

Species Status Assessment Report
for the Sharpnose Shiner
(*Notropis oxyrhynchus*) and Smalleye Shiner (*N. buccula*)

Version 2

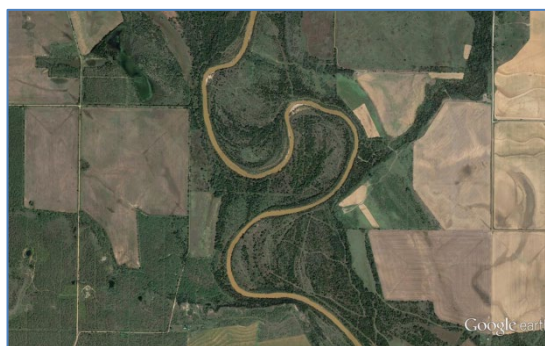
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U.S. Fish and Wildlife Service
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Double Mountain Fork Brazos River



Sharpnose Shiner



Aerial View of Brazos River

Photo credits: Kevin Mayes, Texas Parks and Wildlife Department (top), Clint Robertson, Texas Parks and Wildlife Department (left); Google Earth (right).

EXECUTIVE SUMMARY

This species status assessment (SSA) reports the results of the comprehensive biological status review for the sharpnose shiner (*Notropis oxyrhynchus*) and smalleye shiner (*N. buccula*) and provides a thorough account of the species' overall viability and, conversely, extinction risk. This SSA replaces the previous version published on June 10, 2014. Sharpnose and smalleye shiners are small minnows currently restricted to the contiguous river segments of the upper Brazos River basin in north-central Texas.

To evaluate the biological status of the shiners 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). Both species need a resilient population widely distributed across their range to maintain persistence into the future and avoid extinction. A number of factors influence whether sharpnose and smalleye shiner populations will continue to persist or grow to maximize habitat occupancy and abundance which increases the resiliency of a population to stochastic events. These four factors include (1) wide river channels with diverse habitats including shallow runs, pools, etc., (2) flowing water of sufficient quantity and quality to meet life history and habitat needs, (3) sandy substrates for foraging, and (4) an unobstructed stream reach of sufficient distance to support a successfully reproductive population.

Both shiners are currently restricted almost entirely within the contiguous river segments of the upper Brazos River basin in north-central Texas (Figure ES-1); thus maintaining favorable habitat conditions within these river segments is imperative to the continued existence of both species. Our analysis identified two significant stressors affecting the current and future conditions of these species: river fragmentation (by impoundments and barriers to fish passage) and alterations of the natural streamflow regime (by impoundments, drought, groundwater withdrawal, and saltcedar (*Tamarix spp.*) encroachment) within their range. Secondary factors, such as water quality degradation, likely also impact these species but the extent is not known. These multiple factors are not acting independently, but in unison as combined stressors, which can result in cumulative effects to lower the overall viability of the species. A summary of the species' needs, stressors, and current and future status is presented in Table ES-1.

Our assessment found that the viability of both species of shiner has been reduced (low probability of persistence) in the near term (over about the next 10 years) largely because of the existing limitations of their life history requirements of long, wide, flowing rivers to complete their reproductive cycle. With a short life span allowing only one or two breeding seasons and the need for long, unobstructed flowing river reaches, both species are at a high risk of extirpation when rivers are fragmented by fish barriers and flows are reduced from human use and drought-enhanced water shortages. These conditions have already resulted in substantial range reduction, isolating the one remaining population of both fish to the upper Brazos River basin. The extant population of each shiner species is located in a contiguous stretch of river long enough to support recruitment, is of adequate size, and is generally considered resilient to local or short-term environmental changes. However, with only one location, both species lack redundancy and may lack the genetic and ecological representation to adapt to new or ongoing threats.

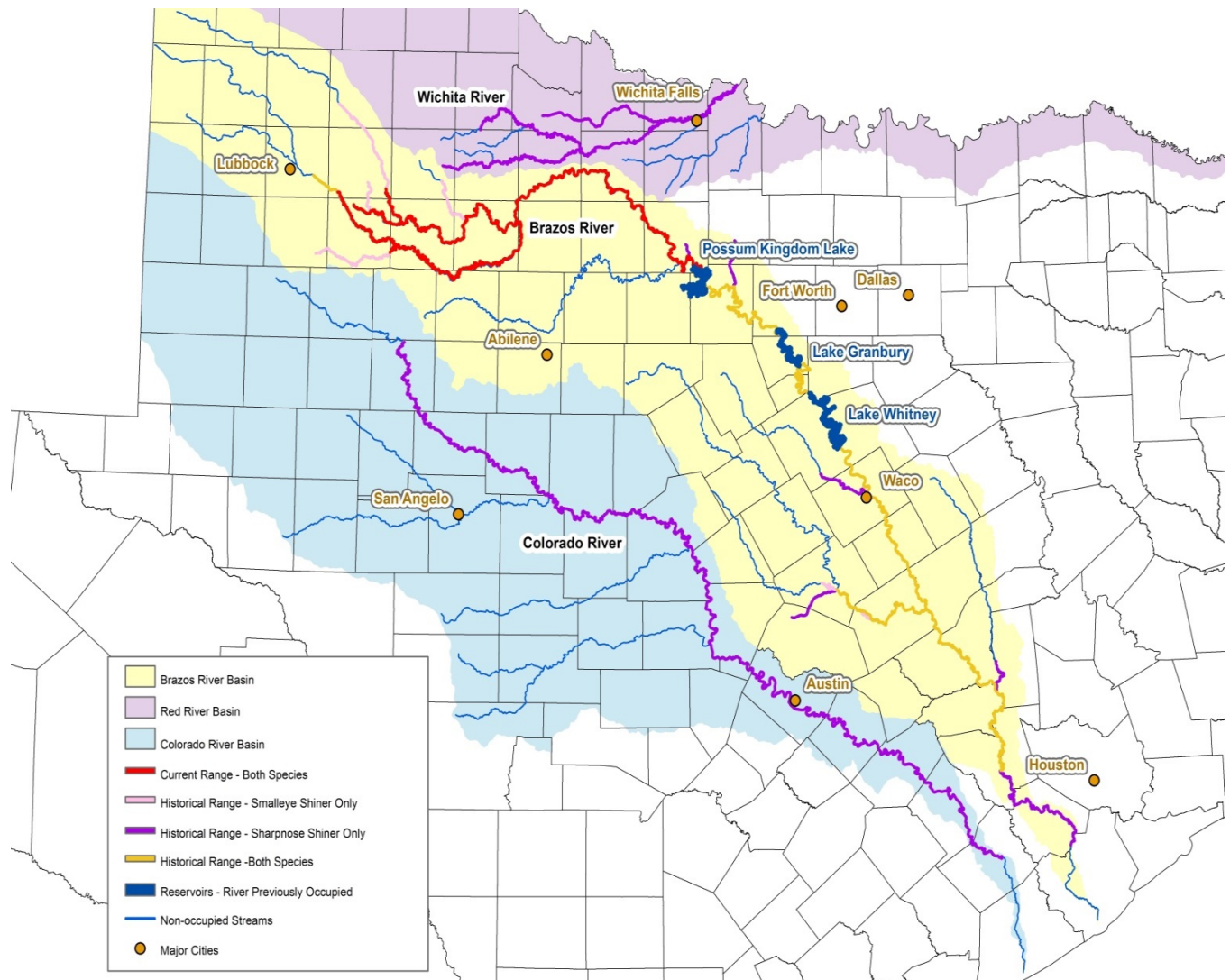


Figure ES-1. An overview map of key points regarding sharpnose and smalleye shiner distributions both historically (pink, purple, and golden lines) and currently (red lines). The Red River basin (pink shading), Brazos River basin (yellow shading) and Colorado River basin (blue shading) are shown with major tributaries not known to be historically or currently occupied represented by blue lines. The three main reservoirs of the middle Brazos River that replaced previously occupied habitat are shown in dark blue and labeled.

Table ES-1. Summary of the status of resource needs of Brazos River shiners and implications for viability.

Scale	RESOURCE		CURRENT STATUS			FUTURE STATUS		
	Resource	Function	Conditions	Causes and Effects	Implications for Viability	Condition	Causes and Effects	Implications for Viability
Individuals	Sandy substrates and shallow, wide channels	Feeding/sheltering	Presumed adequate within extant range. Some losses of resources have occurred in historical range.	Impoundments; instream mining & dredging; saltcedar encroachment	Conditions for individuals are believed to be adequate to support the one extant population.	May be reduced in future in extant range	New impoundments; instream mining & dredging; saltcedar encroachment	Reduced Population Resiliency. Enhanced risk of loss of the one extant population, puts both species at high risk of extinction in the future.
	Adequate prey base	Feeding		Impoundments			New impoundments	
	Water of sufficient quantity and quality to meet life history requirements	Feeding/breeding/sheltering		Impoundments; pollution; golden algal blooms			New impoundments; pollution; golden algal blooms	
Populations	Minimum spawning season flows	Breeding - <i>population resiliency</i>	Reduced mean flows from historical conditions in extant range	Barriers to movement; impoundments; groundwater withdrawal; severe drought	Reduced population resiliency. Risks of loss of one extant population puts both species at high risk of extinction under current conditions.	Flows and unobstructed river length are likely to be further reduced	Barriers; new impoundments; increased groundwater withdrawal; severe drought complicated by climate change; desalinization	Reduced Population Resiliency. Enhanced risk of loss of the one extant population, puts both species at high risk of extinction in the future.
	Elevated spawning season flows	Breeding - <i>population resiliency</i>	Reduced frequency of flood flows from historical conditions in extant range					
	Unobstructed flowing water greater than 275 km in river length	Breeding & migration - <i>population resiliency</i>	One extant length of river remaining in the upper Brazos River					
Rangewide	Larger lengths of unobstructed flowing water in rivers	Migration & recolonization - <i>resiliency, representation, & redundancy</i>	Not currently available; ~50% historical range loss	Impoundments	Reduced resiliency; absence of redundancy and representation	Likely to be further reduced	New impoundments	Reduced Resiliency; Absence of Redundancy and Representation

Long term viability of the shiners depends upon maintaining resilient populations over time within stream segments capable of accommodating their life history requirements, reproduction, and successful recruitment. The availability of these resource needs is affected by potential new reservoir construction within the extant range, increased threats to water quantity such as groundwater withdrawal to meet agricultural and municipal demand, changes to water quality from point and non-point sources, and enhanced chances and severity of drought due to ongoing climate change and water management. Although there is uncertainty regarding the immediacy and extent occupied stream segments may experience fragmentation, changes to water quality, and/or altered flow regimes, we have forecasted what future viability the shiners may have in terms of resiliency, redundancy and representation under various future plausible scenarios and the corresponding conservation actions expected to achieve short- and long-term viability:

Sharpnose Shiner

(1) Upper Brazos River Basin Restoration

- The current population is maintained throughout the currently occupied range (1,002 kilometers (km) [623 miles (mi)] of the Double Mountain Fork and its major tributaries, Salt Fork and its major tributaries, and main stem of the Brazos River).
- Conservation efforts to improve fish passage by removing minor barriers, and improve habitat by controlling saltcedar and protecting water quality, continue to be implemented within the occupied range. Work with stakeholders to develop groundwater and surface water management strategies as well as potential water release strategies in the upper Brazos River basin to provide adequate surface water flows.

(2) Upper Brazos River Basin Restoration and Lower Brazos River Reintroduction

- The current population is maintained throughout the currently occupied range (1,002 km [623 mi] of the Double Mountain Fork and its major tributaries, Salt Fork and its major tributaries, and main stem of the Brazos River).
- Conservation efforts to improve fish passage by removing minor barriers, and improve habitat by controlling saltcedar and protecting water quality, continue to be implemented within the occupied range. Work with stakeholders to develop groundwater and surface water management strategies as well as potential water release strategies in the upper Brazos River basin to provide adequate surface water flows.
- Habitat conditions within the historical range of the sharpnose shiner in the lower Brazos River (421 km [262 mi] un-impounded river segment from the Marlin low water crossing to the Brazoria County line) improve, enabling the establishment of a second population through reintroduction efforts.

(3) Post Reservoir on the Double Mountain Fork and Lower Brazos River Reintroduction

- The population is maintained throughout the Salt Fork and main stem of the Brazos River (currently occupied range (642 km [399 mi])). Post Reservoir is constructed on the North Fork Double Mountain Fork, reducing the available

habitat to 142 km (88 mi) within the Double Mountain Fork and its major tributaries.

- Habitat conditions within the historical range of the sharpnose shiner in the lower Brazos River (421 km [262 mi] un-impounded river segment from the Marlin low water crossing to the Brazoria County line) improve, enabling the establishment of a second population through reintroduction efforts.

(4) Double Mountain Fork and Salt Fork Range Contraction and Lower Brazos River Reintroduction

- Limitations on water availability reduce the range of the existing population to the main stem of the Brazos River and the lower portions of the Salt Fork and Double Mountain Fork.
- Habitat conditions within the historical range of the sharpnose shiner in the lower Brazos River (421 km [262 mi] un-impounded river segment from the Marlin low water crossing to the Brazoria County line) improve, enabling the establishment of a second population through reintroduction efforts.

(5) Double Mountain Fork and Salt Fork Range Loss with Reintroductions in the Lower Brazos River and Colorado River

- Major limitations on water availability reduce the existing population to the main stem of the Brazos River.
- Habitat conditions within the historical range of the sharpnose shiner in the lower Brazos River (421 km [262 mi] un-impounded river segment from the Marlin low water crossing to the Brazoria County line) and Colorado River basin (between O.H. Ivie Reservoir and Lake Buchanan requiring the removal of a single fish passage barrier (275 km [171 mi]) or between Austin and the Altair Dam (285 km [177 mi]) improve, enabling the establishment of a second and third population through reintroduction efforts.

We examine the resiliency, representation, and redundancy of the sharpnose shiner under each of these five plausible scenarios. Resiliency of sharpnose shiner depends on suitable future water quality, availability of flowing water meeting the needs for all life stages, and un-impounded stream lengths greater than 275 km (171 mi). We expect the sharpnose shiner population to experience changes to these aspects of their habitat in different ways under the different scenarios. We projected the expected future resiliency of the population based on the events that would occur under each scenario (Table ES-2). Habitat characteristics for populations in high condition are stream lengths greater than twice the length necessary (>550 km [>342 mi]) for recruitment possessing suitable substrates with sufficient water quantity and quality to accommodate all life stages combined with pulse flows during the spawning season (April – September) in two out of three consecutive years. Populations in high condition are better suited to persist into the future, beyond 50 years, and more able to withstand stochastic events that may occur. Populations in moderate condition have lower resiliency than those in high condition. Habitat characteristics of populations in moderate condition are stream lengths greater than one and a half to twice the length necessary (413 – 550 km [257 – 342 mi]). Finally, habitat characteristics of populations in low condition are the minimum to one and a half the length necessary (275 – 413 km [171 – 257 mi]) for successful recruitment. A population in this

condition would have low resiliency and is not necessarily able to withstand stochastic events and as a result, they are less likely to persist over the next 50 years.

Table ES-2. Sharpnose shiner future viability scenarios.

Scenario		Population Resiliency	Species Viability
1	Double Mountain Fork and its major tributaries to Brazos River – 360 km (224 mi)	High (1,002 km[623 mi])	High
	Salt Fork and its major tributaries to Brazos River – 315 km (196 mi)		
	Main stem Brazos River to Possum Kingdom Lake – 327 km (203 mi)		
2	Double Mountain Fork and its major tributaries to Brazos River – 360 km (224 mi)	High (1,002 km [623 mi])	High
	Salt Fork and its major tributaries to Brazos River – 315 km (196 mi)		
	Main stem Brazos River to Possum Kingdom Lake – 327 km (203 mi)		
	Lower Brazos River below Marlin low water crossing and Brazoria County – 421 km (262 mi)	Moderate (421 km [262 mi])	
3	Double Mountain Fork below Rough Creek to Brazos River – 142 km (88 mi)	High (784 km [487 mi])	High
	Salt Fork and its major tributaries to Brazos River – 315 km (196 mi)		
	Main stem Brazos River to Possum Kingdom Lake – 327 km (203 mi)		
	Lower Brazos River below Marlin low water crossing and Brazoria County – 421 km (262 mi)	Moderate (421 km [262 mi])	
4	Double Mountain Fork below Rough Creek to Brazos River – 142 km (88 mi)	High (554 km [344 mi])	High
	Salt Fork below Croton Creek to Brazos River – 85 km (53 mi)		
	Main stem Brazos River to Possum Kingdom Lake – 327 km (203 mi)		
	Lower Brazos River below Marlin low water crossing and Brazoria County – 421 km (262 mi)	Moderate (421 km [262 mi])	
5	Double Mountain Fork	Ø	Low
	Salt Fork	Ø	
	Main stem Brazos River to Possum Kingdom Lake – 327 km (203 mi)	Low (327 km [203 mi])	
	Lower Brazos River below Marlin low water crossing and Brazoria County – 421 km (262 mi)	Moderate (421 km [262 mi])	
	Colorado River from O.H. Ivie Reservoir to Lake Buchanan – 275 km (171 mi) or Colorado River below Austin to the Altair Dam – 285 km (177 mi)	Low (275 or 285 km [171 or 177 mi])	

Smalleye Shiner

(1) Upper Brazos River Basin Restoration

- The current population is maintained throughout the currently occupied range (1,002 km [623 mi] of the Double Mountain Fork and its major tributaries, Salt Fork and its major tributaries, and main stem of the Brazos River).
- Conservation efforts to improve fish passage by removing minor barriers, and improving habitat by controlling saltcedar and protecting water quality, continue to be implemented within the occupied range. Work with stakeholders to develop groundwater and surface water management strategies as well as potential water release strategies in the upper Brazos River basin to provide adequate surface water flows.

