Species Status Assessment Report for the Texas Hornshell Version 1.2

Adult Texas hornshell from the Black River, New Mexico. Photo by Joel Lusk, U.S. Fish and Wildlife Service.

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This document was prepared by Susan Oetker with assistance from Nathan Allan and the U.S. Fish and Wildlife Service's Texas Hornshell Listing Decision Team (Adam Zerrenner, Amber Miller, Charrish Stevens, Chris Harper, David Hoth, Dawn Gardiner, Debra Bills, Debra Hill, Ernesto Reyes, George Dennis, Jacob Lewis, Caitlin Snyder, Jennifer Smith-Castro, Ty Allen, and Wally Murphy). We also received assistance from David Smith of the U.S. Geological Survey.

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Version 1.0 (July 2016) of this report was available for public review when the Texas hornshell was proposed as an endangered species. This report, version 1.2, is consistent with an internal version 1.1, is the biological background for the final listing rule.

Suggested reference:

U.S. Fish and Wildlife Service. 2018. Species status assessment report for the Texas hornshell (*Popenaias popeii*), Version 1.2. January 2018. Albuquerque, NM.

Species Status Assessment Report For the Texas hornshell (*Popenaias popeii*)

Prepared by the
U.S. Fish and Wildlife Service

EXECUTIVE SUMMARY

This species status assessment reports the results of the comprehensive status review for the Texas hornshell (*Popenaias popeii* (Lea 1857)) and provides a thorough account of the species' overall viability and extinction risk. The Texas hornshell is a freshwater mussel native to the Rio Grande drainage in Texas and New Mexico. The species occurs in medium to large rivers, generally in crevices, undercut riverbanks, travertine shelves, and under large boulders adjacent to runs.

To evaluate the biological status of the Texas hornshell 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). Texas hornshell needs multiple resilient populations distributed widely across its range to maintain its persistence into the future and to avoid extinction. Several factors influence whether Texas hornshell populations will grow to maximize habitat occupancy, which increases the resiliency of a population to stochastic events. These factors are the amount of fine sediments accumulated in the substrate, flowing water, and water quality. As we consider the future viability of the species, more populations with high resiliency distributed across the known range of the species are associated with higher overall species viability.

Texas hornshell is believed to be extirpated from all but five locations in the U.S. and likely from much of Mexico. We have assessed the Texas hornshell's levels of resiliency, redundancy, and representation currently and into the future by ranking the condition of each population. Rankings are a qualitative assessment of the relative condition of occupied streams based on the knowledge and expertise of Service staff, as well as published reports.

Our analysis of the past, current, and future influences on what the Texas hornshell needs for long term viability revealed that there are three influences that pose the largest risk to future viability of the species. These risks are primarily related to habitat changes: the accretion of fine sediments, the loss of flowing water, and impairment of water quality; these are all exacerbated by climate change. Groundwater extraction and drought are expected to result in reduced water levels, which reduce habitat availability and increase fine sediment accumulation in Texas hornshell habitat. Water contamination is a concern for the population in the Black River, New Mexico. Additionally, a low-water weir has been proposed for construction at the downstream end of the Rio Grande – Laredo population, which would eliminate at least 25% of the habitat for that population.

The Texas hornshell faces a variety of risks from loss of stream flow, contamination, and inundation. These risks play a large role in the future viability of the Texas hornshell. If populations lose resiliency, they are more vulnerable to extirpation, with resulting losses in representation and redundancy. Given our uncertainty regarding future water quality, flowing water availability, and substrate suitability within the populations, we have forecasted what the Texas hornshell may have in terms of resiliency, redundancy, and representation under five future plausible scenarios, in which we made the following assumptions about stressors to the populations:

(1) Status Quo:

- Black River – There is a small to moderate water flow reduction due to drought and groundwater extraction, the CCA is not enacted and/or is not successful, the Delaware River reintroduction is not successful, and the risk of a contaminant spill remains high.
- Pecos River – Water quality declines.
- Devils River – There is a small to moderate water flow reduction due to climate change and groundwater extraction.
- Rio Grande – Lower Canyons – There is a small to moderate water flow reduction due to drought, groundwater extraction, and management of the Rio Conchos.
- Rio Grande – Laredo – The low-water weir is not constructed, water quality declines, and there is a small water flow decline.

(2) Conservation:

- Black River – The Delaware River reintroduction is successful, the CCA is enacted and successful, the risk of a contaminant spill is reduced, and there is no substantial flow reduction due to drought or groundwater extraction.
- Pecos River – Water quality does not decline, and the population does not experience effects of small population size.
- Devils River – There is no flow loss due to drought or groundwater extraction.
- Rio Grande – Lower Canyons – There is no flow loss due to climate change, groundwater extraction, or management of the Rio Conchos.
- Rio Grande – Laredo – The low-water weir is not constructed, there is no flow loss due to upstream water management or drought, and water quality does not decline.

(3) Considerable Effects:

- Black River – There is a small to moderate water flow reduction due to climate change and groundwater extraction, the risk of a contaminant spill is reduced, the CCA is not enacted and/or is not successful, and the Delaware River reintroduction is not successful.
- Pecos River – Water quality declines.
- Devils River – There is a small to moderate water flow reduction due to climate change and groundwater extraction.
- Rio Grande – Lower Canyons – There is a small to moderate water flow reduction due to climate change, groundwater extraction, and management of the Rio Conchos.
- Rio Grande – Laredo – The low-water weir is constructed, water quality does not decline, and water flow does not decline.

(4) Major Effects:

- Black River – There is a large water flow reduction due to climate change and groundwater extraction, and the risk of a contaminant spill remains high.
- Pecos River: Water quality declines
- Devils River: There is a small to moderate water flow reduction due to drought and groundwater extraction.
- Rio Grande – Lower Canyons: There is a small to moderate water flow reduction due to drought, groundwater extraction, and management of the Rio Conchos.
- Rio Grande – Laredo: Water quality declines, the low water weir is not constructed, and water flow declines due to upstream water management and drought.

(5) Severe Effects:

- Black River – There is a large water flow reduction due to climate change and groundwater extraction, and the risk of a contaminant spill remains high.
- Pecos River – Water quality declines.
- Devils River – There is a large water flow reduction due to drought and groundwater extraction.
- Rio Grande – Lower Canyons – There is a large water flow reduction due to drought, groundwater extraction, and management of the Rio Conchos.
- Rio Grande – Laredo – The low-water weir is constructed, water quality declines, and water flow is reduced due to upstream water management and drought.

We examined the resiliency, representation, and redundancy of Texas hornshell under each of these plausible scenarios (Table ES-1). Resiliency of Texas hornshell populations depends on future water quality, availability of flowing water, and substrate suitability. We expect the four extant Texas hornshell populations to experience changes to these aspects of their habitat in different ways under the different scenarios. We projected the Texas hornshell's expected future resiliency, representation, and redundancy based on the events that would occur under each scenario (Table ES-2).

Under scenario 1 – Status Quo, we would expect the Texas hornshell's viability to be characterized by a loss of resiliency, representation, and redundancy. No populations would be in high condition, two would be in moderate, and the rest would be extirpated or in low condition. Representation would be at high risk of being lost in the Black river area.

Under scenario 2 – Conservation, we would expect the Texas hornshell's viability to be characterized by higher levels of resiliency, representation, and redundancy than it exhibits under the current condition. Three populations would be in high condition, one population would be in moderate condition, and one would be in low condition. We anticipate all of the current populations to persist and perhaps even experience range expansion.

Under scenario 3 – Considerable Effects, we would expect the Texas hornshell's viability to be characterized by lower levels of resiliency, representation, and redundancy than it has currently. Three populations would be in moderate condition and one would be in low condition; those in low condition could be extirpated. Therefore, we would expect only three populations would persist under somewhat adverse conditions.

Under scenario 4 – Major Effects, we would expect the Texas hornshell's viability to be characterized by lower levels of resiliency, representation, and redundancy than it has currently. Two populations would be in moderate condition and two would be in low condition; those in low condition could be extirpated. Therefore, we would expect only two populations would persist under somewhat adverse conditions.

Under scenario 5 – Severe Effects, we would expect the Texas hornshell's viability to be characterized by additional substantial losses of resiliency, representation, and redundancy. We would only expect one population to persist in moderate condition, which means it would have less resiliency and may not persist beyond 100 years.

Table ES-1. Texas hornshell population conditions in 100 years under each scenario.

	Population Condition				
Population	**Scenario 1 – Status Quo**	**Scenario 2 – Conservation**	**Scenario 3 – Considerable Effects**	**Scenario 4 – Major Effects**	**Scenario 5 – Severe Effects**
Black River	**Low**	**High**	**Moderate**	**Low**	**Low**
Pecos River	**Ø**	**Low**	**Ø**	**Ø**	**Ø**
Devils River	**Low**	**Moderate**	**Low**	**Low**	**Ø**
Rio Grande: Lower Canyons	**Moderate**	**High**	**Moderate**	**Moderate**	**Moderate**
Rio Grande: Laredo	**Moderate**	**High**	**Moderate**	**Moderate**	**Low**

Table ES-2. Species Status Assessment summary for the Texas hornshell.

3Rs	Needs	Current Condition	Future Condition (Viability)
Resiliency: Population (Large populations able to withstand stochastic events)	• Suitable substrate: crevices with seams of fine sediment • Sufficient water quality • Flowing river ecosystems • Sufficient occupied stream length	• 5 populations known to be extant over about 130 river miles • Extirpated from about 650 river miles in U.S. • Population status: o 2 high resiliency o 2 moderate resiliency o 1 low resiliency	Projections based on future scenarios in 100 years: • **Status Quo**: Threats continue on current trajectory. 1 population is extirpated. All other populations experience drop in resiliency. • See Table ES-1 for other scenarios.
Representation (genetic and ecological diversity to maintain adaptive potential)	• Distinct variation in allele frequencies exists between Black River and Rio Grande/Devils River populations • Ecological variation exists between small, spring-fed, headwater streams and larger rivers.	• Genetic representation in Black River and Rio Grande/Devils River. • Headwater and large river ecological settings.	Projections based on future scenarios in 100 years: • **Status Quo**: Populations in both representation areas are likely to persist, but with moderate or low resiliency. Headwater and large river ecological settings maintained. • See Table ES-1 for other scenarios.
Redundancy (Number and distribution of populations to withstand catastrophic events)	• Multiple populations in each area of genetic representation	• Black River has no redundancy: only one population exists. • Rio Grande has 4 populations.	Projections based on future scenarios in 100 years: • **Status Quo**: Rio Grande has 2 populations in moderate condition, Black River and Devil River are in low condition, and the Pecos River is extirpated. • See Table ES-1 for other scenarios.

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CHAPTER 1. INTRODUCTION

The Texas hornshell (*Popenaias popeii* (Lea 1857)) is a freshwater mussel native to the Rio Grande drainage in Texas, New Mexico, and Mexico. The Texas hornshell has been a candidate for listing under the Endangered Species Act of 1973, as amended (Act), since 2001 (66 FR 54808). The Species Status Assessment (SSA) framework (USFWS 2015, entire) is intended to support an in-depth review of the species' biology and threats, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. 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. As such, the SSA Report will be a living document upon which other documents, such as listing rules, recovery plans, and 5-year reviews, would be based if the species warrants listing under the Act.

This SSA Report for the Texas hornshell is intended to provide the biological support for the decision on whether or not to propose to list the species as threatened or endangered and, if so, where to propose designating critical habitat. Importantly, the SSA Report does not result in a decision by the Service on whether this species should be proposed for listing as a threatened or endangered species under the Act. Instead, this SSA Report provides a review of the available information strictly related to the biological status of the Texas hornshell. The listing decision will be made by the Service after reviewing this document and all relevant laws, regulations, and policies, and the results of a proposed decision will be announced in the *Federal Register*, with appropriate opportunities for public input.

For the purpose of this assessment, we generally define viability as the ability of the Texas hornshell to sustain populations in natural river systems over time. Using the SSA framework (Figure 1.1), we consider what the species needs to maintain viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation (Wolf *et al.* 2015, entire).

- **Resiliency** describes the ability of populations to withstand stochastic events (arising from random factors). We can measure resiliency based on metrics of population health; for example, 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.

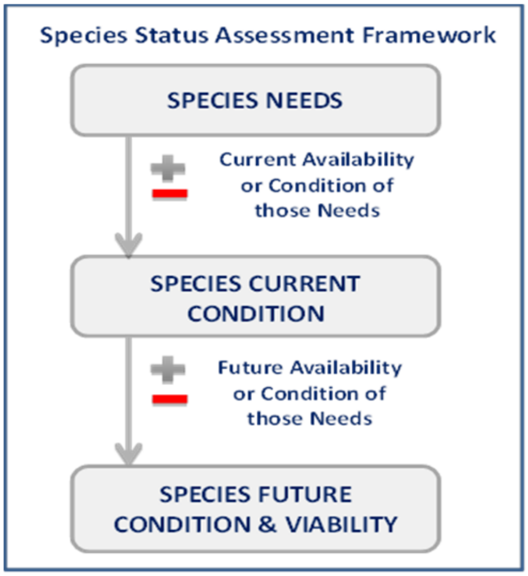

Figure 1.1 Species Status Assessment Framework

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

- **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).

To evaluate the biological status of the Texas hornshell 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 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: (1) the resource needs of individuals and populations (Chapter 2); (2) the Texas hornshell's historical distribution and a framework for determining the distribution of resilient populations across its range for species viability (Chapter 3); (3) reviewing the likely causes of the current and future status of the species and determining which of these risk factors affect the species' viability and to what degree (Chapter 4); and (4) concluding with a description of the viability in terms of resiliency, redundancy, and representation (Chapter 5). 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 Texas hornshell.

CHAPTER 2 – INDIVIDUAL NEEDS
LIFE HISTORY AND BIOLOGY

In this chapter we provide basic biological information about the Texas hornshell, including its taxonomic history, genetics, morphological description, and known life history traits. We then outline the resource needs of individuals and populations of Texas hornshell. Here we report those aspects of the life history of the Texas hornshell that are important to our analysis. For further information about the Texas hornshell refer to Lang (2001) and Carman (2007).

2.1. Taxonomy

The Texas hornshell was described by Lea (1857, p. 102) as *Unio popeii*, from the Devils River, in Texas, and Rio Salado, in Mexico. The species was moved to the genus *Elliptio* by Ortmann (1912, p. 271–272) and afterward given its own subgenus, *Popenaias*, within the genus *Elliptio* (Frierson 1927, p. 38). Subsequently, Heard and Guckert (1970, pp. 336–340) elevated the subgenus *Popenaias* to genus. Currently, Texas hornshell is classified in the unionid subfamily Ambleminae (Campbell *et al.* 2005, pp. 140, 144) and is considered a valid taxon by the scientific community (Turgeon *et al.* 1998, p. 36; Williams *et al.* 2017, p. 42).

The currently accepted classification is:

Phylum: Mollusca
Class: Bivalvia
Order: Unionoida
Family: Unionidae
Subfamily: Ambleminae
Species: *Popenaias popeii*

The Texas hornshell historically ranged throughout the Rio Grande drainage in the United States (New Mexico and Texas) and Mexico. It had been previously thought to occur in Mexican Gulf Coast streams south to the northern Mexican state of Veracruz (Johnson 1999, p. 23) (Figure 2.1), but recent genetic analysis has shown the populations in Mexican Gulf Coast streams to belong to a different, as yet undescribed species (Inoue 2017, p. 1).

2.2. Genetic Diversity

Several genetic studies have been conducted on Texas hornshell. Most notably, Inoue *et al.* (2015, p. 1916) found that the species exhibits significant rangewide genetic structure, with the Black River, New Mexico, population exhibiting significantly different variation in allele frequencies from the Rio Grande – Laredo and Devils River populations. The Black River population likely diverged from the Rio Grande population around 80,000 years ago (Inoue *et al*. 2015, p. 1920) and even exhibits within-population variation between upstream and downstream sites along the Black River, although overall it has considerably less genetic diversity than the Rio Grande populations (Inoue *et al.* 2015, p. 1916). While there have been no genetic samples to date from the Rio Grande – Lower Canyons, Pecos River, or Rio Salado populations, we reasonably assume they are similar to the Rio Grande – Laredo and Devils River populations.

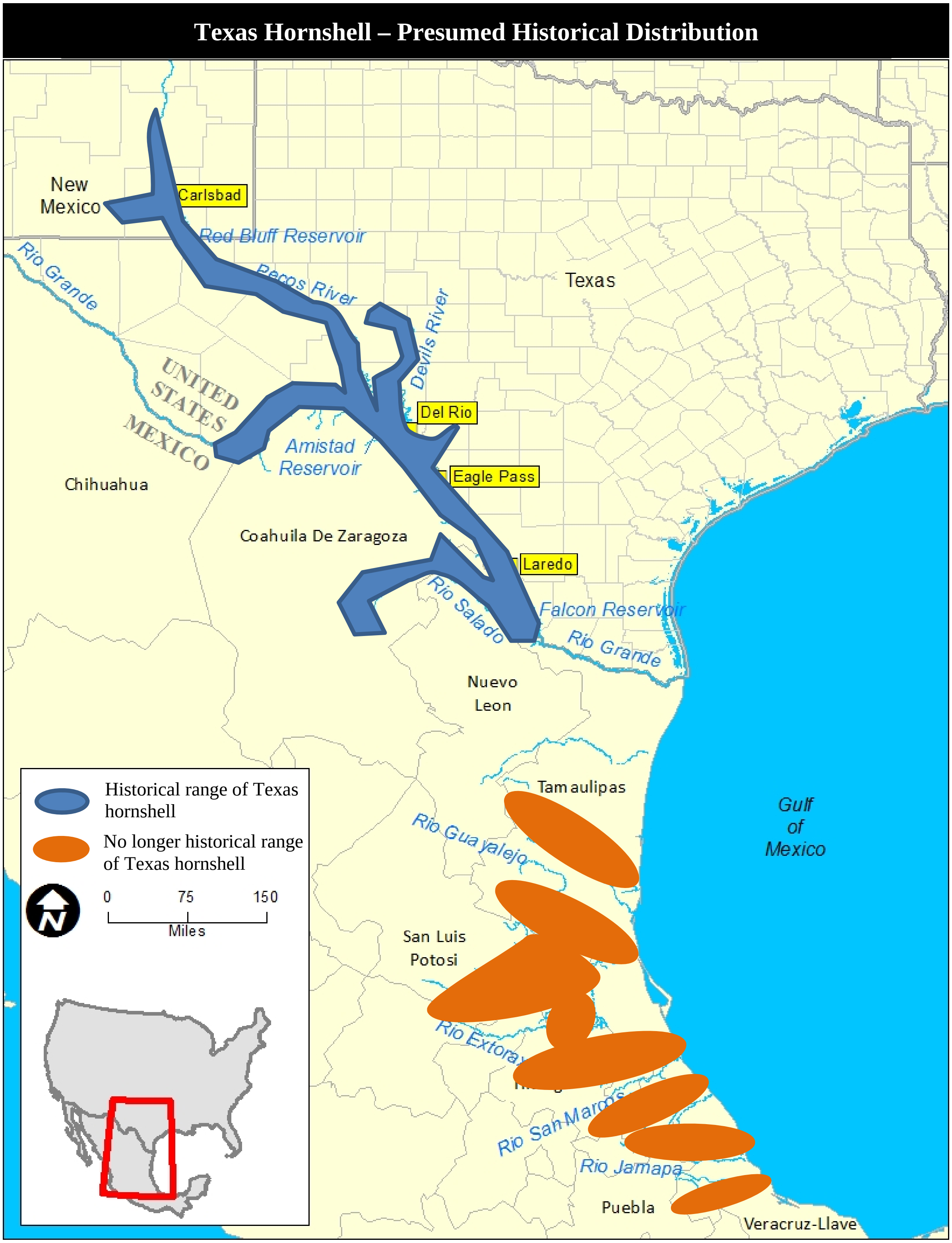

Figure 2.1. Presumed general historical distribution of Texas hornshell. Brown shapes include populations previously thought to be Texas hornshell but have been determined genetically to belong to a different, undescribed species (Inoue 2017, p. 1).

Recent genetic analysis of the museum specimens from the Mexican Gulf Coastal streams has shown that they exhibit more than 12 percent sequence divergence from Texas hornshell, indicating they are a separate species (Inoue 2017, p. 1). These results are consistent with what we would otherwise expect, given the large distance between the Rio Grande and the Mexican Gulf Coastal drainages, as well as the lack of connection between the watershed either historically or currently.

2.3. Morphological Description

The Texas hornshell is a medium sized freshwater mussel with a dark brown to green, elongate, laterally compressed shell (Figure 2.2) (Howells *et al.* 1996, p. 93; Carman 2007, p. 2). Young individuals will often have fairly distinct green rays (lines of color) on the shell (Carman 2007, p. 2). Mature adults can reach lengths of over 110 millimeters (mm; Lang 2001, p. 6). For a more detailed description of the morphological characteristics of Texas hornshell, see Howells *et al.* (1996) and Lang (2001).

Figure 2.2. Adult Texas hornshell from the Black River, New Mexico. Photo by Brian Lang.

2.4. Life History

Freshwater mussels, including the Texas hornshell, have a complex life history (Figure 2.3). 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 gill chamber until they mature and are ready for release. These mature larvae, called glochidia, are obligate parasites (cannot live independently of their hosts) on the gills, head, or fins of fishes (Vaughn and Taylor 1999, p. 913). Glochidia die if they fail to find a 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).

Freshwater mussel species vary in both onset and duration of spawning, how long developing larvae are held in the marsupial gill chambers, and which fish species serve as hosts. For the Texas hornshell, spawning generally occurs from March through August (Smith *et al*. 2003, p. 335), and fertilized eggs are held in the marsupial chambers of females for four to six weeks (Smith *et al.* 2003, p. 337); the species is considered a short-term brooder, compared to other species that will hold mature larvae in the marsupial chamber over winter (Table 2.1). The mechanisms employed by mussel species to increase the likelihood of interaction between host fish and glochidia vary by species. For Texas hornshell, glochidia are released in a sticky mucous net or string (Carman 2007, p. 9); the host fish likely swim into the nets, and the glochidia generally attach to the face or gills of the fish and become encysted in its tissue (Levine *et al.* 2012, pp. 1858). The glochidia will remain encysted for about a month through transformation to the juvenile stage. Once transformed, the juveniles will excyst from the fish and drop to the substrate. The known primary host fishes for the Texas hornshell are river carpsucker (*Carpiodes carpio*), grey redhorse (*Moxostoma congestum*), and red shiner (*Cyprinella lutrensis*) (Levine *et al.* 2012, pp. 1857–1858). The river carpsucker and red shiner are widespread throughout the Texas hornshell's occupied range (Hubbs 1990, pp. 90–91; Levine *et al*. 2012, p. 1857). A total of 24 species of fish have served as successful hosts in laboratory settings (Levine *et al.* 2012, pp. 1857).

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). Throughout the rest of their life cycle, mussels generally remain within the same small area where they excysted from the host fish.

Longevity is not known for the Texas hornshell, although two adult individuals were captured and marked in the Black River in New Mexico in 1997 and were recaptured 15 years later (Inoue *et al.* 2014, p. 5). Species in the subfamily Ambleminae, which includes Texas hornshell, commonly live more than 20 years (Carman 2007, p. 9), so we assume the Texas hornshell can live at least 20 years.

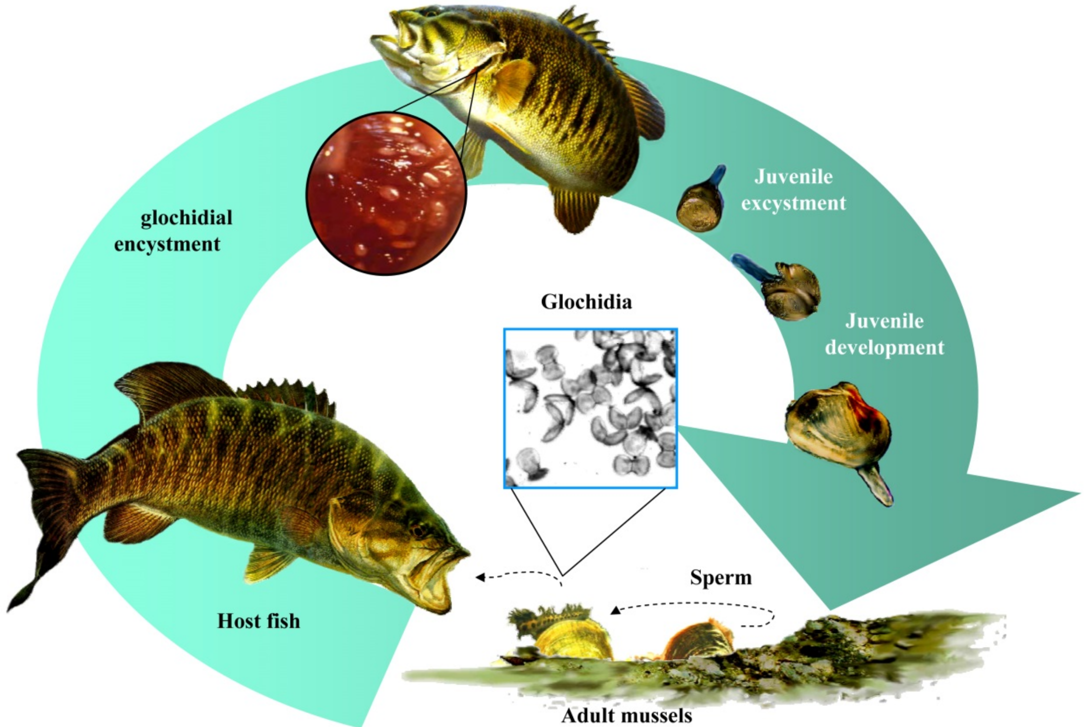

Figure 2.3. General mussel life cycle. Designed by Shane Hanlon, USFWS.

