI 2016; p. 3). This chapter discusses Water-Year Summaries from 2011 and 2015 for selected USGS stream gages, which are available from the National Water Information System: Web Interface (NWIS; https://waterdata.usgs.gov/nwis).

This section of the report considers, by basin, river, and stream segments that, based on the best available information, are believed to be currently occupied by one or more of the Central Texas mussel species (Figure 4.1). Note that each of the seven species occupies different ecological niches and has habitat preferences and sensitivities, and thus, may occupy different portions of the river and stream segments described below.



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

Figure 4.1. Map of the Brazos, Colorado, Guadalupe, and Trinity River Basins of Central Texas.

4.B Brazos River and Basin

The Brazos River originates in the Texas High Plains and terminates directly into the Gulf of Mexico near Freeport, Texas (Sansom 2008, pp. 50, 91). The total length of the Brazos River is 840 miles (TWDB 2018b, p.1). Important tributaries include the Bosque, Leon, Little, and Navasota Rivers, and Yegua Creek. Major cities along the Brazos River include Waco and Bryan-College Station.

The Brazos River Authority (BRA) was created by the Texas Legislature in 1929 to develop, manage and protect the surface water resources of the Brazos River basin (BRA 2018a, p. 1). The first major dam, which created the Possum Kingdom reservoir, was constructed in the upper watershed in 1941 (TIFP-BRA 2010, p. 5). There are now 27 major reservoirs in the Brazos River basin [16 have > 50,000 acre-feet of storage, (BBEST 2012, p. 33], three of which are owned and operated by the BRA: Possum Kingdom (on the Brazos), Granbury (completed on the Brazos in 1969), and Limestone (completed on the Navasota in 1978). The U.S. Army Corps of Engineers (USACE) operates dams on Lake Whitney (hydropower) on the Brazos River, Lakes Proctor and Belton on the Leon River, Stillhouse Hollow on the Lampasas River, Lakes Georgetown and Granger on the San Gabriel River, Lake Somerville on Yegua Creek, and Aquilla on Aquilla Creek (BRA 2014, pp. 4-5). The Allens Creek Reservoir is proposed for construction on Allens Creek near the City of Wallis, to provide water supply and storage for the City of Houston (BRA 2018, p. 1). Water planned to be pumped from the Brazos River during high flows will be stored and released back into the river to meet downstream needs during periods of low flow.

The BRA “Systems Operation Permit” allows BRA to “use the bed and banks of the Brazos River and its tributaries to deliver stored water [from BRA reservoirs] to downstream customers.” The BRA Water Management Plan and System Operations Permit prohibit diversions and water storage when “instantaneous flow values at the reach measurement point are below the applicable base and subsistence flow conditions” (BRA 2014, p. 29). The BRA manages firm supplies, which are considered to be “the reliable supply of water available from the BRA system given existing or expected authorizations” as well as non-firm, or interruptible, supply that becomes available when “special conditions of the System Operation Permit are met” (BRA 2014, pp. 52-3). The BRA Systems Operations Permit and (Conformed) Water Management Plan received final approval by TCEQ in 2018 (BRA 2018f, entire). According to the most recent water plan for the Brazos G area, “system operation of the BRA reservoirs can increase supplies in the Brazos G Area by nearly 167,000-acre feet per year (assuming interruptible supplies can be firmed up through conjunctive operation with other sources), with additional supplies available to the Region H Area in the lower basin. This strategy would more efficiently utilize the existing resources of the BRA by expanding the supply that can be developed from the BRA’s existing reservoirs, thus delaying the need for new reservoirs to meet growing needs in the basin” (TWDB 2015, p. ES-18).

Further, the most recent water plan for the Brazos G area reports that “many locations exhibit larger flows with the implementation of the 2016 Plan than with the base condition. This is due primarily to releases being made from upstream BRA reservoirs as part of the BRA System Operations to the diversions modeled at various locations along the main stem of the Brazos River. The Brazos River near South Bend [in the Upper Brazos] is the only location that shows there are more months where the median streamflow would decrease between the base and the plan conditions than where it would stay the same or increase. These reductions are the result of the implementation of the Cedar Ridge and Lake Creek Reservoirs. The increases in median flow, especially at the Brazos River near Glen Rose, are the results of BRA System Operations releases from Possum Kingdom Reservoir and Lake Granbury. For the South Bend location, the largest decrease occurs in June at 22%. Even with this modest difference in median streamflow, the frequency plots show that the overall change to the flow regime is minor.” (TWDB 2015, pp. 6-8, 6-9).

There are no major dams on the Brazos River below Waco. Lake Whitney (2,000,000 acre-feet, completed in 1951) is the most downriver on-channel reservoir on the Brazos, and in the Lower Brazos flows become more influenced by seasonal precipitation patterns in the basin. Known mussel populations have been identified in this approximately 300-mile lower section of the Brazos River, generally downstream of the City of Waco to near Brazoria, Texas.

Freeport, Texas, is the site of the Dow Chemical plant, which came into operation in 1941 to extract magnesium from seawater to support the World War II effort (Dow Texas Operations 2018, entire). Dow Chemical is the largest water user on the Brazos and holds water rights going back to 1929 (Sansom 2008, pp. 91-3). The Gulf Coast Water Authority "provides water for industry, agriculture, and municipalities in Brazoria, Fort Bend, and Galveston" counties, Texas (GCWA 2018, p.1). The GCWA holds water rights on the Brazos River since 1926, and this water is used to irrigate approximately 18,000-acres of seed rice, to provide municipal water to the cities of Sugar Land, Pearland, and Missouri City, and to deliver water for industry in Texas City, Texas (GCWA 2018, p.1). The GCWA also operates a wastewater treatment plant in Texas City (GCWA, 2018, p.1).

The Brazos Basin provides an important surface water supply for the Region G (57% of existing water supply) and Region H (19% of existing water supply) Regional Water Planning Regions of Texas (TWDB 2016, pp. G-4, H-4). Region G includes the major cities of Abilene, Bryan, College Station, Killeen, Round Rock, Temple, and Waco. Region H includes the Houston metropolitan area.

Dow Chemical Company has one of the oldest water rights in the Brazos, established in 1942. Near the end of the 2011-12 drought [which likely represented a new "drought of record"], the Dow Chemical Company made a "**priority call**" to TCEQ, which then suspended withdrawals by junior rights on the Brazos. When TCEQ suspended these junior rights, certain municipal water and hydropower rights were "**excepted**" under the "Drought Rules" (30 Texas Administrative Code 36.3). Of the 845 suspended water rights, 716 were for irrigation of agricultural products (AgriLife 2015, p. 1). Texas Farm Bureau challenged the Drought Rules and filed suit on behalf of several irrigators, arguing that TCEQ violated the Texas Water Code by suspending some of the junior rights, but not others. The court sided against TCEQ, declaring the Drought Rules invalid, and the ruling stood upon appeal (TCEQ v. Texas Farm Bureau, 2015, pp. 14-15). Thus, the doctrine of prior appropriation, "first in time, first in right" was upheld and can be expected to continue to do so in the future, such that senior water rights, often near the coast, are upheld over more junior rights during drought conditions. In this case, the more junior rights are located upstream from the senior rights. During the 2011 drought, the "frequent and prolonged low flow and high salinity conditions" in the Brazos River impacted Dow's Freeport operations and some portions of the river are reported to have run dry (Reddy et al. 2015, p. 96). While flows in the lower Brazos were low at times, upstream reservoir releases were made to provide for downstream senior water rights and contract holders and these releases served to supplement base flows and improve streamflow conditions during the 2011 drought (BRA 2018e, p. 3).

A **watermaster** was established for the Brazos River (Possum Kingdom Lake and below) by TCEQ in 2014 and has responsibilities which include: allocating water by right, monitoring stream flows and water use, and responding to complaints and enforcing compliance, and "when streamflows diminish, the watermaster will allocate available water among the water right holders according to each user's priority date" (TCEQ 2018a, p. 1).

This report considers four river sections in the Brazos Basin known to support populations of one or more species of Central Texas mussels.

4.B.1 Lower Clear Fork Of The Brazos River

This segment of the Clear Fork of the Brazos River is generally in Throckmorton, Shackelford, Stephens and Young Counties, Texas, and includes portions of TCEQ-classified segments 1207 (Possum Kingdom Lake),1208 (Brazos River above Possum Kingdom Lake), and 1232 (Clear Fork Brazos River). Segment 1208 has impairment for bacteria, and has a concern for chlorophyll (BRA 2017, p. 32). Segment 1232 has impairment for bacteria, and concerns for pH, nitrate, total phosphorus, and chlorophyll a (BRA 2017, p. 41). USGS gage 08084200 (Clear Fork Brazos River at Lueders, TX) reported a low daily mean discharge of 0 cubic feet per second (cfs) in 2011, and a high daily mean discharge approaching 4,000 cfs in 2015 (USGS 2018a, pp. 21, 33), the driest and wettest years on record in Texas, respectively (TWRI 2016, p. 3). A low daily mean discharge of 0.920 cfs was reported on September 2, 2018, and a high daily mean discharge of 816.0 cfs was reported on September 9, 2018 (USGS 2019, p. 20).

As recommended by the 2016 Brazos G Regional Water Plan (TWDB 2016, p. G5), the City of Abilene is "actively pursuing the necessary permits and engineering required" to build the Cedar Ridge Reservoir in Shackelford County on the Clear Fork of the Brazos, which would inundate up to 8,786 acres of land north of Abilene, Texas (HDR 2016, p. 1). The U.S. Army Corps of Engineers is preparing an Environmental Impact Statement in support of this water supply project (USACE 2018, entire).

4.B.2 Upper Brazos River

This segment of the Upper Brazos River is generally from Possum Kingdom Reservoir downstream to Lake Granbury and includes TCEQ segment 1206 (Brazos River below Possum Kingdom Lake), and USGS gage 08089000 near Palo Pinto, Texas. Segment 1206 has no identified impairments (BRA 2017, p. 49). However, concerns do exist for "near non-attainment of macrobenthic communities and impaired habitat from degradation of riparian areas" possibly to due to "changes in historical flow regime and from quarry operations near the river," and an increasing trend in chloride likely due to low flow conditions and discharges (BRA 2017, p. 54). USGS gage 08089000 (Brazos River near Palo Pinto, TX) reported a low daily mean discharge below 50 cubic feet per second (cfs) in 2011, and a high daily mean discharge above 30,000 cfs in 2015 (USGS 2018a, pp. 36, 41), the driest and wettest years on record in Texas, respectively (TWRI 2016, p. 3). A low daily mean discharge of 43.5 cfs was reported on May 19, 2018, and a high daily mean discharge of 9,670 cfs was reported on September 26, 2018 (USGS 2019, p. 26).

This segment is reported to have a fish assemblage of low biotic integrity because of apparent dominance by habitat generalists and notable declines in abundance of fluvial specialists associated with flow alterations (BBEST 2012, pp. 1-4, 4-7, referred to as the Middle Brazos River). However, BRA staff biologists conduct periodic fish community sampling throughout the Upper Brazos River Basin and report finding freshwater drum (a presumed host fish for Texas fawnsfoot) from between Lakes Possum Kingdom and Granbury (BRA 2018e, p.1). This sampling is performed in accordance with protocols developed by TCEQ and TPWD for the purpose of evaluating EPA aquatic life use, and by this metric the fish assemblages rank out as having "high to exceptional" biotic integrity (BRA 2018e, p. 3). Flows at the USGS gage 08089000 were low (below 100 cubic feet per second (cfs) but above 40 cfs) from November 2009 to January 2010 (USGS 2018b, p. 1). Flows in this segment are dominated by releases from the Morris Sheppard Dam which was completed on the Brazos River in 1941 (Dowell 1964, p. 5), with a hydroelectric generating facility that is no longer in use (BRA 2018d, p.1).

This segment was designated as the John Graves Scenic Riverway by the 79th Texas Legislature (SB 1354) in 2005. This designation provides some protections by TCEQ that regulate rock, sand, and gravel mining (TCEQ 2012, pp. 2, 4).

4.B.3 Little River

This occupied segment of the Little River is generally between Holland and Buckholts in Bell and Milam Counties, Texas, and includes portions of TCEQ-classified segment 1213 (Little River). Segment 1213 has impairment for bacteria, and concerns for nitrate and chlorophyll a (BRA 2017, p. 116). The San Gabriel River (segment 1214) has impairments for chloride and sulfate, and concerns for bacteria, nitrate, and phosphorus (BRA 2017, p. 116). Brushy Creek (segment 1244) has impairment for bacteria, and concerns for nitrate and phosphorus and flows in Brushy Creek are "effluent dominant" (BRA 2017, pp. 116, 119). USGS gage 08104500 (Little River near Little River, TX) reported a low daily mean discharge below 100 cubic feet per second (cfs) in 2011, and a high daily mean discharge above 9,000 cfs in 2015 (USGS 2018a, pp. 56, 62), the driest and wettest years on record in Texas, respectively (TWRI 2016, p. 3). A low daily mean discharge of 15.2 cfs was reported on July 27, 2018, and a high daily mean discharge of 1,130 cfs was reported on September 22, 2018 (USGS 2019, p. 38).

USGS gauge 08106500 (Little River at Cameron, TX) reported a low daily mean discharge below 100 cubic feet per second (cfs) in 2011, and a high daily mean discharge above 40,000 cfs in 2015 (USGS 2018a, pp. 65, 71), the driest and wettest years on record in Texas, respectively (TWRI 2016, p. 3). A low daily mean discharge of 25.3 cfs was reported on September 5, 2018, and a high daily mean discharge of 15,300 cfs was reported on March 29, 2018 (USGS 2019, p. 45).

The Little River is 75 miles long from the confluence of the Leon and Lampasas Rivers in Bell County to the Brazos River in Milam County, Texas (Handbook of Texas online 2018b, p. 1). The San Gabriel River is an important tributary, upon which Granger Lake was completed in 1972, and has been impounded since 1980 (HDR 2016b, p.1).

The Little River watershed has 37 permitted discharges (BRA 2017, p. 112). Brushy Creek Regional Wastewater Treatment Plant is operated by the cities of Round Rock, Cedar Park, and Austin, Texas, and discharges into Brushy Creek in Round Rock. Note that the source of this wastewater is from Lake Travis (Colorado River).

The Little River Off-Channel Reservoir (OCR) is proposed as a 4,343-acre impoundment on Pin Oak Creek, a tributary to the Little River, near Cameron in Milam County, Texas. This project contemplates an intake structure for diverting water from either the Little River, or from the main stem of the Brazos River (HDR 2016c, p. 1), and modeled streamflow reductions are reported to be "minimal" to downstream rights (HDR 2016c, p. 2) but negative impacts are likely at the proposed reservoir site and immediately downstream associated with the construction and operation of the project (HDR 2016c, p. 11). Note that the proposed reservoir is not located at a site currently known to support Central Texas mussels, and downstream impacts in the Little River or Brazos River are considered minimal, and if permitted, the Little River OCR would likely be subject to environmental flow requirements (HDR 2016c, p. 10).

Brazos River Authority staff conduct periodic fish community sampling throughout the Little River Basin and report finding a number of species of appropriate host fish for Balcones spike and Texas fawnsfoot, including members of Cyprinidae (minnows: central stoneroller, red shiner, blacktail shiner, ribbon shiner, silverband shiner, mimic shiner, shoal chub, bullhead minnow) and freshwater drum from the Lower San Gabriel and Little rivers (BRA 2018e, p.1).

4.B.4 Middle/Lower Brazos River

This segment of the Brazos River is generally downstream of the confluence with Yegua Creek in Burleson County, Texas, and Rosharon in Fort Bend County, Texas, and includes portions of TCEQ-classified segments 1242 (Brazos River above Navasota River), 1202 (Brazos River below Navasota River), and 1245 (Upper Oyster Creek). Segment 1242 has no impairment, but concern for chlorophyll a; however, several of its tributaries have impairments for bacteria (BRA 2017, p. 128). Segment 1209 (Navasota River below Lake Limestone) has impairment for bacteria, and concerns for dissolved oxygen, nitrate, and phosphorus, and several of its tributaries have impairments for bacteria (BRA 2017, p. 135). Segment 1202 has concerns for chlorophyll a, and several of its tributaries have impairments for bacteria (BRA 2017, p. 154).

USGS gage 08108700 (Brazos River near Bryan, TX) reported a low daily mean discharge near 500 cubic feet per second (cfs) in 2011, and a high daily mean discharge approaching 80,000 cfs in 2015 (USGS 2018a, pp. 74, 83), the driest and wettest years on record in Texas, respectively (TWRI 2016, p. 3). A low daily mean discharge of 211.0 cfs was reported on July 4, 2018, and a high daily mean discharge of 22,900 cfs was reported on March 30, 2018 (USGS 2019, p. 51).

USGS gage 08111500 (Brazos River near Hempstead, TX) reported a low daily mean discharge near 500 cubic feet per second (cfs) in 2011, and a high daily mean discharge approaching 90,000 cfs in 2015 (USGS 2018a, pp. 86, 92), the driest and wettest years on record in Texas, respectively (TWRI 2016, p. 3). A low daily mean discharge of 439.0 cfs was reported on June 30, 2018, and a high daily mean discharge of 38,600 cfs was reported on March 30, 2018 (USGS 2019, p. 57).

USGS gage 08114000 (Brazos River at Richmond, TX) reported a low daily mean discharge near 200 cubic feet per second (cfs) in 2011, and a high daily mean discharge approaching 70,000 cfs in 2015 (USGS 2018a, pp. 95, 101), the driest and wettest years on record in Texas, respectively (TWRI 2016, p. 3). A low daily mean discharge of 574.0 cfs was reported on August 31, 2018, and a high daily mean discharge of 41,200 cfs was reported on April 1, 2018 (USGS 2019, p. 63).

USGS gage 08116650 (Brazos River near Rosharon, TX) reported a low daily mean discharge near 100 cubic feet per second (cfs) in 2011, and a high daily mean discharge approaching 70,000 cfs in 2015 (USGS 2018a, pp. 104, 129), the driest and wettest years on record in Texas, respectively (TWRI 2016, p. 3). A low daily mean discharge of 344.0 cfs was reported on July 3, 2018, and a high daily mean discharge of 38,700 cfs was reported on March 30, 2018 (USGS 2019, p. 69).

Construction of Lake Somerville on Yegua Creek began in 1962 (Dowell 1964, p.8). Construction of Lake Limestone, a water supply reservoir on the Navasota River was completed in 1978 (BRA 2018c, p.1).

The proposed new Allens Creek Reservoir is proposed to divert (pump) water from the Brazos River for storage and later use. Allens Creek itself was found not to have any Texas fawnsfoot, but a section of the Brazos River known as the 4-mile loop, and below, was found to have a "diverse and abundant mussel fauna" including Texas fawnsfoot (Randklev et al. 2014, pp.10-11). The 4-mile loop is located immediately downstream of the confluence with Allens Creek (BRA 2018b, p.1), is in close proximity to the proposed reservoir construction site on Allens Creek (TPWD 1994, p.3), such that downstream effects to Texas fawnsfoot and their habitat are likely during and after reservoir construction. While the Allens Creek Reservoir has been proposed to the State Water Plan, permitting, planning, and construction have not been initiated to date (BRA 2018, p. 4). The water rights for the Allens Creek Reservoir are reported to contain special conditions such that diversions and reservoir releases would be managed in such a way that downstream habitats would not be harmed (BRA 2018, p. 4).

The TIFP and the BRA described the “Middle and Lower Brazos Basin” as including the Brazos downstream of Lake Brazos in Waco, and the Navasota, Leon, and Little Rivers, and Yegua Creek (TIFP-BRA 2010, pp. 6-7). Historically, the Lower Brazos basin was an extensive floodplain forest system with a complex diversity of interconnected oxbows, wetlands, and other habitats, and today is mostly hydrologically intact and represents one of North America’s largest relatively intact floodplain systems (TIFP-BRA 2010, p. 5), despite the fact that much of the current and recent past land use is agricultural, for row-crops and livestock grazing, and much of the floodplain riparian vegetation has been cleared to near the banks, to the detriment of water quality and aquatic habitats in the basin (TIFP-BRA 2010, p.31). Water quality is reported to be improving, but nutrients remain a concern, due to a variety of sources including wastewater outfalls and runoff (TIFP-BRA, 2010 p. 32). Observations of channel incision at the Brazos River at Seymour (in the upper basin, USGS gage 08082500, Baylor County) and Richmond (in the lower basin, USGS gage 0811400, Fort Bend County) suggest that “the rate of channel migration has slowed substantially in the lower Brazos, indicate that the Brazos River has been undergoing long-term adjustments in response to multiple changes in the river basin that have occurred since the early 1990s and has not yet reached a state of dynamic equilibrium” (BBEST 2012, pp. 7-13). Channel alterations associated with altered hydrology can degrade benthic aquatic habitats. Brazos River Authority staff conduct periodic fish community sampling throughout the Middle and Lower Brazos River Basin and report finding freshwater drum (a presumed host fish for Texas fawnsfoot) from the Middle Brazos and the Lower Navasota rivers (BRA 2018e, pp. 1-2).

4.C Colorado River and Basin

The Colorado River originates in the Texas High Plains, is the longest river with a drainage basin within the State of Texas, and flows into Matagorda Bay (Sansom 2008, pp. 50, 94). The total length of the Colorado River is 865 miles (TWDB 2018d, p. 1). Ninety percent (90%) of the Colorado Basin drainage is above the City of Austin (Sansom 2008, p. 93) and flows through the Highland Lakes (see discussion below). Important tributaries to the Colorado include the Concho, San Saba, Llano, and Pedernales Rivers, which are sometimes called the “Hill Country Rivers.”

O.H. Ivie Reservoir, on the “Upper” Colorado River, just below the confluence with the Concho River, was completed in 1990 and is owned and operated by the Colorado River Municipal Water District (CRMWD) for water supply and recreational purposes (TWDB 2018, p. 1). CRMWD also operates the J.B. Thomas and E.V. Spence Reservoirs on the Colorado River above O.H. Ivie (CRMWD 2018, p. 1), and participates in Region F Water Planning.

The Colorado Basin provides an important surface water supply for the Region K (Lower Colorado; 71% of existing supply) Regional Water Planning Region of Texas and also provides 8% of the existing water supply for Region F (TWDB 2016, pp. F-4, K-4.) Region K includes the major cities of Austin, Bay City, Pflugerville, and Fredericksburg, Texas.

The Upper Colorado River Authority (UCRA) was created in 1935 to “protect the watershed of Tom Green, Coke, and other contiguous counties” (UCRA 2018, p. 1). The UCRA has been involved in several water quality enhancement projects throughout their service area in Coke, Concho, Crockett, Glasscock, Irion, Menard, Mitchell, Nolan, Reagan, Runnels, Schleicher, Sterling, Taylor, and Tom Green counties (UCRA 2018, p.1).

The Lower Colorado River Authority (LCRA) manages the Lower Colorado River and was created by the Texas Legislature in 1934 for the purposes of flood control, water supply, and rural electrification (LCRA

2018a, pp. 1-2). A series of six “Highland Lake Dams” were built on the lower Colorado River in Central Texas between 1890 and 1942, including the Buchanan Dam on Lake Buchanan, Inks Dam on Inks Lake, Wirtz Dam on Lake LBJ, Starcke Dam on Lake Marble Falls, Mansfield Dam on Lake Travis, and the Tom Miller Dam on Lake Austin. This series of dams are operated by the LCRA to provide hydroelectricity, flood management, and water supply to over 1 million residents of the Austin metropolitan area, and for industrial and agricultural purposes in the lower Colorado River basin (LCRA 2018b, p.1). Special conditions have been incorporated into the water rights permits of the LCRA-managed Highland Lakes such that instream flows and freshwater inputs are maintained in the Lower Colorado River and to the Matagorda Bay estuary system (Loeffler 2015, p.3).

LCRA manages Lake Buchanan and Lake Travis (the only two of the Highland Lakes with storage) according to a Water Management Plan (WMP) that is subject to review and approval by TCEQ to deliver both “firm” and “interruptible” water demands as well as environmental flow needs for the Lower Colorado River (LCRA 2015, p. ES-1). LCRA provides water for agricultural irrigation in the lower basin through its irrigation operations at Garwood, Lakeside, Gulf Coast, and Pierce Ranch (LCRA 2015, p. ES-6), primarily for rice farming and represents, on average, 70% of LCRA’s total annual water use (LCRA 2015, p. 2-4). Irrigation operations were curtailed due to drought conditions in 2012 and 2013 (LCRA 2015, p. 2-5) and in 2014 and 2015. **Firm water** can be delivered during “worst case” drought conditions (referenced to the Drought of Record) and represents senior downstream water rights (LCRA 2015, p. ES-4). **Interruptible stored water** is stored in Lakes Buchanan and Travis and can be “cut off” or “curtailed” during droughts or other shortages and is used almost entirely to support agricultural irrigation operations, but also supports environmental flow needs in the lower basin (LCRA 2015, p. ES-4). LCRA can release stored water from Buchanan and Travis Reservoirs to supplement “run-of-river” water supplies to help meet additional agricultural irrigation demands during drought conditions, and to support environmental flows in the lower basin (LCRA 2015, p. ES-7). The LCRA WMP establishes a minimum combined storage for Buchanan and Travis at 600,000 acre-feet as a trigger point for protecting firm water rights during a “Drought Worse than Drought of Record” (LCRA 2015, p. ES-7) and commits 33,440 acre-feet per year of firm water for environmental flow purposes (LCRA 2015, p ES-8). LCRA also provides firm water as back up to maintain the cooling reservoir for the South Texas Project Nuclear Operating Company (STPNOC; LCRA 2015, p. 1-7; LCRA 2014b, p. 47) and to the City of Austin Water Utility and other municipalities (LCRA 2015, p. 2-3). Environmental flows are informed by a 2008 instream flow study that investigated aquatic habitats and subsistence flow recommendations designed to support February-March spawning of the state-threatened blue sucker near Columbus (*Cycleptus elongatus*; LCRA 2015, p. 2-6). LCRA generates hydropower at each of the Highland Lake dams, but only when water is released for other purposes, and those releases are planned to maximize generation potential (LCRA 2015, p. 2-9). Thus, LCRA has some capacity to implement management actions to ameliorate the effects of droughts on flows in the lower sections of the Colorado River.

There are no major dams on the Colorado River below Austin, save a saltwater barrier weir dam at Bay City. A reservoir is under construction at Garwood that is intended as a “scalping” reservoir to supply irrigation needs downriver during drought. There are a total of 31 major reservoirs in the Colorado River basin, including the Highland Lakes (TWDB 2018d, p. 1). LCRA is constructing new off-channel reservoirs in lower sections of the Colorado River including the Arbuckle Reservoir at Lane City in Wharton County, and the Prairie Conservation Reservoir near Eagle Lake in Colorado County (LCRA 2018c, p. 1). These new dams and construction projects are not expected to adversely affect flows or water levels downstream once constructed, provided they are managed to “scalp” water during high flow events and store it for later use during drought. However, the construction of these dams, and operation of pumps to fill the reservoirs, could disturb the substrate if mussel habitats are present near the impoundments and intake facilities.

According to the LCRA WMP, the primary water quality threats in the Highland Lakes and Lower

Colorado River are nonpoint source pollution (pollutants and contaminants from stormwater runoff), point source pollution (discharges from industry and wastewater treatment plants), soil erosion, reservoir sedimentation, and reduced dissolved oxygen (LCRA 2015, p. 1-6). To address these concerns, LCRA is an active participant in the Colorado River Watch Network and the Texas Clean Rivers Program (LCRA 2015, p.1-6). The City of Austin and each of the other river authorities mentioned in this report similarly participates in the Texas Clean Rivers program. Drought has been reported to be "a major cause of water quality and quantity problems" over the past 5 years (LCRA 2017, p. 114).

This report considers eight river segments in the Colorado Basin known to support populations of one or more species of Central Texas Mussels.

4.C.1 Lower Elm Creek

This segment of Elm Creek is generally near Ballinger, in Runnels County, Texas, and is not included in a TCEQ-classified segment but drains to 1426 (Colorado River below E.V. Spence Reservoir). Segment 1426 has impairments for salts, and concerns for bacteria and chlorophyll (LCRA 2017, p. 24). This small watershed is dominated by agricultural land uses and is relatively small and otherwise intact. In Elm Creek at Ballinger (USGS gage 08127000), annual average daily flows range from <10 to >120 cfs between 1983 and 2008 (BBEST 2011, p. 2-36). USGS gage 08127000 (Elm Creek at Ballinger, TX) reported a low daily mean discharge of 0 cubic feet per second (cfs) in 2011, and a high daily mean discharge above 2,000 cfs in 2015 (USGS 2018a, pp. 132, 149), the driest and wettest years on record in Texas, respectively (TWRI 2016, p. 3). A low daily mean of 0 cfs was reported for much of water year 2018, and a high daily mean charge of 186.0 cfs was reported on August 14, 2019 (USGS 2019, p. 75). Elm Creek at Ballinger is reported to have a number of small springs and seeps and that "much of the creek is reservoir-like with short riffles over bedrock downstream of the dams at low flows" (BBEST 2011, p. 2-38).

4.C.2 Lower Concho River

This segment of the Concho River is generally near Paint Rock, in Concho County, Texas, and includes portions of TCEQ-classified segment 1421 (Concho River) and 1433 (O.H. Ivie Reservoir). Segment 1433 has concern for nutrients (LCRA 2017, p. 30). Segment 1421 has impairments for dissolved oxygen and bacteria, and concerns for nutrients and chlorophyll (LCRA 2017, p. 34). USGS gage 08136500 (Concho River at Paint Rock, TX) reported a low daily mean discharge of 0 cubic feet per second (cfs) in 2011, and a high daily mean discharge approaching 5,000 cfs in 2015 (USGS 2018a, pp. 152, 169), the driest and wettest years on record in Texas, respectively (TWRI 2016, p. 3). A low daily mean discharge of 0.010 cfs was reported on June 28, 2018, and a high daily mean discharge of 961.0 cfs was reported on September 22, 2018 (USGS 2019, p. 81).

This segment is downstream from three impoundments, Lake Nasworthy, O.C. Fisher Lake, and Twin Buttes Reservoir. These three reservoirs provide a public water supply for the area and regulate both low and high streamflow. The construction of these dams, together with persistent drought and a lack of water available for controlled releases, has resulted in reduced flood peaks and a "downward" trend in stream discharge (USGS 2012, pp.6-8, Figure 6, pp.13-15). The confluence of the Concho and Colorado rivers is now inundated by O.H. Ivie Reservoir (BBEST 2011, p. 2-46). The Concho River at Paint Rock (USGS gage 08136500) has experienced substantial declines in annual average daily flows since 1931 (BBEST 2011, p. 2-47) and 8% of days from 1916 to 2010 exhibited no flow (BBEST 2011, p. 2-55). The Concho River at Paint Rock has naturally occurring elevated nitrate and chloride levels (BBEST 2011, p. 2-54).

A **watermaster** was established for the Concho River by TCEQ in 2005 and has responsibilities which include: allocating water by right, monitoring stream flows and water use, responding to complaints and enforcing compliance, and “when streamflows diminish, the watermaster will allocate available water among the water right holders according to each user’s priority date” (TCEQ 2018b, p.1).

4.C.3 Upper/Middle San Saba River

This segment of the San Saba River is generally in Menard, Mason, and McCulloch counties, Texas, and includes portions of TCEQ-classified segment 1416 (San Saba River). Segment 1416 has impairment for bacteria (LCRA 2017, p. 66). Most of the flows in the Upper San Saba River (in Menard County, Texas) are from Edwards Formation springs, where it may be considered a “gaining stream” except for, and due to, a change in the underlying geology, a “losing reach” near the Menard/Mason County line (LBG-Guyton 2002, p.3, Figure 1). As such, the “upper” (above Menard) and “middle” (below Menard) reaches of the San Saba River in Menard County are considered separately from the “lower” (in McCulloch County) reaches of the San Saba River, of which flows are mostly contributed by Brady Creek, as well as by local precipitation. It is in this “losing reach” where drought effects are especially noticeable, as some flows may percolate downward. The Menard County Underground Water District is the primary groundwater district in Menard County and has some authority for regulating groundwater withdrawals (MCUWD 2012, p. 1). The Menard Irrigation Company maintains approximately 9.7 miles of open ditch canal (the Noyes Canal, Menard Irrigation Canal; USGS 1953, p. 1), that bypasses the San Saba River, approx. 5 miles west and approx. 5 miles east of Menard, Texas. The canal was completed in 1876 and has been operated by the Menard Irrigation Company since 1905. Much of the “middle” San Saba River below Menard is reported to have gone “dry for 10 of the last 16 years” by landowners downstream of Menard (Carollo 2015, p. 2). Regardless of the cause, low flows in the San Saba River have resulted in significant stream drying and stranded Central Texas mussels have been identified following dewatering as recently as 2015 near and below the “losing reach” (TPWD 2015, p. 3). During the 2011-13 drought, streamflows in the San Saba River were critically low, and well below the 33rd percentile of 14 cfs (to as low as 3 cfs at Menard USGS gage 08144500) and 23 cfs (at Brady LCRA hydromet site 1563), such that several water rights in Schleicher, Menard, and McCulloch counties were suspended to provide for the riparian rights of downstream livestock raisers (TCEQ 2013b, entire).

4.C.4 Lower San Saba River (and Middle Colorado River)

This segment of the San Saba River is generally between the confluence with Brady Creek and the confluence with the Colorado River in San Saba, County, Texas and includes portions of TCEQ-classified segment 1416 (San Saba River). The San Saba River is hydraulically/hydrologically connected to the Colorado River, as there is no major dam at the confluence of the two rivers. Thus, this segment also includes the Colorado River between Pecan Bayou and Lake Buchanan in San Saba, Mills, and Lampasas Counties, Texas, and includes portions of TCEQ-classified segment 1409 (Colorado River above Lake Buchanan) and 1410 (Colorado River below O.H. Ivie Reservoir).

Some of the flow in the Lower San Saba River is derived from Brady Creek, which receives wastewater inputs from the City of Brady, Texas. Brady Creek has impairment for bacteria and concerns for nutrients and chlorophyll (LCRA 2017, p. 68). The 1 million gallon per day (MGD) wastewater treatment plant was constructed in 1963 and is expected to be replaced with a 0.99 MGD, due to obsolescence (TWDB 2015, p. 6; City of Brady 2017, pp. ii-iii).

The Lower San Saba River (San Saba River at San Saba, USGS gage 08146000) is reported to flow 99.6% of the time, with groundwater contributing most of the streamflow (Wolaver et al. 2014, p. 9). In the San Saba River at San Saba, the Edward-Trinity Aquifer is the source of springs and baseflow and annual average daily flows range from <100 to >400 cfs (BBEST 2011, p. 2-79). During the drought of 2011-2013, essentially all of the water in the Lower Colorado River and entering the Highland Lakes was from the San Saba River - highlighting the importance of these spring inputs. USGS gage 08146000 (San Saba River at San Saba, TX) reported a low daily mean discharge between 5-10 cubic feet per second (cfs) in 2011, and a high daily mean discharge above 2,000 cfs in 2015 (USGS 2018a, pp. 175, 180), the driest and wettest years on record in Texas, respectively (TWRI 2016, p. 3). A low daily mean discharge of 2.82 cfs was reported on August 2, 2018, and a high daily mean discharge of 5,250 cfs was reported on September 10, 2018 (USGS 2019, p. 87).

In the Colorado River near San Saba (USGS gage 08147000), annual average daily flows have declined from 1923 to 1990 (BBEST 2011, p. 2-25). For this control point, it has been determined that the existing channel currently appears to be stable, but reductions in the magnitude and frequency of flows could result in major instability in the future, leading to channel incision and bank collapses (BBEST 2011, p. 3-128). The USGS gage 08147000 (Colorado River near San Saba, TX) reported a low daily mean discharge below 1 cubic foot per second (cfs) in 2011, and a high daily mean discharge above 20,000 cfs in 2015 (USGS 2018a, pp. 183, 189), the driest and wettest years on record in Texas, respectively (TWRI 2016, p. 3). A low daily mean discharge of 2.12 cfs was reported on August 7, 2018, and a high daily mean discharge of 5,130 cfs was reported on September 10, 2018 (USGS 2019, p. 93).

4.C.5 Llano River

This segment of the Llano River includes the South Llano River, and is generally in Kimble, Mason, and Llano Counties, Texas, and includes portions of TCEQ-classified segment 1415 (Llano River). No water quality standard impairments or concerns are reported for this segment, but an increasing trend for bacteria towards level that warrant concern has been observed (LCRA 2017, pp. 76-77). It is reported that "the Llano River watershed remains largely rural…(and) there are fewer irrigated field compared to surrounding watersheds" (LCRA 2017, p. 76). The Llano River is largely spring fed (BBEST 2011, p. 2-88). The USGS gage 08151500 (Llano River at Llano, TX) reported a low daily mean discharge below 3 cubic feet per second (cfs) in 2011, and a high daily mean discharge above 25,000 cfs in 2015 (USGS 2018a, pp. 192, 198), the driest and wettest years on record in Texas, respectively (TWRI 2016, p. 3). A low daily mean discharge of 0.060 cfs was reported on August 8, 2018, and a high daily mean discharge of 7,820 cfs was reported on September 23, 2018 (USGS 2019, p. 99).

Some conservation is underway in the Llano River Basin, including efforts of the Llano River Watershed Alliance, the Upper Llano River Watershed Protection Plan, and voluntary habitat restoration on private lands coordinated through the Landowner Incentive Program and similar efforts by state and federal biologists, and non-governmental organizations (NGO) (Broad et al. 2016, pp. 53-70). It has been reported that "stakeholders identified loss of spring flow, spread of invasive species and potential for declines in water quality and stream flows as their primary concerns" (LCRA 2017, p. 77).

Segments of the North Llano River, near Junction, experienced very low flows during drought conditions from May to October 2011 (USGS 2013, p.18), and daily mean stream flows in the Llano River, near Junction, were below 10 cfs in July-August 2011 (USGS 2013, p.19). In the Llano River at Llano (just below the Llano City Lake, USGS gage 08151500), annual daily average flows ranged from <100 to >1000 cfs from 1940 to 2010 (BBEST 2011, p. 2-89).

4.C.6 Pedernales River

This segment of the Pedernales River is generally from near Fredericksburg to near Hye in Gillespie and Blanco, Counties, Texas, and includes portions of TCEQ-classified segment 1414 (Pedernales River).

Segment 1414 has no water quality standard impairments or concerns, but it is noted that “occasional, intense thunderstorms over the watershed create heavy rainfall that dramatically increases the flow in the river…transport(ing) large amounts of silt and organic debris downstream and into Lake Travis” (LCRA 2017, p. 82). The USGS gage 08153500 (Pedernales River near Johnson City, TX) reported a low daily mean discharge of 0 cubic feet per second (cfs) in 2011, and a high daily mean discharge of 40,000 cfs in 2015 (USGS 2018a, pp. 201, 206), the driest and wettest years on record in Texas, respectively (TWRI 2016, p. 3). A low daily mean discharge of 0.0 cfs was reported on July 2, 2018, and a high daily mean discharge of 390.0 cfs was reported on September 17, 2018 (USGS 2019, p. 105).

Some conservation is underway in the Pedernales River Basin, including voluntary habitat restoration on private lands coordinated through the Landowner Incentive Program and similar efforts by state and federal biologists, and NGOs (TPWD 2018b, p. 2).

4.C.7 Onion Creek

This segment of Onion Creek is generally from Interstate 35 to the confluence with the Colorado River, near Del Valle in Travis County, Texas, and includes portions of TCEQ-classified segment 1427 (Onion Creek). Segment 1427 has impairments for salts (sulfate), and a tributary, Slaughter Creek, has impairments for biology and concerns for dissolved oxygen (LCRA 2017, p. 98). Onion Creek below Driftwood ceases to flow, but perennial pools are maintained. The Onion Creek near Driftwood (upstream from this segment, USGS gage 08158700) experienced 484 days (ending October 9, 2009) of no flow due to persistent drought in Central Texas, and approximately 9% of the days exhibited no flow between 1979 to 2009 (BBEST 2011, p. 2-117). A low daily mean discharge of 0.0 cfs was reported for several days in July and August 2018, and a high daily mean discharge of 620.0 cfs was reported on September 22, 2018 (USGS 2019, p. 153).

Onion Creek is bisected by the rechange zone of the Barton Springs Segment of the Edwards Aquifer, and the recharge zone is subject to dewatering, resulting in a barrier for mussels and host fish movements (City of Austin 2018d, p. 4). Several privately owned lowhead in-channel dams currently exist along upper and lower Onion Creek, which further provide barriers to fish passage and mussel dispersal (City of Austin 2018d, p. 4).

The upper part of the watershed is still relatively undeveloped while the lower part of the watershed is becoming increasingly urbanized (Gilroy and Richter 2010, p. 1). The City of Austin, as well as Travis and Hays Counties, and several NGOs, have made efforts to improve Onion Creek and its watershed. These efforts include buyouts for homes built in the floodplain and subject to flood damage (City of Austin 2018, p. 1a). Additionally, the City of Austin Watershed Protection Department and Austin Water are involved with a suite of conservation programs including riparian area restoration, storm water quality monitoring, bank stabilization, and pursuit of conservation easements and fee simple land acquisitions and management of Water Quality Protection Lands.

Onion Creek currently receives no municipal wastewater discharges (City of Austin 2018d, p. 4). As development in the Onion Creek watershed continues, Onion Creek will likely receive additional return flows from treatment plants, and runoff from increased impervious cover in the watershed, leading to alterations in the natural hydrology of the system. The City of Dripping Springs has plans to upgrade its South Regional Wastewater Collection, Treatment, and Disposal Facility, and seeks authorization to discharge to Walnut Springs Creek, a tributary to Onion Creek above the recharge zone, although significant reuse is proposed (City of Dripping Springs 2018, entire).

4.C.8 Lower Colorado River

This segment of the Colorado River is well below the City of Austin, generally from Columbus to Bay City in Colorado, Wharton, and Matagorda Counties, Texas, and includes portions of TCEQ-classified segment 1402 (Colorado River below La Grange). Segment 1402 has impairments for bacteria, and concerns for nutrients and chlorophyll (LCRA 2017, p. 105). The USGS gage 08161000 (Colorado River at Columbus, TX) reported a low daily mean discharge below 500 cubic feet per second (cfs) in 2011, and a high daily mean discharge above 60,000 cfs in 2015 (USGS 2018a, pp. 209, 214), the driest and wettest years on record in Texas, respectively (TWRI 2016, p. 3). A low daily mean discharge of 458.0 cfs was reported on February 19, 2018, and a high daily mean discharge of 21,900 cfs was reported on March 30, 2018 (USGS 2019, p. 111).

The USGS gage 08162000 (Colorado River at Wharton, TX) reported a low daily mean discharge below 200 cubic feet per second (cfs) in 2011, and a high daily mean discharge above 50,000 cfs in 2015 (USGS 2018a, pp. 217, 222), the driest and wettest years on record in Texas, respectively (TWRI 2016, p. 3). A low daily mean discharge of 212.0 cfs was reported on July 2, 2018, and a high daily mean discharge of 20,800 cfs was reported on March 31, 2018 (USGS 2019, p. 117).

The hydrology of the Lower Colorado River has been altered significantly following the completion of Buchanan (in 1937) and Mansfield (in 1940) dams, with annual daily average flows ranging from up to 150,000 cfs before 1940 to not more than 40,000 cfs following construction of the dams and the 1950-1956 Drought of Record (at the Austin gage; BIO-WEST, Inc. 2008, p. 16). The management of surface water releases from the Highland Lakes can result in variable surface elevations and daily fluctuations in flow from less than 100 cfs to more than 10,000 cfs (City of Austin 2018d, p 5).

The City of Austin Water Utility is the primary municipal customer of the Lower Colorado River Authority (LCRA 2014a, p. ES-5). The Highland Lakes, specifically Lakes Buchanan and Travis, provide the primary municipal and industrial water supply for the Austin, Texas, metropolitan area. The Austin City Council created the Water Forward Task Force to support the City of Austin's development of a new water plan for Austin: "The goal of the Water Forward plan is to ensure a diversified, sustainable, and resilient water future, with a strong emphasis on water conservation. This plan will consider a range of strategies such as water conservation, water reuse, aquifer storage and recovery (ASR), and others." (City of Austin 2018c, p. 1).

The City of Austin Water Utility manages two major wastewater treatment plants, Walnut Creek and South Austin Regional, with a total permitted capacity of 150 million gallons per day, discharging to the Colorado River below Austin (City of Austin 2018b, p.1).

In the Colorado River at Columbus (USGS gage 08161000), it has been determined that the existing channel currently appears to be stable, or perhaps degrading slightly, but reductions in the magnitude and frequency of flows could result in major instability in the future, leading to channel incision and bank collapses (BBEST 2011, p. 3-128).

One site on the Lower Colorado River, near Altair, Texas, and known as the "Altair Riffle" once represented high quality habitat conditions for Texas pimpleback and Texas fatmucket, but a large flood in August and September 2017 resulted in > 160,000 cfs and extensive scour of mussel habitats and "changes to channel bathymetry" (Bonner et al. 2018, pp. 240, 243, 266, 273). Bonner et al. 2018 report that "freshwater mussels in the lower Colorado River are most commonly utilizing moderate-depth low-energy habitats with silt and boulder substrates" and that Texas pimpleback showed a particular affinity for "high-energy" riffles (p. 244).

4.D. Guadalupe River and Basin

The Guadalupe River is hydrologically connected to the San Antonio River, but the two basins are considered distinct and managed separately. The Guadalupe River originates from springs in the Texas Hill Country in Kerr County, near Hunt, Texas and flows into the Gulf of Mexico at San Antonio Bay after having joined the San Antonio River (Sansom 2008, pp.70, 97-99) near the town of Tivoli, Texas. The total length of the Guadalupe River is 432 miles (BBEST 2011, p. 2.1). The San Antonio River has a long history of alteration, development, water management, conservation and restoration associated with the San Antonio metropolitan area. The San Antonio River is managed by the San Antonio River Authority, which has jurisdiction in Bexar, Wilson, Karnes and Goliad Counties (SARA 2018, p.1). Historically, springs contributed much of the baseflow to the San Antonio River, but today flows are largely influenced by wastewater treatment plant discharges (BBEST 2011, p. 2.7).

Important tributaries to the Guadalupe River include the Comal, San Marcos, and Blanco Rivers. The Guadalupe River is free-flowing from the confluence with the San Marcos to the Gulf of Mexico, save a saltwater barrier downstream of Victoria, Texas (Sansom 2008, p. 50). The San Marcos and Comal Rivers are supported by important spring systems, which sustain the base flows during periods of low precipitation. During low flow periods, “the springs can contribute much of the base flow of the lower [Guadalupe] river all the way to the estuary” (Sansom 2008, pp. 72-3). While Comal Springs went dry during the 1950-57 “drought of record” (Sansom 2008, pp. 32, 63), spring flows from the San Marcos and Comal Springs systems are now maintained, in part, by protective measures of conservation partners and the Edwards Aquifer Habitat Conservation Plan. It has been estimated that “up to 70% of the flow of the Guadalupe River at the coast during a drought of record is from the San Marcos Springs” (Sansom 2008, p. 194). The Blanco River, another tributary to the Guadalupe River, does not have significant spring influence and ceases to flow during periods of low precipitation. The Blanco River, like many of the Hill Country rivers, is prone to severe flooding (Sansom 2008, p. 73).

The Upper Guadalupe River Authority (UGRA) was created by the Texas Legislature in 1939 to “protect, develop, and manage the water quantity, quality, and sustainability in the Guadalupe River watershed in Kerr County” Texas (UGRA 2018a, p. 1). The UGRA is the lead “surface water steward for the Upper Guadalupe River (TCEQ segment 1806) and has planned and implemented multiple Clean Water Act projects to improve water quality in Kerr County, Texas (UGRA 2018b, p.1).