(2) Upper Brazos River Basin Restoration and Lower Brazos River Reintroduction

- The current population is maintained throughout the currently occupied range (1,002 km [623 mi] of the Double Mountain Fork and its major tributaries, Salt Fork and its major tributaries, and main stem of the Brazos River).
- Conservation efforts to improve fish passage by removing minor barriers, and improve habitat by controlling saltcedar and protecting water quality, continue to be implemented within the occupied range. Work with stakeholders to develop groundwater and surface water management strategies as well as potential water release strategies in the upper Brazos River basin to provide adequate surface water flows.
- Habitat conditions within the historical range of the smalleye shiner in the lower Brazos River (421 km [262 mi] un-impounded river segment from the Marlin low water crossing to the Brazoria County line) improve, enabling the establishment of a second population through reintroduction efforts.

(3) Post Reservoir on the Double Mountain Fork and Lower Brazos River Reintroduction

- The population is maintained throughout the Salt Fork and main stem of the Brazos River (currently occupied range (642 km [399 mi])). Post Reservoir is constructed on the North Fork Double Mountain Fork, reducing the population to 142 km (88 mi) within the Double Mountain Fork and its major tributaries.
- Habitat conditions within the historical range of the smalleye shiner in the lower Brazos River (421 km [262 mi] un-impounded river segment from the Marlin low water crossing to the Brazoria County line) improve, enabling the establishment of a second population through reintroduction efforts.

(4) Double Mountain Fork and Salt Fork Range Contraction and Lower Brazos River Reintroduction

- Limitations on water availability reduce the range of the existing population to the main stem of the Brazos River and the lower portions of the Salt Fork and Double Mountain Fork.
- Habitat conditions within the historical range of the smalleye shiner in the lower Brazos River (421 km [262 mi] un-impounded river segment from the Marlin low

water crossing to the Brazoria County line) improve, enabling the establishment of a second population through reintroduction efforts.

(5) Double Mountain Fork and Salt Fork Range Loss with Reintroductions in the Lower Brazos River

- Major limitations on water availability reduce the existing population to the main stem of the Brazos River.
- Habitat conditions within the historical range of the smalleye shiner in the lower Brazos River (421 km [262 mi] un-impounded river segment from the Marlin low water crossing to the Brazoria County line) improve, enabling the establishment of a second population through reintroduction efforts.

We examine the resiliency, representation, and redundancy of the smalleye shiner under each of these five plausible scenarios. Resiliency of smalleye shiner depends on suitable future water quality, availability of flowing water meeting the needs for all life stages, and un-impounded stream lengths greater than 275 km (171 mi). We expect the smalleye shiner population to experience changes to these aspects of their habitat in different ways under the different scenarios. We projected the expected future resiliency of the population based on the events that would occur under each scenario (Table ES-3). Habitat characteristics of populations in high condition are stream lengths greater than twice the length necessary (>550 km [>342 mi]) for recruitment possessing suitable substrates with sufficient water quantity and quality to accommodate all life stages combined with pulse flows during the spawning season (April – September) in two out of three consecutive years. Populations in high condition are better suited to persist into the future, beyond 50 years, and more able to withstand stochastic events that may occur. Populations in moderate condition have lower resiliency than those in high condition. Habitat characteristics of populations in moderate condition are stream lengths greater than one and a half to twice the length necessary (413 – 550 km [257 – 342 mi]). Finally, habitat characteristics of populations in low condition are the minimum to one and a half the length necessary (275 – 413 km [171 – 257 mi]) for successful recruitment. A population in this condition would have low resiliency and is not necessarily able to withstand stochastic events and as a result, they are less likely to persist over the next 50 years.

Table ES-3. Smalleye shiner future viability scenarios.

Scenario		Population Resiliency	Species Viability
1	Double Mountain Fork and its major tributaries to Brazos River – 360 km (224 mi)	High (1,002 km[623 mi])	High
	Salt Fork and its major tributaries to Brazos River – 315 km (196 mi)		
	Main stem Brazos River to Possum Kingdom Lake – 327 km (203 mi)		
2	Double Mountain Fork and its major tributaries to Brazos River – 360 km (224 mi)	High (1,002 km [623 mi])	High
	Salt Fork and its major tributaries to Brazos River – 315 km (196 mi)		
	Main stem Brazos River to Possum Kingdom Lake – 327 km (203 mi)		
	Lower Brazos River below Marlin low water crossing and Brazoria County – 421 km (262 mi)	Moderate (421 km [262 mi])	
3	Double Mountain Fork below Rough Creek to Brazos River – 142 km (88 mi)	High (748 km [487 mi])	High
	Salt Fork and its major tributaries to Brazos River – 315 km (196 mi)		
	Main stem Brazos River to Possum Kingdom Lake – 327 km (203 mi)		
	Lower Brazos River below Marlin low water crossing and Brazoria County – 421 km (262 mi)	Moderate (421 km [262 mi])	
4	Double Mountain Fork below Rough Creek to Brazos River – 142 km (88 mi)	High (554 km [344 mi])	High
	Salt Fork below Croton Creek to Brazos River – 85 km (53 mi)		
	Main stem Brazos River to Possum Kingdom Lake – 327 km (203 mi)		
	Lower Brazos River below Marlin low water crossing and Brazoria County – 421 km (262 mi)	Moderate (421 km [262 mi])	
5	Double Mountain Fork	Ø	Low
	Salt Fork		
	Main stem Brazos River to Possum Kingdom Lake – 327 km (203 mi)	Low (327 km [203 mi])	
	Lower Brazos River below Marlin low water crossing and Brazoria County – 421 km (262 mi)	Moderate (421 km [262 mi])	

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CHAPTER 1 – INTRODUCTION

Sharpnose shiner (*Notropis oxyrinchus*) and smalleye shiner (*Notropis buccula*) (shiners) are small minnows currently restricted almost entirely to the contiguous river segments of the upper Brazos River basin in north-central Texas. The two fishes have been of conservation concern since 1982 (47 FR 58454) and in 2014, both were listed as endangered with critical habitat designations under the Endangered Species Act of 1973, as amended (Act). The SSA framework is intended to be an in-depth, all-inclusive review of the species biology and threats to evaluate its biological status based on whether the species has the resources and conditions it needs 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 many other documents such as listing rules, recovery plans, and 5-year reviews will be based.

For the purpose of this assessment, we define **viability** as the ability of these species to sustain populations in the wild over time (in this case, 50 years). Using the SSA framework, we describe these species' viability in terms of their **resiliency**, **redundancy**, and **representation** (3Rs).

- **Resiliency** is defined as the ability of a species to withstand stochastic events (arising from random factors). We can measure resiliency based on metrics of population health such as birth versus death rates and population size. Healthy populations are more resilient and better able to withstand disturbances such as random fluctuations in birth rates (demographic stochasticity), variations in rainfall (environmental stochasticity), or the effects of anthropogenic activities.
- **Redundancy** is defined as the ability of a species to withstand catastrophic events (a rare destructive natural event or episode involving many populations and occurring suddenly). Redundancy is about spreading the risk and can be measured through the duplication and distribution of resilient populations across the range of the species. The greater the number of resilient populations a species has distributed over a larger landscape, the better it can withstand catastrophic events.
- **Representation** is defined as the ability of a species to adapt to changing environmental conditions. Representation can be measured through the breadth of genetic diversity within and among populations and the ecological diversity (also called environmental variation or diversity) of populations across the species' range. 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, such as is the case with the shiners, we evaluate representation based on the extent of, and variability of habitat characteristics within, their geographical range.

To evaluate the viability of the shiners in the future, we assessed a range of reasonable future conditions to allow us to consider the species' resiliency, redundancy, and representation. This

SSA Report provides a thorough assessment of biology and natural history of the two shiners and assesses demographic risks, threats, and limiting factors in the context of determining the viability and risks of extinction for the species. Herein, we compile biological data and a description of past, present, and likely future threats facing the two shiners. The format for this SSA Report includes the species' resource needs for the individual, population, and rangewide (Chapter 2); analyzing the current range and distribution of these species to assess current viability and risk of extinction in terms of resiliency, redundancy, and representation (Chapter 3); reviewing the likely influences to viability (threats) that affect the current and future biological status of these species (Chapter 4); an assessment of the future conditions and availability of the species' resource needs and the how that may affect the species' resiliency, redundancy, and representation (Chapter 5); and conservation opportunities to enhance species viability (Chapter 6). For a glossary of other terms used in this SSA Report, reference Appendix A.

CHAPTER 2 – SPECIES NEEDS, LIFE HISTORY AND BIOLOGY

In this chapter we provide basic biological information about sharpnose and smalleye shiners, including their physical environment, taxonomic history and relationships, morphological description, and reproductive and other life history traits. We then outline the resource needs of individuals and populations of the shiners. These resources (water quantity and quality and stream reach lengths that provide suitable habitat conditions) are the key factors that determine the health and viability of the shiners. Finally, we briefly consider the rangewide needs for each species in the context of their historical ranges.

2.1 Biology and Life History

2.1.1 Physical Environment

The sharpnose shiner is a minnow endemic to the Brazos River, Red River, and Colorado River basins that occurs within Texas and whose headwaters lie within the semi-arid High Plains ecoregion. The smalleye shiner is a minnow endemic to the Brazos River only. Sharpnose and smalleye shiners are primarily known from the Brazos River basin; therefore, this basin serves as the focal point of discussions regarding the physical environment upon which these species are associated. To facilitate analysis, the Service partitions the Brazos River into three sections defined as the upper Brazos River upstream of Possum Kingdom Lake, the middle Brazos River between Possum Kingdom Lake, and the low-water crossing near the City of Marlin, Falls County, Texas; and the lower Brazos River downstream of the low-water crossing to the Gulf of Mexico (Figure 1).

Originating in New Mexico and terminating at the Gulf of Mexico, the Brazos River basin covers approximately 1,000 linear kilometers (km) (621.4 miles (mi)) and more than 11 million hectares (27.5 million acres) of Texas and the climate differs from the arid regions at the extreme upstream portions of the upper Brazos River basin where 20 to 24 inches (in) (50 to 61 centimeters (cm)) of annual precipitation occurs to the wetter region at its mouth where 40 to 44 in (102 to 112 cm) of annual precipitation occurs (Brazos G Regional Water Planning Group (BGRWPG) 2010, pp. 1–11). The southeastern portion of the upper Brazos River upstream of Possum Kingdom Lake includes portions of the Double Mountain Fork, Salt Fork, and Brazos River main stem. The river channel in this location is generally wide and shallow with sandy substrates. Periodic occurrences of reduced precipitation in upper Brazos River have resulted in intermittent flow causing the formation of isolated pools as the river runs dry.

The middle Brazos River has several impoundments including those forming Possum Kingdom Lake, Lake Granbury, Lake Whitney, and Lake Brazos. The middle Brazos River typically has streamflow throughout the year, but it is influenced by dams and reservoirs as discussed in Chapter 3. The impoundments of the middle Brazos River effectively isolate the upper, middle, and lower Brazos River from one another by restricting fish migration and altering natural stream flow and water quality.

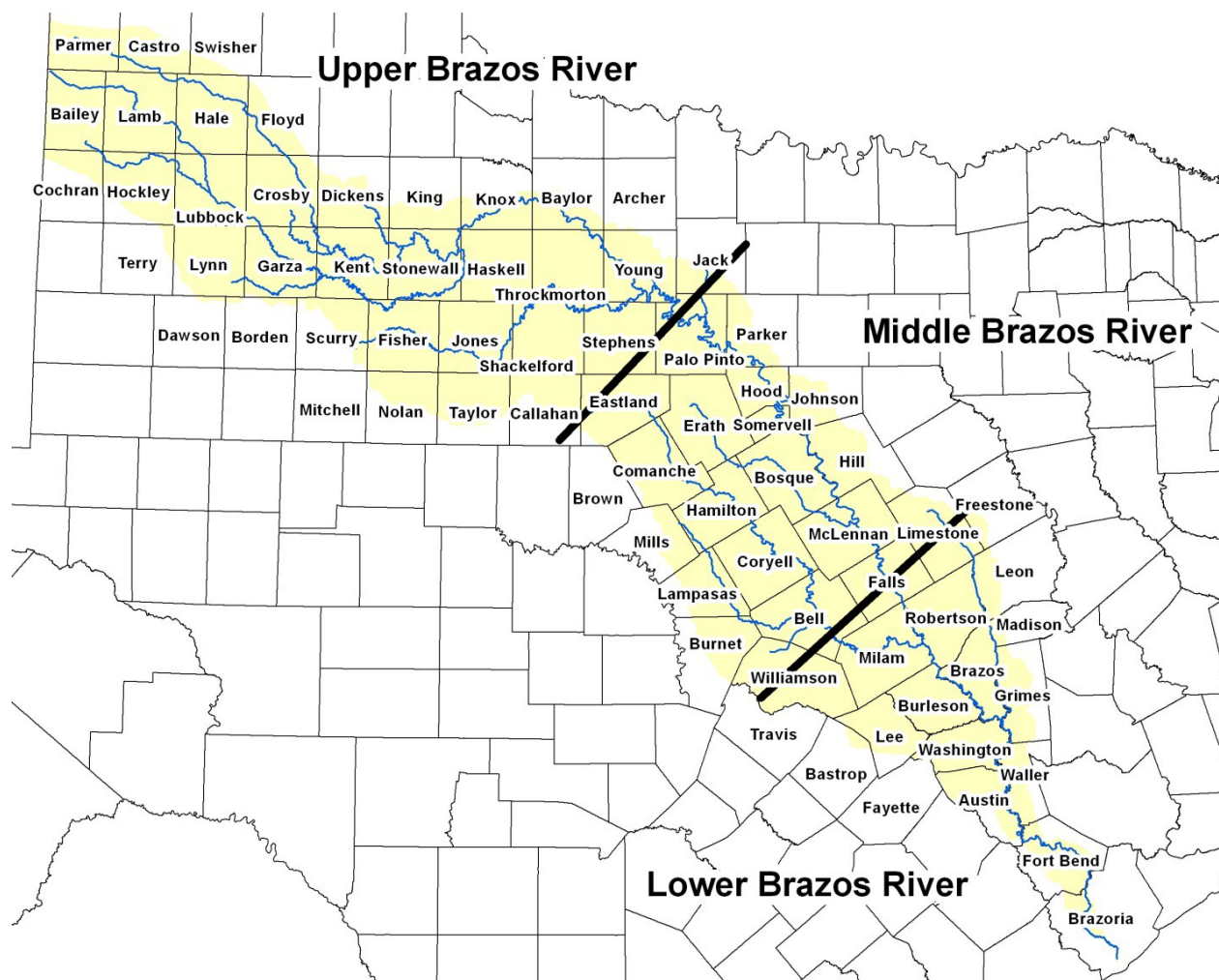


Figure 1. The Brazos River basin (yellow shading) partitioned into the upper, middle, and lower reaches.

The flow regime and substrates of the middle Brazos River are not typical of what was historically present. Monthly data (1923–2013) from the U.S. Geological Survey (USGS) streamflow gage 08091000 Brazos River near Glen Rose, Texas (downstream of both Possum Kingdom Lake and Lake Granbury) indicate the construction of Possum Kingdom Lake in 1941 resulted in a 17 percent drop in average yearly flow from pre-impoundment historical conditions (pre-dam average 1580.9 cfs, post dam average 1318.4 cfs) and the construction of Lake Granbury in 1969 further reduced the average yearly flow to a total loss of 36 percent at this gage station (1006.7 average cfs). The lower Brazos River is wider and deeper than the upper Brazos River, is not impounded by large reservoirs, and retains some of its natural features. The upper Brazos River is typical of the physical environment in which these species are currently associated.