2.5. Resource Needs (Habitat) of Individuals

Adult Texas hornshell occur in medium to large rivers, generally in crevices, undercut riverbanks, travertine shelves, and under large boulders adjacent to runs (Table 2.1) (Carman 2007, p. 6; Karatayev *et al.* 2015, p. 2; Randklev *et al.* 2016, p. 5; Randklev *et al.* 2017, p. 5). However, in the Devils River, the species is found in gravel beds at the heads of riffles and rapids (Randklev *et al.* 2016, p. 11). Small-grained material, such as clay, silt, or sand, gathers in these crevices and provides suitable anchoring substrate. These areas are considered to be flow refuges from the large flood events that occur regularly in the rivers this species occupies. Texas hornshell are able to use these flow refuges to avoid being swept away as large volumes of water move through the system, as there is relatively little particle movement in the flow refuges, even during flooding (Strayer 1999, p. 472). Texas hornshell are not known from lakes, ponds, or reservoirs.

Little is known about the specific feeding habits of Texas hornshell. Like all adult freshwater mussels, Texas hornshell are filter feeders, siphoning suspended phytoplankton and detritus from the water column (Yeager *et al.* 1994, p. 221; Carman 2007, p. 8). Juvenile Texas hornshell live in the sediment and most likely feed interstitially rather than from the water column, using the large muscular foot to sweep organic and inorganic particles found among the substrate into the shell opening (Yeager *et al.* 1994, p. 220, 221).

Table 2.1. Life history and resource needs of the Texas hornshell

Life Stage	Resource Needs (Habitat)	References
Glochidia – Host Fish Attachment - **March through August, primarily**	• Presence of host fish (primarily river carpsucker, grey redhorse and red shiner)	Smith *et al*. 2003, p. 335 Levine *et al*. 2012, p. 1858
Juveniles - **Excystment from host fish through ~40mm shell length**	• Flow refuges such as crevices, undercut riverbanks, travertine shelves, and large boulders Likely similar habitat to adults • Low salinity (~0.9 ppt) • Low ammonia (~0.7 mg/L) • Low levels of copper and other contaminants • Dissolved oxygen levels within substrate >1.3mg/L • Flowing water	Sparks and Strayer 1998, p. 132 Augspurger *et al*. 2003, p. 2574 Augspurger *et al*. 2007, p. 2025 Carman 2007, p. 6
Adults - **>40mm shell length**	• Flow refuges such as crevices, undercut riverbanks, travertine shelves, and large boulders • In the Devils River, cobble/gravel riverbeds • Seams of small-grained sediment, such as clay, silt, or sand, which provides suitable substrate for anchoring. • Dissolved oxygen levels in water column above 3 mg/L • Phytoplankton and detritus for food • Water temperature <40º Celsius (104º Fahrenheit) • Flowing water	Yeager *et al.* 1994, p. 221 Nichols and Garling 2000, p. 881 Chen *et al.* 2001, p. 214 Lang 2001, Appendix A, pp. 6–7 Carman 2007, p. 6 Spooner and Vaughn 2008, pp. 308, 315 Randklev *et al.* 2017, p. 5

CHAPTER 3 – POPULATION AND SPECIES NEEDS AND CURRENT CONDITION

In this chapter we consider the Texas hornshell's historical distribution, its current distribution, and what the species needs for viability. We first review the historical information on the range and distribution of the species. We next review the conceptual needs of the species, including population resiliency, redundancy, and representation to support viability and reduce the likelihood of extinction. Finally we consider the current conditions of the Texas hornshell populations.

3.1. Historical Range and Distribution

The Texas hornshell is native to the Rio Grande (known in Mexico as the Rio Bravo) drainage in Texas, New Mexico, and northern Mexico (Figure 3.1). Texas hornshell occurred historically in the Pecos River system from the North Spring River, near Roswell, Chaves County, New Mexico (Johnson 1999, p. 22); in the Black River in Eddy County, New Mexico (Lang 2001, pp. 1–2); and throughout the Pecos River downstream of Roswell, NM to the confluence with the Rio Grande. In the Rio Grande system, Texas hornshell occurred from Bullis Ford (Dean Canyon), Brewster County, Texas, downstream to just below the current location of Falcon Dam, Starr County, Texas[1], including the Devils River, Las Moras Creek, and the Rio Salado, all tributaries to the Rio Grande (Howells 1999, p. 21; Johnson 1999, p. 23) (Figure 3.1). The species has been reported as far downstream in the Rio Grande as Brownsville, Texas, but the accuracy of the reported location for this record is questionable due to the calcium carbonate on the shell; calcium carbonate levels are not high in the Rio Grande near Brownsville, and therefore would not have accumulated on mussel shells like this specimen (Neck 1987, p. 151). Another record of Texas hornshell from that area (Mercedes, Texas) (Chamberlain 1930, p. 734) was misidentified as Texas hornshell but is now known to be another species, the Tampico pearlymussel (*Cyrtonaias tampicoensis*) (Neck and Metcalf 1988, p. 262). We presume Texas hornshell occurred throughout perennially flowing portions of river systems in which we have historical records (Figure 3.2).

Texas hornshell were thought extirpated altogether from Texas from the mid-1970s until 2008, with no live collections from the Rio Grande (Burlakova and Karatayev 2014, p. 5). Reports of Texas hornshell from the Llano and South Concho Rivers in central Texas (Strenth *et al.* 2004, p. 225) are far outside the species' range. Further surveys have not found Texas hornshell in these rivers, and no populations are known from there; therefore, these rivers are not considered part of the species' historical range (Karatayev *et al.* 2015, p. 3).

As discussed above, museum records indicate the species occurred in numerous coastal drainages along the eastern coast of Mexico as far south as northern Veracruz (Johnson 1999, p. 23). We now know those records belong to a separate, as yet undescribed species (Inoue 2017, p. 1). The Rio Salado, a Rio Grande tributary, and its tributaries in north-central Mexico (state of Coahuila), were visited in the early 2000s and 2017 and no live Texas hornshell were found,

[1] Karatayev *et al*. (2015, p.10) described the Texas hornshell's historical distribution in the Rio Grande as extending as far downstream as Brownsville, Texas, and referenced museum collections; however, Neck (1987, p. 151), Neck and Metcalf (1988, p. 262), and Randklev (pers. comm. 2015) have investigated the specimens reported below the area of Falcon Dam and determined these records are either misidentifications or the location was reported in error.

although several dead shells (non-fossilized) were found in Rio Sabinas, an upstream tributary of Rio Salado (Strenth *et al.* 2004, p. 225), and several subfossil shells were found in the Rio Nadadores, another tributary of the Rio Salado (Hein *et al.* 2017, p. 3).

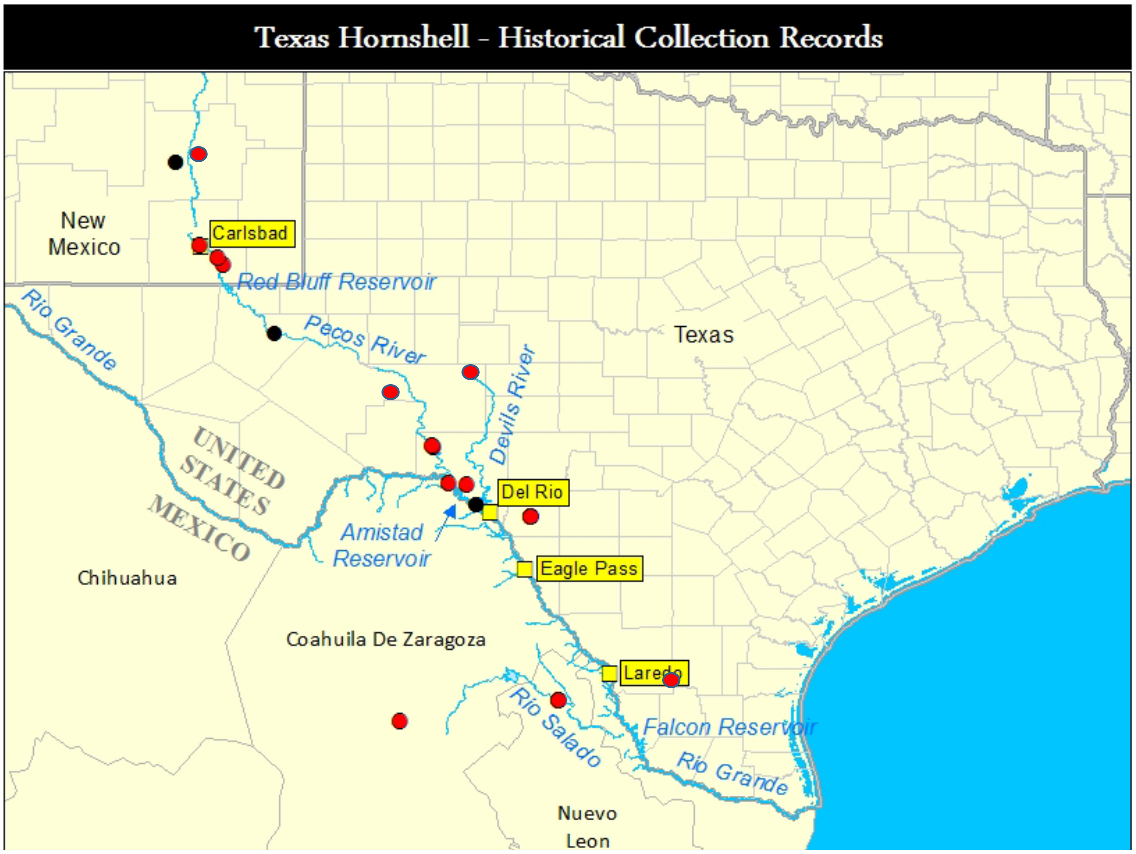

Figure 3.1. Historical collection records of Texas hornshell. Data from the Mussel Project (2015) and historical reports. Not all current populations are reflected in historical locations due to remoteness of many locations.

3.2. Current Range and Distribution

In this assessment, we define a population of Texas hornshell at a larger scale than the 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 abundance throughout the population's occupied reach. Currently, five known populations of Texas hornshell remain: the Black River, Pecos River, Devils River, Lower Canyons of the Rio Grande, and the Lower Rio Grande near Laredo, Texas (Figure 3.2). Each population is discussed below.

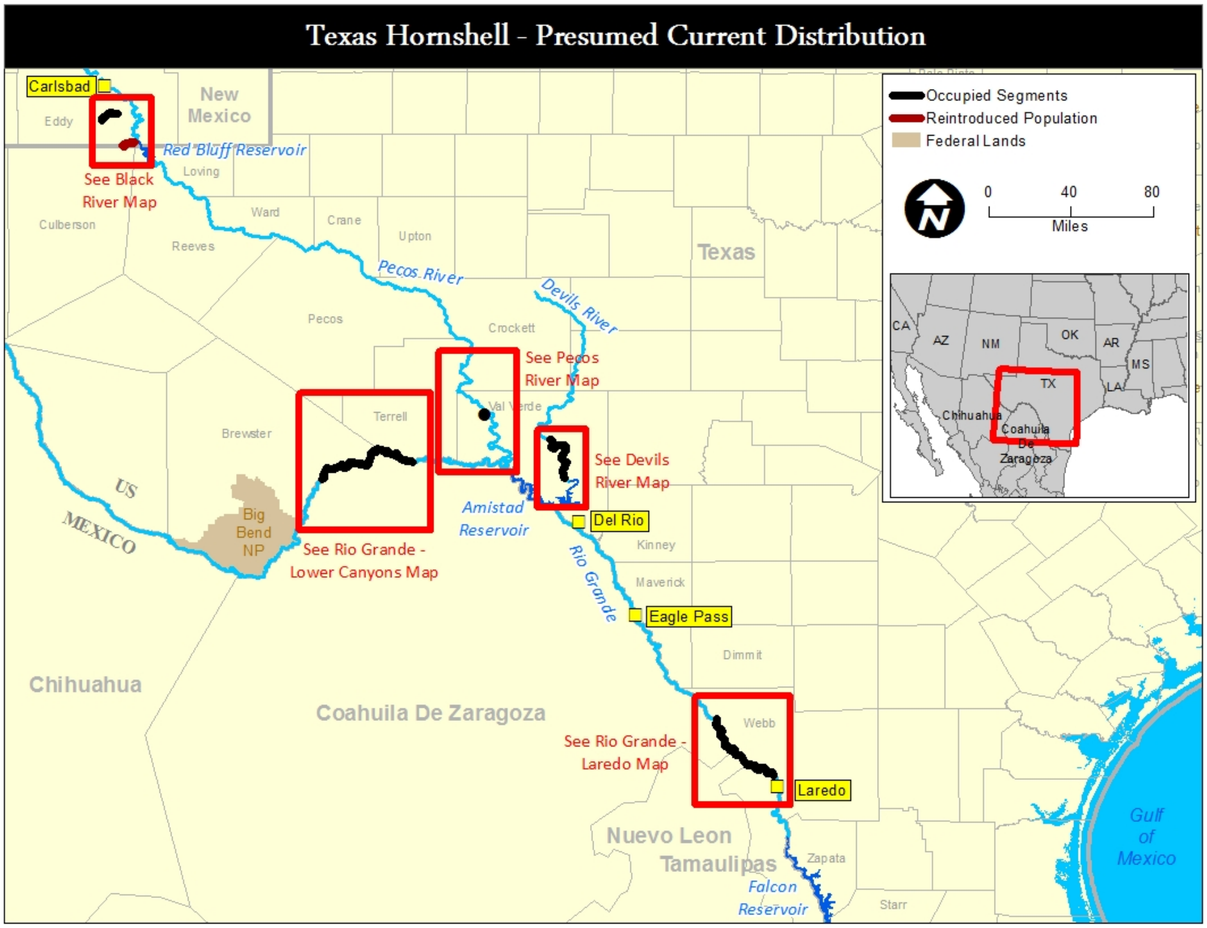

Figure 3.2. Presumed current range of Texas hornshell.

3.2.1. Black River and Delaware River (Figure 3.3)

In the Black River, live Texas hornshell were discovered in 1996, although shells had been found in the area previously (Neck 1984, p. 11; Lang 2001, pp. 1–2). The Black River, in Eddy County, New Mexico, originates from several groundwater-fed springs and flows approximately 30 miles (mi) (48 kilometers (km)) through the Chihuahuan Desert until its confluence with the Pecos River (Inoue *et al.* 2014, p. 3) near Malaga, NM. Extensive population monitoring (Lang 2001, entire; 2006, entire; 2010, entire; 2011, entire) and a long-term mark-recapture study (Inoue *et al.* 2014, entire) have yielded significant information about the population size and extent. Texas hornshell occur in approximately 8.7 mi (14.0 km) of the middle Black River (Figure 3.3), between two low-head (small) dams (Lang 2001, p. 20). The total population size has been estimated at approximately 48,000 individuals (95% CI: 28,849–74,127) (Inoue *et al.* 2014, p. 7), with a diversity of size classes, primarily aggregated in flow refuges within narrow riffles. The population remained relatively stable over the 15 year study period from 1997 – 2012 (Inoue *et al.* 2014, p. 6).

The occupied section of the Black River experiences perennial flow, with mean daily discharge ranging from 3 to over 900 cubic feet per second (cfs), with a mean average daily discharge of about 10 cfs between 2002 and 2007 (Carman 2007, p. 17). The Black River typically experiences its lowest flow in March, at the end of the dry season when upstream water users are withdrawing their maximum allotted water amounts for irrigated agriculture; peak discharges occur from July through September in association with short term, seasonal rain events (Carman 2007, p. 17). Salinity in the occupied section of the Black River is typically around 0.9 parts per thousand (ppt) and increases downstream (Carman 2007, p. 6).

Texas hornshell occupy a section of the Black River characterized by undercut banks and boulders that provide the flow refuges typical of Texas hornshell habitat (Lang 2001, p. 21). The thalweg (deepest portion of the stream) of the Black River contains coarse gravel and rocks; very few if any Texas hornshell have been found in this habitat. Similarly, areas of unstable silt in the Black River are not habitat for the Texas hornshell (Lang 2001, p. 21).

Texas hornshell historically occurred in the Delaware River, also in Eddy County, New Mexico (Lang 2001, p. 20), as well as in the Texas portion of the river (Bonner and Littrell 2016, p. 5). The Delaware River originates in Texas and flows for approximately 70 mi (113 km) into New Mexico before its confluence with the Pecos River upstream of Red Bluff Reservoir. The river is intermittent in places, which likely led to the extirpation of Texas hornshell. Habitat improvements undertaken by the Bureau of Land Management (BLM) have resulted in perennial flow through the rehabilitated section of the Delaware River (BLM 2005, p. 1). Due to these improvements, Texas hornshell were reintroduced into the Delaware River in 2014 (BLM 2013, p. 2; Trujillo 2015, p. 1). As a positive sign, NMDGF biologists captured two gray redhorse from the Delaware River that appeared to be infested with Texas hornshell glochidia (NMDGF 2017, p. 1). Unfortunately, in August 2017, a ruptured pipeline released 18,000 barrels of produced water and 11 barrels of oil into the Delaware River upstream of the reintroduction site (Eaton 2017, p. 1). Subsequent surveys found two individuals alive, out of 80 that have been introduced. Monitoring of the reintroduction area and spill effects is ongoing.

The watershed of the Black and Delaware rivers is characterized by rural ranching and farming, as well as oil and gas development. Diverted river water and groundwater are used for irrigation of farms and ranches as well as hydraulic fracturing (Bren School of Environmental Management 2014, pp. 32, 130). Additionally, there are only a few roads that cross the Black River at low-water crossings and therefore traffic, including local and industrial, is concentrated in these areas.

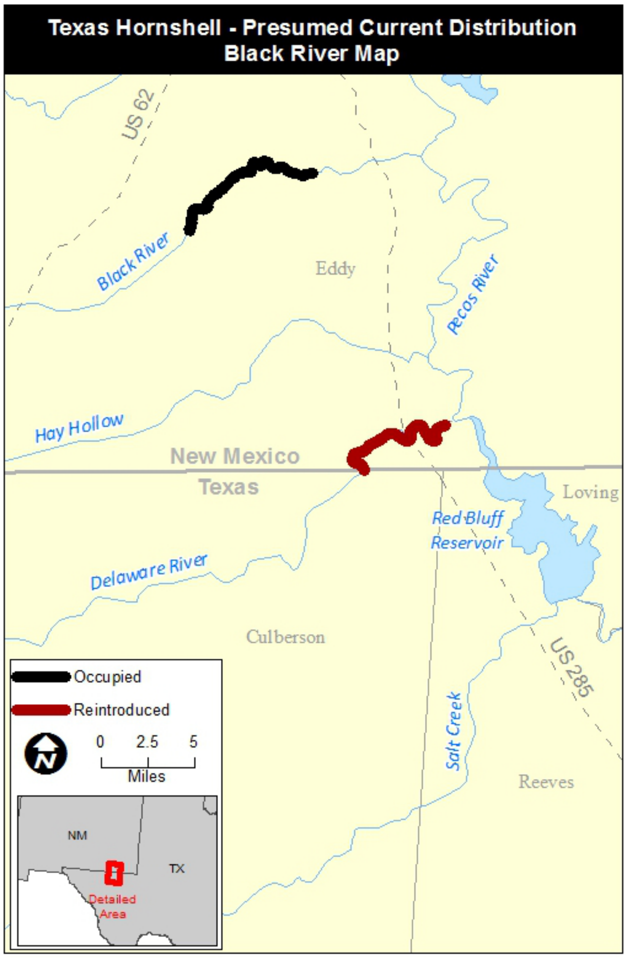

Figure 3.3. Location of Texas hornshell population in the Black River and Delaware River reintroduction area. Data from NMDGF.

3.2.2 Pecos River (Figure 3.4)

In the Pecos River, inundation from Amistad Reservoir has resulted in the extirpation of Texas hornshell from the lower reaches of the river. Additionally, salinity levels are too high for freshwater mussel habitation in much of the Pecos River from the confluence with the Black River, in New Mexico, downstream to the confluence with Independence Creek. However, three live Texas hornshell were collected from a small section of the Pecos River downstream of the confluence with Independence Creek and upstream of Amistad Reservoir near Pandale, in Val Verde County, TX, as well as numerous shells (Bosman *et al.* 2016, p. 6; Randklev *et al.* 2016, p. 9). Elsewhere downstream, only dead shells were found in 2016, although they were numerous (Bosman *et al.* 2016, p. 6; Randklev *et al.* 2016, p. 9). Live individuals had not been collected at this location since 1973 (Randklev *et al.* 2016, p. 4).

Because the sample size of live individuals is so small (3 live individuals found in recent years), it is difficult to draw many conclusions about the population. The population appears to be extremely small, and no evidence of reproduction was noted.

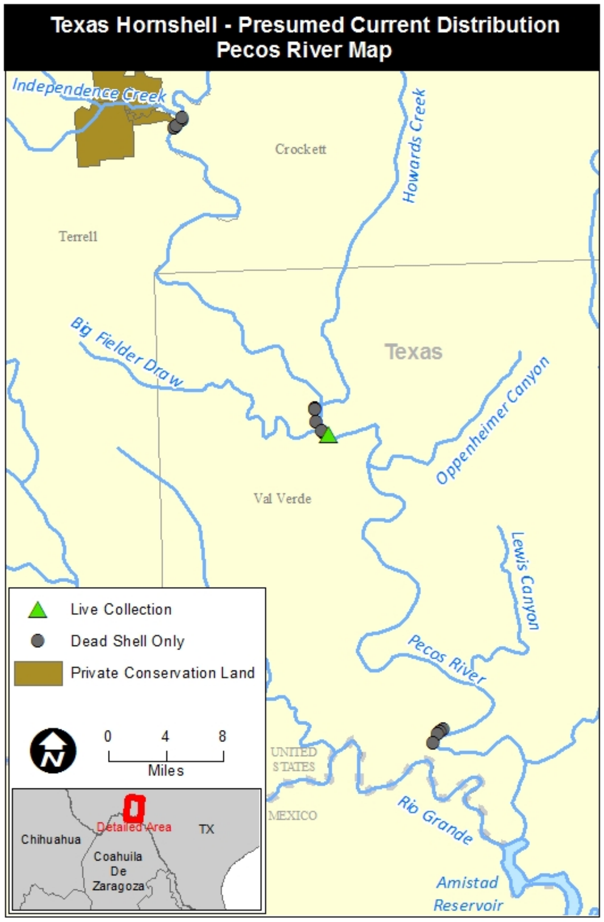

Figure 3.4. Location of Pecos River Texas hornshell population. Data from Randklev *et al.* (2016).

3.2.3. Devils River (Figure 3.5)

The Devils River, in Val Verde County, Texas, flows for about 60 mi (90 km) from the spring-fed headwaters into Amistad Reservoir on the Rio Grande (The Nature Conservancy (TNC) 2004, p. 7). Texas hornshell were historically found in Devils River and were known to occupy only the lower reaches of the river, which are currently inundated by Amistad Reservoir (Neck 1984, p. 11; Johnson 1999, p. 23; Burlakova and Karatayev 2014, p. 19). In recent years, 11 individuals were collected from upstream in the Devils River between 2008 and 2014 (Burlakova and Karatayev 2014, p. 16; Karatayev *et al.* 2015, p. 4). More intensive surveys conducted in 2014, 2015, and 2017, including 20 sites, have yielded more than 150 individuals in approximately 29 mi (47 km) of the river— all from The Nature Conservancy's Dolan Falls Preserve and the Devils River State Natural Area's Dan A. Hughes Unit (formerly known as the Big Satan Unit) (Randklev et al. 2015, pp. 6–7; Diaz 2017, p. 1).. Because of the increased number of individuals collected in 2014 and 2105, it is likely that the Devils River population is more numerous than previously thought, although we do not expect that this population is particularly large based on the limited number of collections to date. Interestingly, Texas hornshell in the Devils River occupy different habitats than those in the rest of the range; instead of being found under rock slabs and in travertine shelves, they occupy gravel beds at the heads of riffles or in clean-swept pools with bedrock (Randklev *et al.* 2015, p. 8). Even though the number of collected individuals is small, several young individuals were found, as well as females brooding glochidia (gravid females) (Randklev *et al.* 2015, p. 8), indicating reproduction and recruitment (offspring survive to join the reproducing population) are occurring in the Devils River population.