The Guadalupe Blanco River Authority (GBRA) was created by the Texas Legislature in 1933 and reauthorized in 1935 for “control, storing, preservation and distribution of storm and flood waters, the waters of rivers and streams, including the Guadalupe and Blanco Rivers and their tributaries for irrigation, power, and all other useful purposes” (GBRA enabling act).

The Guadalupe Basin provides an important surface water supply for the Region L (South Central Texas; 18% of existing supply) Regional Water Planning Area of Texas and also provides 2% of the existing water supply for Region J (Plateau, TWDB 2016, pp. J-4, L-4). Region L includes the cities of San Antonio, Victoria, Seguin, New Braunfels, and San Marcos, and together derives more than 60% of its existing water supply from groundwater (*i.e.*, aquifer sources). Region J includes Kerrville and similarly derives nearly 70% of its existing water supply from groundwater (*i.e.*, aquifer sources).

Canyon Reservoir was completed in 1964 and is managed by the USACE and the GBRA to provide flood control, surface water supply, and hydro-electricity for the City of New Braunfels (GBRA 2018a). Hypolimnetic (deep, cold water) releases support a recreational rainbow and brown trout fishery in an approximately 24-mile segment from below Canyon Dam to the City of New Braunfels (TPWD 2018, p.

1). GBRA is the owner and operator of Lake Dunlap, Lake McQueeney, Lake Placid, Lake Nolte, Lake H-4, and Lake Wood, in Guadalupe and Gonzales Counties, Texas. This series of small hydroelectric dams was completed in 1932 and generate electricity for the Guadalupe Valley Electric Cooperative (GBRA 2018a, p. 2). These reservoirs, which are located generally above the confluence with the San Marcos River also provide recreation value for nearby communities. One of these dams experienced a partial failure in March of 2016, dewatering Lake Wood; GBRA has plans to repair this dam and others that make up the Guadalupe Valley Hydroelectric System (GBRA 2018b, p.1).

In 2016, following five years of litigation concerning flows and the endangered whooping crane, the GBRA and The Aransas Project (TAP) signed an agreement, which they called a "white paper", entitled "Affirmation and Restructuring of the Shared Vision for the Guadalupe River System and San Antonio Bay." This white paper addresses the needs of whooping cranes and their habitats, as well as long-term water supply and flow issues in the basin and lays out a vision to work cooperatively with stakeholders to achieve a plan "for ensuring water supply, a healthy bay and protected endangered species, including whooping cranes and mussels" (GBRA-TAP 2016, p.6).

The City of Blanco is pursuing an expanded municipal wastewater discharge permit to the Blanco River. This report considers two river segments in the Guadalupe Basin known to support populations of one or more species of Central Texas mussels.

4.D.1 Upper Guadalupe River

This segment of the Guadalupe River is generally from Kerrville to Comfort in Kerr and Kendall Counties, Texas, and includes portions of TCEQ-classified segment 1806 (Guadalupe River above Canyon Lake). Segment 1806 has impairment for biological habitat and a concern for bacteria was removed in 2014, and some of its tributaries have impairments for bacteria, and dissolved oxygen (GBRA 2018f, p. 15). The USGS gage 08167000 (Guadalupe River at Comfort, TX) reported a low daily mean discharge near 5 cubic feet per second (cfs) in 2011, and a high daily mean discharge above 70,000 cfs in 2015 (USGS 2018a, pp. 225, 231), the driest and wettest years on record in Texas, respectively (TWRI 2016, p. 3). A low daily mean discharge of 0.0 cfs was reported on July 26, 2018, and a high daily mean discharge of 1,500 cfs was reported on September 22, 2018 (USGS 2019, p. 122).

A section of the Guadalupe River, near Spring Branch, experienced very low flow conditions (<1 cfs daily mean) during drought conditions from July to October 2011 (USGS 2013a, p. 20). The USGS gage 08167500 (Guadalupe River near Spring Branch, TX) reported a low daily mean discharge of 0 cubic feet per second (cfs) in 2011, and a high daily mean discharge approaching 60,000 cfs in 2015 (USGS 2018a, pp. 234, 243), the driest and wettest years on record in Texas, respectively (TWRI 2016, p. 3). A low daily mean discharge of 0.0 cfs was reported for several days in July and August 2018, and a high daily mean discharge of 9,540 cfs was reported on September 9, 2018 (USGS 2019, p. 127).

4.D.2 Lower Guadalupe River (and Lower San Marcos River)

This segment of the Guadalupe River is generally from Gonzales to Cuero, and then on to Victoria in Gonzales, DeWitt, and Victoria Counties, Texas, and includes portions of TCEQ-classified segment 1803 (Guadalupe River below San Marcos River) and 1808 (Lower San Marcos River). Segment 1803 has concerns for nitrate and a concern for bacteria was removed in 2014, and some of its tributaries have water quality standard impairments or concerns (GBRA 2018f, p. 15). Segment 1808 has no reported impairments or concerns (GBRA 2018f, p. 15). The USGS gage 08173900 (Guadalupe River at Gonzales, TX) reported a low daily mean discharge below 200 cubic feet per second (cfs) in 2011, and a high daily mean discharge above 40,000 cfs in 2015 (USGS 2018a, pp. 246, 251), the driest and wettest years on record in Texas, respectively (TWRI 2016, p. 3). A low daily mean discharge of 307.0 cfs was reported on June 11, 2018, and a high daily mean discharge of 14,200 cfs was reported on March 30, 2018 (USGS 2019, p. 135).

The USGS gage 08175800 (Guadalupe River at Cuero, TX) reported a low daily mean discharge below 200 cubic feet per second (cfs) in 2011, and a high daily mean discharge approaching 50,000 cfs in 2015 (USGS 2018a, pp. 254, 262), the driest and wettest years on record in Texas, respectively (TWRI 2016, p. 3). A low daily mean discharge of 254.0 cfs was reported on March 31, 2018, and a high daily mean discharge of 12,400 cfs was reported on March 31, 2018 (USGS 2019, p. 141).

The USGS gage 08176500 (Guadalupe River at Victoria, TX) reported a low daily mean discharge below 200 cubic feet per second (cfs) in 2011, and a high daily mean discharge approaching 50,000 cfs in 2015 (USGS 2018a, pp. 265, 270), the driest and wettest years on record in Texas, respectively (TWRI 2016, p. 3). A low daily mean discharge of 290.0 cfs was reported on August 29, 2018, and a high daily mean discharge of 11,900 cfs was reported on April 1, 2018 (USGS 2019, p. 147).

The San Marcos River joins the Guadalupe just above Gonzales, Texas. The Blanco and San Marcos are the principal tributaries of the Guadalupe River (USGS 2013b, p.2). The San Antonio River joins with the Guadalupe River near Tivoli, Texas, well below any known mussel populations described in this report.

Flows in the Lower Guadalupe River originate primarily from Canyon Lake releases (near the City of New Braunfels), major springs of the Edwards aquifer (Comal, San Marcos, and Hueco Springs), and alluvial base flow (other groundwater seeping into streams), with Canyon Lake and the major springs contributing most of the streamflow under normal conditions (USGS 2013b, p. 2). Spring flow from Comal Springs, the largest spring in the southwest United States (Brune 1975, p. 39), usually contributes approximately 20% of the flows for the lower Guadalupe River, but during summer months of drought years, spring flow can contribute as much as 50% of the streamflow because of reduced inflows from tributaries and return flows (USGS 2008, p.13). Wolaver et al. (2014) report relatively flat flow duration curves for the Guadalupe River at the Cuero and Victoria gages (08175800 and 08176500, respectively), illustrating the importance of significant stable spring inputs in support stable flow regimes in the Lower Guadalupe River (p. 11). Stable flow regimes are generally considered favorable for the development of diverse and abundant mussel communities (Haag and Warren 1998, pp. 303, 304; Haag and Warren 2007, p. 32).

The San Marcos River and, in turn, the Lower Guadalupe River, benefit from spring flow protections associated with the Edwards Aquifer Authority Habitat Conservation Plan (EAHCP), which includes provisions to reduce groundwater pumping when aquifer levels fall below predefined elevations. Thus, spring flows at the Comal River (a 3-mile-long spring-fed tributary to the Guadalupe River at New Braunfels, Texas) remain at or above 40 cfs and flows from the San Marcos springs are similarly protected (NAS 2015, p. 36). Because the San Marcos Springs continued to flow during the drought of record of the 1950s, while the Comal Springs ceased to flow, it is assumed that pumping to protect the Comal Springs will also protect the San Marcos Springs, the second largest springs complex in Texas (Brune 1975, p. 45), which are located only 16 miles apart (Sansom 2008, p.63). Thus, flows in the Lower Guadalupe River, contributed by the Comal and San Marcos Rivers, are relatively secure given management and conservation efforts by the EAHCP and partners (NAS 2015, p. 36). As part of the EAHCP, a Watershed Protection Plan (WPP) has been proposed for the Upper San Marcos River that includes those areas in the vicinity of the City of San Marcos and Texas State University (Gleason et al. 2016, entire).

Perkin and Bonner (2011) documented changes in fish communities and changing flow regimes in the

Guadalupe and San Marcos Rivers, following the completion of several low head dams on both rivers and the 1964 construction of Canyon Reservoir on the Guadalupe River. In the Upper Guadalupe River near Spring Branch, mean annual flow and frequency of small and large floods increased (Perkin and Bonner 2011, p. 569). In the Lower Guadalupe River near Victoria, mean annual flow increased while the frequency of small and large floods decreased (Perkin and Bonner, p. 569). In the San Marcos River near Luling, mean annual flow increased while the frequency of small and large floods decreased (Perkin and Bonner 2011, p. 570). These changes were attributed to both low flows during the "drought of record" in the 1950's and by the construction of dams and other flood control structures (Perkin and Bonner 2011, p. 574). In general, these shifts in flow regimes favored fishes that were "habitat generalists" rather than "fluvial specialists" while the fish assemblages remained relatively intact (Perkin and Bonner 2011, p. 575).

The City of San Marcos' municipal supply is approximately 75% surface water from Canyon Lake (Guadalupe River) and 25% groundwater from the Edwards Aquifer (City of San Marcos 2018a, p. 1). The City of San Marcos operates a "high-quality wastewater treatment plant and water system rated superior by the State of Texas" (City of San Macros 2018b, p. 1) that discharges into the San Marcos River below the City of San Marcos.

4.E Trinity River and Basin

The Trinity River originates as several forks (West Fork, Clear Fork, Elm Fork, East Fork) originating in North Central Texas and combining near Dallas, Texas, where the Trinity River supplies municipal water to over 6 million residents of the DFW metropolitan area and flows into the Gulf of Mexico at Trinity Bay (and Galveston Bay) below Lake Livingston which provides municipal water for the Houston metropolitan area, which includes over 6 million residents (Sansom 2008, pp. 55, 88). The total length of the Trinity River is 550 miles, wholly in Texas (TWDB 2018). The Trinity is the only basin in Texas that provides water to both a major metropolitan area in the upper basin and a major metropolitan area in the lower basin (TRA 2017, p. 41).

The Trinity River Authority (TRA) was created by the Texas Legislature in 1955, and owns and operates Lake Livingston Dam, which was completed to form Lake Livingston in 1971. Reuse has been a major part of the TRA's water planning strategy following the 1950-57 drought. Reuse rights were contemplated when construction of Lake Livingston was constructed on the Trinity in 1969 to provide municipal water the City of Houston, and reuse continues to represent a significant portion of TRAs water supply (TRA 2012, pp. 35-6). There are a total of 32 major reservoirs in the Trinity River Basin (TWDB 2018, p. 1). There remains an undammed segment of the "Middle" Trinity River between Richland-Chambers and Livingston Reservoirs.

The Tarrant Regional Water District provides water supply, flood protection, and recreation opportunities for residents of Tarrant County, Texas, and owns and operates four major reservoirs, including Lake Bridgeport, Eagle Mountain Lake, Cedar Creek Lake, and Richland-Chambers Lake. The Richland-Chambers Dam and Reservoir was completed in 1989 and built on two tributaries to the Trinity River, Richland, and Chambers Creeks (TWDB 2018, p. 1).

The Trinity Basin provides an important surface water supply for the Region C (49% of existing supply) and Region H (42% of existing supply) Regional Water Planning Area of Texas (TWDB 2016, pp. C-4, H-4). Region C includes the Dallas-Fort Worth metropolitan area and Region H includes the Houston metropolitan area; these two Regions are expected to provide over half of the State's population growth over the next fifty (50) years, between 2020 and 2070 (TWDB 2017, p.3). Additional flows from other river basins, such as the Sabine and Sulfur, contribute to the return flows to the Trinity River. The Upper

Trinity River Water Quality Compact was created in 1975 to improve water quality, such that return flows can now be reused, and water rights assigned to reused return flows such that some percent of discharges are guaranteed to downstream users (TRA 2017, p. 41). Approximately 30% of the Tarrant River Authority's return flows are to Lake Livingston (TRA 2017, p. 41), and reuse flows alone are apparently adequate to meet established environmental flow prescriptions for the Trinity River (TRA 2017, pp. 42, 49). Return flows contribute more than 90% of the flow to the Trinity River below Dallas during prolonged dry periods (TRA 2012, p.49) and thus base flow is artificially elevated. Low flows in the Trinity River have been increasing since 1939, with increasing volumes of wastewater discharged from the Dallas-Fort Worth area (measured at the Trinity River at Rosser USGS gage 08062500; BBEST 2009, p. 11).

The North Texas Municipal Water District (NTMWD) is a public water utility that services the northeast portion of the Dallas-Fort Worth metropolitan area including Collin County, Texas, and the East Fork Water Reuse Project, an 1840-acre wetland project that diverts water from the East Fork of the Trinity River and pumps it back to Lavon Lake and the Wylie Water Treatment Plan for drinking water (NTMWD 2018a, p. 1). NTMWD's TCEQ permit provides for minimum flows at the John Bunker Sands wetlands of 26 cfs, which represents approximately 30% of the local basin return flows to the East Fork of the Trinity River (NTMWD 2018b, p. 2).

The Trinity River in the Dallas Fort Worth metropolitan area has a long history of transfer of water from other basins including the Red, Sulfur, and Sabine. For example, Neck (1990) notes that during the drought of the 1950's, over 90,000-acre-feet of water was diverted from the Red River into Lake Dallas (now part of Lake Lewisville; p.17) on the Elm Fork of the Trinity River. The Trinity River near Oakwood, Texas, is the site of USGS stream gage 080650000, and this "control point" has established subsistence, base, and pulse flows defined for winter, spring, summer, and fall (TCEQ 2011e, p.6). The annual minimum flow at USGS gage 0806500 near Oakwood, Texas has increased from less than 200 cfs to more than 400 cfs since 1930, due to return flows and transfers from other basins (TRA 2017, p. 42). During periods of low rainfall, the flow in the mainstem Trinity River between Dallas and Lake Livingston is almost entirely wastewater effluent (i.e., return flows; TRA 2012, p. 24). Today, because of a combination of "reservoir management, wastewater discharges, and flows imported from other watershed" streamflows in the main stem Trinity River in the summer are higher than they would have been under natural conditions (Sansom 2008, p. 56).

The Trinity River has a long history of water quality degradation (Randklev et al. 2010, p. 2366), particularly between Dallas and Lake Livingston, but recent improvements following decades of wastewater treatment upgrades (reviewed in USGS 1998, entire) have led to the partial recovery of fish over the past 40+ years (Perkin and Bonner 2016, p. 91; entire for full discussion) along with benthic macroinvertebrate communities. Frequent summer fish kills occurred in the 1980s to early 1990s as high flow events disturbed previously buried organic matter and resulted in anoxic conditions (i.e., the "black rise"; BBEST 2009, p. 66).

This report considers two river segments in the Trinity Basin known to support populations of one or more species of Central Texas Mussels.

4.E.1 Lower East Fork of the Trinity River

This segment of the East Fork of the Trinity River is generally below Seagoville in Kaufman and Dallas counties, Texas, to the confluence with the main stem of the Trinity River and includes portions of TCEQ segment 0819 (East Fork Trinity River). Segment 0819 has impairments for sulfate and TDS, which apparently are related to low flows, and concerns for chlorophyll a, nitrate, and phosphorus (TRA 2018a, pp. 105-106.) The USGS gage 08062000 (East Fork Trinity River near Crandall, TX) reported a low daily mean discharge above 20 cubic feet per second (cfs) in 2011, and a high daily mean discharge approaching 30,000 cfs in 2015 (USGS 2018a, pp. 3, 9), the driest and wettest years on record in Texas, respectively (TWRI 2016, p. 3). A low daily mean discharge of 25.4 cfs was reported on June 9, 2018, and a high daily mean discharge of 14,300 cfs was reported on February 23, 2018 (USGS 2019, p. 8).

The East Fork Water Reuse Project was completed in 2009 and diverts some flows from the East Fork to a created wetlands complex for treatment and ultimate reuse (i.e., the John Bunker Sands Wetland Center, NTMWD 2018a, p. 1).

4.E.2 Middle Trinity River

This segment of the Trinity River is generally between Richland-Chambers Reservoir and Lake Livingston, above and below Oakwood, Texas, in Anderson, Freestone, Houston, Leon, and Madison Counties, and includes portions of TCEQ segment 0804 (Trinity River above Lake Livingston) and TCEQ segment 0803 (Lake Livingston). Segment 0804 has concerns for chlorophyll a, nitrate, and phosphorus, and it is reported that "nutrient loadings come from upstream wastewater treatment facilities" and "at base flows this segment is effluent dominated and has high levels of nutrients" and some of its tributaries have impairments or concerns for aquatic life (TRA 2018a, p. 119). Segment 0803 has impairments for sulfate and concerns for chlorophyll a (TRA 2018a, pp. 124-125). The USGS gage 08065000 (Trinity River near Oakwood, TX) reported a low daily mean discharge above 500 cubic feet per second (cfs) in 2011, and a high daily mean discharge approaching 80,000 cfs in 2015 (USGS 2018a, pp. 12, 18), the driest and wettest years on record in Texas, respectively (TWRI 2016, p. 3). A low daily mean discharge of 414.0 cfs was reported on September 1, 2018, and a high daily mean discharge of 28,500 cfs was reported on March 5, 2018 (USGS 2019, p. 14). In the Trinity River at Oakwood (USGS gage 806500) flows have increased since 1955 as return flows increased (BBEST 2009, p. 268).

Randklev et al. (2017a, p.7) observe that peak floods occur frequently (approximately annually or more frequent) in the Trinity River, and hypothesize that water management practices, which result in discharges >= 400 m3/s appear to be limiting mussels in bank habitats and having negative impacts on mussel communities and populations in the middle Trinity River.

Chapter 5 - Current Conditions

5.A General current conditions of Central Texas Mussels

This assessment defines a mussel population as a stream reach that is a collection of mussel beds through which host fish infested with glochidia may travel, allowing for dispersal of juveniles among and within mussel beds. This chapter discusses the current populations of each species and assesses the resiliency of each population.

Methodology for Population Resiliency Assessment

For each species and each population, we developed and assigned condition categories for three population and habitat factors (i.e., Occupied Stream Length, Abundance, Reproduction, Substrate Condition, Flowing Water, and Water Quality; See Chapter 3.C Needs of Central Texas Mussels). The population factor for occupied habitat was calculated using ArcGIS by summing the stream miles between locations known to be occupied since 2000 for the whole population. The other five factors were scored by U.S. Fish and Wildlife Service biologists as informed by information available in our files. For each population, the six categories were assigned a numerical value: 3 for healthy, 2 for moderately healthy, 1 for unhealthy, and 0 for extirpated or functionally extirpated. For each population, these six factors were averaged, and the average condition value was then compared with the individual category value for population abundance. In determining the overall condition, no overall condition was allowed to exceed the population abundance (i.e., overall population condition was capped at the population abundance condition). The current condition category is a qualitative estimate based on the analysis of the three population factors and three habitat elements. Table 5.1 displays the presumed ranges of probabilities of the persistence of a population with a given current condition category over 20 years (about three to five mussel generations).

Table 5.1. Presumed probability of persistence for overall current condition categories, reported as likely to fall within the following ranges.

Likelihood of Persistence:	Healthy	Moderately Healthy	Unhealthy	Extirpated/Functionally Extirpated
Range of Presumed Probability of Persistence over ~20 years	**90 – 100%**	**60 – 90%**	**10 – 60%**	**0 – 10%**
Range of Presumed Probability of Extirpation over ~20 years	**0 – 10%**	**10 – 40%**	**40 – 90%**	**90 – 100%**

5.B False spike

5.B.1 Current Distribution

False spike was suspected of being extinct until living individuals were discovered in the Guadalupe River basin in 2011-2013 (Howells 2014, p. 85). Randklev et al. (2017, p.11) surveyed 13 sites in the Guadalupe River drainage in DeWitt and Victoria counties and found **1** live false spike individual near

Cuero, TX (Figure 5.1). The currently occupied stream length of the false spike population is 102.6 stream miles, which equates to approximately 20% of the presumed 512 stream mile historical range for the species. This approximate range reduction assumes the species continuously occupied its entire historical range, which is unlikely given the species' specialized habitat preferences.

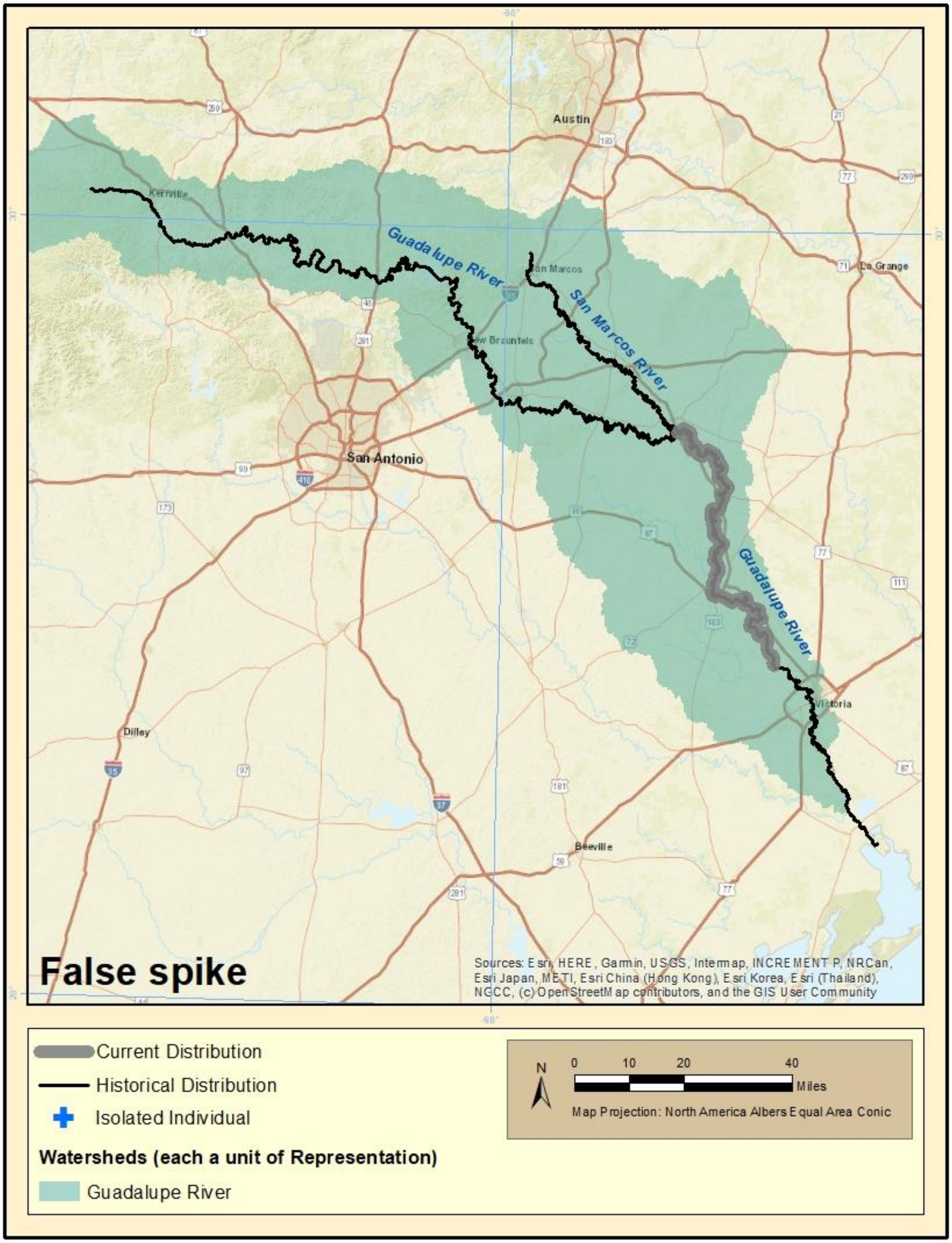


Figure 5.1. Location of current populations of false spike in the Guadalupe River.

Lower Guadalupe River

The Lower Guadalupe River population of false spike extends for 102.6 stream miles from the Highway 183 bridge crossing near Gonzales, Texas, downstream to the Farm-to-Market (FM) 447 bridge crossing near Victoria, Texas. This population occurs in Guadalupe River in Gonzales, DeWitt, and Victoria counties, Texas.

The Lower Guadalupe River population of false spike is the only population known for the species. Recent surveys that documented living individuals were conducted in 2011, by Randklev et al. 2011 (pp. 17-18) who report finding **7** live individuals, from near the edge of a gravel bar, in the Guadalupe River near Gonzales, Texas. Mabe and Kennedy (2013, pp. 298-9) observed **8** living false spike and collected recent shells from stable substrates in "a shallow run just upstream of a moderately-sized riffle" of the Lower Guadalupe River near Cuero, Texas, in 2012.

The most comprehensive survey of the Lower Guadalupe River was completed in 2014-15 when Tsakiris and Randklev (2016a, p. 13) observed a total of **652** false spike out of a total of over 21,000 mussels. False spike was observed only from riffle habitats, and not below Cuero, Texas, indicating very low abundances in the reaches just above Victoria, Texas. Bonner et al. (2018, p. 37) found no living individuals in the upper Guadalupe River.

5.B.2 Areas Presumed Extirpated

False spike is presumed to have been extirpated from much of its historical range throughout the Guadalupe Basin of Central Texas (reviewed in Randklev et al. 2017c, pp. 12-13). In fact, false spike was thought to be extinct for nearly 40 years, since the 1970s (Burlakova and Karatayev 2012, p. 13) until the species was rediscovered in 2011 (Randklev et al. 2011, entire).

False spike was previously thought to have occurred in the Rio Grande Basin (Randklev et al. 2013a, p.19) but those specimens have since been assigned to *Sphenonaias taumilapana* (Pfeiffer et al. 2016, p. 285). False spike is now absent from the Leon River (Randklev et al. 2013, p. 390), but historically occurred in there, based on archaeological evidence (shell middens; Popejoy et al. 2016, p. 477).

Randklev et al. (2017c, p. 11) report searching for, but not finding any false spike in the San Saba and Pedernales rivers. Bonner et al. (2018) report searching for, but not finding any false spike in the Upper Guadalupe basin and Middle Colorado basin (p. 26), and in the Lower Colorado basin (p. 12).

5.B.3 Current Conditions

To summarize the overall current conditions of false spike populations, we assigned the population to one of four categories (healthy, moderately healthy, unhealthy, or functionally extirpated) based on the population factors and habitat elements discussed in Chapter 3 and as displayed in Table 5.2. Table 5.3 presents the overall condition of false spike population as displayed in Figure 5.2.

Table 5.2. Population and habitat characteristics of the false spike populations used to assign condition categories in Table 5.3

	Population Factors			Habitat Factors		
Condition	**Occupied Stream Length**	**Index of Abundance**	**Evidence of Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**
Healthy	> 50 river miles	Found in nearly all available habitats surveyed during a reasonable survey effort. More than 100 individuals found per population survey.	50% or more sites with juveniles (< 35 mm) detected and gravid females present during the breeding season and fish hosts present.	Riffle and run habitats present. Gravel and cobble substrates sufficient to provide lodging habitat. Low evidence of excessive sediment in the substrate matrix.	Flowing water present year-round. Water levels sufficient to keep known habitats constantly submerged. No documented habitat exposure.	No known incidence of contaminant spills, low dissolved oxygen, or evidence of exposure extreme high or low temperatures.
Moderately Healthy	49–20 river miles	Found in approx. 50% of all available habitats surveyed during a reasonable survey effort. Between 26 – 99 individuals found per population survey.	25–50% of sites with juveniles (< 35 mm) detected, gravid females present during the breeding season and fish hosts present in at least moderate abundance.	Riffle and run habitats present. Gravel and cobble substrates sufficient to provide lodging habitat. Some to moderate levels of excess sediment in the substrate matrix.	Flowing water present almost year-round. Few instances of zero flow days and minimal exposure of portions of known habitats to dewatering.	Contaminants known, low dissolved oxygen and temperature extremes documented. Levels not high enough to risk extirpation.
Unhealthy	< 19 river miles	Found in few areas of suitable habitat during a reasonable survey effort. Between 2 – 25 individuals found per population survey.	< 25% of sites with juveniles (<35 mm) detected, gravid females present during the breeding season, and fish host present in low abundance and/or ability to disperse is reduced.	Riffle and run habitats eroded, unstable, or being buried by mobilized sediments from upstream sources.	Flowing water not present year-round. Summer records of zero flow days. However, at least some pools stay sufficiently wetted, cool, and oxygenated.	Known exposure to contaminants, low dissolved oxygen, and documented cases of excessive water temperatures extremes. Water quality parameters diminished such that exposure threatens mussel survival.
Extirpated/ Functionally Extirpated	none	Very few or no live individuals documented during surveys (≤1).	No evidence suggesting that juveniles or gravid females are present. Fish host not known to occur.	No suitable habitat present.	Streambed dry or the number of zero flow days high enough to result in dewatered habitats, precluding survival of mussels.	Water quality degradation such that occupancy of otherwise suitable habitat is precluded.

Table 5.3. Current condition of known false spike populations.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Guadalupe	**Lower Guadalupe**	Healthy	Healthy	Moderate	Moderate	Moderate	Moderate	**Moderate**

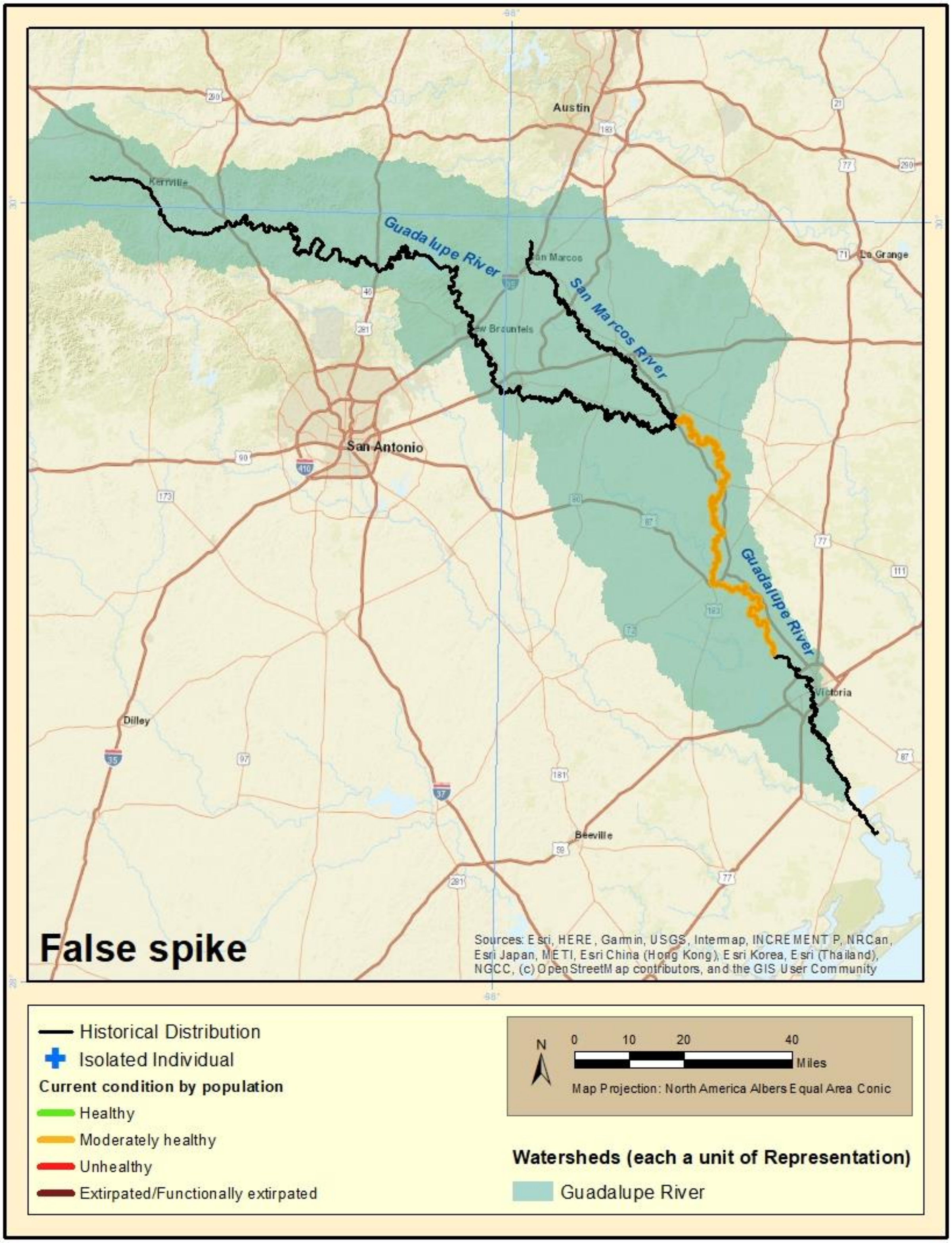


Figure 5.2. Location and current overall condition for the population of false spike in the Guadalupe River basin.

5.B.4 Current Population Resiliency

Currently, the only known remaining population of false spike occurs in the Lower Guadalupe River. This population is currently assessed to be in moderately healthy condition. However, because the species currently exists in the form of a single population, overall, the species has low resiliency.

We do not expect any significant differences in localized adaptations within this population as the entire population occurs in similar habitat and faces similar stressors. As such, we consider this species to have representation in a single population.

5.B.5 Current Species Representation

The false spike only occupies one known population in the Lower Guadalupe River. We do not expect any significant differences in localized adaptations within this population as the entire population occurs in similar habitat and faces similar stressors. As such, we consider this species to have representation in a single population. Any representation that historically occurred throughout other portions of the Guadalupe River basin has been lost.

5.B.6 Current Species Redundancy

Within this identified representation area, the Guadalupe River basin has only one currently known population and therefore the false spike lacks any redundancy.

5.C Balcones spike

5.C.1 Current Distribution

Randklev et al. (2017, p.11) surveyed 117 sites in the Brazos and Colorado River drainages and found a total of 30 live Balcones spike individuals from seven locations (Figure 5.3). Twenty-two of these individuals were from the Little River. The currently occupied stream length of the Balcones spike population is 83 stream miles, which equates to approximately 2.9% of the presumed 2,835 stream mile historical range for the species. This approximate range reduction assumes the species continuously occupied its entire historical range, which is unlikely given the species' specialized habitat preferences.

Little River

Balcones spike is known to occur within the Brazos River basin only in the Little River and two tributaries, Brushy Creek and the San Gabriel River. The species is presumed to be extirpated from the entire mainstem Brazos River. In the Little River main stem, Balcones spike occupies 20.4 stream miles from the FM 1915 bridge crossing downstream to the confluence with the San Gabriel River, all in Milam County. In the San Gabriel River, Balcones spike occupies 17.9 stream miles between the FM 428 bridge crossing downstream to the County Road (CR) 428 bridge crossing, in Williamson and Milam counties, Texas. In Brushy Creek, Balcones spike occupies only 2.9 stream miles from the FM 908 bridge crossing downstream to the confluence with the San Gabriel River, all within Milam County, Texas.

Balcones spike was discovered in the Little River basin in 2012 from the lower San Gabriel River in Milam County, Texas, and in 2012 and 2013, **3** live individuals in run habitats with cobble/gravel substrate were documented (Randklev et al. 2013a, pp. 18-19). The Little River is not known to have been surveyed for mussels prior to 2012. Randklev et al. (2017, p.11) found **29** live individuals in the

Little River in 2015 during qualitative (n=22) and quantitative surveys (n=7), noted some evidence of reproduction and that most of these individuals were found in riffle habitats. Two live individuals (with some evidence of brooding) were reported in riffles in the San Gabriel River (a tributary to the Little River) just below Granger dam, along with **5** live individuals (with some evidence of brooding) from Brushy Creek near the confluence with the San Gabriel (Randklev et al. 2017, p.17). Bonner et al. (2018) report searching for, but not finding, any Balcones spike in the Little River basin (p. 26) but did report "recently dead shells with nacre still intact" (p. 21).

In June 2021, Bio-West and BRA biologists completed surveys in the lower San Gabriel River downstream of Granger Lake and collected **13** live Balcones spike (Littrell 2021a, entire). The biologists reported that 8 of the 13 collected Balcones spike were gravid at the time of collection.

In August 2021, Bio-West and BRAbiologists completed surveys in Brushy Creek near the FM 905 crossing and collected **1** live Balcones spike (Littrell 2021b, entire).

Lower San Saba River

The current population of Balcones spike in the San Saba River is known to occur from the CR 340 bridge crossing downstream to the confluence of the San Saba River with the Colorado River. This population occupies approximately 41.8 stream miles of the San Saba River in San Saba County, Texas.

The Lower San Saba River population of Balcones spike appears to be in decline. In 2012, **3** live individuals were found at two sites in the lower San Saba River, in San Saba County, Texas. There was evidence of possible reproduction (oocytes in sampled gonadal fluid), and individuals were collected from coarse gravel habitats adjacent to runs (Randklev et al. 2013a, p. 19). One of these individuals was previously reported by Sowards et al. (2013, p. 64) who reported finding a single live individual from a riffle habitat in the San Saba River "11.3 km east of the City of San Saba" in July 2012. Tsakiris and Randklev (2014, p. 11) reported finding one live Balcones spike at each of two locations (CR 340 and CR 126 bridge crossings).

Randklev et al. (2017c, p.11) returned to the San Saba River and found no live individuals in the San Saba River. Recently, Bonner et al. (2018, entire) surveyed two sites in the San Saba River and found no live individuals and no shell material. Randklev et al. (2017c, p. 12) report that historic museum records indicated that Balcones spike had been collected from the upper San Saba River in Menard County, Texas, by Simpson in 1914 and by Strecker in 1931.

Llano River

The Llano River population of Balcones spike is by far the smallest population, and is known to persist only in the immediate vicinity of the FM 1871 bridge crossing in Mason County, Texas. This population is less than one mile in length and likely is made up of only a few small mussel beds. Because of easy highway access and close proximity to major cities, this population is frequently sampled by mussel collectors and researchers.

The Llano River population of Balcones spike appears to be very small. Randklev et al. (2013a, p. 19) report finding a single live individual from the Llano River near Mason, Texas, in August 2013, from a small pool habitat with gravel/cobble substrate. Service biologists (USFWS 2017, p. 2) found one live individual in the Llano River near Mason, Texas during a reconnaissance survey. This live individual was 35mm long indicating that a recent reproduction event had occurred, approximately 1–5 years before. Additionally, one dead Balcones spike was recovered from the site and showed signs of depredation, presumably by a raccoon; this mussel was < 40 mm in total length and assumed to be a sub-adult. The dead Balcones spike was discovered in the small spaces between large cobble in a shallow edge habitat.

Randklev et al. (2017c, p.11) found only one live individual, in a pool, out of 20 sample sites. The individual was 37 mm in total shell length. While no evidence of reproduction was noted, recent reproduction is inferred based on the size of the sub-adult individual. Bonner et al. (2018, entire) found no live individuals during recent sampling of the FM 1871 site in the Llano River.

In 2021, consultants completed a relocation of freshwater mussels at the FM 1871 bridge crossing of the Llano River near Mason, Texas in response to a proposed bridge replacement project at the existing crossing. During this relocation, the team collected **14** live Balcones spike (referred to as false spike in reference) and relocated them to a site upstream of the bridge crossing's proposed construction footprint (Blankenship, 2021, entire).

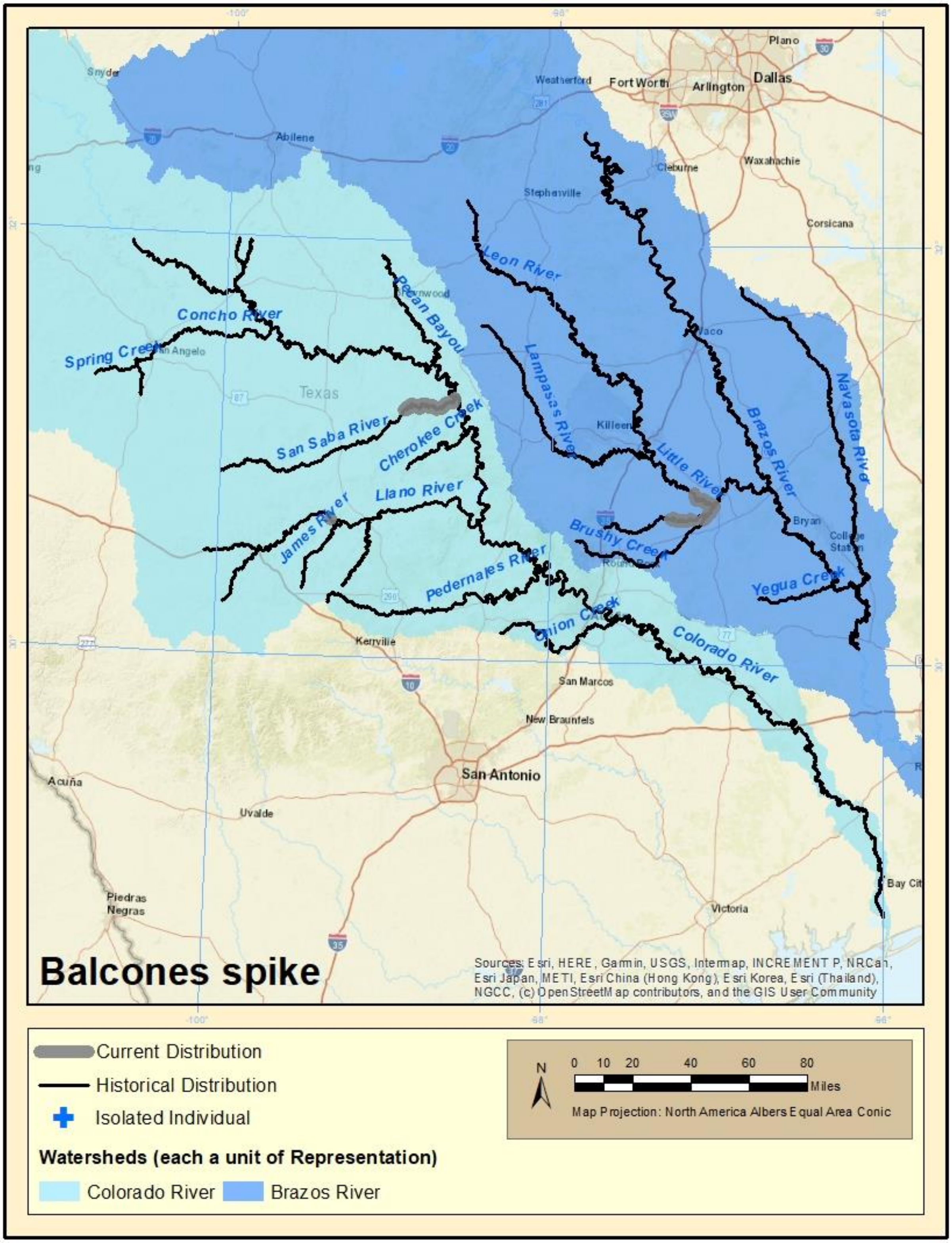


Figure 5.3. Location of current populations of Balcones spike in the Brazos and Colorado Rivers.

5.C.2 Areas Presumed Extirpated

Balcones spike is presumed to have been extirpated from much of its historical range throughout the Brazos and Colorado Basins of Central Texas (reviewed in Randklev et al. 2017c, pp. 12-13).

Balcones spike is now absent from the Leon River (Randklev et al. 2013, p. 390), but historically occurred there, based on archaeological evidence (shell middens; Popejoy et al. 2016, p. 477).

Randklev et al. (2017c, p. 11) report searching for, but not finding any Balcones spike in the San Saba and Pedernales rivers. Bonner et al. (2018) report searching for, but not finding any Balcones spike in the Middle Colorado basin (p. 26), and in the Lower Colorado basin (p. 12).

5.C.3 Current Conditions

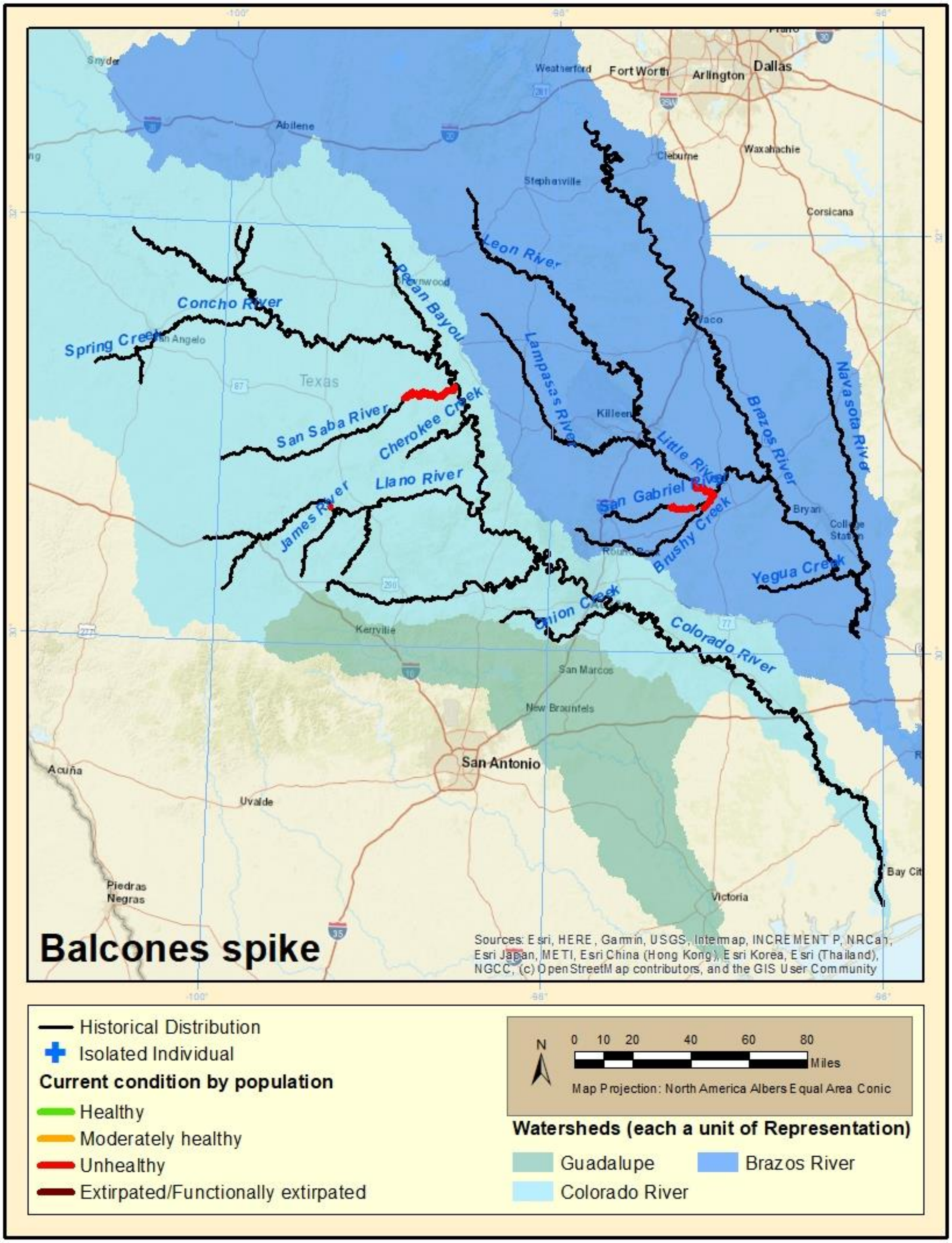
To summarize the overall current conditions of Balcones spike populations, we assigned each population to one of four categories (healthy, moderately healthy, unhealthy, or functionally extirpated) based on the population factors and habitat elements discussed in Chapter 3 and as displayed in Table 5.4. Table 5.5 presents the overall condition of Balcones spike populations as displayed in Figure 5.4.