2.1.2 Taxonomy and Genetics

Sharpnose shiner

The sharpnose shiner (*Notropis oxyrhynchus*) was first collected in 1884 (Cohen *et al.* 2014), but was not described until 1951 by Hubbs and Bonham, who speculated that its closest relative was *N. percobromus* (= *atherinoides*), which occurs in the Red River system to the north of the Brazos River drainage and in river systems to the east (Gilbert 1980a, p. 291). Phylogenetic analysis of the genus *Notropis* also indicates a close relationship between the sharpnose shiner and *N. atherinoides* (emerald shiner; Bielawski and Gold 2001, p. 660). Based on cladistic analysis of morphological characteristics, Coburn (1982, p. 166) suggests the sharpnose shiner is more closely associated with *N. jemezianus* (Rio Grande shiner), and belongs to the *N. shumardi* (silverband shiner) group, although the phylogenetic analysis of Bielawski and Gold (2001, entire) provides a more conclusive assessment. A review of the current literature indicates the species is a valid taxon (Gilbert 1980a, p. 291; Hubbs *et al.* 2008, p. 23; Froese and Pauly 2012, entire).

There is little published information regarding the genetics of sharpnose shiners, although all Notropids possess 50 diploid chromosomes ($2n = 50$; Amemiya *et al.* 1992, p. 516). Analysis of the cytochrome b gene supports sharpnose shiner monophyly with seven other *Notropis* species, with the sharpnose shiner being most closely associated with *N. atherinoides* (Bielawski and Gold 2001, pp. 660–661). The sharpnose shiner genome size is approximately 2.08 picograms (Gold *et al.* 1990, p. 15), or roughly 2.03 gigabases.

Smalleye shiner

The smalleye shiner (*N. buccula*) was first described by Cross in 1953 (pp. 252–259). At that time, Cross (1953, p. 258) placed the smalleye shiner (then *N. bairdi buccula*) as a new subspecies of the Red River shiner, *N. bairdi bairdi*, due to morphological similarity. Cross (1953, p. 258) suggested that the morphological differences between the two fish were minor and environmentally induced, not genetically fixed. Its taxonomic status was raised to full species by Hubbs (1957, p. 6) (Gilbert 1980b, p. 242). A review of the current literature indicates the species is a valid taxon (Gilbert 1980b, p. 242; Hubbs *et al.* 2008, p. 22; Froese and Pauly 2012, entire). There is no published information regarding the genetics of the smalleye shiner, although all Notropids possess 50 diploid chromosomes ($2n = 50$; Amemiya *et al.* 1992, p. 516).

2.1.3 Morphological Descriptions

Sharpnose shiner

The sharpnose shiner is a small, slender minnow (Figure 2; Hubbs *et al.* 1991, p. 21). Coloration is typically olive dorsally, silver-white ventrally, and silver laterally with a faint midlateral stripe most notable posteriorly (Thomas *et al.* 2007, p. 68). Adult sharpnose shiners are approximately 3 to 5 cm (1.2 to 2.0 in) in standard length, have a strongly curved ventral contour, and an oblique mouth (Hubbs and Bonham 1951, pp. 94–95). The head of the sharpnose shiner is more than one-fourth the standard length and is very sharp in both dorsal and lateral views (Hubbs and Bonham 1951, pp. 93–95). The anal fin has pigmentation at the base (Thomas *et al.* 2007, p.68), is slightly falcate, and has more than nine rays (typically 10)

while the dorsal fin has eight rays and begins behind the insertion of the pelvic fin (Hubbs and Bonham 1951, p. 95). The pharyngeal teeth number 2,4–4,2 (Hubbs and Bonham 1951, p. 95).

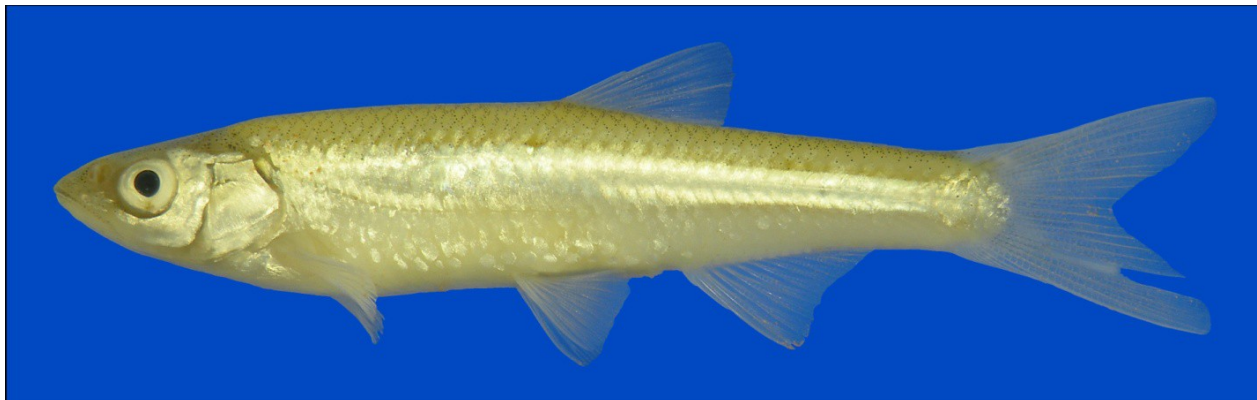


Figure 2. Sharpnose shiner, *Notropis oxyrhynchus*. Photo by Chad Thomas, Texas State University, San Marcos.

Smalleye shiner

The smalleye shiner is a small, pallid minnow, measuring 3.5 to 4.4 cm (1.4 to 1.7 in; Figure 3; Cross 1953, pp. 252–254). Coloration is typically olive-green with scales outlined by dark pigment dorsally, white ventrally, and silver laterally with a midlateral stripe scattered anteriorly and concentrated posteriorly (Thomas *et al.* 2007, p. 61). Melanophore distribution may give the appearance that the smalleye shiner is dotted dorsally or checkered laterally at the abdomen (Cross 1953, p. 254). The dorsal and pelvic fins have eight rays while the anal fin has seven rays; pharyngeal teeth number 0,4–4,0; its mouth is subterminal; and its snout length is greater than the distance from the anterior tip of the lower jaw to the posterior tip of the maxillary (Cross 1953, p. 252; Thomas *et al.* 2007, p. 61). As with other fishes of the minnow family Cyprinidae, the smalleye shiner can prove difficult to separate from closely related congeners. Moss and Mayes (1993, p. 14) found this confusion in historical collections to be most common with the chub shiner (*N. potteri*), silverband shiner (*N. shumardi*), and sand shiner (*N. stramineus*).



Figure 3. Smalleye shiner, *Notropis buccula*. Photo by Chad Thomas, Texas State University, San Marcos.

2.1.4 Reproduction

Sharpnose and smalleye shiners are broadcast-spawners with external fertilization, meaning that eggs and sperm are released into the water column where fertilization subsequently occurs (Durham and Wilde 2009a, p. 21). Based on studies of similar species, cyprinid (minnows) eggs spawned into the pelagic zone (open water not near the river bottom) typically become semi-buoyant within 10 to 30 minutes (Platanía and Altenbach 1998, p. 565), allowing them to drift through the water column for one or two days prior to hatching (Platanía and Altenbach 1998, p. 565; Moore 1944, p. 211). Pre-juvenile stages drift in the water column for an additional two to three days post-hatching before developing into a free-swimming juvenile stage (Moore 1944, pp. 211–212; Perkin and Gido 2011, p. 372). Once capable of horizontal swimming, sharpnose shiners and smalleye shiners likely behave similarly to Arkansas River shiners (*N. girardi*) (Moore 1944, p. 213) and move to the margins of the main channel, to eddies, and to water near tributary mouths where flow velocity is reduced and food sources are more abundant.

Mean annual fecundity of age-1 and age-2 females is 379.3 and 1379.9 eggs, respectively, in sharpnose shiners and 443.3 and 2175.4 eggs, respectively, in smalleye shiners (Durham 2007, p. 119). Sharpnose and smalleye shiners spawn continuously during their reproductive season, a strategy that is adaptive to stochastic environments and ensures that at least some offspring are potentially produced (Durham 2007, pp. 27–28; Durham and Wilde 2008, p. 538). Given the limited survival and longevity of these shiners, most individuals have only one reproductive season during their lifetime (Durham 2007, p. 27).

Spawning occurs asynchronously from April through September during periods of no- and low-flow, and large, synchronized spawning events occur during high streamflow events (Durham 2007, p. 24; Durham and Wilde 2008, entire; Durham and Wilde 2009a, p. 26). Field observation of sharpnose shiner and smalleye shiner in the upper Brazos River basin indicate successful survival to the juvenile fish stage does not occur during periods completely lacking flow (Durham and Wilde 2009a, p. 24). In no-flow conditions with only isolated pools for aquatic habitat, the ichthyoplankton of broadcast spawners—semi-buoyant eggs and larvae—are likely to sink and suffocate in the anoxic sediments and are more susceptible to predation (Platanía and Altenbach 1998, p. 565; Dudley and Platanía 2007, p. 2083).

2.1.5 Survival and Longevity

Survival rate and longevity are important to fully understand the status of imperiled species. Survival rates under natural conditions provide baseline data and insight into the potential effects future threats may have on the survivability of the species. An understanding of longevity is important in determining the ability of the species to withstand prolonged or persistent threats. A description of sharpnose and smalleye shiner survival and longevity is provided below.

Sharpnose shiner

The maximum lifespan for this species is less than 3 years (Marks 1999, p. 69). Mean daily survival rate (the likelihood that an individual will survive to the next day) is approximately

0.934 (Wilde and Durham 2008, p. 831) and when extrapolated over the course of the first year (age-0), second year (age-1), and third year (age-2), yearly survival rates (the likelihood that an individual will survive to the next year) are 0.0018, 0.1218, and 0.0, respectively (Durham 2007, p. 119). The susceptibility of early life stages (egg and developing larvae) to predation and unfavorable environmental conditions results in the low observed survival of age-0 fish (Durham 2007, p. 89). Although the survival of sharpnose shiners at all life stages is critically important to the overall health of their population, the reduced survival of early life stages suggests the most conservation benefit would be gained by alleviating factors affecting these stages.

Smalleye shiner

The maximum life span of the smalleye shiner is less than 3 years (Marks 1999, p. 69). Mean daily survival rate is approximately 0.937 (Wilde and Durham 2008, p. 831) and when extrapolated over the course of the first year (age-0), second year (age-1), and third year (age-2), survival rates are 0.0015, 0.107, and 0.0, respectively (Durham 2007, p. 119; Durham and Wilde 2009b, p. 669). The susceptibility of early life stages to predation and unfavorable environmental conditions results in the low observed survival of age-0 fish (Durham 2007, p. 89). Although the survival of smalleye shiners at all life stages is critically important to the overall health of their population, the reduced survival of early life stages (egg and developing larvae) suggest the most conservation benefit would be gained by alleviating factors affecting these stages.

2.2 Individual Needs

2.2.1 Microhabitat Requirements

Sharpnose and smalleye shiners are associated with fairly shallow, flowing water, often less than 0.5 meter (m) (1.6 feet (ft)) deep (Moss and Mayes 1993, pp. 21–22; Marks 1999, p. 86; Ostrand 2000, p. 33). Wilde (2012a, entire) measured stream depth at upper Brazos River basin sample locations containing sharpnose shiner and smalleye shiner from 2008 through 2012 and estimated mean depths of 0.25 m (0.8 ft) (range: 0.02–0.80 m (0.07–2.6 ft)) and 0.24 m (0.8 ft) (range: 0.02–0.86 m (0.07–2.8 ft)), for each species respectively. The average, wetted stream width (the width of the water within the river channel) at the time of successful fish collection from five upper Brazos River basin locations sampled multiple times from 2008 through 2012 was 34.1 m (111.9 ft) (range: 1.9–76.3 m (6.2–250.3 ft)) and 34.3 m (112.5 ft) (range: 1.9–76.3 m (6.2–250.3 ft)), for sharpnose shiners and smalleye shiners respectively (Wilde 2012a, entire). Moss and Mays (1993, p. 21) estimated a mean channel width of 59 m (193.6 ft) and 42 m (137.8 ft) at locations containing sharpnose and smalleye shiners, respectively, although the sharpnose shiner locations also included locations downstream of Possum Kingdom Lake.

Both species are most often associated with sandy substrates. However, in the lower Brazos River the sharpnose shiner occasionally occurred in areas characterized by large gravel and cobble (Moss and Mayes 1993, p. 22), and the smalleye shiner was occasionally found in areas of silt over sand or sand and small gravel (Moss and Mayes 1993, p. 22). Sharpnose and smalleye shiners are known to forage in sandy sediments, which may explain their preference for sandy substrates. Hubbs and Bonham (1951, p. 95) suggested that the sharpnose shiner is

likely a midwater to near-surface swimmer based on morphology. Moss and Mayes (1993, p. 23) found that smalleye shiners avoid very shallow water (< 3 cm, 1 in) at the river's edge, although it could not be discounted that this avoidance was due to the presence of additional silt in the substrate rather than a response to water depth. There is no evidence suggesting these species seek refuge in overbank areas of the floodplain in which to develop or grow, although adults may seek low-velocity refugia such as overbank areas and shallow channel edges during flood pulses to minimize being transported downstream. The use of a wide variety of microhabitats may be advantageous to fish inhabiting rivers with fluctuating environmental conditions because dispersal into available microhabitats may result in discovery of temporarily superior conditions in some river segments (Matthews and Hill 1980, p. 61). However, not all freshwater minnows display microhabitat breadth usage to the same degree. Red shiner (*Cyprinella lutrensis*) exhibits a wide use of microhabitats while Arkansas River shiner (*N. girardi*) displays a much more narrow use of microhabitats in the Canadian River (Matthews and Hill 1980, p. 61). Microhabitat partitioning among fish species in highly fluctuating environments, such as those of arid prairie streams like the upper Brazos River basin, is probably of limited importance and fish assemblage structure is likely reliant upon abiotic physiological and chemical factors (Matthews and Hill 1980, p. 63). Additionally, the relative importance of specific abiotic microhabitat characteristics to sharpnose and smalleye shiners may vary as river conditions also vary (Wilde and Durham 2013, p. 7).

2.2.2 Physiological Tolerances

Sharpnose and smalleye shiners are physiologically tolerant of the natural and abiotically variable conditions typical of the arid, High Plains streams in which they evolved. Often, little information is known regarding the physiological limits of rare species to changes in water quality, or their tolerance to a variety of organic and inorganic pollutants that are routinely introduced to U.S. waterways through point and non-point sources. However, recent studies of the sharpnose and smalleye shiners have provided limited insight into their tolerances for changes to basic water chemistry, including elevated temperature, dissolved oxygen (DO), salinity, and turbidity.

Sharpnose shiner

When acclimated to water temperatures of 30 degrees Celsius (°C) (86 degrees Fahrenheit (°F)) in a laboratory setting, sharpnose shiner has an acute critical thermal maximum (the temperature at which a fish lost equilibrium and failed to right itself) of approximately 39.2°C (102.6°F; Ostrand and Wilde 2001, p. 744). The chronic upper thermal limit (the temperature a species can withstand for extended periods) for this species has not been assessed, although chronic thermal limits of most organisms are typically less than acute critical thermal maxima. Isolated pools in the upper Brazos River naturally approach 36°C (96.8°F; Marks 1999, p. 87; Ostrand 2000, p. 69). Of five upper Brazos River fish species analyzed by Ostrand and Wilde (2001, p. 744), which included the Red River pupfish (*Cyprinodon rubrofluviatilis*), plains killifish (*Fundulus zebrinus*), plains minnow (*Hybognathus placitus*), smalleye shiner, and sharpnose shiner, both the sharpnose shiner and smalleye shiner were the least tolerant of elevated temperature.

At 25°C (77°F), sharpnose shiners lose equilibrium at DO concentrations less than 2.66

milligrams per liter (mg/L) (2.66 parts per million (ppm)) and were the least tolerant of hypoxic (low DO) conditions among five Brazos River species tested (Ostrand and Wilde 2001, p. 745). The DO level in isolated pools of the upper Brazos River basin is known to drop slightly below the laboratory-derived minimum tolerance of 2.66 mg/L (2.66 ppm) for this species, although it has not generally resulted in observed fish kills in the wild (Ostrand and Wilde 2001, pp. 745–746) suggesting that this species may be capable of acclimating to low DO concentrations (Ostrand and Wilde 2001, p. 746). However, DO concentrations in isolated pools along the upper Brazos River occasionally drop well below 1 mg/L (1 ppm) due to a lack of flow, a level where this species would be unable to survive (Ostrand and Marks 2000, p. 256).