The Devils River represents a relatively intact watershed, with no dams, little development, and much of it under conservation management. The upstream Texas hornshell site is located on Dolan Falls Preserve, which is 4,800 acres (ac) (1,943 hectares (ha)) owned by TNC, as well as an additional 13,722 ac (5,553 ha) managed under a conservation easement. TNC also owns Nix 2 Ranch (87,000 ac (35,209 ha)), and Texas Parks and Wildlife Department (TPWD) owns the Devils River State Natural Area (37,000 ac (15,000 ha)), resulting in conservation management of much of the land along the river (TNC 2004, p. 9; TPWD 2016, p. 1).

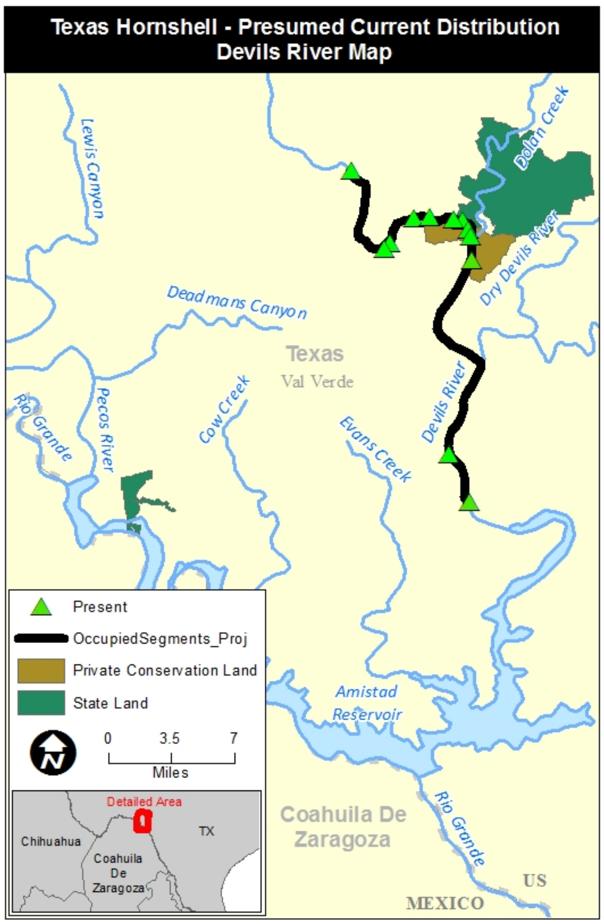

Figure 3.5. Location of Devils River Texas hornshell population. Data from Randklev *et al.* (2015).

3.2.4. Rio Grande – Lower Canyons (Figure 3.6)

One of two remaining populations of Texas hornshell in the Rio Grande is found in the Lower Canyons, just downstream of Big Bend National Park, in Terrell County, Texas. Burlakova and Karatayev (2014, p. 16) found the species in low density (~40 individuals per km) in this region of the Rio Grande. Subsequent surveys by Randklev *et al.* (2015, entire) confirmed the presence of Texas hornshell in approximately 18.5 mi (~30 km) of the Lower Canyons in two sections, finding that the species occupies approximately 63% of sites with suitable (rocky) habitat. For purposes of this analysis, we presume the entire section between these collections is occupied – approximately 62 mi (100 km). Sites in the Rio Grande – Lower Canyons reach vary in density, with the densest sites near Sanderson Canyon, Terrell County, Texas, and decreasing downstream (Randklev *et al.* 2015, p. 13); the average density of Texas hornshell at each site is lower compared to the Black River and Rio Grande – Laredo (5 ± 14 individuals per site). Texas hornshell may occur between the known occupied sections, near the confluence with San Francisco Creek (Howells 2001, p. 6), but limited access has prevented recent surveys from determining current occupancy of this reach. Young individuals and gravid females have been found throughout the Lower Canyons reach, indicating recruitment is occurring (Randklev *et al.* 2015, p. 8). Occupancy modeling reveals that Texas hornshell are dependent on spring inflows and rocky habitats in the Lower Canyons reach (Randklev *et al.* 2017, pp. 5–6).

The Rio Grande – Lower Canyons reach extends for approximately 127 mi (204 km) below Big Bend National Park through private lands along the U.S.-Mexico border. This portion of the Rio Grande is largely spring-fed (Donnelly 2007, p. 3; Bennett *et al.* 2009, p. 1). It was designated a National Wild and Scenic River in 1978 (Garrett and Edwards 2004, p. 396), which affords some protection from Federal development projects, but does not limit state, local, or private development (National Wild and Scenic Rivers System 2016, p. 1). The Lower Canyons reach is characterized by swift rapids interspersed by pools, often bounded by high canyon walls (Garrett and Edwards 2004, p. 396). This reach is bounded downstream by the inflow areas to Amistad Reservoir, which was constructed in 1969.

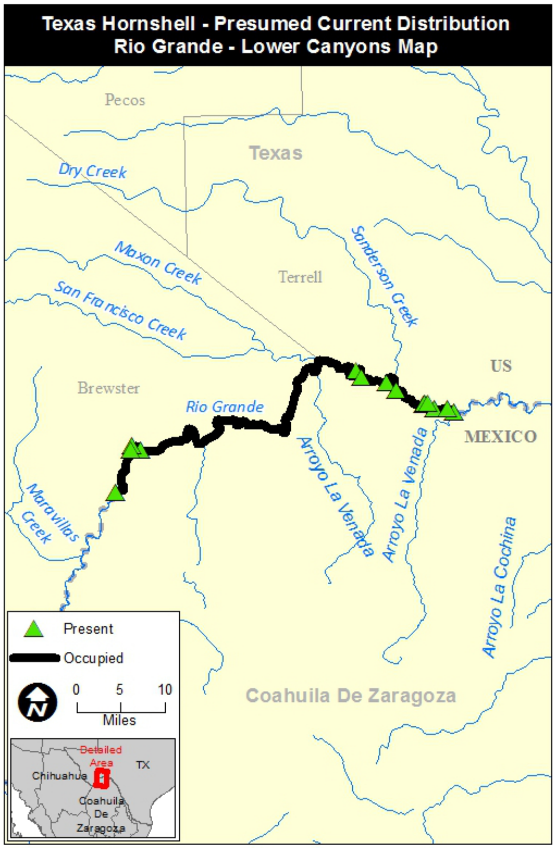

Figure 3.6. Location of Texas hornshell population in the Lower Canyons of the Rio Grande. Data from Randklev *et al.* (2015).

3.2.5. Rio Grande – Laredo (Figure 3.7)

The largest Texas hornshell population occurs from Laredo, Texas (near La Bota Ranch just northwest of Laredo), upstream approximately 56 mi (90 km) (Randklev *et al.* 2015, p. 7). The density in this reach is high, with some habitat patches containing more than 8,000 individuals (Karatayev *et al.* 2015, p. 4) and 100% of surveyed patches of suitable habitat containing Texas hornshell (Randklev *et al.* 2015, p. 7). Throughout this reach, the density of Texas hornshell is estimated to be 170 ± 131 individuals per suitable (rocky) habitat site (Randklev *et al.* 2015, p. 7). Young individuals and gravid females have been found throughout the Laredo reach, indicating reproduction and recruitment are occurring (Randklev *et al.* 2015, p. 8). No live Texas hornshell have been found downstream of the city of Laredo in recent years. Suitable habitat may occur upstream approximately 37 mi (~60 km), but surveys have not yet been completed (Randklev 2016, pers. comm.). Occupancy modeling revealed that Texas hornshell are dependent on appropriate water quality in this reach (Randklev *et al.* 2017, pp. 5–6).

The Rio Grande in the Laredo area is heavily influenced by development along the Texas – Mexico border. Rapid human population growth as well as industrialization on the Mexican side has stressed the existing wastewater treatment facilities, and Rio Grande water quality is quite impaired as a result (Texas Clean Rivers Program 2013, p. 7). The river also has a high sedimentation load in this reach (Texas Clean Rivers Program 2013, p. 9). Flows are regulated by releases from Amistad Reservoir based on hydropower generation and water deliveries for downstream irrigation needs (Texas Water Development Board 2016, p. 1); water management in the Rio Grande is governed by treaty (Texas Commission on Environmental Quality 2016, p. 3-4).

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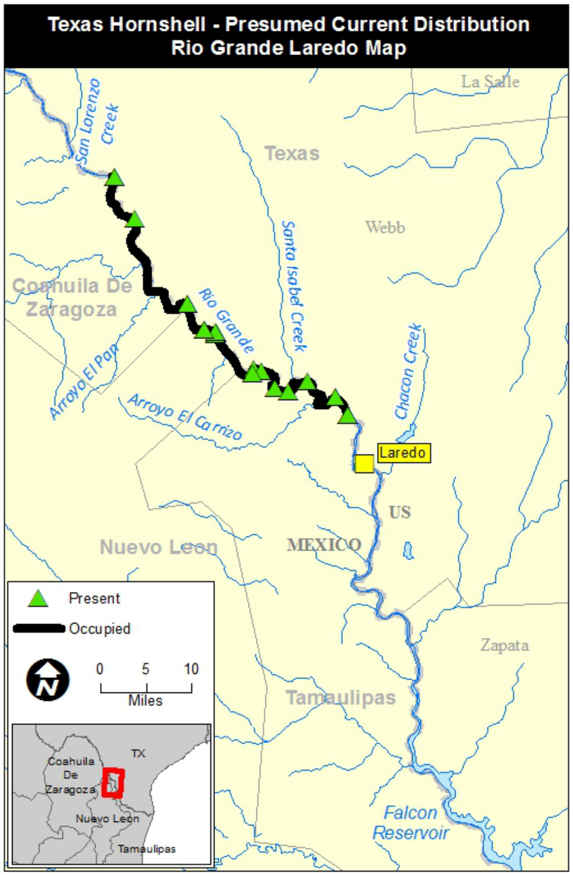

Figure 3.7. Location of Texas hornshell population in the Rio Grande near Laredo. Data from Randklev *et al.* (2015).

3.2.6. Rio Salado Basin

The Teas hornshell historically occurred in the Rio Salado basin, which is a tributary to the Rio Grande in Mexico. Rio Salado and several tributaries were surveyed in the early 2000s, with several recently dead shells collected in 2001 and 2002 in a tributary to Rio Salado, the Rio Sabinas (Strenth *et al.* 2004, p. 225). The surveyed portions of riverbed were reported to be dry with no evidence of recent water flow, so it is unlikely these shells represent a significant Texas hornshell population.

In the mainstem Rio Salado, several old shells and one recently dead shell were collected at two sites in 2002 (Strenth *et al.* 2004, p. 227). As with the Rio Sabinas, the river exhibited no flow; at one site, household waste was reported. These rivers, and many others in this region of Mexico, have been noted as losing flow and becoming dry or intermittent since the mid-1990s (Contreras-B. and Lozano-V. 1994, p. 381).

In 2017, four sites in the Rio Salado system were visited, including the Rio Salado, Rio Salado, Rio San Rodrigo, and Rio Nadadores (Hein *et al.* 2017, entire). While several of the locations contained apparently suitable habitat, no live individuals were found at any location, and subfossil (*e.g.* at least several decades old) shells were collected in the Rio Nadadores. Therefore, for the purposes of our analysis, we presume Texas hornshell has been extirpated from the Rio Salado and its tributaries.

3.2.7. Areas Presumed Extirpated

The Texas hornshell historically occupied approximately 850 river mi (~1,370 river km) in the U.S., and it is presumed to be extirpated from approximately 75% of this range (Karatayev *et al.* 2015, p. 7). Areas from which we presume Texas hornshell has been extirpated include the North Spring River, Las Moras Creek, the Rio Grande between the Lower Canyons and the Laredo reaches, and the Rio Grande between Laredo and Falcon Dam. The areas of presumed extirpation are discussed briefly below.

North Spring River

Texas hornshell were reported from the North Spring River near Roswell, New Mexico, in 1902 (Johnson 1999, p. 22). This stream is located on the Roswell Country Club, and habitat modifications made in the mid-1900s have resulted in a channel that is frequently dry and is no longer suitable for aquatic-dependent species (NMDGF 2005, p. 18).

Las Moras Creek

Las Moras Creek, in Kinney County, Texas, also contained a population of Texas hornshell (Johnson 1999, p. 23), and they were once considered abundant there (Karatayev *et al.* 2015, p. 11). However, frequent vegetation removal in the 1970s (Murray 1975, p. 43; Neck 1984, p. 11) and chlorination of the headwater spring to form a swimming pool (USFWS 2005, p. 1.4-5) have resulted in the extirpation of the species from the stream. Multiple surveys since then have not yielded any evidence of Texas hornshell (*e.g.* Murray 1975, p. 43; Howells *et al.* 1997, p. 121; Karatayev *et al.* 2015, p. 11).

Rio Grande – Between Lower Canyons Reach and Laredo Reach

There are very few reports of Texas hornshell for the reach of the Rio Grande between the Lower Canyons (around the current location of Amistad Reservoir) and the upper limits of the Laredo population (around the city of Eagle Pass, Texas), likely due to upstream and downstream effects of Amistad Dam. Karatayev *et al.* (2012, p. 214) report its collection by Metcalf from the Rio Grande near Del Rio, Texas, in 1972, and two individuals were collected near that area between 2008 and 2011 (Karatayev *et al.* 2015, p. 8). However, subsequent surveys of that area (as well as the entire reach) have yielded no Texas hornshell, live or dead, indicating the species is either extirpated or exists at such low densities it cannot be detected (Randklev *et al.* 2015, pp. 7, 13–14). Regardless, this reach clearly does not contain a significant population of Texas hornshell.

Rio Grande – Downstream of Laredo

Historically, Texas hornshell occurred in the Rio Grande downstream of Laredo to just downstream of the current location of Falcon Dam, Starr County, Texas (Johnson 1999, p. 23). As stated above, the species has been reported as far downstream in the Rio Grande as Brownsville, Texas, but this record is questionable due to the calcium carbonate on the shell, which would not be possible near Brownsville (Neck 1987, p. 151). Another record of Texas hornshell reported from that area of the Rio Grande (near Mercedes, Texas) (Chamberlain 1930, p. 734) is clearly not Texas hornshell but is instead another species, the Tampico pearlymussel (*Cyrtonaias tampicoensis*) (Neck and Metcalf 1988, p. 262). Below Laredo, only long dead and subfossil shells were found downstream of the Laredo Sewage Plant wastewater treatment plant (Karatayev *et al*., 2015, p. 9). Recent surveys upstream and downstream of Falcon Reservoir have yielded no Texas hornshell, alive or dead (Randklev *et al.* 2015, p. 15).

3.3. Needs of Texas Hornshell

As discussed in Chapter 1, for the purpose of this assessment, we define **viability** as the ability of the species to sustain populations in the wild over time (in this case, 100 years). Using the SSA framework, we describe the species' viability by characterizing the status of the species in terms of its **resiliency**, **redundancy**, and **representation** (the 3Rs). Using various time frames and the current and projected levels of the 3Rs, we thereby describe the species' level of viability over time.

3.3.1. Population Resiliency

For the Texas hornshell to maintain viability, its populations or some portion thereof must be resilient. Stochastic events that have the potential to affect Texas hornshell populations include high flow events, drought, pollutant discharge, and accumulation of fine sediment. A number of factors influence the resiliency of populations, including occupied stream length, abundance, and recruitment. Influencing those factors are elements of Texas hornshell habitat that determine whether Texas hornshell populations can grow to maximize habitat occupancy, thereby increasing the resiliency of populations. These factors and habitat elements are discussed below and shown in Figure 3.8.

Population Factors

Occupied Stream Length – Most freshwater mussels, including Texas hornshell, 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. 983). As discussed above, we define a population of Texas hornshell at a larger scale than the 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 Texas hornshell 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.

Abundance – Mussel abundance in a given stream reach is a product of the number of mussel beds times the density of mussels within those beds. For populations of Texas hornshell to be 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 population in the stream reach to recover from any one event. We measure Texas hornshell abundance by the number of beds within the population, and the estimated density of Texas hornshell within each. We consider densities similar to the Black River and Rio Grande – Laredo mussel beds to be relatively high (approaching an average of 200 individuals per 150 m^2) and assume they are generally sufficient to support resilient populations.

Reproduction – Resilient Texas hornshell 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 population of Texas hornshell 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. Conversely, a population that is less dense but has many young and/or gravid individuals may be likely to grow more dense in the future. Detection of very young juvenile mussels during routine abundance and distribution surveys happens extremely rarely due to sampling bias – sampling for this species involves tactile searches; mussels below about 35 millimeters (mm) are very hard to detect. Therefore, reproduction is verified by repeatedly capturing small-sized individuals near the low end of the detectable range size (~35 mm) over time and by capturing gravid females during the reproductively active time of year (generally, March – August (Smith *et al.* 2003, p. 335)).

Habitat Elements that Influence Resiliency

Substrate – Texas hornshell occur in flow refuges such as crevices, undercut riverbanks, travertine shelves, and large boulders. These refuges must have seams of clay or other fine sediments within which the mussels may anchor, but not so much excess sediment that the mussels are smothered. Those areas with clean-swept substrate with seams of fine sediments are considered to have suitable substrate, and those with copious fine sediment both in crevices and on the stream bottom are considered less suitable.

Flowing Water – Texas hornshell need flowing water for survival. They are not found in lakes or in pools without flow, or in areas that are regularly dewatered. River reaches with continuous flow are considered suitable habitat, while those with little or no flow are considered not suitable.

Water Quality – Freshwater mussels, as a group, are sensitive to changes in water quality parameters such as dissolved oxygen, salinity, ammonia, and pollutants (see Chapter 4 for more information). Habitats with appropriate levels of these parameters are considered suitable, while those habitats with levels outside of the appropriate ranges are considered less suitable.

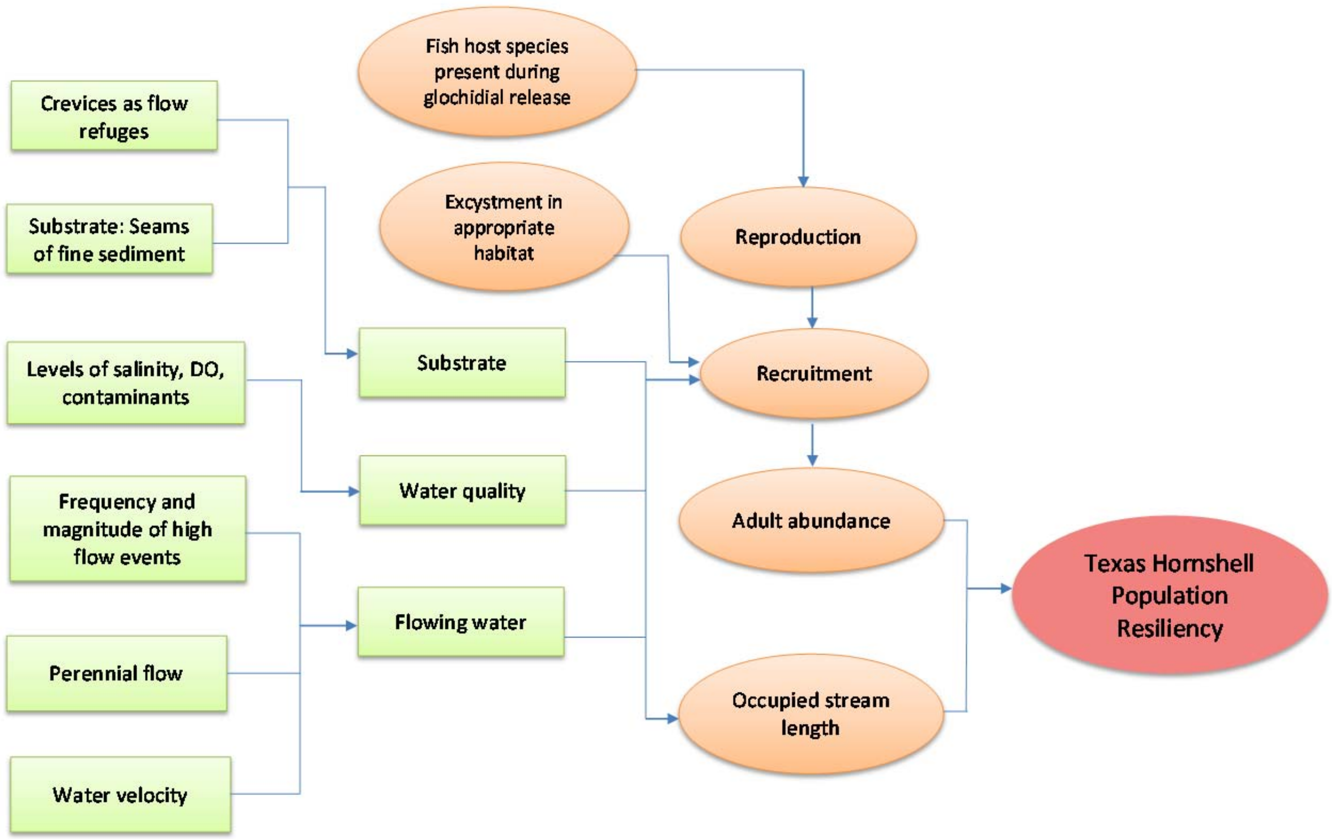

Figure 3.8. Texas hornshell population ecology.

3.3.2. Species Representation

Maintaining representation in the form of genetic or ecological diversity is important to maintain the Texas hornshell's capacity to adapt to future environmental changes. As discussed above, Texas hornshell populations in the Rio Grande and Devils River have distinct variation in allele frequencies from those in the Black River (Inoue *et al.* 2015, p. 1916). Mussels, like Texas hornshell, need to retain populations throughout their range to maintain the overall potential genetic and life history attributes that can buffer the species' response to environmental changes over time (Jones *et al.* 2006, p. 531). The Texas hornshell has likely lost genetic diversity as populations have been extirpated. As such, maintaining the remaining representation in the form of genetic diversity may be important to the capacity of the Texas hornshell to adapt to future environmental change.

The Texas hornshell occupied rivers in several ecological settings, as well. The Black River, Devils River, and Las Moras Creek are small, headwater, spring-fed streams, while the Rio Grande is a large river that flows through canyons and downstream to the sandier coastal plain.

3.3.3 Species Redundancy

The Texas hornshell needs to have multiple resilient populations distributed throughout its range to provide for redundancy. The more populations, and the wider the distribution of those populations, the more redundancy the species will exhibit. Redundancy reduces the risk that a large portion of the species' range will be negatively affected by a catastrophic natural or anthropogenic event at a given point in time. Species that are well-distributed across their historical range are considered less susceptible to extinction and more likely to be viable than species confined to a small portion of their range (Carroll *et al.* 2010, entire; Redford *et al.* 2011, entire). Historically, most Texas hornshell populations were likely connected by fish migration throughout the Rio Grande, upstream through the Pecos River, and throughout the tributaries, but due to impoundments and river reaches with unsuitable water quality (for example, high salinity) they are currently isolated from one another, and repopulation of extirpated locations is unlikely to occur without human assistance.

3.4 Current Conditions

The available information indicates that the Texas hornshell is currently restricted to approximately 15% of its known range in the U.S., which includes five populations in the Rio Grande basin in New Mexico and Texas. The species has been extirpated from a large portion of the Rio Grande, as well as Las Moras Creek (Texas), North Spring River (New Mexico), and presumably the Pecos River (New Mexico and Texas) and Rio Salado (Strenth *et al.* 2004, p. 225; Hein *et al.* 2017, entire).