Table 5.4. Population and habitat characteristics of the Balcones spike populations used to assign condition categories in Table 5.5.

	Population Factors			**Habitat Factors**		
Condition	**Occupied Stream Length**	**Index of Abundance**	**Evidence of Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**
Healthy	> 50 river miles	Found in nearly all available habitats surveyed during a reasonable survey effort. More than 100 individuals found per population survey.	50% or more sites with juveniles (< 35 mm) detected and gravid females present during the breeding season and fish hosts present.	Riffle and run habitats present. Gravel and cobble substrates sufficient to provide lodging habitat. Low evidence of excessive sediment in the substrate matrix.	Flowing water present year-round. Water levels sufficient to keep known habitats constantly submerged. No documented habitat exposure.	No known incidence of contaminant spills, low dissolved oxygen, or evidence of exposure extreme high or low temperatures
Moderately Healthy	49–20 river miles	Found in approx. 50% of all available habitats surveyed during a reasonable survey effort. Between 26 – 99 individuals found per population survey.	25–50% of sites with juveniles (< 35 mm) detected, gravid females present during the breeding season and fish hosts present in at least moderate abundance.	Riffle and run habitats present. Gravel and cobble substrates sufficient to provide lodging habitat. Some to moderate levels of excess sediment in the substrate matrix.	Flowing water present almost year-round. Few instances of zero flow days and minimal exposure of portions of known habitats to dewatering.	Contaminants known, low dissolved oxygen and temperature extremes documented. Levels not high enough to risk extirpation.
Unhealthy	< 19 river miles	Found in few areas of suitable habitat during a reasonable survey effort. Between 2 – 25 individuals found per population survey.	< 25% of sites with juveniles (<35 mm) detected, gravid females present during the breeding season, and fish host present in low abundance and/or ability to disperse is reduced.	Riffle and run habitats eroded, unstable, or being buried by mobilized sediments from upstream sources.	Flowing water not present year-round. Summer records of zero flow days. However, at least some pools stay sufficiently wetted, cool, and oxygenated.	Known exposure to contaminants, low dissolved oxygen, and documented cases of excessive water temperatures extremes. Water quality parameters diminished such that exposure threatens mussel survival.
Extirpated/ Functionally Extirpated	none	Very few or no live individuals documented during surveys (≤ 1).	No evidence suggesting that juveniles or gravid females are present. Fish host not known to occur.	No suitable habitat present.	Streambed dry or the number of zero flow days high enough to result in dewatered habitats, precluding survival of mussels.	Water quality degradation such that occupancy of otherwise suitable habitat is precluded.

Table 5.5. Current condition of known Balcones spike populations.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Colorado	**Lower San Saba**	Moderate	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
	Llano	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
Brazos	**Little**	Moderate	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

Figure 5.4. Location and current overall condition for each of the three populations of the Balcones spike in the Brazos and Colorado River basins.

5.C.4 Current Population Resiliency

Currently, the Balcones spike is known to exist as three populations occurring in the Brazos and Colorado River basins.

In the Brazos basin, Balcones spike is currently known to exist only in the Little River basin, a tributary to the Brazos River. Within the Little River population, the species exists in the San Gabriel River, Brushy Creek, and main stem Little River. This single population is quite small and has an overall unhealthy current condition and, therefore, low resiliency.

The Colorado River basin has two known populations: the lower San Saba River and Llano River populations. These two populations are small and isolated from one another and considered to be in unhealthy condition overall, corresponding to low resiliency.

5.C.5 Current Species Representation

We consider the Balcones spike to have representation in the form of genetic and ecological diversity in two basins: the Brazos and Colorado. Because there is no freshwater connection between the two basins, we treat each population as a separate area of representation.

5.C.6 Current Species Redundancy

Within this identified representation area, the Brazos River basin has only one known current population and therefore lacks any redundancy. The Colorado River basin has two separate populations, providing only limited redundancy.

5.D Texas fatmucket

5.D.1 Current Distribution

Texas fatmucket appears to be currently restricted to upper reaches of major tributaries within the Colorado River Basin (Randklev et al. 2017, p. 4) (Figure 5.5). The total current distribution of Texas fatmucket, summed across the five populations from the Colorado River basin, is a combined stream length of approximately 295 miles. This current distribution represents approximately 20% of the total presumed historic range of 1,444 stream miles. This approximate range reduction assumes the species continuously occupied its entire historical range, which is unlikely given the species’ specialized habitat preferences.

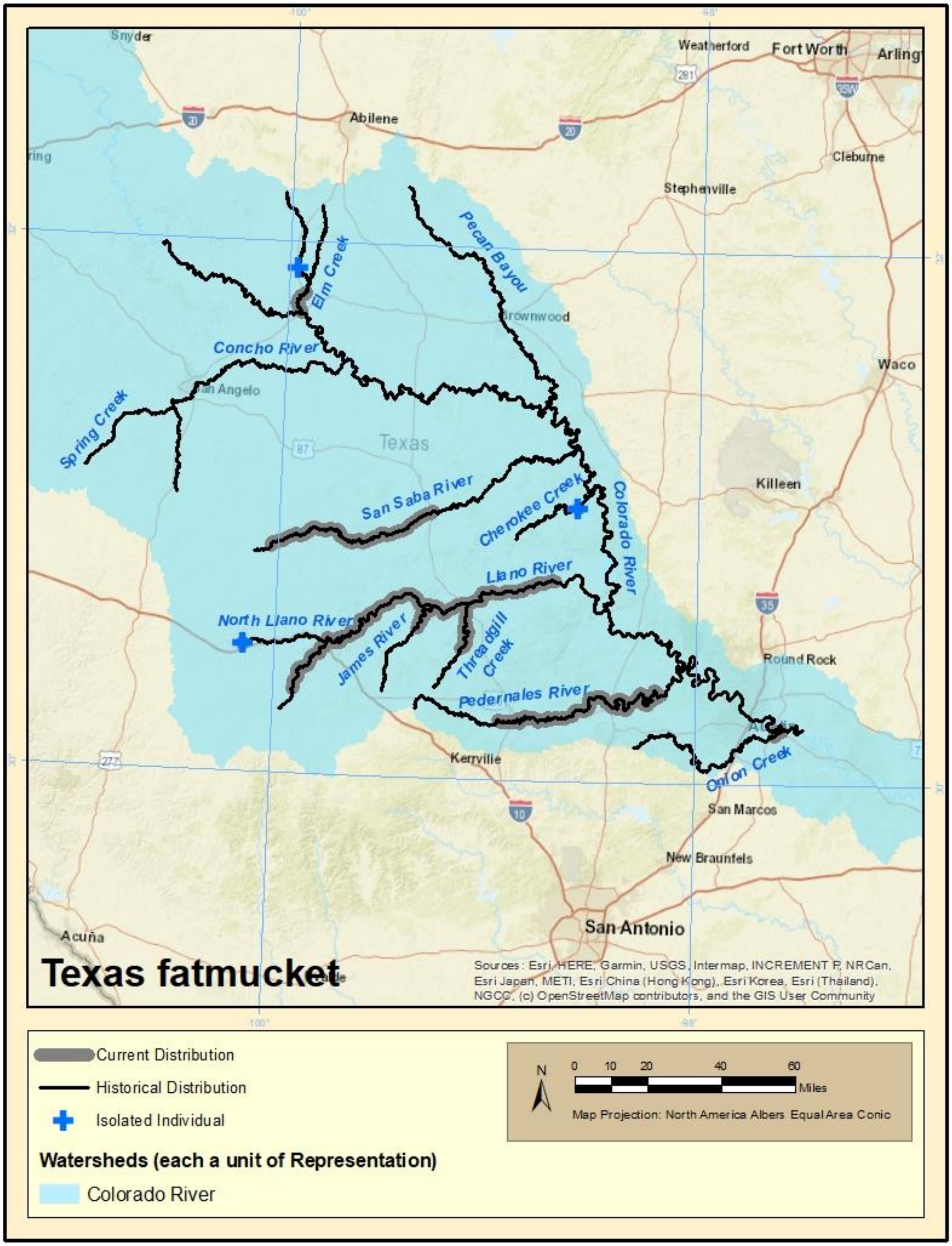


Figure 5.5. Location of each of the five current populations of Texas fatmucket in the Colorado River.

Elm Creek

The Texas fatmucket currently occupies about 8.7 stream miles of the Elm Creek. This population extends from the CR 330 bridge on Elm Creek downstream to the confluence with the Colorado River in Runnels County, Texas.

Howells (2006, p. 63) noted that live individuals of Texas fatmucket were encountered in surveys during 1993 (10 live) and 1995 (2 live). Since that time only two dead shells were noted during surveys in 2005 at this same site (Elm Creek near FM 216).

Burlakova and Karatayev (2010) reported collecting **1** live and 1 recently dead Texas fatmucket Elm Creek at County Road 261 in Runnels County in 2008 and report that none were found in the Colorado River west of Ballinger or from Bluff Creek north of Ballinger (p. 12).

Upper/Middle San Saba River

The population of Texas fatmucket is known to persist between the US 190 and U S87 bridge crossings of the San Saba River and inhabits a total of 62 river miles across Menard, Mason, and McCulloch counties, Texas.

Early reports of Texas fatmucket in the upper San Saba River are limited. Burlakova and Karatayev (2010) report finding **1** live Texas fatmucket in the San Saba River in Menard County in 2005 (p. 12). Howells (2006, p. 64) noted that **1** live Texas fatmucket was encountered during surveys in July 2005 and one half-shell. At the same site, **3** live individuals were noted during surveys in 1997.

Additional surveys continued to find low numbers of individuals. Braun et al. (2012, pp. 5, 14) report that three sites were surveyed in the San Saba River basin and at one location (Beyer Road Crossing, near Bois D'Arc Creek) **8** live individuals were collected as well as shell material of various ages. Service biologists found a total of **5** live Texas fatmucket during two separate surveys near the Bois D'Arc crossing on the San Saba River in 2013 (Braun et al. 2014, pp. 14-15). Tsakiris and Randklev (2014, p. 11) reported finding no live Texas fatmucket (or dead shell) from two locations, CR 340 and CR 126 bridge crossings, during surveys for other species.

More recent surveys were focused on known locations. In 2016, Service biologists (USFWS 2017, pp. 3-5) reported finding a total of **29** live Texas fatmucket at two sites in the San Saba River in Menard and McCulloch Counties, Texas.

Seagroves and Schwalb (2017, p. 11) reported finding **87** live Texas fatmucket from a single site following multiple sampling events in 2016. Randklev et al. (2017) report finding **71** live Texas fatmucket from 6 of 19 sites in the San Saba River, in Menard and McCulloch counties, Texas (pp. 42, 50).

Biologists from the Service, TPWD, and Texas A&M University found **5** fresh dead Texas fatmucket as well as other mussel species from 2 sites in the San Saba River (Menard County, Texas) during extremely low flow conditions. Those biologists concluded the mortality resulted from a combination of very low flow levels and increased predation (USFWS 2018, entire).

Service biologists found **18** live Texas fatmucket at one site in the San Saba River in Menard County, Texas. Live individuals ranged from 41-68mm total length. Four individuals showed evidence of inflated and swollen gills (indicating gravidity), two of which were taken to Inks Dam National Fish Hatchery as broodstock for captive propagation efforts. Those individuals were tagged, DNA swabbed, and returned to the point of capture, and culture methods with those individuals' glochidia are underway at this time (USFWS 2019, entire).

Llano River

The Llano River population of Texas fatmucket extends from the lower 20.9 miles of the South Fork of the Llano River to the mainstem of the Llano River for an additional 89.6 miles to the City of Llano's second municipal water storage lake, known as Llano City Lake. In addition to the mainstem Llano River, two of its tributaries, the James River and Threadgill Creek, are occupied with 11.5 and 5.4 stream miles, respectively. This accounts for a total of 127.4 stream miles of occupied habitat. The Llano River population is found in Kimble, Mason, and Llano counties, Texas, and includes a very small section of Threadgill Creek extending into northern Gillespie County.

In the Llano River, Texas fatmucket can be locally abundant. Burlakova and Karatayev (2010) report in August 2009 finding **3** live and 2 recently dead Texas fatmucket, in the Llano River "in the roots of cypress trees and other vegetation along steep banks" including at the FM 385 crossing near Yates in Kimble County (pp. 12-3). Sowards et al. (2012) report finding **33** live Texas fatmucket from the FM1871 crossing of the Llano River in Mason County, Texas, from "crevices in the bedrock containing loose deposits of silt and gravel" (p.4). Braun et al. (2012, p. 14) report finding no live, but fresh dead (mantle tissue present) shells at two sites in the Llano River near Castell (FM 2768) and Junction, Texas (CR 385).

Service biologists (USFWS 2016, p. 1) found **10** live Texas fatmucket from one site in the Llano River near Mason, Texas. This site was sampled on two different occasions, and the survey focus areas did not overlap (e.g., upstream of the bridge and downstream of the bridge), so recorded individuals are not likely to be repeat captures.

Seagroves and Schwalb (2017, p. 11) reported finding **72** live Texas fatmucket from one site during multiple surveys in 2016.

A number of surveys occurred in 2017 including Randklev et al. (2017c) who report finding **47** live Texas fatmucket from 7 of 20 sites in the Llano River (p. 42), in Mason and Llano Counties, Texas (p. 50). Additionally, Service biologists (USFWS 2017, p. 10) found five Texas fatmucket during a presence/absence survey at one location near Mason, Texas. Notes indicate that several individuals appear to be female and shell length measurements suggest that one was a juvenile (i.e., evidence of reproduction and subsequent recruitment).

BIO-WEST, Inc. (2018) reported capturing and removing **635** Texas fatmucket from Llano Park Lake on the Llano River near the City of Llano in Llano County, Texas, during a reservoir drawdown and complete dewatering event that occurred in November/December 2017 (pp. 2-3). These individuals represented a range of size classes (p. 3). Approximately 90 of these individuals were collected and taken for use in ongoing research projects. The remaining individuals were relocated 2-3 miles downstream (p. 3). No information about the survival of these translocated individuals was available at the writing of this report.

In 2019, an interagency team of biologists (TPWD, TX A&M, Baylor and the Service) located **6** live Texas fatmucket in the North Fork of the Llano River near Roosevelt, Texas (Randklev 2019b, entire).

In 2021, consultants completed a relocation of freshwater mussels at the FM 1871 bridge crossing of the Llano River near Mason, Texas in response to a proposed bridge replacement project at the existing crossing. During this relocation, the team collected **99** live Texas fatmucket and relocated them to a site upstream of the bridge crossing's proposed construction footprint (Blankenship, 2021).

Pedernales River

The Texas fatmucket is currently known to persist in the Pedernales River from the confluence of Live Oak Creek downstream to about the Ranch Road(RR) 3238 bridge crossing. This population also extends 2.5 stream miles upstream into Live Oak Creek. Presumably, these locations are connected and experience gene flow by host fish movements. In total, the Pedernales River population occupies 78.8 stream miles, including the section of Live Oak Creek. This population is largely contained in Gillespie and Blanco Counties with a small section of the Pedernales River reach extending into Hays County, Texas.

Texas fatmucket is known from the Pedernales River and several tributaries. Howells (2004, p. 8) reported **1** live and one shell with multiple single valves present in Live Oak Creek in 2003. Howells (2006, p. 65) reported 17 dead shells in 2004 and two live and three dead shells from 2005 during multiple surveys at the same site in Live Oak Creek. Additionally, Burlakova and Karatayev (2010) reported collecting **2** live Texas fatmucket in from Live Oak Creek (Gillespie County, Texas) in 2005 (p. 12).

Johnson et al. (2011) report finding **1** partially gravid female Texas fatmucket downstream of the Boos Lane Crossing of the Pedernales River in Gillespie, County, on April 22, 2011 (pp. 3-4), and Braun et al. (2012, p. 14) reported finding no live but fresh dead (mantle tissue present) at the same site the following year. Sowards et al. (2012) report finding **1** Texas fatmucket under the US 290 crossing of Rocky Creek (a Pedernales tributary) in Blanco, County, "in a loose gravel patch" (p. 4). Randklev et al. (2017) reported finding **18** live Texas fatmucket from 7 of 19 sites in the Pedernales River (p. 42), including 4 individuals from 2 sites in bank habitats in Live Oak Creek, and 7 individuals from a site upstream of the confluence with Live Oak Creek (near Fredericksburg, in Gillespie County, Texas; pp.43, 50).

Onion Creek

The Texas fatmucket population in Onion Creek is one of the smallest known. This population only occurs in the approximately 25-mile stream reach from just upstream of the Interstate 35 crossing to the Onion Creek and Colorado River confluence. This population is made up largely of only a handful of individuals that were found in the early 2000s and than again in recent years (see below for further discussion). The Onion Creek population is located entirely within Travis County, Texas. Wilkins et al. (2011) report finding **3** live Texas fatmucket near the SH 71 crossing of Onion Creek, in August 2010 (p. 9). However, subsequent surveys in 2012, 2013, and 2018 yielded no live or fresh dead Texas fatmucket (Sowards et al. 2012, p. 5; Cordova et al. 2013, p. 1; Bonner et al. 2018 p. 7; Inoue 2018, p. 1).

Inoue (2018, p. 1) searched for Texas fatmucket near the US Highway (Hwy) 71 crossing of Onion Creek with SCUBA for about 2.5 hours and found no sign of living or dead shell Texas fatmucket, but noted some more common species, including yellow sandshell and giant floater. Surveys noted that habitat consisted of a clay bottom with a silt and fine sand matrix, a habitat condition not expected to be suitable for Texas fatmucket.

In 2018, City of Austin biologists reported finding **1** live Texas fatmucket in Onion Creek near the confluence of the Colorado River and collected non-lethal DNA samples. Genetic confirmation concluded that this specimen is in fact Texas fatmucket (City of Austin 2018, entire). This individual also represented the first report of a live Texas fatmucket from Onion Creek since 2010.

In May 2021, TXDOT biologists collected **4** live Texas fatmucket near the SH 71 crossing of Onion Creek in Travis County, Texas during a preliminary study for an upcoming bridge repair project (Blair, 2021a). Animals were returned to their collection point and Servicebiologists were notified. These live animals were re-collected at a later date in May with the assistance of Servicebiologists. One female was determined to be gravid and was transported to Inks Dam National Fish Hatchery for propagation use, and the remaining live Texas fatmucket were relocated to suitable upstream habitats.

In 2021, TXDOT biologists reported finding **1** live, gravid Texas fatmucket beneath the Interstate 35 crossing of Onion Creek in Travis County, Texas (Blair, 2021b). The live Texas fatmucket was relocated by TXDOT personnel to suitable habitat upstream of the proposed bridge construction project.

Isolated Texas fatmucket Records

ELM CREEK

In June 2019, surveys were conducted in Bluff and Elm creeks. During these surveys biologists from TPWD, the Service, and Texas A&M University located **2** live and one fresh-dead Texas fatmucket. These individuals represent the first live individuals encountered at these sites in nearly a decade (Randklev 2019b, entire).

CHEROKEE CREEK

Texas State University and Bio-West biologists completed a survey of Cherokee Creek in 2017. During this survey, the team collected **2** live Texas fatmucket from the lower reaches of the stream (Bonner 2018, p. 31). The presence of **13** live Texas fatmucket in Cherokee Creek were then confirmed by a team of biologists from Texas A&M University in 2019 (Inoue et al. 2019, p. 6).

NORTH LLANO RIVER

TPWD biologists (2015) reported finding a total of **11** live Texas fatmucket near Sutton County Park on the North Fork of the Llano River. However, due to downstream water quantity issues (the North Fork of the Llano River dries during summertime drought conditions) this location is most likely isolated from other individuals in the Llano River system (Inoue et al. 2019, p. 21).

5.D.2 Areas Presumed Extirpated

Texas fatmucket is historically known from the upper portions of the Colorado Basin and is not thought to have occurred in the lower portions of those basins in the “coastal plain” (Howells 2014, pp. 41-2; and reviewed in Randklev et al. 2017, pp. 39-40). While several lone individuals were found in the Middle Colorado River (Bonner et al. 2018, pp. 20, 29), existing data do not support evidence of a population. This small, isolated watershed likely does not represent a currently reproducing population. Bonner et al. (2018) report searching for, and not finding, Texas fatmucket from Pecan Bayou (p. 7).

The middle portion of the San Saba River regularly goes dry, and the 2011-2012 droughts had a particularly large impact on this reach. Burlakova and Karatayev (2012, p. 14) found 65 very recently dead individuals in this area of the river during this drought. Scattered individuals may still persist in this reach, but existing data do not suggest evidence of a reproducing population.

5.D.3 Current Conditions of Texas fatmucket

To summarize the overall current conditions of Texas fatmucket populations, we sorted them into three categories (healthy, moderately healthy, and unhealthy) based on the population factors and habitat elements discussed in Chapter 3 and displayed in Table 5.6. Table 5.7 shows the overall condition of Texas fatmucket populations, as displayed in Figure 5.6.

Table 5.6. Population and habitat characteristics of Texas fatmucket populations used to create condition categories in Table 5.7.

	Population Factors			**Habitat Factors**		
Condition	**Occupied Stream Length**	**Index of Abundance**	**Evidence of Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**
Healthy	> 50 river miles	Found in nearly all available habitats surveyed during a reasonable survey effort. More than 100 individuals found per population survey.	50% or more sites with juveniles (< 35 mm) detected and gravid females present during the breeding season and fish hosts present.	Bedrock fissures and/or vegetative crevices present. Substrate sufficient to provide anchoring within crevices but not filled with sediment.	Flowing water present year-round. No recorded periods of zero flow days. Water levels sufficient to keep known habitats submerged.	No known incidence of contaminant spills, low dissolved oxygen, or evidence of exposure extreme high or low temperatures.
Moderately Healthy	49–20 river miles	Found in approx. 50% of all available habitats surveyed during a reasonable survey effort. Between 26 – 99 individuals found per population survey.	25–50% of sites with juveniles (< 35 mm) detected, gravid females present during the breeding season and fish hosts present in at least moderate abundance.	Bedrock fissures and crevices present. Substrate sufficient in places to provide anchoring while other areas scoured or too heavily filled with sediment.	Flowing water present almost year-round. Few instances of zero flow days or minimal exposure of portions of known habitats.	Contaminants known, low dissolved oxygen and temperature extremes documented. Levels not high enough to risk extirpation.
Unhealthy	< 19 river miles	Found in few areas of suitable habitat during a reasonable survey effort. Between 2 – 25 individuals found per population survey.	< 25% of sites with juveniles (<35 mm) detected, gravid females present during the breeding season, and fish host present in low abundance and/or ability to disperse is reduced.	Fissures and crevices obstructed with excess sediment. Relatively high amount of sedimentation and filling of interstitial spaces.	Flowing water does not persist year-round. Summer records of zero flow days while pools stay wetted and sufficiently cool and oxygenated.	Known exposure to contaminants, low dissolved oxygen, and documented cases of excessive water temperatures extremes. Water quality parameters diminished such that exposure threatens mussel survival.
Extirpated/ Func. Extirpated	none	Very few or no live individuals documented during surveys (≤ 1).	No evidence suggesting that juveniles or gravid females are present. Fish host not known to occur.	No suitable habitats present.	Dry stream bed or zero flow days high enough to preclude survival.	Water quality degradation such that occupancy of otherwise suitable habitat is precluded.

Table 5.7. Current condition of Texas fatmucket populations.

		Population Factors			**Habitat Factors**			
Basin	**Population**	**Occupied Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Colorado	**Elm Creek**	Unhealthy	Unhealthy	Unhealthy	Moderate	Unhealthy	Unhealthy	**Unhealthy**
	San Saba	Healthy	Moderate	Moderate	Moderate	Moderate	Moderate	**Moderate**
	Llano	Healthy	Moderate	Unhealthy	Moderate	Moderate	Moderate	**Moderate**
	Pedernales	Healthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
	Onion Creek	Moderate	Unhealthy	Unhealthy	Unhealthy	Moderate	Unhealthy	**Unhealthy**

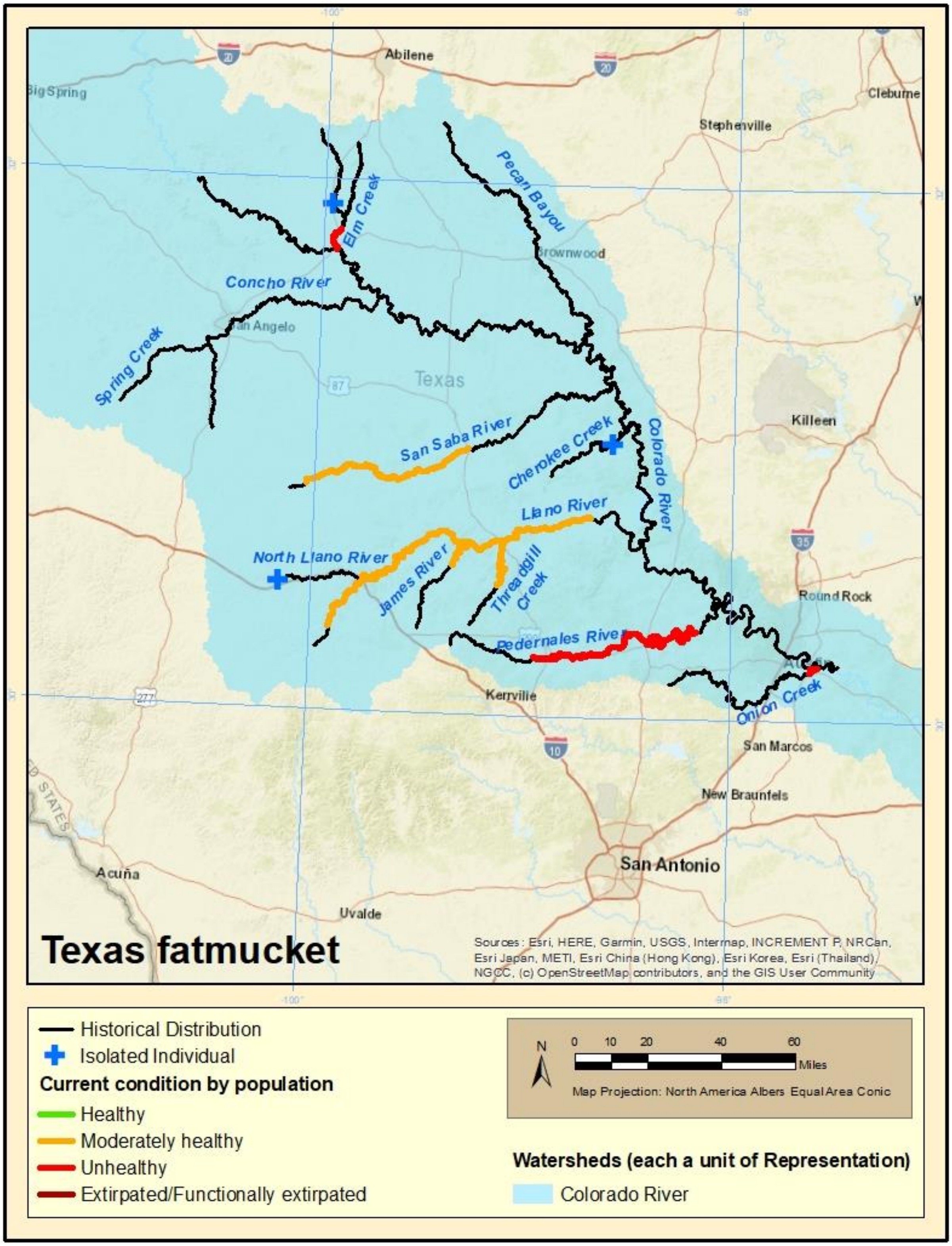


Figure 5.6. Location and current condition for the five current populations of Texas fatmucket in the Colorado River basin.

5.D.4 Current Population Resiliency

The Texas fatmucket is known to currently occur in the Colorado River basin. There are five populations of Texas fatmucket. Two of the populations are currently in moderately healthy condition and three are in unhealthy condition.

5.D.5 Current Species Representation

We consider the Texas fatmucket to have representation in the form of genetic and ecological diversity in the Colorado River basin. As discussed in Chapter 2, the genetic structure of these five populations indicates that there is some level of genetic differentiation among populations (Inoue et al. 2018, pp. 4, 10, 13).

5.D.6 Current Species Redundancy

Within these identified representation areas, the Colorado River basin has five separate populations and therefore a moderate level of redundancy.

5.E Texas fawnsfoot

5.E.1 Current Distribution

Texas fawnsfoot occurs in the lower reaches of the Colorado and Brazos Rivers, (Randklev et al. 2017, p. 4), as well as in the main stem of the Trinity River (Figure 5.7). Among these three basins, Texas fawnsfoot currently inhabits 659.7 stream miles of a presumed 3,540.5 stream miles, representing 18.7% of its presumed historical distribution. This approximate range reduction assumes the species continuously occupied its entire historical range, which is unlikely given the species' specialized habitat preferences.

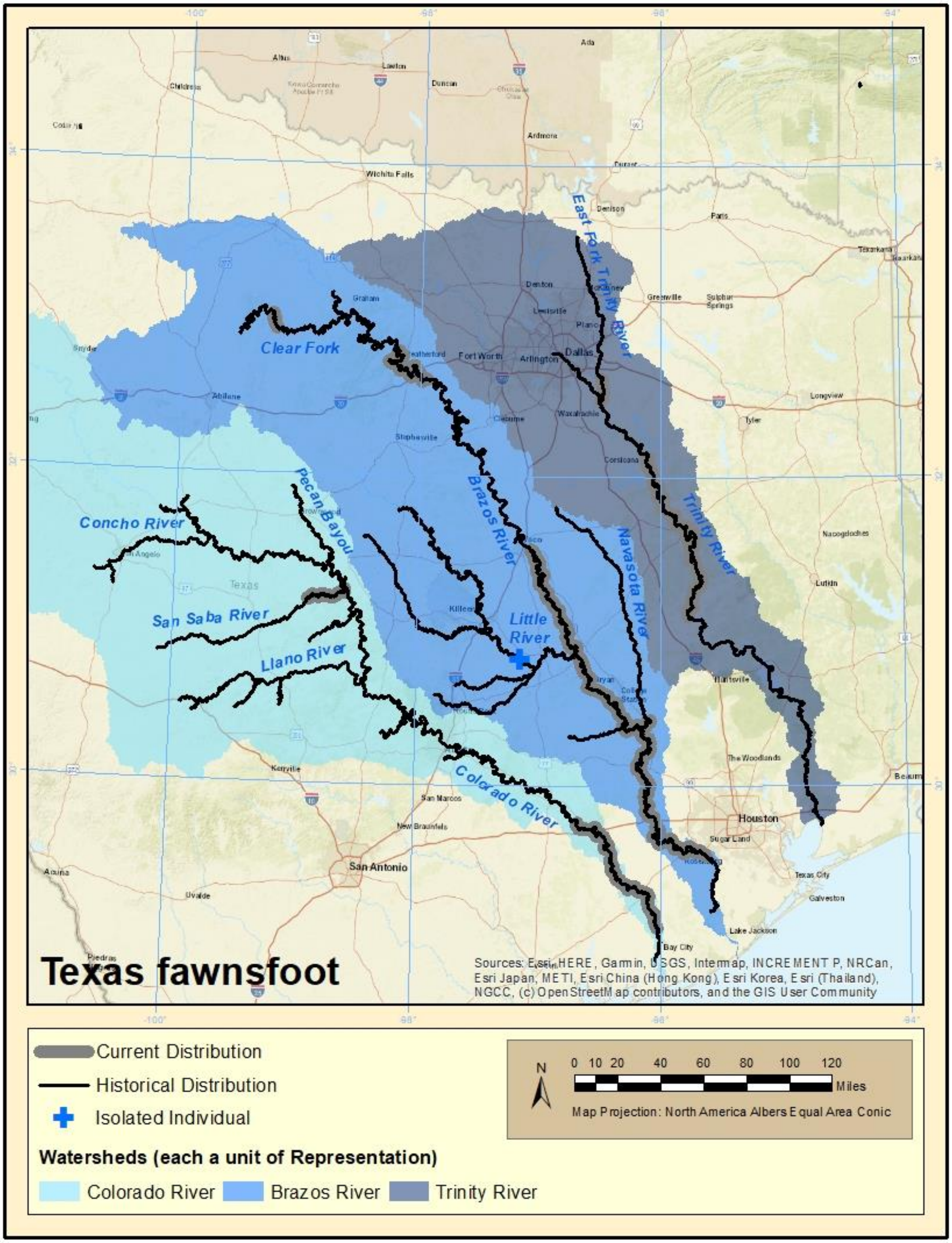


Figure 5.7. Location of each of the seven current populations of Texas fawnsfoot in the Trinity, Brazos, and Colorado Rivers.

Lower East Fork of the Trinity River

The East Fork Trinity River population is 11.8 stream miles in length and extends upstream of the Trinity River confluence to roughly the Hwy 187 bridge crossing. This stretch of river is in Kaufman County and extends to the Kaufman and Ellis Counties northeastern border.

Randklev et al. (2017b, p. 16) reported finding **40** Texas fawnsfoot in bank and riffle habitats of the Trinity River. The species was more abundant in the middle reaches relative to the other reaches including the East Fork (pp. 10, 16). Additionally, Randklev (2018, p. 1) reported finding **12** live Texas fawnsfoot from the East Fork of the Trinity River among three sites surveyed in 2017.

Middle Trinity River

The Texas fawnsfoot is found in the mainstem Trinity River just upstream of the Hwy 287 crossing downstream to the Madison and Walker counties, for a total of 139.8 stream miles. This section of river flows through Navarro County, Anderson, Leon, Houston, and Madison counties, Texas.

Texas fawnsfoot appears to have been extirpated from approximately 90% of its historical range in the Trinity Basin (Randklev et al. 2017, p. 11). Randklev et al. (2017) surveyed the Trinity River drainage in 2014-2017 and found that mussel species richness and abundances were “greatest in the middle Trinity near Oakwood, TX, and in the Elm Fork of the Trinity River” although richness and abundance were both reduced immediately downstream of the Dallas-Fort Worth metroplex and Lake Livingston (p. 2). In total, fifty-nine **59** live Texas fawnsfoot were found throughout this reach between 2016 and 2017.

Lower Clear Fork of the Brazos River

This population occurs in the Clear Fork of the Brazos River from near Fort Griffin, at the US Hwy 283 bridge crossing, upstream 12.2 miles to the CR 292 bridge crossing, in Shackelford and Throckmorton counties, Texas.

In 2010, HDR Engineering, Inc. was contracted to perform 56 mussel surveys throughout the Clear Fork Brazos River basin. In total, **one** live Texas fawnsfoot, and 264 dead individuals were found. Surveys were conducted in the Clear Fork of the Brazos River, and in several tributary streams (Mulberry, Elm, and Deadman creeks). The only live Texas fawnsfoot was recovered from the Clear Fork Brazos near Fort Griffin (HDR Engineering 2010, pp. 4-6; HDR Engineering 2011, p. 4).

Bonner et al. (2018) surveyed the Clear Fork of the Brazos River and in the Brazos River above Possum Kingdom Reservoir basin (p. 15), but report “dead shell material suggesting a once diverse mussel community” possibly resulting from widespread dewatering of the river during the drought years of 2011-13 (p. 25). No live Texas fawnsfoot were found.

Upper Brazos River

The Texas fawnsfoot population in the upper Brazos River extends from the Hwy 180 crossing downstream to Interstate Hwy 20 for a total of 62.2 stream miles, in Palo Pinto and Parker counties, Texas between Possum Kingdom and Granbury Lakes.

Bonner et al. (2018, p. 10) found **1** live Texas fawnsfoot in the Brazos River near the US Hwy 281 bridge crossing, and Randklev (2018, p. 1) found a total of **23** live Texas fawnsfoot in the upper Brazos River upstream of Interstate Hwy 20 to approximately the Hwy 180 bridge crossing.

Middle/Lower Brazos River

This population of Texas fawnsfoot occupies a total of 331.9 miles of the Brazos River mainstem from State Highway 6 crossing (south of the City of Waco) downstream to about two miles south of the Highway 69 crossing near Sugar Land, Texas. This population occurs in McLennan, Falls, Robertson, Milam, Brazos, Burleson, Grimes, Washington, Waller, Austin, and Fort Bend counties, Texas. The population also extends into the lower 14.5 miles of the Navasota River (a Brazos River tributary) in Grimes and Brazos counties, Texas. In total, this population occupies 346.4 stream miles. However, the areas with the greatest known abundances are in the lower Brazos River downstream of the Navasota River confluence.

In 2009, Randlev et al. (2010, pp. 297-8) found a population of Texas fawnsfoot in the Brazos River near its confluence with the Navasota River (Grimes and Washington counties, Texas), 8 km southwest of Navasota, Texas, in a reach of the river "characterized by steep banks with extensive riparian vegetation" in a "shallow pool with soft sandy sediment" and report that their finding is "the first record of a population of *T. macrodon* since its initial description in 1859." This finding was also reported in Randklev et al. (2010) where the site was described as near SH 105 on the left bank of the river (pp. 17,19, 51).

Burlakova and Karatayev (2010) reported collecting **1** Texas fawnsfoot and few recent dead from 27 locations along the Brazos River in 2006-2007 (p. 17). Howells (2010) reported 34 fresh dead Texas fawnsfoot shells were collected from the Brazos River downstream of Highway 21 in Brazos and Burleson Counties, Texas, and that the shells represented "both sexes as well as mixed sizes and ages" (pp. 21-2).

Pease et al. (2014) report finding a single subfossil (long dead) was found at the Highway 67 Bridge crossing near Glen Rose, in Somervell County, Texas in 2012 (p. 13).

Randklev et al. (2014) found approximately **188** live Texas fawnsfoot from 29 of 92 sites sampled in the Lower Brazos River from Austin and Fort Bend Counties (pp. 22-37, 44-45), mainly from bank habitats with moderate water depth, slow to moderate flows, and fine firmly compacted sediments (p. 2).

Tsakiris and Randklev (2016) report finding **21** live Texas fawnsfoot from 2 sites in the lower portions of Yegua Creek, at the confluence with the Brazos River (pp. 122-3).

In September 2017, biologists from the Service, TXDOT, and TPWD found a total of **28** live Texas fawnsfoot at the FM 413 bridge crossing. These mussels were relocated upstream. In addition, 18 shells were collected with no tissue inside and 24 fresh dead shells (with tissue intact) were found, 12 of these were retained for genetic analysis (Tidwell 2017, entire). These animals were all quite small, suggesting evidence of recent reproduction and recruitment. The animals were found in a shallow area, downstream of an island forming around a bridge pylon in sand and small gravel particles. Several individuals were < 20 mm (total shell length) with evidence of byssal threads for attachment, a characteristic of juvenile mussels.

In August 2021, Bio-West and BRA completed surveys approximately 7.5 miles upstream of the Intestate 20 crossing of the Brazos River and collected **1** live Texas fawnsfoot.

Further research into the population dynamics of this species and predator/prey interactions with its presumed affiliate host fish, the molluscivorous freshwater drum, may help explain apparently moderately low abundances of the Texas fawnsfoot in the Lower Brazos River.

Lower San Saba/Middle Colorado River

The population occurs from the CR 340 bridge crossing downstream to the Colorado confluence and for the first one mile the Colorado River downstream of the San Saba River confluence. This population of Texas fawnsfoot has a total stream distance of approximately 43 miles, in San Saba and Mills counties, Texas.

Howells (2000) reported finding one fresh dead Texas fawnsfoot shell from the Colorado River upstream of State Hwy 16 (and above the confluence with the San Saba River) in Mills and San Saba counties, Texas, and reports it as "the largest specimen reported to date" (56 mm total shell length; pp. 25-6). Sowards et al. (2013) reported finding three live individuals from a series of run-riffle-pool habitats in the San Saba River, east of the City of San Saba, in July 2012 (pp. 64-5). Tsakiris and Randklev (2014, p. 11) reported finding **7** live Texas fawnsfoot from two locations on the San Saba River (at the CR 340 and CR 126 bridge crossings). Most recently, in 2017, Randklev et al. (2017) reported surveying the San Saba River, and no live Texas fawnsfoot or shells were found (p. 135). Bonner et al. 2018 report 1 Texas fatmucket (14 mm length) was collected from the Middle Colorado River near San Saba, Texas (p. 265).

Biologists with the Service and Texas A&M University discovered **1** live Texas fawnsfoot while conducting quadrat sampling with excavation in the lower San Saba River near the confluence with the Colorado River. This individual was a juvenile (12mm), indicating recent reproduction (USFWS 2018, entire).

Lower Colorado River

This Texas fawnsfoot population stretches for a 108.6-mile river area. Texas fawnsfoot are known to occur from about 9 river miles upstream of the US Hwy 71 crossing west of Columbus, Texas, downstream approximately to the Texas State Highway 35 crossing east of Bay City, Texas. The population occurs in Colorado, Wharton, and Matagorda Counties.

Burlakova and Karatayev (2010) reported collecting **52** Texas fawnsfoot "on a sandy shore of the Colorado River", near Garwood in Colorado County in April 2009 (p. 17). Near that location in 2013, Service biologists found **4** gravid females during two surveys near the same site (FM 950 crossing) in the vicinity of Garwood, Texas. Service biologists found ten live Texas fawnsfoot during a survey at approximately this same location in 2016.

In 2015, Service biologists found over **10** Texas fawnsfoot and fresh dead shells in bank habitats and shallow water in the Colorado River near Lane City in Wharton County, Texas.

Most recently, Bonner et al. (2018) found **9** live Texas fawnsfoot from 7 sites in the Lower Colorado River basin (p. 28), from Colorado County to Matagorda County (p. 21).

Isolated Texas fawnsfoot Records

LITTLE RIVER AND BRUSHY CREEK

Randklev et al. (2017) reported finding **4** live Texas fawnsfoot from 2 of 9 sites in the Little River, near Buckholts in Milam County (p. 139), but not from the San Gabriel River (searched 20 sites) and Brushy Creek (searched 30 sites) in Williamson and Milam counties, Texas (p. 148).

In August 2021, Bio-West and BRA biologists completed surveys in Little River and Brushy Creek and collected **3** live Texas fawnsfoot from 2 sites near the FM 1915 crossing in the Little River and **1** live Texas fawnsfoot near the FM 908 crossing of Brushy Creek.

5.E.2 Areas Presumed Extirpated

Texas fawnsfoot was historically distributed throughout the Colorado and Brazos basins (Howells 2014, p. 111-2; and reviewed in Randklev et al. 2017c, pp. 136-7) and in the Trinity basin (Randklev et al. 2017b, p. 11). Texas fawnsfoot historically occurred in the Leon River (Brazos Basin) but is now absent (Popejoy et al. 2016, p. 477). Randklev et al. (2017c, p. 135) surveyed for Texas fawnsfoot in the Llano, San Saba, and Pedernales rivers and found no individuals or dead shell material.

5.E.3 Current Conditions

To summarize the overall current conditions of Texas fawnsfoot populations, we sorted them into three categories (healthy, moderately healthy, and unhealthy) based on the population factors and habitat elements discussed in Chapter 3 and displayed in Table 5.8. Table 5.9 shows the overall condition of Texas fawnsfoot populations, as displayed in Figure 5.8.

Table 5.8. Population and habitat characteristics of Texas fawnsfoot populations used to create condition categories in Table 5.9.

	Population Factors			**Habitat Factors**		
Condition	**Occupied Stream Length**	**Index of Abundance**	**Evidence of Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**
Healthy	> 50 river miles	Found in nearly all available habitats surveyed during a reasonable survey effort. More than 100 individuals found per population survey.	50% or more sites with juveniles (< 35 mm) detected and gravid females present during the breeding season and fish hosts present.	Clay, mud, and sandbanks present. Streambanks stable and excessive erosion not documented.	Flowing water present year-round and sufficient to maintain water quality. No recorded periods of zero flow days. No documentation of dewatered habitats.	No known incidence of contaminant spills, low dissolved oxygen, or evidence of exposure extreme high or low temperatures
Moderately Healthy	49–20 river miles	Found in approx. 50% of all available habitats surveyed during a reasonable survey effort. Between 26 – 99 individuals found per population survey.	25–50% of sites with juveniles (< 35 mm) detected, gravid females present during the breeding season and fish hosts present in at least moderate abundance.	Clay, mud, and sand banks present. Streambanks mostly stable with some erosion/scouring.	Flowing water present year-round, but water levels approaching low levels. No instance of zero flow days and stream bank drying deviates from appropriate hydrology, with limited habitat desiccation.	Contaminants known, low dissolved oxygen and temperature extremes documented. Levels not high enough to risk extirpation.
Unhealthy	< 19 river miles	Found in few areas of suitable habitat during a reasonable survey effort. Between 2 – 25 individuals found per population survey.	< 25% of sites with juveniles (<35 mm) detected, gravid females present during the breeding season, and fish host present in low abundance and/or ability to disperse is reduced.	Stream unstable and substantial erosion occurring associated with high flow events. Suitable substrate limited to isolated locations, based on site-specific hydrogeological conditions.	Flowing water does not persist annually. Stream banks documented to dry during low flow. Habitat dewatering occurs somewhat regularly.	Known exposure to contaminants, low dissolved oxygen, and documented cases of excessive water temperatures extremes. Water quality parameters diminished such that exposure threatens mussel survival.
Extirpated/ Func. Extirpated	none	Very few or no live individuals documented during surveys (≤ 1).	No evidence suggesting that juveniles or gravid females are present. Fish host not known to occur.	No suitable habitat present.	Dry stream bed or zero flow days high enough to preclude survival.	Water quality degradation such that occupancy of otherwise suitable habitat is precluded.