Based on short-term (48 hour) static laboratory exposures to adult sharpnose shiners at 25°C (77°F), the concentration of sodium chloride that is lethal to 50 percent of exposed individuals, known as the LC50 value, is approximately 15 parts per thousand (ppt) (specific conductance of approximately 25 millisiemens per cm (mS/cm); Ostrand and Wilde 2001, p. 744). No mortality occurred at approximately 12 ppt of sodium chloride (specific conductance of approximately 22 mS/cm; Ostrand and Wilde 2001, p. 744). However, this information should be used with caution since short-term tests conducted in a laboratory setting may not be representative of long-term exposures that occur in the wild (i.e., *in situ*). It is common for LC50 values to decrease (i.e., mortality occurring at lower concentrations) when exposure times increase or early life stages are tested since short-term exposures to adult fish are generally considered to be less sensitive. Therefore, toxicity information based on acute testing of adults should be viewed in the context of its limitations, and should not be interpreted as protective of all life stages (e.g., larval fish) in the wild or under longer exposure scenarios.

Sharpnose shiner abundance and distribution is influenced by a salinity gradient as individuals shift toward areas within their physiological tolerances (Ostrand 2000, p. 87; Ostrand and Wilde 2001, p. 747). Of the five upper Brazos River fish species analyzed by Ostrand and Wilde (2001, p. 744), the sharpnose shiner was the least tolerant of elevated salinity. Sampling isolated pools along the upper Brazos River during the summer found that sharpnose shiners are not present in pools with a specific conductance greater than 30 mS/cm (approximately 18 ppt; Ostrand 2000, p. 50) and that sharpnose shiner abundance is negatively associated with increasing salinity (Ostrand 2000, pp. 50, 71). Salt plumes originating from natural springs along tributaries of the Salt Fork Brazos River are thought to cause mortality of sharpnose shiners under low flow conditions (Wilde 2012b, pers. comm.).

Although turbidity (the suspension of solid particles in the water column) can be very high in the Brazos River (>4002 nephelometric turbidity units (NTU)), particularly after rain events with significant stormwater runoff, it has not been shown to cause declines in abundance for this species (Ostrand 2000, p. 55). This suggests sharpnose shiners are capable of tolerating high turbidity for extended periods.

Sharpnose shiners, like other native fishes of the upper Brazos River, are relatively tolerant of the highly variable water conditions typical of arid prairie streams, including naturally elevated temperature, salinity, and turbidity, and low DO (Table 1). However, these tolerances are exceeded at times, and abiotically induced mortality resulting from low DO in isolated pools is known to occur, and mortality may also result from naturally occurring salt plumes under low

flow conditions.

Table 1. Physiological tolerances¹ of sharpnose and smalleye shiners based on acute (short term, 48 hour) lab tests. See text for additional information.

Metric	Sharpnose	Smalleye
Acute thermal maximum	39.2°C (102.6°F)	40.6°C (105.1°F)
Acute thermal minimum	unknown	unknown
Salinity LC50*	15 ppt	18 ppt
Conductivity*	25 mS/cm	30 mS/cm
DO*	2.66 mg/L	2.11 mg/L
Turbidity maximum	unknown	unknown

*At 25°C

¹ Note: Prolonged exposures above or below tolerance levels may cause harm to fish.

Smalleye shiner

When acclimated to water temperatures of 30°C (86°F) for at least two weeks in a laboratory setting, smalleye shiners have an acute critical thermal maximum of approximately 40.6°C (105.1°F; Ostrand and Wilde 2001, p. 744). The chronic upper thermal limit for this species has not been assessed, although chronic thermal limits of most organisms are typically below acute critical thermal maxima. Isolated pools in the upper Brazos River naturally approach 36°C (98.6°F; Marks 1999, p. 87; Ostrand 2000, p. 69). The smalleye shiner had statistically equivalent thermal tolerance as sharpnose shiners (Ostrand and Wilde 2001, p. 744).

At 25°C (77°F), smalleye shiners lose equilibrium at DO concentrations below 2.11 mg/L and were the second-least tolerant (after the sharpnose shiner) of hypoxic (low DO levels) conditions among five Brazos River fish species tested (Ostrand and Wilde 2001, p. 745). The DO levels in isolated pools of the upper Brazos River basin commonly drop slightly below the laboratory- derived minimum tolerance of this species, without resulting in observed fish kills (Ostrand and Wilde 2001, pp. 745–746). As a result it has been suggested that this species may be capable of acclimating to slightly lower oxygen concentrations than those tested in the laboratory (Ostrand and Wilde 2001, p. 746). However, when oxygen concentrations drop below 1 mg/L, as is common in isolated pools along the upper Brazos River during dry weather, mortality will result (Ostrand and Marks 2000, p. 256).

Based on short-term (48 hour) static laboratory exposures to adult smalleye shiners at 25°C (77°F), the LC50 for sodium chloride is approximately 18 ppt (specific conductance of approximately 30 mS/cm; Ostrand and Wilde 2001, p. 744). No mortality occurred at approximately 16 ppt of sodium chloride (specific conductance of approximately 27 mS/cm; Ostrand and Wilde 2001, p. 744). However, as stated above, short-term tests conducted in a laboratory setting provide limited insight into long-term exposures that occur in natural settings. It is common for LC50 values to decrease when exposure times increase or early life stages are tested since short-term exposures to adult fish are generally considered to be less sensitive. Therefore, toxicity information based on acute testing of adults should be viewed with caution and may not be protective of early life stages (i.e., larval fish) or exposure times beyond 48 hours.

Smalleye shiner abundance and distribution is influenced by a salinity gradient as individuals shift toward areas within their physiological tolerances (Ostrand 2000, p. 87; Ostrand and Wilde 2001, p. 747). Of the five upper Brazos River fish species analyzed by Ostrand and Wilde (2001, p. 744), the smalleye shiner was the second least tolerant (after the sharpnose shiner) of elevated salinity. Sampling isolated pools along the upper Brazos River indicated that smalleye shiners are not present in pools with a specific conductance greater than 30 mS/cm (approximately 18ppt; Ostrand 2000, p. 50) and that smalleye shiner abundance is negatively associated with increasing salinity (Ostrand 2000, pp. 50, 71). Salt plumes originating along tributaries of the Salt Fork Brazos River are thought to cause mortality of smalleye shiners (Wilde 2012b, pers. comm.).

Although turbidity can naturally be very high in the upper Brazos River (>4002 NTU) following a rain event, it does not appear to cause declines in abundance for this species (Ostrand 2000, p. 55), suggesting that smalleye shiners are capable of tolerating extreme turbidity for extended periods.

Smalleye shiners, like other native fishes of the upper Brazos River, are adapted to the highly variable water conditions typical of arid prairie streams, including naturally elevated temperature, salinity, and turbidity, and low DO (Table 1). However, environmentally induced mortality resulting from low DO in isolated pools is known to occur, and mortality may also occur from naturally occurring salt plumes. Their relative intolerance to changes in abiotic factors such as low DO compared to fish with which sharpnose and smalleye shiners coexist in the upper Brazos River basin suggests they are more vulnerable and may be at a competitive disadvantage for limited resources during summer drought conditions, although additional research is needed to verify this statement.

2.2.3 Feeding Habits

Sharpnose and smalleye shiner are generalist feeders, relying on a variety of food items to sustain growth and reproduction. Both species have similar feeding habits described below.

Sharpnose shiner

Averaged over one year, the gut contents (by weight) of sharpnose shiners consist primarily of invertebrates (71 percent), sand-silt (18 percent), plant material (7 percent), and detritus (4 percent) (Marks *et al.* 2001, p. 331). However, feeding habits vary by season with most of the sand-silt gut contents occurring mid-summer, plant contents during spring and summer, and detritus contents during spring and fall (Marks *et al.* 2001, p. 330). Invertebrate consumption, primarily insects, make up a majority of the diet of the sharpnose shiner except during mid-summer when pools become isolated and the gut contents shifts primarily to sand-silt and plant material (Marks *et al.* 2001, pp. 330–332). The prevalence of sand-silt in the digestive tract of the sharpnose shiner suggests that this species forages among sediments on the river bottom (Moss and Mayes 1993, p. 33; Marks *et al.* 2001, p. 332). The proportion of terrestrial insects in the diet of the sharpnose shiner also suggests that during periods of prey availability this species

feeds more frequently in the water column than the smalleye shiner (Moss and Mayes 1993, p. 33; Marks *et al.* 2001, p. 332).

Smalleye shiner

Averaged over one year, the gut contents (by weight) of smalleye shiners consist primarily of sand-silt (42 percent), invertebrates (38 percent), detritus (14 percent), and plant material (5 percent; Marks *et al.* 2001, pp. 330–331). However, feeding habits vary by season with most of the sand-silt gut contents occurring mid-summer through fall, plant gut contents during spring and summer, and detritus gut contents during spring and fall (Marks *et al.* 2001, p. 330). The prevalence of sand-silt and detritus in the gut of the smalleye shiner suggests that this species forages among sediments on the river bottom throughout the year (Moss and Mayes 1993, p. 35; Marks *et al.* 2001, pp. 330–332). Although the presence of terrestrial insects in the diet of smalleye shiners is not as prevalent as that of sharpnose shiners, terrestrial insects are consumed (Moss and Mayes 1993, p. 33; Marks *et al.* 2001, p. 332).

2.3 Population Needs

2.3.1 Abundance

Populations require a minimum number of individuals to assure stability and persistence. This is often referred to as the minimum viable population and is generally calculated through a population viability analysis that estimates extinction risk given a number of input variables. There are no published minimum viable population estimates for sharpnose or smalleye shiners; therefore, it is unknown how many fish are required to sustain populations of these fish. However, population health is dependent on water availability and other life history needs found within their habitats, which can be assessed and evaluated.

2.3.2 Streamflow Requirements

The streamflow regime (timing and magnitude of flow variation) is one of the most important aspects of river ecology to which native species become adapted. Maintaining streamflows is important to provide habitat for both species; however, adult sharpnose and smalleye shiners are capable of surviving temporarily in isolated pools with no flow, provided water quality conditions remain within their physiological tolerances (Ostrand and Wilde 2004, pp. 1329–1338). As discussed previously, both species are also capable of spawning during periods of no flow (Durham 2007, p. 24); however, successful survival to the juvenile fish stage does not occur during periods lacking flow (Durham and Wilde 2009a, p. 24). The greatest proportion of young-of-year fish are produced during elevated streamflow events indicating the importance of flowing water for successful reproduction and recruitment (Durham and Wilde 2009a, p. 26).

Based on current life history information, population dynamics modeling estimates a mean summer (May – September) water discharge of approximately $2.61 \text{ m}^3 \text{ s}^{-1}$ (92 cfs) is necessary to sustain populations of sharpnose shiners (Durham 2007, p. 110), while a higher mean discharge of approximately $6.43 \text{ m}^3 \text{ s}^{-1}$ (227 cfs) is necessary for smalleye shiners (Durham and Wilde 2009b, p. 670). Discharge values were calculated using a population dynamics model containing population age structure, age-specific survival, and age-specific fecundity (Durham

2007, p. 101; Durham and Wilde 2009b, p. 668).

Durham (2007, p. 107) also constructed two alternative models (a static model assuming no change in abundance through time, and a constant- λ (lambda) model assuming constant rate of population growth) to compare to the sharpnose shiner discharge model. The smalleye shiner discharge model was additionally compared to an inverse discharge model, where abundance varied inversely to discharge (Durham and Wilde 2009b, p. 669). For the smalleye shiner, the discharge model was the best predictor of fish abundance (Durham and Wilde 2009b, p. 670) and predicted abundance very closely to field observation (Durham 2007, p. 109). For the sharpnose shiner, the discharge model predicted actual fish abundance well with the exception of the final year of the study, in which it greatly over-predicted fish abundance (Durham 2007, pp. 109–110). In the absence of additional studies, the minimum mean discharges during the spawning season (April – September) of $2.61 \text{ m}^3\text{s}^{-1}$ (92 cfs) and $6.43 \text{ m}^3\text{s}^{-1}$ (227 cfs) are the best available estimates of discharge required to sustain populations (i.e., to maintain a population growth rate of 1.0) of the sharpnose and smalleye shiner in the upper Brazos River, respectively. Lack of attainment of these flow requirements in any single year does not insinuate the fish populations will be driven to extinction, but rather the population will likely decrease in size. However, if river flows are further reduced such that flow requirements are not met during multiple, consecutive reproductive seasons the continual decline of population numbers will eventually lead to their extirpation and extinction. The number of consecutive years failing to meet flow requirements necessary to drive the fish species to extinction will likely be dependent on a number of factors, including the number and intensity of pulse flows and by how much the minimum required flow was deficient.

The difference between estimated minimum mean discharges for the two species can be partially explained by the differences in observed age-0 survival of these species in the field. Smalleye shiners have a lower observed age-0 survival (Durham 2007, p. 119) suggesting they may require higher flows to sustain their population. The sharpnose shiner discharge model's failure to accurately predict fish abundance during the final year of the study also suggests additional parameters not accounted for during modeling may be important. There is more statistical confidence in the smalleye shiner discharge model that more accurately predicted abundance. Regardless, given the minimum mean discharge estimated for the smalleye shiner exceeds that estimated for the sharpnose shiner, management or attainment of discharge at the smalleye shiner level will also protect sharpnose shiners.

Although sharpnose and smalleye shiners have instream flow requirements to support reproduction, given their diminutive size they likely also have a maximum flow they can tolerate before being transported downstream unless lower-velocity refugia are present. The maximum swimming rate of the sharpnose and smalleye shiner is approximately 0.53 and 0.49 meters per second (m/s) (1.7 and 1.6 ft/s), respectively (Leavy and Bonner 2009, p. 76). Fully grown Topeka shiners (*N. topeka*), a similar species, are capable of swimming in water velocities of 0.40 m/s (1.3 ft/s) for more than 200 minutes but would likely be carried downstream at higher velocities in the absence of lower-velocity refugia such as backwaters and stream edges (Adams *et al.* 2000, p. 182; Dodds *et al.* 2004, p. 212). The swimming capabilities of sharpnose and smalleye shiners could be important in determining the suitability of deeply incised river segments lacking low-velocity refugia, as might occur from saltcedar

encroachment or man-made channelization.

2.3.3 Stream Reach Length Requirements

Considering sharpnose and smalleye shiners broadcast spawn semi-buoyant eggs that remain ichthyoplanktonic (floating in the water column) for up to five days before larval fish are capable of independent swimming, there is some minimum stream reach length that can support successful recruitment in these species. This minimum reach length is largely dependent on discharge, channel morphology, and water temperature (Dudley and Platania 2007, p. 2082). Although the development times for the sharpnose and smalleye shiner at different temperatures have not been assessed, similar cyprinid species develop a gas bladder (an internal gas-filled sac providing control over fish buoyancy) and are capable of free-swimming approximately 4 days post-spawning at 25°C (77°F), up to 7 days at 20°C (68°F), and up to 10 days at 15°C (59°F; Dudley and Platania 2007, p. 2082). Laboratory observation of sharpnose shiner development appears to support these development times (Wilde 2012b, pers. comm.). At a flow speed of 0.3 m/s and temperature of approximately 25°C—a typical early or late spawning season flow speed and temperature for the upper Brazos River (Ostrand 2000, pp. 33, 41) — ichthyoplanktonic life stages of these species can be expected to travel more than 103 km (64 mi) in the four days required to develop into a free-swimming fish. Platania and Altenbach (1998, p. 566) estimated that at a drift rate of 3 km/h (0.83 m/s) cyprinid eggs could be transported 72 to 144 km (45 to 89 mi) before hatching and that developing larvae could drift another 216 km (134 mi) before developing the capability for free-swimming. Sharpnose and smalleye shiners synchronize spawning with elevated streamflow events, suggesting that flow speeds are much higher, and drift distances much greater, when the greatest number of young are produced. However, drifting eggs and larvae may also be caught behind flood pulses, or entrained in slackwaters and eddies, reducing the distance they are transported downstream (Hoagstrom and Turner 2013, entire). If the upper Brazos River becomes more deeply incised, narrower, and channelized (such as might occur from saltcedar encroachment), lower-velocity refugia will be less available and transport distances of ichthyoplanktonic life history stages may be greater.

The drift distances of developing eggs and larvae of broadcast-spawning cyprinids suggest that stream reach length is an important factor in determining the success of reproductive effort in these species. For example, Dudley and Platania (2007, p. 2080) found that reaches less than 100 km (62 mi) do not retain pelagophils (broadcast-spawning freshwater fishes with buoyant eggs) and that reaches greater than 100 km (62 mi) retain at least some percentage of native pelagophils. Perkin *et al.* (2010, p. 6) found that extirpated populations of pelagophils were associated with average river reaches of 144 km (89 mi) or less, declining populations with reaches of approximately 205 km (127 mi), and stable populations with reach lengths over 425 km (264 mi). Modeling population status and reach length indicated extirpation of eight different Great Plains broadcast-spawning minnow species occurred in fragments less than 115 km (71 mi; Perkin *et al.* 2010, p. 7) and that no extirpations were recorded in reaches greater than 275 km (171 mi). Perkin and Gido (2011, p. 374) estimated that the congeneric Arkansas River shiner (*N. girardi*) needs a minimum unfragmented river reach length of 217 km (135 mi) to ensure population persistence.