3.4.1. Current Population Resiliency

Methodology

To summarize the overall current conditions of Texas hornshell populations, we sorted them into three categories (high, moderate, and low) based on the population factors and habitat elements discussed above (Tables 3.1 and 3.2) (see section 3.3.1 Population Resiliency). We also included in the table areas that are (or are presumed to be) extirpated to show the entire current condition of the species. The current condition category is a qualitative estimate based on the analysis of the three population factors and three habitat elements. In determining the summary categories, we gave double weight to the population factors than the habitat elements because, to some degree, the population factors would already reflect habitat elements that are currently influencing the populations. Table 3.3 displays the presumed ranges of probabilities of persistence of a population with a given current condition category over 50 years (about 3 generations of Texas hornshell). These ranges were not calculated; instead, they serve to communicate what we mean when we describe the current condition of a population.

Table 3.1 Population and habitat characteristics used to create condition categories in Table 3.2

	Population Factors			Habitat Elements		
Condition Category	**Habitat Quantity**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**
High	>50 mi	Occupies most rocky habitats surveyed, and more than 100/sample/site OR Density at high end of known range (around 200 individuals/150 m^2)	more than 50% of sites with small individuals (~35mm) and gravid females during the breeding season	Rocky habitats present: Crevices, undercut riverbanks, travertine shelves, large boulders. Seams of fine sediment, not so much as to fill in crevices.	Water flowing at a rate sufficient to remove most fine sediment from stream bottom	No known contaminant, salinity, or temperature problems
Moderate	20-50 mi	Occupies ~half rocky habitats surveyed and ~20-99 sample/site	25-50% of sites with small individuals (~35mm) and gravid females during the breeding season	Rocky habitats present, some sediment accumulating on the stream bottom and some crevices	Water flow not sufficient to consistently remove most fine sediment on the stream bottom	Contaminants or high temperatures known to occur, but not at a level to put population at risk of being extirpated.
Low	<20 mi	Few rocky habitats occupied, less than ~20/sample/site	Fewer than 25% of sites with small individuals (~35mm) and gravid females during the breeding season	Few rocky habitats present. A lot of fine sediment obscuring crevices that do exist.	Water not flowing: nearly inundated, or very little water	Contaminants, salinity, or temperature at levels high enough to put the population at risk of being extirpated.
Ø	None	None	Population is presumed extirpated	N/A	Stream bottom is dry or completely inundated.	Contaminants or water quality parameters preclude mussel habitation.

Table 3.2. Resiliency of Texas hornshell populations. For extirpated streams, stream length estimates are for historical distributions. See Table 3.1 for description of condition categories.

	Population Factors				Habitat Elements			
Population	**Estimated Occupied Stream Length**	**Habitat Quantity**	**Abundance**	**Reproduction**	**Substrate**	**Flowing Water**	**Water Quality**	**Current Condition**
Black River	8.7 mi (14 km)	**Low**[$]	**High**[$]	**High**[$]	**Moderate**[°,⊗]	**High**	**High**[⊗]	**Moderate**
Lower Pecos River	?	**Low**[✦]	**Low**[✦]	**Low**[✦]	?	**Moderate**	**Low**	**Low**
Devils River	~29 mi (47 km)	**Moderate**[^]	**Low**[^]	**Moderate**[^]	**High**[^]	**Moderate**	**High**[^,✓,⬩]	**Moderate**
Rio Grande: Lower Canyons	~62 mi (100 km)	**High**[^]	**Moderate**[^]	**High**[^]	**Moderate**	**High**	**High**	**High**
Rio Grande: Laredo	56 mi (90 km)	**High**[^]	**High**[^]	**High**[^]	**Moderate**[✧]	**High**	**Moderate**[⬩]	**High**
North Spring River	~5 mi (8 km)	**Ø**	**Ø**	**Ø**	**Low**[@]	**Low**[@]	**Low**[@]	**Ø**
Upper Pecos River	~420 mi (680 km)	**Ø**	**Ø**	**Ø**	**Low**	**Low**	**Low**[10]	**Ø**
Las Moras Creek	~37 mi (60 km)	**Ø**[∞,✧]	**Ø**[∞,✧]	**Ø**[∞,✧]	**Low**[∞]	**Moderate**[*]	**Low**[∞]	**Ø**
Rio Grande: between Lower Canyons and Laredo	~200 mi (320 km)	**Ø**[^]	**Ø**[^]	**Ø**[^]	**Moderate**	**High**	**Moderate**[⬩]	**Ø**
Mexico: Rio Salado	~500 mi (800 km)	**Ø**[+]	**Ø**[+]	**Ø**[+]	**Low**[+]	**Low**[#,+]	**Low**[+]	**Ø**

[*]Howells 1996, p. 42, [^]Randklev *et al.* 2015, pp. 7–8, [$]Inoue *et al.* 2014, pp. 6–11 [#]Contreras-B. and Lozano-V. 1994, p. 381 [@]New Mexico Department of Game and Fish 2005, p. 18 [+]Strenth *et al.* 2004, p. 225–226 [✓]The Nature Conservancy 2004, p. 18 [⬩]Texas Clean Rivers Program 2013, p. 12 [°]Lang 2010, p. 8 [⊗]Bren School of Environmental Management 2014, p. 114, [∞]Murray 1975, p. 43, [✧]Burlakova and Karatayev 2014, p. 17, [✦]Randklev *et al.* 2016, p. 8.

Table 3.3. Presumed probability of persistence of current condition categories.

Likelihood of Persistence:	High	Moderate	Low
Range of Presumed Probability of Persistence over ~50 years	**90 – 100%**	**66 – 90%**	**0 – 66%**
Range of Presumed Probability of Extirpation over ~50 years	**0 – 10%**	**10 – 33%**	**33 – 100%**

Overall, the extant populations occur in areas of relatively good habitat and water quality, but they vary in size and abundance. All extant populations except the Pecos River population show some evidence of recent reproduction. We consider the Rio Grande populations to be in high condition due to their prevalence and abundance, and these populations appear to be recruiting well. The Black River population is quite dense and recruitment also appears to be high, but the short size of the occupied reach limits this population's resiliency. The Devils River population appears to be small, although evidence of recruitment has been observed here as well. Finally, because only one old individual was found alive in the Pecos River among many dead shells, the Pecos River population is in low condition.

3.4.2. Current Species Representation

We consider the Texas hornshell to have representation in the form of genetic diversity in three areas: (1) the Black River population, (2) populations in the Rio Grande, Devils River, and Pecos River, and (3) the Gulf Coast of Mexico (Figure 3.9). The Rio Salado is a tributary of the Rio Grande, and so any extant populations in that drainage would be considered to fall into the Rio Grande representation area.

3.4.3. Current Species Redundancy

Within these identified representation areas, the Black River exhibits no redundancy – it is the only population exhibiting the unique variation in allele frequencies seen in that population. The Rio Grande representation area has some redundancy, as four populations (Rio Grande – Lower Canyons, Rio Grande – Laredo, Pecos River, and Devils River) have or are assumed to have similar genetic diversity (see section 2.2. Genetic Diversity, above) (Figure 3.9).

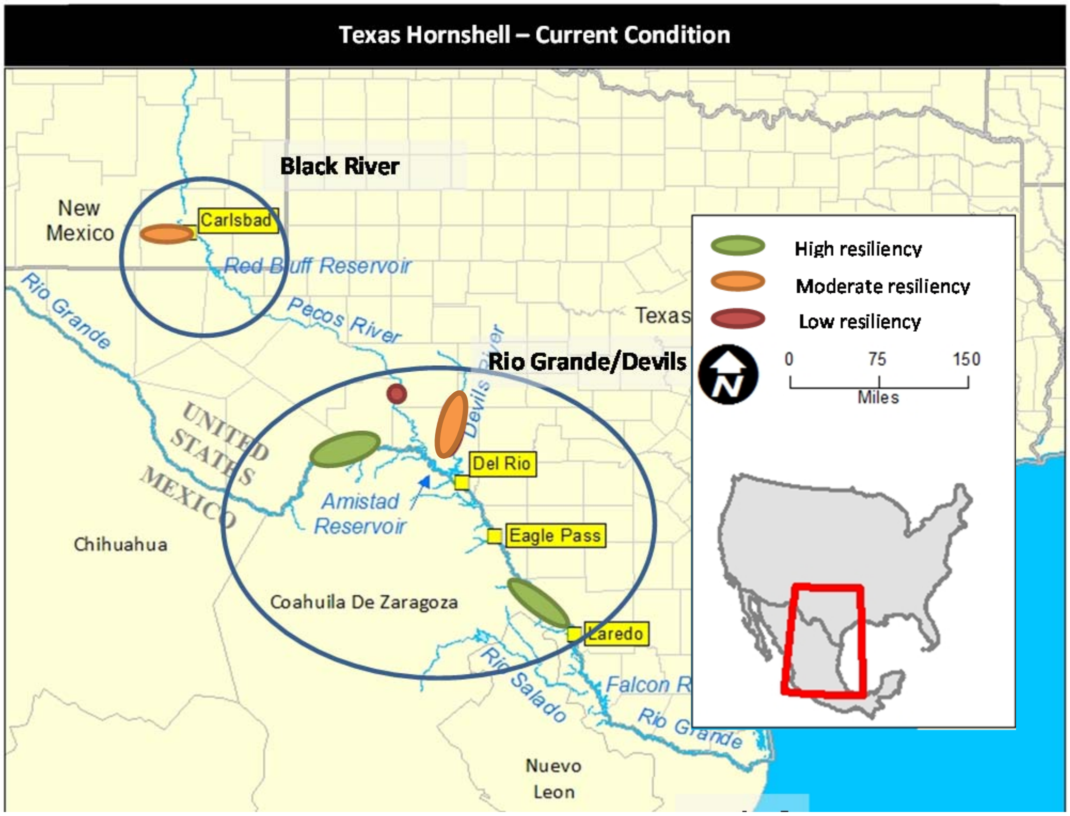

Figure 3.9. Current resiliency, redundancy, and representation of Texas hornshell.

CHAPTER 4 –INFLUENCES ON VIABILITY

> **Note:** This chapter contains **summaries** of the risks. For further information and additional references, see the tables in **Appendix B**.

In this chapter, we evaluate the past, current, and future influences that are affecting what the Texas hornshell needs for long term viability. We analyzed these factors in detail using the tables in Appendix B in terms of causes and effects to the species. These tables analyze the pathways by which each influence affects the species, and each of the causes is examined for its historical, current, and potential future effects on the species' status. 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 the Texas hornshell) 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 Texas hornshell populations, such as overutilization for commercial and scientific purposes and disease, are not discussed in this SSA report.

4.1. Increased Fine Sediment

Texas hornshell require seams of fine sediment under boulders and bedrock and in streambanks in order to anchor themselves into place on the stream bottom; however, too much fine sediment can fill in these crevices and smother any mussels within those spaces. Under natural conditions, 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). However, the 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) has caused sediment to accumulate to some degree at all populations. 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 that cannot adapt 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 Texas hornshell, these sources include streambank erosion from agricultural activities, livestock grazing, and roads, among others (Figure 4.1).

Interstitial spaces (small openings between rocks and gravels) in the substrate 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.

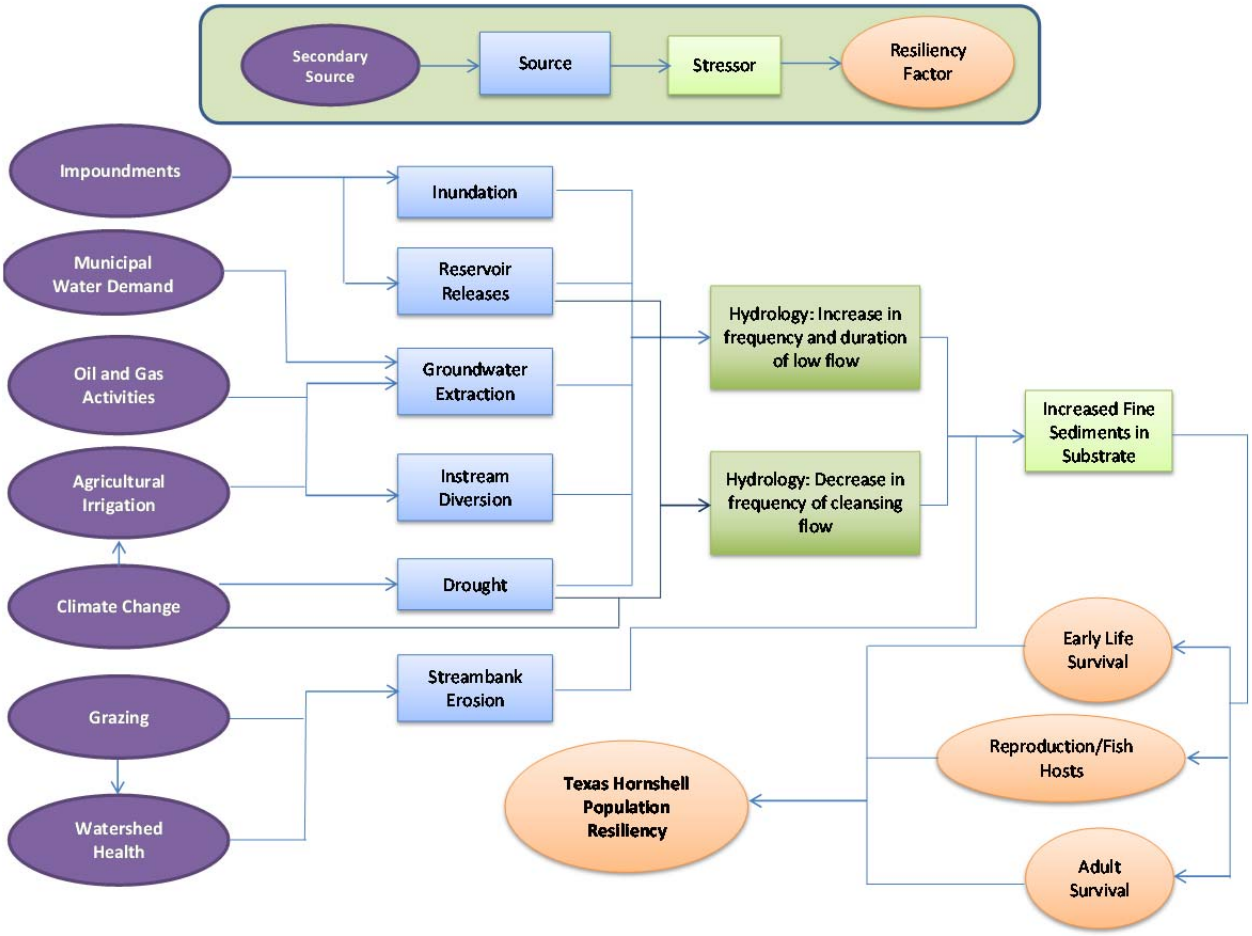

Figure 4.1. Sources of fine sediments within Texas hornshell populations.

4.2. Water Quality Impairment

Water quality can be impaired 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 discharges, including spills, industrial sources, municipal effluents, and agricultural runoff. These sources contribute organic compounds, heavy metals, pesticides, herbicides, and a wide variety of newly emerging contaminants to the aquatic environment. Ammonia is of particular concern below water treatment plants because freshwater mussels have been shown to be particularly sensitive to increased ammonia levels (Augspurger *et al.* 2003, p. 2569). It is likely for this reason that Texas hornshell are not found for many miles downstream of two wastewater treatment plants that discharge into the Rio Grande: at Nuevo Laredo, Mexico, and Eagle Pass, Texas (Karatayev *et al.* 2015, p. 14).

An additional type of water quality impairment is alteration of water quality parameters such as dissolved oxygen, temperature, and salinity levels. Dissolved oxygen levels may be reduced from increased nutrients in the water column from runoff or wastewater effluent, and juveniles seem to be particularly sensitive to low dissolved oxygen (Sparks and Strayer 1998, pp. 132–133). Increased water temperature from climate change and from low flows during drought can exacerbate low dissolved oxygen levels as well as have its own effects on both juvenile and adult mussels. Finally, salinity appears to be particularly limiting to Texas hornshell. The aquifer near Malaga, New Mexico, contains saline water. As the saline water emerges from the ground, it is diluted by surface flow. As surface flow decreases, however, the salinity in the river increases. Additionally, aquifers have become increasingly saline due to salinized water recharge (Hoagstrom 2009, p. 35). Irrigation return flows exacerbate salinity levels as salts build up on irrigated land and then are washed into the riverway. The Pecos River from the confluence with the Black River to the confluence with Independence Creek has become particularly saline in the past few decades, with levels at 7 parts per million (ppm) or higher – too high for freshwater mussel habitation. Additionally, the Black River downstream of the Texas hornshell population has had salinity levels in the range of 6 ppm, which may be one reason the population has been extirpated from the downstream reach.

Contaminant spills are also a concern. In particular, the Black River population is vulnerable to spills from the high volume of truck traffic crossing the river at low water access points (Bren School of Environmental Management 2014, p. 26). Due to the topography and steep slopes of these areas, spilled contaminants and contaminated soils could directly enter the surface water of the river and negatively impact the species (Boyer 1986, p. 300) and downstream habitat.

A reduction in surface flow from drought, instream diversion, or groundwater extraction concentrates contaminant and salinity levels and increases water temperatures in streams and exacerbates effects to Texas hornshell. See Figure 4.2 for a depiction of how water quality affects Texas hornshell populations.

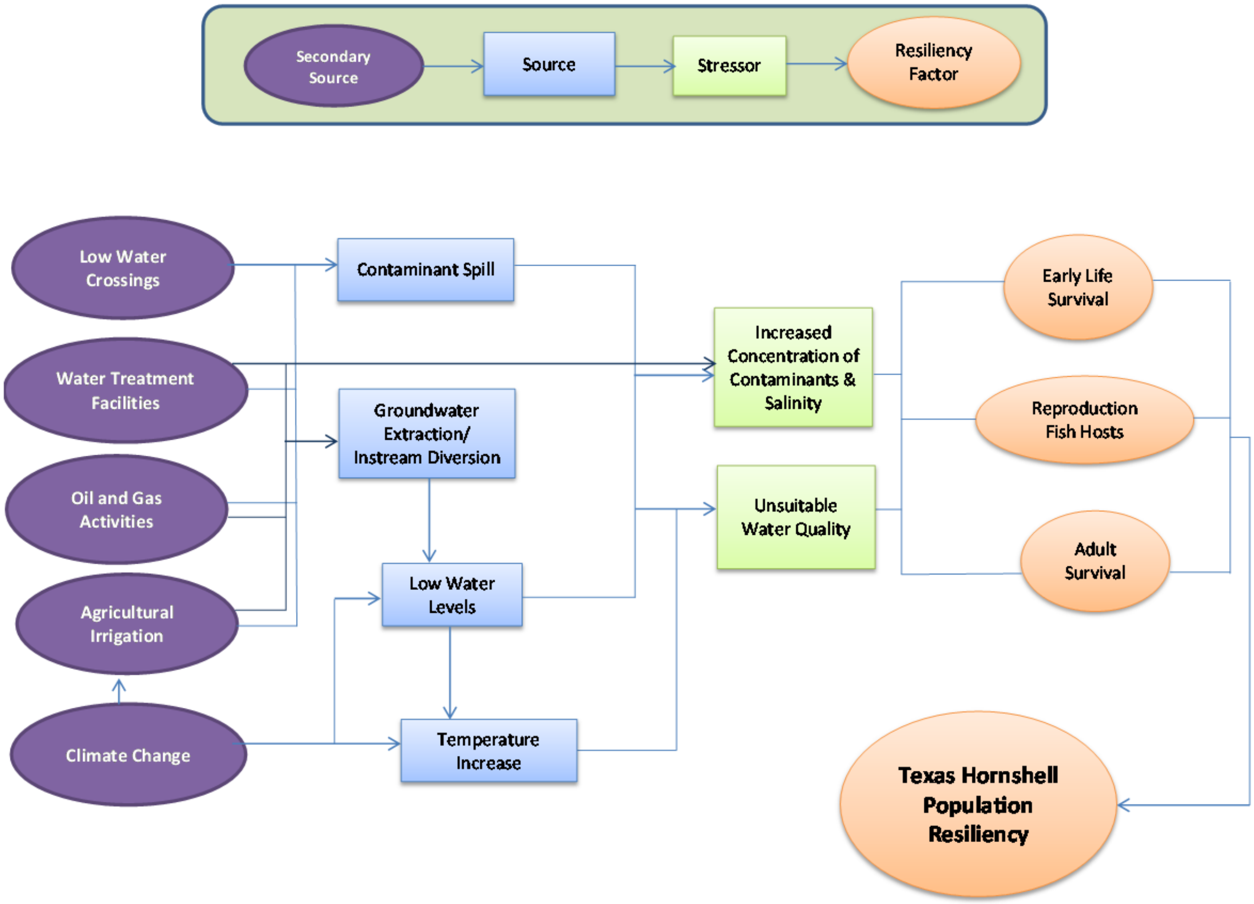

Figure 4.2. Sources of water quality impairment within Texas hornshell populations.

4.3. Loss of Flowing Water

Texas hornshell populations need flowing water in order to survive. Low flow events (including stream drying) and inundation can eliminate appropriate habitat for Texas hornshell, and while the species can survive these events if they last for a short time, populations that experience these events regularly will not persist (Figure 4.3).

Inundation has primarily occurred upstream of dams, both large (such as Amistad, Falcon, and Red Bluff Dams) and small (low water crossings, diversion dams, such as those on the Black River). Inundation causes an increase in sediment deposition, eliminating the crevices this species inhabits. In large reservoirs, deep water is very cold and often devoid of oxygen and necessary nutrients. Cold water (less than 11 °Celsius (C) (52 °Fahrenheit (F))) has been shown to stunt mussel growth and delay or hinder spawning. Because glochidial release may be temperature dependent, it is likely that relict individuals living in the constantly cold hypolimnion (deepest portion of the reservoir) in these reservoirs may never reproduce, or reproduce less frequently.

At the Rio Grande – Laredo population, a low-water weir has been proposed for construction (Rio Grande Regional Water Planning Group 2010, p. 4-74) just downstream of the La Bota area, which contains the largest known and most dense Texas hornshell bed within the Rio Grande – Laredo population and rangewide. The impounded area would extend approximately 14 mi (22.5 km) upstream, effectively eliminating habitat for Texas hornshell from 25% of the currently occupied area and likely leading to extirpation of the densest sites within this population.

Very low water levels are detrimental to Texas hornshell populations, as well. Droughts that have occurred in the recent past have led to extremely low flows in rivers across the desert Southwest. The rivers inhabited by Texas hornshell have some resiliency to drought because they are spring fed (Black and Devils Rivers) and very large (Rio Grande), but drought in combination with increased groundwater pumping and regulated reservoir releases may lead to lower river flows of longer duration than have been recorded in the past. Streamflow in the Rio Grande downstream of the confluence with the Rio Conchos (near the Rio Grande – Lower Canyons population) has been declining since the 1980s (Miyazono *et al.* 2015, p. A-3), and overall river discharge for the Rio Grande is projected to continue to decline due to increased drought as a result of climate change (Nohara *et al.* 2006, p. 1087). The Rio Grande – Lower Canyons is very incised, and the population occurs in crevices along the steep banks. Reductions in discharge in this area may lead to a higher proportion of the population being exposed than similar decreases at other populations.

In the Black River, groundwater extraction for oil and gas activities in combination with drought is likely to result in reduced stream flow in the future. In the Devils River, future water withdrawals from aquifers that support spring flows in the range of the Texas hornshell could result in reduction of critical spring flows and river drying, and a clear connection has been made between groundwater and surface water levels in the Devils River (Toll *et al.* 2017, p. 47). In particular, proposals to withdraw water from the nearby aquifer and deliver the water to municipalities have been proposed multiple times (*e.g.* Val Verde Water Company 2013, pp. 1–2). To date, none have been approved. As spring flows decline due to drought or groundwater lowering from pumping, habitat for the Texas hornshell is reduced and could eventually cease to exist. While Texas hornshell 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.