Table 5.9. Current condition of Texas fawnsfoot populations.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Brazos	**Clear Fork Brazos**	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
	Upper Brazos	Healthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
	Lower Brazos	Healthy	Moderate	Moderate	Moderate	Healthy	Moderate	**Moderate**
Colorado	**Lower San Saba**	Moderate	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	**Unhealthy**
	Lower Colorado	Healthy	Moderate	Healthy	Moderate	Moderate	Moderate	**Moderate**
Trinity	**East Fork Trinity**	Unhealthy	Moderate	Unhealthy	Moderate	Moderate	Moderate	**Moderate**
	Trinity	Healthy	Moderate	Unhealthy	Moderate	Moderate	Moderate	**Moderate**

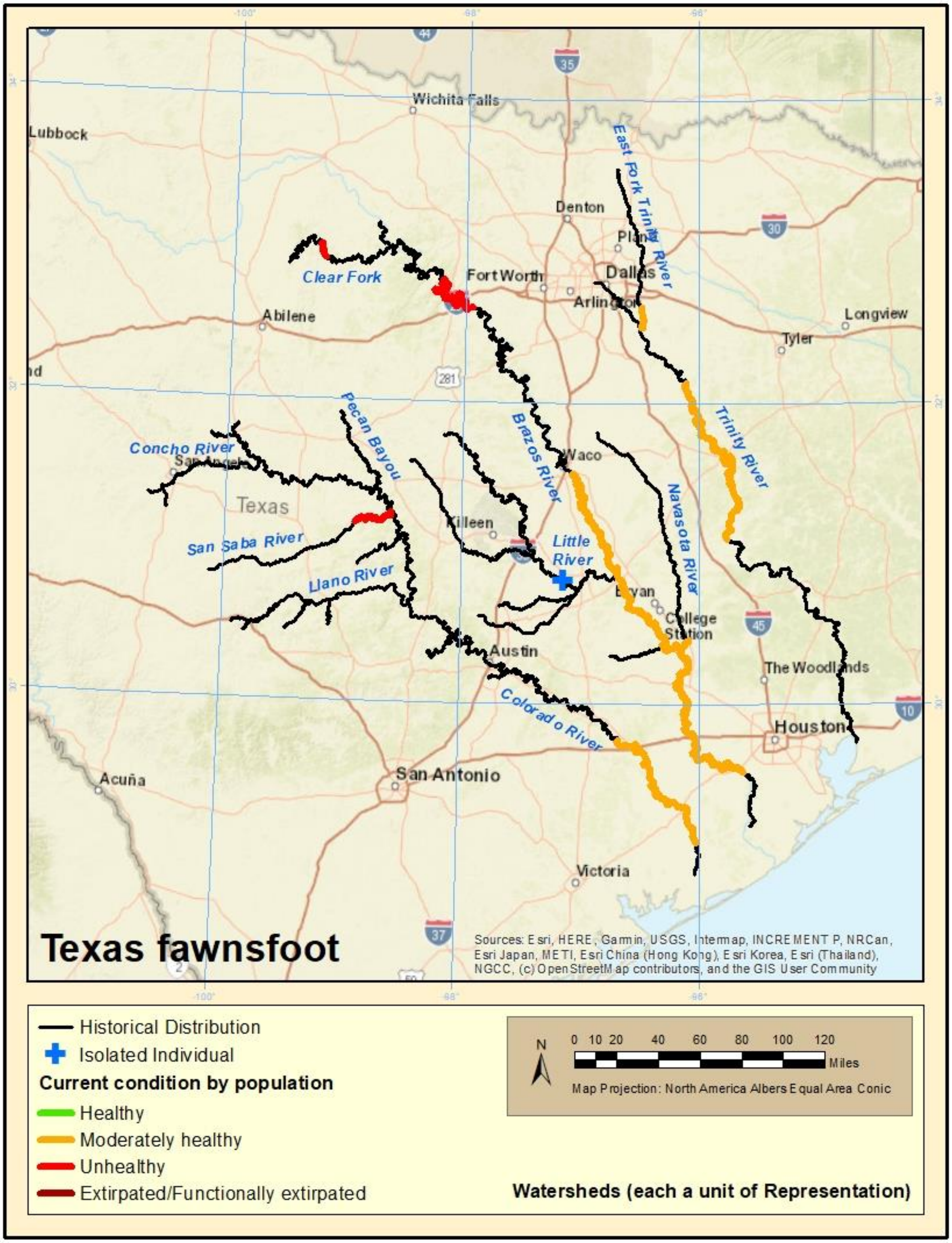


Figure 5.8. Location and current condition of the seven populations of the Texas fawnsfoot in the Trinity, Brazos, and Colorado River basins.

5.E.4 Current Population Resiliency

The Texas fawnsfoot is known to occur in three river basins: the Trinity, Brazos, and Colorado. The species has a total of seven populations spread across these three basins. In the Trinity River basin, two populations are currently isolated from one another and are in moderately healthy condition. The Trinity River populations both exhibit low resiliency. The Brazos River contains three populations of Texas fawnsfoot: the Clear Fork Brazos, upper Brazos, and lower Brazos River populations. Prior to dam construction, these populations were likely all once connected, but now they are isolated from one another. Two of the populations are in unhealthy condition and one is moderately healthy. The Colorado basin contains two isolated populations of Texas fawnsfoot. The lower Colorado population is currently moderately healthy and has a relatively large geographic area. The San Saba River population is unhealthy and therefore has low resiliency.

5.E.5 Current Species Representation

We consider the Texas fawnsfoot to have representation in each of three river basins: the Trinity, Brazos, and Colorado River basins (Figure 5.8).

5.E.6 Current Species Redundancy

Within these identified representation areas, Texas fawnsfoot is known from two populations in the Trinity River basin, three in the Brazos River basin, and two in the Colorado River basin.

5.F Texas pimpleback

5.F.1 Current Condition

Texas pimpleback is known from the Colorado River basin. Texas pimpleback currently is found in a combined 325 river miles of a presumed historical range of 1,574.2 stream miles. The species is believed to currently occur in approximately 21% of its historical range. This approximate range reduction assumes the species continuously occupied its entire historical range, which is unlikely given the species' specialized habitat preferences.

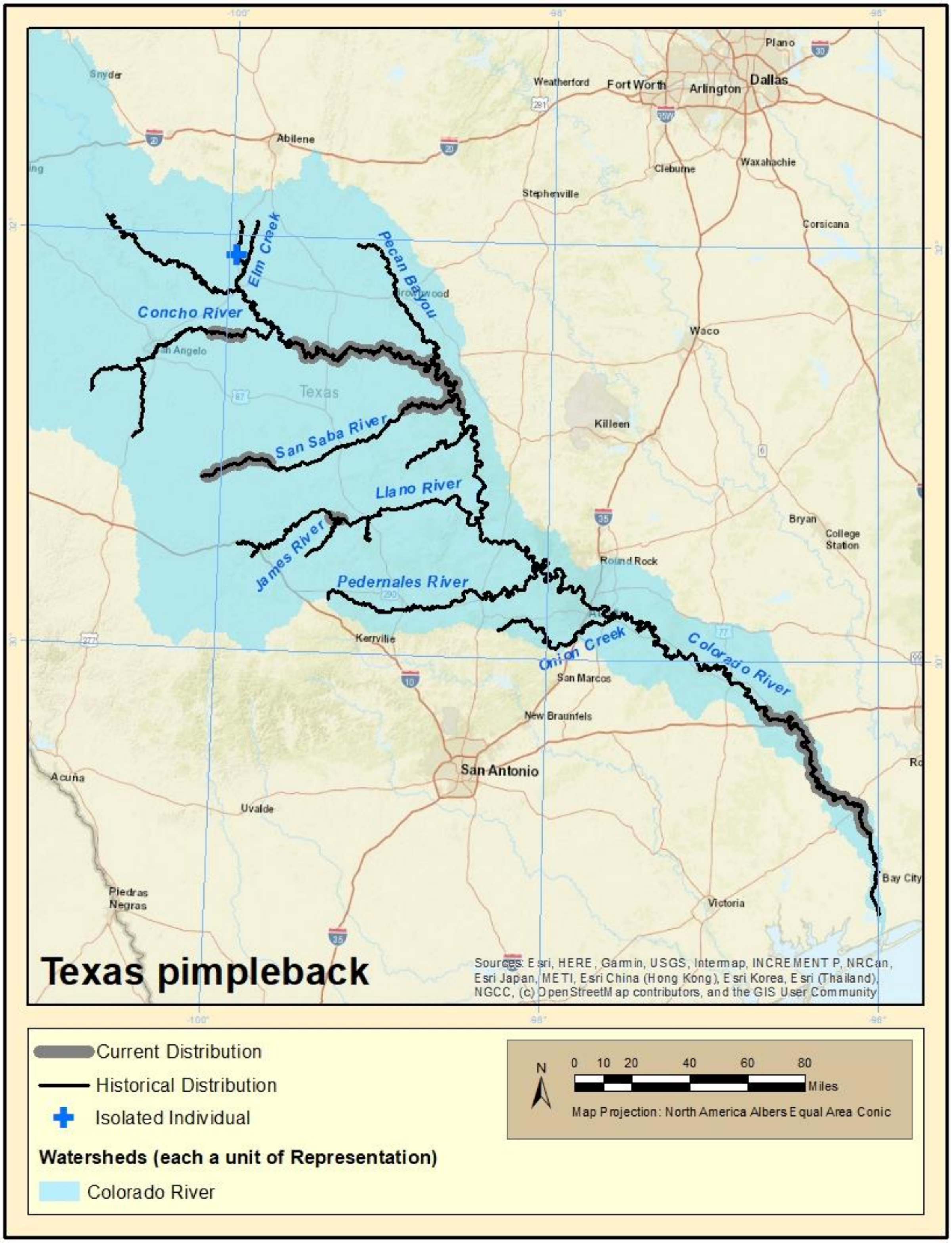


Figure 5.9. Location of each of the five current populations of Texas pimpleback in the Colorado River basin.

Lower Concho River

This population extends for 14.1 stream miles from the FM 381 bridge crossing to the US Hwy 83 bridge crossing near Paint Rock and entirely within Concho County, Texas. This population of Texas pimpleback appears to be very small, if not already extirpated, and apparently consists entirely of only large, old individuals; evidence of a population that is not reproducing and recruiting new cohorts. Burlakova and Karatayev (2010) reported collecting **47** live Texas pimpleback in July-August 2008 and stated that this population was probably the only large remaining population of the species, and that the population did not appear to be reproducing (p. 11). This population experienced very low flows during the 2011-12 drought (Burlakova and Kratayev 2010, pp. 101-1), and very few live individuals have been found since that drought (Blair 2018, p. 1). The population was apparently experiencing a lack of recruitment prior to the drought, and the drought appeared to have likely eliminated the adults. The North Concho River frequently goes dry during the summer, and streamflows were "at or below normal during all of 2011, except for a brief period of storm runoff in August 2011" (USGS 2013, pp. 13, 18).

At another site in the Concho River, Howells (2000, p. 23) reported finding dead shells of Texas pimpleback in abundance in Concho County, Texas, where the flow had been so reduced such that only isolated pools remained watered. Similarly, Howells (2000, p. 23) reported finding dead shells of Texas pimpleback from the Paint Rock City Park, in a dry reach of the Concho River with only isolated pools.

Blair (2018, entire) reported searching for and finding only one live Texas pimpleback in the Concho River near Paint Rock in 2012. During multiple surveys by other researchers in 2013, and 2016 no live Texas pimplebacks were recorded. This apparent lack of any small or large animals, alive or dead shell, suggests that population is functionally, if not actually, extirpated.

Upper San Saba River

This population extends for 29.6 stream miles from the FM 864 bridge crossing downstream to the RR 2092 bridge crossing in Menard County, Texas.

Service biologists collected fresh dead shells from the San Saba River near Menard, Texas, in 2013. Randklev et al. (2017, p. 108) found one live Texas pimpleback from a riffle near Menard, Texas in 2017.

Lower San Saba and Middle Colorado River

The Texas pimpleback population occurs in the lower 41.9 miles of the San Saba River, from the CR 340 crossing downstream to the Colorado River confluence. The population occurs in the Colorado River from the FM 503 crossing (downstream of lake O.H. Ivie) to the Hwy 190 crossing just downstream of the Colorado-San Saba River confluence for a total Colorado River population of 136.5 miles. In total, this population is 178.4 stream miles long and is in San Saba, McCulloch, Mills, Brown, and Coleman counties, Texas.

Howells (2000, pp. 25-6) found 3 fresh dead Texas pimpleback shells from the Colorado River upstream of SH-16 above the confluence with the San Saba River, in Mills and San Saba Counties, Texas. Similarly, in 2011, three live individuals were found in the Colorado River downstream of CR 266 (Randklev 2018, p. 1).

In 2012, **21** live Texas pimpleback were found from 4 different sites in the San Saba River in San Saba County Texas, and in 2013, **15** live animals were found from the San Saba River in San Saba County, Texas (Braun et al. p. 14-15).

Sowards et al. (2013) reported finding **247** live individuals from a series of run-riffle-pool habitats in the San Saba River, east of the City of San Saba, in July 2012 (pp. 64-5), and Tsakiris and Randklev (2014, p. 11) reported finding **481** live Texas pimplebacks from two locations (CR 340 and CR 126 bridge crossings) in the San Saba River.

In 2017, Service biologists found **15** live Texas pimpleback during surveys in San Saba County (CR 340) crossing (USFWS 2017, p. 6) and **5** live Texas pimpleback from the San Saba River near San Saba, Texas (USFWS 2017, p. 9).

Bonner et al. (2018) reported finding **97** live Texas pimpleback from 6 sites in the "Middle Colorado River" basin, defined as from O.H. Ivie Reservoir to Lake Buchanan (pp. 6, 29), with the majority of occurrences in San Saba County, below the San Saba River confluence (p. 19), and reported new observations of five live individuals below O.H. Ivie Reservoir in Coleman County, Texas (p. 22). A mark-recapture study reported capturing 394 Texas pimpleback and estimated that 254 – 490 Texas pimpleback occur within a 300 m^2 sampling area in the Middle Colorado River near San Saba, Texas (Bonner et al. 2018, pp. 267-8).

In 2018, Service and Texas A&M biologists found a total of **42** live Texas pimpleback from two sites in the lower San Saba River near the confluence with the Colorado River mainstem (USFWS 2018, entire). These specimens included adult and juvenile mussels, which indicated evidence of reproduction in recent years.

In 2019, Service biologists found **23** live Texas pimplebacks from one site in the mainstem Colorado River below the confluence of the San Saba River in Lampasas County, Texas. Individuals encountered during this survey ranged in total length from 32-79mm and included juveniles and adults, providing evidence of a recent reproduction event. Five individuals were transported to Inks Dam National Fish Hatchery for captive broodstock. One female Texas pimpleback expelled conglutinates, which were collected for use in efforts supporting captive propagation. All five individuals were tagged, DNA swabbed, and returned to the site of capture (USFWS 2019, entire).

Llano River

The Llano River population of Texas pimpleback occupies only 4.9 miles of the Llano River from FM 1871 downstream to the RR 2389 bridge crossing in Mason County. Mussel populations in this area including Texas pimpleback see considerable scientific and research collection activities due to its ease of access and proximate location to major cities.

Sowards et al. (2012) report finding **10** live Texas pimpleback from the FM1871 bridge crossing of the Llano River in Mason County, Texas, from "gravel deposits containing macrophytes" (p. 4).

In 2016, Service biologists found one live Texas pimpleback from one site near Mason, Texas during a reconnaissance survey. Biologists noted the presence of several old shells including one that had been tagged (unknown source) in an apparent previous study. Additionally, in 2016 Service biologists found eight live Texas pimpleback from one site near Mason, Texas during a reconnaissance survey. Biologists noted the presence of multiple size classes (26–55 mm total length) indicating possible recent recruitment.

Randklev et al. (2017) report finding **23** live Texas pimpleback from 3 sites on the Llano River, near Mason, Texas, upstream of the confluence with the James River, in pool and pool/run habitats, and note some evidence of recruitment (p. 108).

BIO-WEST, Inc. (2018) reported finding and relocating **1** Texas pimpleback from Llano Park Lake on the Llano River near the City of Llano in Llano County, Texas, during a reservoir drawdown and dewatering event that took place in November and December of 2017 (pp. 2-3).

In 2021, consultants completed a relocation of freshwater mussels at the FM 1871 bridge crossing of the Llano River near Mason, TX in response to a proposed bridge replacement project at the existing crossing. During this relocation, the team collected **46** live Texas pimpleback and relocated them to a site upstream of the bridge crossing's proposed construction footprint (Blankenship, 2021; entire).

Lower Colorado River

The Texas pimpleback is known to occur currently in the lower Colorado River from about 9 miles upstream of the US Hwy 71 crossing (near Columbus, Texas) downstream to Jarvis Creek confluence (southeast of Lane City). In total, this population occupies 98.2 stream miles in Colorado and Wharton counties, Texas.

In 2014, the Service located **49** live Texas pimpleback during a survey at a long-term monitoring site near FM 950 bridge crossing in Garwood. In 2015, Service biologists found **3** live animals at a long-term monitoring site and LCRA pumping station; both sites were near Lane City, in Wharton County, Texas (USFWS 2016, entire). Bonner et al. (2018) report searching for, and finding, **30** live Texas pimpleback from 6 sites in the "Lower Colorado River" basin, defined as from Longhorn Dam to Bay City Dam (pp. 6, 28), with the occurrences being from Colorado County (above Columbus) to Wharton County (near Wharton, p. 19).

Isolated Texas pimpleback Records

BLUFF CREEK

During June 2019, biologists from Texas A&M University located **1** live Texas pimpleback and 1 fresh dead specimen from Bluff Creek, a tributary to Elm Creek. Additionally, during the same survey effort **1** live Texas pimpleback and 1 recently dead shell was located in Elm Creek. Before these surveys, Texas pimpleback were believed extirpated from this isolated basin due in large part to 2011-2013 droughts (Randklev 2019b, entire).

5.F.2 Areas Presumed Extirpated

Texas pimpleback was historically distributed throughout the Colorado River basin (Howells 2014, p. 93-4; reviewed in Randklev et al. 2017, pp. 109-10). The species is likely extirpated from the Pedernales River (Randklev et al. 2017, p. 108).

5.F.3 Current Conditions of Texas pimpleback

To summarize the overall current conditions of Texas pimpleback populations, we sorted them into three categories (healthy, moderately healthy, and unhealthy) based on the population factors and habitat elements discussed in Chapter 3 and displayed in Table 5.10. Table 5.11 shows the overall conditions of Texas pimpleback populations, as displayed in Figure 5.10.

Table 5.10. Population and habitat characteristics of Texas pimpleback populations used to inform condition categories in Table 5.11

	Population Factors			**Habitat Factors**		
Condition	**Occupied Stream Length**	**Index of Abundance**	**Evidence of Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**
Healthy	> 50 river miles	Found in nearly all available habitats surveyed during a reasonable survey effort. More than 100 individuals found per population survey.	50% or more sites with juveniles (< 35 mm) detected and gravid females present during the breeding season and fish hosts present.	Riffle and crevice habitat present. Gravel and cobble substrate sufficient to provide lodging.	Flowing water present year-round and sufficient to maintain temperature and dissolved oxygen. No recorded periods of zero flow days. No documented habitat exposure.	No known incidence of contaminant spills, low dissolved oxygen, or evidence of exposure extreme high or low temperatures.
Moderately Healthy	49 – 20 river miles	Found in approx. 50% of all available habitats surveyed during a reasonable survey effort. Between 26 – 99 individuals found per population survey.	25–50% of sites with juveniles (< 35 mm) detected, gravid females present during the breeding season and fish hosts present in at least moderate abundance.	Riffle and crevice habitat present. Gravel and cobble substrate sufficient to provide lodging with some sediment deposition.	Flowing water present year-round, but water levels approaching low levels. No instances of zero flow days and riffle dewatering not documented.	Contaminants known, low dissolved oxygen and temperature extremes documented. Levels not high enough to risk extirpation.
Unhealthy	< 19 river miles	Found in few areas of suitable habitat during a reasonable survey effort. Between 2 – 25 individuals found per population survey.	< 25% of sites with juveniles (<35 mm) detected, gravid females present during the breeding season, and fish host present in low abundance and/or ability to disperse is reduced.	Riffles eroded or upstream sediments deposited at high enough level to preclude inhabitation.	Zero flow days or riffle dewatering documented within previous decade.	Known exposure to contaminants, low dissolved oxygen, and documented cases of excessive water temperatures extremes. Water quality parameters diminished such that exposure threatens mussel survival.
Extirpated/ Functionally Extirpated	none	Very few or no live individuals documented during surveys (≤ 1).	No evidence suggesting that juveniles or gravid females are present. Fish host not known to occur.	No suitable habitat present.	Dry stream bed or zero flow days high enough to preclude survival.	Water quality degradation such that occupancy of otherwise suitable habitat is precluded.

Table 5.11. Current condition of Texas pimpleback populations.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Colorado	**Concho**	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
	Colorado & San Saba	Healthy	Healthy	Unhealthy	Moderate	Moderate	Moderate	**Moderate**
	Upper San Saba	Moderate	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
	Llano	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	**Unhealthy**
	Lower Colorado	Healthy	Moderate	Unhealthy	Moderate	Moderate	Moderate	**Moderate**

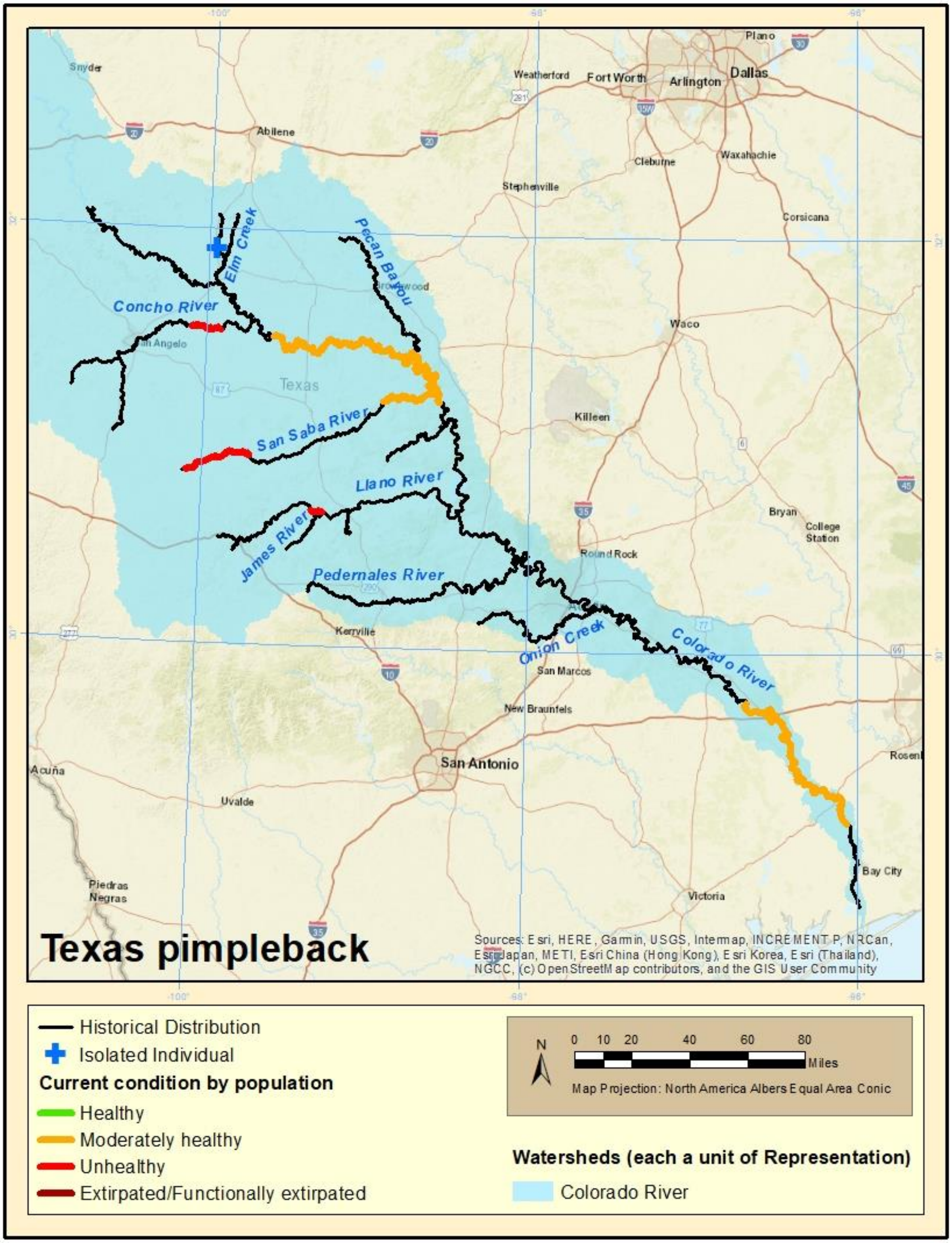


Figure 5.10. Location and overall current population condition for all five populations of Texas pimpleback in the Colorado River basin.

5.F.4 Current Population Resiliency

The Texas pimpleback is known to currently occur in the Colorado River basin. Currently, there are five known populations. Three of these populations are currently unhealthy while the remaining two populations (including the largest known population) are in moderate condition. The San Saba and middle Colorado population is the most robust and would be most resilient against stochastic events, such as floods.

5.F.5 Current Species Representation

We consider the Texas pimpleback to have representation in the Colorado River basins (Figure 5.9). Current research indicates that all the known Texas pimpleback in the Guadalupe River basin are actually a distinct species, the recently described Guadalupe orb (*Cyclonaias necki)* (Burlakova et al. 2018, entire).

5.F.6 Current Species Redundancy

Within these identified representation areas, the Texas pimpleback has five populations in the Colorado River basin.

5.G Guadalupe fatmucket

5.G.1 Current Condition

Guadalupe fatmucket appears to be currently restricted to one population in the Guadalupe River basin (Randklev et al. 2017, p. 4) (Figure 5.11). The total current distribution of Guadalupe fatmucket, summed across the Upper Guadalupe River population, is a combined stream length of approximately 53 miles. This current distribution represents approximately 16.8% of the total presumed historic range of 317.5 stream miles. This approximate range reduction assumes the species continuously occupied its entire historical range, which is unlikely given the species' specialized habitat preferences.

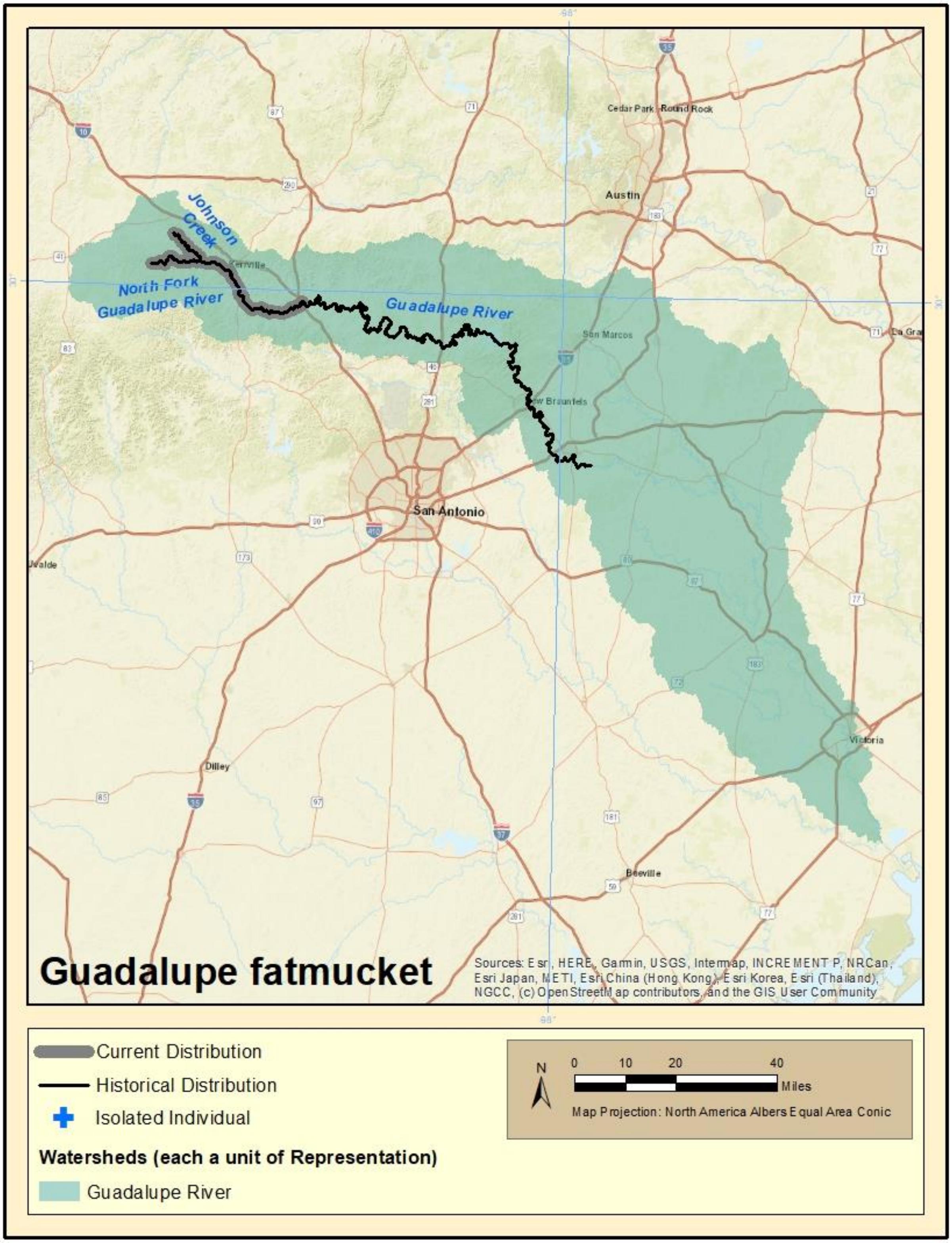


Figure 5.11. Location of the only known population of Guadalupe fatmucket in the Guadalupe River basin.

Upper Guadalupe River

This population extends from the origination of the Guadalupe River mainstem (where the North and South Fork Guadalupe Rivers converge) to the Hwy 27 crossing near Comfort, Texas. This population also extends 7 miles upstream into the North Fork Guadalupe River from the confluence of the North and South Guadalupe Forks to Camp Waldemar (just upstream of the FM1340 bridge). Additionally, this population extends just over 10 miles upstream into the Johnson Creek. The entire Guadalupe fatmucket population in the Guadalupe River is 54 stream miles in length and is found in Kerr and Kendall counties, Texas.

Guadalupe fatmucket have been found consistently in low numbers in the Upper Guadalupe River. Howells (2000) reports a collection of 2 and one-half Guadalupe fatmucket shells by Upper Guadalupe River Authority from the North Fork of the Guadalupe River upstream of Hunt, Texas, at FM 1340 in Kerr County (p. 27). Subsequently, Howells (2006, p. 72) reports twenty dead Guadalupe fatmucket shells from a survey in 1998 and one dead shell and **6** live individuals from the same site in 2005.

Burlakova and Karatayev (2010) reported collecting **6** live Guadalupe fatmucket from the Guadalupe River in Kerr County in 2005 (p.12). Service biologists (USFWS 2013, p. 1) found **2** live Guadalupe fatmucket downstream of the dam near Hayes Park in Kerr Co in 2013. During this survey it was noted that females were displaying mantle lures; therefore, we presume these females were gravid. Bonner et al. (2018) report finding **16** Guadalupe fatmucket from 4 sites in the Upper Guadalupe River between Hunt and Center Point, in Kerr County, Texas (p. 19) in bank and pool habitats (p. 24).

Inoue (2018, entire) searched for Guadalupe fatmucket near the Ehlers Road crossing of the Guadalupe River and found **22** living individuals. They were collected and removed from the wild for ongoing genetic work.

Service and TPWD biologists encountered **4** live Guadalupe fatmucket (three females and one male) in Johnson Creek in the Guadalupe River basin (USFWS 2018, entire). This is the first known record of the species from this area.

In the North Fork of the Guadalupe River, Pulliam (2018, entire) found **2** live Guadalupe fatmucket. This represents the first live individuals documented on the North Fork Guadalupe River in over 15 years.

In the North Fork of the Guadalupe River, Service biologists found relatively old valves (representing 2 individuals) of Guadalupe fatmucket at the FM 1340 bridge crossing near the Bear Creek Boy Scouts of America camp (USFWS 2019, entire).

During surveys in June 2019, Service and TX A&M biologists found **6** live Guadalupe fatmucket in the North Fork of the Guadalupe River upstream of Hunt, Texas (Randklev 2019b, entire).

5.G.2 Areas Presumed Extirpated

Guadalupe fatmucket is historically known from the upper portions of the Guadalupe basin and is not thought to have occurred in the lower portions of this basins in the "coastal plain" (Howells 2014, pp. 41-2; and reviewed in Randklev et al. 2017, pp. 39-40).

5.G.3 Current Conditions of Guadalupe fatmucket

To summarize the overall current conditions of Guadalupe fatmucket populations, we sorted them into three categories (healthy, moderately healthy, and unhealthy) based on the population factors and habitat elements discussed in Chapter 3 and displayed in Table 5.12. Table 5.13 shows the overall condition of Guadalupe fatmucket populations, as displayed in Figure 5.12.

Table 5.12. Population and habitat characteristics of Guadalupe fatmucket populations used to create condition categories in Table 5.13.

	Population Factors			**Habitat Factors**		
Condition	**Occupied Stream Length**	**Index of Abundance**	**Evidence of Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**
Healthy	> 50 river miles	Found in nearly all available habitats surveyed during a reasonable survey effort. More than 100 individuals found per population survey.	50% or more sites with juveniles (< 35 mm) detected and gravid females present during the breeding season and fish hosts present.	Bedrock fissures and/or vegetative crevices present. Substrate sufficient to provide anchoring within crevices but not filled with sediment.	Flowing water present year-round. No recorded periods of zero flow days. Water levels sufficient to keep known habitats submerged.	No known incidence of contaminant spills, low dissolved oxygen, or evidence of exposure extreme high or low temperatures.
Moderately Healthy	49–20 river miles	Found in approx. 50% of all available habitats surveyed during a reasonable survey effort. Between 26 – 99 individuals found per population survey.	25–50% of sites with juveniles (< 35 mm) detected, gravid females present during the breeding season and fish hosts present in at least moderate abundance.	Bedrock fissures and crevices present. Substrate sufficient in places to provide anchoring while other areas scoured or too heavily filled with sediment.	Flowing water present almost year-round. Few instances of zero flow days or minimal exposure of portions of known habitats.	Contaminants known, low dissolved oxygen and temperature extremes documented. Levels not high enough to risk extirpation.
Unhealthy	< 19 river miles	Found in few areas of suitable habitat during a reasonable survey effort. Between 2 – 25 individuals found per population survey.	< 25% of sites with juveniles (<35 mm) detected, gravid females present during the breeding season, and fish host present in low abundance and/or ability to disperse is reduced.	Fissures and crevices obstructed with excess sediment. Relatively high amount of sedimentation and filling of interstitial spaces.	Flowing water does not persist year-round. Summer records of zero flow days while pools stay wetted and sufficiently cool and oxygenated.	Known exposure to contaminants, low dissolved oxygen, and documented cases of excessive water temperatures extremes. Water quality parameters diminished such that exposure threatens mussel survival.
Extirpated/ Func. Extirpated	none	Very few or no live individuals documented during surveys (≤ 1).	No evidence suggesting that juveniles or gravid females are present. Fish host not known to occur.	No suitable habitats present.	Dry stream bed or zero flow days high enough to preclude survival.	Water quality degradation such that occupancy of otherwise suitable habitat is precluded.

Table 5.13. Current condition of Guadalupe fatmucket population.

		Population Factors			Habitat Factors			
Basin	**Population**	**Occupied Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Guadalupe	**Guadalupe**	Healthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**

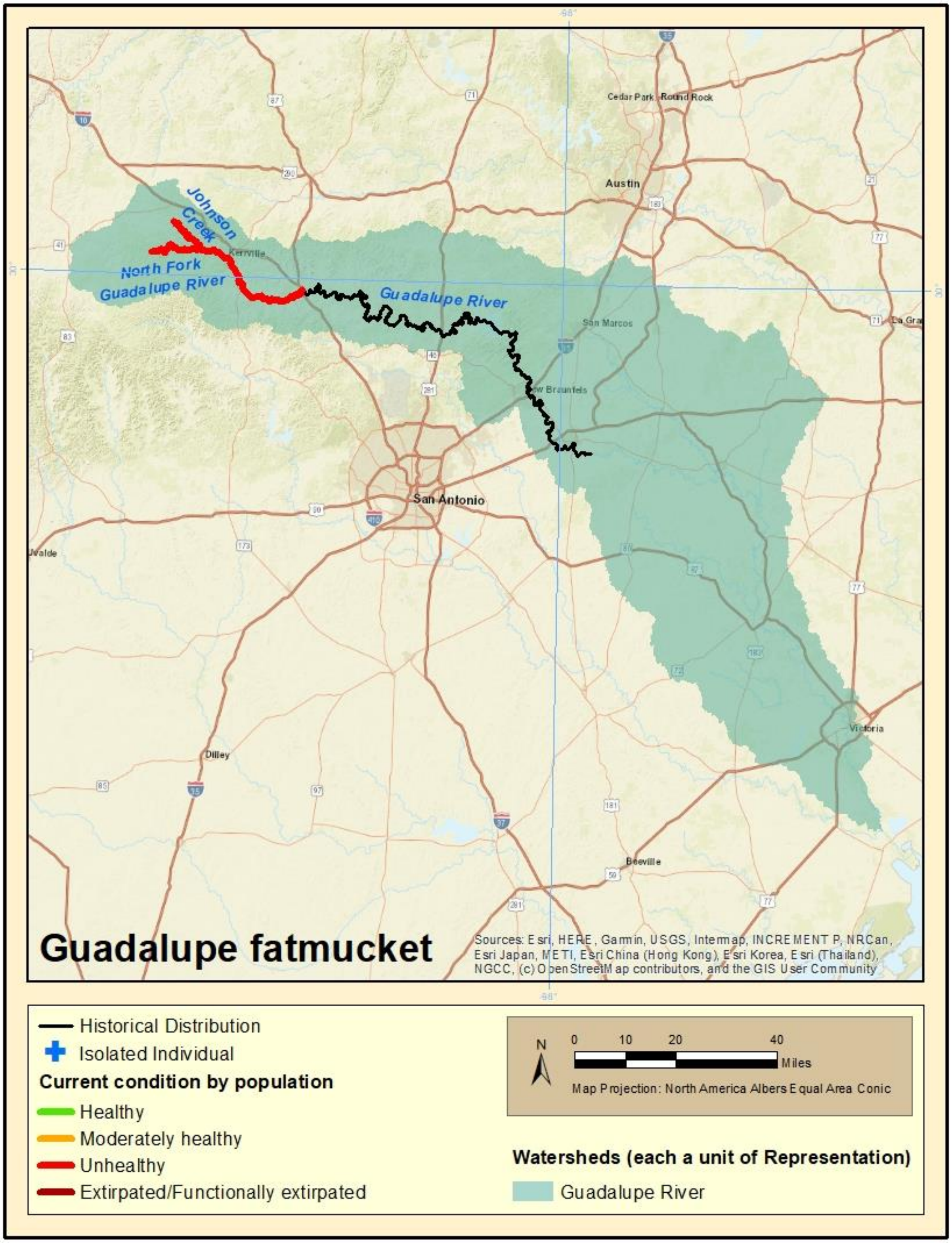


Figure 5.12. Location and overall current population condition of Guadalupe fatmucket in the Guadalupe River basin.

5.G.4 Current Population Resiliency

The Guadalupe fatmucket is known to currently occur in the Guadalupe River basin. The Guadalupe basin contains the only known population of Guadalupe fatmucket. This population is currently unhealthy due to a combination of low abundance and low evidence of recruitment, which are likely correlated and possibly related to Allee effects of small populations (Terui et al. 2015, pp. 2, 7-8; Mosley et al. 2014, p. 2147).

5.G.5 Current Species Representation

We consider the Guadalupe fatmucket to have representation from a single population in the upper reaches of the Guadalupe River and connected tributaries near Kerrville, Texas.

5.G.6 Current Species Redundancy

The Guadalupe River basin has one current population and therefore exhibits no redundancy.

5.H Guadalupe orb

5.H.1 Current Distribution[3]

Guadalupe orb is known from the Guadalupe River basin. Given the presumed historical distribution of the species, the Guadalupe orb currently occupies about 54% of its potential historical range. The Guadalupe orb is currently found in 276 river miles of a presumed historical range of 506 stream miles. This approximate range reduction assumes the species continuously occupied its entire historical range, which is unlikely given the species' specialized habitat preferences.

Two populations of the Guadalupe orb are known: one in unhealthy condition in the upper reaches of the Guadalupe River and another in moderate condition in the lower Guadalupe River, which also extends upstream into the San Marcos River.

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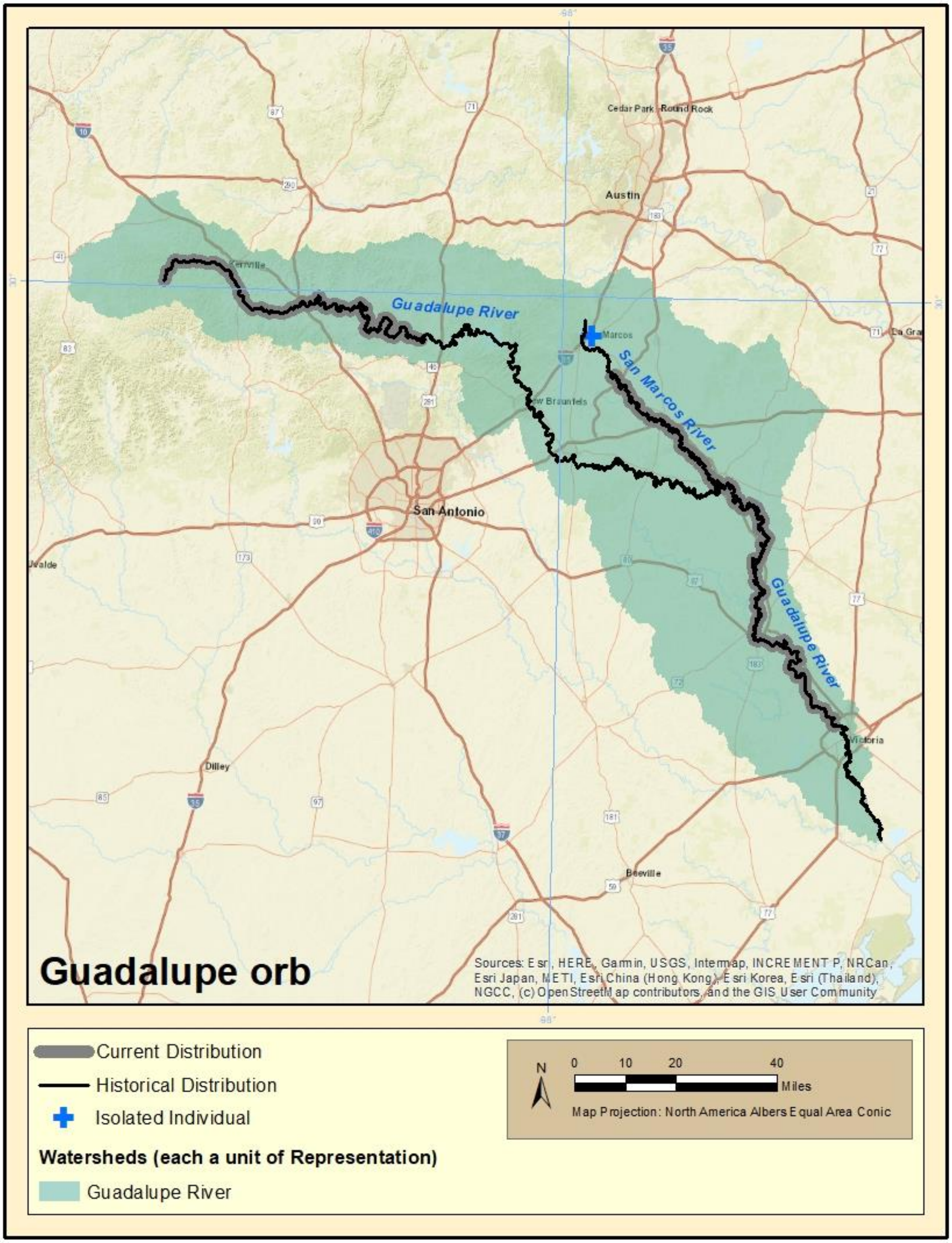
[3] All distribution information presented in section 5.H references survey work conducted before this species was determined to be a distinct species from Texas pimpleback. Although it is recognized as Guadalupe orb in this document, much of the survey work and distribution literature cited in this section will refer to these populations as Texas pimpleback.



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

Figure 5.13. Location of the two current populations of Guadalupe orb in the Guadalupe River basin.

Upper Guadalupe River

This population of Guadalupe orb occurs from approximately the origination of the Guadalupe River (confluence of the North and South Fork Guadalupe Rivers) downstream to the Guadalupe River State Park, above Canyon Lake. This population also extends upstream into a small portion of the South Fork Guadalupe River. In total, this population occupies 94.5 stream miles in Kerr, Kendall, and Comal counties, Texas.

In 2013, Service biologists located **1** live Guadalupe orb below the UGRA dam on the Guadalupe River in Kerr County, Texas (Braun et al. 2012, pp. 14-15).

In 2018, TPWD and Service biologists located **2** live Guadalupe orbs in the South Fork Guadalupe River (USFWS 2018, entire).

In 2018, Bonner et al. (2018) reported finding **10** live Guadalupe orb from 2 sites in the Upper Guadalupe River between Hunt and Center Point, in Kerr County, Texas (pp. 19, 31).

Inoue (2018, entire) searched for and found **10** living Guadalupe orb near the Ehlers Road crossing of the Guadalupe River near Comfort, Texas.

In 2022, University of Texas-Austin biologists found **1** live Guadalupe orb upstream of the FM 3351 crossing of the Guadalupe River near Boerne, Texas (Smith 2022, entire).

Lower Guadalupe River

In the lower section of the Guadalupe River, the Guadalupe orb occupies a total of 65.3 stream miles in the San Marcos River (a tributary to the Guadalupe River) from the FM 1977 bridge crossing in Caldwell County, Texas, downstream to the Guadalupe River confluence. The San Marcos River population includes the stream contained within Palmetto State Park. Continuing downstream of the San Marcos River confluence, the population extends 116.5 miles to approximately the US Hwy 77 crossing of the Guadalupe River. This population is the largest and most robust, and is in Caldwell, Guadalupe, Gonzales, DeWitt, and Victoria counties, Texas.

In 2012, Service biologists encountered one (**1**) live individual near the Hwy 77 crossing in Victoria County, and in 2013, Service biologists located **7** live Guadalupe orb and several fresh dead shells at Highway 77 near Victoria, Texas on the Guadalupe River in Victoria County, Texas (Braun et al. 2012, pp. 14-15).

In 2011, **166** Guadalupe orb were relocated from a TXDOT bridge construction project on the San Marcos River at the FM 20 crossing near Fentress, Texas (Randklev 2019a, entire; Sowards et al. 2012, entire). Mussels encountered during these surveys ranged in total length from 28.9mm to 62.9mm total, representing multiple size classes (Sowards et al. 2012, p. 8). Individuals were relocated to one of two locations, either 400 meters upstream of the project area or 450 meters downstream. The species was already present at both relocation sites.

Tsakiris and Randklev (2016) observed a total of **893** Guadalupe orb, out of a total of over 21,000 mussels, during a comprehensive survey effort of the Lower Guadalupe River in 2014-15 (p. 13) and individuals were found in all survey locations between Gonzalez and Victoria, Texas, but only in riffle habitats. Randklev et al. (2017) reported finding **41** live Guadalupe orb from 8 of 13 sites surveyed in the Lower Guadalupe River, between Cuero and Victoria, Texas (p. 111) but note that persistent high flows precluded access to riffle habitats, which are known to be the "optimal mesohabitat for the species" (p.

108).

Interagency surveys conducted in 2018 yielded a total of **92** live (mix of adult and juvenile) Guadalupe orb from the San Marcos River near Palmetto State Park (TPWD 2018d, entire).

Isolated Guadalupe orb Records

BLANCO RIVER

In May 2020, a Bio-West biologist collected **1** live Guadalupe orb in the Blanco River in San Marcos, Texas. This collection was completed opportunistically and was not part of a larger survey effort. No additional survey efforts have yet been completed to document additional Guadalupe orb presence or to determine abundances or distribution in the Blanco River (Sullivan, 2020; entire).

5.H.2 Areas Presumed Extirpated

Guadalupe orb was historically distributed throughout the Guadalupe River basin (Howells 2014, p. 93-4; reviewed in Randklev et al. 2017, pp. 109-10). The species was once believed to occur in both the Colorado and Guadalupe River systems. However, recent studies and taxonomic descriptions suggest this species was never present in the Colorado River basin (Burlakova et al. 2018, entire). The species was presumed to be extirpated from the San Marcos River where one long dead individual was found in 2010 (Wilkins et al. 2011, p. 3) but recent surveys have since documented the species in this watershed (see 5.G.1).