Given the information available, the minimum reach for successful recruitment of the

sharpnose and smalleye shiners may be similar to that of the congeneric Arkansas River shiner at approximately 217 km (135 mi) (Perkin and Gido 2011, p. 374). However, until more specific information is available for sharpnose and smalleye shiners, a reach length of greater than 275 km (171 mi) is recommended for long-term survival of these species considering Perkin *et al.* (2010, p. 7) observed no extirpations of broadcast-spawning minnows in river reaches greater than this length. A required length of 275 km (171 mi) is further corroborated by Wilde and Urbanczyk's (2013, entire) analysis of presence/absence of sharpnose and smalleye shiners. They estimate a required river length of approximately 599 km (372 mi) for species persistence, although the authors acknowledge this length is likely an overestimate due to fish survey record and reach length bias (Wilde and Urbanczyk 2013, p. 5). The longest reach from which one or both species had become extirpated was approximately 258 river km (168 river mi) and the authors' logistic curve shows a marked increase in probability of persistence at fragment lengths greater than 275 km (171 mi) (Wilde and Urbanczyk 2013, p. 3–4). The sicklefin chub (*Macrhybopsis meeki*), another suspected broadcaster spawner, has the highest predicted presence in river segments over 301 km (187 mi) downstream from an impoundment (Dieterman and Galat 2004, p. 585). Recruitment may occur in river segments shorter than 275 km (171 mi); for instance, when elevated water temperatures decrease larval development time, when flow speeds are low, yet adequate to suspend eggs and larvae, or when ichthyoplanktonic life stages are entrained in slackwaters and eddies. However, under fragmented river conditions, these species are expected to lose a portion of their reproductive effort (i.e., eggs and larvae) to downstream reservoirs or to the next river segment, leading to a lack of population sustainability in river reaches shorter than 275 km (171 mi) (Dudley and Platania 2007, p. 2074). Eggs and larvae lost to large downstream reservoirs likely succumb to the factors explained above, while those lost over falls, weirs, low-water crossings, and small impoundments may survive but may be unable to migrate back upstream to suitable habitat as adults. Since eggs and larvae are transported downstream during development, juveniles and adults likely migrate back upstream prior to spawning or their current and historical populations might eventually have been forced into downstream impoundments or the Gulf of Mexico. In artificially constructed flowing water, field-caught Rio Grande silvery minnows (*Hybognathus amarus*) orient themselves upstream and are capable of moving distances greater than 100 km (61 mi) within a few days, indicating this broadcast spawning species is capable of long distance upstream migration following downstream dispersal of ichthyoplanktonic life history stages (Bestgen *et al.* 2010, p. 440).

Conceptually, when streamflow decreases sharpnose and smalleye shiners may swim downstream until suitable conditions for survival and reproduction are met, although additional studies are required to fully characterize the migratory response of these species. Although direct experimental assessment of downstream cyprinid migration in response to river drying and drought is not well documented, several papers suggest it may occur. Winston *et al.* (1991, p.103) speculated one reason for the extirpation of the plains minnow, Red River shiner, speckled chub (*Macrhybopsis aestivalis*), and chub shiner above Lake Altus on the North Fork of the Red River was due to being poorly adapted to lentic conditions as they were forced to move into the lake when the upstream river dried up during late summer. Mammoliti (2002, p. 223) and Schlosser (1995, p. 79) suggest some lentic fish species seek refuge downstream in response to drought. The endangered Topeka shiner also migrates downstream into impounded reservoirs during drought, where they are subjected to predation

by lentic species (Service 2009, p. 17). Lake (2011, pp. 221–222) indicates that fish species of an intermittent Iowa stream migrate downstream in response to drought, while some fish of an artificial stream in New Zealand migrate upstream. Hodges and Magoulick (2011, pp. 518–519) found that some species increase movement as water availability decreases in a perennial Arkansas stream, although some species moved directionally towards pools while others moved non-directionally. When higher streamflows return, fish that migrated downstream could recolonize upstream reaches. For example, the Pecos bluntnose shiner (*N. simus pecosensis*) is a broadcast-spawning minnow restricted to a 333-km (207 mi) section of the Pecos River whose eggs and juvenile life stages are carried downstream with flowing water. However, they are occasionally depopulated in upstream reaches when water flow becomes intermittent or drying occurs, but individuals that sought temporary refuge downstream in spring-fed refugia later recolonize desiccated habitats when streamflow returns (Hoagstrom *et al.* 2008, entire).

In summary, the best available science suggests the primary needs of sharpnose and smalleye populations include a minimum, unobstructed, wide, flat, flowing river segment length of greater than 275 km (171 mi) to support development of their early life history stages. Although sharpnose and smalleye shiners are capable of successfully producing offspring during periods of flow rapid enough to complete their life history stages, reproductive activity is increased during elevated streamflow events (such as pulse flows occurring during stormwater runoff), suggesting these elevated flows are likely important to the long term viability of these species. Downstream transport of their ichthyoplanktonic life history stages may be greater during periods of elevated flow when reproductive activity is increased.

2.4 Species Rangewide Needs

2.4.1 Historical Range

In determining the historical range of the sharpnose shiner and smalleye shiner, the Service has included only river segments from which confirmed historical records (1884–2012) have been collected. Some of our information is based on unpublished museum records that are available in museum databases, for example, historical fish collections housed at the University of Texas- Texas Natural History Collection and cited as Hendrickson and Cohen (2010) and Cohen (2012).

Sharpnose shiner

The natural historical distribution of the sharpnose shiner is considered to include the Brazos, Colorado, and Wichita River basins (Table 2, Figure 4). Museum records (1940–2012) clearly indicate that this species was once relatively common throughout the Brazos River basin including portions of the upper basin, the middle basin, and the lower basin (Table 2). Within the Brazos River drainage system, the furthest upstream record is from 1967 in the North Fork Double Mountain Fork Brazos River near the Crosby-Garza County line (Hendrickson and Cohen 2010). The furthest downstream record is from 1951 in the Brazos River near central Fort Bend County (Moss and Mayes 1993, p. 20). The sharpnose shiner has never been collected from the Clear Fork of the Brazos River.

The sharpnose shiner was also recorded in the Wichita River system of the Red River basin in the 1950s (Table 2). It is suspected that the sharpnose shiner population that once existed in the Wichita River system was a natural expansion, presumably from the transfer of flood waters between the Salt Fork Brazos River and the South Fork of the Wichita River (Lewis and Dalquest 1957, p. 42). A single sharpnose shiner was also recorded from the Lake Arrowhead area of the Little Wichita River in 1975 (Hendrickson and Cohen 2010; Cohen 2012, unpublished data). Given the unsuitability of impounded reservoirs to support reproductive populations of this species, we presume the Lake Arrowhead record is a human introduction.

It is likely the sharpnose shiner historically and naturally occurred in the Colorado River basin for two reasons. First, several historical museum records have documented the species over a wide range of dates and from a wide area of the Colorado River (Cohen and Hendrickson 2013, p. 11 and Cohen *et al.* 2014, p. 14). Second, the Brazos River has been hydrologically connected to the Colorado River in the past, providing opportunities for fish from the Brazos River to move into the Colorado River.

Sharpnose shiner records in the Colorado River basin have previously been assumed to be human-mediated bait fish introductions based on the location of collections near reservoirs where bait might have been released by anglers (Moss and Mayes 1993, p. 15; Hubbs *et al.* 2008, p. 23), but this assumption appears to be based on a single record from the Lake Travis area, near Austin, Texas (Jurgens 1954, p. 155). Cohen *et al.* 2014 (p. 12) re-evaluated the nativity of the sharpnose shiner to the Colorado River system and identified five verifiable records and one unverified record attributing the sharpnose shiner's nativity to this river system. The five verifiable records include 12 specimens collected in Austin in 1884 (Jordan and Gilbert 1886), an unspecified number of specimens collected near Colorado City in 1940 (Hendrickson and Cohen 2010; Cohen 2012, unpublished data), 10 specimens collected near Wharton in 1940 (Hendrickson and Cohen 2010; Cohen 2012, unpublished data), five specimens collected near Robert Lee in 1955 (Hendrickson and Cohen 2010), and one near San Saba in 1952 (Hubbs *et al.* 2008, p. 23; Hendrickson and Cohen 2010; Cohen 2012, unpublished data). The unverified record is from 1963 in the San Saba River near Fort McKavett, Menard County, Texas (Hendrickson and Cohen 2010; Cohen 2012, unpublished data), but Cohen *et al.* 2014 (p.12) speculates that this record may be a misidentification as the specimen was captured in a tributary off the main stem of the river.

Table 2. Records of collections of naturally occurring sharpnose shiners

River Basin	Stream	References
Upper Brazos River	N. Fork Double Mountain Fork	1, 2, 3, 5
	Double Mountain Fork	1, 2, 3, 4, 5, 6
	Salt Fork	1, 2, 3, 4, 5, 6
	Brazos River Main Stem	1, 2, 3, 4, 5, 6
	Croton Creek	7
Middle Brazos River	Brazos River	1, 2, 8
	Keechi Creek	2
	Lower Bosque River	2
	Towash Creek	2
	Coon Creek	2
Lower Brazos River	Brazos River	1, 2, 9, 15
	Salado Creek/Little River	2
	Navasota River	9
Red River	North Wichita River	10
	South Wichita River	10
	Wichita River	10
	Beaver Creek	2
Colorado River	Colorado River	2, 11, 12, 13, 16
	Hurst Creek Slough	14

References: (1) Moss and Mayes 1993, pp. 19–20; (2) Hendrickson and Cohen 2010; (3) Wilde 2011, p. 21; (4) Marks *et al.* 2001, p. 328; (5) Ostrand 2000, p. 34; (6) Durham 2007, p. 95; (7) Johnson *et al.* 1982, p. 14; (8) Forshage 1972, p. 11; (9) Hubbs and Bonham 1951, pp. 95–96; (10) Lewis and Dalquest 1957, pp. 42, 49–52; (11) Cohen 2012, unpublished data; (12) Hubbs *et al.* 2008, p. 23; (13) Wang 2004, pp. 28, 127; (14) Jurgens 1954, p. 155; (15) Winemiller *et al.* 2004, p. 25; and (16) Cohen *et al.* 2014, p. 5.

Fish have likely had opportunities to naturally move between the Brazos River and Colorado River by hydrological connectivity during past flood events. For example, historical flood records indicate that the lower Colorado and lower Brazos Rivers were connected during a December 1913 flood by a 100-km-wide (65-mi) lake (Slade and Patton 2003, entire; Williams 2010, p. 1). In 1869 the Colorado River had a flood of equal or greater magnitude (Slade and Patton 2003, entire), and although it is not recorded that the two rivers were also joined at this time, it may have occurred. Flood events of slightly lesser magnitude were also recorded in 1833, 1836, 1843, 1852, and 1870 (Slade and Patton 2003, entire) that could have connected the two rivers. Given the apparent intensity and frequency of flood events on both the lower Brazos and Colorado Rivers prior to their impoundment, it appears likely that sharpnose shiners could have naturally moved between the two basins. This is further corroborated by the historical prevalence of abrupt changes in course (channel migration) of the downstream portions of Texas rivers which may have occasionally brought river channels closer together (Phillips 2009, entire) or merged them completely at their mouths (Blum and Hattier-Womack 2009, pp. 26–35). Therefore, the now extirpated population of sharpnose

shiners in the Colorado River is tentatively considered part of its natural, historical range. Recent investigations into museum specimens historically collected from the Colorado River suggest the occurrence of this species in this river may have been widespread but exceptionally rare (Cohen *et al.* 2014, entire). The wide geographic and temporal distribution of these collections would indicate there were natural populations of the sharpnose shiner historically in the Colorado River. Although, based on the small number of individuals reported and the scarcity of these records, we presume the population was not historically abundant in the Colorado River basin and that the Brazos River served as the source population.

Smalleye shiner

The natural historical distribution of the smalleye shiner is considered to be limited to the Brazos River basin (Table 3, Figure 5). Records (1940–2012) clearly indicate that this species was once common throughout much of the Brazos River basin (Table 3, Figure 5). Within the Brazos River drainage system, the furthest upstream records are from 1964 and 1969 in the White River and North Fork Double Mountain Fork Brazos River, respectively (Hendrickson and Cohen 2010; Cohen 2012, unpublished data). The furthest downstream record is from 1953 in the Brazos River near the City of Hempstead, Waller County (Moss and Mayes 1993, p. 20). The smalleye shiner has never been collected from the Clear Fork of the Brazos River or the Red River basin.

Table 3. Records of collections of naturally occurring smalleye shiners

River Basin	Stream	References
Upper Brazos River	N. Fork Double Mountain Fork	1, 2, 3, 5
	Double Mountain Fork upstream of N. Fork Double Mountain Fork*	1, 5
	Double Mountain Fork	1, 2, 3, 4, 5, 6
	Salt Fork	1, 2, 3, 4, 5, 6
	Brazos River Main Stem	1, 2, 3, 4, 5, 6
	Croton Creek	1
	White River	2
Middle Brazos River	Brazos River	1, 2, 7
	Coon Creek	2
Lower Brazos River	Brazos River	1, 2
	Lampasas River	1, 2

References: (1) Moss and Mayes 1993, pp. 17–18; (2) Hendrickson and Cohen 2010; (3) Wilde 2011, p. 21; (4) Marks *et al.* 2001, p. 328; (5) Ostrand 2000, p. 34; (6) Durham 2007, p. 95; and (7) Cross 1953, p. 252. **Some references and sources inaccurately refer to the portion of the Double Mountain Fork Brazos River upstream of the confluence with the North Fork Double Mountain Fork Brazos River as “South Fork Double Mountain Fork Brazos River.” For brevity, this document will refer to this portion of the Double Mountain Fork Brazos River as “Double Mountain Fork upstream of North Fork Double Mountain Fork.”*

In the early 1950s, the smalleye shiner was recorded from the Colorado River near the City of Austin (Moss and Mayes 1993, p. 113; Wang 2004, pp. 27, 126). Although records of the

smalleye shiner in the Colorado River basin are generally assumed to be human-mediated bait fish introductions (Gilbert 1980b, p. 242; Wang 2004, p. 27; Hubbs *et al.* 2008, p. 22), it cannot be discounted that flooding between the Colorado River and the Brazos River may have naturally transferred this species between basins (see discussion above under Historical Range, Sharpnose Shiner). However, collection records suggest smalleye shiners were not as abundant as sharpnose shiners in the lower Brazos River and likely did not successfully colonize the Colorado River during intense flood events.

This is corroborated by the fact that, unlike the sharpnose shiner, there is a lack of records for the smalleye shiner throughout the Colorado River, which suggests it did not occur naturally in this basin. Based on the lack of other collection records, we presume that the one record from the Austin area was a bait fish introduction and that the smalleye shiner did not naturally occur in the Colorado River.

In summary, although the sharpnose shiner and smalleye shiner are associated with arid prairie streams such as the Brazos River, their rangewide needs revolve around the length and flows of unfragmented habitat contiguous with, and downstream of, currently occupied areas of the upper Brazos River.