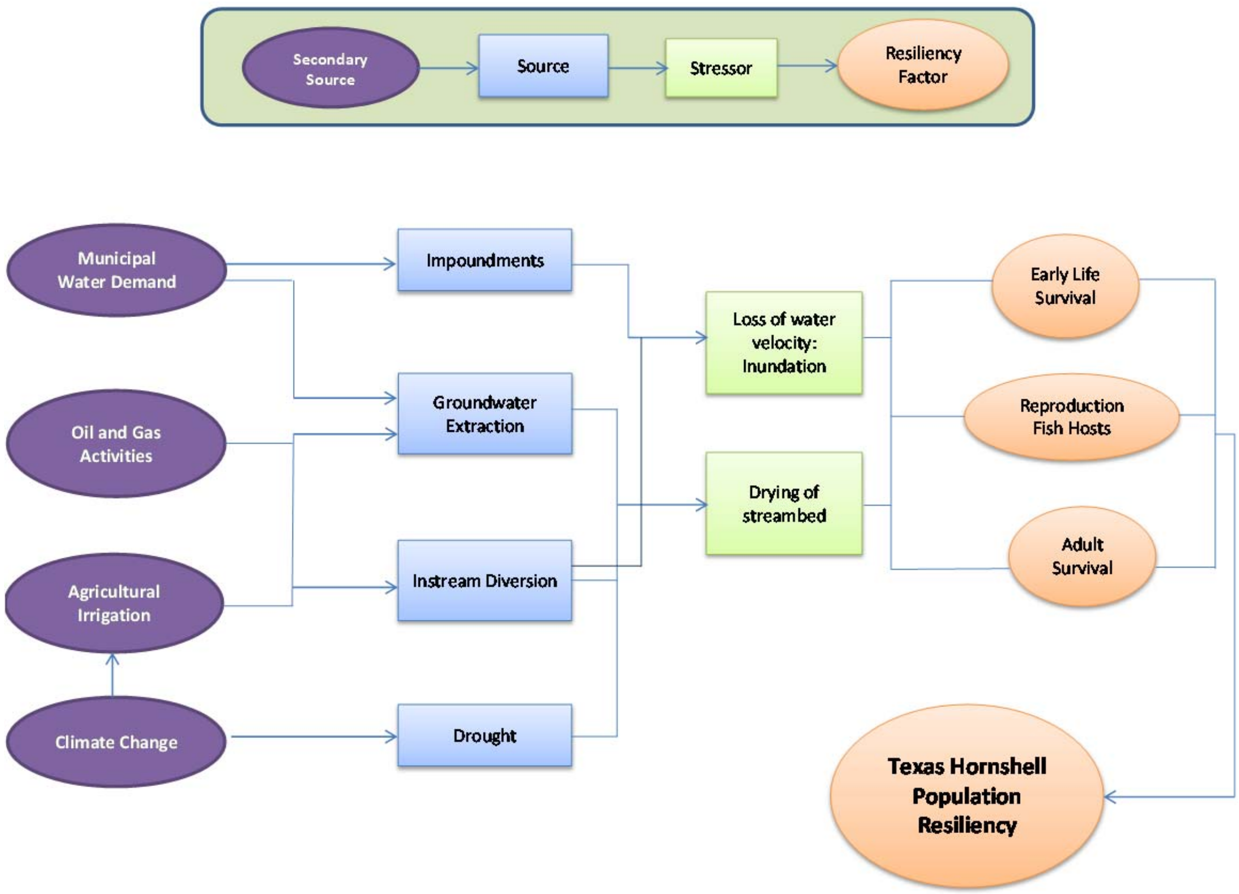

Figure 4.3. Sources of flow loss within Texas hornshell populations.

4.4. Barriers to Fish Movement

The Texas hornshell was likely historically distributed throughout the Rio Grande, Pecos River, Devils River, and Black River in Texas and New Mexico, as well as throughout the rivers draining to the Gulf of Mexico from which it was known when few natural barriers existed to prevent migration (via host species) among suitable habitats. The species colonized new areas through movement of infested host fish, and newly metamorphosed juveniles would excyst from host fish in new locations. Today, the remaining populations are significantly isolated from one another such that recolonization of areas previously extirpated is extremely unlikely if not impossible due to existing contemporary barriers to host fish movement. The Black River is isolated from the rest of the populations by high salinity reaches of the Pecos River, as well as Red Bluff Reservoir, and is hundreds of river miles from the nearest extant population. Amistad Reservoir separates the three Texas populations from each other, isolating the Rio Grande – Lower Canyons, Devils River, and Rio Grande – Laredo populations. There is currently no opportunity for interaction among any of the five extant U.S. populations.

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 (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.

Two of the Texas hornshell's primary host fish species (river carpsucker and red shiner) are known to be common, widespread species. We do not expect the distribution of host fish to be a limiting factor in Texas hornshell distribution.

4.5. Increased Predation

Predation on freshwater mussels is a natural ecological interaction. Raccoons, snapping turtles, and fish are known to prey upon Texas hornshell. Under natural conditions, the level of predation occurring within Texas hornshell 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 Devils Rivers, and muskrat predation has also been reported on the Black River. As drought and low flow are predicted to occur more often and for longer periods due to the effects of future climate change, the Devils River in particular is expected to experience additional predation pressure into the future, and it may become more of a concern in the Black River (Figure 4.4). Predation is expected to be less of a problem for the Rio Grande and Pecos populations, as the rivers are significantly larger than the Black and Devils Rivers and Texas hornshell are less likely to be found in exposed or very shallow portions of the stream.

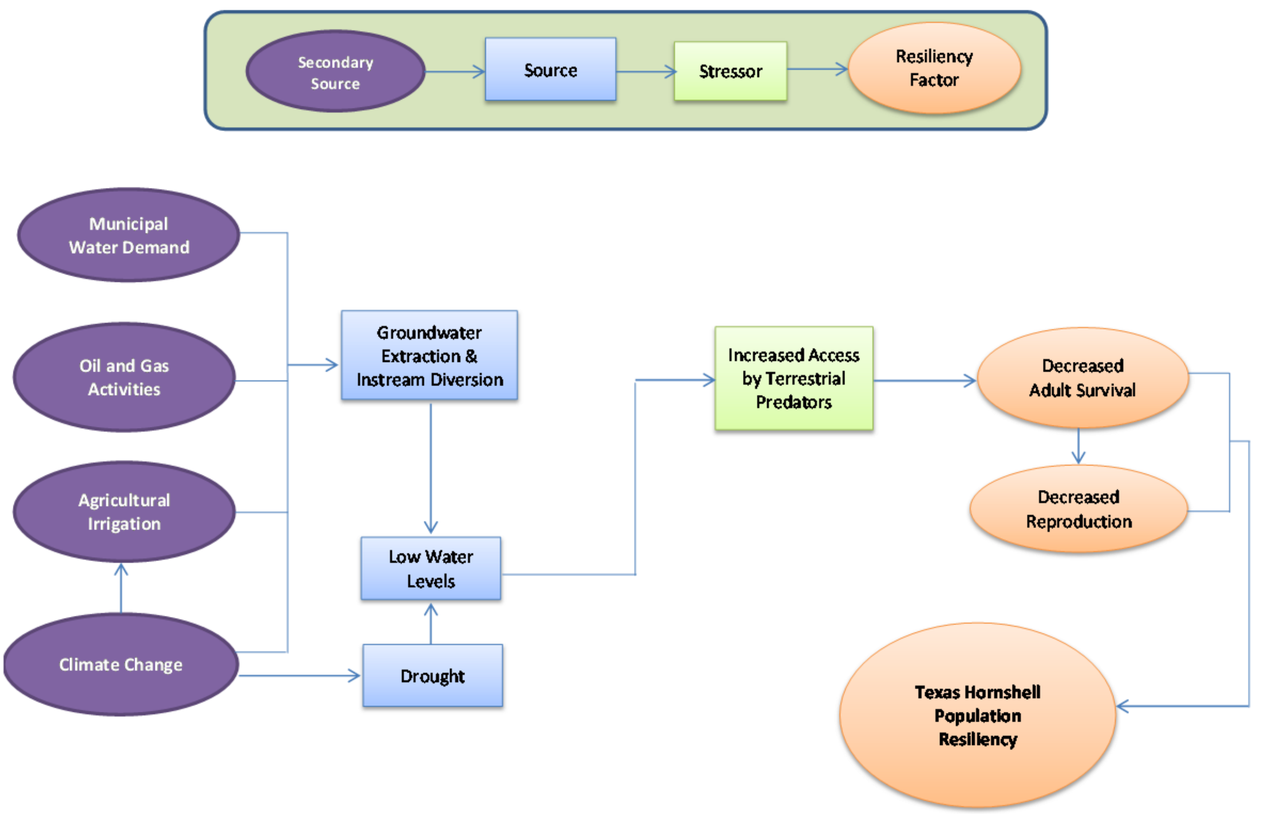

Figure 4.4. Sources of increased predation within Texas hornshell populations.

4.6. Climate Change

Climate change has already begun, 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 the Southwest is expected to be greatest in the summer (IPCC 2013, pp. 11–12), and annual mean precipitation is very likely to decrease in the Southwest (IPCC 2013, pp. 11–12; Ray *et al.* 2008, p. 1). In Texas, the number of extreme hot days (high temperatures exceeding 95º Fahrenheit) are expected to double by around 2050 (Kinniburgh *et al.* 2015, p. 83), and Texas is considered one of the "hotspots" of climate change in North America; west Texas is an area expected to show greater responsiveness to the effects of climate change (Diffenbaugh *et al.* 2008, p. 3). 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.* 2012, p. 3). 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 Texas hornshell (Kinniburgh *et al.* 2015, p. 88), 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). In our analysis of the future condition of the Texas hornshell, we considered climate change to be an exacerbating factor in the increase of fine sediments, changes in water quality, loss of flowing water, and predation.

4.7. Management Actions

Though only about 7% of known occupied habitat for the Texas hornshell is in New Mexico, it is an area that holds important genetic diversity for the species. The Service collaborated with water users, oil and gas developers, landowners, and other partners to develop Candidate Conservation Agreements (CCAs) and Candidate Conservation Agreements with Assurances (CCAAs) for the species on State, Federal and private lands. These agreements provide voluntary conservation that will, if executed properly, reduce threats to the species while improving physical habitat and water quality. The key conservation measures in the agreements are designed to limit oil and gas development to areas outside of the Black and Delaware River floodplains, minimize erosion, and maintain minimum water flows in the rivers. Along with these measures, the partners to the agreement are evaluating alternatives to the multiple low water crossings on the Black River. Partners are considering alternate crossing locations, which could include bridges designed to allow host fishes to pass through in addition to decreasing potential contamination events. These agreements were approved by the Service in October 2017.

In Texas, The Nature Conservancy and TPWD manage lands under their purview in the Devils River watershed to maintain and enhance the native communities, including Texas hornshell. In the Rio Grande, we are not aware of any management actions for Texas hornshell. The Texas Comptroller of Public Accounts has established an Endangered Species Task Force and has funded much of the recent research in Texas on Texas hornshell, which has led to greater understanding of the species' distribution in the state.

4.8. Summary

Our analysis of the past, current, and future influences on what the Texas hornshell needs for long term viability revealed that there are three influences that pose the largest risk to future viability of the species. These risks are primarily related to habitat changes: the accretion of fine sediments, the loss of flowing water, and impairment of water quality; these are all exacerbated by climate change. We did not assess overutilization for scientific and commercial purposes or disease, because these risks do not appear to be occurring at a level that affects Texas hornshell populations. The accretion of fine sediments, the loss of flowing water, and impairment of water quality, as well as management efforts, are carried forward in our assessment of the future conditions of Texas hornshell populations and the viability of the species overall.

CHAPTER 5 – VIABILITY

We have considered what the Texas hornshell needs for viability and the current condition of those needs (Chapters 2 and 3), and we reviewed the risk factors that are driving the historical, current, and future conditions of the species (Chapter 4 and Appendix B). We now consider what the species' future conditions are likely to be. We apply our future forecasts to the concepts of resiliency, redundancy, and representation to describe the future viability of the Texas hornshell.

5.1. Introduction

The Texas hornshell has declined significantly in overall distribution and abundance, with the species currently occupying approximately 15% of its historical range in the U.S. Between half and a third of the Texas hornshell's historical range occurred in Mexico, and we have no information about the species' status there. The resulting remnant populations occupy shorter reaches compared to presumed historical populations, and they are all isolated from one another. The primary historical reason for this reduction in range was reservoir construction and unsuitable water quality. Large reservoirs have been constructed on the Rio Grande and Pecos River, and much of the Pecos River upstream of the confluence with Independence Creek now has salinity levels too high for mussel habitation (Hoagstrom 2009, p. 28).

The effects of these reservoirs extend beyond fragmentation of populations; the resultant releases rarely mimic natural flow regimes, and the change in timing and frequency of cleansing flows results in increases in fine sediments and predation and decreased water quality. Add to this the exacerbating effects of climate change – increased temperature and decreased stream flow – and Texas hornshell populations face varying levels of risk into the future. For the populations occupying the smaller reaches (such as the Black River, Devils River, and Pecos River populations), a single stochastic event such as contaminant spill or drought could eliminate an entire population of Texas hornshell. These effects are heightened at the species level because the isolation of the populations prohibits natural recolonization from host fish carrying Texas hornshell glochidia, which likely happened in the past and allowed for the species to ebb and flow from suitable areas.

Populations in both large and small reaches face risks from natural and anthropogenic sources. Climate change has already begun to affect the regions of Texas and New Mexico where Texas hornshell occurs, resulting in higher air temperatures, increased evaporation, increased groundwater pumping, and changing precipitation patterns such that water levels rangewide have already reached historic lows (Dean and Schmidt 2011, p. 336; Bren School of Environmental Management 2014, p. 50). These low water levels put the population at elevated risk of habitat loss from increased fine sediments, poor water quality, and increase predation risk. Additionally, the low-water weir proposed for the Rio Grande – Laredo population would eliminate 25% of the occupied reach, including the densest mussel beds in the reach and of the species.

These risks, alone or in combination, could result in the extirpation of additional populations, further reducing the overall redundancy and representation of the species. Historically, the species, with a large range of interconnected populations, would have been resilient to stochastic events such as drought and sedimentation because even if some populations were extirpated by such events, they could be recolonized over time by dispersal from nearby surviving populations. This connectivity would have made for a highly resilient species overall. However, under current conditions, restoring that connectivity on a large scale is not feasible due to large reservoirs and unsuitably high salinity levels between populations.

As a consequence of these current conditions, the viability of the Texas hornshell now primarily depends on maintaining the remaining isolated populations and potentially restoring new populations where feasible.

5.1.1. Scenarios

Because we have significant uncertainty regarding if and when flow loss, water quality impairment, or impoundment construction may occur, we have forecasted what the Texas hornshell may have in terms of resiliency, redundancy, and representation under five plausible future scenarios. These future scenarios forecast Texas hornshell viability over the next 10, 50, and 100 years. We chose 10 years to evaluate what is likely to occur in the near term, and 50 and 100 years because they are within the range of the available hydrological and climate change model forecasts and provide us with a shorter and longer term analysis (Mace and Wade 2008, entire; Texas Water Development Board 2008, entire). The Status Quo scenario evaluates the condition of Texas hornshell if there is no increase in risks to the populations from what exists today, while the other scenarios evaluate the response of the species to changes in those risks. For each scenario we describe the stressors that would occur in each population.

(1) Status Quo:

- Black River – There is a small to moderate water flow reduction due to drought and groundwater extraction, the CCA is not enacted and/or is not successful, the Delaware River reintroduction is not successful, and the risk of a contaminant spill remains high.
- Pecos River – Water quality declines.
- Devils River – There is a small to moderate water flow reduction due to climate change and groundwater extraction.
- Rio Grande – Lower Canyons – There is a small to moderate water flow reduction due to drought, groundwater extraction, and management of the Rio Conchos.
- Rio Grande – Laredo – The low-water weir is not constructed, water quality declines, and there is a small water flow decline.

(2) Conservation:

- Black River – The Delaware River reintroduction is successful, the CCA is enacted and successful, the risk of a contaminant spill is reduced, and there is no substantial flow reduction due to drought or groundwater extraction.
- Pecos River – Water quality does not decline, and the population does not experience effects of small population size.
- Devils River – There is no flow loss due to drought or groundwater extraction.
- Rio Grande – Lower Canyons – There is no flow loss due to climate change, groundwater extraction, or management of the Rio Conchos.

- Rio Grande – Laredo – The low-water weir is not constructed, there is no flow loss due to upstream water management or drought, and water quality does not decline.

(3) Considerable Effects:

- Black River – There is a small to moderate water flow reduction due to climate change and groundwater extraction, the risk of a contaminant spill is reduced, the CCA is not enacted and/or is not successful, and the Delaware River reintroduction is not successful.
- Pecos River – Water quality declines.
- Devils River – There is a small to moderate water flow reduction due to climate change and groundwater extraction.
- Rio Grande – Lower Canyons – There is a small to moderate water flow reduction due to climate change, groundwater extraction, and management of the Rio Conchos.
- Rio Grande – Laredo – The low-water weir is constructed, water quality does not decline, and water flow does not decline.

(4) Major Effects:

- Black River – There is a large water flow reduction due to climate change and groundwater extraction, and the risk of a contaminant spill remains high.
- Pecos River: Water quality declines
- Devils River: There is a small to moderate water flow reduction due to drought and groundwater extraction.
- Rio Grande – Lower Canyons: There is a small to moderate water flow reduction due to drought, groundwater extraction, and management of the Rio Conchos.
- Rio Grande – Laredo: Water quality declines, the low water weir is not constructed, and water flow declines due to upstream water management and drought.

(5) Severe Effects:

- Black River – There is a large water flow reduction due to climate change and groundwater extraction, and the risk of a contaminant spill remains high.
- Pecos River – Water quality declines.
- Devils River – There is a large water flow reduction due to drought and groundwater extraction.
- Rio Grande – Lower Canyons – There is a large water flow reduction due to drought, groundwater extraction, and management of the Rio Conchos.
- Rio Grande – Laredo – The low-water weir is constructed, water quality declines, and water flow is reduced due to upstream water management and drought.

We examine the resiliency, representation, and redundancy of the Texas hornshell under each of these five plausible scenarios. Resiliency of Texas hornshell populations depends on future water quality, availability of flowing water, and substrate suitability. We expect the four extant Texas hornshell populations 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 did not include an assessment of reproduction for the future scenarios; in the future, the abundance of the population will reflect whether or not reproduction and recruitment are occurring. We then projected an overall condition for each population. For these projections, populations in high condition are expected to have high resiliency at that time period; i.e., they are at the high end of the known density range, they are reproducing successfully, and they occupy habitat of sufficient size to allow for ebbs and flows of density of mussel beds within the population. Populations in high condition are expected to persist into the future, beyond 100 years, and have the ability to withstand stochastic events that may occur. Populations in moderate condition have less resiliency than those in high condition, but the majority (~70 – 90%) of these populations are expected to persist beyond 100 years. Populations in moderate condition are smaller and less dense than those in high condition. Finally, those populations in low condition have low resiliency and are not necessarily able to withstand stochastic events. As a result, they are less likely to persist 100 years.

For each scenario, we estimated the likelihood of that scenario occurring in 10, 50, and 100 years. We used the scale in Table 5.1 to estimate these likelihoods.

Table 5.1. Explanation of confidence terminologies used to estimate the likelihood of scenario occurrence.

Confidence Terminology	Explanation
Highly likely	We are more than **90% sure** that this scenario will occur.
Moderately likely	We are **70 to 90% sure** that this scenario will occur.
Somewhat likely	We are **50 to 70% sure** that this scenario will occur
Unlikely	We are less than **50% sure** that this scenario will occur. Indicates high uncertainty.

5.2. Scenario 1 – Status Quo

Under the Status Quo scenario, those factors that are having an influence on populations of Texas hornshell continue at current rates. Low levels of climate change are already occurring, leading to lowered streamflow at nearly all locations. In this scenario, the risk of a contaminant spill in the Black River remains high, the CCA is not implemented, and the Delaware River reintroduction is not successful (Table 5.2).

5.2.1. Resiliency

Black River – In the Status Quo scenario, the Black River population experiences a small to moderate water flow reduction due to water extraction and climate change. The reduction in water would result in fewer cleansing flows, and so fine sediments would accumulate in the crevices occupied by Texas hornshell, reducing the amount of suitable locations for the species, and reducing the abundance of the population to moderate. The distribution of Texas hornshell in the Black River would remain small. However, because the risk of a contaminant spill would remain high, it is highly likely the population would be affected by a spill. Therefore, water quality and abundance would be low.

Pecos River - The population in the Pecos River experiences water quality decline from reduced water flow and the resultant decreases in water quality, including increased salinity and temperature. The small population would be extirpated from the effects of poor water quality.

Devils River – Under the Status Quo scenario, the Devils River would experience a reduction in flow due to groundwater extraction and drought, as a result of climate change. The low flows this population experiences during dry times would become more frequent and prolonged. Because Texas hornshell in the Devils River occur at the heads of riffles, they are vulnerable to complete flow loss when water levels drop. The reduction in cleansing flows would result in the accumulation of fine sediments, reducing substrate quality. Low flows would also affect water quality parameters such as temperature and dissolved oxygen. Additionally, the species is already vulnerable to predation from terrestrial predators during times of low flow; predation would occur more frequently. Overall, because the population is currently small and would be unlikely to grow, the Devils River population would be in low condition and would be vulnerable to extirpation.

Rio Grande – Lower Canyons – The Rio Grande – Lower Canyons population would experience a small to moderate reduction in flow due to groundwater extraction or drought as a result of climate change, and management of the Rio Conchos would not provide reliable water. This section of the Rio Grande is relatively deep and incised, and the population of Texas hornshell in this reach primarily occurs in crevices along the banks. Water flow reductions would expose a high proportion of the existing population; therefore, this reduction in flow would likely have a larger effect on the population size than in other populations – although at a small to moderate decrease in water flow we still expect abundance to be maintained at moderate levels. Overall, we expect the Rio Grande – Lower Canyons population would be in moderate condition in this scenario, due to the population's moderate abundance combined with a reduction in flow.

Rio Grande – Laredo – In the Status Quo scenario, the low water weir would not be constructed, but water flow would decline due to upstream water management and drought due to climate change. This declining water flow would decrease water quality and therefore population abundance. Overall, the Rio Grande – Laredo population would be in moderate condition.

The Status Quo scenario projects the condition of Texas hornshell populations if the current risks continue on the same trajectory they are on now. Overall, two populations would be in moderate condition, two in low condition, and the Pecos River population would be extirpated.

Table 5.2. Texas hornshell population resiliency under scenario 1 – Status Quo.

	Population Factors		Habitat Elements			
Population	**Habitat Quantity**	**Abundance**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall**
Black River	Low	Low	Moderate	Moderate	Low	Low
Pecos River	Ø	Ø	?	Low	Low	Ø
Devils River	Moderate	Low	Low	Low	Moderate	Low
Rio Grande: Lower Canyons	High	Moderate	Moderate	Moderate	Moderate	Moderate
Rio Grande: Laredo	High	Moderate	Moderate	Moderate	Moderate	Moderate

5.2.2. Representation

As identified above, we consider the Texas hornshell to have representation in the form of genetic diversity in two areas: (1) the Black River population and (2) populations in the Rio Grande, Pecos River, and Devils River. In the Status Quo scenario, the current level of representation would be maintained, although the Black River population would remain small and relatively vulnerable to extirpation and therefore there is a possibility of loss of that area of representation. The Pecos River population would be extirpated, and the Devils River population would be in low condition and vulnerable to extirpation, but populations in the Rio Grande would be likely to be maintained, preserving that area of representation. Overall representation could be similar to current levels or could be reduced (Figure 5.1).

5.2.3. Redundancy

Within these identified representation areas, we then examined what redundancy would exist under the various scenarios. Under the Status Quo scenario, redundancy would be reduced. The Black River area would remain small with no redundancy, and relatively vulnerable to extirpation. The Rio Grande area would lose redundancy with extirpation of the Pecos River population and potential extirpation of the Devils River population (Figure 5.1).