5.H.3 Current Conditions of Guadalupe orb

To summarize the overall current conditions of Guadalupe orb populations, we sorted them into three categories (healthy, moderately healthy, and unhealthy) based on the population factors and habitat elements discussed in Chapter 3 and displayed in Table 5.14. Table 5.15 shows the overall conditions of Guadalupe orb populations, as displayed in Figure 5.14.

Table 5.14. Population and habitat characteristics of Guadalupe orb populations used to inform condition categories in Table 5.15.

	Population Factors			**Habitat Factors**		
Condition	**Occupied Stream Length**	**Index of Abundance**	**Evidence of Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**
Healthy	> 50 river miles	Found in nearly all available habitats surveyed during a reasonable survey effort. More than 100 individuals found per population survey.	50% or more sites with juveniles (< 35 mm) detected and gravid females present during the breeding season and fish hosts present.	Riffle and crevice habitat present. Gravel and cobble substrate sufficient to provide lodging.	Flowing water present year-round and sufficient to maintain temperature and dissolved oxygen. No recorded periods of zero flow days. No documented habitat exposure.	No known incidence of contaminant spills, low dissolved oxygen, or evidence of exposure extreme high or low temperatures.
Moderately Healthy	49 – 20 river miles	Found in approx. 50% of all available habitats surveyed during a reasonable survey effort. Between 26 – 99 individuals found per population survey.	25–50% of sites with juveniles (< 35 mm) detected, gravid females present during the breeding season and fish hosts present in at least moderate abundance.	Riffle and crevice habitat present. Gravel and cobble substrate sufficient to provide lodging with some sediment deposition.	Flowing water present year-round, but water levels approaching low levels. No instances of zero flow days and riffle dewatering not documented.	Contaminants known, low dissolved oxygen and temperature extremes documented. Levels not high enough to risk extirpation.
Unhealthy	< 19 river miles	Found in few areas of suitable habitat during a reasonable survey effort. Between 2 – 25 individuals found per population survey.	< 25% of sites with juveniles (<35 mm) detected, gravid females present during the breeding season, and fish host present in low abundance and/or ability to disperse is reduced.	Riffles eroded or upstream sediments deposited at high enough level to preclude inhabitation.	Zero flow days or riffle dewatering documented within previous decade.	Known exposure to contaminants, low dissolved oxygen, and documented cases of excessive water temperatures extremes. Water quality parameters diminished such that exposure threatens mussel survival.
Extirpated/ Functionally Extirpated	none	Very few or no live individuals documented during surveys (≤ 1).	No evidence suggesting that juveniles or gravid females are present. Fish host not known to occur.	No suitable habitat present.	Dry stream bed or zero flow days high enough to preclude survival.	Water quality degradation such that occupancy of otherwise suitable habitat is precluded.

Table 5.15. Current condition of Guadalupe orb populations.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Guadalupe	**Upper Guadalupe**	Healthy	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	**Unhealthy**
	San Marcos & Lower Guadalupe	Healthy	Healthy	Moderate	Moderate	Moderate	Moderate	**Moderate**

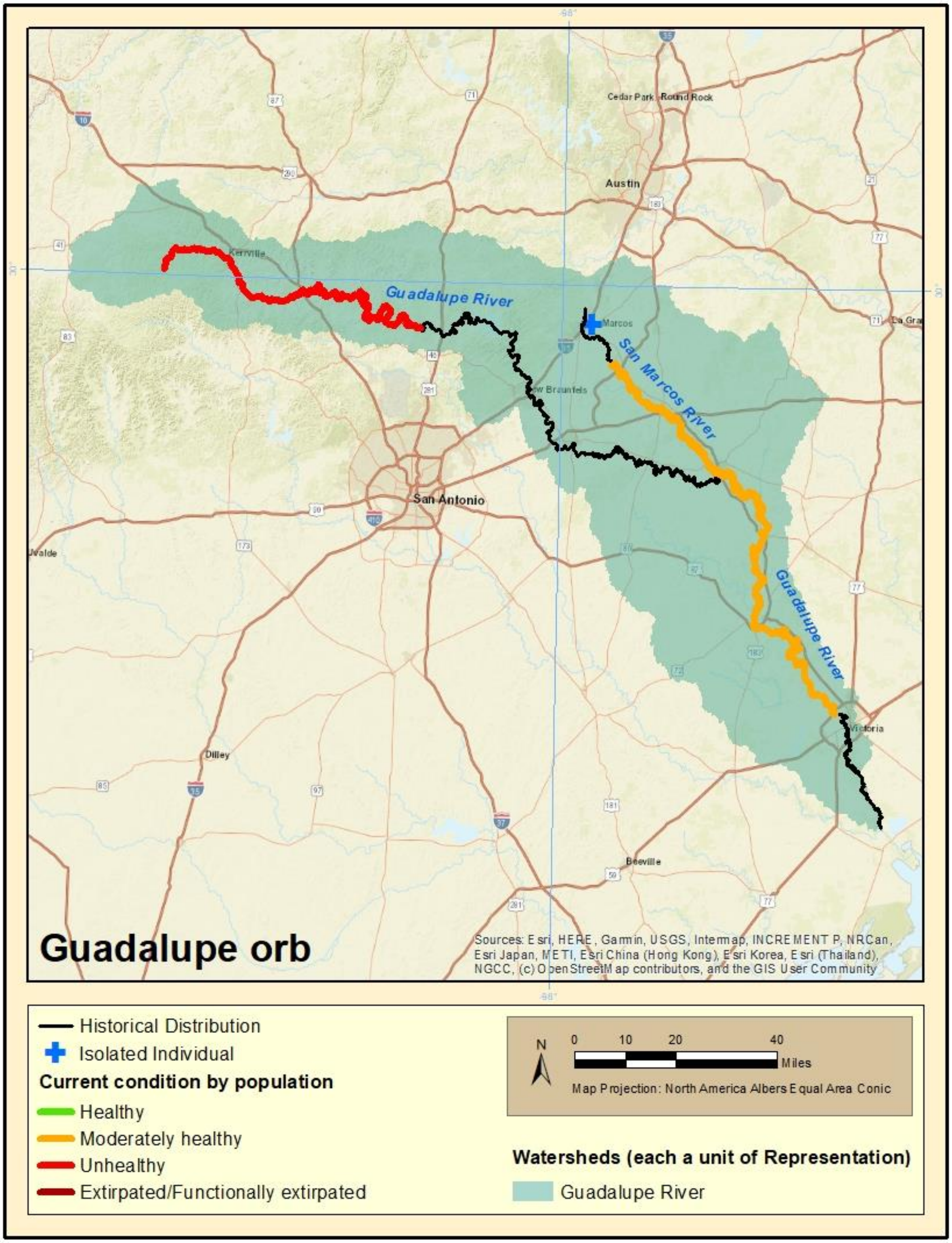


Figure 5.14. Location and overall current population conditions of Guadalupe orb in the Guadalupe River basin.

5.H.4 Current Population Resiliency

The Guadalupe orb is known to currently occur in the Guadalupe River basin. Currently, there are two known populations. One is in unhealthy condition in the upper Guadalupe River. The Lower Guadalupe River population, which also extends into the San Marcos River, is in moderate condition.

5.H.5 Current Species Representation

We consider the Guadalupe orb to have representation in only one river basin (Figure 5.13).

5.H.6 Current Species Redundancy

Within these identified representation areas, the Guadalupe orb has only two populations in the Guadalupe River basin. Therefore, the species exhibits low redundancy.

5.I Summary of current conditions of Central Texas Mussels

All seven species of Central Texas mussels exhibit various levels of resiliency, redundancy, and representation across the major river basins in which they occur. However, no population seems to contain all of the necessary habitat and population factors necessary to warrant a strong, healthy mussel population. Given our analysis of current condition, none of the species were considered to be in healthy condition overall. While some species have aspects, or factors, that are healthy (such as stream length, or abundance) none of the species has all of the factors necessary to support a highly resilient population.

Chapter 6 - Factors influencing viability

This chapter evaluates the past, current, and future factors that may affect Central Texas mussel populations and influence the needs for long-term species viability. Each of these factors is explored in the "Cause and Effects Tables" appended to this report as **Appendix B**. The Cause and Effects Tables analyze, in detail, the pathways by which each factor influences a population and species. Further, each of the causes is examined for its historical, current, and potential future effects on the species' status. These factors include: (1) increased fine sediment, (2) changes in water quality, (3) altered hydrology in the form of inundation, (4) altered hydrology in the form of loss of flow and scour of substrate, (5) predation and collection and (6) barriers to fish movement.

Current and potential future effects, along with current expected distribution and abundance, determine present viability and, therefore, vulnerability to extinction. We organized these influences around the stressors (i.e., changes in the resources needed by each species) and discuss the sources of those stressors. For more information about each of these influences, see Appendix B. Those risks that are not known to have effects on Central Texas mussel populations are not discussed in this SSA report.

6.A.1 Increased fine sediment

Juvenile and adult Central Texas mussels inhabit microsites that have abundant **interstitial spaces**, or small openings in an otherwise closed matrix of substrate, created by gravel, cobble, boulders, bedrock crevices, tree roots, and other vegetation, with some amount of fine sediment (i.e., clay and silt) necessary to provide appropriate shelter. However, excessive amounts of fine sediments can reduce the number of appropriate microsites in an otherwise suitable mussel bed by filling in these interstitial spaces and can smother mussels in place. Central Texas mussels generally require stable substrates, and loose silt deposits do not generally provide for substrate stability. Interstitial spaces provide essential habitat for juvenile mussels. Juvenile freshwater mussels burrow into interstitial substrates, making them particularly susceptible to degradation of this habitat feature. When clogged with sand or silt, interstitial flow rates and spaces may become reduced (Brim Box and Mossa 1999, p. 100), thus reducing juvenile habitat availability. While adult mussels can be physically buried by excessive sediment, "the main impacts of excess sedimentation on unionids are often sublethal" and include interference with feeding mediated by valve closure (Brim Box and Mossa 1999, p. 101). Many land use activities can result in excessive erosion, sediment production and channel instability; including, but not limited to, logging, crop farming, ranching, mining, and urbanization (Brim Box and Mossa 1999, p. 102).

Under a natural flow regime, a river or stream is in equilibrium in the context of sediment load, such that as sediments are naturally washed away from one microsite to another and the amount of sediment in the substrate is relatively stable, given that different reaches within a river or stream may be aggrading or degrading sediment (Poff et al. 1997, pp. 770-2). Current and past human activities result in enhanced sedimentation in river systems and **legacy sediment**, resulting from past land disturbance and reservoir construction, continues to persist and influence river processes and sediment dynamics (Wohl 2015, p. 31, pp. 39-42) and these legacy effects can result in degradation of mussel habitats. Fine sediments collect on the streambed and in crevices during low flow events, and much of the sediment is washed downstream during high flow events (also known as cleansing flows) and deposited elsewhere. However, increased frequency of low flow events (from groundwater extraction, instream surface flow diversions, and drought) combined with a decrease in cleansing flows (from reservoir management and drought) causes sediment to accumulate. Sediments deposited by large scale flooding or other disturbance may persist for several years until adequate cleansing flows can redistribute that sediment downstream. When water velocity decreases, which can occur from reduced streamflow or inundation, water loses its ability to carry sediment in suspension; sediment falls to the substrate, eventually smothering mussels not adapted to soft substrates (Watters 2000, p. 263). Sediment accumulation can be exacerbated when there is a simultaneous increase in the sources of fine sediments in a watershed. In the range of the Central Texas mussels, these sources include streambank erosion from development, agricultural activities, livestock and wildlife grazing and browsing, in-channel disturbances, roads, and crossings, among others (Poff et al. 1997, p. 773). In areas with ongoing development, runoff can transport substantial amounts of sediment from ground disturbance related to construction activities with inadequate or absent sedimentation controls. While these construction impacts can be transient (lasting only during the construction phase), the long-term effects of development are long lasting and can result in hydrological alterations as increased impervious cover increases run off and resulting shear stress causes streambank instability and additional sedimentation.

6.A.2 Changes in water quality

Above all else, freshwater mussels require water in sufficient quantity and quality on a consistent basis to complete their life cycles and those of their host fish. Urban growth and other anthropogenic activities across Texas are placing increased demands on limited water supplies that in turn, can have deleterious effects on water quality. Water quality can be degraded through contamination or alteration of water chemistry. Chemical contaminants are ubiquitous throughout the environment and are a major reason for the current declining status of freshwater mussel species nationwide (Augspurger et al. 2007, p. 2025). Chemicals enter the environment through both point and nonpoint source discharges, including hazardous spills, industrial wastewater, municipal effluents, and agricultural runoff. These sources contribute organic compounds, trace metals, pesticides, and a wide variety of newly emerging contaminants (e.g., pharmaceuticals) that comprise some 85,000 chemicals in commerce today that are released to the aquatic environment (EPA 2018, p. 1). The extent to which environmental contaminants adversely affect aquatic biota can vary depending on many variables such as concentration, volume, and timing of the release, but species diversity and abundance consistently ranks lower in waters that are known to be polluted or otherwise impaired by contaminants. Freshwater mussels are not generally found for many miles downstream of municipal wastewater treatment plants (Gillis et al. 2017, p. 460; Goudreau et al. 1993, p. 211; Horne and McIntosh, p. 119). For example, transplanted common freshwater mussels (*Amblema plicata* and *Corbicula fluminea*) showed reduced growth and survival below a wastewater treatment plant (WWTP) outfall relative to sites located upstream of the WWTP in Wilbager Creek (a tributary to the Colorado River in Travis County, Texas). Water chemistry was altered by the wastewater flows at downstream sites, with elevated constituents in the water column that included copper, potassium, magnesium, and zinc (Nobles and Zhang 2015, p.11; Duncan and Nobles 2012, p. 8). Contaminants released during hazardous spills are also of concern. Although spills are relatively short-term events and may be localized, depending on the types of substances and volume released, water resources nearby can be severely impacted and degraded for years after the incident.

Ammonia is of particular concern below wastewater treatment plants because freshwater mussels have been shown to be particularly sensitive to increased ammonia levels (Augspurger et al. 2003, p. 2569). Elevated concentrations of un-ionized ammonia (NH_3) in the interstitial spaces of benthic habitats (> 0.2 parts per billion) have been implicated in the reproductive failure of other freshwater mussel populations (Strayer and Malcom 2012, pp. 1787-8), and sublethal effects (valve closures) have recently been described as TAN approaches 2.0 mg/L (milligrams per liter = ppm; Bonner et al. 2018, p. 186). Quantitative estimates of the effects of un-ionized ammonia in the water column are currently unknown, and relationships between total ammonia N and un-ionized ammonia (NH_3) are dependent on pH and temperature (see inset on next page). Recent laboratory studies suggest that for smooth pimpleback (*Cyclonaias houstonensis*; a species native to Central Texas but not included in the Central Texas mussels), the revised EPA ammonia benchmarks are sufficient to protect from "short term effects of ammonia on metabolic rate (RMR) and ability to extract oxygen even under low oxygen conditions (RI and DO_{crit})" (Bonner et al. 2018, p. 151). However, the long-term effects of chronic exposure (i.e., years or decades) to freshwater mussels has yet to be experimentally investigated. Although a comprehensive review of ammonia related impacts to Central Texas mussels is beyond the scope of this document, municipal wastewater is known to contain both ionized and un-ionized ammonia and wastewater discharge permits issued by TCEQ do not always impose limits on ammonia, particularly for smaller volume dischargers, so at a minimum there are likely to be elevated concentrations of ammonia in the immediate mixing zone of some WWTP outfalls. To give some insight into the potential scope of WWTP related impacts, there are approximately 480 discharge permits issued for the Brazos River watershed alone from its headwaters above Possum Kingdom Lake down to the Gulf of Mexico (TCEQ 2018c, entire). In addition, some industrial permits, such as animal processing facilities, have ammonia limits in the range of 3 to 4 mg/L or higher which exceeds levels that inhibited growth in juvenile fatmucket (*Lampsilis siliquoidea*) and rainbow mussel (*Villosa iris*) during 28-day chronic tests (0.37 to 1.2 mg total ammonia N/L; no-observed-effect concentration and lowest-observed – effect concentration, respectively) (Wang et al. 2007, entire). Immature mussels (i.e., juveniles and glochidia) are especially sensitive to water quality degradation and contaminants (Cope et al. 2008, p. 456, Wang et al. 2017, p. 791-792; Wang et al. 2018, p. 3041).

> **Ammonia toxicity as explained by Dr. Jim Stoeckel of Auburn University *in* Bonner et al. 2018, p. 147-8:**
> "Ammonia in surface waters is typically reported as total ammonia nitrogen (TAN). This refers to the combined concentration of nitrogen (mg/L) occurring in the two co-existing forms of ammonia, ionized (NH_4^+) and un-ionized (NH_3). Un-ionized ammonia is the most toxic form. The proportion of un-ionized to ionized (NH_3:NH_4^+) ammonia increases with increasing pH and temperature. Thus, ammonia becomes more toxic with increases in temperature and/or pH even if the concentration of ammonia, measured as TAN, remains the same. The U.S. EPA 2013 ammonia benchmark is 17 mg TAN/L for acute (1 hour average) exposure and 1.9 mg TAN/L for chronic (30 day rolling average) exposure. These benchmarks are referred to as "criterion minimum concentrations" (CMC) and represent a concentration that is expected to be lethal to < 50% of individuals in sensitive species. They specifically apply to a pH of 7 and a temperature of 20°C during the summer months. The toxicity of 17 (acute) and 1.9 (chronic) mg TAN/L benchmark concentrations would therefore increase and may no longer be sufficiently protective of unionid mussels. The EPA is cognizant of this issue and provides tables to adjust benchmark concentrations for specific temperature and pH values. Un-ionized ammonia can affect organisms such as mussels via multiple mechanisms that increase ventilation rates (volume of water passing through gills per unit time), gill damage, and a reduction in the ability of blood (hemolymph) to carry oxygen."

An additional type of water quality degradation is alteration of water quality parameters such as dissolved oxygen, temperature, and salinity levels. Dissolved oxygen levels may be reduced from increased nutrient inputs or other sources of organic matter that increase the biochemical oxygen demand in the water column as microorganisms decompose waste. Organic waste can originate from storm water or irrigation runoff or wastewater effluent, and juvenile mussels seem to be particularly sensitive to low dissolved oxygen (with sublethal effects evident at 2 ppm and lethal effects evident at 1.3 ppm; Sparks and Strayer 1998, pp. 132-133). Increased water temperature (over 30° C and approaching 40° C) from climate change and from low flows during drought can exacerbate low dissolved oxygen levels in addition to other drought-related effects on both juvenile and adult mussels. Finally, high salinity concentrations are an additional concern in certain watersheds, where dissolved salts can be particularly limiting to Central Texas Mussels. Upper portions of the Brazos and Colorado Rivers, originating from the Texas High Plains, contain saline water, sourced from both natural geological formations, and from oil and gas development. Salinity in river water is diluted by surface flow and as surface flow decreases salt concentrations increase, resulting in adverse effects on freshwater mussels. Even low levels of salinity (2-4 ppt) have been demonstrated to have substantial negative effects on reproductive success, metabolic rates, and survival of freshwater mussels (Blakeslee et al. 2013, p. 2853). Bonner et al. (2018, pp. 155-6) suggest that the behavioral response of valve closure to high salinity concentrations (> 2 ppt) is the likely mechanism for reduced metabolic rates, reduced feeding, and reduced and reproductive success based on reported sublethal effects of salinity > 2 ppt for Texas pimpleback, which closed tightly when exposed to salinity > 4 ppt for 7 days. For additional information, the reader is referred to USFWS (2006b, entire) for a comprehensive discussion of water quality requirements for aquatic species in Texas.

Water quality and quantity are interdependent, so reductions in surface flow from drought, instream diversion, and groundwater extraction serves to concentrate contaminants by reducing flows that would otherwise dilute point and non-point source pollution. For example, salinity inherently poses a greater risk to aquatic biota under low flow conditions as salinity concentrations and water temperatures increase. Drought conditions can place additional stressors on stream systems beyond reduce flow by exacerbating contaminant related effects to aquatic biota, including Central Texas mussels. Not only can temperature be a biological, physical, and chemical stressor, the toxicity of many pollutants to aquatic organisms increases at higher temperatures (e.g., ammonia, mercury). We foresee threats to water quality increasing into the future as demand and competition for limited water resources grows.

6.A.3 Altered Hydrology – Inundation

Central Texas mussels are adapted to flowing water (**lotic** habitats) rather than standing water (**lentic** habitats) and require free-flowing water to survive. Low flow events (including stream drying) and inundation can eliminate appropriate habitat for Central Texas mussels, and while these species can survive these events for a very short duration, populations that experience prolonged drying events or repeated drying events will not persist.

Inundation has primarily occurred upstream of dams, both large (such as the Highland Lakes and other major flood control and water supply reservoirs) and small (low water crossings and diversion dams typical of the tributaries and occurring usually on privately owned lands). Inundation causes an increase in sediment deposition, eliminating the crevices that many Central Texas mussel species inhabit. Inundation also includes the effects of reservoir releases where frequent variation in surface water elevation acts to make habitats unsuitable for Central Texas mussels. In large reservoirs, deep water is very cold and often devoid of oxygen and necessary nutrients. Cold water (less than 11 °Celsius (C) or 52 °Fahrenheit (F)) has been shown to stunt mussel growth and delay or hinder spawning. The Central Texas mussels are not known to tolerate inundation under large reservoirs. Further, deep water reservoirs with bottom release (like Canyon Reservoir, which supports a recreational rainbow and brown trout fishery) can affect water temperatures several miles downriver. The water temperature remains below 21.1°C for the first 6.3-km (3.9 miles) of the 22.2-km (13.8 miles) Canyon Reservoir tailrace (TPWD 2007c, p. ii).

The construction of dams, and inundation of reservoirs, and management of water releases have significant effects on the natural hydrology of a river or stream. For example, dams trap sediment in reservoirs and managed releases typically do not conform to the natural flow regime (i.e., higher baseflows, and peak flows of reduced intensity but longer duration). Rivers transport not only water but also sediment, which is transported mostly as suspended load (held by the water column), increases as a power function (greater than linear) of flow, and most sediment transport occurs during floods (Kondolf 1997, p.533). It follows that increased severity of flooding would result in greater sediment transport, with important effects on substrate stability and benthic habitats for freshwater mussels, and other organisms dependent on stable benthic habitats. Further, water released by dams is usually clear and does not carry a sediment load and is considered “hungry water because the excess energy is typically expended on erosion of the channel bed and banks…resulting in incision (downcutting of the bed) and coarsening of the bed material until a new equilibrium is reached” (Kondolf 1997, p.535). Conversely, depending on how dam releases are conducted, reduced flood peaks can lead to accumulations of fine sediment in the riverbed (i.e., loss of flushing flows, Kondolf 1997, pp. 535, 548).

Operation of flood-control, water-supply and recreation reservoirs results in altered hydrologic regimes, including an attenuation of both high- and low-flow events. Flood control dams store flood waters and then release them in a controlled manner, this extended release of flood waters can result in significant scour, and loss of substrates that provide mussel habitat. Along with this change in the flow of water, sediment dynamics are affected as sediment is trapped above and scoured below major impoundments. These changes in water and sediment transport have negatively affected freshwater mussels and their habitats.

6.A.4 Altered Hydrology – Flow Loss and Scour

Very low water levels are detrimental to Central Texas mussel populations as well. Droughts that have occurred in the recent past have led to extremely low flows in several Central Texas rivers. Many of these rivers have some resiliency to drought because they are spring fed (Colorado tributaries, Guadalupe), are very large (lower Brazos and Colorado), or have significant return flows (Trinity) but drought in combination with increased groundwater pumping may lead to lower river flows of longer duration than have been recorded in the past. Reservoir releases can be managed to some extent during drought conditions to prevent complete dewatering below many major reservoirs.

Streamflow in the Colorado River above the Highland Lakes and downstream of the confluence with Concho River has been declining since the 1960s, as evidenced by annual daily mean streamflow (USGS 2008b, pp. 812, 814, 848, 870, 878, 880), and overall river discharge for each of the rivers can be expected to continue to decline due to increased drought as a result of climate change, absent significant return flows (less reuse). There are a few exceptions, including the Llano River at Llano (USGS 2008b, p. 892), Pedernales River at Fredericksburg (USGS 2008b, p. 896), Onion Creek near Driftwood, and Onion Creek at Hwy 183 (flows appear to become more erratic, characteristic of a developing watershed; USGS 2008b, pp. 930, 946). In the San Saba River, continuing or increasing surface and alluvial aquifer groundwater withdrawals in combination with drought is likely to result in reduced streamflow in the future. Flows have declined due to drought in the Brazos River in recent years upstream of Lake Whitney (USGSb 2008, pp. 578, 600, 626, 638, and BRA 2018e, p. 6) although baseflows are maintained somewhat due to releases from Lake Granbury and other reservoirs in the upper basin (USGS 2008b, p. 644 and BRA 2018e, p. 6). In the middle Brazos, USACE dams have reduced the magnitude of floods on the mainstem of the Brazos River downstream of Lake Whitney (USGS 2008b, pp. 652, 676 766, 776; BRA 2018e, p. 6), while flows in the lower Brazos and Navasota appear to have higher baseflows due to water supply operations in the upper basin (USGS 2008b, p. 754, 766, 776 and BRA 2018e, p. 6). Lake Limestone releases also appear to be contributing to higher base flows in the Lower Brazos (BRA 2018e, p. 6). Flows have declined in the upper Guadalupe (USGS 2008b, pp. 992, 994, 1000, 1018) but appear relatively unchanged at Comfort and Spring Branch and in the San Marcos River (USGS 2008b, pp. 1004, 1006, 1022), and in the lower Guadalupe River (USGS 2008b, pp. 1036, 1040). In the lower sections of the Colorado River, lower flows and reduced high flow events are more common now decades after major reservoirs were constructed (USGS 2008b, pp. 964, 966). In the Trinity River, low flows are higher than they were in the past (USGS 2008b, pp. 370, 398, 400, 430) because of substantial return flows from Dallas area wastewater treatment plants.

Many of the tributary streams (i.e., Concho, San Saba, Llano, Pedernales Rivers) historically received significant groundwater inputs from multiple springs associated with the Edwards and other aquifers. As spring flows decline due to drought or groundwater lowering from pumping, habitat for Central Texas mussels in the tributary streams is reduced and could eventually cease to exist. While Central Texas mussels may survive short periods of low flow, as low flows persist, mussels face oxygen deprivation, increased water temperature, and, ultimately, stranding, reducing survivorship, reproduction, and recruitment in the population. High-flow events lead to increased risk of physical removal, transport, and burial (entrainment) as unstable substrates are transported downstream by flood waters and later redeposited in locations that may not be suitable. Low-flow events lead to increased risk of **desiccation** (physical stranding and drying) and exposure to elevated water temperature and other water quality degradations, such as contaminants, as well as to predation. For example, sections of the San Saba River, downstream of Menard, Texas, experienced very low flows during the summer of 2015, which lead to dewatering of occupied habitats as evidenced by observations of recent dead shell material of Texas pimpleback and Texas fatmucket (Geeslin et al. 2015, pp. 2-3). Service, TPWD and TxDOT biologists in 2017 noted at one site on the Brazos River near Highbank, Texas, the presence of 42 dead to fresh dead (with tissue intact) Texas fawnsfoot mussels that likely died as a result of recent drought or scouring events (Tidwell 2017, entire). Conversely, Bonner et al. 2018 noted that a habitat suitability and mussel mark and recapture study site in the lower Colorado River near Altair, Texas suffered significant changes in both mussel community structure and bathymetry during extensive flooding in August 2017, as a result of Hurricane Harvey (p. 266). This study site was selected as it previously held the highest mussel abundance (pp. 242-3) and represented high quality habitat within the Colorado basin, pre-flooding events. Survey results indicated a significant decrease in mussel abundance on the scale of nearly two orders of magnitude (p. 266). This location had two of the Central Texas mussels (Texas fawnsfoot and Texas pimpleback) present during initial surveys in 2017 and another candidate species (Smooth pimpleback) that is pending review (p. 242).

The distribution of mussel communities and their habitats is affected by large floods returning at least once during the typical life span of an individual mussel (generally from 3 to 30 years), as mediated by the presence of **flow refuges**, where shear stress is relatively low and where sediments are relatively stable, and “must either tolerate high-frequency disturbances or be eliminated and can colonize areas that are infrequently disturbed between events” (Strayer 1999, pp. 468-9). Shear stress and **relative substrate stability** (RSS) are limiting to mussel abundance and species richness (Randklev et al. 2017a, p. 7) and **riffle** habitats may be more resilient to high flow events than **littoral** (bank) habitats.

The Central Texas mussels have historically and are today exposed to extreme hydrological conditions, including severe drought leading to dewatering, and heavy rains leading to damaging scour events and movement of mussels and substrate. The usual drought/flood cycle in Central Texas can be characterized by long periods of time absent of rain interrupted by short periods of heavy rain, resulting in flooding. These same patterns led to the development of flood control and storage reservoirs throughout Texas in the twentieth century. Howells (2000) provides a summary of drought conditions in Texas from 1995-9, characterized by prolonged drought conditions punctuated by severe floods, and their impacts on native unionids and reports that “although no sampling efforts were mounted to document [the] impact on rare endemic unionids, species like...Texas pimpleback, Texas fatmucket, and Texas fawnsfoot were almost certainly reduced in numbers, especially at sites that dried completely” (p.ii). It follows that given the extreme and variable climate of Central Texas, mussels must have life history strategies, and other adaptations, that allow them to persist by withstanding severe conditions, and/or repopulating during more favorable conditions. However, it is also likely that there is a limit to how the mussels might respond to increasing variability, frequency, and severity of extreme weather events.

Sand and gravel can be mined from rivers or from adjacent alluvial deposits, and instream gravels often require less processing and are thus more attractive from a business perspective (Kondolf 1997, p. 541). Instream mining directly affects river habitats, and can indirectly affect river habitats through channel incision, bed coarsening, and lateral channel instability (Kondolf 1997, p. 541). Excavation of pits in or near to the channel can create a knickpoint, which can contribute to erosion (and mobilization of substrate) associated with head cutting (Kondolf 1997, p. 541). Off-channel mining of floodplain pits can become involved during floods, such that the pits become hydrologically connected, and thus can affect sediment dynamics in the stream or river (Kondolf 1997, p. 545).

6.A.5 Predation, Collection, Disease, and Invasive Species

Predation on freshwater mussels is a natural ecological interaction. Raccoons, snapping turtles, and fish are known to prey upon Central Texas mussels. Under natural conditions, the level of predation occurring within Central Texas mussel populations is not likely to pose a significant risk to any given population. However, during periods of low flow, terrestrial predators have increased access to portions of the river that are otherwise too deep under normal flow conditions. High levels of predation during drought have been observed on the Llano and San Saba rivers. As drought and low flow are predicted to occur more often and for longer periods due to the effects of future climate change, the Hill Country tributaries (of the Colorado River) in particular are expected to experience additional predation pressure into the future, and this may become especially problematic in the Llano and San Saba Rivers. Predation is expected to be less of a problem for the lower portions of the main stem river populations, as the rivers are significantly larger than the tributary streams and Central Texas mussels are thus less likely to be found in exposed or very shallow habitats.

Certain mussel beds within some populations, due to ease of access, are vulnerable to over-collection and vandalism. These areas, primarily on the Llano and San Saba Rivers, have well known and well documented mussel beds that are often sampled multiple times annually by various researchers for various scientific projects. Given the additional stressors aforementioned in this chapter, these populations are being put at additional risk due to over collection and over harvest for scientific needs. Service biologists recently hosted what is planned to be an annual mussel research and coordination meeting to help adaptively manage monitoring and scientific collection of certain populations and foster increased collaboration among researchers (USFWS 2018, p.1).

6.A.6 Barriers to fish movement

Central Texas mussels historically colonized new areas through movement of infested host fish, as newly metamorphosed juveniles would excyst from host fish in new locations. Today, the remaining Central Texas mussel populations are significantly isolated from one another by major reservoirs such that recolonization of areas previously extirpated is extremely unlikely if not impossible due to existing contemporary barriers to host fish movement. There is currently no opportunity for interaction among any of the extant Central Texas mussel populations as they are all fragmented from one another by reservoirs.

The overall distribution of mussels is, in part, a function of the dispersal of their host fish. There is limited potential for immigration between populations other than through the attached glochidia being transported to a new area or to another population. Small populations are more affected by this limited immigration potential because they are susceptible to genetic drift, resulting from random loss of genetic diversity, and inbreeding depression. At the species level, populations that are eliminated due to stochastic events cannot be recolonized naturally, leading to reduced overall redundancy and representation.

Many of the Central Texas mussels known or assumed primary host fish species are known to be common, widespread species in the Central Texas river basins. We know that populations of mussels and their host fish have become fragmented and isolated over time following the construction of major dams and reservoirs throughout Central Texas. We do not currently have information demonstrating that the distribution of host fish is a factor currently limiting the distribution of Central Texas mussel species. However, a recent study suggested that the currently restricted distribution of false spike, Guadalupe orb, and other related species, could be related to declining abundance of their host fish, particularly those fish having small home ranges and specialized habitat affinities (e.g., Dudding et al. 2019, entire). Further research into the relationships between each of the Central Texas mussel species and their host fish is needed to more fully examine the possible role of declining host fish abundance in explaining mussel population declines.

6.A.7 Climate Change

Climate change has been documented as has already taken place, and continued greenhouse gas emissions at or above current rates will cause further warming (Intergovernmental Panel on Climate Change (IPCC) 2013, pp. 11-12). Warming in Texas is expected to be greatest in the summer (Maloney et al. 2014, p. 2236, Fig. 3). In Texas, the number of extremely hot days (high temperatures exceeding 95º Fahrenheit) is expected to double by around 2050 (Kinniburgh et al. 2015, p. 83). West Texas is an area expected to show greater responsiveness to the effects of climate change (Diffenbaugh et al. 2008, p. 3). Changes in stream temperatures are expected to reflect changes in air temperature, at a rate of approximately 0.6 – 0.8°C increase in stream water temperature for every 1°C increase in air temperature (Morrill et al. 2005, pp. 1-2, 15) and with implications for temperature-dependent water quality parameters such as DO and ammonia toxicity. Given that the Central Texas mussels exist at or near the ecophysiogical edge of climate and habitat gradients of unionid biogeography in North America, it is likely that they may be particularly vulnerable to future climate changes in combination with current and future stressors (Burlakova et al. 2011a, pp. 156, 161, 163; Burlakova et al. 2011b, pp. 395, 403).

While projected changes to rainfall in Texas are small (USGCRP 2017, p. 217), higher temperatures caused by anthropogenic forcings leads to increased soil water deficits because of higher rates of evapotranspiration, and is likely to result in increasing drought severity in future climate scenarios just as "extreme precipitation, one of the controlling factors in flood statistics, is observed to have generally increased and is projected to continue to do so across the United States in a warming atmosphere" (USGCRP 2017, p. 231). Even if precipitation and groundwater recharge remain at current levels, increased groundwater pumping and resultant aquifer shortages due to increased temperatures are nearly certain (Loaiciga et al. 2000, p. 193; Mace and Wade 2008, pp. 662, 664-665; Taylor et al. 2013, p. 3). Higher temperatures are also expected to lead to increased evaporative losses from reservoirs, which could negatively affect downstream releases and flows (Friedrich et al. 2018). Effects of climate change, such as air temperature increases and an increase in drought frequency and intensity, have been shown to be occurring throughout the range of Central Texas mussels (USGCRP 2017, p. 188; Andreadis and Lettenmaier 2006, p. 3), and these effects are expected to exacerbate several of the stressors discussed above, such as water temperature and flow loss (Wuebbles et al. 2013, p. 16). A recent review of future climate projections for Texas concludes that both droughts and floods could become more common in Central Texas, and projects that years like 2011 (the warmest on record) could be commonplace by the year 2100 (Mullens and McPherson 2017, pp. 3, 6). This trend of more frequent drought is attributed to increases in hot temperatures, and the number of days at or above 100°F are projected to "increase in both consecutive events and the total number of days" (Mullens and McPherson 2017, p. 14-15). Similarly, floods are projected to become more common and severe because of increases in the magnitude of extreme precipitation (Mullens and McPherson 2017, p. 20).

In the analysis of the future condition of the Central Texas mussels, which follows as **Chapter 7**, climate change is considered to be an exacerbating factor, contributing to the increase of fine sediments, changes in water quality, loss of flowing water, and predation.

6.A.8 Management Actions

Since the 2011 12-month finding on three of the Central Texas Mussels (USFWS 2011, entire) many agencies, NGOs and other interested parties have been working to develop voluntary agreements[4] with private landowners to restore or enhance habitats for fish and wildlife in the region, including the Central Texas mussels. These agreements provide voluntary conservation including habitat enhancements that will, if executed properly, reduce threats to the species while improving in-stream physical habitat and water quality, as well as adjacent riparian and upland habitats.

Some publicly and privately owned lands in the watersheds occupied by Central Texas mussels are protected with conservation easements or are otherwise managed to support populations of native fish, wildlife, and plant populations.

Work is underway to evaluate methods of captive propagation for the Central Texas mussel species at the Service's hatchery and research facilities (San Marcos Aquatic Research Center, Inks Dam National Fish Hatchery, and Uvalde National Fish Hatchery), including efforts to collect gravid females from the wild to infest host fish (Bonner et al. 2018, pp. 8, 9, 11).

6.A.9 Summary

Our analysis of the past, current, and future influences on what the Central Texas mussels need for long term viability revealed that there are three influences that pose the largest risk to the future viability of the species. These risks are primarily related to habitat changes: the accretion of fine sediments, the loss of flowing water, and degradation of water quality; these are all exacerbated by climate change.

The accretion of fine sediments, the loss of flowing water, changes in hydrology including floods leading to scour and subsequent substrate unsuitability, inundation under reservoirs, the degradation of water quality, predation, collection, disease, and invasive species are carried forward in our assessment of the future conditions of Central Texas mussel populations and the viability of each species overall.

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[4] The Service's Partners for Fish and Wildlife Program Private Lands Agreements and sub-recipient Cooperative Agreements, TPWD Landowner Incentive Program Agreements, USDA-NRCS Conservation plans including proposed Working Lands for Wildlife Project (NRCS 2019a, entire) and Conservation Technical Assistance (NRCS 2019b, entire), among others.

Chapter 7 - Viability and Future Conditions

This report has considered what the seven species of Central Texas mussels need for viability and the current condition of those needs (Chapters 3 and 5) and reviewed the risk factors that are driving the historical, current, and future conditions of the species (Chapter 6 and Appendix B). The report now considers what the species' future conditions are likely to be in the foreseeable future. We apply our forecasts to the concepts of resiliency, redundancy, and representation to describe future viability of the seven species of Central Texas mussels.

7.A Introduction

Each of the seven species of Central Texas mussels has declined significantly in terms of overall distribution and abundance, relative to historical conditions, and over the past 100 or more years. Most of the known populations currently exist in very low abundances, with limited evidence of recruitment, and occupy much less habitat. Furthermore, existing available habitats are reduced in terms of quality and quantity, relative to historical conditions over the past 100 or more years.

Beginning around the turn of the twentieth century, and by 1970, over 100 major dams had been constructed and reservoirs created across Texas, including several reservoirs in the Brazos and Trinity basins, the chain of Highland Lakes on the Lower Colorado River, the Guadalupe Valley Hydroelectric Project and the Canyon Reservoir on the Guadalupe River (Dowell 1964, pp. 3-8). The inundation and subsequent altered hydrology and sediment dynamics associated with operation of these flood-control, hydropower, and municipal supply reservoirs have resulted in irreversible changes to the natural flow regime of these rivers and ultimately has re-shaped these aquatic ecosystems, as well as the fish and invertebrate communities that depend on them, including populations of the seven species of Central Texas mussels.

Water quality impacts were common in many of the major rivers before modern sanitation, and in 1925 the Texas Department of Health called the Trinity a "mythological river of death" (USGS 1998, p. 19). Fortunately, today, water quality has improved with dramatically improved wastewater treatment technology, such that fish populations have rebounded but not completely recovered (Perkin and Bonner 2016, p. 97). However, water quality degradation continues to affect mussels and their habitats, especially as low flow conditions and excessive sedimentation interact to diminish instream habitats, and substrate-mobilizing and mussel-scouring flood events have become more extreme if not more frequent.

Additionally, while host fish may still be adequately represented in contemporary fish assemblages, access to fish hosts can be reduced during critical reproductive times by barriers such the many low-water crossings and low-head dams that now exist on the landscape. Low flows lead to dewatering of habitats and desiccation of individuals, elevated water temperatures (above 30°C and approaching 40°C) and other quality degradations (low DO and elevated TAN), as well as increased exposure to predation. Diminished access to host fish leads to reduced reproductive success just as barriers to fish passage impede the movement of fish, and thus compromise the ability of mussels to disperse and colonize new habitats following a disturbance (Schwalb et al. 2013, p. 1). Lastly, freshwater mussels have long been utilized by humans, for food and for bait, for pearls and buttons and for artificial pearl nuclei and even today rare mussels are vulnerable to human collection (Bogan 1993, pp. 604-5).

Populations of each of the seven Central Texas mussels face risks from natural and anthropogenic sources in both large and small river segments. Future higher air temperatures, higher rates of evaporation and transpiration, and changing precipitation patterns are expected in Central Texas (Jiang and Yang 2012, pp. 234-9, 242). Future climate changes are expected to lead to human responses such as increased groundwater pumping and surface water diversions, associated with increasing demands for and decreasing availability of freshwater resources in the state (reviewed in Banner et al. 2010, entire).

These risks, alone or in combination, could result in the extirpation of additional mussel populations, further reducing the overall redundancy and representation of each of the seven species of Central Texas mussels. Historically, each species, with a large range of interconnected populations (i.e., with meta-population dynamics), would have been resilient to stochastic events such as drought, excessive sedimentation, and scouring floods because even if some locations were extirpated by such events, they could be recolonized over time by dispersal from nearby survivors and facilitated by movements by "affiliate species" of host fish (Douda et al. 2012, p. 536). This connectivity across potential habitats would have made for highly resilient species overall, as evidenced by the long and successful evolutionary history of freshwater mussels as a taxonomic group, and in North America in particular. However, under current conditions, restoration of that connectivity on a regional scale is not feasible. As a consequence of these current conditions, the viability of the seven species of Central Texas mussels now primarily depends on maintaining the remaining isolated populations and potentially restoring new populations where feasible.

7.B. Future Scenarios and Considerations

Because of significant uncertainty regarding if and when flow loss, water quality degradations, extreme flooding and scour/substrate mobilizing events, or impoundment construction may occur, we have forecasted future viability for each of the seven species of Central Texas mussels in terms of resiliency, redundancy, and representation under four plausible future scenarios (Table 7.1). Each scenario is projected across up to three time steps and considers the biological status of mussel populations and their habitats in ten, twenty-five, and fifty years. Ten years represents one to two generations of mussels, assuming an average reproductive life span of five to ten years. Twenty-five years similarly represents two to four mussel generations. Fifty years represents five or more generations of mussels and corresponds with the current planning horizon of the State Water Plans (from 2020 to 2070), a period of time for which the human population of the State of Texas is expected to grow 88% from 27 million to 51 million (TWDB 2017, p. 3) with much of the growth of human population occurring in the watersheds these seven species of mussels currently occupy (TWDB 2017, pp. 50-51).

The future scenarios also consider the interactive effects of future climate change, described by Representative Concentration Pathways (RCPs) scenarios contributed by the Working Group III (WGIII) to the Fifth Assessment Report (AR5) and described in the most recent Synthesis Report of the Intergovernmental Panel on Climate Change (IPCC 2014, pp. 9, 22, 57). There are four RCPs that span the range of year 2100 radiative forcing values from 2.6 to 8.5 W/m^2 (van Vuuren et al. 2011, p.5). Scenarios 1 and 2 assume RCP4.5, a medium stabilization scenario where CO_2 emissions continue to increase through mid-21st century, but then decline and atmospheric carbon dioxide concentrations are between 580 and 720 ppm CO_2 between 2050 and 2100, representing an approximate +2.5-degree Celsius (ºC) temperature change relative to 1861-80 (IPCC 2014, p. 9, Figure SPM.5). Scenario 3 assumes RCP6.0 where atmospheric carbon dioxide concentrations are between 720 and 1000 ppm CO_2 between 2050 and 2100, representing an approximate +3.5 ºC temperature change relative to 1861-80 (IPCC 2014, p. 9, Figure SPM.5). Scenario 4 assumes RCP8.5 where atmospheric carbon dioxide concentrations are above 1000 ppm CO_2 between 2050 and 2100, representing an approximate +4.5 ºC temperature change relative to 1861-80 (IPCC 2014, p. 9, Figure SPM.5). The "business as usual" scenario is expected to fall between RCP6.0 and RCP8.5 (IPCC 2014, p. 57). The most recent IPCC Synthesis Report projects global temperature change to 2100 and beyond (IPCC 2014, p. 8). A recent study suggests that, because of uncertainty in long-run economic growth rates, there is "a greater than 35% probability that emissions concentrations will exceed those assumed in the most severe of the available climate change scenarios

(RCP8.5)" by 2100 (Christensen et al. 2018, p. 1).

This species status assessment and report makes the following assumptions informed by the most recent Synthesis Report of the Intergovernmental Panel on Climate Change (IPCC 2014, entire) and other scientific studies. The IPCC Synthesis Report considers RCP4.5 and RCP6.0 as intermediate scenarios and RCP8.5 as having "very high" greenhouse gas emissions (IPCC 2014, p. 8). Under RCP4.5, current conditions, including a continued trend towards increased warming, frequency and severity of extreme events, such as droughts and floods, are expected to continue. Global mean surface temperature change is projected "*more likely than not*" to exceed 1.5 ºC by 2100, relative to 1850-1900 (IPCC 2014, p. 60). Under RCP6.0, future conditions include an increasing trend towards increased warming, increased frequency and severity of extreme events, such as droughts and floods, are expected to manifest under future climate projections. Global mean surface temperature change is projected "*likely*" to exceed 2.0 ºC by 2100, perhaps as high as 3.1 ºC, relative to 1850-1900 (IPCC 2014, p. 60). Under RCP8.5, future conditions include a much increasing trend towards increased frequency and severity of extreme events, such as droughts and floods, are expected to manifest under future climate projections. Global mean surface temperature change is projected "*likely*" to exceed 2.0 ºC by 2100, perhaps as high as 4.8 ºC, relative to 1850-1900 (IPCC 2014, p. 60). Because of the influence of temperature on evapotranspiration, climate change is expected to result in drier soils with less runoff and under RCP8.5 by 2100, "no region of the planet is projected to experience significantly higher levels of annual average surface soil moisture…even though much higher precipitation is projected in some regions" (USGCRP 2017, pp. 232-8).

For all IPCC RCP scenarios, extreme precipitation events over most mid-latitude land masses (like North America) will very likely become more intense and frequent as global mean surface temperature increases (IPCC 2014, p. 60) and, as such, future temperature and precipitation patterns are likely to become more variable and extreme, with drought and flooding events occurring more frequently and with higher severity in the southwestern United States (Seager et al. 2007, pp. 1183-4) and Texas (Shafer et al. 2014, pp. 443-446) including Central and South Texas (Jiang and Yang 2012, pp. 238-242; Mullens and McPherson, pp. 15-21). The magnitude of these changes is expected to increase with time even without increasing greenhouse gas emissions as even steady-state or slightly reduced emissions would produce increased atmospheric concentrations. Given the inertia of the climate system, and regardless of future emissions, the risk of flooding is expected to increase over the next 25-50 years, and these increases in the severity of extreme floods are expected to affect human systems (reviewed in Willner et al. 2018, entire, and Hirabayashi et al. 2013, entire), as well as freshwater mussels, aquatic organisms, and freshwater ecosystems in general.