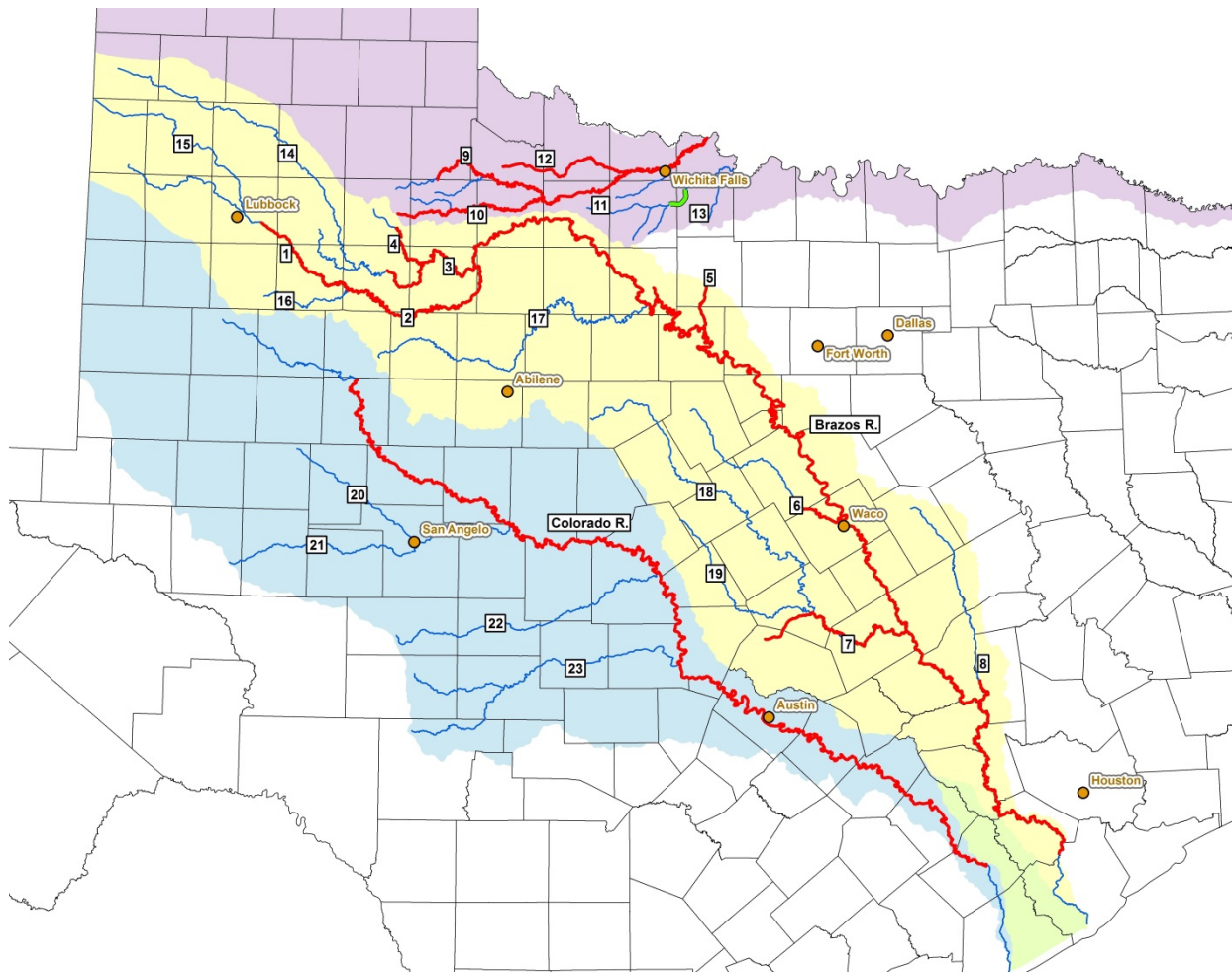


Figure 4. Maximum historical range of the sharpnose shiner, *Notropis oxyrhynchus*. Red lines represent naturally occurring areas while the green line represents areas suspected of human-mediated dispersal. The Red River basin (pink shading), Brazos River basin (yellow shading), Colorado River basin (blue shading), Brazos-Colorado River basin (green shading), and rivers and large streams (blue lines) of these basins are also shown. Large rivers and tributaries are labeled as follows: 1) North Fork Double Mountain Fork Brazos River, 2) Double Mountain Fork Brazos River, 3) Salt Fork Brazos River, 4) Croton Creek, 5) Keechi Creek, 6) (Lower) Bosque River, 7) Little River/Salado Creek, 8) Navasota River, 9) North Wichita River, 10) South Wichita River, 11) Wichita River, 12) Beaver Creek, 13) Lake Arrowhead on the Little Wichita River, 14) White River, 15) Running Water Draw, 16) Double Mountain Fork upstream of N. Fork Double Mountain Fork Brazos River, 17) Clear Fork of the Brazos River, 18) Leon River, 19) Lampasas River, 20) North Concho River, 21) Middle Concho River, 22) San Saba River, 23) Llano River.

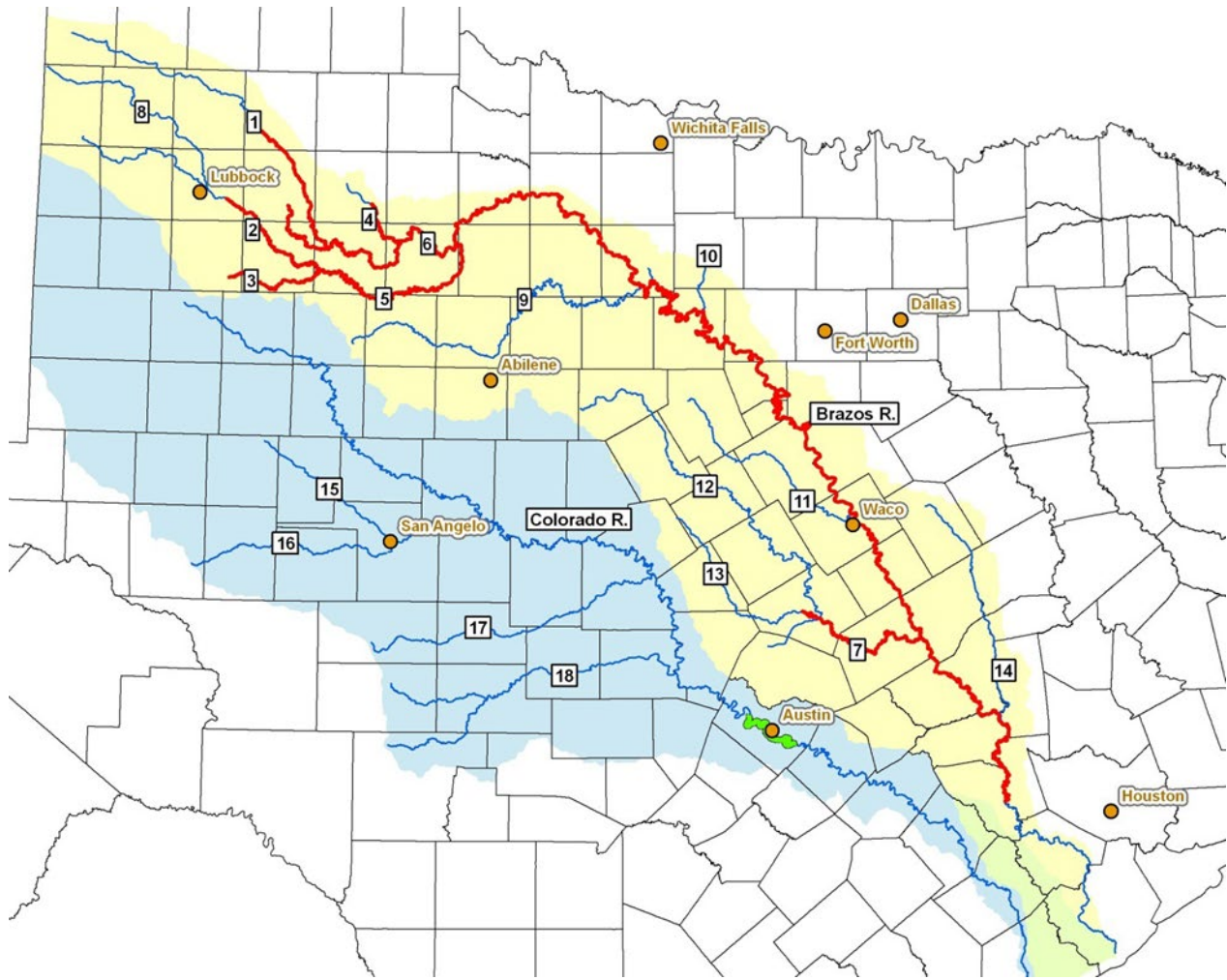


Figure 5. Maximum historical range of the smalleye shiner, *Notropis buccula*. Red lines represent naturally occurring areas while green lines represent areas suspected of human-mediated dispersal. The Brazos River basin (yellow shading), Colorado River basin (blue shading), Brazos-Colorado River basin (green shading), and rivers and large streams (blue lines) of these basins are also shown. Large rivers and tributaries are labeled as follows: 1) White River, 2) North Fork Double Mountain Fork Brazos River, 3) Double Mountain Fork upstream of N. Fork Double Mountain Fork Brazos River, 4) Croton Creek, 5) Double Mountain Fork Brazos River, 6) Salt Fork Brazos River, 7) Little River, 8) Running Water Draw, 9) Clear Fork Brazos River, 10) Keechi Creek, 11) (Lower) Bosque River, 12) Leon River, 13) Lampasas River, 14) Navasota River, 15) North Concho River, 16) Middle Concho River, 17) San Saba River, 18) Llano River.

2.4.2 Rangewide Needs

Rangewide, sharpnose and smalleye shiners need multiple resilient populations to support long-term persistence and viability of the species. Resiliency is defined as the ability of a population to withstand stochastic events and is often represented by a population's size and productivity. There are no estimates of minimum viable population size for these species; however, they are adapted to the abiotically variable conditions of the upper Brazos River, suggesting they are resilient to short-term (less than 1 year) stochastic events typical of prairie streams such as elevated temperatures, changes in water chemistry, and short-term loss of river flow (Dodds *et al.* 2004, p. 214). Following such stochastic events, these fish would recolonize stretches of river that had been uninhabitable.

Occupied Stream Length – Both species of shiner require an approximate minimum of 275 km (171 mi) of un-fragmented stream length for recruitment. Multiple stream lengths in excess of 275 km to withstand the stochastic events described above would support the long-term viability of both species. Therefore at the species level, sharpnose and smalleye shiners must occupy stream reaches long enough with adequate stream flows such that stochastic events that affect portions of the population would not result in extirpation of the species and allow for recolonization when suitable conditions return. Decreasing water availability, increasing drought, and increasing river fragmentation are stressors on the remaining populations of sharpnose and smalleye shiners. As such, these species require a range distribution capable of supporting a portion of their existing populations despite potential catastrophic loss of other portions.

Recruitment – Reproduction and recruitment of young individuals into the reproducing population contribute to the resiliency of sharpnose and smalleye shiner populations. 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. Because these fish only live for one or two years, populations are particularly vulnerable when the necessary streamflow conditions for reproduction are lacking for more than one season. Thus these species require adequate pulse flows within a two year cycle to improve recruitment.

In summary, although the sharpnose shiner and smalleye shiner are associated with arid prairie streams such as the Brazos River, their resource needs revolve around the following:

- Occupation of stream reaches long enough with adequate stream flows such that stochastic events that affect portions of the population would not result in extirpation of the species and allow for recolonization when suitable conditions return
- Adequate pulse flows within a two-year cycle to maintain recruitment
- Avoidance of further habitat fragmentation downstream of, and contiguous with, occupied portions of the upper Brazos River in a manner that provides perpetual riverine refugia from the ongoing threats (particularly drought).

2.5 Summary of Needs

The most important needs of sharpnose and smalleye shiner individuals and populations are listed below:

Individuals

- Sandy substrates and shallow, flowing channels for feeding,
- Adequate prey base, and
- Water quality conditions within physiological tolerances of both species.

Populations

- Unobstructed (no fish passage barriers) flowing water greater than 275 km (171 mi) in river length,
- Minimum mean spawning season flows of approximately $6.43 \text{ m}^3 \text{ s}^{-1}$ (227 cfs) for the smalleye shiner and $2.61 \text{ m}^3 \text{ s}^{-1}$ (92 cfs) for the sharpnose shiner to support reproduction and population growth (see Streamflow Requirements section for additional details), and
- Elevated streamflow events (i.e., high flow pulses and overbanking flows) during the spawning season to support synchronized reproductive efforts.

Rangewide

- Avoidance of further habitat fragmentation or elongation of unfragmented river downstream of, and contiguous with, occupied portions of the upper Brazos River in a manner that provides perpetual riverine refugia from the ongoing threats (particularly drought).

CHAPTER 3 – SPECIES CURRENT CONDITIONS

In this chapter we review the current conditions of these species at population and rangewide levels. We look at the available information on actual population sizes and review the current range and distribution of the species. We also provide a summary of the current conditions of streamflows and intact stream reaches, two important resource needs for both species.

Sharpnose and smalleye shiners have experienced substantial reductions in their ranges. Sharpnose shiner was known to historically and naturally inhabit approximately 3,417 km (2,123 mi) of river segments in the Brazos, Red, and Colorado River basins, but now the only sustainable population is restricted to approximately 1,002 km (623 mi) of the upper Brazos River basin, a greater than 70 percent reduction. The smalleye shiner was known to historically and naturally inhabit approximately 2,067 km (1,284 mi) of river segments in the Brazos River basin, but now the only sustainable population is restricted to approximately 1,009 km (627 mi) of the upper Brazos River basin, a greater than 51 percent reduction. Additional details of the sharpnose and smalleye shiners' current ranges and conditions are discussed below.

3.1 Condition of Populations

3.1.1 Current Abundance

In recent years, the sharpnose shiner has become less abundant in the Salt Fork and upstream of the North Fork Double Mountain Fork and Double Mountain Fork confluence (Durham 2007, p. 10; Wilde 2011, pp. 6, 21, 26) than previously recorded (Moss and Mayes 1993, p. 19; Ostrand 2000, p. 34). During 1997 and 1998, 250 sharpnose shiners were collected in the Salt Fork Brazos River (5 sites, 8 surveys each), 284 from the North Fork Double Mountain Fork Brazos River (2 sites, 8 surveys each), and none from the Double Mountain Fork upstream of the North Fork Double Mountain Fork (1 site, 8 surveys; Ostrand 2000, p. 34). Using similar sampling effort (determined by textual description) as in 1997 and 1998, between the spring of 2008 and spring of 2012, only 12 sharpnose shiners were collected in the Salt Fork Brazos River (6 sites, 8 surveys each), 42 from the North Fork Double Mountain Fork Brazos River (3 sites, 8 surveys each), and none from the Double Mountain Fork upstream of the North Fork Double Mountain Fork (2 sites, 8 surveys each), representing a 95 percent, 85 percent, and zero percent decrease in abundance over approximately 10 years, respectively (Wilde 2015a, p. 21). They remain relatively abundant in the Double Mountain Fork downstream of the North Fork Double Mountain Fork and main stem of the upper Brazos River, with 1,106 and 4,793 individuals collected between 2008 and 2012, respectively (Wilde 2012a, p. 21). Although sharpnose shiners are still present in the upper Brazos River, between fall 2009 and spring 2012 there has been a steady decline in the number of fish caught during biannual surveys from 1,717 fish caught in fall 2009 down to just 450 caught in spring 2014 (Wilde 2015, p. 18). Shiner abundance was likely influenced by stream drying conditions in 2011. No captive population of this species is known to occur.

The smalleye shiner has also become less abundant in the Salt Fork, North Fork Double Mountain Fork, and Double Mountain Fork upstream of North Fork Double Mountain Fork

within the upper Brazos River basin (Ostrand 2000, p. 34; Durham 2007, p. 10; Wilde 2011, pp. 6, 21, 26). During 1997 and 1998, 938 smalleye shiners were collected in the Salt Fork Brazos River, 1,451 from the North Fork Double Mountain Fork Brazos River, and 28 from the Double Mountain Fork upstream of North Fork Double Mountain Fork (Ostrand 2000, p. 34). Using similar sampling effort between the spring of 2008 and spring of 2012, only 379 smalleye shiners have been collected from the Salt Fork, 720 from the North Fork Double Mountain Fork, and zero from the Double Mountain Fork upstream of North Fork Double Mountain Fork, representing a 60 percent, 50 percent, and 100 percent decrease in abundance, respectively (Wilde 2012a, p. 21). They remain relatively abundant in the Double Mountain Fork downstream of North Fork Double Mountain Fork and main stem of the upper Brazos River, with 1,846 and 4,415 individuals collected between 2008 and 2012, respectively (Wilde 2012a, p. 21). Smalleye shiners do not display the same decreasing trend in abundance as does the sharpnose shiner but rather a rise and decrease in abundance from year to year (Wilde 2015, p. 18). No captive population of this species is known to occur.

Although sharpnose and smalleye shiners were released in the lower Brazos River by the Texas Parks and Wildlife Department (TPWD) in May 2012, due to the number and age of the released fish and the previous decline of these species in the lower Brazos River, it is unlikely recruitment occurred, and both species are presumed extirpated from this river segment. Approximately five months after the release of sharpnose and smalleye shiners in the lower Brazos River, nearly four hours of field sampling (716.28 m of river seined) at the release site and both upstream and downstream of the release site did not result in the capture of either species (Hendrickson 2013, p. 20, 23), which corroborates the likely extirpation of released sharpnose and smalleye shiners from the lower Brazos River. In 2012, Hendrickson (2013, p. 16, 23) failed to capture a single sharpnose shiner or smalleye shiner from 20 sites (more than 20 seining hours and 6836 m of river seined) throughout the middle and lower Brazos River despite capturing 65,840 individuals of 46 other species (including 11 other cyprinid species). Fish surveys in the lower Brazos River by TPWD in 2014 and Brazos River Authority in 2014–2015 also failed to collect either of these species (TPWD 2016, p. 18).