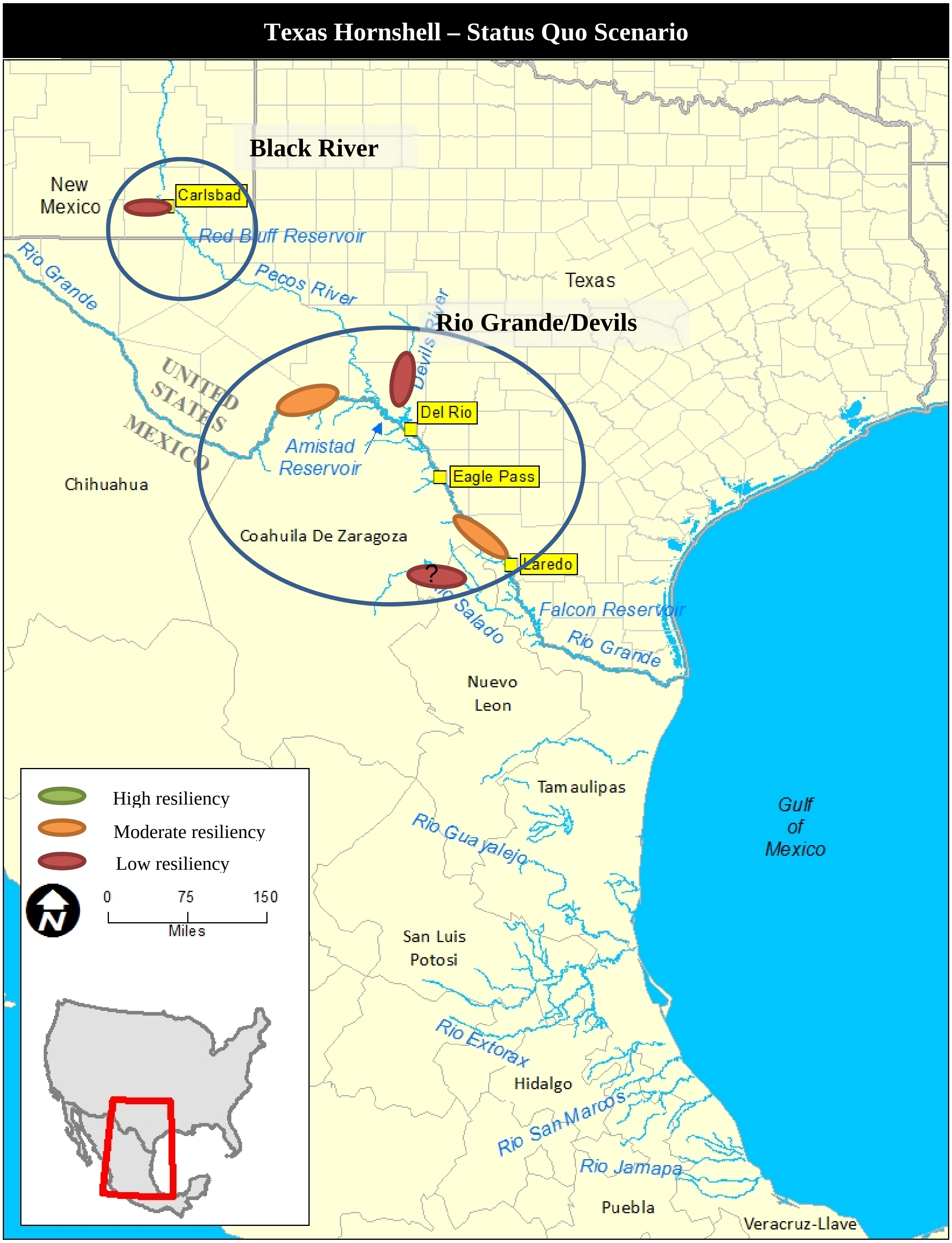

Figure 5.1. Resiliency, representation, and redundancy of Texas hornshell under the Status Quo scenario.

5.3. Scenario 2 – Conservation

Under the Conservation scenario, all populations retain their current condition, the Delaware River reintroduction is successful, and the CCA on the Black River is implemented and successful at maintaining and improving habitat quality (Table 5.3).

5.3.1. Resiliency

Black River – Under this scenario, the Black River population would not experience any contaminant spills or measurable decline in water availability. The population would maintain its current high density. Although the substrate in the Black River has a moderate level of fine sediment, enough cleansing flows continue to occur to maintain habitat availability for the species. Additionally, we expect under this scenario that the CCA that is currently under development would be fully implemented and successful, further maintaining flowing water availability, water quality, and substrate.

We do not expect under this scenario that the population would expand within the Black River, given the existence of diversion dams and higher salinity levels downstream. However, in the best case scenario we would expect the reintroduction of Texas hornshell to the Delaware River to be successful, which would result in increased resiliency of these populations. Overall, the Black River population's overall condition would be expected to be high.

Pecos River – Under the Conservation scenario, the Pecos River population continues to persist. Water flow does not decline and water quality does not cause extirpation of the population.

Devils River – Under the Conservation scenario, the Devils River would maintain flowing water conditions, and groundwater extraction and climate change would not result in reduced flows in the occupied reach of the river. The population would maintain low abundance in the currently occupied reach, and substrate and water quality would remain high. Overall, this population would be in moderate condition.

Rio Grande – Lower Canyons – The Rio Grande – Lower Canyons population would also not experience water flow reductions from Rio Conchos management, climate change, or reduced groundwater inputs under the Conservation scenario. Habitat quantity and all three habitat elements would retain their current condition, and while the population is not particularly dense, it would maintain abundance at moderate levels. Overall, the Rio Grande – Lower Canyons population would remain in high condition.

Rio Grande – Laredo – Under the Conservation scenario, the Rio Grande – Laredo population would maintain high abundance over a large area. Substrate and water quality would remain in moderate condition, with no contaminant spills, and the low-water weir would not be constructed. Water flow would not decline. Overall, the Rio Grande – Laredo population would remain in high condition.

The Conservation scenario provides an idea of the Texas hornshell's best plausible condition over the next 100 years (Figure 5.1). Other than the potential successful reintroduction into the

Delaware River – mussel reintroductions are notoriously challenging, although methods are improving (Haag and Williams 2014, p. 53) – this scenario presumes all populations are able to maintain or improve their current condition. Overall, there would be three populations in high condition, one in moderate condition, and one in low condition. Over the next 10 years, this scenario is somewhat likely to occur, but over time the probability of occurrence diminishes as we expect climate change to continue, thereby increasing the likelihood of drought and increased groundwater extraction. At midcentury and in 100 years the best case scenario has a low likelihood of occurrence due to climate change and groundwater extraction predictions (Loaiciga *et al.* 2000, p. 193; Taylor *et al.* 2012, p. 3; see **Appendix B, Loss of Flowing Water** for further discussion of water flow predictions).

Table 5.3. Texas hornshell population resiliency under scenario 1 – best case.

	Population Factors		Habitat Elements			
Population	**Habitat Quantity**	**Abundance**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall**
Black River	**Moderate**	**High**	**Moderate**	**High**	**High**	**High**
Pecos River	**Low**	**Low**	**?**	**Moderate**	**Low**	**Low**
Devils River	**Moderate**	**Low**	**High**	**Moderate**	**High**	**Moderate**
Rio Grande: Lower Canyons	**High**	**Moderate**	**Moderate**	**High**	**High**	**High**
Rio Grande: Laredo	**High**	**High**	**Moderate**	**High**	**Moderate**	**High**

5.3.2. Representation

As identified above, we consider the Texas hornshell to have representation in the form of genetic diversity in two areas: (1) the Black River population and (2) populations in the Rio Grande, Pecos River, and Devils River. Under the best case scenario, Texas hornshell representation is maintained (Figure 5.2). The species would retain populations in the two known representation areas. The genetic diversity present in each area would persist, and the species would maintain its adaptive capacity.

5.3.3. Redundancy

Within these identified representation areas, we then examined what redundancy would exist under the various scenarios. Under the best case scenario, Texas hornshell would exhibit maximum possible redundancy (Figure 5.2). The Black River would gain redundancy with the species' successful reintroduction into the Delaware River. The Rio Grande would maintain four populations.

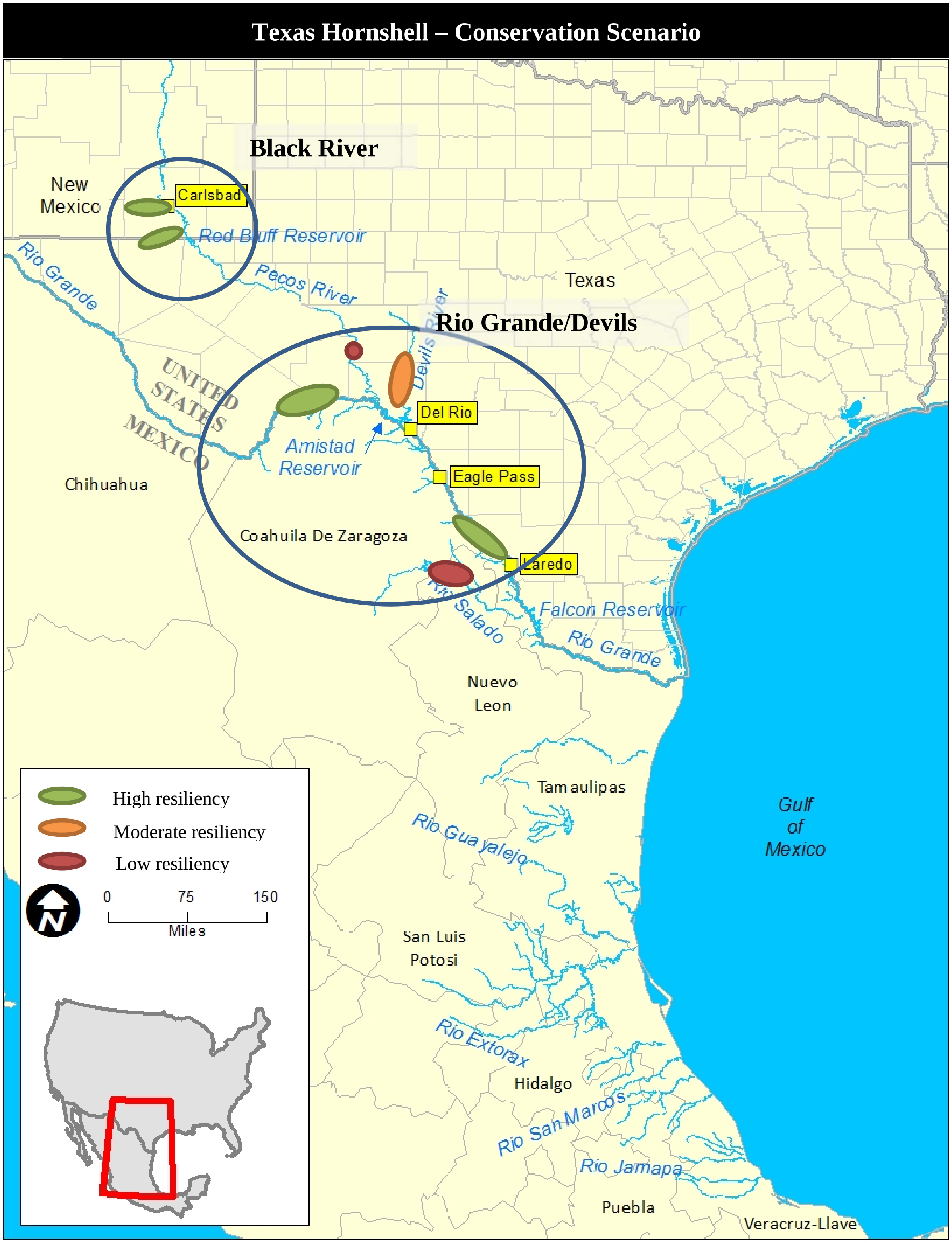

Figure 5.2. Resiliency, representation, and redundancy of Texas hornshell under the Conservation scenario.

5.4. Scenario 3 – Considerable Effects

Under the Considerable Effects scenario, some of the risks we have forecasted would occur. In general we selected those risks that are most likely to occur, although some risks are challenging to predict. In this scenario, there is a small to moderate water flow reduction for the populations in the Black River, Devils River, and Rio Grande – Lower Canyons, the Pecos River would experience a decline in water quality, and the low-water weir would be constructed at the Rio Grande – Laredo population (Table 5.4).

5.4.1. Resiliency

Black River – In the Considerable Effects scenario, the Black River population experiences a small to moderate water flow reduction due to water extraction and drought due to climate change. The reduction in water flow would result in fewer cleansing flows, and so fine sediments would accumulate in the crevices occupied by Texas hornshell, reducing the amount of suitable locations for the species and affecting substrate quality. The distribution of Texas hornshell in the Black River would remain small. However, given the overall high density of the species in the Black River currently, the population would remain in moderate condition overall, under a moderate water reduction scenario.

Pecos River – Under the Considerable Effects scenario, the population in the Pecos River experiences water quality decline from reduced water flow and the resultant decreases in water quality, including increased salinity and temperature. The small population would be extirpated from the effects of poor water quality.

Devils River – Under the Considerable Effects scenario, the Devils River would experience a reduction in flow due to groundwater extraction and drought, as a result of climate change. The low flows this population experiences during dry times would become more frequent and prolonged. Because Texas hornshell in the Devils River occur at the heads of riffles, they are vulnerable to complete flow loss when water levels drop. The reduction in cleansing flows would result in the accumulation of fine sediments, reducing substrate quality. Low flows would also affect water quality parameters such as temperature and dissolved oxygen. Additionally, the species is already vulnerable to predation from terrestrial predators during times of low flow; predation would occur more frequently. Overall, because the population is currently small and would be unlikely to grow, the Devils River population would be in low condition and would be vulnerable to extirpation.

Rio Grande – Lower Canyons – Under the Considerable Effects scenario, the Rio Grande – Lower Canyons population would experience a small to moderate reduction in flow due to groundwater extraction or drought as a result of climate change, and management of the Rio Conchos would not provide reliable water. This section of the Rio Grande is relatively deep and incised, and the population of Texas hornshell in this reach primarily occurs in crevices along the banks. Water flow reductions would expose a high proportion of the existing population; therefore, this reduction in flow would likely have a larger effect on the population size than in other populations – although at a small to moderate decrease in water flow we still expect abundance to be maintained at moderate levels. Overall, we expect the Rio Grande – Lower Canyons population would be in moderate condition in this scenario, due to the population's moderate abundance combined with a reduction in flow.

Rio Grande – Laredo – In the Considerable Effects scenario, the low-water weir is constructed at the downstream extent of the Rio Grande – Laredo population. Water quality would be maintained at its current moderate level. This population would not experience a reduction in water flow. The construction of the weir would eliminate Texas hornshell from at least the lowest 14 mi (22.5 km) of the reach due to inundation. The Rio Grande – Laredo reach contains the largest known population of Texas hornshell (Karatayev *et al.* 2015, p. 4), and the species is known to be quite abundant in rocky habitats within the inundation zone of the weir (Randklev *et al.* 2015, p. 7). If the weir were constructed, habitat quantity would be reduced by at least 25% and fall into the moderate category. We expect abundance would be moderate at best in occupied areas, since the densest portion of the population would be eliminated. Overall, this population would be in moderate condition if the weir were constructed.

The Considerable Effects scenario provides a reasonably likely snapshot of the Texas hornshell's condition over the next 100 years. Overall, there would be three populations in moderate condition and one in low condition. Over the next 10 years, this scenario has a low likelihood of occurrence, but at midcentury it is moderately likely to occur, and in 100 years it is very likely to occur due to climate change and groundwater extraction predictions (Loaiciga *et al.* 2000, p. 193; Taylor *et al.* 2012, p. 3; see **Appendix B, Loss of Flowing Water** for further discussion of water flow predictions).

Table 5.4. Texas hornshell population resiliency under scenario 3 – Considerable Effects.

	Population Factors		Habitat Elements			
Population	**Habitat Quantity**	**Abundance**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall**
Black River	Low	Moderate	Moderate	Moderate	High	Moderate
Pecos River	Ø	Ø	?	Low	Low	Ø
Devils River	Low	Low	Moderate	Low	Moderate	Low
Rio Grande: Lower Canyons	High	Moderate	Moderate	Moderate	High	Moderate
Rio Grande: Laredo	Moderate	Moderate	Moderate	High	Moderate	Moderate

5.4.2. Representation

In the Considerable Effects scenario, the current level of representation in the U.S. may be maintained, although the Black River population would remain small and relatively vulnerable to extirpation and therefore there is a possibility of loss of that area of representation. Overall representation could be similar to current levels or could be reduced (Figure 5.3).

5.4.3. Redundancy

Under the Considerable Effects scenario, redundancy would be generally maintained, although the Black River area would remain small with no redundancy, and relatively vulnerable to extirpation. The Rio Grande area would lose redundancy with extirpation of the Pecos River population and potential extirpation of the Devils River population (Figure 5.3).

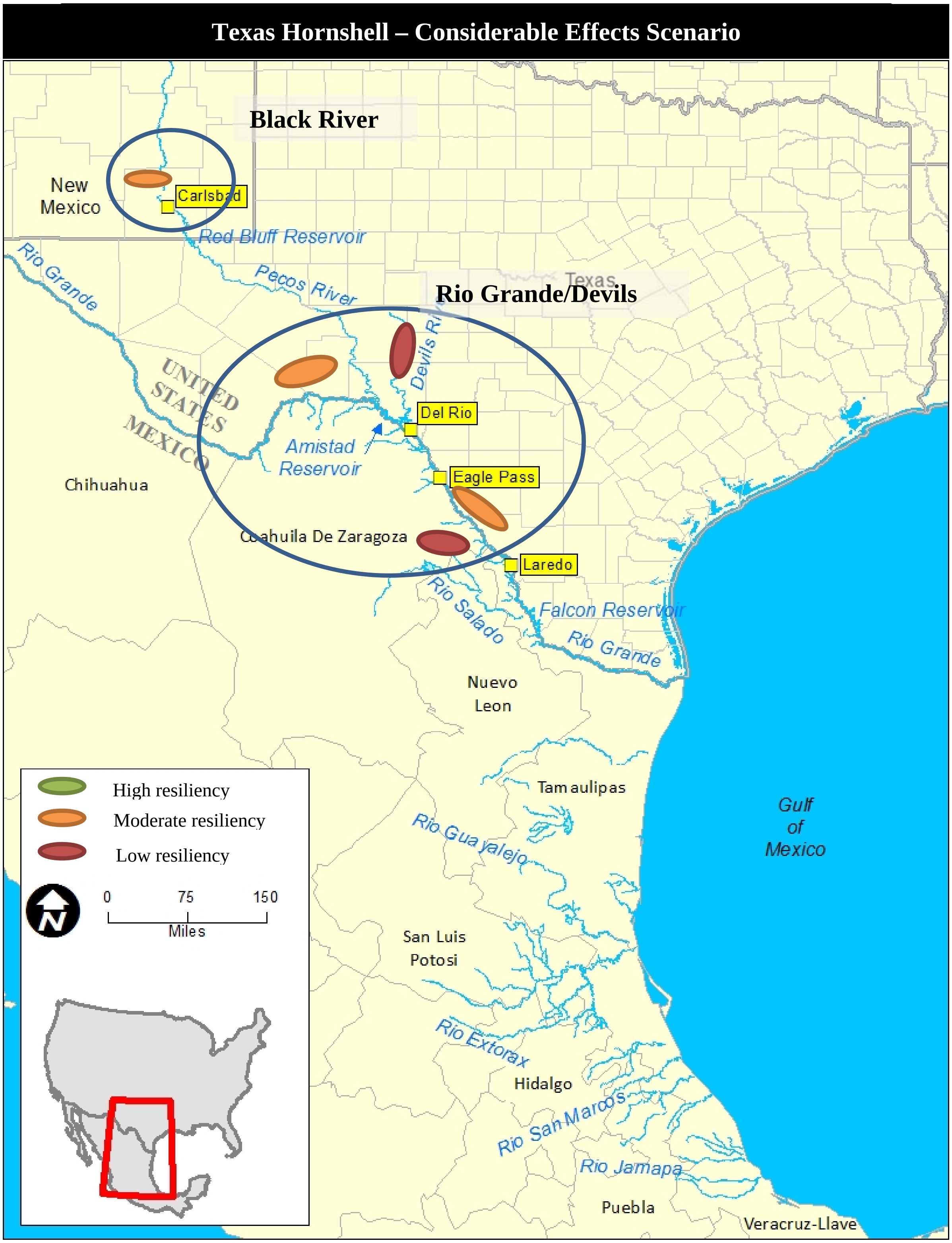

Figure 5.3. Resiliency, representation, and redundancy of Texas hornshell under the Considerable Effects scenario.

5.5 Scenario 4 – Major Effects

Under the Major Effects scenario, some of the risks we have forecasted would occur. In this scenario, there is a large water flow reduction for the population in the Black River, the Devils River, and Rio Grande – Lower Canyons populations experience a small to moderate water flow reduction, the Pecos River population experiences a decline in water quality, and the low-water weir would be constructed at the Rio Grande – Laredo population (Table 5.4).

5.5.1. Resiliency

Black River – Under the Major Effects scenario, the Black River would experience a moderate to large reduction in water flow due to a large amount of groundwater extraction, in combination with increased drought as a result of climate change. This water flow reduction would decrease the frequency and duration of cleansing flows that would maintain substrate suitability for Texas hornshell, and many bank habitats currently occupied by Texas hornshell would be exposed. Under the Major Effects scenario we would expect the population in the Black River to be in low condition with a potential for extirpation.

Pecos River – Under the Major Effects scenario, the population in the Pecos River experiences water quality decline from reduced water flow and the resultant decreases in water quality, including increased salinity and temperature. The small population would be extirpated from the effects of poor water quality.

Devils River – Under the Major Effects scenario, the Devils River would experience a reduction in flow due to groundwater extraction and drought, as a result of climate change. The low flows this population experiences during dry times would become more frequent and prolonged. Because Texas hornshell in the Devils River occur at the heads of riffles, they are vulnerable to complete flow loss when water levels drop. The reduction in cleansing flows would result in the accumulation of fine sediments, reducing substrate quality. Low flows would also affect water quality parameters such as temperature and dissolved oxygen. Additionally, the species is already vulnerable to predation from terrestrial predators during times of low flow; predation would occur more frequently. Overall, because the population is currently small and would be unlikely to grow, the Devils River population would be in low condition and would be highly vulnerable to extirpation.

Rio Grande – Lower Canyons – Under the Major Effects scenario, the Rio Grande – Lower Canyons population would experience a small to moderate reduction in flow due to groundwater extraction or drought as a result of climate change, and management of the Rio Conchos would not provide reliable water. This section of the Rio Grande is relatively deep and incised, and the population of Texas hornshell in this reach primarily occurs in crevices along the banks. Water flow reductions would expose a high proportion of the existing population; therefore, this reduction in flow would likely have a larger effect on the population size than in other populations – although at a small to moderate decrease in water flow we still expect abundance to be maintained at moderate levels. Overall, we expect the Rio Grande – Lower Canyons population would be in moderate condition in this scenario, due to the population's moderate abundance combined with a reduction in flow.

Rio Grande – Laredo – In the Major Effects scenario, the low-water weir would not be constructed, but water flow would decline due to upstream water management and drought due to climate change. This declining water flow would decrease water quality and therefore population abundance. Overall, the Rio Grande – Laredo population would be in moderate condition.

The Major Effects scenario provides a snapshot of the Texas hornshell's condition over the next 100 years. Overall, there would be two populations in moderate condition and two in low condition in the U.S. Two populations along the Gulf Coast of Mexico, plus one in the Rio Salado, would be in low condition. Over the next 10 years, this scenario has a low likelihood of occurrence, but at midcentury it is somewhat likely to occur, and in 100 years it is moderately likely to occur due to climate change and groundwater extraction predictions (Loaiciga *et al.* 2000, p. 193; Taylor *et al.* 2012, p. 3; see **Appendix B, Loss of Flowing Water** for further discussion of water flow predictions).

Table 5.5. Texas hornshell population resiliency under scenario 4 – Major Effects.

	Population Factors		**Habitat Elements**			
Population	**Habitat Quantity**	**Abundance**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall**
Black River	Low	Low	Low	Low	Moderate	Low
Pecos River	Ø	Ø	?	Low	Low	Ø
Devils River	Low	Low	Moderate	Low	Moderate	Low
Rio Grande: Lower Canyons	High	Moderate	Moderate	Moderate	High	Moderate
Rio Grande: Laredo	High	Moderate	Moderate	Moderate	Moderate	Moderate

5.5.2. Representation

In the Major Effects scenario, the current level of representation in the U.S. may be maintained, although the Black River population would remain small and relatively vulnerable to extirpation and therefore there is a possibility of loss of that area of representation. Overall representation could be similar to current levels or could be reduced (Figure 5.4).

5.5.3. Redundancy

Under the Major Effects scenario, redundancy would be reduced, as the Black River area would remain small with no redundancy, and relatively vulnerable to extirpation. The Rio Grande area would lose redundancy with extirpation of the Pecos River population and potential extirpation of the Devils River population (Figure 5.4).