Future human demand for water resources, due to human population growth and limitations of existing supply, is expected to interact with climate effects and exacerbate the effects of droughts on surface water resources in Texas, which could possibly compete with the "environmental flow" needs of freshwater mussels and other flow-dependent aquatic organisms (Wolaver et al. 2014, pp. 1-2).

The upper portions of the basins, including tributaries, will be more sensitive to changes in precipitation patterns and withdrawals, relative to the lower portions of the basins, where flows are increasingly dominated by wastewater (or other) return flows and where significant senior water rights located at the "bottom" of the basin help to protect flows. However, while minimum flows may be maintained, other artifacts of the altered hydrology may have deleterious effects to mussels and their habitats through altered water quality, and changes in sediment transport (more extreme deposition and scour) leading to reductions in habitat quality and quantity.

The City of Austin commissioned a report that projected future climate for Austin, Texas, using nine models from the Coupled Model Intercomparison Project phase 5 (CMIP5) under RCP4.5 and RCP8.5

scenarios (Hayhoe 2014, p. 3). This report found, using downscaled projections for Camp Mabry, that summer average high temperature could increase from 93.8 ºF to 97.9 ºf under RCP4.5 and to 100.2 ºF under RCP8.5, annual precipitation is likely to be largely unchanged (33.7 inches per year to 33.6 inches per year and 33.3 inches per year under RCP4.5 and RCP8.5, respectively), but that the number of extreme precipitation events (wet days having > 2 inches in 24 hours) could increase from 2.2 events per year to 2.8 under RCP4.5 and to 2.7 under RCP8.5 (Hayhoe 2014, p. 8). The report concluded that "climate in Texas is already changing…consistent with larger-scale trends" and projected changes include "increases in annual and seasonal average temperature...little change in annual average precipitation…more frequent extreme precipitation…and more frequent drought conditions in summer due to hotter weather" (Hayhoe 2014, p. 9).

This species status assessment report describes and suggests four plausible future scenarios (Table 7.2). The first scenario, Scenario 1, extrapolates the current direction and magnitude of current population trends and condition trajectories to the future, and represents a continuation of current conditions projected across the next 10, 25, and 50 years. That is, existing declines in habitat and population condition factors continue to decline, and past droughts and floods re-occur at approximately the same interval and magnitude for the next 50 years. Scenario 1 assumes that ongoing, or at least initiated, activities continue over the next 50 years and includes actions that might either benefit or hinder the future resiliency of Central Texas mussel populations. The second scenario, Scenario 2, explores possible conservation strategies that if implemented, could maintain the status quo current conditions, thus slowing or halting declines in habitat and population conditions in 10–25 years and in some cases slightly reversing declines to improve habitat and population conditions in 25–50 years. Scenario 2 implements new conservation strategies that may or may not have been actually proposed but known currently ongoing strategies are also included in Scenario 1. Both Scenario 1 and Scenario 2 assume RCP4.5 climate change predictions, representing fairly optimistic emissions conditions and resulting climate forcings. Like Scenario 1, both Scenario 3 and Scenario 4 also project current population trends and condition categories in the future, but instead apply RCP6.0 and RCP8.5 predictions. Further, Scenario 3 also includes anthropogenic actions, such as the construction of new reservoirs, wastewater treatment plants, and other currently proposed projects. Scenario 4 includes all actions expected to take place under Scenario 3 and adds the construction of projects that have not actually been proposed. Most notably, Scenario 3 and Scenario 4 manifest as futures where the hydrological conditions of many of the rivers and streams currently occupied by Central Texas mussels are altered such that base flows are diminished, floods are more severe if not more frequent, such that mussels and their habitats are adversely affected through degradation of water and habitat quality and quantity. These altered hydrological conditions are primarily caused by a combination anthropogenic factors and climate forcings.

Table 7.1. Four Future Scenarios, by RCP* and time step.

Future Scenario	**RCP***	**10–years**	**25-years**	**50-years**
1 - Scenario 1	4.5	0–10 yrs.	10–25 yrs.	25–50 yrs.
2 - Scenario 2	4.5	▨	0–25 yrs.	25–50 yrs.
3 - Scenario 3	6.0	▨	0–25 yrs.	25–50 yrs.
4 - Scenario 4	8.5	▨	0–25 yrs.	25–50 yrs.
*RCP = Representative Concentration Pathway Scenario (IPCC 2014, pp. 9, 57)				

We examined the resiliency, representation, and redundancy of the seven mussel species under each of these four plausible scenarios for each the three time periods (Table 7.2). We only projected Scenario 1 at the 10-year time step, as we do not expect there to be many differences between any of the scenarios in 10 years; in other words, no matter which trajectory the species are following, the populations are likely to look the same in 10 years at the scale of our analysis. Resiliency of populations of these species depends on future water quality, availability of flowing water, and substrate suitability and how these habitat factors influence species reproduction, abundance, and the amount of habitat occupied. We expect the extant populations of these mussel species to experience changes to these aspects of their habitat in different ways under the different scenarios. We projected the expected future resiliency of each population based on the events that would occur under each scenario. We then projected the overall condition for each population based on these habitat and population factors. For these projections, populations in healthy condition are expected to have high resiliency at that time period, i.e., they occupy habitat of sufficient size to allow for ebbs and flows of density of mussel beds within the population. Populations in healthy condition are expected to persist into the future (> 90 % chance of persistence beyond 20 years) and have the ability to withstand stochastic events that may occur. Populations in moderately healthy condition have lower resiliency than those in healthy condition, but the majority (60–90 %) are expected to persist beyond 20 years. Populations in moderately healthy condition are smaller and less dense than those in healthy condition. Populations in unhealthy condition have low resiliency and are not necessarily able to withstand stochastic events. As a result, they are less likely to persist beyond 20 years (10–60 % chance). Finally, populations are considered extirpated, either completely (lack of individuals) or functionally (lack of reproduction) and have very low resiliency and have less than a 10 % chance of persistence beyond 20 years.

7.B.1 Scenario 1

Scenario 1 considers a future where the current levels of existing degradation as well as existing conservation, current as of the preparation of this SSA report, continue for the next 50 years (Table 7.2), and those effects on mussels and their habitats are considered over the next 0–10, 10–25, and 25–50 years. Existing planned and initiated conservation efforts will continue but are not significantly expanded. Planned but not initiated efforts are considered in Scenario 2 rather than Scenario 1. Existing patterns of development, including urbanization, irrigation, and other water uses continue increasing trends. Construction of new reservoirs currently under development are completed and inundated, with effects to mussels evident in the next 0–10 years.

7.B.2 Scenario 2

Scenario 2 considers a future where "feasible and appropriate conservation plans" are implemented over the next 0–25 and 25–50 years (Table 7.2). Scenario 2 considers which conservation actions could be implemented in the next 0–25 years, and what improvements to mussels and their habitats could be accomplished in the next 0–25 and 25–50 years. These positive conservation actions, if implemented, are expected to maintain, or improve somewhat, habitat and population conditions at the status quo over the next 25 to 50 years.

Scenario 2 assumes that some actions of positive intervention are thoughtfully designed and executed as "feasible and appropriate conservation plans." Such plans may be implemented by a combination of federal, state, and local governments, including river authorities, municipalities, and other "water regulators" along with NGO conservation groups, private landowners, and other stakeholders informed by government, academic, and consulting biologists with expertise in the conservation of freshwater mussels and their habitats. Some elements of such conservation plans include the following:

- Establishment of a research center and comprehensive program to conduct basic and applied research into the biology, ecology, management, conservation, and restoration of populations of rare mussels, including the Central Texas Mussels. One example of such a research center that is well known is the Alabama Aquatic Biodiversity Center. This report acknowledges several efforts that are currently underway including: Texas A&M AgriLife Research and Extension Center at Dallas, partnerships between Texas State University and the Service's San Marcos Aquatics Resources Center and Inks Dam and Uvalde National Fish Hatcheries (partially funded by the State of Texas Office of the Comptroller's Endangered Species Program), efforts by the TPWD, and individual and collaborative efforts by River Authorities in Texas. While none of these efforts yet represent an "established research center and comprehensive program," this report considers it practicable that one or more of these efforts could rise to that level in the next 0–25 years. This effort would include development and implementation of genetics management plans to inform the current, past, and desired future genetic structure by population for each species.

- Establishment of a framework, like an interagency working group, to achieve coordination and collaboration among researchers and other collectors of Central Texas mussels. Such a framework would help facilitate collaborative research and conservation efforts. This report acknowledges several efforts currently underway including the Texas Freshwater Mussel Conservation Society, which hosts biennial research symposia and identification workshops, the Comptroller's Office Freshwater Mussel Working Group, and other informal collaborations. While none of these efforts alone, or in combination, yet represent an "established framework", this report considers it practicable that one or more of these efforts could rise to that level in the next 0–25 years.

- Complementary to this effort to foster collaboration is an effort to control "loosely" regulated collection and scientific use. This effort could come out of an interagency working group or could possibly be implemented by the TPWD.

- Active efforts to protect, maintain, and improve existing water quality in waters affecting important mussel populations. Evaluation of enhanced wastewater management efforts such that discharges to sensitive receiving waters containing important local mussel populations is prohibited. Evaluation of possible local regulations mitigate against the negative effects of development somewhat by including impervious cover limits, flood plain modification prohibitions, stormwater runoff treatment, and riparian area protections. Make efforts to reduced currently permitted discharges of pollutants into the river systems. Other examples include improved watershed management, management of livestock access to riparian areas, upgraded wastewater treatment facilities, etc.

- Active efforts to protect, maintain, and improve existing water quantity in waters known to be important for mussel populations. This report acknowledges several efforts currently underway including: The TIFP (also known as Senate Bill 2), and the Environmental Flows Process (also known as Senate Bill 3).

- Active efforts to protect, maintain, and improve existing habitats for important mussel populations.

- Implementation of private lands voluntary habitat enhancement and restoration programs at various scales, from the watershed to the local riparian and instream environment. This report acknowledges several efforts currently underway including: The Texas Landowner Incentive Program (LIP), a collaborative effort of TPWD's Wildlife and Inland Fisheries Divisions, the Service, and other partners, to enhance habitats for terrestrial and aquatic species. A Natural Resources Conservation Service (NRCS) Working Lands for Wildlife (WLFW) Project is currently being implemented in the Lower Colorado River Basin to encourage producers to implement water quality and other conservation practices to benefit freshwater mussels, among other species (NRCS 2019a, entire). Scenario 2 considers that established programs, like LIP and WLFW, will continue and expand, and that other proposed projects will be successfully implemented in the next 0–25 years, and will have meaningful effects in the next 25–50 years.

- Management of exotic species and diseases. Scenario 2 considers that positive efforts will be made to mitigate against future threats of emerging exotic species and diseases. Examples include zebra mussels and trematodes.

- Reintroduction and repatriation of mussels in currently extirpated populations only and following restoration of suitable habitats. Compared with the other three Central Texas mussels, Texas fatmucket currently shows the greatest potential for successful captive propagation. This scenario includes the reintroduction of Texas fatmucket in Onion Creek in the next 0–25 years, with the population becoming moderately healthy in the next 25–50 years. Such reintroductions and repatriations are not possible today but are expected to be possible in the next 0–25 years and would require collaborations between the Service and others.

7.B.3 Scenario 3

Scenario 3 considers a future where conditions are no better for the species than the status quo Current Conditions. Scenario 3 considers intermediate climate effects, including more frequent and intense droughts, where droughts are broken by major flooding (Table 7.2). Scenario 3 also considers additional ground- and surface-water demands associated with increased human demand and decreased availability given intermediate climate effects. Reductions in streamflow, due to decreased inputs and enhanced evapotranspiration, are expected to occur in all streams and rivers, and those effects will be more pronounced in the upper basins (see inset).

> *Total annual runoff to the Colorado River is projected to decrease under all climate change scenarios by 2050. The decreases in the Colorado River streamflow near Lake Travis is projected to range from 17 percent to 38 percent with greater changes in the upper basin and smaller changes in the lower basin (downstream of Austin). An important finding is that annual streamflow is projected to decrease even under scenarios that exhibit small increases in precipitation. At these moderate precipitation increases, evapotranspiration is the dominant hydrologic process affecting runoff changes. In the lower basin, incremental runoff changes in the Colorado River from Lake Travis to Bay City range from a reduction of 5 percent to an increase of 13 percent largely depending on the precipitation projections in this region. Net evaporation is projected to increase for all scenarios in the upper and middle basin, ranging from 1.7 to 6.6 inches annually. Most scenarios also exhibit increases in the lower basin, but one scenario with increasing precipitation shows decreases in this region.*
>
> *By 2080, three of the four climate change scenarios show continued reductions in streamflow and increasing net evaporation. Streamflows reductions range from 11 percent to 48 percent in the Colorado River near Lake Travis for these three scenarios. One scenario (CCSM B1), exhibiting a large change in precipitation patterns in the upper basin, projects increases in runoff of approximately 25 percent.*
>
> ***-- C2HM HILL (2008, p. ES-2) Climate Change Study***

Scenario 3 considers additional water projects, like wastewater treatment plant outfalls, only if currently proposed or planned. Proposed new reservoirs from the 2017 State Water Plan (TWDB, 2016) are constructed in the next 10–25 years, and any effects from completion of these dams are manifest in the next 25–50 years. Necessary routine maintenance as well as repair and replacement of existing old dams (i.e., the Guadalupe Valley Hydroelectric Reservoirs) occurs in the next 10–25 years, and any effects from those repairs are manifest in the next 25–50 years.

7.B.4 Scenario 4

Scenario 4 considers a future where conditions are not better for the species than the status quo Current Conditions. Scenario 4 considers severe climate effects, including more frequent and intense droughts, where droughts are broken by major flooding (Table 7.2). Scenario 4 considers additional ground- and surface-water demands associated with increased human demand and decreased availability given severe climate effects. Scenario 4 considers additional water projects, like wastewater treatment plant outfalls, even if not currently proposed, as well as possible new reservoirs and other construction projects.

Table 7.2. Generalizations for projected trends in Habitat Factors by basin and occupied segment in Scenario 1, over time, and with notes from Scenario 2, Scenario 3, and Scenario 4.

Basin	**0–10 years**	**10–25 years**	**25–50 years**
Brazos (Upper) *Lower Clear Fork of the Brazos*	Flows will continue at existing low levels, with at least one critical dewatering event likely in the next 10 years, due to a combination of drought and withdrawals. Water quality degradation, due to elevated chlorides and bacteria, will continue, especially during low flow events (for chlorides) and following runoff events (for bacteria). Habitat quality will continue in its current status of degradation due to excessive sedimentation, scouring events that move unstable substrates, and low flow events that expose shallow habitats to desiccation. The City of Abilene Cedar Ridge Reservoir will be built in the next 10 years, inundating 29-miles of the Clear Fork of the Brazos and 43-miles of tributary streams, also resulting in "downstream impacts associated with hydrologic alterations" (FR 2018, p. 16062).	Flows will continue to decline to very low levels, with multiple critical dewatering events likely in the next 25 years, due to a combination of drought and withdrawals. Water quality degradation, due to chlorides and bacteria, will continue, especially during low flow events. Voluntary conservation strategies are planned and implemented to protect flows, water quality, and riparian habitats and adjacent uplands. But opportunities are limited given the drought exposure. Droughts are exacerbated by changing weather patterns and increased human demands under RCP6.0. Construction of the proposed Cedar Ridge Reservoir is completed, affecting mussels and their habitats downstream, due to changes in flows and habitat quality following construction and operation of the new reservoir. Droughts are much exacerbated by changing weather patterns and increased human demands under RCP8.5 and significant hydrological alterations are manifest.	Trend of declining flows and critical dewatering continues over the next 25–50 years, due to a combination of drought and withdrawals. Trend of declining water quality continues, especially given the effects with of diminishing flows on water quality and habitat availability. Habitat quality declines with increased sedimentation, exposure and desiccation associated with low flow events, and scouring associated with occasional floods. Some improvements to the habitat factors are gained following establishment of voluntary conservation programs implemented to improve riparian and adjacent upland habitats. Same as 10–25 years. Same as 10–25 years.
Brazos (Lower)	Flows will continue such that water quality exists at "adequate"	In the Little River, flows will become more and more influenced by return flows and urban	In the Little River, flows will become more and more influenced by return flows

Basin	**0–10 years**	**10–25 years**	**25–50 years**
Little River *Middle/ Lower Brazos River*	levels and altered hydrology (associated with reservoir management and return flows) will continue for the next 10 years. Flooding continues to become more severe because of continued development and land use practices that contribute to runoff in the watershed. Water quality degradation, due to bacteria and suspended solids (sedimentation) continues. Habitat quality degradations, due to development and land use practices in the watershed, will continue.	development (higher base flows, more flash flooding and scour). Water quantity will continue at "adequate" levels, but the hydrographs will continue to shift towards more of a "return flows hydrology" with infrastructure development on the Little River and its tributaries. In the Middle/Lower Brazos, flows will continue such that water quality exists at "adequate" levels, and altered hydrology (associated with reservoir management, return flows, and environmental flow considerations) will continue for the next 25 years. More flooding due to continued development and land use in the watershed. Water quality degradations will continue, due to development and land use in the watershed. Habitat quality will be diminished by flow alterations (floods), sedimentation, and mobilization of substrate. Conservation strategies are planned and implemented to protect flows, water quality, and riparian habitats and adjacent uplands. Droughts are exacerbated by changing weather patterns and increased human demands under RCP6.0. These effects are mitigated somewhat by return flows. The proposed Little River Off-Channel Reservoir is completed and affects mussels and their habitats in the vicinity of and downstream of the impoundment and diversion structures. The proposed Allens Creek Reservoir is constructed and will have detrimental effects to downstream	and urban development (higher base flows, more flash flooding and scour). Water quantity will continue at "adequate" levels, but the hydrographs will continue to shift towards more of a "return flows hydrology" with infrastructure development on the Little River and its tributaries. In the Middle/Lower Brazos, flows will continue such that water quality exists at "adequate" levels and altered hydrology (associated with reservoir management and return flows) will continue for the next 25–50 years. More flooding due to continued development and land use in the watershed. Water quality degradations will continue, due to development and land use in the watershed. Habitat quality will be diminished by flow alterations (floods), sedimentation, and mobilization of substrate. Some improvements to the habitat factors are gained following establishment of conservation programs. Negative impacts to habitat factors cause declines in habitat conditions, due to anthropogenic impacts and climate forcing associated with continued increasing human demand and climate change. Same as 10–25 years.

Basin	0–10 years	10–25 years	25–50 years
		mussels and their habitats. Droughts are much exacerbated by changing weather patterns and increased human demands under RCP8.5. These effects are mitigated somewhat by return flows, depending on the amount of reuse.	
Colorado (Upper) *Lower Elm Creek* *Lower Concho River* *Upper/ Middle San Saba River* *Lower San Saba River* *Llano River* *Pedernales River* *Onion Creek*	Flows will continue to be variable, and low at times, due to seasonal patterns of rainfall (i.e., drought), surface-water diversion and ground-water extraction. During these dry periods, water quantity, quality, and habitat only marginally meet the needs of the species. Some segments may begin to receive additional return flows, which bring more reliable water quantity, altered flows (more flooding), and uncertain effects to water quality. Water quality in upper Onion Creek will be degraded by additional effluent discharge from the Dripping Springs WWTP and associated development. The projected discharges from the Dripping Springs WWTP will not substantially affect the flows of Onion Creek below the	Low and variable flows, exacerbated by climate change and concomitant increased demand, will continue such that water quantity, quality, and habitat are no longer suitable for meeting the needs of the species in many reaches of occupied segments. Water quality will be diminished by low flows and land use practices in the watershed, along with development where it may be occurring. Habitat quality will be diminished by low flows, sedimentation, and by flash flooding events (exacerbated by climate change, land use, and development). Conservation strategies are planned and implemented to protect flows, water quality, and riparian habitats and adjacent uplands. Texas fatmucket restored in Onion Creek. Conservation strategies that mitigate the effects of development on hydrologic alteration and water quality degradation are adopted. Droughts are exacerbated by changing weather patterns and increased human demands under RCP6.0. Droughts are much exacerbated by changing weather patterns and increased human demands under RCP8.5.	Trend of declining flows and critical dewatering continues over the next 25–50 years, due to a combination of drought and withdrawals. Trend of declining water quality continues, especially given the effects with of diminishing flows on water quality and habitat availability. Habitat quality declines with increased sedimentation, exposure and desiccation associated with low flow events, and scouring associated with occasional floods. Implemented conservation strategies successfully mitigate risks of further declines, and in some cases reverse declines, in habitat factors and result in modest improvement in population factors. Texas fatmucket is successfully restored in Onion Creek. Conservation strategies that mitigate the effects of development on hydrologic alteration and water quality degradation are successful. Negative impacts to habitat factors cause declines in habitat conditions, due to

Basin	0–10 years	10–25 years	25–50 years
	recharge zone (City of Austin 2018d, p. 8). Water quality in lower Onion Creek will diminish with increasing development and land use changes in the watershed, although existing impervious cover limitations are enforced by local governments including City of Dripping Springs and City of Austin. Some conservation (water quality protection initiatives, land acquisition, conservation easements, etc.) is being planned and implemented in Onion Creek.		anthropogenic impacts and climate forcing associated with continued increasing human demand and climate change. A combination of climate forcings and anthropogenic responses to water shortages results in significant and severe alteration of hydrological conditions, such that both dewatering events and scouring floods are more frequent and severe.
Colorado (Lower) *Lower Colorado River*	Flows will continue at existing “adequate” levels, and existing altered hydrology (associated with reservoir management) will continue for the next 10 years. Habitat quality will continue to be diminished by low flows, sedimentation, and by flooding.	Flows will become more and more influenced by return flows and development (higher base flows, more flash flooding and scour). Flows will continue at “adequate” levels, but the hydrographs will continue to shift towards more of a “return flows hydrology” with infrastructure development in the Austin metro area. Irrigation use downstream will continue to affect water quantity as surface water diversions and pumping result in lower flows, increasing risk of exposure, quality effects, and habitat degradation, especially during drought years. Water quality degradations likely to continue. Habitat quality diminishments likely to continue.	Flows will become more and more influenced by return flows and development (higher base flows, more flash flooding and scour). Flows will usually continue at “adequate” levels, but the hydrographs will continue to shift towards more of a “return flows hydrology” with infrastructure development in the Austin metro area. Return flows will no longer be sufficient to mitigate the effects of drought as demand for reclaimed water will increase over time, especially during droughts. Irrigation use downstream will continue to affect water quantity as surface water

Basin	0–10 years	10–25 years	25–50 years
		Conservation strategies are planned and implemented to protect flows, water quality, and riparian habitats and adjacent uplands. Droughts are exacerbated by changing weather patterns and increased human demands under RCP6.0. These effects are mitigated somewhat by return flows. Droughts are much exacerbated by changing weather patterns and increased human demands under RCP8.5. These effects are mitigated somewhat by return flows, depending on the amount of reuse.	diversions and pumping result in lower flows, increasing risk of exposure, quality effects, and habitat degradation, especially during drought years. Water quality degradations likely to continue. Habitat quality diminishments likely to continue. Implemented conservation strategies successfully mitigate risks of further declines, and in some cases reverse declines, in habitat factors and result in modest improvement in population factors. Negative impacts to habitat factors cause declines in habitat conditions, due to anthropogenic impacts and climate forcing associated with continued increasing human demand and climate change. A combination of climate forcings and anthropogenic responses to water shortages results in significant and severe alteration of hydrological conditions, such that both dewatering events and scouring floods are more frequent and severe.
Guadalupe (Upper) *Upper Guadalupe River*	Flows will continue to be variable, and sometimes low, due to seasonal patterns of rainfall and surface-water diversion and ground-water extraction.	Because of spring flow, flows will continue to be variable, and sometimes low, due to seasonal patterns of rainfall and surface-water diversion and ground-water extraction. Flash floods will increase in severity, resulting in more scour	Because of spring flow, flows will continue to be variable, and sometimes low, due to seasonal patterns of rainfall and surface-water diversion and ground-water extraction. Flash floods will increase in

Basin	0–10 years	10–25 years	25–50 years
		and loss of habitat. Conservation strategies are planned and implemented to protect flows, water quality, and riparian habitats and adjacent uplands. Droughts are exacerbated by changing weather patterns and increased human demands under RCP6.0. Droughts are much exacerbated by changing weather patterns and increased human demands under RCP8.5.	severity, resulting in more scour and loss of habitat. Implemented conservation strategies successfully mitigate risks of further declines, and in some cases reverse declines, in habitat factors and result in modest improvement in population factors. Negative impacts to habitat factors cause declines in habitat conditions, due to anthropogenic impacts and climate forcing associated with continued increasing human demand and climate change. A combination of climate forcings and anthropogenic responses to water shortages results in significant and severe alteration of hydrological conditions, such that both dewatering events and scouring floods are more frequent and severe.
Guadalupe (Lower) *Lower Guadalupe River* *Lower San Marcos River*	Flows will continue at existing “adequate” levels, and existing altered hydrology (associated with reservoir management) will continue for the next 10 years. Protected spring flows from the San Marcos (EAHCP) and Guadalupe Rivers (GBRA-TAP agreement) will, and with increasing return flow contributions	Flows will continue at existing “adequate” levels, and existing altered hydrology (associated with reservoir management) will continue for the next 25 years. Protected spring flows from the San Marcos and Guadalupe Rivers will, as increasing return flow contributions from municipal return flows will sustain “adequate” water quantity. Conservation strategies are planned and implemented to protect flows, water quality, and riparian habitats and adjacent uplands.	Flows will continue at existing “adequate” levels, and existing altered hydrology (associated with reservoir management) will continue. Benefits from flow protections will continue. Implementation of conservation strategies successfully maintains status quo current habitat factors. Negative impacts to habitat factors cause declines in habitat conditions, due to

Basin	0–10 years	10–25 years	25–50 years
	from municipal return flows, will sustain "adequate" water quantity in the Lower parts of this basin, during dry times.	Droughts are exacerbated by changing weather patterns and increased human demands under RCP6.0. These effects are mitigated somewhat by return flows, depending on the amount of reuse. Droughts are much exacerbated by changing weather patterns and increased human demands under RCP8.5. These effects are mitigated somewhat by return flows, depending on the amount of reuse.	anthropogenic impacts and climate forcing associated with continued increasing human demand and climate change. A combination of climate forcings and anthropogenic responses to water shortages results in significant and severe alteration of hydrological conditions, such that both dewatering events and scouring floods are more frequent and severe.
Trinity *Lower East Fork of the Trinity River*	In this highly managed system: Flows will continue at existing "adequate" levels, and existing altered hydrology (associated with reservoir management) will continue for the next 10 years. Return flows, and management of reuse flows, are expected to maintain "adequate" flow. Some flow protections exist associated with permitting of the East Fork Water Reuse Project (NTMD).	In this highly managed system, likely no significant changes, but rather a continuation of current trends. Conservation strategies are planned and implemented to protect flows, water quality, and riparian habitats and adjacent uplands. Droughts are exacerbated by changing weather patterns and increased human demands under RCP6.0. These effects are mitigated somewhat by return flows, depending on the amount of reuse. Droughts are much exacerbated by changing weather patterns and increased human demands under RCP8.5. These effects are mitigated somewhat by return flows, depending on the amount of reuse.	In this highly managed system, likely no significant changes, but rather a continuation of current trends. Conservation strategies planned are implemented. Negative impacts to habitat factors cause declines in habitat conditions, due to anthropogenic impacts and climate forcing associated with continued increasing human demand and climate change. A combination of climate forcings and anthropogenic responses to water shortages results in significant and severe alteration of hydrological conditions.
Trinity *Middle Trinity River*	In this highly managed system: Flows will continue at existing "adequate" levels, and existing altered hydrology (associated with reservoir management	In this highly managed system, likely no significant changes, but rather a continuation of current trends. Flows will continue at existing "adequate" levels, and existing altered hydrology (associated with	In this highly managed system, likely no significant changes, but rather a continuation of current trends. Flows will continue at existing "adequate" levels,

Basin	0–10 years	10–25 years	25–50 years
	and stormwater runoff from significant urban development) will continue for the next 10 years. Return flows, significant reuse, interbasin transfers, downstream senior rights, and agreements with the City of Houston guarantee that at least “30% of return flows originating in the Trinity basin will remain in the river to Lake Livingston (TRA letter 2018).	reservoir management and stormwater runoff from significant urban development) will continue for the next 25 years. Return flows, significant reuse, interbasin transfers, downstream senior rights, and agreements with the City of Houston guarantee that at least “30% of return flows originating in the Trinity basin will remain in the river to Lake Livingston (TRA letter 2018). Hydrological alterations (higher baseflows due return flows and exaggerated flooding due to increased impervious cover) expected to increase (greater departure from a “natural flow” regime) with increasing human development. Water quality continues to improve following improved treatment of reused water. Conservation strategies are planned and implemented to protect flows, water quality, and riparian habitats and adjacent uplands. Droughts are exacerbated by changing weather patterns and increased human demands under RCP6.0. These effects are mitigated somewhat by return flows, depending on the amount of reuse. Droughts are much exacerbated by changing weather patterns and increased human demands under RCP8.5. These effects are mitigated somewhat by return flows, depending on the amount of reuse.	and existing altered hydrology (associated with reservoir management and stormwater runoff from significant urban development) will continue, and perhaps increase, over the next 50 years, due to additional reuse and interbasin transfers. Return flows, significant reuse, interbasin transfers, downstream senior rights, and agreements with the City of Houston guarantee that at least “30% of return flows originating in the Trinity basin will remain in the river to Lake Livingston (TRA letter 2018). Hydrological alterations (higher baseflows due return flows and exaggerated flooding due to increased impervious cover) expected to increase (greater departure from a “natural flow” regime) with increasing human development. Water quality continues to improve following improved treatment of reused water. Same as 10–25. Same as 10–25.
Assumptions	● Return flows (wastewater effluent, interbasin exchange, groundwater “converted” to surface water) will continue to contribute to base flows in the lower portions of the basins below major metropolitan areas (DFW,		

Basin	0–10 years	10–25 years	25–50 years
	Austin, and to a lesser extent, Waco, and San Marcos). However, reuse may increase in the future, which could result in reductions to return flows. ● Drought (seasonal rainfall patterns combined with associated increased withdrawals/diversions) is expected to increasingly have adverse effects on flows in the upper portions of the basins, and tributaries. Drought effects in the lower basins are mitigated for the most part by return flows (see above). ● In the future, floods are expected to be more severe if not more frequent. Climate change and land use changes are expected to exacerbate flooding in the future		

7.C Viability (Resiliency, Redundancy, and Representation)

This section generally reviews the viability of the seven Central Texas mussel species under each of the four scenarios. The output of the scenarios at each time step for each species are included in Appendix C, and synopses of the effects to the populations over time are included in Appendix D.

7.C.1. Scenario 1

Resiliency

Under Scenario 1, populations of six of the seven Central Texas mussel species decline in resiliency over time as those factors that are having an influence on populations of Central Texas mussels continue at current rates (Table 7.3). The effects of current levels of climate change continue to result in low streamflow, which lead to increased sedimentation, reduced water quality, and occasional desiccation. Population extirpations occur to six of the seven species, with no species having any populations in better than moderate condition. Those populations in unhealthy condition are particularly vulnerable to extirpation.

Redundancy

Six of the seven Central Texas mussels lose redundancy under Scenario 1 (Table 7.3). Under our projections, only the Texas fawnsfoot and Texas fatmucket would have more than one population in a representation area in 50 years. All populations of Texas pimpleback and Guadalupe fatmucket are projected to become extirpated in 50 years under this scenario.

Representation

Under Scenario 1, three of the seven species of Central Texas mussels lose an area of representation (Table 7.3). Texas fawnsfoot may maintain representation in each watershed, but three of its four remaining populations are projected to be in unhealthy condition and vulnerable to extirpation. The remaining species have lost areas of representation and, therefore, adaptive capacity to future environmental change.

Table 7.3. Condition of the Central Texas mussel populations under Scenario 1 in the Guadalupe, Colorado, Brazos, and Trinity River watersheds. [Healthy (H); (M) Moderately healthy (M); Unhealthy (U); Extirpated/Functionally extirpated (X)].

Watershed	**False spike**			**Balcones spike**			**Texas pimpleback**			**Texas fatmucket**			**Texas fawnsfoot**			**Guadalupe fatmucket**			**Guadalupe orb**		
	10	25	50	10	25	50	10	25	50	10	25	50	10	25	50	10	25	50	10	25	50
Guadalupe River																					
Upper Guadalupe																**U**	**U**	**X**	**U**	**U**	**X**
Lower Guadalupe	**M**	**M**	**M**																		
San Marcos/Lower Guadalupe																			**M**	**M**	**M**
Colorado River																					
Bluff and Elm Creek										**U**	**X**	**X**									
Concho							**X**	**X**	**X**												
Upper/Middle San Saba							**U**	**X**	**X**	**M**	**U**	**U**									
Lower San Saba				**X**	**X**	**X**							**X**	**X**	**X**						
Upper Colorado and Lower San Saba							**M**	**U**	**X**												
Llano				**U**	**X**	**X**	**U**	**X**	**X**	**M**	**U**	**U**									
Pedernales										**U**	**U**	**X**									
Onion Creek										**X**	**X**	**X**									
Lower Colorado							**M**	**U**	**X**				**M**	**U**	**U**						
Brazos River																					
Clear Fork Brazos													**X**	**X**	**X**						
Upper Brazos													**U**	**X**	**X**						
Little River				**U**	**U**	**U**															
Lower Brazos													**M**	**M**	**M**						
Trinity River																					
East Fork Trinity													**U**	**U**	**U**						
Lower Trinity													**U**	**U**	**U**						
# of Populations	1			3			5			5			7			1			2		
Healthy	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Moderately healthy	1	1	1	0	0	0	2	0	0	2	0	0	2	1	1	0	0	0	1	1	1
Unhealthy	0	0	0	2	1	1	2	2	0	2	3	2	3	3	3	1	1	0	1	1	0
Extirpated/Functionally extirpated	0	0	0	1	1	2	1	3	5	1	2	3	2	3	3	0	0	1	0	0	1
# of Representation Units (Watersheds)	1	1	1	2	1	1	1	1	0	1	1-	1	3	3	3	1	1	0	1	1	1

7.C.2. Scenario 2

Resiliency

Under Scenario 2, populations of all seven Central Texas mussel species generally maintain, or slightly improve, resiliency over time as conservation measures are implemented to counteract existing stressors (Table 7.4). The effects of current levels of climate change continue to result in low stream flows, which lead to increased sedimentation, reduced water quality, and occasional desiccation, but water conservation measures and riparian improvements aid some populations. Even so, three of the seven species experience at least one population extirpation, and only false spike and Texas fawnsfoot have single populations in healthy condition; all other populations are in moderate or worse condition. Those populations in unhealthy condition are particularly vulnerable to extirpation.

Redundancy

Five of seven Central Texas mussels generally maintain redundancy under Scenario 2 (Table 7.4). The remaining 2 species currently exist as single populations and lack redundancy to begin. Under our projections, several populations are extirpated but not to the same degree as in other scenarios.

Representation

Under Scenario 2, all seven Central Texas mussels generally maintain representation over time (Table 7.4). Balcones spike has single, unhealthy populations in two representation areas even under the conservation scenario, but we do not project complete loss of any representation area by any species under this scenario.

Table 7.4. Condition of seven Central Texas mussel species populations under Scenario 2 in the Guadalupe, Colorado, Brazos, and Trinity River watersheds. [Healthy (H); (M) Moderately healthy (M); Unhealthy (U); Extirpated/Functionally extirpated (X)].

Watershed	**False spike**		**Balcones spike**		**Texas pimpleback**		**Texas fatmucket**		**Texas fawnsfoot**		**Guadalupe fatmucket**		**Guadalupe orb**	
	25	50	25	50	25	50	25	50	25	50	25	50	25	50
Guadalupe River														
Upper Guadalupe											**U**	**M**	**U**	**U**
Lower Guadalupe	**M**	**H**												
San Marcos/Lower Guadalupe													**M**	**M**
Colorado River														
Bluff and Elm Creek							**U**	**U**						
Concho					**X**	**X**								
Upper/Middle San Saba					**U**	**M**	**U**	**U**						
Lower San Saba			**U**	**U**					**X**	**U**				
Upper Colorado and Lower San Saba					**U**	**U**								
Llano			**X**	**X**	**U**	**M**	**M**	**M**						
Pedernales							**U**	**U**						
Onion Creek							**U**	**M**						
Lower Colorado					**M**	**M**			**M**	**H**				
Brazos River														
Clear Fork Brazos									**U**	**U**				
Upper Brazos									**U**	**X**				
Little River			**U**	**U**										
Lower Brazos									**M**	**M**				
Trinity River														
East Fork Trinity									**M**	**M**				
Lower Trinity									**M**	**M**				
# of Populations	1		3		5		5		7		1		2	
Healthy	0	1	0	0	0	0	0	0	0	1	0	0	0	0
Moderately Healthy	1	0	0	0	1	3	1	2	4	3	0	1	1	1
Unhealthy	0	0	2	2	3	1	4	3	2	2	1	0	1	1
Extirpated/Functionally Extirpated	0	0	1	1	1	1	0	0	1	1	0	0	0	0
# of Representation Units (Watersheds)	1	1	2	2	1	1	1	1	3	3	1	1	1	1

7.C.3. Scenario 3

Resiliency

Under Scenario 3, populations of all seven Central Texas mussel species decline in resiliency over time as climate change begins to affect populations (Table 7.5). The effects of intermediate levels of climate change result in lower stream flows, which lead to increased sedimentation, reduced water quality, and desiccation. Population extirpations occur to all seven species, and no species with populations in any condition better than unhealthy are projected within 50 years; those populations in unhealthy condition are particularly vulnerable to extirpation. Furthermore, false spike, Texas fatmucket, and Guadalupe orb only have one population in unhealthy condition, leaving those three species the most vulnerable to extinction.

Redundancy

Six of the seven Central Texas mussels lose redundancy under Scenario 3 (Table 7.5). False spike does not lose redundancy as it is only currently represented in one area of representation. Under our projections, only the Texas fawnsfoot would have more than one population in 50 years. All populations remaining of all species are projected to be in unhealthy condition and vulnerable to extirpation.

Representation

Under Scenario 3, four of the seven species of Central Texas mussels lose an area of representation (Table 7.5) and, therefore, adaptive capacity to future environmental change. Texas fawnsfoot may maintain representation in each watershed in 50 years, but remaining populations are projected to be in unhealthy condition and are vulnerable to extirpation.

Table 7.5. Condition of four Central Texas mussel species populations under Scenario 3 in the Guadalupe, Colorado, Brazos, and Trinity River watersheds. [Healthy (H); (M) Moderately healthy (M); Unhealthy (U); Extirpated/Functionally extirpated (X)]

Watershed	**False spike**		**Balcones spike**		**Texas pimpleback**		**Texas fatmucket**		**Texas fawnsfoot**		**Guadalupe fatmucket**		**Guadalupe orb**	
	25	50	25	50	25	50	25	50	25	50	25	50	25	50
Guadalupe River														
Upper Guadalupe											**U**	**X**	**U**	**X**
Lower Guadalupe	**M**	**U**												
San Marcos/Lower Guadalupe													**M**	**U**
Colorado River														
Bluff and Elm Creek							**X**	**X**						
Concho					**X**	**X**								
Upper/Middle San Saba					**X**	**X**	**U**	**X**						
Lower San Saba			**X**	**X**					**X**	**X**				
Upper Colorado and Lower San Saba					**U**	**X**								
Llano			**X**	**X**	**X**	**X**	**U**	**U**						
Pedernales							**U**	**X**						
Onion Creek							**X**	**X**						
Lower Colorado					**U**	**X**			**M**	**U**				
Brazos River														
Clear Fork Brazos									**X**	**X**				
Upper Brazos									**X**	**X**				
Little River			**U**	**X**										
Lower Brazos									**M**	**U**				
Trinity River														
East Fork Trinity									**U**	**U**				
Lower Trinity									**U**	**U**				
# of Populations	1		3		5		5		7		1		2	
Healthy	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Moderately healthy	1	0	0	0	0	0	0	0	2	0	0	0	1	0
Unhealthy	0	1	1	0	2	0	3	1	2	4	1	0	1	1
Extirpated/Functionally extirpated	0	0	2	3	3	5	2	4	3	3	0	1	0	1
# of Representation Units (Watersheds)	1	1	1	0	1	0	1	1	3	3	1	0	1	1

7.C.4. Scenario 4

Resiliency

Under Scenario 4, populations of all seven Central Texas mussel species decline in resiliency over time as severe climate change begins to affect populations (Table 7.6). The effects of strong levels of climate change result in even lower stream flows, which lead to increased sedimentation, reduced water quality, and desiccation. Population extirpations occur to all seven species, and no species with populations in any condition better than unhealthy in 50 years. Those populations in unhealthy condition are particularly vulnerable to extirpation. Texas pimpleback and Guadalupe fatmucket are projected to be completely extirpated within 25 years. Furthermore, false spike, Texas fatmucket, and Guadalupe orb are projected to only have one population in unhealthy condition remaining in 50 years, leaving those three species vulnerable to extinction.

Redundancy

Six of the seven Central Texas mussels lose redundancy under Scenario 4 (Table 7.6). False spike does not lose redundancy as it is only currently represented in area of representation. Under our projections, only the Texas fawnsfoot would have more than one population in 50 years although these three remaining populations are projected to be in unhealthy condition. The remaining single populations of false spike, Texas fatmucket, and Guadalupe orb are also projected to be in unhealthy condition and vulnerable to extirpation.

Representation

Under Scenario 4, four of the seven species of Central Texas mussels lose an area of representation (Table 7.6), and therefore, adaptive capacity to future environmental change. The remaining populations of all species projected to remain in 50 years are in unhealthy condition and are vulnerable to extirpation. All species are extremely vulnerable to extinction under Scenario 4.

Table 7.6. Condition of four Central Texas freshwater mussel species populations under Scenario 4 in the Guadalupe, Colorado, Brazos, and Trinity River watersheds. [Healthy (H); (M) Moderately healthy (M); Unhealthy (U); Extirpated/Functionally extirpated (X)]

Watershed	**False spike**		**Balcones spike**		**Texas pimpleback**		**Texas fatmucket**		**Texas fawnsfoot**		**Guadalupe fatmucket**		**Guadalupe orb**	
	25	50	25	50	25	50	25	50	25	50	25	50	25	50
Guadalupe River														
Upper Guadalupe											**X**	**X**	**X**	**X**
Lower Guadalupe	**M**	**U**												
San Marcos/Lower Guadalupe													**M**	**U**
Colorado River														
Bluff and Elm Creek							**X**	**X**						
Concho					**X**	**X**								
Upper/Middle San Saba					**X**	**X**	**U**	**X**						
Lower San Saba			**X**	**X**					**X**	**X**				
Upper Colorado and Lower San Saba					**X**	**X**								
Llano			**X**	**X**	**X**	**X**	**U**	**U**						
Pedernales							**X**	**X**						
Onion Creek							**X**	**X**						
Lower Colorado					**X**	**X**			**U**	**X**				
Brazos River														
Clear Fork Brazos									**X**	**X**				
Upper Brazos									**X**	**X**				
Little River			**X**	**X**										
Lower Brazos									**M**	**U**				
Trinity River														
East Fork Trinity									**U**	**U**				
Lower Trinity									**U**	**U**				
# of Populations	1		3		5		5		7		1		2	
Healthy	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Moderately healthy	1	0	0	0	0	0	0	0	1	0	0	0	1	0
Unhealthy	0	1	0	0	0	0	2	1	3	2	1	0	1	1
Extirpated/Functionally extirpated	0	0	3	3	5	5	3	4	3	3	0	1	1	1
# of Representation Units (Watersheds)	1	1	0	0	0	0	1	1	3	1	1	0	1	1

7.D Status Assessment Summary

Using the best available information, this report used scenario planning to forecast the likely future condition of the false spike, Balcones spike, Texas fatmucket, Texas fawnsfoot, Texas pimpleback, Guadalupe fatmucket, and Guadalupe orb across the range of habitats they occupy in Central Texas. The goal of this report is to describe the viability of each species in terms of resiliency, representation, and redundancy. This report considers the possible future condition of each species, and a range of potential scenarios that include important influences on the current and future status of the false spike, Balcones spike, Texas fatmucket, Texas fawnsfoot, Texas pimpleback, Guadalupe fatmucket, and Guadalupe orb. The results of this analysis describe a range of possible future conditions, whereby populations of these species are likely to persist into the future.

Each of these species face a variety of risks from a range of hydrological alterations to their habitats, including loss of flow leading to dewatering, excessive flows leading to scouring, water quality degradations, degradation of suitable substrates due to excessive sedimentation and other processes, inundation, and population isolation. Other factors contribute, or exacerbate exposure, to these risks but are not directly driving population condition. These secondary factors include depredation, disease, invasive species, over-collection and/or vandalism, exposure to environmental contaminants, and host fish interactions, among others.

These risks together substantially affect the future viability of the seven Central Texas mussel species. If population resiliency (the ability to withstand stochastic events and described by demographic factors including population size and growth rate) is diminished, populations are more vulnerable to extirpation. Population extirpations result in losses to redundancy (the ability of a species to withstand catastrophic events) and diminishment of species representation (important breadth of genetic and ecological diversity).

False spike is currently represented by one moderately healthy population. Within 50 years, under the best conditions and with additional conservation (Scenario 2), given the ongoing effects of climate change and human activities on altered hydrology and habitat degradation, this one population is expected to be in healthy condition (Table 7.4). Given the likelihood of increased climate and anthropogenic effects in the foreseeable future (Scenario 4), this population is expected to become unhealthy in 50 years (Table 7.6).

Balcones spike is currently represented by three unhealthy populations. Within 50 years, even under the best conditions and with additional conservation (Scenario 2), given the ongoing effects of climate change and human activities on altered hydrology and habitat degradation, one population is expected to become functionally extirpated and two are expected to be in an overall unhealthy condition, (Table 7.4). Given the likelihood of increased climate and anthropogenic effects in the foreseeable future (Scenario 4), all three populations are expected to become functionally extirpated in 50 years (Table 7.6).

Texas fatmucket is currently represented by two moderately healthy populations, two unhealthy populations, and one functionally extirpated population. Within 50 years, even under the best conditions and with additional conservation (Scenario 2), given the ongoing effects of climate change and human activities on altered hydrology and habitat degradation, two populations are in moderately healthy condition (including the functionally extirpated population), and three are in unhealthy condition (Table 7.4). Given the likelihood of increased climate and anthropogenic effects in the foreseeable future (Scenario 4), four populations are expected to become functionally extirpated, leaving just one unhealthy population remaining in 50 years (Table 7.6).

Texas fawnsfoot is currently represented by four moderately healthy populations and three unhealthy populations. Within 50 years, even under the best conditions and with additional conservation (Scenario 2), given the ongoing effects of climate change and human activities on altered hydrology and habitat degradation, one population is in healthy condition, one population is in moderately healthy condition, four populations are in unhealthy condition, and one population is functionally extirpated (Table 7.4). Given the likelihood of increased climate and anthropogenic effects in the foreseeable future (Scenario 4), as many as five populations are expected to become functionally extirpated, leaving no more than three unhealthy populations remaining in 50 years (Table 7.6).

Texas pimpleback is currently represented by two moderately healthy populations and three unhealthy populations. Within 50 years, even under the best conditions and with additional conservation (Scenario 2), given the ongoing effects of climate change and human activities on altered hydrology and habitat degradation, three populations are in moderately healthy condition, one is in unhealthy condition, and one population is functionally extirpated (Table 7.4). Given the likelihood of increased climate and anthropogenic effects in the foreseeable future (Scenario 4), all five populations are expected to become functionally extirpated in 50 years (Table 7.6).