3.1.2 Streamflows

The best available dynamic population modeling estimates mean spawning season (April – September) flows of $6.43 \text{ m}^3\text{s}^{-1}$ (227 cfs) and $2.61 \text{ m}^3\text{s}^{-1}$ (92 cfs) are required to indefinitely sustain populations of smalleye and sharpnose shiners, respectively (Durham and Wilde 2009b, p. 670; Durham 2007, p. 110). However, it is suspected that the mean flow rates less than these are likely to support enough reproductive success to lessen the extent of population declines, especially when elevated flood-flow events and synchronized spawning events occur at least once during the spawning season. Between 1940 and 2013 (74 years) in the upper Brazos River, 25 spawning seasons did not meet the estimated minimum mean summer discharge requirement to sustain smalleye shiner population growth while 9 did not sustain estimated levels required for sharpnose shiners. Drought conditions coupled with anthropogenic factors (i.e., impoundments and groundwater withdrawal) have reduced streamflow in the upper Brazos River beyond that which has historically occurred in this reach. The drought of 2011 was the worst single-year drought on record (TWDB 2017, p. 15–16) and flow in the Brazos River was non-existent or negligible for much of the sharpnose and smalleye shiner spawning

season. There was no observed successful reproduction or recruitment of either the sharpnose or smalleye shiner in the upper Brazos River in 2011 (Wilde 2012b, pers. comm.). Prolonged lack of streamflow and a lack of elevated streamflow events that trigger synchronized spawning affect both individual- and population-level survival and reproductive efforts and recruitment success.

3.1.3 Stream Reach Length

The estimated minimum unobstructed reach length required to meet reproductive needs of individuals and populations as a whole (≥ 275 km (171 mi)) occurs in only two geographically separate locations within the confirmed, maximum historical range of both species. Table 4 identifies the approximate length of specific river segments within the Brazos, Wichita, and Colorado River systems that were once inhabited by one or both species.

Three separate river segments with confirmed historical records of the sharpnose shiner retain the minimum unobstructed length required for the successful reproduction and recruitment of these species: the upper Brazos River (upstream of Possum Kingdom Lake and includes the Brazos River main stem and the Salt and Double Mountain Forks of the Brazos River), the lower Brazos River, and the Colorado River downstream of the City of Austin. Only two separate river segments with confirmed historical records of the smalleye shiner retain the minimum unobstructed length required for the successful recruitment of these species: the upper Brazos River (upstream of Possum Kingdom Lake and includes the Brazos River main stem and the Salt and Double Mountain Forks of the Brazos River) and the lower Brazos River.

The upper Brazos River is currently inhabited by both species and has the only potentially viable populations remaining. In 2013, a previously exposed pipeline crossing the Brazos River in Throckmorton County, approximately 130 river km (80 mi) upstream of the downstream portion, was reinforced with a concrete protective mat capable of acting as a fish barrier during periods of moderate and low flow (Label 26 on Figure 8). This site was visited on February 27, 2013 and November 1, 2016, where at both times it acted as barrier to upstream fish movement. If the pipeline reinforcement remains unchanged and functions (even occasionally) as a barrier to fish movement, it effectively reduces the length of the upper Brazos River reaches by approximately 130 km (80 mi).

In addition to the pipeline crossing above, updated aerial imagery of occupied areas of the upper Brazos River basin also indicates that a number of other low-water crossings and unknown structures may occasionally impact fish movement. There appear to be three low-water crossings and two unidentified structures crossing the channel of the Double Mountain Fork Brazos River having the potential to occasionally impact upstream fish migration depending on water depth and flow. The Double Mountain Fork Brazos River has a road crossing approximately 0.40 km (0.25 mi) upstream of its confluence with the North Fork Double Mountain Fork that appears to restrict water movement. It is unclear under what conditions this road crossing would allow fish migration upstream and downstream. Within the North Fork Double Mountain Fork, there is currently one unknown structure having the potential to occasionally impact upstream fish migration depending on water depth and flow. In 2017, a low-water crossing in Kent County impairing fish passage in this stream was removed and the streambed was restored to near its natural condition. The Salt Fork Brazos River has two low

water crossings and one unknown man-made structure having the potential to occasionally impact upstream fish migration depending on water depth and flow. There are numerous other low-water crossings throughout the upper Brazos River basin but they do not appear to restrict flow or fish movement. The extent of privately owned land in the upper Brazos River basin limits public access to the river channel to assess the potential impacts (i.e., fish passage) of these structures.

Table 4. Important river segment lengths (km) of the Brazos, Red, and Colorado River basins. These segment lengths were calculated using data from the USGS high-resolution National Hydrological Flowline Dataset (USGS 2008, shapefile). Asterisks (*) identify reaches that meet the estimated minimum length requirement. Segment lengths do not account for occasional fish movement barriers such as low-water crossings. † indicates additional information in text.

Brazos River

Segment (Upstream to Downstream)	Length
<i>Upper Brazos</i> †	
Double Mtn Fork → Possum Kingdom Lake	673 km*
Salt Fork → Possum Kingdom Lake	601 km*
<i>Middle Brazos</i>	
Possum Kingdom Lake → Lake Granbury	190 km
Lake Granbury → Lake Whitney	118 km
Lake Whitney → Lake Brazos (Waco)	66 km
Lake Brazos → Marlin Falls LWC	72 km
<i>Lower Brazos</i>	
Marlin Falls LWC → Brazoria Co. Northern Border	504 km*

Red River

Segment (Upstream to Downstream)	Length
S. Wichita River → Lake Kemp	269 km
N. Wichita River → Lake Kemp	249 km
Lake Kemp → Diversion Lake	23 km
Diversion Lake → Red River Confluence	180 km
Santa Rosa Lake (Beaver Creek) → Red River	232 km

Colorado River

Segment (Upstream to Downstream)	Length
Lake JB Thomas → EV Spence Reservoir	190 km
EV Spence → O.H. Ivie Reservoir	135 km
O.H. Ivie Reservoir → Unknown dam near Goldthwaite	180 km
Unknown dam near Goldthwaite → Lake Buchanan	113 km
Downstream of Austin → Altair Dam	292 km*
Altair Dam → Lane City Dam	90 km

Sharpnose and smalleye shiners were both known to occur throughout the Brazos River but

were subsequently extirpated in the 180 km (112 mi) reach between Possum Kingdom Lake (impounded in 1941) and Lake Granbury (impounded in 1969), the 99 km (62 mi) reach between Lake Granbury and Lake Whitney (impounded in 1951), and the 64 km (40 mi) reach between Lake Whitney and Lake Brazos (impounded in 1970). However, it is unlikely that reach length was the sole contributing factor to the extirpation of sharpnose and smalleye shiners in these reaches as other factors (alteration of flow and sediment transport regimes, habitat modification, and water quality degradation) may have also contributed to their decline.

A 422 km (262 mi) stretch of the lower Brazos River (downstream of the low-water crossing near Marlin, Texas, to the southern border of Fort Bend County, Texas) was once known to be inhabited by both species and remains un-impounded. As described previously, in the lower Brazos River the smalleye shiner is apparently extirpated and the sharpnose shiner is either extirpated or in severe decline, having not been recorded since 2006, and then only in very small numbers (Gelwick and Li, 2002, p. 11; Brazos River Authority 2007, p. 15; Bonner 2012, pers. comm.). It is unclear why both species are either extirpated or in severe decline in the lower Brazos River, although it is not currently suspected to be a result of insufficient reach length or altered flow regime. The lower Brazos River differs from the upper portion by being deeper and having higher current velocities, less sandy substrate, more stable flows, and altered water chemistry for measures such as temperature, total dissolved solids, and conductivity (Anderson *et al.* 1983, p. 83). Downstream of the impoundments of the middle Brazos River, habitat commonly utilized by sharpnose and smalleye shiners is limited and is less suitable for native prairie cyprinids such as these species (Moss and Mayes 1993, pp. 37–38). It is possible that the lower Brazos River was never capable of supporting a self-sustaining population without constant emigration from upstream sources and that it always acted as a population sink. Given the historical decline and disappearance of both species in the lower Brazos River, the May 2012 release was likely insufficient to restart a population. Habitat within the Wichita and Colorado Rivers is substantially fragmented by impoundments and other barriers making sharpnose shiner survival and recruitment unlikely. As each species has only a single viable population in the upper Brazos River (and nowhere else), effects to each population affect the species as a whole.

3.2 Conditions of Species Rangewide

Sharpnose shiner

Despite historically being common throughout the Brazos River, since 1993 the sharpnose shiner has been primarily restricted to the Brazos River and its major tributaries upstream of Possum Kingdom Lake with very few specimens collected in the lower Brazos River downstream of the City of Marlin, Falls County, Texas (Figure 6; Moss and Mayes 1993, pp. 12–13). Several survey efforts have failed to collect sharpnose shiners from locations downstream of Possum Kingdom Lake where they were historically present (Anderson *et al.* 1983, p. 84; Linam *et al.* 1994, pp. 8–9; Armstrong 1998, pp. 13–15; Brazos River Authority 1999, Appendix 2; Labay 2010, pp. 35–54; Brazos River Authority 2007, p. 15; Wilde 2000 & 2001, unpublished data; Hendrickson 2013, pp. 16, 23). The sharpnose shiner has not been collected from the Brazos River downstream of Possum Kingdom Lake since 2006, when one specimen was collected from the confluence with the Navasota River in Washington County (Brazos River Authority 2007, p. 15). The most recent collections prior to the 2006 collection

were: in 2001 from the Brazos River at its confluence with Allens Creek, Austin County, where three individuals were collected (Gelwick and Li 2002, p. 11); and in 2004, when two fish were collected from the Brazos River near Hempstead, Washington County; and another six individuals from the Brazos River near Bryan, Brazos County (Winemiller *et al.* 2004, pp. 25, 47).

Although recent literature and a few substantial collection efforts indicate that this species was likely extirpated from the Brazos River downstream of Possum Kingdom Lake (Durham and Wilde 2009a, p. 21; Labay 2010, pp. 35–54; Wilde 2000 & 2001, unpublished data; Hendrickson 2013, pp. 16, 23), it cannot be discounted that a very small number of individuals could remain. Regardless, the status of the sharpnose shiner downstream of Possum Kingdom Lake is either extirpated or in severe decline (Bonner and Runyan 2007, p. 16) to the point of near extirpation with limited chance of natural recovery without significant conservation efforts. The lower Brazos River is much wider and deeper, likely has a lower salinity, supports lentic-adapted piscivorous fish, and historically experienced higher magnitude flows than the upper Brazos River, making it less suitable as sharpnose and smalleye shiner habitat. Therefore, it is likely sharpnose shiners were never capable of sustaining a population in the lower Brazos River without constant emigration from upstream sources – now prevented by impoundments – and that the lower Brazos River always acted as a population sink (Wilde 2012b, pers. comm.).

On May 29, 2012, approximately 372 sharpnose shiners were released in the lower Brazos River by state fish biologists. These fish (one and two years of age) were collected from isolated pools in the upper Brazos River during the summer of 2011 (Campoy 2011, entire) and were nearing the end of their lifespan (Mayes 2012, pers. comm.). Given the possible extirpation of the species in the lower Brazos River prior to their reintroduction, the number of individuals released, and that the released individuals were nearing their maximum life expectancy, it is unlikely that adequate recruitment occurred. Thus, we do not expect this effort to result in a new population being established in the lower Brazos River. Additional survey efforts are needed to fully investigate the status of this species in the lower Brazos River; however, given available information, the Service suspects there are so few individuals remaining in the Brazos River downstream of Possum Kingdom Lake that the species is functionally extirpated (i.e., not enough individuals remain to support a persistent population).

The sharpnose shiner is presumed to be extirpated from the Wichita River system of the Red River basin (Wilde *et al.* 2008, pp. 26–28; Wilde *et al.* 1996, p. 15), the Colorado River basin (Bonner 2012, pers. comm.; Wilde 2012b, pers. comm.; Cohen and Hendrickson 2013, p. 11; Figure 6), the middle Brazos River, and functionally extirpated from the lower Brazos River, indicating a greater than 70 percent reduction in occupied range. This has resulted in the isolation of only one potentially viable population in the upper Brazos River. Even in the upper Brazos River, the effects of streamflow reduction and habitat fragmentation from drought and other threats appear to be negatively affecting sharpnose shiner abundance.

Smalleye shiner

Despite historically being common throughout the Brazos River, by 1993 the smalleye shiner was apparently restricted to the Brazos River and its major tributaries upstream of Possum

Kingdom Lake with no specimens collected in the middle and lower Brazos River basin (Moss and Mayes 1993, p. 11; Figure 7). Several survey efforts have failed to collect smalleye shiners from locations downstream of Possum Kingdom Lake where they were historically present (Anderson *et al.* 1983, p. 84; Linam *et al.* 1994, pp. 8–9; Armstrong 1998, pp. 13–15; Brazos River Authority 1999, Appendix 2; Wilde 2000 & 2001, unpublished data; Brazos River Authority 2007, p. 15; Labay 2010, pp. 35–54; Hendrickson 2013, p. 16, 23). The smalleye shiner has not been collected from the Brazos River downstream of Possum Kingdom Lake since 1986, when eight specimens were collected near the City of Hempstead in Washington County (Hendrickson and Cohen 2010). The most recent record prior to 1986 was from the

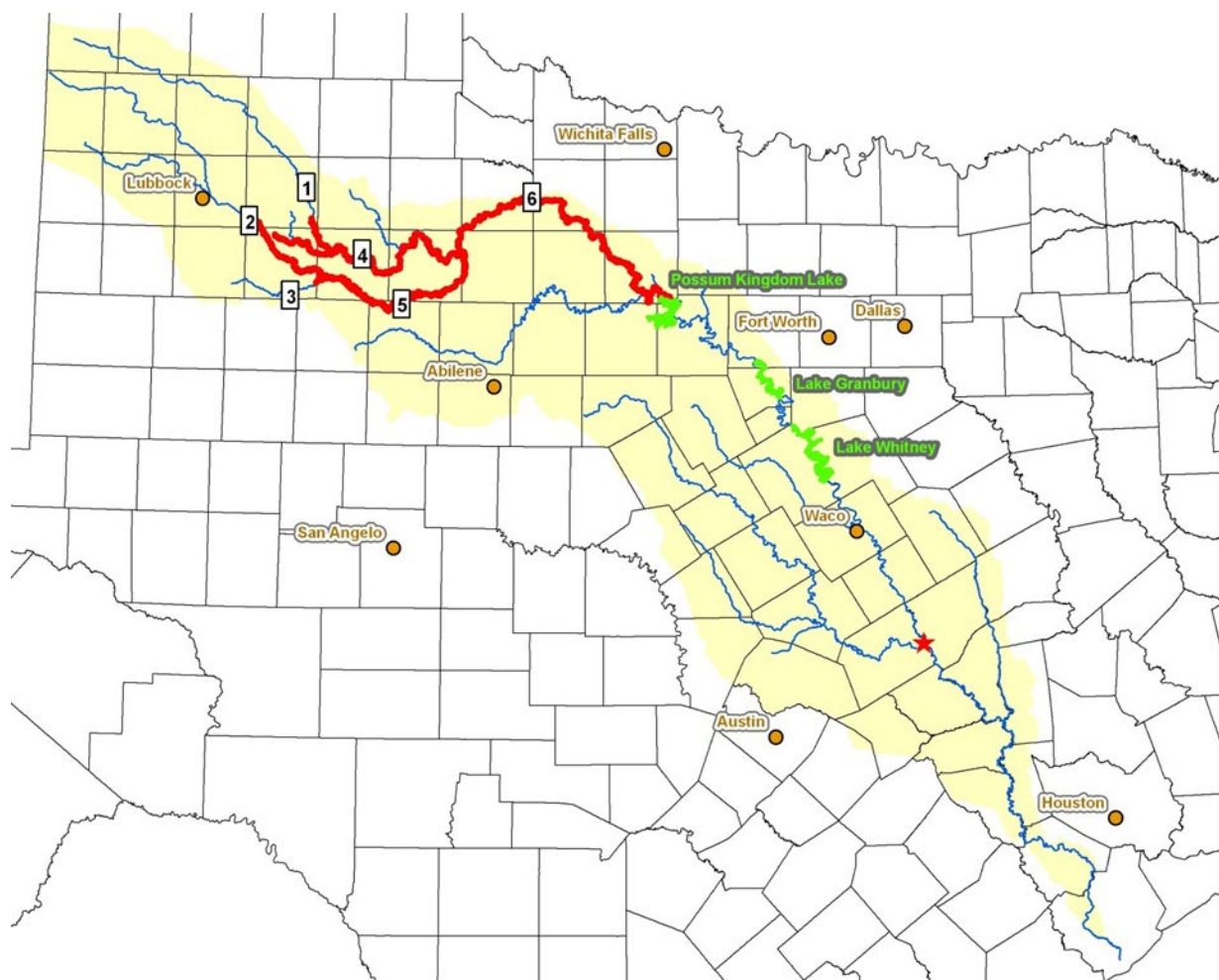


Figure 6. The current range of the sharpnose shiner, *Notropis oxyrhynchus*. The Brazos River basin (yellow shading) and the three main channel reservoirs (green) of the middle Brazos River are also shown. The red star indicates the location of sharpnose shiner release in May of 2012. Occupied segments of sharpnose shiner habitat are labeled as follows: 1) White River, 2) North Fork Double Mountain Fork Brazos River, 3) Double Mountain Fork upstream of North Fork Double Mountain Fork, 4) Salt Fork Brazos River, 5) Double Mountain Fork Brazos River, 6) Brazos River.