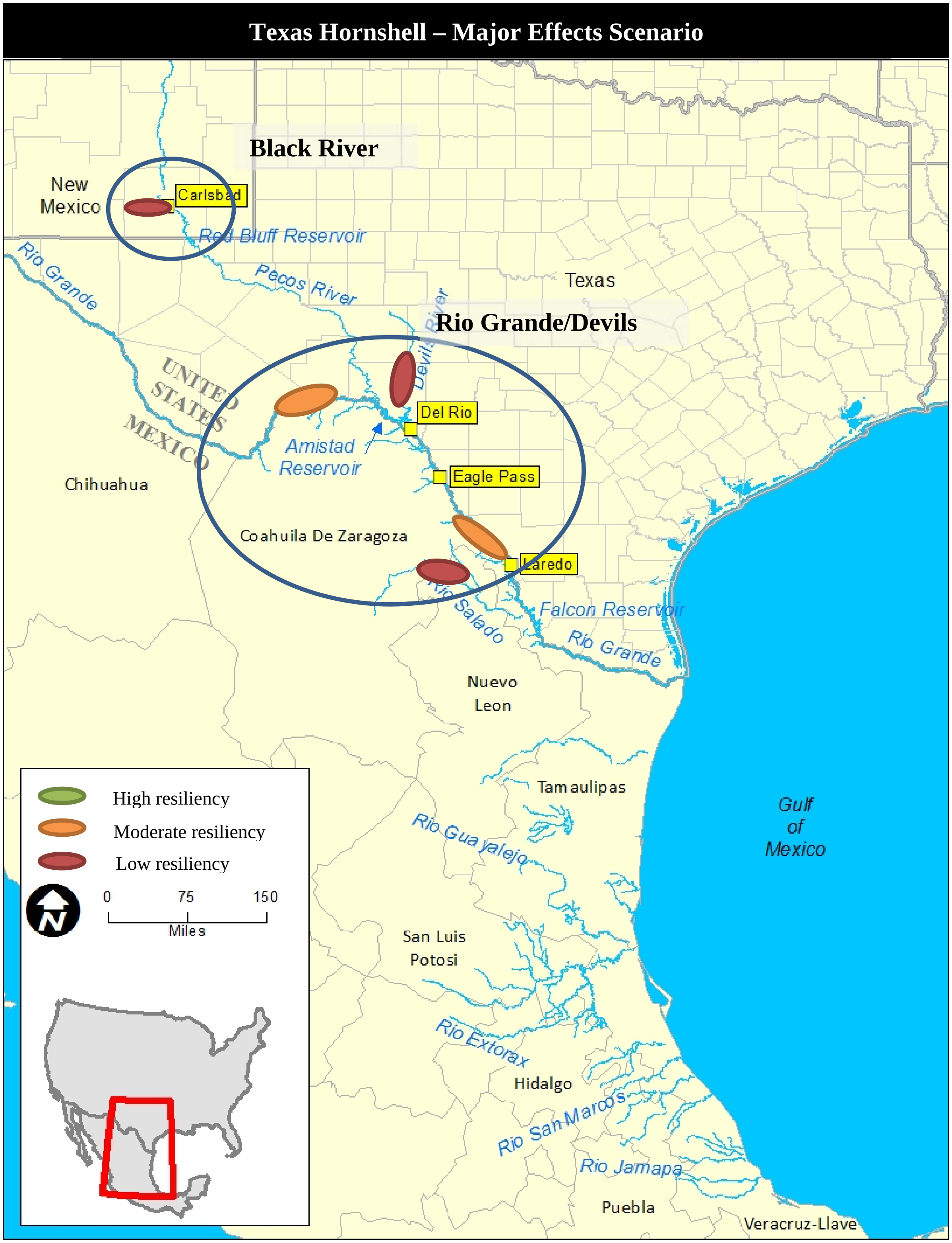

Figure 5.4. Resiliency, representation, and redundancy of Texas hornshell under the Major Effects scenario.

5.6. Scenario 5 – Severe Effects

In the Severe Effects scenario, the Black River, Devils River, and Rio Grande – Lower Canyons populations would experience a moderate to large reduction in water flow due to groundwater extraction and drought (Table 5.6). Additionally, the risk of a contaminant spill on the Black River remains high, and the Pecos River and Rio Grande – Laredo populations would experience a decline in water quality either due to a spill or from non-point sources. The low-water weir would be constructed at the lower extent of the Rio Grande – Laredo population.

5.6.1. Resiliency

Black River – Under the Severe Effects scenario, the Black River would experience a moderate to large reduction in water flow due to groundwater extraction and climate change. This would reduce the frequency and duration of cleansing flows that would maintain substrate suitability for Texas hornshell, and many bank habitats currently occupied by Texas hornshell would be exposed. Additionally, because the risk of a contaminants spill remains high, we expect that if a spill occurred at one of the low water crossings the resulting contamination would likely severely reduce or eliminate Texas hornshell downstream of the spill site. If this occurred at the upstream extent of the population, the entire population could be eliminated. Under the Severe Effects scenario we would expect the population in the Black River to be in low condition with a potential for extirpation.

Pecos River – Under the Severe Effects scenario, the population in the Pecos River experiences water quality decline from reduced water flow and the resultant decreases in water quality, including increased salinity and temperature. The small population would be extirpated from the effects of poor water quality.

Devils River – Under the Severe Effects scenario, groundwater extraction and drought due to climate change lead to very reduced water levels in the Devils River. Habitats occupied by Texas hornshell would likely be eliminated due to lack of water, or the reduction in frequency and duration of cleansing flows would result in a loss of crevices available to the species. Water quality would decline due to the effects of low water levels. Predation from terrestrial predators would increase. Because the population is currently quite small, we expect the population in the Devils River would be extirpated under the worst case scenario.

Rio Grande – Lower Canyons – Under the Severe Effects scenario, the Rio Grande – Lower Canyons population would experience a moderate to large reduction in water flow due to groundwater extraction and climate change. With a large reduction in water flow, many bank habitats inhabited by Texas hornshell would be exposed; therefore, habitat quantity would decrease to no higher than moderate. Water quality would likely be moderate, as the river in this section would likely become isolated pools as the shallow riffles and runs between pools would have extremely low water or would be dry. The reduction in frequency and duration of cleansing flows would result in a reduction of suitable substrate for the species. Overall, under the Severe Effects scenario the Rio Grande – Lower Canyons population would be in moderate condition.

Rio Grande – Laredo – Under the Severe Effects scenario, the Rio Grande – Laredo population would experience a drop in water quality from point and/or non-point sources. Additionally, the low-water weir would be constructed at the downstream extent of the population. Due to weir construction, the lower 14 mi (22.5 km) of the occupied reach would be unsuitable due to inundation, and the remaining population would decline due to diminished water quality. Substrate would remain in moderate condition, and water flow would be unlikely to be reduced significantly. Overall, under the worst case scenario the Rio Grande – Laredo population would be in low condition.

The Severe Effects scenario provides an idea of the Texas hornshell's worst plausible condition over the next 100 years. This scenario displays what could occur if all of the projected risks were to occur. Under this scenario, one population would be in moderate condition and three in low condition. Over the next 10 years, this scenario has a low likelihood of occurrence, but at midcentury it is somewhat likely to occur, and in 100 years it is moderately likely to occur due to climate change and groundwater extraction predictions (Loaiciga *et al.* 2000, p. 193; Taylor *et al.* 2012, p. 3; see **Appendix B, Loss of Flowing Water** for further discussion of water flow predictions).

Table 5.6. Texas hornshell population resiliency under scenario 5 – Severe Effects.

	Population Factors		Habitat Elements			
Population	**Habitat Quantity**	**Abundance**	**Substrate**	**Flowing Water**	**Water Quality**	**Overall**
Black River	Low	Low	Low	Moderate	Low	Low
Pecos River	Ø	Ø	?	Low	Low	Ø
Devils River	Low	Low	Low	Low	Moderate	Ø
Rio Grande: Lower Canyons	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Rio Grande: Laredo	Moderate	Low	Moderate	High	Low	Low

5.6.2. Representation

In the Severe Effects scenario, we would expect representation to be maintained only in the Rio Grande representation area. We project that the Devils River and Pecos River populations would be extirpated, and the Black River and Rio Grande – Laredo populations would be at high risk of extirpation. Representation would be much reduced from current levels (Figure 5.5).

5.6.3. Redundancy

Under the Severe Effects scenario the species would have very little redundancy overall. The Black River population would be either very small or extirpated. In the Rio Grande, the Devils River and Pecos River populations would be extirpated, and the Rio Grande – Laredo population would either be extirpated or small. There would essentially be no redundancy in the Rio Grande as the Rio Grande – Lower Canyons population is the only one we would expect to persist.

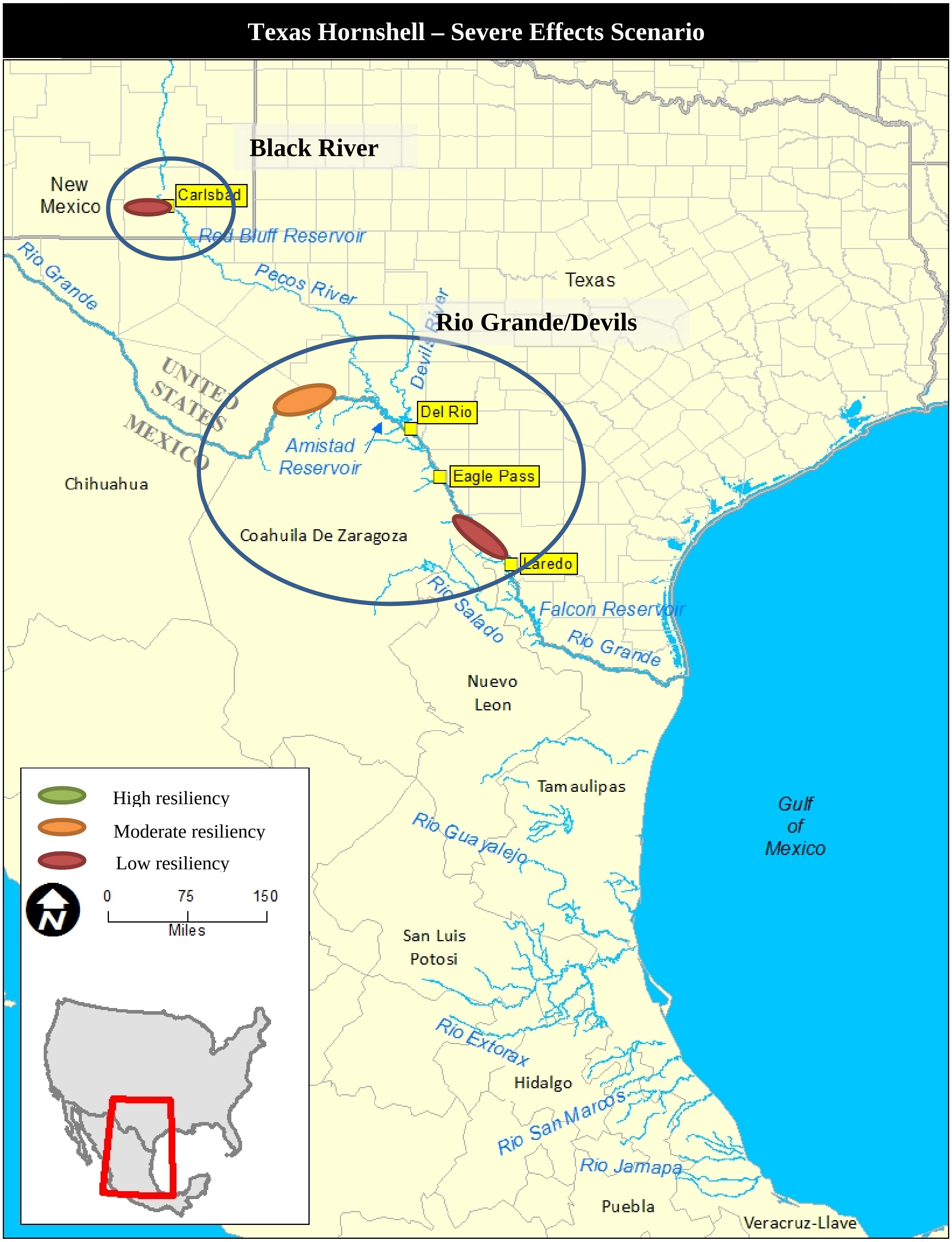

Figure 5.5. Resiliency, representation, and redundancy of Texas hornshell under the Severe Effects scenario.

5.5. Status Assessment Summary

We used the best available information to forecast the likely future condition of the Texas hornshell. Our goal was to describe the viability of the species in a manner that will address the needs of the species in terms of resiliency, representation, and redundancy. We considered the possible future condition of the species. We considered a range of potential scenarios that we think are important influences on the status of the species. Our results describe a range of possible conditions in terms of how many and where Texas hornshell populations are likely to persist into the future (Table 5.7).

Table 5.7. Texas hornshell population conditions under each scenario.

	Population Condition				
Population	**Scenario 1 – Status Quo**	**Scenario 2 – Conservation**	**Scenario 3 – Considerable Effects**	**Scenario 4 – Major Effects**	**Scenario 5 – Severe Effects**
Black River	**Low**	**High**	**Moderate**	**Low**	**Low**
Pecos River	**Ø**	**Low**	**Ø**	**Ø**	**Ø**
Devils River	**Low**	**Moderate**	**Low**	**Low**	**Ø**
Rio Grande: Lower Canyons	**Moderate**	**High**	**Moderate**	**Moderate**	**Moderate**
Rio Grande: Laredo	**Moderate**	**High**	**Moderate**	**Moderate**	**Low**
Likelihood of Scenario Occurring at:					
10 years	Moderately likely	Somewhat likely	Unlikely	Unlikely	Unlikely
50 years	Very likely	Unlikely	Moderately likely	Somewhat likely	Somewhat likely
100 years	Somewhat likely	Unlikely	Very likely	Moderately likely	Moderately likely

Texas hornshell face a variety of risks from loss of stream flow, contamination, and inundation. These risks play a large role in the future viability of the Texas hornshell. If populations lose resiliency, they are more vulnerable to extirpation, with resulting losses in representation and redundancy.

Under scenario 1 – Status Quo, we would expect the Texas hornshell's viability to be characterized by a loss of resiliency, representation, and redundancy. No populations would be in high condition, two would be in moderate, and the rest would be extirpated or in low condition. Representation would be at high risk of being lost in the Black river area.

Under scenario 2 – Conservation, we would expect the Texas hornshell's viability to be characterized by higher levels of resiliency, representation, and redundancy than it exhibits under the current condition. Three populations would be in high condition, one in moderate, and one in low condition. We anticipate all of the current populations to persist and perhaps even experience range expansion.

Under scenario 3 – Considerable Effects, we would expect the Texas hornshell's viability to be characterized by lower levels of resiliency, representation, and redundancy than it has currently. Three populations would be in moderate condition and one would be in low condition; those in low condition could be extirpated. Therefore, we would expect only two populations would persist under somewhat adverse conditions.

Under scenario 4 – Major Effects, we would expect the Texas hornshell's viability to be characterized by lower levels of resiliency, representation, and redundancy than it has currently. Two populations would be in moderate condition and two would be in low condition; those in low condition could be extirpated. Therefore, we would expect only two populations would persist under somewhat adverse conditions.

Under scenario 5 – Severe Effects, we would expect the Texas hornshell's viability to be characterized by additional substantial losses of resiliency, representation, and redundancy. We would only expect one population to persist in moderate condition, which means it would have less resiliency and may not persist beyond 100 years.

APPENDIX A

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APPENDIX B

Evaluating Causes and Effects for Texas Hornshell Species Status Assessment

This table of Confidence Terminologies explains what we mean when we characterize our confidence levels in the cause and effects tables on the following pages.

Confidence Terminology	Explanation
Highly Confident	We are more than **90% sure** that this relationship or assumption accurately reflects the reality in the wild as supported by documented accounts or research and/or strongly consistent with accepted conservation biology principles.
Moderately Confident	We are **70 to 90% sure** that this relationship or assumption accurately reflects the reality in the wild as supported by some available information and/or consistent with accepted conservation biology principles.
Somewhat Confident	We are **50 to 70% sure** that this relationship or assumption accurately reflects the reality in the wild as supported by some available information and/or consistent with accepted conservation biology principles.
Low Confidence	We are less than **50% sure** that this relationship or assumption accurately reflects the reality in the wild, as there is little or no supporting available information and/or uncertainty consistency with accepted conservation biology principles. Indicates areas of high uncertainty.

THEME: Increased fine sediment			
[ESA Factor(s): A,E]	**Analysis**	Confidence / Uncertainty	Supporting Information
SOURCE(S)	***Decreased streamflow** from reduced precipitation, groundwater extraction, and reservoir releases ***Decreased stream velocities** from reduced streamflow and impoundments. As water velocity decreases, water loses its ability to carry sediment; which falls to the substrate. ***Additional inputs of sediment** from streambank erosion from activities in the watershed such as grazing, roads, and oil and gas development.	**Highly** confident that these are the primary sources of sedimentation for Texas hornshell populations	Milhous 1998, p. 79 Brim Box and Mossa 1999, p. 100 Watters 2000, p. 263
- Activity(ies)	In the range of Texas hornshell, these activities include irrigation, water extraction for municipal use and oil and gas activities, grazing, and roads, among others.		
STRESSOR(S)	Siltation and general sediment runoff is a pervasive problem in streams and has been implicated in the decline of stream mussel populations. Specific biological effects on Texas hornshell from excessive sediment include smothering of adults and juveniles, complete loss of habitat through sedimentation of the crevices inhabited by the species, reduced juvenile habitat, and increased substrate instability. Interstitial spaces (small openings between rocks and gravels) in the substrate provide essential habitat for juvenile mussels. Fine sediments can lodge between coarser grains of the substrate to form a hardpan layer. When clogged with sand or silt, interstitial flow rates and spaces may become reduced, thus reducing juvenile habitat availability and oxygen permeability. Juvenile freshwater mussels, including Texas hornshell juveniles, burrow into interstitial substrates, making it particularly susceptible to degradation of this habitat feature.	**High** confidence in the relationship between siltation and freshwater mussels, in general. **Moderately** confident that these effects apply equally to Texas hornshell. **High** confidence that crevices filled in with sediment are not suitable habitat for Texas hornshell.	Sparks and Strayer 1998, p. 129 Brim Box and Mossa 1999, pp. 99, 100 Fraley and Ahlstedt 2000, pp. 193–194 Carmen 2007, p. 20
- Affected Resource(s)	Juveniles and adults.		

THEME: Increased fine sediment			
[ESA Factor(s): A,E]	**Analysis**	Confidence / Uncertainty	Supporting Information
- Exposure of Stressor(s)	Under natural conditions, fine sediments collect on the streambed and in crevices during low flow events, and they are washed downstream during high flow events (also known as cleansing flows). However, the increased frequency of low flow events (from groundwater extraction, surface flow diversions, and drought) combined with a decrease in cleansing flows (from reservoir management and drought) has caused sediment to accumulate to some degree at all populations. In the Black River, grazing and oil and gas activities in the watershed has led to additional sources of fine sediments, which are scoured during high flow events and deposited as high flows recede. Texas hornshell have been eliminated from two beds in the Black River; these extirpations have been attributed to channel scouring, sediment loading, and resulting sediment deposition from frequent large-volume flood events in 2000 and 2009. For the Rio Grande and Devils River populations, low flow and reduction or elimination of spring flow in the region have been reported for decades. These locations experience fine sediment accumulation as a function of low water flow rather than from increased sediment inputs. In the Rio Grande, dams at Elephant Butte, New Mexico, and on the Conchos River have reduced the number and duration of cleansing flows, such that the channel has aggraded and incised. Currently, the Black River and Rio Grande - Laredo populations are experiencing fine sediment accumulation to a degree that substrate quality is affected.	**High** confidence in the effects of sedimentation on freshwater mussels.	Garrett et al 1992, p. 259 Milhous 1998, p. 79 Carman 2007, p. 20 Dean and Schmidt 2011, pp. 12-13 Lang 2010, p. 8 Bren School of Environmental Management 2014, p. 114 Inoue et al 2014, p. 9

THEME: Increased fine sediment			
[ESA Factor(s): A,E]	**Analysis**	Confidence / Uncertainty	Supporting Information
- Immediacy of Stressor(s)	**Historical:** The Devils River and Black River experienced overgrazing in the past, which was a source of excessive sedimentation. The construction of dams on the Rio Grande and Conchos River in the 1910s reduced the frequency and duration of flood pulses in the Rio Grande, such that the channel has aggraded and incised. **Current:** Oil and gas activities and grazing are ongoing in the Black River watershed. This combined with reduced cleansing flows has resulted in the accumulation of fine sediments. All populations are experiencing reduced flood frequency and duration from drought (exacerbated by climate change; see 3. Loss of Flowing Water for more information about climate change in this region). Grazing is no longer occurring in the Devils River watershed and the overall watershed health is good, resulting in low levels of fine sediment accumulation. **Future:** We expect lower flows to occur more often at all populations and for longer periods due to climate change. Grazing and oil and gas development are expected to continue on the Black River. Overall, we expect fine sediment to increase at all locations under most conditions.	**Historic: Highly confident** **Current: Highly confident** **Future: Moderately confident** that climate change will reduce the frequency and duration of cleansing flows.	The Nature Conservancy 2004, p. 24 Dean and Schmidt 2011, p. 4 Bren School of Environmental Management 2014, p. 114 Inoue et al 2014, p. 9 National Park Service 2016, p. 2
Changes in Resource(s)	Substrate suitability for juvenile and adult Texas hornshell		
Response to Stressors: **- INDIVIDUALS**	Specific impacts on juvenile and adult mussels from silt and sediments include clogged gills, which reduce feeding and respiratory efficiency, impair reproductive activity, disrupt metabolic processes, and reduce growth rates; and the physical smothering of mussels under a blanket of silt.	**High** confidence	Sparks and Strayer 1998, p. 129 Brim Box and Mossa 1999, pp. 99, 100
POPULATION & SPECIES RESPONSES			
Effects of Stressors: **- POPULATIONS [RESILIENCY]**	Some levels of sedimentation may be tolerated by Texas hornshell, as the rivers inhabited by the species are relatively turbid and silt-laden. However, when enough sediment is deposited into the cracks and crevices in which Texas hornshell are found, they become smothered and die. If this occurs over a long enough time and over enough of the inhabited reach, resiliency would be reduced.	**Moderately confident**	

THEME: Increased fine sediment			
[ESA Factor(s): A,E]	**Analysis**	Confidence / Uncertainty	Supporting Information
- SCOPE	Elimination of Texas hornshell from mussel beds due to large amounts of sediment deposition has been documented on the Black River in two locations in recent years. In the future, we expect this may continue to occur sporadically. Low water levels on the Devils River will likely lead to additional sediment accumulation at this population, as well.	**Moderately confident**	Carman 2007, p. 20 Lang 2010, p. 8

THEME: Changes in water quality			
[ESA Factor(s): A,E]	**Analysis**	Confidence / Uncertainty	Supporting Information
SOURCE(S)	Changes in water quality parameters such as dissolved oxygen, salinity, increased temperature, and contaminants. Sources of these changes include: **Low dissolved oxygen:** Slow moving, warm water generally has low dissolved oxygen levels relative to the needs of the species. Additionally, high amounts of nutrients, such as nitrogen and phosphorus, in streams can stimulate excessive plant growth (algae and periphyton, among others), which in turn can reduce dissolved oxygen levels when dead plant material decomposes. **Salinity:** Increased evapotranspiration associated with irrigated agriculture and saline water intrusion into the aquifer. Aquifers have become increasingly saline due to salinized water recharge. **Increased temperature:** Drought and increased air temperature due to climate change **Contaminants:** Point sources, such as spills and wastewater treatment plants, and non-point sources, such as agriculture. These sources contribute organic compounds, heavy metals, pesticides, herbicides, and a wide variety of newly emerging contaminants to the aquatic environment. Sources of ammonia include agricultural activities (animal feedlots and nitrogenous fertilizers), municipal wastewater treatment plants, and industrial waste, as well as precipitation and natural processes (decomposition of organic nitrogen). In the Black River, as of 2014 there were 179 oil and gas wells in the basin, and they are a potential source of contaminants if a spill occurs, either at a well pad or a road crossing. Trucks carrying produced brine water and petroleum products cross these low water crossings multiple times daily.	**High** confidence	Augsperger et al. 2003, p. 2569 Newton 2003, p, 2543 Miyamoto et al 2006, p. 3 Augsperger et al. 2007, pp. 2025, 2026 Carman 2007, p. 23 Hoagstrom 2009, pp. 28, 33, 35 Mantua et al 2010, p. 196 Lang 2011, p. 19 Bren School of Environmental Management 2014, pp. 74, 114
- Activity(ies)	**Low dissolved oxygen:** wastewater discharge, groundwater extraction, climate change **Salinity:** Irrigation, groundwater extraction, climate change **Increased temperature:** Groundwater extraction, climate change **Contaminants:** Spills, industrial sources, municipal effluents, and agriculture runoff. Ammonia may be particularly high downstream of wastewater treatment plant discharges.	**High** confidence	Augsperger et al. 2003, p. 2569 Strayer et al 2004, p. 436 Mace and Wade 2008, p. 656 Hoagstrom 2009, pp. 28, 33, 35 Mantua et al 2010, p. 196