Guadalupe fatmucket is currently represented by one unhealthy population. Within 50 years, under the best conditions and with additional conservation (Scenario 2), given the ongoing effects of climate change and human activities on altered hydrology and habitat degradation, this population is projected to be in moderately healthy condition (Table 7.4). Given the likelihood of increased climate change and anthropogenic effects in the foreseeable future (Scenario 4), this population is expected to become functionally extirpated in 50 years (Table 7.6).

Guadalupe orb is currently represented by one moderately healthy and one unhealthy population. Within 50 years, under the best conditions and with additional conservation (Scenario 2), given the ongoing effects of climate change and human activities on altered hydrology and habitat degradation, the condition of these populations is projected to remain the same (Table 7.4). Given the likelihood of increased climate change and anthropogenic effects in the foreseeable future (Scenario 4), these populations are expected to become unhealthy and functionally extirpated in 50 years (Table 7.6).

7.E SUPPLEMENTARY TABLES AND FIGURES

Summary of future population conditions by river basin:

Guadalupe River, Table 7.7
Colorado River, Table 7.8
Brazos River, Table 7.9
Trinity River, Table 7.10

Summary of future population condition by species:

False spike, Table 7.11, Figure 7.1
Balcones spike, Table 7.12, Figure 7.2
Texas fatmucket, Table 7.13, Figure 7.3
Texas fawnsfoot, Table 7.14, Figure 7.4
Texas pimpleback, Table 7.15, Figure 7.5
Guadalupe fatmucket, Table 7.16, Figure 7.6
Guadalupe orb, Table 7.17, Figure 7.7

Table 7.7. Number of populations of false spike, Guadalupe fatmucket, and Guadalupe orb by population[a] condition under future scenarios[b] in the Guadalupe River watershed.

		False spike				**Guadalupe fatmucket**				**Guadalupe orb**			
Scenario	Years	**H**	**M**	**U**	**X**	**H**	**M**	**U**	**X**	**H**	**M**	**U**	**X**
1	10		1				1	1				1	
	25		1				1	1				1	
	50		1				1		1				1
2	25		1				1	1				1	
	50	1					1	1			1		
3	25		1				1	1				1	
	50			1				1					1
4	25		1				1						1
	50			1				1					1

[a] Healthy (H); Moderately healthy (M); Unhealthy (U); Extirpated/Functionally extirpated (X).
See Table 5.1 for more information.

[b] 1: Continuation (of current conditions); 2: (Additional) conservation; 3: RCP6.0;
4: RCP 8.5.
See Table 7.1 for more information.

Table 7.8. Number of populations of Balcones spike, Texas pimpleback, Texas fatmucket, and Texas fawnsfoot by population condition[a] under future scenarios[b] in the Colorado River watershed.

		Balcones spike				**Texas pimpleback**				**Texas fatmucket**				**Texas fawnsfoot**			
Scenario	Years	**H**	**M**	**U**	**X**	**H**	**M**	**U**	**X**	**H**	**M**	**U**	**X**	**H**	**M**	**U**	**X**
1	10			1	1		2	2	1		2	2	1		1		1
	25				2			2	3			3	2		1		1
	50				2				5			2	3			1	1
2	25			1	1		1	3	1		1	4			1		1
	50			1	1		3	1	1		2	3		1		1	
3	25				2				3			3	2		1		1
	50				2				5			1	4			1	1
4	25				2				5			2	3			1	1
	50				2				5			1	4				2

[a] Healthy (H); Moderately healthy (M); Unhealthy (U); Extirpated/Functionally extirpated (X).
See Table 5.1 for more information.

[b] 1: Continuation (of current conditions); 2: (Additional) conservation; 3: RCP6.0;
4: RCP 8.5.
See Table 7.1 for more information.

Table 7.9. Number of populations of Balcones spike and Texas fawnsfoot by population condition[a] under future scenarios[b] in the Brazos River watershed.

		Balcones spike				**Texas fawnsfoot**			
Scenario	Years	**H**	**M**	**U**	**X**	**H**	**M**	**U**	**X**
1	10			1			1	1	1
	25			1			1		2
	50			1			1		2
2	25			1			1	2	
	50			1			1	1	1
3	25			1			1		2
	50				1			1	2
4	25				1			2	3
	50				1				1

[a] Healthy (H); Moderately healthy (M); Unhealthy (U); Extirpated/Functionally extirpated (X). See Table 5.1 for more information.

[b] 1: Continuation (of current conditions); 2: (Additional) conservation; 3: RCP6.0; 4: RCP 8.5.
See Table 7.1 for more information.

Table 7.10. Number of populations of Texas fawnsfoot by population condition[a] under future scenarios[b] in the Trinity River watershed.

		Texas fawnsfoot			
Scenario	Years	**H**	**M**	**U**	**X**
1	10			2	
	25			2	
	50			2	
2	25		2		
	50		2		
3	25			2	
	50			2	
4	25			2	
	50			2	

[a] Healthy (H); Moderately healthy (M); Unhealthy (U); Extirpated/Functionally extirpated (X). See Table 5.1 for more information.

[b] 1: Continuation (of current conditions); 2: (Additional) conservation; 3: RCP6.0; 4: RCP 8.5.
See Table 7.1 for more information.

Table 7.11. Condition[a] of false spike populations under future scenarios[b] (See Table 7.1 for more information) in the Guadalupe River watershed.

			Years		
Watershed	**Population**	**Scenario**	10	25	50
Guadalupe River	Lower Guadalupe	1	**M**	**M**	**M**
		2		**M**	**H**
		3		**M**	**U**
		4		**M**	**U**

[a] Healthy (H); Moderately healthy (M); Unhealthy (U); Extirpated/Functionally extirpated (X). See Table 5.1 for more information.

[b] 1: Continuation (of current conditions); 2: (Additional) conservation; 3: RCP6.0; 4: RCP 8.5.
See Table 7.1 for more information.

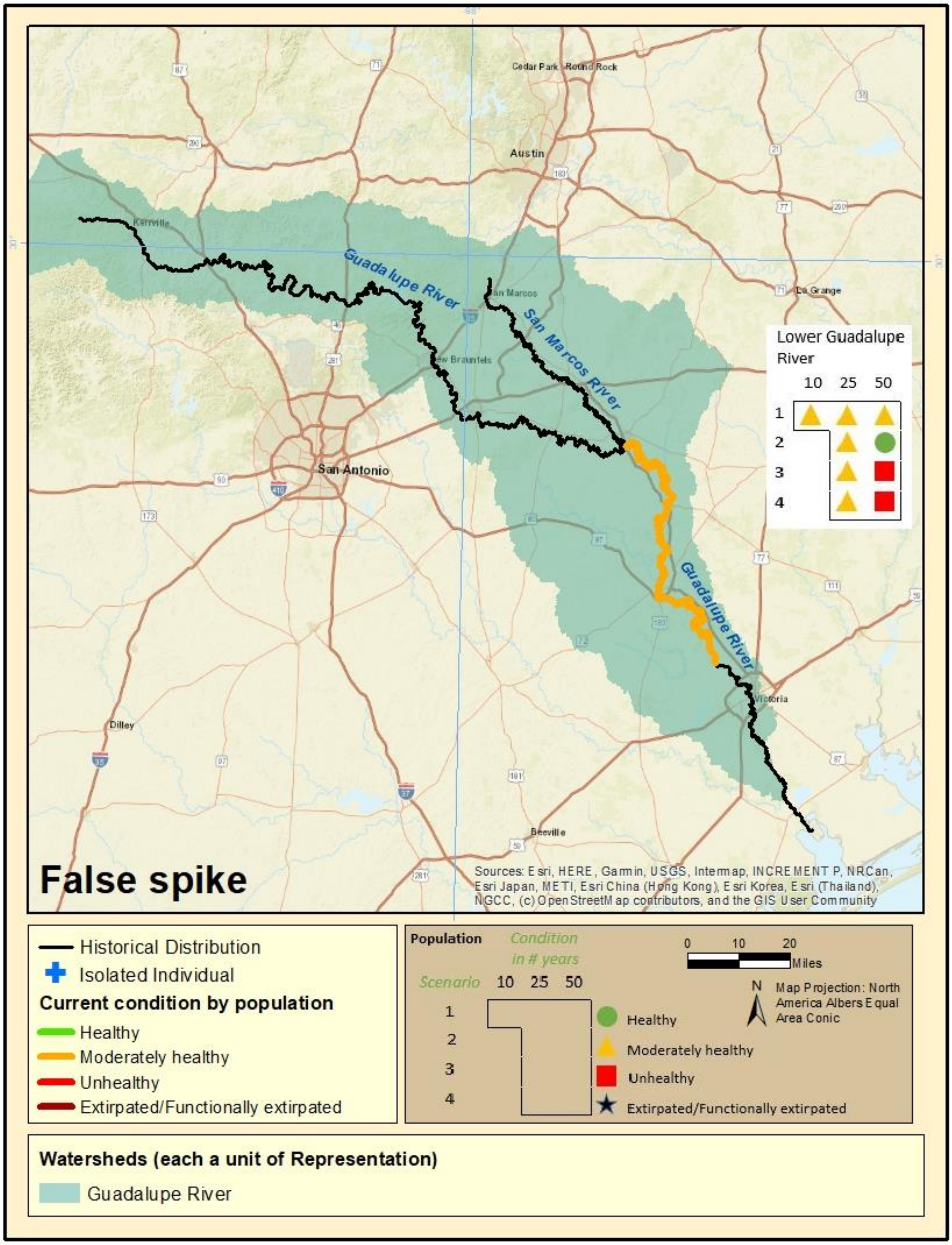

Figure 7.1. Current and projected future resiliency, representation, and redundancy of false spike under all scenarios and time steps.

Table 7.12. Condition[a] of Balcones spike populations under future scenarios[b] (See Table 7.1 for more information) in the Colorado and Brazos River watersheds.

			Years		
Watershed	**Population**	**Scenario**	10	25	50
Colorado River	Lower San Saba	1	**X**	**X**	**X**
		2		**U**	**U**
		3		**X**	**X**
		4		**X**	**X**
	Llano	1	**U**	**X**	**X**
		2		**X**	**X**
		3		**X**	**X**
		4		**X**	**X**
Brazos River	Little River	1	**U**	**U**	**U**
		2		**U**	**U**
		3		**U**	**X**
		4		**X**	**X**

[a] Healthy (H); Moderately healthy (M); Unhealthy (U); Extirpated/Functionally extirpated (X). See Table 5.1 for more information.

[b] 1: Continuation (of current conditions); 2: (Additional) conservation; 3: RCP6.0; 4: RCP 8.5. See Table 7.1 for more information.

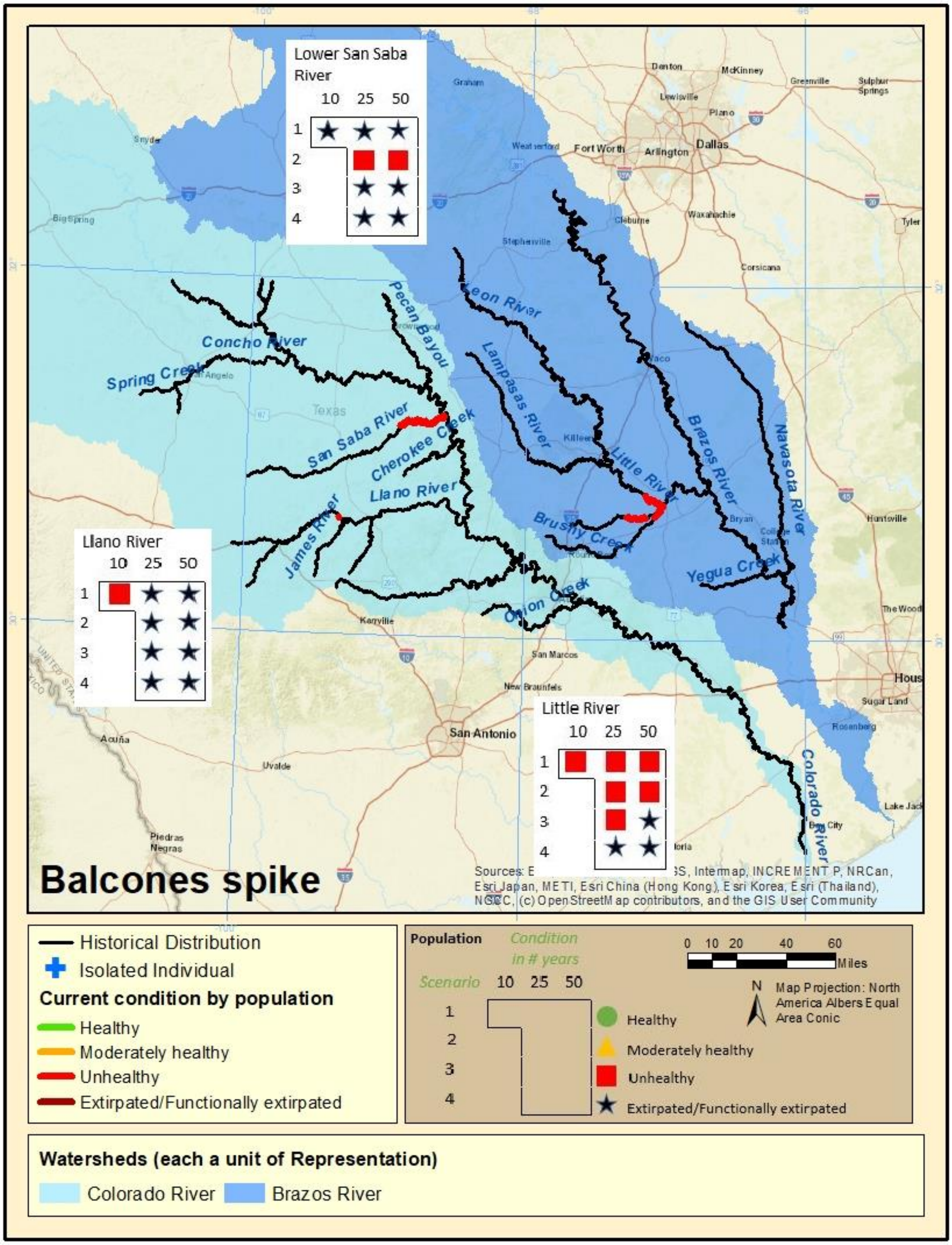

Figure 7.2. Current and projected future resiliency, representation, and redundancy of Balcones spike under all scenarios and time steps

Table 7.13. Condition[a] of Texas fatmucket populations under future scenarios[b] (See Table 7.1 for more information) in the Colorado River watershed.

			Years		
Watershed	**Population**	**Scenario**	10	25	50
Colorado River	Bluff and Elm Creek	1	**U**	**X**	**X**
		2		**U**	**U**
		3		**X**	**X**
		4		**X**	**X**
	Upper/Middle San Saba River	1	**M**	**U**	**U**
		2		**U**	**U**
		3		**U**	**X**
		4		**U**	**X**
	Llano River	1	**M**	**U**	**U**
		2		**M**	**M**
		3		**U**	**U**
		4		**U**	**U**
	Pedernales River	1	**U**	**U**	**X**
		2		**U**	**U**
		3		**U**	**X**
		4		**X**	**X**
	Onion Creek	1	**X**	**X**	**X**
		2		**U**	**M**
		3		**X**	**X**
		4		**X**	**X**

[a] Healthy (H); Moderately healthy (M); Unhealthy (U); Extirpated/Functionally extirpated (X). See Table 5.1 for more information.

[b] 1: Continuation (of current conditions); 2: (Additional) conservation; 3: RCP6.0; 4: RCP 8.5.
See Table 7.1 for more information.

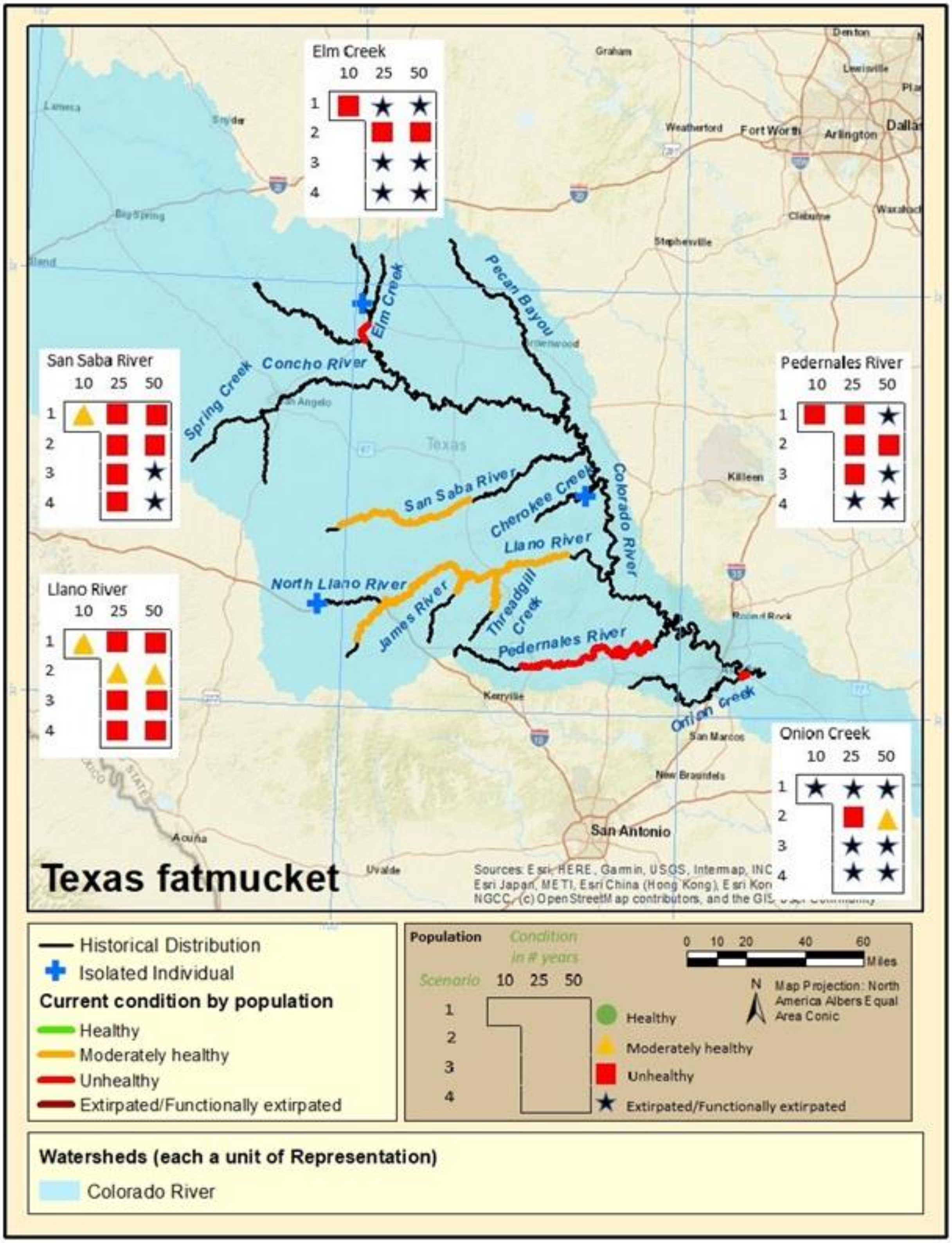

Figure 7.3. Current and projected future resiliency, representation, and redundancy of Texas fatmucket under all scenarios and time steps.

Table 7.14. Condition[a] of Texas fawnsfoot populations under future scenarios[b] (See Table 7.1 for more information) in the Colorado, Brazos, and Trinity River watersheds.

			Years		
Watershed	**Population**	**Scenario**	10	25	50
Colorado River	Lower San Saba River	1	**X**	**X**	**X**
		2		**X**	**U**
		3		**X**	**X**
		4		**X**	**X**
	Lower Colorado	1	**M**	**M**	**U**
		2		**M**	**H**
		3		**M**	**U**
		4		**U**	**X**
Brazos River	Clear Fork Brazos	1	**X**	**X**	**X**
		2		**U**	**U**
		3		**X**	**X**
		4		**X**	**X**
	Upper Brazos	1	**U**	**X**	**X**
		2		**U**	**X**
		3		**X**	**X**
		4		**X**	**X**
	Lower Brazos	1	**M**	**M**	**M**
		2		**M**	**M**
		3		**M**	**U**
		4		**U**	**U**
Trinity River	East Fork Trinity	1	**U**	**U**	**U**
		2		**M**	**M**
		3		**U**	**U**
		4		**U**	**U**
	Lower Trinity	1	**U**	**U**	**U**
		2		**M**	**M**
		3		**U**	**U**
		4		**U**	**U**

[a] Healthy (H); Moderately healthy (M); Unhealthy (U); Extirpated/Functionally extirpated (X). See Table 5.1 for more information.

[b] 1: Continuation (of current conditions); 2: (Additional) conservation; 3: RCP6.0; 4: RCP 8.5. See Table 7.1 for more information.

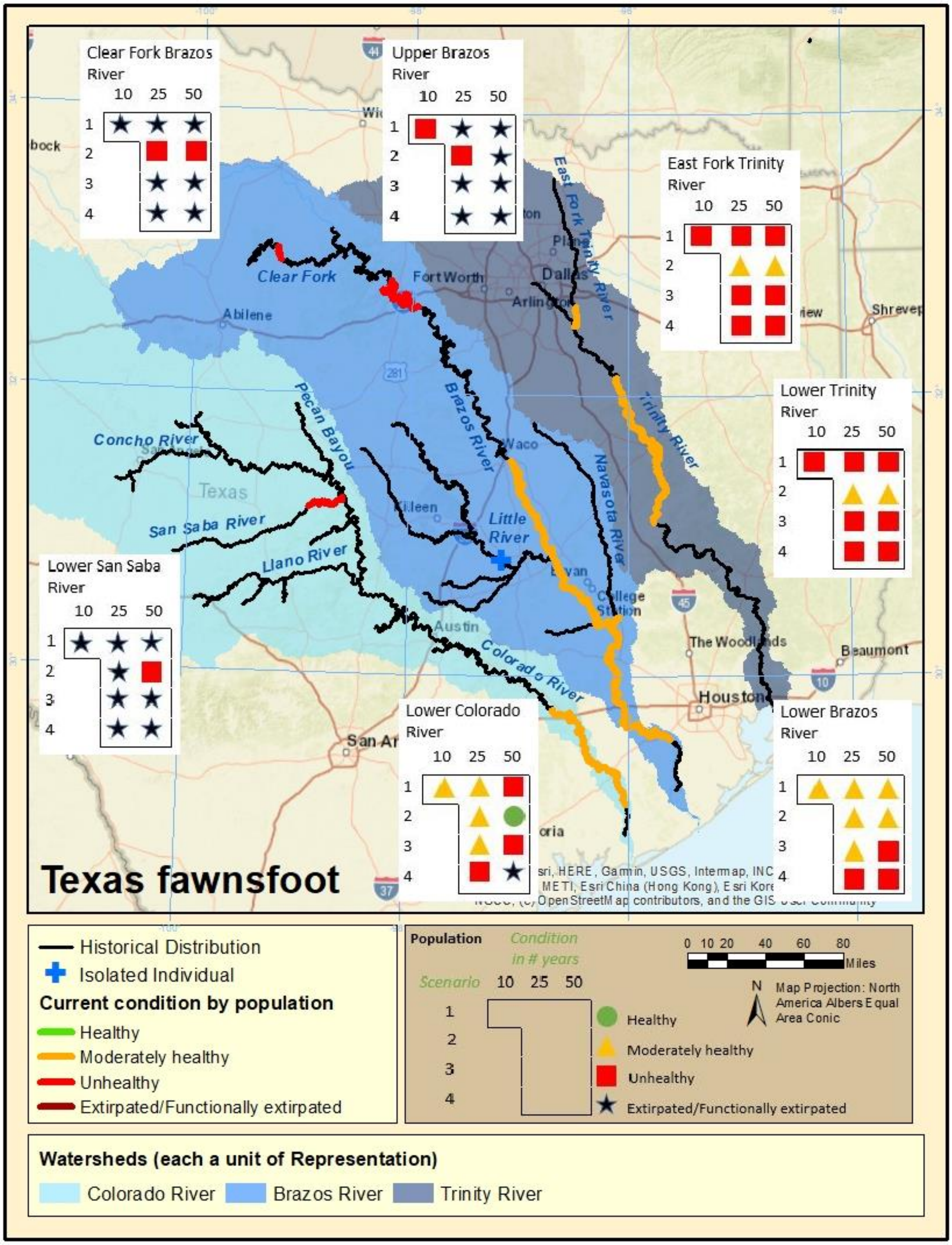

Figure 7.4. Current and projected future resiliency, representation, and redundancy of Texas fawnsfoot under all scenarios and time steps.

Table 7.15. Condition[a] of Texas pimpleback populations under future scenarios[b] (See Table 7.1 for more information) in the Colorado River watershed.

			Years		
Watershed	**Population**	**Scenario**	10	25	50
Colorado River	Concho	1	**X**	**X**	**X**
		2		**X**	**X**
		3		**X**	**X**
		4		**X**	**X**
	Upper San Saba	1	**U**	**X**	**X**
		2		**U**	**M**
		3		**X**	**X**
		4		**X**	**X**
	Upper Colorado and Lower San Saba	1	**M**	**U**	**X**
		2		**U**	**U**
		3		**U**	**X**
		4		**X**	**X**
	Llano	1	**U**	**X**	**X**
		2		**U**	**M**
		3		**X**	**X**
		4		**X**	**X**
	Lower Colorado	1	**M**	**U**	**X**
		2		**M**	**M**
		3		**U**	**X**
		4		**X**	**X**

[a] Healthy (H); Moderately healthy (M); Unhealthy (U); Extirpated/Functionally extirpated (X).
See Table 5.1 for more information.

[b] 1: Continuation (of current conditions); 2: (Additional) conservation; 3: RCP6.0;
4: RCP 8.5.
See Table 7.1 for more information.

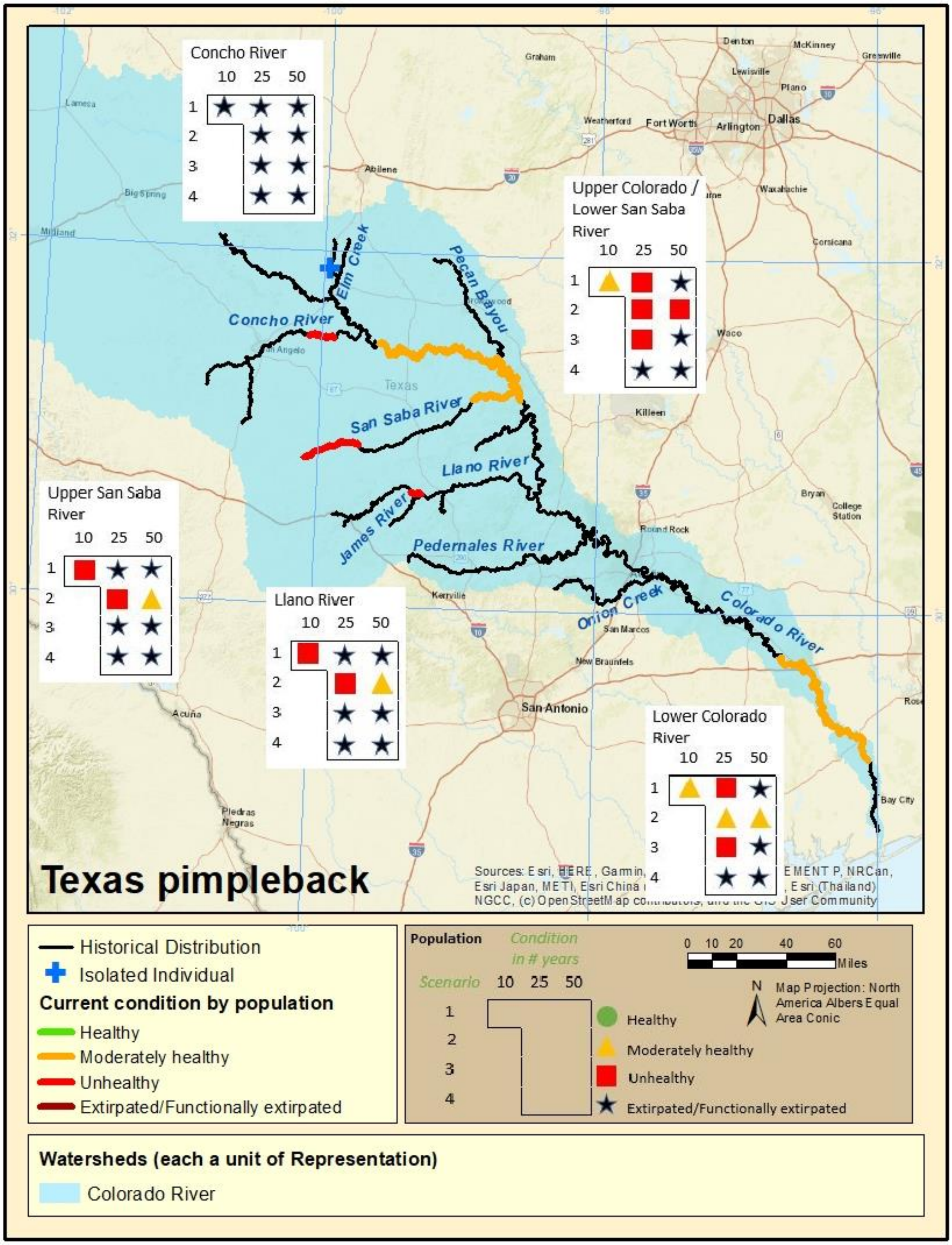

Figure 7.5. Current and projected future resiliency, representation, and redundancy of Texas pimpleback under all scenarios and time steps.

Table 7.16. Condition[a] of Guadalupe fatmucket populations under future scenarios[b] (See Table 7.1 for more information) in the Guadalupe River watershed.

			Years		
Watershed	**Population**	**Scenario**	10	25	50
Guadalupe River	Upper Guadalupe	1	**U**	**U**	**X**
		2		**U**	**M**
		3		**U**	**X**
		4		**X**	**X**

[a] Healthy (H); Moderately healthy (M); Unhealthy (U); Extirpated/Functionally extirpated (X).
See Table 5.1 for more information.

[b] 1: Continuation (of current conditions); 2: (Additional) conservation; 3: RCP6.0;
4: RCP 8.5.
See Table 7.1 for more information.

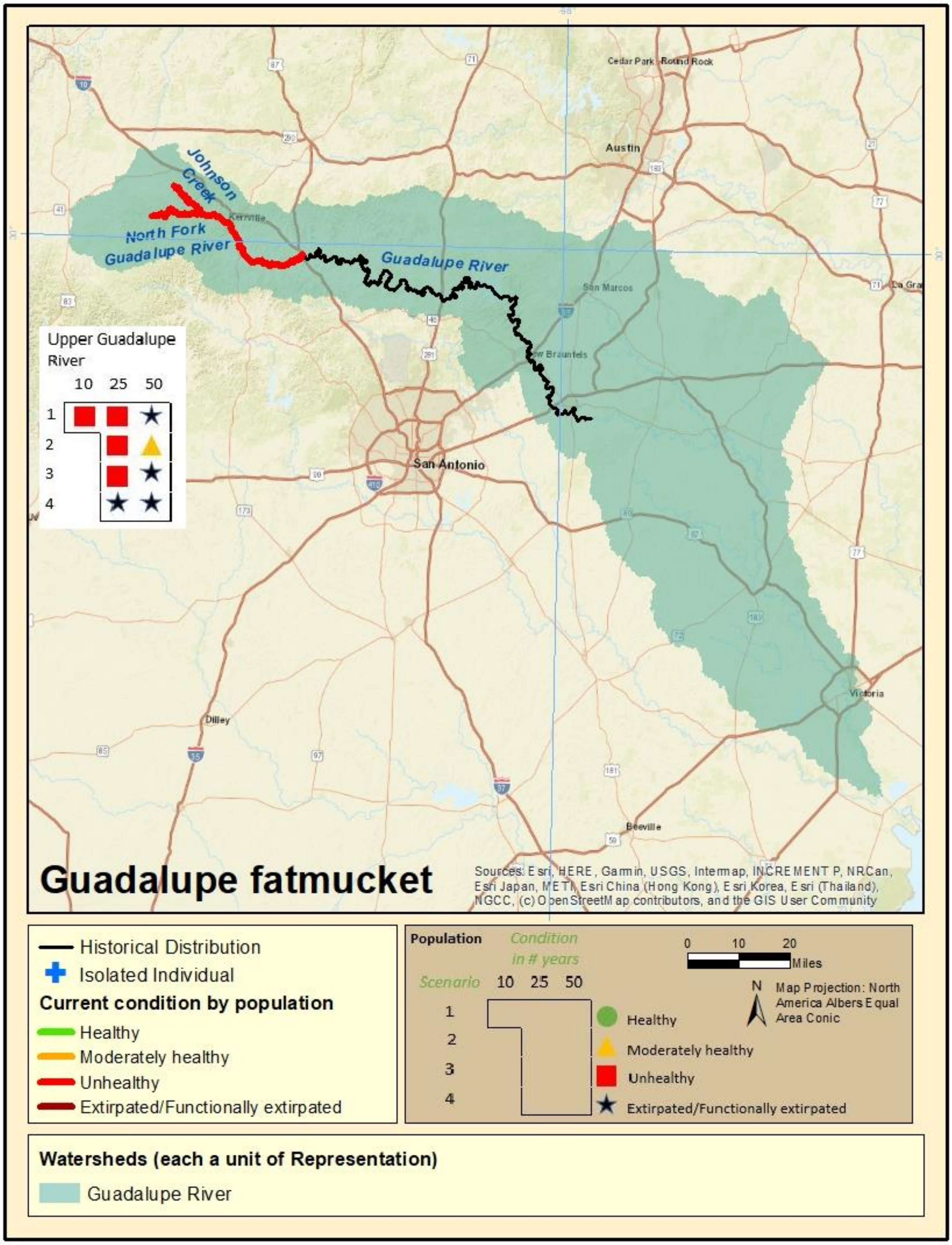

Figure 7.6. Current and projected future resiliency, representation, and redundancy of Guadalupe fatmucket under all scenarios and time steps.

Table 7.17. Condition[a] of Guadalupe orb populations under future scenarios[b] (See Table 7.1 for more information) in the Guadalupe River watershed.

			Years		
Watershed	**Population**	**Scenario**	10	25	50
Guadalupe River	Upper Guadalupe	1	**U**	**U**	**X**
		2		**U**	**U**
		3		**U**	**X**
		4		**X**	**X**
	San Marcos/Lower Guadalupe	1	**M**	**M**	**M**
		2		**M**	**M**
		3		**M**	**U**
		4		**M**	**U**

[a] Healthy (H); Moderately healthy (M); Unhealthy (U); Extirpated/Functionally extirpated (X). See Table 5.1 for more information.

[b] 1: Continuation (of current conditions); 2: (Additional) conservation; 3: RCP6.0; 4: RCP 8.5. See Table 7.1 for more information.

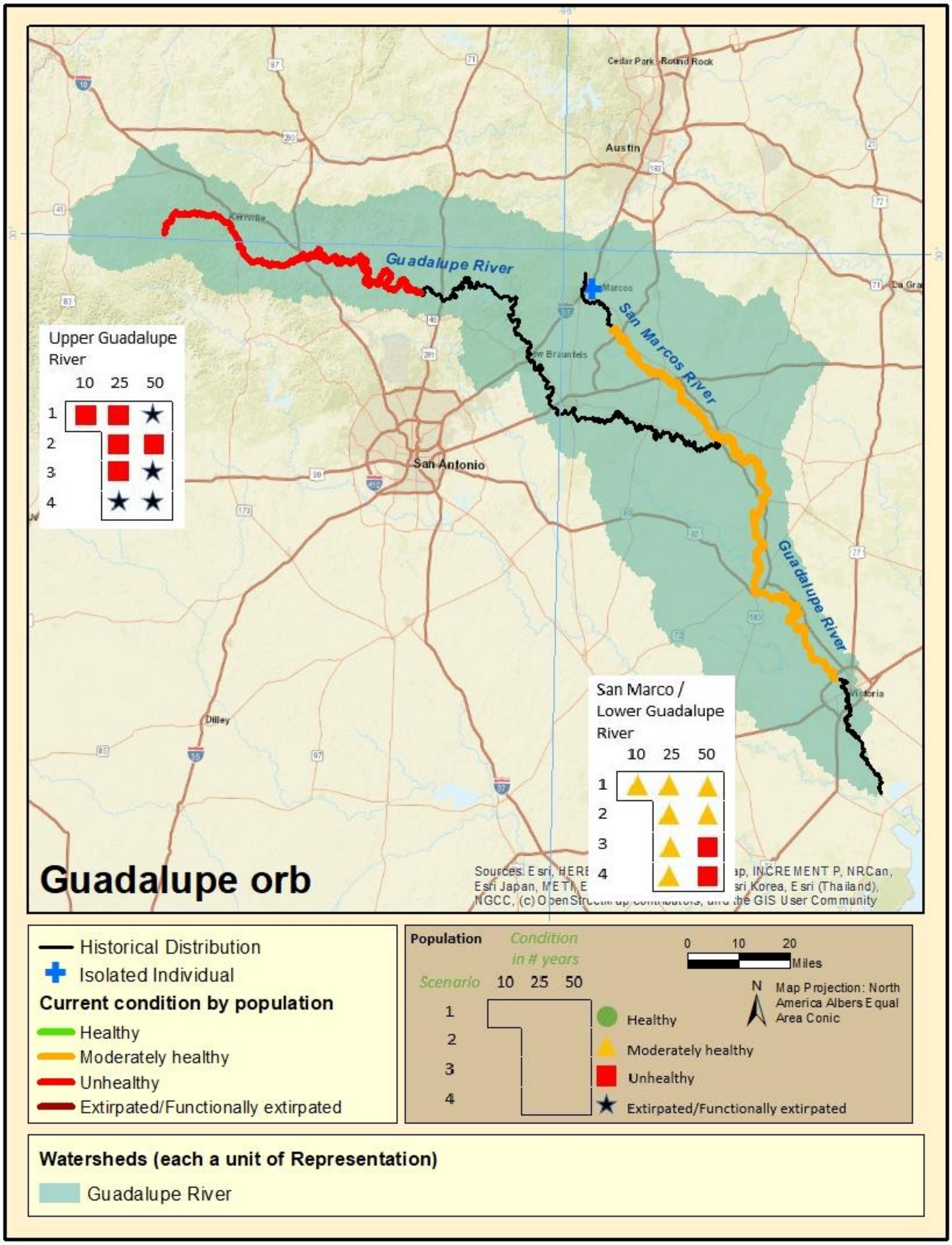

Figure 7.7. Current and projected future resiliency, representation, and redundancy of Guadalupe orb under all scenarios and time steps.

Appendix A – Literature Cited

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Appendix B – Evaluating Causes and Effects of Stressors for Central Texas Mussels Species Status Assessment

Appendix C - Future Condition Tables for Central Texas Mussels

C.1. False spike

C.1.a Scenario 1

Table C.1. False spike population conditions under Scenario 1 (Continuation) in 10 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Guadalupe	**Lower Guadalupe**	Healthy	Healthy	Moderate	Moderate	Moderate	Moderate	**Moderate**

Table C.2. False spike population conditions under Scenario 1 (Continuation) in 25 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Guadalupe	**Lower Guadalupe**	Healthy	Healthy	Moderate	Moderate	Moderate	Moderate	**Moderate**

Table C.3. False spike population conditions under Scenario 1 (Continuation) in 50 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Guadalupe	**Lower Guadalupe**	Healthy	Healthy	Moderate	Moderate	Unhealthy	Unhealthy	**Moderate**

C.1.b Scenario 2

Table C.4. False spike population conditions under Scenario 2 (Conservation) in 25 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Guadalupe	**Lower Guadalupe**	Healthy	Healthy	Moderate	Moderate	Moderate	Moderate	**Moderate**

Table C.5. False spike population conditions under Scenario 2 (Conservation) in 50 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Guadalupe	**Lower Guadalupe**	Healthy	Healthy	Healthy	Moderate	Moderate	Moderate	**Healthy**

C.1.c Scenario 3

Table C.6. False spike population conditions under Scenario 3 (RCP 6.0) in 25 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Guadalupe	**Lower Guadalupe**	Healthy	Healthy	Moderate	Moderate	Moderate	Moderate	**Moderate**

Table C.7. False spike population conditions under Scenario 3 (RCP 6.0) in 50 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Guadalupe	**Lower Guadalupe**	Healthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**

C.1.d Scenario 4

Table C.8. False spike population conditions under Scenario 4 (RCP 8.5) in 25 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Guadalupe	**Lower Guadalupe**	Healthy	Moderate	Moderate	Moderate	Moderate	Moderate	**Moderate**

Table C.9. False spike population conditions under Scenario 4 (RCP 8.5) in 50 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Guadalupe	**Lower Guadalupe**	Moderate	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**

C.2. Balcones spike

C.2.a Scenario 1

Table C.10. Balcones spike population conditions under Scenario 1 (Continuation) in 10 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Colorado	**Lower San Saba**	Func. Ext.	Func. Ext.	Func. Ext.	Moderate	Moderate	Moderate	**Func. Ext.**
	Llano	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
Brazos	**Little**	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**

Table C.11. Balcones spike population conditions under Scenario 1 (Continuation) in 25 years

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Colorado	**Lower San Saba**	Func. Ext.	Func. Ext.	Func. Ext.	Moderate	Moderate	Moderate	**Func. Ext.**
	Llano	Func. Ext.	Func. Ext.	Func. Ext.	Moderate	Moderate	Moderate	**Func. Ext.**
Brazos	**Little**	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**

Table C.12. Balcones spike population conditions under Scenario 1 (Continuation) in 50 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Colorado	**Lower San Saba**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Llano	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Brazos	**Little**	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**

C.2.b Scenario 2

Table C.13. Balcones spike population conditions under Scenario 2 (Conservation) in 25 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Colorado	**Lower San Saba**	Moderate	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
	Llano	Func. Ext.	Func. Ext.	Func. Ext.	Moderate	Moderate	Moderate	**Func. Ext.**
Brazos	**Little**	Moderate	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**

Table C.14. Balcones spike population conditions under Scenario 2 (Conservation) in 50 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Colorado	**Lower San Saba**	Moderate	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
	Llano	Func. Ext.	Func. Ext.	Func. Ext.	Moderate	Moderate	Moderate	**Func. Ext.**
Brazos	**Little**	Moderate	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**

C.2.c Scenario 3

Table C.15. Balcones spike population conditions under Scenario 3 (RCP 6.0) in 25 years.

		Population Factors			**Habitat Factors**			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Colorado	**Lower San Saba**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Llano	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Brazos	**Little**	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**

Table C.16. Balcones spike population conditions under Scenario 3 (RCP 6.0) in 50 years.

		Population Factors			**Habitat Factors**			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Colorado	**Lower San Saba**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Llano	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Brazos	**Little**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

C.2.d Scenario 4

Table C.17. Balcones spike population conditions under Scenario 4 (RCP 8.5) in 25 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Colorado	**Lower San Saba**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Llano	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Brazos	**Little**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

Table C.18. Balcones spike population conditions under Scenario 4 (RCP 8.5) in 50 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Colorado	**Lower San Saba**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Llano	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Brazos	**Little**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

C.3. Texas fatmucket

C.3.a Scenario 1

Table C.19. Texas fatmucket population conditions under Scenario 1 (Continuation) in 10 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Colorado	**Elm Creek**	Unhealthy	Unhealthy	Unhealthy	Moderate	Unhealthy	Unhealthy	**Unhealthy**
	San Saba	Healthy	Moderate	Moderate	Moderate	Moderate	Moderate	**Moderate**
	Llano	Healthy	Moderate	Unhealthy	Moderate	Moderate	Moderate	**Moderate**
	Pedernales	Moderate	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
	Onion Creek	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Moderate	Unhealthy	**Func. Ext.**

Table C.20. Texas fatmucket population conditions under Scenario 1 (Continuation) in 25 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Colorado	**Elm Creek**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	San Saba	Moderate	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
	Llano	Healthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
	Pedernales	Moderate	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
	Onion Creek	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Moderate	Unhealthy	**Func. Ext.**

Table C.21. Texas fatmucket population conditions under Scenario 1 (Continuation) in 50 years.

		Population Factors			**Habitat Factors**			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Colorado	**Elm Creek**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	San Saba	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
	Llano	Moderate	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
	Pedernales	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Onion Creek	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

C.3.b Scenario 2

Table C.22. Texas fatmucket population conditions under Scenario 2 (Conservation) in 25 years.

		Population Factors			**Habitat Factors**			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Colorado	**Elm Creek**	Unhealthy	Unhealthy	Unhealthy	Moderate	Unhealthy	Moderate	**Unhealthy**
	San Saba	Moderate	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
	Llano	Healthy	Moderate	Unhealthy	Moderate	Moderate	Moderate	**Moderate**
	Pedernales	Moderate	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
	Onion Creek	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**

Table C.23. Texas fatmucket population conditions under Scenario 2 (Conservation) in 50 years.

		Population Factors			**Habitat Factors**			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Colorado	**Elm Creek**	Unhealthy	Unhealthy	Unhealthy	Moderate	Unhealthy	Moderate	**Unhealthy**
	San Saba	Moderate	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
	Llano	Healthy	Moderate	Moderate	Moderate	Moderate	Moderate	**Moderate**
	Pedernales	Moderate	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
	Onion Creek	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	**Moderate**

C.3.c Scenario 3

Table C.24. Texas fatmucket population conditions under Scenario 3 (RCP 6.0) in 25 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Colorado	**Elm Creek**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	San Saba	Moderate	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
	Llano	Healthy	Unhealthy	Unhealthy	Moderate	Unhealthy	Moderate	**Unhealthy**
	Pedernales	Moderate	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
	Onion Creek	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

Table C.25. Texas fatmucket population conditions under Scenario 3 (RCP 6.0) in 50 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Colorado	**Elm Creek**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	San Saba	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Llano	Moderate	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
	Pedernales	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Onion Creek	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

C.3.d Scenario 4

Table C.26. Texas fatmucket population conditions under Scenario 4 (RCP 8.5) in 25 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Colorado	**Elm Creek**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	San Saba	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
	Llano	Moderate	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
	Pedernales	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Onion Creek	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

Table C.27. Texas fatmucket population conditions under Scenario 4 (RCP 8.5) in 50 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Colorado	**Elm Creek**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	San Saba	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Llano	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
	Pedernales	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Onion Creek	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

C.4. Texas fawnsfoot

C.4.a Scenario 1

Table C.28. Texas fawnsfoot population conditions under Scenario 1 (Continuation) in 10 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Brazos	**Clear Fork Brazos**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Upper Brazos	Healthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Moderate	**Unhealthy**
	Lower Brazos	Healthy	Moderate	Moderate	Moderate	Healthy	Moderate	**Moderate**
Colorado	**Lower San Saba**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Moderate	Moderate	**Func. Ext.**
	Lower Colorado	Healthy	Moderate	Healthy	Moderate	Moderate	Moderate	**Moderate**
Trinity	**East Fork Trinity**	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
	Trinity	Healthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Moderate	**Unhealthy**

Table C.29. Texas fawnsfoot population conditions under Scenario 1 (Continuation) in 25 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Brazos	**Clear Fork Brazos**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Upper Brazos	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Moderate	**Func. Ext.**
	Lower Brazos	Moderate	Moderate	Moderate	Moderate	Healthy	Moderate	**Moderate**
Colorado	**Lower San Saba**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Moderate	Moderate	**Func. Ext.**
	Lower Colorado	Healthy	Moderate	Moderate	Unhealthy	Unhealthy	Unhealthy	**Moderate**
Trinity	**East Fork Trinity**	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
	Trinity	Healthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**

Table C.30. Texas fawnsfoot population conditions under Scenario 1 (Continuation) in 50 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Brazos	**Clear Fork Brazos**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Upper Brazos	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Moderate	**Func. Ext.**
	Lower Brazos	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	**Moderate**
Colorado	**Lower San Saba**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Lower Colorado	Moderate	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
Trinity	**East Fork Trinity**	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
	Trinity	Healthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**

C.4.b Scenario 2

Table C.31. Texas fawnsfoot population conditions under Scenario 2 (Conservation) in 25 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Brazos	**Clear Fork Brazos**	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
	Upper Brazos	Healthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Moderate	**Unhealthy**
	Lower Brazos	Healthy	Moderate	Moderate	Moderate	Healthy	Moderate	**Moderate**
Colorado	**Lower San Saba**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Moderate	Moderate	**Func. Ext.**
	Lower Colorado	Healthy	Moderate	Healthy	Moderate	Moderate	Moderate	**Moderate**
Trinity	**East Fork Trinity**	Unhealthy	Moderate	Unhealthy	Moderate	Moderate	Moderate	**Moderate**
	Trinity	Healthy	Moderate	Unhealthy	Moderate	Moderate	Moderate	**Moderate**

Table C.32. Texas fawnsfoot population conditions under Scenario 2 (Conservation) in 50 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Brazos	**Clear Fork Brazos**	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
	Upper Brazos	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Moderate	**Func. Ext.**
	Lower Brazos	Healthy	Moderate	Moderate	Moderate	Healthy	Moderate	**Moderate**
Colorado	**Lower San Saba**	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
	Lower Colorado	Healthy	Healthy	Healthy	Moderate	Moderate	Moderate	**Healthy**
Trinity	**East Fork Trinity**	Unhealthy	Moderate	Unhealthy	Moderate	Moderate	Moderate	Moderate
	Trinity	Healthy	Moderate	Unhealthy	Moderate	Moderate	Moderate	Moderate

C.4.c Scenario 3

Table C.33. Texas fawnsfoot population conditions under Scenario 3 (RCP 6.0) in 25 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Brazos	**Clear Fork Brazos**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Upper Brazos	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Moderate	**Func. Ext.**
	Lower Brazos	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	**Moderate**
Colorado	**Lower San Saba**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Lower Colorado	Moderate	Moderate	Moderate	Unhealthy	Unhealthy	Unhealthy	**Moderate**
Trinity	**East Fork Trinity**	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
	Trinity	Healthy	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	**Unhealthy**

Table C.34. Texas fawnsfoot population conditions under Scenario 3 (RCP 6.0) in 50 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Brazos	**Clear Fork Brazos**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Upper Brazos	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Moderate	**Func. Ext.**
	Lower Brazos	Moderate	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
Colorado	**Lower San Saba**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Lower Colorado	Moderate	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
Trinity	**East Fork Trinity**	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
	Trinity	Moderate	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	**Unhealthy**

C.4.d Scenario 4

Table C.35. Texas fawnsfoot population conditions under Scenario 4 (RCP 8.5) in 25 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Brazos	**Clear Fork Brazos**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Upper Brazos	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Moderate	**Func. Ext.**
	Lower Brazos	Moderate	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
Colorado	**Lower San Saba**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Lower Colorado	Moderate	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
Trinity	**East Fork Trinity**	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
	Trinity	Healthy	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	**Unhealthy**

Table C.36. Texas fawnsfoot population conditions under Scenario 4 (RCP 8.5) in 50 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Brazos	**Clear Fork Brazos**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Upper Brazos	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Moderate	**Func. Ext.**
	Lower Brazos	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
Colorado	**Lower San Saba**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Lower Colorado	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Trinity	**East Fork Trinity**	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
	Trinity	Moderate	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	**Unhealthy**

C.5. Texas pimpleback

C.5.a Scenario 1

Table C.37. Texas pimpleback population conditions under Scenario 1 (Continuation) in 10 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Colorado	**Concho**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Colorado & San Saba	Healthy	Moderate	Unhealthy	Moderate	Moderate	Moderate	**Moderate**
	Upper San Saba	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
	Llano	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	**Unhealthy**
	Lower Colorado	Healthy	Moderate	Unhealthy	Moderate	Moderate	Moderate	**Moderate**

Table C.38. Texas pimpleback population conditions under Scenario 1 (Continuation) in 25 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Colorado	**Concho**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Colorado & San Saba	Moderate	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Moderate**
	Upper San Saba	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Moderate	**Func. Ext.**
	Llano	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Moderate	Moderate	**Func. Ext.**
	Lower Colorado	Moderate	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**

Table C.39. Texas pimpleback population conditions under Scenario 1 (Continuation) in 50 years.

		Population Factors			**Habitat Factors**			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Colorado	**Concho**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Colorado & San Saba	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Upper San Saba	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Llano	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Lower Colorado	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

C.5.b Scenario 2

Table C.40. Texas pimpleback population conditions under Scenario 2 (Conservation) in 25 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Colorado	**Concho**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Colorado & San Saba	Moderate	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
	Upper San Saba	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
	Llano	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	**Unhealthy**
	Lower Colorado	Healthy	Moderate	Moderate	Moderate	Moderate	Moderate	**Moderate**

Table C.41. Texas pimpleback population conditions under Scenario 2 (Conservation) in 50 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Colorado	**Concho**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Colorado & San Saba	Moderate	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
	Upper San Saba	Unhealthy	Moderate	Moderate	Moderate	Moderate	Moderate	**Moderate**
	Llano	Unhealthy	Moderate	Moderate	Unhealthy	Moderate	Moderate	**Moderate**
	Lower Colorado	Healthy	Moderate	Moderate	Moderate	Moderate	Moderate	**Moderate**

C.5.c Scenario 3

Table C.42. Texas pimpleback population conditions under Scenario 3 (RCP 6.0) in 25 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Colorado	**Concho**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Colorado & San Saba	Moderate	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
	Upper San Saba	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Llano	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Lower Colorado	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**

Table C.43. Texas pimpleback population conditions under Scenario 3 (RCP 6.0) in 50 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Colorado	**Concho**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Colorado & San Saba	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Upper San Saba	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Llano	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Lower Colorado	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

C.5.d Scenario 4

Table C.44. Texas pimpleback population conditions under Scenario 4 (RCP 8.5) in 25 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Colorado	**Concho**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Colorado & San Saba	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Upper San Saba	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Llano	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Lower Colorado	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

Table C.45. Texas pimpleback population conditions under Scenario 4 (RCP 8.5) in 50 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Colorado	**Concho**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Colorado & San Saba	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Upper San Saba	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Llano	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	Lower Colorado	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

C.6. Guadalupe fatmucket

C.6.a Scenario 1

Table C.46. Guadalupe fatmucket population conditions under Scenario 1 (Continuation) in 10 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Guadalupe	**Guadalupe**	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**

Table C.47. Guadalupe fatmucket population conditions under Scenario 1 (Continuation) in 25 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Guadalupe	**Guadalupe**	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**

Table C.48. Guadalupe fatmucket population conditions under Scenario 1 (Continuation) in 50 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Guadalupe	**Guadalupe**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

C.6.b Scenario 2

Table C.49. Guadalupe fatmucket population conditions under Scenario 2 (Conservation) in 25 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Guadalupe	**Guadalupe**	Moderate	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**

Table C.50. Guadalupe fatmucket population conditions under Scenario 2 (Conservation) in 50 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Guadalupe	**Guadalupe**	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	**Moderate**

C.6.c Scenario 3

Table C.51. Guadalupe fatmucket population conditions under Scenario 3 (RCP 6.0) in 25 years.

		Population Factors			**Habitat Factors**			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Guadalupe	**Guadalupe**	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**

Table C.52. Guadalupe fatmucket population conditions under Scenario 3 (RCP 6.0) in 50 years.

		Population Factors			**Habitat Factors**			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Guadalupe	**Guadalupe**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

C.6.d Scenario 4

Table C.53. Guadalupe fatmucket population conditions under Scenario 4 (RCP 8.5) in 25 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Guadalupe	**Guadalupe**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

Table C.54. Guadalupe fatmucket population conditions under Scenario 4 (RCP 8.5) in 50 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Guadalupe	**Guadalupe**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

C.7. Guadalupe orb

C.7.a Scenario 1

Table C.55. Guadalupe orb population conditions under Scenario 1 (Continuation) in 10 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Guadalupe	**Upper Guadalupe**	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	**Unhealthy**
	San Marcos & Lower Guadalupe	Healthy	Moderate	Moderate	Moderate	Moderate	Moderate	**Moderate**

Table C.56. Guadalupe orb population conditions under Scenario 1 (Continuation) in 25 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Guadalupe	**Upper Guadalupe**	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
	San Marcos & Lower Guadalupe	Healthy	Moderate	Moderate	Moderate	Moderate	Moderate	**Moderate**

Table C.57. Guadalupe orb population conditions under Scenario 1 (Continuation) in 50 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Guadalupe	**Upper Guadalupe**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	San Marcos & Lower Guadalupe	Healthy	Moderate	Moderate	Moderate	Moderate	Moderate	**Moderate**

C.7.b Scenario 2

Table C.58. Guadalupe orb population conditions under Scenario 2 (Conservation) in 25 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Guadalupe	**Upper Guadalupe**	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	**Unhealthy**
	San Marcos & Lower Guadalupe	Healthy	Moderate	Moderate	Moderate	Moderate	Moderate	**Moderate**

Table C.59. Guadalupe orb population conditions under Scenario 2 (Conservation) in 50 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Guadalupe	**Upper Guadalupe**	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	**Unhealthy**
	San Marcos & Lower Guadalupe	Healthy	Moderate	Moderate	Moderate	Moderate	Moderate	**Moderate**

C.7.c Scenario 3

Table C.60. Guadalupe orb population conditions under Scenario 3 (RCP 6.0) in 25 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Guadalupe	**Upper Guadalupe**	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
	San Marcos & Lower Guadalupe	Healthy	Moderate	Moderate	Moderate	Moderate	Moderate	**Moderate**

Table C.61. Guadalupe orb population conditions under Scenario 3 (RCP 6.0) in 50 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Guadalupe	**Upper Guadalupe**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	San Marcos & Lower Guadalupe	Healthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**

C.7.d Scenario 4

Table C.62. Guadalupe orb population conditions under Scenario 4 (RCP 8.5) in 25 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Guadalupe	**Upper Guadalupe**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	San Marcos & Lower Guadalupe	Moderate	Moderate	Moderate	Unhealthy	Unhealthy	Unhealthy	**Moderate**

Table C.63. Guadalupe orb population conditions under Scenario 4 (RCP 8.5) in 50 years.

		Population Factors			Habitat Factors			
Basin	**Population**	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Guadalupe	**Upper Guadalupe**	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
	San Marcos & Lower Guadalupe	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**

Appendix D– results by population

Freshwater mussels, as a taxonomic group in North America, have faced a multitude of threats; including, habitat destruction, reduced access to host fish, commercial exploitation, and introduced species (Bogan 1993, pp. 603-5). The Central Texas mussels are vulnerable to each those "big-picture" stressors, but are also subject to the following stressors, in particular: (reviewed in detail of Chapter 6, this report).

- Increased fine sediment
- Changes in water quality
- Altered hydrology: inundation
- Altered hydrology: flow loss and scour
- Predation, collection, disease, and invasive species
- Barriers to fish movement affecting access to affiliate species of host fish

Additionally, there is the potential that positive management actions can be made to improve the current and future population conditions of the Central Texas mussels. While there is high certainty that climate effects have and will continue to occur, some uncertainty remains in the relative magnitude of these effects (i.e., intermediate versus severe). What is constant in the climate change predictions is enhanced evaporative demand (i.e., overall drying) and that precipitation patterns will become more extreme.

Important uncertainties relevant to the future condition of identified populations include: erosion and sediment dynamics associated with development patterns, climate change effects on stream inputs and outputs (through evapotranspiration and other losses), changes to hydrology due to the effects of increasing climate extremes and management actions, human responses to decreased inputs and increased outputs, construction of reservoirs and wastewater treatment plants, return flows and reuse, development of alternative water supplies, and effects of invasive species, among others.

This appendix contains summaries of the results of the status assessment by the population of each species. For specific discussion of how the stressors act upon the species, see Chapter 6 (Factors Influencing Viability) and Appendix B (Cause and Effects Tables), and for discussion of details of each scenario and the specific activities occurring in each major river basin, see Chapter 7 (Viability and Future Conditions).

D.1 FALSE SPIKE

False spike is currently represented by one population in the Guadalupe River basin.

The currently moderately healthy **Lower Guadalupe** (Table D.1) population will continue to be resilient to degradation of habitat factors, due to healthy abundances, large amount of occupied habitat, and evidence of reproduction and recruitment, and is expected to become unhealthy in 50 years only in Scenarios 3 and 4, where flows become diminished somewhat under increasingly severe climate scenarios. In all other cases, this population remains moderately healthy or healthy in 50 years due to a combination of habitat and demographic factors. Some conservation actions could improve the viability of this population somewhat if implemented in the next 10 years. These actions include measures to maintain and improve the status quo conditions of the habitat factors, through habitat restoration, flows management, and continued improvements to water quality. Additional opportunities for enhanced resiliency exist in the form of possible "mussel-friendly" improvements to the Guadalupe Valley Electric Cooperative string of dams above this population. Continued flow protections, afforded by the EAHCP, contribute substantially to the resiliency of this population. For as long as stream flows provide much of the base flow to the Lower Guadalupe River, this population will be relatively resilient to climate forcings, compared to the other river systems that lack this subsidized base flow.

Table D.1. Projection of false spike population conditions in the Lower Guadalupe River currently and in 50 years under four future scenarios.

	Population Factors			**Habitat Factors**			
Scenario	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Current	Healthy	Healthy	Moderate	Moderate	Moderate	Moderate	**Moderate**
Scenario 1	Healthy	Healthy	Moderate	Moderate	Unhealthy	Unhealthy	**Moderate**
Scenario 2	Healthy	Healthy	Healthy	Moderate	Moderate	Moderate	**Healthy**
Scenario 3	Healthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
Scenario 4	Moderate	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**

In Scenario 1, within 50 years, the Lower Guadalupe River population would be moderately healthy. In both Scenario 3 and 4, the unhealthy Lower Guadalupe River population would remain extant in 50 years.

D.2 BALCONES SPIKE

Balcones spike is currently represented by two populations in the Colorado River basin and one population in the Brazos River basin.

The currently unhealthy **Lower San Saba River** population (Table D.2) will continue to be threatened by very low habitat occupancy, low abundances, and a lack of reproduction and subsequent recruitment, despite the currently moderately healthy substrate, water quantity, and water quality conditions, and is expected to become functionally extirpated in the next 10 years. Future degradation of habitat factors is expected as flows continue to be diminished by climate forcings, most notably altered precipitation patterns (dewatering droughts and scouring floods) combined with enhanced evaporative demands, and anthropogenic withdrawals to support existing and future demands for municipal and agricultural water. Because reduced flows and other hydrologic alterations exacerbate the effects of and interact with degraded substrate and water quality, each of the three habitat factors is expected to become unhealthy in 50 years. Some conservation actions could improve the viability of this population somewhat if implemented in the next 10 years. These actions include measures to maintain and improve the status quo conditions of the habitat factors, through habitat restoration and flows management. Improvements to the Brady, Texas wastewater treatment plant (currently underway) could have a combination of positive and negative effects to the downstream mussel, with uncertain effects on water quality and sediment dynamics.

Table D.2. Projection of Balcones spike population conditions in the Lower San Saba River currently and in 50 years under four future scenarios.

	Population Factors			**Habitat Factors**			
Scenario	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Current	Moderate	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
Scenario 1	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 2	Moderate	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
Scenario 3	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 4	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

The currently unhealthy **Llano River** population (Table D.3) will continue to be threatened by low habitat occupancy, low abundances, and low reproduction and subsequent recruitment, despite the currently moderately healthy substrate, water quantity, and water quality conditions, and is expected to become functionally extirpated in the next 25 years. Future degradation of habitat factors is expected as flows continue to be diminished by climate forcings, most notably altered precipitation patterns (dewatering droughts and scouring floods) combined with enhanced evaporative demands, and anthropogenic withdrawals to support existing and future demands for municipal and agricultural water. Likewise, the currently small population will become smaller as older individuals leave the population and new individuals fail to recruit into the population, as evidenced by an apparent lack of reproduction. Because reduced flows and other hydrologic alterations exacerbate the effects of and interact with degraded substrate and water quality, each of the three habitat factors is expected to become unhealthy in 50 years. Given the limited spatial extent of this population, low population size, and apparent lack of reproduction provide little hope that conservation actions could improve the viability of this population somewhat if implemented in the next 50 years. This population, due to ease of access to the location, is especially vulnerable to the threat of over-collection and vandalism. We expect this population to be extirpated in 50 years under all scenarios.

Table D.3. Projection of Balcones spike population conditions in the Llano River currently and in 50 years under four future scenarios.

	Population Factors			**Habitat Factors**			
Scenario	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Current	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
Scenario 1	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 2	Func. Ext.	Func. Ext.	Func. Ext.	Moderate	Moderate	Moderate	**Func. Ext.**
Scenario 3	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 4	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

The currently unhealthy **Little River** population (Table D.4) is expected to remain unhealthy in 25 years, becoming functionally extirpated in 50 years under Scenarios 3 and 4. Habitat factors are expected to decline to unhealthy in 25 years, because of alterations to flows and water quality associated primarily with increasing development in the watershed as the Austin metropolitan area continues to expand. Climate forcings remain a concern that is mediated somewhat by the likelihood that enhanced return flows associated with the development and use alternative water supplies will bolster base flows somewhat. The boost from return flows will likely be limited by the need for reuse and additional water conservation in 50 years. Because of the relatively small size of the Little River basin, some conservation actions could improve the viability of this population somewhat if implemented in the next 10 years. These actions include measures to maintain and improve the status quo conditions of the habitat factors, through habitat restoration, flows management, and continued improvements to water quality. For example, it may be possible to manage releases from Belton, Stillhouse, and Granger Lakes to provide flows to benefit this population. Further, opportunities may exist to restore and enhance riparian and adjacent upland habitats in the watershed.

Table D.4. Projection of Balcones spike population conditions in the Little River currently and in 50 years under four future scenarios.

	Population Factors			**Habitat Factors**			
Scenario	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Current	Moderate	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
Scenario 1	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
Scenario 2	Moderate	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
Scenario 3	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 4	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

In Scenario 1, within 50 years, the Lower San Saba River and Llano River populations are projected to become functionally extirpated, and the Little River population would be unhealthy.

D.3 TEXAS FATMUCKET

Texas fatmucket is currently represented by five populations (including one believed to be functionally extirpated) in the Colorado River basin.

The currently unhealthy **Elm Creek** population (Table D.5) is expected to become functionally extinct in the next 50 years in all future scenarios except for Scenario 2 where the population is maintained at status quo unhealthy conditions through implementation of positive soil and water conservation measures in the relatively small and agriculturally dominated watershed of Elm Creek. The population will continue to be threatened by existing unhealthy amount of occupied stream length and unhealthy low population abundance and unhealthy low levels of reproduction and subsequent recruitment into the population. Likewise, habitat factors in all but the most optimistic scenario are considered to be unhealthy because of excessive sedimentation and deterioration of substrate, altered hydrology associated with anthropogenic activities and climate forcing, and water quality degradation. Because of the relatively small size of the watershed, some opportunities exist to engage agricultural producers and municipal users in improving water quality, and perhaps water quantity in the watershed. However, because this population is small in terms of occupied stream miles and is hydrologically isolated from larger populations, it will likely never be more resilient than unhealthy.

Table D.5. Projection of Texas fatmucket population conditions in Elm Creek currently and in 50 years under four future scenarios.

	Population Factors			**Habitat Factors**			
Scenario	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Current	Unhealthy	Unhealthy	Unhealthy	Moderate	Unhealthy	Unhealthy	**Unhealthy**
Scenario 1	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 2	Unhealthy	Unhealthy	Unhealthy	Moderate	Unhealthy	Moderate	**Unhealthy**
Scenario 3	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 4	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

The currently moderately healthy **San Saba River** population (Table D.6) is expected to become unhealthy or functionally extirpated in the next 50 years, depending on the influence of climate change over the next 25+ years. The San Saba River population is threatened by habitat degradation in the form of excessive sedimentation, reduced flows due to anthropogenic influences and climate forcing, and water quality degradation primarily associated with low flows. Because of the complex geology of the San Saba River, certain sections of the river are considered "losing reaches" that are especially sensitive to reductions in flow associated with pumping and drought. In fact, this "losing stretch" of the river is subject to repeated drying and is dependent on the lower "gaining reaches" reaches for recolonization following a prolonged drought. There is some evidence that Texas fatmucket can persist at low levels in pools and in crevices for some length of time during a dewatering event. However, available habitat is limited during prolonged low flow conditions, which are almost certain to occur with increasing frequency in the future. Reductions in available habitat due to dewatering also make mussels more vulnerable to predation. Some mussel beds within this population, due to ease of access, are vulnerable to the threat of over-collection and vandalism.

Table D.6. Projection of Texas fatmucket population conditions in the San Saba River currently and in 50 years under four future scenarios.

	Population Factors			Habitat Factors			
Scenario	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Current	Healthy	Moderate	Moderate	Moderate	Moderate	Moderate	**Moderate**
Scenario 1	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
Scenario 2	Moderate	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
Scenario 3	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 4	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

The currently moderately healthy **Llano River** population (Table D.7) is expected to become unhealthy, in the next 50 years under scenarios 1, 3 and 4, as population factors including abundance decline due to unhealthy reproductive conditions and over-collection. Declining flows in scenarios 3 and 4 results in unhealthy habitat factors, compounding the effects of currently unhealthy reproduction conditions. In Scenario 2, population factors are improved through adaptive management of collection, and moderately healthy habitat factors are maintained through voluntary programs and management of pumping during drought to mitigate against severe dewatering events. This population, due to ease of access to the location, is especially vulnerable to the threat of over-collection and vandalism.

Table D.7. Projection of Texas fatmucket population conditions in the Llano River currently and in 50 years under four future scenarios.

	Population Factors			Habitat Factors			
Scenario	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Current	Healthy	Moderate	Unhealthy	Moderate	Moderate	Moderate	**Moderate**
Scenario 1	Moderate	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
Scenario 2	Healthy	Moderate	Moderate	Moderate	Moderate	Moderate	**Moderate**
Scenario 3	Moderate	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
Scenario 4	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**

The currently unhealthy **Pedernales River** population (Table D.8) is expected to become functionally extinct in the next 50 years in all scenarios except for Scenario 2, in which current habitat and population factors are maintained through conservation actions. This population will continue to be threatened by unhealthy population factors, generally in terms of low abundance and low reproduction and subsequent recruitment of individuals into the population. This population will also be influenced by future development near Fredericksburg, as well as by continuing and exacerbated climate forcings. The Pedernales River is a flashy system, especially in the lower reaches in the vicinity of Pedernales Falls State Park, and below. Regardless, give the current low observed abundances and hydrologic isolation from other larger populations, this population is not expected to be very resilient now or into the future.

Table D.8. Projection of Texas fatmucket population conditions in the Pedernales River currently and in 50 years under four future scenarios.

	Population Factors			Habitat Factors			
Scenario	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Current	Healthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
Scenario 1	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 2	Moderate	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
Scenario 3	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 4	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

The currently functionally extirpated **Onion Creek** population (Table D.9) is expected to remain functionally extirpated in the next 50 years in all scenarios except for Scenario 2, which assumes that the habitat factors can be improved somewhat by habitat enhancement in the watershed, by water quality protections as the watershed develops, and by restoration of populations by repatriation of hatchery-reared individuals. Given that Texas fatmucket has apparently been extirpated from Onion Creek, and it is hydrologically isolated from any other population, repatriation using hatchery-produced stock in Onion Creek may be appropriate if the habitat can be restored. Scenario 2 assumes that Texas fatmucket can be restored to Onion Creek and that Onion Creek can be managed through partnerships in cooperation with conservation partners and private landowners, and other interested parties. Given the spatial extent of Onion Creek, and its isolation, it is expected that the population will remain functionally extirpated without positive conservation that could ultimately result in a moderately healthy managed population in 50 years.

Table D.9. Projection of Texas fatmucket population conditions in Onion Creek currently and in 50 years under four future scenarios.

	Population Factors			Habitat Factors			
Scenario	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Current	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Moderate	Unhealthy	**Func. Ext.**
Scenario 1	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 2	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	**Moderate**
Scenario 3	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 4	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

D.4 TEXAS FAWNSFOOT

Texas fawnsfoot is currently represented by 3 populations in the Brazos River basin, 2 populations in the Colorado River basin, and 2 populations in the Trinity River basin.

The currently unhealthy **Clear Fork of the Brazos River** population (Table D.10) is threatened by unhealthy population factors, namely low abundance, and low reproduction, and by unhealthy habitat factors. This population likely experienced extensive mortality associated with prolonged dewatering during the 2011-13 drought combined with ambient water quality degradations associated with naturally occurring elevated salinity levels from the upper reaches of the river. This population is likely functionally extirpated, although more survey effort may be needed to reach that conclusion. Further, the proposed Cedar Ridge Reservoir, if constructed, will likely result in significant hydrologic alterations, all of which would not be expected to improve the overall condition of this population of Texas fawnsfoot. This population is not expected to be resilient in the future, regardless of scenario.

Table D.10. Projection of Texas fawnsfoot population conditions in the Clear Fork of the Brazos River currently and in 50 years under four future scenarios.

	Population Factors			**Habitat Factors**			
Scenario	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Current	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
Scenario 1	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 2	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
Scenario 3	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 4	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

The currently unhealthy **Upper Brazos River** population (Table D.11) is similarly threatened by low abundances and lack of reproduction, and by reduced flows associated with drought, anthropogenic actions and by current and future climate forcings, and by water quality degradations associated with naturally-occurring salinity. Under all scenarios, this population is expected to become functionally extirpated in the next 50 years, principally due to unhealthy abundance and reproduction factors. This population is not expected to be resilient in the future, regardless of scenario.

Table D.11. Projection of Texas fawnsfoot population conditions in the Upper Brazos River currently and in 50 years under four future scenarios.

	Population Factors			**Habitat Factors**			
Scenario	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Current	Healthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
Scenario 1	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Moderate	**Func. Ext.**
Scenario 2	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Moderate	**Func. Ext.**
Scenario 3	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Moderate	**Func. Ext.**
Scenario 4	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Moderate	**Func. Ext.**

The currently moderately healthy **Lower Brazos River** population (Table D.12) generally benefits from having a moderately healthy habitat occupancy, as well as observed moderately healthy abundance and evidence of reproduction and recruitment. Likewise, habitat factors are moderately healthy to healthy, likely because of the lack of major impoundments and diversions in the Brazos River below Waco, Texas. In the next 50 years, assuming Scenario 1 or Scenario 2 conditions, this population remains moderately healthy. In Scenarios 3 and 4, the population declines to an unhealthy condition as anthropogenic activities interact with additional climate forcings, and the Lower Brazos River becomes more utilized for municipal and other needs. Because Texas fawnsfoot occupies primarily bank habitats in this system, even small reductions in flows can reduce water elevations such that bank habitats become dewatered or otherwise exposed to predation, sedimentation, and elevated water temperatures. This habitat affinity may also make this population vulnerable to the threat of sand and gravel mining in the lower reaches of this segment. The planned Allens Creek off-channel reservoir is located near an especially abundant location of Texas fawnsfoot, and construction and subsequent operation of this reservoir are not expected to improve the condition of this population. While this system is apparently fairly resilient, Texas fawnsfoot has yet to be collected in abundance. Regardless, Texas fawnsfoot is not currently found in high abundances in the Lower Brazos River, and future habitat degradation will likely reduce the resiliency of this population.

Table D.12. Projection of Texas fawnsfoot population conditions in the Lower Brazos River currently and in 50 years under four future scenarios.

	Population Factors			**Habitat Factors**			
Scenario	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Current	Healthy	Moderate	Moderate	Moderate	Healthy	Moderate	**Moderate**
Scenario 1	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	**Moderate**
Scenario 2	Healthy	Moderate	Moderate	Moderate	Healthy	Moderate	**Moderate**
Scenario 3	Moderate	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
Scenario 4	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**

The currently unhealthy **Lower San Saba River** population (Table D.13) is subject to unhealthy population factors, namely low abundance and apparent lack of reproductive success and subsequent recruitment of new individuals to the population. Habitat factors are currently unhealthy overall, due primarily to degraded substrate conditions caused, in part, by reductions in flowing water over time due to a combination of anthropogenic activities and drought. In all scenarios except for Scenario 2, over the next 50 years, this population becomes functionally extirpated as unhealthy habitat factors contribute to further declines in reproduction, leading to subsequent declines in abundance and occupied stream length over time. Conservation in Scenario 2, would enhance substrate conditions, maintain flows, and improve water quality in the Lower San Saba River; the population would, therefore, be likely to maintain current population factors.

Table D.13. Projection of Texas fawnsfoot population conditions in the Lower San Saba River currently and in 50 years under four future scenarios.

	Population Factors			**Habitat Factors**			
Scenario	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Current	Moderate	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	**Unhealthy**
Scenario 1	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 2	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
Scenario 3	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 4	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

The currently moderately healthy **Lower Colorado River** population (Table D.14) is expected to remain extant over the next 50 years in all scenarios except Scenario 4. The Lower Colorado River is expected to remain flowing to provide water to downstream senior rights. But like the Lower Brazos River population, the Lower Colorado River is vulnerable to reduced flows and associated habitat degradation, because the Texas fawnsfoot occurs in bank habitats that are likely to become exposed to desiccation, predation, and increased water temperatures as river elevations decline while the river still flows in its main channel (i.e., thalweg). In Scenario 2, flows are managed such that the bank habitats are adequately wetted, and releases are managed such that excessive scour is reduced, leading to an overall healthy condition in 50 years. In Scenario 1 and 3, flows are reduced, negatively affecting substrate quality and water quality (through increased sediment load and water temperature) such that reproduction and abundance are negatively affected, leading to overall unhealthy population condition. In Scenario 4, bank habitats are dewatered frequently, and scour associated with floods from major storms and dam releases degrade habitat factors to the point that the already low and slow to reproduce population can no longer persist.

Table D.14. Projection of Texas fawnsfoot population conditions in the Lower Colorado River currently and in 50 years under four future scenarios.

	Population Factors			Habitat Factors			
Scenario	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Current	Healthy	Moderate	Healthy	Moderate	Moderate	Moderate	**Moderate**
Scenario 1	Moderate	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
Scenario 2	Healthy	Healthy	Healthy	Moderate	Moderate	Moderate	**Healthy**
Scenario 3	Moderate	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
Scenario 4	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

The currently moderately healthy **East Fork of the Trinity River** population (Table D.15) is characterized by moderately healthy habitat factors, which are expected to remain moderately healthy over the next 50 years in all scenarios, largely because of the influence of return flows in this highly managed segment. This population occupies a small spatial extent, making it especially vulnerable to a single stochastic event such as a spill or flood. Further, no evidence of reproduction exists for this population. Currently unhealthy low levels of reproduction are expected to lead to unhealthy low abundances and an overall unhealthy population condition in 50 years for Scenario 1. In Scenario 3 and Scenario 4, habitat factors decline but remain in the moderately healthy range given interactions between additional climate forcings and water demands, combined with current unhealthy levels of reproduction, are expected to lead to unhealthy low abundance and with more frequent and prolonged periods minimum flows over the next 50 years. That is, while the habitat factors remain in the moderately healthy category, they still decline somewhat (i.e., flows are more often closer to the managed minimum flow requirement rather than almost always meeting the requirement). This population is small and isolated from the middle and lower Trinity River population, by unsuitable habitat affected primarily be altered hydrology as flows from the Dallas-Fort Worth metro area are too flashy to provide suitable habitat for Texas fawnsfoot. This population has low resilience, but that low resilience can likely be maintained through conservation actions by parties that are currently involved in managing the occupied sections of the East Fork of the Trinity River, to the extent that future return flows are adequate for maintaining this population.

Table D.15. Projection of Texas fawnsfoot population conditions in the East Fork of the Trinity River currently and in 50 years under four future scenarios.

	Population Factors			Habitat Factors			
Scenario	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Current	Unhealthy	Moderate	Unhealthy	Moderate	Moderate	Moderate	**Moderate**
Scenario 1	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
Scenario 2	Unhealthy	Moderate	Unhealthy	Moderate	Moderate	Moderate	**Moderate**
Scenario 3	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
Scenario 4	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**

The currently unhealthy **Trinity River** population (Table D.16) is subject to moderately healthy habitat factors as water quality has improved substantially over the past 30 years, as streamflow is subsidized by return flows originating in part from other basins and the fact that a relatively long and unobstructed run of river currently exists. The population factors include unhealthy low levels of reproduction, which leads to unhealthy low abundances in all future scenarios in 50 years. Occupied stream length remains healthy in Scenario 1 and 2 but degrades to moderately healthy as anthropogenic activities and climate forcings combine to further alter the hydrology of the system, largely through excessive scour reducing quality and quantity of flow-protected bank habitats. In all future scenarios, the Trinity River population of Texas fawnsfoot is expected to maintain an unhealthy overall population condition.

Table D.16. Projection of Texas fawnsfoot population conditions in the Trinity River currently and in 50 years under four future scenarios.

	Population Factors			Habitat Factors			
Scenario	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Current	Healthy	Moderate	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
Scenario 1	Healthy	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
Scenario 2	Healthy	Moderate	Unhealthy	Moderate	Moderate	Moderate	**Moderate**
Scenario 3	Moderate	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	**Unhealthy**
Scenario 4	Moderate	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	**Unhealthy**

In Summary, within 50 years and assuming Scenario 1, three of seven populations become functionally extirpated, three would be in unhealthy condition, and one population would be moderately healthy. Assuming Scenario 3 and Scenario 4, four and five populations become functionally extirpated, respectively.

D.5 TEXAS PIMPLEBACK

Texas pimpleback is currently represented by five populations in the Colorado River basin. Reproductive output is currently in an unhealthy low condition, in each of the five populations.

The currently unhealthy **Concho River** population (Table D.17) is threatened by unhealthy habitat factors, most notably unhealthy low levels of flowing water combined with unhealthy water and substrate quality. The Concho River population is also experiencing unhealthy population condition as evidenced by low occupied stream length, low abundance, and low reproduction, largely as a consequence of unhealthy habitat conditions during the 2011-12 drought. This population is vulnerable to future low water events, and in every scenario, and within 50 years, this population is functionally extirpated due to unhealthy habitat conditions and concomitant low abundance and reproductive failure.

Table D.17. Projection of Texas pimpleback population conditions in the Concho River currently and in 50 years under four future scenarios.

	Population Factors			Habitat Factors			
Scenario	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Current	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
Scenario 1	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 2	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 3	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 4	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

The currently moderately healthy **Middle Colorado River and Lower San Saba River** population (Table D.18) is similarly threatened by unhealthy habitat conditions, due to a combination of reduced flows, degraded water quality, and substrate degradation. Within 50 years, this population is expected to become functionally extirpated in all scenarios, except for Scenario 2. Scenario 2 establishes positive conservation programs that maintain flows during droughts, which serves to maintain status quo moderately healthy water and substrate quality. However, due to currently unhealthy levels of reproductive output, abundance declines to unhealthy and occupied stream length declines to moderately healthy levels after 50 years, even given these conservation measures. The resiliency of this population is likely tied to the capacity for the lower San Saba River to sustain adequate base flows and thus is sensitive to hydrologic changes associated with anthropogenic actions and climate forcings. Some mussel beds within this population, due to ease of access, are vulnerable to the threat of over-collection and vandalism, which negatively affects each of the three population factors. Scenario 2 establishes a monitoring and regulatory framework to lessen the adverse effects of over-collection and vandalism.

Table D.18. Projection of Texas pimpleback population conditions in the Middle Colorado and San Saba Rivers currently and in 50 years under four future scenarios.

	Population Factors			**Habitat Factors**			
Scenario	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Current	Healthy	Healthy	Unhealthy	Moderate	Moderate	Moderate	**Moderate**
Scenario 1	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 2	Moderate	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
Scenario 3	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 4	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

The currently unhealthy **Upper San Saba River** population (Table D.19) is similarly dependent on current and future sustainability of spring-fed base flows in the Upper San Saba River. This population is expected to become functionally extirpated within 50 years in all scenarios except for Scenario 2, due to unhealthy habitat factors interacting with existing unhealthy reproduction conditions, combined with threats of reduced spring flows during future droughts (i.e., repeat of 2011). Because of the proximity of this location to the springs, this population is somewhat more resilient than the lower San Saba River, such that if conservation actions are implemented, including flows management during drought, the population may be able to sustain in a moderately healthy condition. In scenarios 1, 3, and 4 flow reductions result in declines in habitat factors to unhealthy conditions. Because of the "losing reach" near Hext, Texas, that serves to separate the upper and lower San Saba River populations, along with differences in substrate, this population is isolated and no longer connected to the lower San Saba River population.

Table D.19. Projection of Texas pimpleback population conditions in the Upper San Saba River currently and in 50 years under four future scenarios.

	Population Factors			**Habitat Factors**			
Scenario	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Current	Moderate	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
Scenario 1	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 2	Unhealthy	Moderate	Moderate	Moderate	Moderate	Moderate	**Moderate**
Scenario 3	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 4	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

The currently unhealthy **Llano River** population (Table D.20) occupies a very short stream length, which is negatively affected by substrate degradation during periods of low flows. Within 50 years, this population is expected to become functionally extirpated in all scenarios, except for Scenario 2 due to unhealthy habitat factors interacting with existing unhealthy population abundance and reproduction conditions, combined with threats of reduced spring flows during future droughts (i.e., repeat of 2011). Scenario 2 establishes positive conservation programs that maintain flows during droughts, which serves to maintain status quo moderately healthy riffle habitats, improving reproductive output and abundance, lifting the overall population condition to moderately healthy. This population, due to ease of access to the location, is especially vulnerable to the threat of over-collection and vandalism, which negatively affects each of the three population factors. Scenario 2 establishes an adaptive management monitoring and regulatory framework to lessen the adverse effects of over-collection and vandalism.

Table D.20. Projection of Texas pimpleback population conditions in the Llano River currently and in 50 years under four future scenarios.

	Population Factors			**Habitat Factors**			
Scenario	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Current	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	**Unhealthy**
Scenario 1	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 2	Unhealthy	Moderate	Moderate	Unhealthy	Moderate	Moderate	**Moderate**
Scenario 3	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 4	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

The currently moderately healthy **Lower Colorado River** population (Table D.21) becomes functionally extirpated within 50 years under all scenarios except for Scenario 2, which establishes an adaptive framework for monitoring mussel populations and managing flows during critical dry periods. Being a riffle specialist, the Texas pimpleback is especially sensitive to hydrological alterations leading to both extreme drying (dewatering) during low flow events, and to extreme high flow events leading to scouring of substrate and movement of mature individuals to sites that may or may not be appropriate (as evidenced by the August 2017 scouring flood event that substantially degraded the quality of the Altair Riffle in the Lower Colorado River, a formerly robust mussel bed). The frequency and severity of extremely low- and high-flow events are influenced by anthropogenic actions and climate forcings, and interactions between the two. If status quo habitat factors can be maintained, in light of continuing climate change and growing water demands, then it may be possible to maintain moderately healthy overall population condition for Texas pimpleback in the Lower Colorado River.

Table D.21. Projection of Texas pimpleback population conditions in the Lower Colorado River currently and in 50 years under four future scenarios.

	Population Factors			**Habitat Factors**			
Scenario	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Current	Healthy	Moderate	Unhealthy	Moderate	Moderate	Moderate	**Moderate**
Scenario 1	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 2	Healthy	Moderate	Moderate	Moderate	Moderate	Moderate	**Moderate**
Scenario 3	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 4	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

In Summary, within 50 years and assuming Scenario 1, each of the five populations would be functionally extirpated. Assuming Scenario 3 and Scenario 4, each of the five populations would also be functionally extirpated within 50 years. Assuming Scenario 2, one population would be functionally extirpated, one would be unhealthy, and three would be moderately healthy in 50 years.

D.6 GUADALUPE FATMUCKET

The Guadalupe fatmucket is currently represented by one unhealthy population in the **Guadalupe River** (Table D.22). It is expected to become functionally extirpated in the next 50 years due to a combination of population and habitat factors, most notably low abundances and risks of low flow events due to drought. This population is likely very dependent on maintenance of base flows thorough groundwater (i.e., spring) influences. Scenario 2 includes some positive conservation actions that could possibly increase the resiliency of the population to moderately healthy after 50 years.

Table D.22. Projection of Guadalupe fatmucket population conditions in the Guadalupe River currently and in 50 years under four future scenarios.

	Population Factors			**Habitat Factors**			
Scenario	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Current	Moderate	Unhealthy	Unhealthy	Moderate	Moderate	Moderate	**Unhealthy**
Scenario 1	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 2	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	**Moderate**
Scenario 3	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 4	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

D.7 GUADALUPE ORB

The Guadalupe orb is currently represented by two moderately healthy populations in the **Upper Guadalupe River** as well as the **San Marcos River and Lower Guadalupe River**.

The currently unhealthy **Upper Guadalupe River** population (Table D. 23) currently occupies a long stream length, with moderately healthy water quality and quantity conditions. However, because of unhealthy low abundance and an apparent lack of reproduction, and poor substrate conditions, this population is overall unhealthy and is expected to become functionally extirpated within 50 years, under all scenarios except for Scenario 2. This population is expected to be sensitive to potential changes in groundwater inputs to stream flow and thus is vulnerable to ongoing and future hydrological alterations that reduce flows during critical conditions, resulting in substrate quality degradations. If conservation programs conceived of in Scenario 2 can successfully maintain status quo habitat conditions, then this population is expected to be in an unhealthy overall condition due to declines in abundance and occupied stream length due to apparent reproductive failures.

Table D.23. Projection of Guadalupe orb population conditions in the Upper Guadalupe River currently and in 50 years under four future scenarios.

	Population Factors			**Habitat Factors**			
Scenario	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Current	Healthy	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	**Unhealthy**
Scenario 1	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 2	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Moderate	Moderate	**Unhealthy**
Scenario 3	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**
Scenario 4	Func. Ext.	Func. Ext.	Func. Ext.	Unhealthy	Unhealthy	Unhealthy	**Func. Ext.**

In the **San Marcos and Lower Guadalupe River**, the Guadalupe orb population (Table D.24) currently occupies a relatively long stream length, is observed in relatively high abundances, and provides evidence of moderately healthy reproduction. Moderately healthy substrate conditions, flowing water, and water quality contributes to an overall moderately healthy population condition, which is expected to persist for the next 50 years under Scenario 1 and Scenario 2. Significant spring complexes contribute substantially to baseflow during dry periods in this system and are expected to continue to contribute to baseflows for the next 50 years due to conservation measures implemented by the EAHCP partners, bolstering the resiliency of this population. Under Scenario 3 and Scenario 4, the combination of anthropogenic actions with climate forcings negatively affects the hydrologic status of this section of the river and reduces the habitat factors to unhealthy condition due to lowered stream flows. Unhealthy habitat conditions are expected to lead to reductions in reproduction and abundance conditions, leading to an overall unhealthy population condition within 50 years, under Scenario 3 and Scenario 4.

Table D.24. Projection of Guadalupe orb population conditions in the San Marcos and Lower Guadalupe Rivers currently and in 50 years under four future scenarios.

	Population Factors			**Habitat Factors**			
Scenario	**Stream Length**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall Condition**
Current	Healthy	Healthy	Moderate	Moderate	Moderate	Moderate	**Moderate**
Scenario 1	Healthy	Moderate	Moderate	Moderate	Moderate	Moderate	**Moderate**
Scenario 2	Healthy	Moderate	Moderate	Moderate	Moderate	Moderate	**Moderate**
Scenario 3	Healthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**
Scenario 4	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	Unhealthy	**Unhealthy**

In summary, within 50 years and assuming Scenario 1, one of two populations would be functionally extirpated, and one would be moderately healthy. Assuming Scenario 3 and 4, the sole surviving population would be in and unhealthy overall condition within 50 years. Assuming Scenario 2, one population would be unhealthy, and one would be moderately healthy in 50 years.

Appendix E - Glossary of Terms Used in This Document

Bradytictia - Long-term brooders; these species brood glochidia over the winter instead of releasing them immediately.

Clade - A group of organisms believed to have evolved from a common ancestor.

Congener - Organisms within the same genus.

Conglutinates - Cohesive or enveloped masses of eggs or glochidia, formed as molds in the female demibranchs.

Curtail or cutback (water) – to reduce the amount of water supply being provided.

Demibranch- The V-shaped structure of gills common to species in the Class Bivalvia.

Desiccation - Extreme drying.

Entrainment - The entrapment of one substance by another substance; in this instance the entrapment of mussels by sediment or other immovable barriers during high-flow events (flood and scour).

Firm Water – Water that can be supplied on a consistent (or "firm") basis from lakes Buchanan and Travis through a repeat of the worst drought in recorded history for the lower Colorado River basin, which is the drought of the 1940s and 50s, while honoring all downstream water rights. This drought is known as the Drought of Record.

Flow refuges - Hydraulic shelters, where shear stress is relatively low and where sediments are relatively stable during large floods.

Glochidia - Parasitic larvae of freshwater mussels.

Gravid - Condition of having glochidia within the gills of a female mussel.

Haplotype - A group of genes within an organism that was inherited together from a single parent.

Hypolimnion - The lower layer of water in a stratified lake, typically cooler than the water above and relatively stagnant.

Incurrent siphon - The tubular structure used to draw water into the body of the mussel.

Interruptible Stored Water – Water from lakes Buchanan and Travis that must be cut back or cut off during drought or times of shortage to ensure that LCRA can meet Firm Water customer demands.

Interstitial spaces - Small openings in an otherwise closed matrix of substrate.

Legacy sediment – sediments deposited as a result of past human activities that persist and continue to influence river processes (Wohl 2015, p. 31).

Lentic - Standing water habitats typical of ponds, lakes, and reservoirs.

Littoral - Describing bank habitats.

Lotic - Flowing water habitats typical of springs, streams, and rivers.

Malacologist - Scientist that studies mollusks, including freshwater mussels.

Marsupial chamber - Specialized areas of the gills in which fertilized eggs are held until maturation.

Molluscivorous - Mollusk-eating.

Mussel bed - An aggregation of mussels, of one or more species, at a mesohabitat scale.

Phylogenetic - Relating to the evolutionary development and diversification of a species.

Positive rheotaxis - Behavior in which an organism orients and swims against oncoming flows.

Priority call - A senior water right holder (one who has held that right the longest) can make a call for water over one with a junior right (one held for a shorter time).

Recruitment - Survival of juveniles to join the adult, reproducing population.

Redundancy -The ability of a species to withstand catastrophic events.

Representation - The ability of a species to adapt to changing environmental conditions over time.

Resiliency - The ability of populations to withstand stochastic disturbance.

Riffle - A rocky or shallow part of a river or stream with rough water.

Run-of-river flows – The flow in the river that is available under law at a given point in time to honor a water right with a given priority date. Rights to use run-of river flows for beneficial uses, rights to store inflows in reservoirs, and pass-through of inflows and releases from reservoirs, are regulated by the TCEQ.

Sexual Dimorphism - Differences in form between male and female individuals of the same species.

Tachytictia - Short-term brooding; tachytictic mussel species spawn in the spring, embryos and larvae are developed and released as glochidia that same season.

The 3Rs - The conservation biology principles of representation, resiliency, and redundancy used to evaluate the current and future conditions a species

Unionids - Freshwater mussels of the family Unionidae.

Viability - The ability of the Central Texas mussels to sustain populations in natural river systems over time.

Watermaster - In some parts of the state, watermasters allocate water between users and ensure compliance with water rights.