THEME: Changes in water quality			
[ESA Factor(s): A,E]	**Analysis**	Confidence / Uncertainty	Supporting Information
STRESSOR(S)	**Low dissolved oxygen:** Juveniles are particularly susceptible to low dissolved oxygen levels, although adult metabolism levels are lower in areas of lower dissolved oxygen. Juveniles will reduce feeding behavior between 2 - 4 mg/L, and mortality has been shown to occur at levels below 1.3 mg/L. **Salinity**: Texas hornshell cannot tolerate salinity levels of 7 ppt for more than short periods of time. Juvenile mussels of other species have been shown to experience complete mortality after 7 days at levels greater than 4 ppt. **Increased temperature:** Glochidial release may be associated with water temperature; increased stream temperature may cause the timing of release to change. Depending the degree of change in temperature, this could cause species/host interactions to be out of sync. However, mussel species can have very different reactions to increased temperature depending on their thermal tolerance; Texas hornshell is likely a thermally tolerant species, given its southern distribution and occurrence in streams with temperatures higher than streams inhabited by most other mussel species. A water temperature increase of several degrees appears unlikely to affect the species on its own. Instead, increased water temperature can exacerbate other water quality problems, such as the effects of contaminants. **Chemical contaminants:** The release of pollutants into streams from point and nonpoint sources have immediate impacts on water quality conditions and may make environments unsuitable for habitation by mussels. Early life stages of freshwater mussels are some of the most sensitive organisms of all species to ammonia and copper, with mortality occurring at levels lower than current EPA criteria. Additionally, sublethal effects of contaminants over time can result in reduced filtration efficiency, reduced growth, decreased reproduction, changes in enzyme activity, and behavioral changes to all mussel life stages. Even wastewater discharges with low ammonia levels have been shown to negatively affect mussel populations.	**Moderately** confident	Naimo 1995, pp. 351–352 Sparks and Strayer 1998, pp. 129, 132 Watters and O'Dee 2000, p. 136 Blakeslee et al 2013, p. 2851 Strayer et al. 2004, p. 436 Cherry et al. 2005, p. 378 Augsperger et al 2007, p. 2025 Spooner and Vaughn 2008, p. 313 Gillis et al 2010, p. 2519 Gillis 2012, p. 354 Gillis et al 2014, p. 3
- Affected Resource(s)	Water quality		

THEME: Changes in water quality			
[ESA Factor(s): A,E]	**Analysis**	Confidence / Uncertainty	Supporting Information
- Exposure of Stressor(s)	**Low Dissolved Oxygen:** The Devils River population experiences low water levels fairly regularly during dry times of the year, and any Texas hornshell found in pools with little flow likely experience low dissolved oxygen, as well. Additionally, there are several wastewater treatment plants on the Rio Grande. Increased nutrients cause increased productivity and result in decreased dissolved oxygen. **Salinity:** On the lower Black River, salinized irrigation return flows have increased salinity of this portion of the river. Within the occupied area of the Black River, salinity is about 0.9 ppt, but increases significantly downstream of the Carlsbad Irrigation District Dam near the confluence with the Pecos River to 2.8 ppt. Additionally, salinity levels in the Pecos River downstream of the Black River confluence range from 6.0-7.0 ppt. Salinity is expected to be a primary reason the species has been extirpated from the majority of the Pecos River. The Rio Grande has also experienced increases in salinity, as well. **Increased temperature:** Stream temperatures across the range of the Texas hornshell are expected to increase by several degrees Celsius due to climate change. See 3. Loss of Flowing Water for a more detailed discussion of the effects of climate change in this region. **Contaminants:** Ammonia is particularly toxic to mussels, and highest concentrations typically occur in mussel microhabitats, increasing their likelihood of exposure. The Rio Grande is known for contaminant concerns, and downstream of the Laredo population has been noted as having high levels of a suite of chemical contaminants, and the reach near Eagle Pass has had high ammonia levels. The numerous point and non-point sources on the Rio Grande means this is a continuing concern. In the Black and Delaware Rivers, the amount of traffic from oil and gas production has already led to a spill of produced water on the Delaware River.	**Moderately** confident	Howells 2001b, p. 47 Lang 2001, p. 23 Augsperger et al. 2003, p. 2574 Mace and Wade 2008, p. 656 Hoagstrom 2009, p. 28 TCEQ 2013, p. 3

THEME: Changes in water quality			
[ESA Factor(s): A,E]	**Analysis**	Confidence / Uncertainty	Supporting Information
- Immediacy of Stressor(s)	**Low dissolved oxygen:** We expect this to be occurring occasionally currently, and for the incidence to increase as climate change causes lower water levels. Low dissolved oxygen levels were detected in the Rio Grande near Eagle Pass and Del Rio in 2013. There are no known dissolved oxygen concerns in the Devils River. **Salinity:** Salt intrusion is historically known to occur on the Pecos River, although water was fresh enough for humans to drink. Salinity has increased in recent times such that locations in Texas are the most saline locations on the Pecos River today, exceeding 30,000 ppm, encompassing the presumed historical range of Texas hornshell in the Pecos River upstream of Independence Creek. **Increased temperature:** In the short term, Texas hornshell may be exposed to high temperatures when water levels drop during drought. Pools with no or little water flow increase in temperature. Over time, the average temperature of streams in this region is expected to increase by 2 degrees C, drought will occur more often, and so Texas hornshell will be exposed to high temperatures more often. **Contaminants:** There are more than 3000 product assembly plants on the Mexican side of the Rio Grande that were built since 1994, which increases the potential for toxic contamination in the Rio Grande. In 2013, the Rio Grande below Falcon Reservoir and near Del Rio and Eagle Pass, TX, was noted as having high ammonia levels, perhaps explaining the absence of Texas hornshell from these reaches. We expect water quality to remain a concern in the Rio Grande into the future. There are no known contaminants in the Devils River. The risk of a spill on the Black and Delaware Rivers is imminent due to the amount of oil and gas production in the region, the high speeds of trucks carrying produced water, and the low water crossings they must traverse. A spill occurred on the Delaware River in August 2017.	**Moderately** confident	Mace and Wade 2008, p. 656 Hoagstrom 2009, p. 36 Upper Rio Grande Basin and Bay Expert Science Team 2012, pp. 1-9, 4-15 Texas Clean Rivers Program 2013, pp. 7, 11, 12 Allen pers. comm. 2017, p. 1
Changes in Resource(s)	Water becomes less suitable or unsuitable.		

THEME: Changes in water quality			
[ESA Factor(s): A,E]	**Analysis**	Confidence / Uncertainty	Supporting Information
Response to Stressors: - INDIVIDUALS	**Low dissolved oxygen:** Adults and juveniles reduce activity and ultimately die. **Salinity:** Overall, freshwater mussels cannot live fore extended periods in saline waters. Juvenile *Elliptio complanata* have been shown to experience complete mortality after 7 days at 4 pp, although this species is likely less saline-tolerant than Texas hornshell. No work has been conducted on Texas hornshell juveniles, but adults have shown behavioral signs of physiological stress, followed by death, at salinity of 7.0 ppt. **Increased temperature:** Individuals exposed to high temperatures may experience thermal stress. This generally occurs at temperatures over 40 degrees C, for thermally tolerant species (which we expect Texas hornshell to be). If this exposure lasts for more than a short period, individuals may die. increased water temperatures may also affect the timing of glochidial release. **Contaminants:** Ammonia, chlorine, and copper are particularly toxic to juvenile mussels. Glochidia also appear to be very sensitive to certain toxicants, such as heavy metals. Even at low levels, certain heavy metals, such as copper, may inhibit glochidial attachment to fish hosts.	**Moderately** confident	Havlik and Marking 1987, p. 13 Sparks and Strayer 1998, pp. 129, 132 Watters and O'Dee 2000, p. 136 Lang 2001, p. 25 Spooner and Vaughn 2008, p. 313 Blakeslee et al 2013, p. 2851
POPULATION & SPECIES RESPONSES			
Effects of Stressors: - POPULATIONS [RESILIENCY]	Populations in areas affected by changed water quality parameters can be eliminated.		

THEME: Changes in water quality			
[ESA Factor(s): A,E]	**Analysis**	Confidence / Uncertainty	Supporting Information
- SCOPE	**Low dissolved oxygen:** Low dissolved oxygen is most likely to occur in reaches with low water levels and/or sources of effluent. **Salinity:** Nearly all populations of Texas hornshell affected by salinity to some degree, although the salinity in the Devils River is lower. The Black River is isolated from the remainder of the range by very high salinity levels in the Pecos River. **Increased temperature:** Temperatures are expected to increase more in small streams that are more vulnerable to low water levels, such as the Devils River. **Contaminants:** Ammonia concentrations increase with increasing temperature and low-flow conditions, which may be exacerbated during low-flow events in streams. The Rio Grande populations of Texas hornshell are particularly vulnerable to contaminants, as there are numerous sources along the river. In the vicinity of the Black River, contamination of a nearby spring, Rattlesnake Spring, from natural gas wells occurred in the late 1980s. We expect the Black River to be exposed to contamination from this activity in the future. In the Devils River watershed, there is some oil and gas activity, but it is not prevalent. In the Rio Grande, Texas hornshell are not found for many miles downstream of two water treatment plants that discharge into the Rio Grande: at Nuevo Laredo, Mexico, and Eagle Pass, Texas.	**Moderately** confident	The Nature Conservancy 2004, p. 25 Cherry et al. 2005, p. 378 Cooper et al. 2005, p. 381 Miyamoto et al 2006 p. 15 National Park Service 2011, p. 9 Texas Clean Rivers Program 2013, p. 12 Karatayev et al 2015, p. 14

THEME: Loss of flowing water			
[ESA Factor(s): A,E]	**Analysis**	Confidence / Uncertainty	Supporting Information
SOURCE(S)	**Stream drying:** Climate change, drought, groundwater extraction **Inundation:** Large and small dams	**High** confidence	
- Activity(ies)	Oil and gas drilling, agricultural irrigation, municipal water supply, and flood control. In the Black River, surface water is removed from the river for irrigation, including Rattlesnake and Blue springs and the Carlsbad Irrigation District's Black River Canal at the CID diversion dam. Studies have shown that flows at the springs and in the river are also affected by groundwater withdrawals, particularly those from the valley. Groundwater in the Black River watershed is also being used for hydraulic fracturing for oil and gas activities. Between 4.3 acre-feet (187,308 ft^3 (5,304 m^3)) and 10.7 acre-feet (466,091 ft^3 13,198 m^3)) of water is used for each hydraulic fracturing job. Currently, groundwater pumping near the Devils River is not high enough to show significant effects to the Texas hornshell population. Dams have been built throughout the range of Texas hornshell, fragmenting populations and eliminating habitat.	**High** confidence	The Nature Conservancy 2004, p. 23 Carman 2007, p. 15 Bren School of Environmental Management 2014, pp. 79, 130
STRESSOR(S)	**Stream drying:** Mussels can tolerate short periods of time out of water. If the stream is not completely dry but has very low flow, they may be able to close their valves until conditions improve. However, as low flows persist, they face oxygen deprivation, increased water temperature, and, ultimately, stranding. **Inundation:** Texas hornshell have not been found inhabiting reservoirs or ponded areas, likely due to smothering by deposited sediment and the lack of use of that habitat by host fish. In large reservoirs, deep water is very cold and often devoid of oxygen and necessary nutrients. Cold water (less than 11 °C (52 °F)) has been shown to stunt mussel growth. Because mussel reproduction may be tied to temperature, it is likely that individuals living in the constantly cold hypolimnion in these channels may never reproduce, or reproduce less frequently.	**Moderately** confident	Hanson et al. 1988, p. 352 Watters 2000, p. 264 Watters and O'Dee 2000, p. 455 Golladay et al. 2004, p. 501 Carman 2007, p. 6 Galbraith et al 2010 p. 1180
- Affected Resource(s)	Water and, as water velocity slows, substrate		

THEME: Loss of flowing water			
[ESA Factor(s): A,E]	**Analysis**	Confidence / Uncertainty	Supporting Information
- Exposure of Stressor(s) (continues on next page)	**Stream drying:** As with many areas of North America, the range of the Texas hornshell is projected to experience an overall warming trend over the next 50 to 100 years. Although precipitation models vary substantially, with some even predicting increased precipitation annually, a consensus is emerging that evaporation rates are likely to increase significantly, and annual runoff is expected to decrease in Texas and southeastern New Mexico by 10 to 30 percent. Many models are also predicting that seasonal variability in flow rates is likely to increase with more precipitation occurring in the wet seasons and more extended dry periods, with a greater likelihood for more extreme droughts. Near the Devils River, several municipalities are seeking additional water sources to support growing water consumption needs. If the groundwater extraction is approved, significant amounts of water may be removed and piped to other localities. To date, none have been approved, but pumping proposals have continued to be submitted. If this occurs, the Devils River could see a drop in flow due to reduced groundwater levels. In the Pecos River downstream of Red Bluff Reservoir, irrigation districts divert pulse flows, and stream drying in this reach is not uncommon. In the Black River, instream flow is affected by local precipitation, high altitude groundwater recharge, local groundwater table elevation, evapotranspiration, and anthropogenic water use. As oil and gas development increases, groundwater extraction is expected to increase, and we expect instream flow to be reduced.	**Moderately** confident	Metcalf 1982, p. 45 The Nature Conservancy 2004, pp. 23-24 USFWS 2005, p. 1.7-3 Carman 2007, p. 15 Donnelly 2007, p. 4 CH2M HILL 2008, p. 6-4 Mace and Wade 2008, p. 656 Texas Water Development Board 2008, p. 16 Dean and Schmidt 2011, pp. 4, 6 Rio Grande Water Planning Group 2010, p. 4–75 Burlakova et al. 2011, p. 7 URGBBEST 2012, pp. 1-9, 1-12, 1-14 Val Verde Water Company 2013, pp. 1-2 Carter et al 2015, p. 15

THEME: Loss of flowing water			
[ESA Factor(s): A,E]	**Analysis**	Confidence / Uncertainty	Supporting Information
- Exposure of Stressor(s) **(cont.)**	The Rio Conchos in Mexico is a major source of river flow in the Rio Grande. Due to water withdrawal, reduced precipitation, and the construction of Elephant Butte Dam in New Mexico, 90% of water flow in the Rio Grande at Big Bend is from the Rio Conchos. However, during times of drought (such as between 1994 and 2003), the contribution of the Rio Conchos has fallen to as low as 40 percent. Total flow in the Rio Grande has declined in the 20th century, as have flood flows. Additionally, groundwater models have demonstrated that an increase in groundwater extraction in Val Verde and Terrell Counties, TX, will likely result in a decrease in river flow. The management of the Rio Conchos as well as groundwater extraction from nearby aquifers will have a large effect on the availability of water at the Rio Grande - Lower Canyons population. **Inundation:** Significant mussel populations, including Texas hornshell, were lost in the lower Pecos River canyon reaches and lower Devils River of Texas due to inundation by Amistad Reservoir, completed in 1968. Falcon Reservoir on the Rio Grande likely eliminated mussel habitat when it was built in 1953. Construction of McMillan Dam in the early 20th century, replaced by Brantley Dam in 1988, may account for extirpations from the Pecos River near the Seven Rivers confluence, Eddy County, New Mexico, and Red Bluff Dam, in Texas, further eliminated habitat on the Pecos River. Several smaller impoundments and diversion dams exist on the Black River, downstream of the extant population. There is a low-water diversion dam proposed for the Rio Grande near Laredo, Texas, just downstream of the recently discovered large Texas hornshell population. The depths proposed for the dam (between 8.3 and 14.1 meters (27.2 and 46.2 feet)) would be sufficient to inundate about 14 miles of habitat, including the downstream, most dense reach. The Texas hornshell cannot tolerate the inundation and subsequent siltation that such an impoundment would cause. To date, no decision has been made on the dam.		

THEME: Loss of flowing water			
[ESA Factor(s): A,E]	**Analysis**	Confidence / Uncertainty	Supporting Information
- Immediacy of Stressor(s)	**Stream drying:** Drought is expected to increase in frequency and magnitude due to climate change. In the Black River, mean monthly discharge has already declined since the mid-1990s, and mean monthly temperatures have increased over the past 100 years. In the Black River, survivorship is positively correlated with discharge; as mean monthly discharge decreases, we expect Texas hornshell survivorship to decrease, as well. The Black River is expected to lose streamflow due to air temperature increases and reduced precipitation. The Rio Grande has experienced reduced streamflow and precipitation below the confluence with the Rio Conchos since the mid-1980s, and overall discharge is projected to decrease by 26.7% by 2100. In the Devils River, USGS data indicates mean daily flows have been decreasing since 1978. As early as 1955, river flow reductions have been attributed to groundwater pumping. Excessive groundwater withdrawal in the basin is a potentially devastating event. The extirpation of Texas hornshell from the North Spring River has been attributed to groundwater withdrawal from the Roswell Artesian Basin. Effects of climate change are only expected to increase into the future as droughts become more frequent and air temperatures increase, resulting in more groundwater extraction. **Inundation**: The low water weir proposed for Laredo has not been approved or funded by the Texas Water Development Board; however, community leaders are pursuing approval through congress and plans for the weir have been developed.	**Moderately** confident	The Nature Conservancy 2004, p. 23 USFWS 2005, p. 3 Nohara et al. 2006, p. 1087 Carman 2007, p. 14 Bren School of Environmental Management 2014, p. 91 Inoue et al. 2014, pp. 7, 9 Miyazono *et al.* 2015, appendix A Reyes 2015, p. 1

THEME: Loss of flowing water			
[ESA Factor(s): A,E]	**Analysis**	Confidence / Uncertainty	Supporting Information
Changes in Resource(s)	**Stream drying**: A completely dry streambed eliminates habitat for Texas hornshell. Lowered flows can cause stagnant pools to form, which over a period of time can become unsuitable for Texas hornshell as water temperatures increase and dissolved oxygen decreases. Low water levels for a short period of time may be endured periodically, but over the long term mortality of mussels can be similar between reaches that are completely dry or those that remain wetted at very low flow. **Inundation:** Texas hornshell in inundated reaches of river may survive for some time, but the likelihood of reproduction is reduced. If large amounts of sediment are deposited on the mussel bed, Texas hornshell will likely die.	**High** confidence	Haag and Warren 2008, p. 1173
Response to Stressors: - INDIVIDUALS	**Stream drying**: Texas hornshell in dry reaches will become desiccated. Those in reaches with very low flow may experience temperature stress and the effects of low dissolved oxygen. If the condition persists, they will likely die. **Inundation:** Individuals in inundated reaches will likely not reproduce. Those smothered with deposited sediment will die.	**High** confidence	
POPULATION & SPECIES RESPONSES			
Effects of Stressors: - POPULATIONS [RESILIENCY]	Populations in areas affected by loss of flowing water can be eliminated.		
- SCOPE	**Stream drying:** All populations are likely to be affected by lowered streamflow in the future. The Devils River experiences low flow during drought periods currently. The Devils River and Black River populations are the most vulnerable to lowered flow due to groundwater extraction. **Inundation:** The Texas hornshell's current condition is greatly formed by the past construction of reservoirs, which eliminated habitat and fragmented populations. The proposed construction of a low water weir on top of the Rio Grande - Laredo population could have devastating effects to that population.	**Moderately** confident	

THEME: Barriers to fish movement			
[ESA Factor(s): A]	**Analysis**	Confidence / Uncertainty	Supporting Information
SOURCE(S)	Dams, diversions, reservoirs	**High** confidence	
- Activity(ies)	Dam construction, water withdrawals, flood control	**High** confidence	
STRESSOR(S)	The overall distribution of mussels is a function of the dispersal of their hosts. The distributions of the fragile papershell (*Leptodea fragilis*) and pink heelsplitter (*Potamilus alatus*) in five midwestern rivers have been limited by the presence of low-head dams. These dams were non-navigable (without locks), lacked fish ladders, and varied in height from 1 to 17.7 m (3 ft to 58 ft), and the host fish could not disperse through them. The multiple dams throughout the range of Texas hornshell (Brantley, Red Bluff, Amistad, and Falcon, as well as other small dams and diversions) have fragmented its range in a similar way. Fragmented populations are susceptible to genetic drift (change of gene frequencies in a population over time), and inbreeding depression. Inbreeding depression can result in death, decreased fertility, smaller body size, loss of vigor, reduced fitness, and various chromosomal abnormalities.	**High** confidence	Watters 1996, pp. 80, 83 Turner et al 2000, p. 783 Berg et al 2007, pp. 1436 -1437
- Affected Resource(s)	Dam construction fragments the range of Texas hornshell, leaving remaining habitats and populations isolated by the structures as well as by extensive areas of deep uninhabitable, impounded waters. Dams impound river habitats throughout almost the entire range of the species, and these impoundments have left isolated patches of remnant habitat between impounded reaches.	**High** confidence	
- Exposure of Stressor(s)	Brantley Dam and smaller diversion dams in New Mexico, Red Bluff Dam in Texas on the Pecos River, and Amistad and Falcon dams in Texas on the Rio Grande.	**High** confidence	
- Immediacy of Stressor(s)	These dams have been in existence since the mid 1900s, fragmenting the range of Texas hornshell since that time. An additional low water weir has been proposed for the downstream section of the Rio Grande - Laredo population. While this would shrink the Rio Grande - Laredo population, we do not expect the Texas hornshell's range to be further fragmented by the reservoir, as Texas hornshell have been extirpated from the Rio Grande downstream of Laredo.	**High** confidence	Rio Grande Water Planning Group 2010, p. 4–75

THEME: Barriers to fish movement			
[ESA Factor(s): A]	**Analysis**	Confidence / Uncertainty	Supporting Information
Changes in Resource(s)	Host fish are unable to travel between Texas hornshell populations, isolating existing populations from one another. Genetic exchange between populations has been eliminated, and any populations that may be extirpated through stochastic events will not be naturally recolonized.	**High** confidence	Inoue *et al.* 2015, p. 1916
Response to Stressors: **- INDIVIDUALS**	Habitat fragmentation acts on the population level. Individuals are unaffected.	**Moderately** confident	
POPULATION & SPECIES RESPONSES			
Effects of Stressors: **- POPULATIONS [RESILIENCY]**	Population resiliency is decreased if isolation results in such genetic isolation that genetic drift occurs. We do not currently expect that Texas hornshell population resiliency has been affected. However, if populations are extirpated they will not be recolonized naturally.	**Moderately** confident	
- SCOPE	The entire range of Texas hornshell has been fragmented by large dams and reservoirs.	**High** confidence	

THEME: Predation			
[ESA Factor(s): C]	**Analysis**	Confidence / Uncertainty	Supporting Information
SOURCE(S)	Increased terrestrial predation from muskrats and raccoons.		
- Activity(ies)	As stream flows decline, access by terrestrial predators increases, causing higher mortality to the population than would otherwise be experienced.	**High** confidence	
STRESSOR(S)	Predation on freshwater mussels is a natural ecological interaction. Raccoons, snapping turtles, and fish are known to prey upon Texas hornshell. Under natural conditions, the level of predation occurring within Texas hornshell populations is not likely to be a significant risk to that population. However, during periods of low flow, terrestrial predators have increased access to portions of the river that are generally too deep under normal flow conditions. Muskrats and raccoons are known to prey upon live Texas hornshell, as evidenced by freshly fragmented valves strewn along vegetated riverbank margins in the Black and Devils Rivers.	**Moderately** confident	Carman 2007, p. 11 Robertson 2016, p. 1
- Affected Resource(s)	Individuals are killed.	**High** confidence	
- Exposure of Stressor(s)	As stream flows decline, access by terrestrial predators increases, increasing predation rates by raccoons and muskrats.	**High** confidence	Golladay et al 2004, p. 503
- Immediacy of Stressor(s)	Mortality due to predation have been observed on the Devils River during low flow periods in 2015. In the Black River, muskrat predation has also been observed. As drought and low flow are predicted to occur more often and for longer periods due to climate change, the Black and Devils Rivers are expected to experience additional predation pressure in the future.	**Somewhat** confident	Lang 2001, p. 26 Robertson 2016, p. 1
Changes in Resource(s)	Mussels preyed upon die.	**High** confidence	
Response to Stressors: - INDIVIDUALS	Mussels preyed upon die.	**High** confidence	

THEME: Predation			
[ESA Factor(s): C]	**Analysis**	Confidence / Uncertainty	Supporting Information
POPULATION & SPECIES RESPONSES			
Effects of Stressors: **- POPULATIONS [RESILIENCY]**	Predation on freshwater mussels is a natural ecological interaction. Otters, raccoons, snapping turtles, and fish are known to prey upon Texas hornshell. Under natural conditions, the level of predation occurring within Texas hornshell populations is not expected to be a significant risk. However, populations that are already at risk from low flow conditions during drought are further affected by increased access by terrestrial predators. Populations experiencing this combination of low flow and high predation have less resiliency and a higher risk of extirpation than those not experiencing those pressures.	**Somewhat** confident	
- SCOPE	The Devils and Black Rivers are primarily susceptible to low flow events and, therefore, increased predation levels.		