Brazos River near the City of Waco, McLennan County, in 1970, when one fish was collected (Cohen 2012, unpublished data). Recent literature and a few substantial collection efforts indicate that this species is likely extirpated from the Brazos River downstream of Possum Kingdom Lake (Wilde 2000 & 2001, unpublished data; Bonner and Runyan 2007, p. 16; Durham and Wilde 2009a, p. 21; Durham and Wilde 2009b, pp. 666–667; Labay 2010, pp. 35–54; Hendrickson 2013, p. 16, 23).

It is possible smalleye shiners were never capable of sustaining a population in the lower Brazos River without constant emigration from upstream sources – now prevented by impoundment – and that the lower Brazos River always acted as a population sink (Bonner 2012, pers. comm.; Wilde 2012b, pers. comm.). However, on May 29, 2012, approximately 372 smalleye shiners were released in the lower Brazos River by state fish biologists (Figure 7; Mayes 2012, pers. comm.). These fish (one and two years of age) were collected from isolated pools in the upper Brazos River during the summer of 2011 (Campoy 2011, entire) and were nearing the end of their lifespan (Mayes 2012, pers. comm.). Given the previous extirpation of this species in the lower Brazos River, and the age of the released individuals, it is unlikely the release effort was adequate to restart a population of this species in the lower Brazos River.

The smalleye shiner is presumed to be extirpated from the middle Brazos River, and functionally extirpated from the lower Brazos River, indicating a greater than 51 percent reduction in occupied range. This has resulted in the isolation of only one potentially viable population in the upper Brazos River. Even in the upper Brazos River, the effects of streamflow reduction, drought, habitat fragmentation, and other threats appear to be negatively affecting smalleye shiner abundance.

3.3 Summary of Current Conditions

Sharpnose and smalleye shiners are currently restricted to the upper Brazos River basin, where occupied river segments retain the shallow channels with sandy substrates preferred by adult and juvenile individuals of these species. These river segments also appear to retain an adequate prey base for feeding and water quality is generally within the physiological tolerances of both species.

At the population level, both species likely require unobstructed flowing water greater than 275 km (171 mi) in river length to support recruitment over the long term. Occupied portions of the upper Brazos River reach up to 673 river km (418 mi). Although occupied segments of the upper Brazos River do not currently contain large, main channel impoundments, there are several smaller structures (low-water crossings, pipeline reinforcements, minor impoundments) that may occasionally act as fish barriers under low and moderate flow conditions. The lower Brazos River is the only other river segment of sufficient length to support sharpnose and smalleye shiner recruitment that was once occupied by both species. However, the lower Brazos River has different flow characteristics and channel morphology than the upper Brazos River. These species may not be well adapted to the conditions of the lower Brazos River and it is likely they historically required constant emigration from upstream sources to survive in this river segment. Despite retaining sufficient length for successful recruitment of these shiners,

both species are extirpated or functionally extirpated from the lower Brazos River.

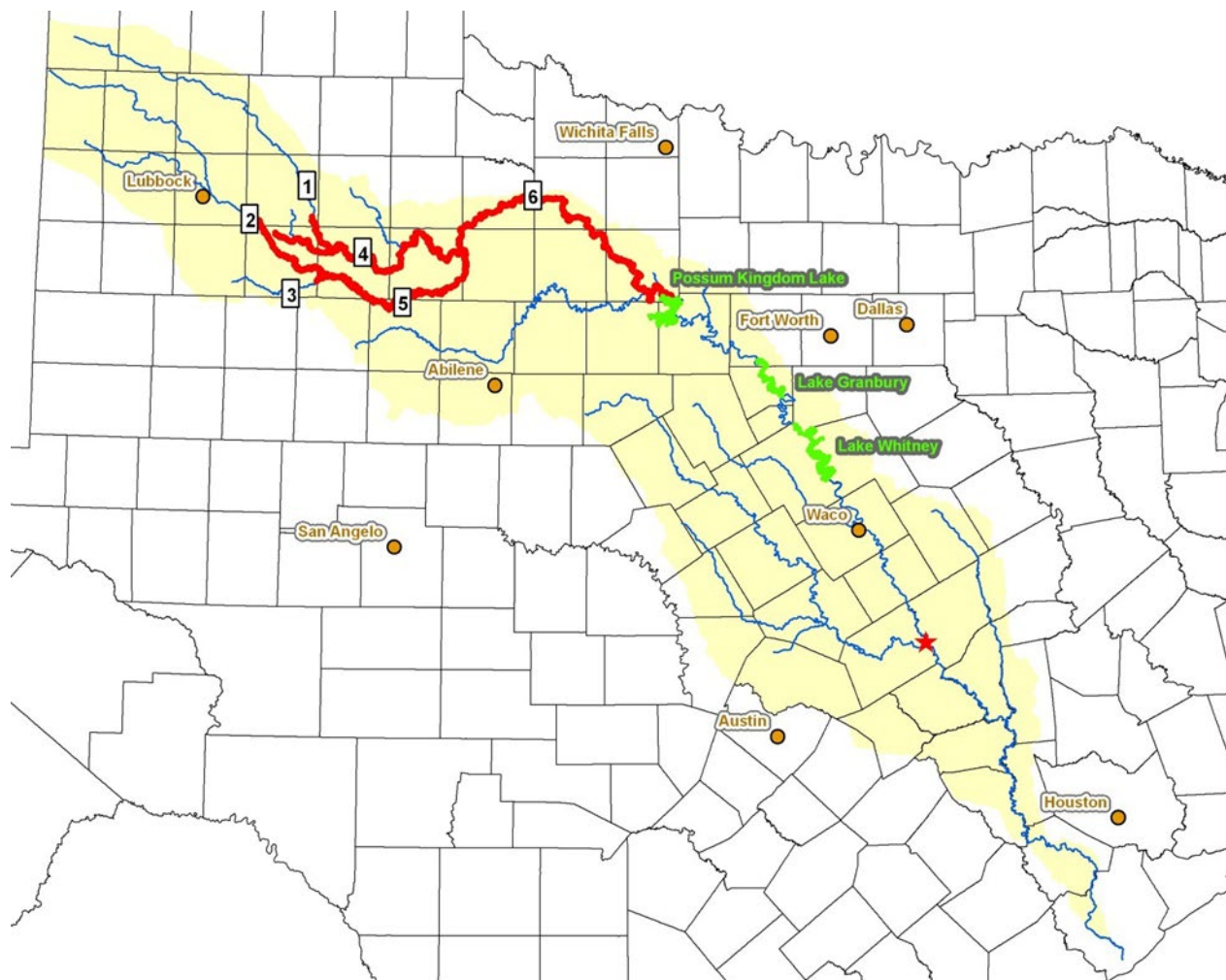


Figure 7. The current range of the smalleye shiner, *Notropis buccula*. The Brazos River basin (yellow shading) and the three main channel reservoirs (green) of the middle Brazos River are also shown. The red star indicates the location of smalleye shiner release in May of 2012. Occupied segments of smalleye shiner habitat are labeled as follows: 1) White River, 2) North Fork Double Mountain Fork Brazos River, 3) Double Mountain Fork upstream of North Fork Double Mountain Fork, 4) Salt Fork Brazos River, 5) Double Mountain Fork Brazos River, 6) Brazos River.

In addition to unobstructed river length, sharpnose and smalleye shiner populations require sufficient flow to trigger synchronized spawning and to keep their planktonic life stages afloat. The upper Brazos River often experiences intermittent flow during the dry summer season. Increased water sequestration by upstream reservoirs, spring flow reduction due to groundwater withdrawal, and increasing drought exacerbated by climate change further reduce streamflow of occupied segments of the upper Brazos River. Although intermittent flow is likely a natural occurrence in the upper Brazos River, and these species recolonize river segments following recovery of suitable habitat conditions, the frequency and intensity of river flow reductions appear to be increasing. Increased flow reduction and impediment of migration due to fragmentation will negatively impact sharpnose and smalleye shiner populations beyond a level at which these species have the natural resiliency to recover.

3.4 Current Species Viability

As the sharpnose and smalleye shiner are currently restricted to a single population in the upper Brazos River basin, this section combines the current condition (3Rs) at the population and species level for both species.

3.4.1 Resiliency

Sharpnose and smalleye shiners are associated with arid prairie streams. As such, they are relatively tolerant of variation in water temperature, salinity, dissolved oxygen, and turbidity. As mobile, synchronous and asynchronous broadcast spawners capable of rapid reproduction, both species are expected to be relatively tolerant of short-term drought conditions, temporary river pooling, and other short-term alterations to their aquatic environment. However, impoundments have altered the natural arid prairie stream environment by restricting the lengths of river available for reproduction/recruitment and by acting as barriers to fish migration during and after severe environmental perturbations. Prior to impoundment, sharpnose and smalleye shiners likely moved downstream during poor environmental conditions. Downstream individuals would also be capable of migrating upstream when favorable flow conditions returned to recolonize lost habitats. Presumably, this life history strategy historically provided a high level of resiliency for populations of both species to be able to withstand disturbances of high magnitude and duration through migration and recolonization. Due to stream fragmentation by impoundments, this ability to withstand environmental disturbances has been reduced, severely limiting the resiliency of the species both now and into the future. If additional reservoirs are constructed within the current range of both species, current habitats would be further fragmented and the species' resiliency further reduced.

Impoundments and other stressors (such as groundwater withdrawals) may affect the flow regime to the extent that they limit minimum streamflows necessary for successful reproduction and population growth. Stressors in the upper Brazos River basin that preclude successful reproduction/recruitment and persist over two successive spawning seasons will not only affect individuals, but would likely lead to complete population extirpation. Since there is only one extant population remaining for both smalleye and sharpnose shiner, this would also result in

species extinction. The potential for this kind of extinction event is heightened by climate conditions, which has increased the probability of severe droughts in this region. The resiliency of these populations (the ability to withstand randomly occurring events of varying magnitude and duration) is limited because fish barriers restrict their ability to migrate from drought conditions and recolonize river segments upon return of favorable conditions.

3.4.2 Redundancy

Currently sharpnose and smalleye shiners are each restricted to single populations in the upper Brazos River upstream of Possum Kingdom Lake. Although a small number of fish were released into the lower Brazos River in 2012, these populations are likely either functionally or completely extirpated. Due to the existence of only a single population of each species in the upper Brazos River basin, all of the potential effects to this population also serve to affect the species as a whole. Therefore, both the sharpnose and smalleye shiner currently have no redundancy (i.e., multiple populations) by which to survive a catastrophic event in the upper Brazos River basin. Any future event or action that extirpates the populations in the upper Brazos River basin would result in the extinction of the species. However, prior to the major impoundments that fragmented the Brazos River (Lakes Whitney, Possum Kingdom, and Granbury), the individuals occupying the river likely represented a single population of each species. As such, the smalleye shiner may have historically existed as a narrow-range endemic, with a single large population in the Brazos River. Thus, redundancy in the smalleye shiner is unchanged, but its resiliency has been reduced as discussed above. The sharpnose shiner historically existed in redundant populations in the Colorado and Wichita rivers. Future events similar to the severe drought conditions in 2011 that resulted in a complete lack of successful reproductive effort and juvenile recruitment in both species (Wilde 2012b, pers. comm.), may expose the entire range of both species to risk of complete loss. Given these species generally only survive through two reproductive seasons, back-to-back severe drought years could result in their localized extirpation or even extinction without human intervention.

Based on river fragment length alone, there is only one additional location within the species' historical range that could potentially support populations of these fish. The lower Brazos River is a location where both species once occurred naturally and remains sufficiently unfragmented to support successful reproduction/recruitment in these species, but otherwise this river reach does not likely contain the necessary elements required by either species. Both species declined to the point of either complete extirpation or functional extirpation from this area for reasons that remain unclear, indicating that reintroduction efforts in the lower Brazos River may not be successful long term. The lower Brazos River differs from the upper portion by being deeper and having more rapid current, less sandy substrate, more stable flows, and differing in water chemistry measures such as salinity, DO, and temperature. Because the lower Brazos River is downstream of the impoundments of the middle Brazos River, habitat commonly utilized by sharpnose and smalleye shiners (i.e., wide shallow river channel) is limited and is less suitable for these species (Moss and Mayes 1993, pp. 37–38). Therefore, it is possible the lower Brazos River was never capable of supporting a self-sustaining population without constant emigration from upstream sources, potentially functioned as a refuge during long intense droughts prior to reservoir construction, and always acted as a sink.

3.4.3 Representation

The genetic ability of sharpnose and smalleye shiners to adapt to environmental conditions is not well understood. As of 2017, no detailed genetic analyses have been performed on the genetic variability of persisting individuals compared to historical populations, nor have any genetic or population viability analyses been performed. Despite an obvious restriction of their range and decline in abundance, and given the persistence of both species in the upper Brazos River since the impoundment of Possum Kingdom Lake in 1941, it is possible that their genetic variation is sufficient to survive the naturally occurring conditions of the arid prairie stream environments in which they evolved. It is unknown whether these species have the genetic variability or the time required to adapt to projected future changes resulting from habitat fragmentation and loss of river flow because it is not expected that their basic life history strategies for broadcast-spawning would change.

Genetic evaluation of sharpnose and smalleye shiners would be needed to determine to what extent, if any, they have lost genetic variability due to range contraction. Representation can also be evaluated by the ecological diversity of populations across a species' range. The smalleye shiner's historical range was limited to the Brazos River, for which the most obvious extent of ecological diversity would be the differences in the upper, middle, and lower river. The sharpnose shiner's historical range included the same ecological variation within the Brazos River, but also potentially included other ecological settings within the Colorado and Wichita Rivers. Due to the current ranges of both species being restricted to the upper Brazos River, any previous ecological diversity provided by the former range may have been lost.

CHAPTER 4 – INFLUENCES ON VIABILITY

In this chapter we evaluate the past, current, and future stressors affecting the shiners and their resource needs. The most important stressors are related to loss of the specific water resources that individuals and populations need to complete their life history. Although factors affecting all life-history stages (egg, larvae, juvenile, and adult) of these species are important, the survival needs of adult fish are generally met due to their ability to withstand the conditions of arid prairies streams; however, the resource needs of these species' early ichthyoplanktonic life-history stages (egg and larva) are limited within their existing ranges. The sources of habitat loss are primarily related to the construction of dams and impoundments which both alter streamflows and reduce unobstructed stream lengths. Additional sources of habitat loss include groundwater withdrawals, climate change and drought, invasive saltcedar, desalinization, water quality degradation, and instream gravel mining and dredging.

This analysis concentrates on stressors and their sources affecting the biological status of the species. The analysis concentrates on the upper Brazos River basin because it contains the last remaining potentially viable population of sharpnose and smalleye shiners. Although the effects of the analyzed stressors on sharpnose and smalleye shiners are considered primarily for the upper Brazos River (except where specifically stated otherwise), we expect that nearly all of the stressors have historically occurred and continue to occur to a similar extent as in the Brazos River within the other historically occupied river basins and stream reaches. We also expect the response of sharpnose and smalleye shiners would be and have been similar within these other areas as to those analyzed below.

4.1 Impoundments

4.1.1 Impacts to fish and the environment

The U.S. Army Corps of Engineers recognizes at least 566 dams in Texas with 135 within the Brazos River basin, 77 within the Colorado River basin, and 50 within the Red River basin. River fragmentation by dam construction occurs throughout the State, and arid regions are particularly sensitive to the negative effects of fragmentation (Dudley and Platania 2007, p. 2084). The negative effects of impoundments on riverine systems by changing temperature regimes, flow regimes, sediment transport, sedimentation, water quality, channel morphology, nutrient availability, and by acting as barriers to fish passage are well documented and are discussed as applicable below (Edwards 1978, p. 71; Anderson *et al.* 1983, p. 81; Gore and Bryant, Jr. 1986, p. 333; Winston *et al.* 1991, p. 98; Poff *et al.* 1997, p. 773; Pringle 1997, p. 428; Luttrell *et al.* 1999, p. 981; Wilde and Ostrand 1999, p. 203; Bonner and Wilde 2000, p. 189; Schrank *et al.* 2001, p. 419; Bunn and Arthington 2002, p. 495; Eberle *et al.* 2002, p. 186; Mammoliti 2002, pp. 223–226; Quist *et al.* 2005, p. 53; Dudley and Platania 2007, p. 2081; Suttkus and Mettee 2009, p. 3; Perkin *et al.* 2010, p. 2; Perkin and Gido 2011, pp. 379–380). Figure 8 shows the impoundments and reservoirs of the upper Brazos River basin.

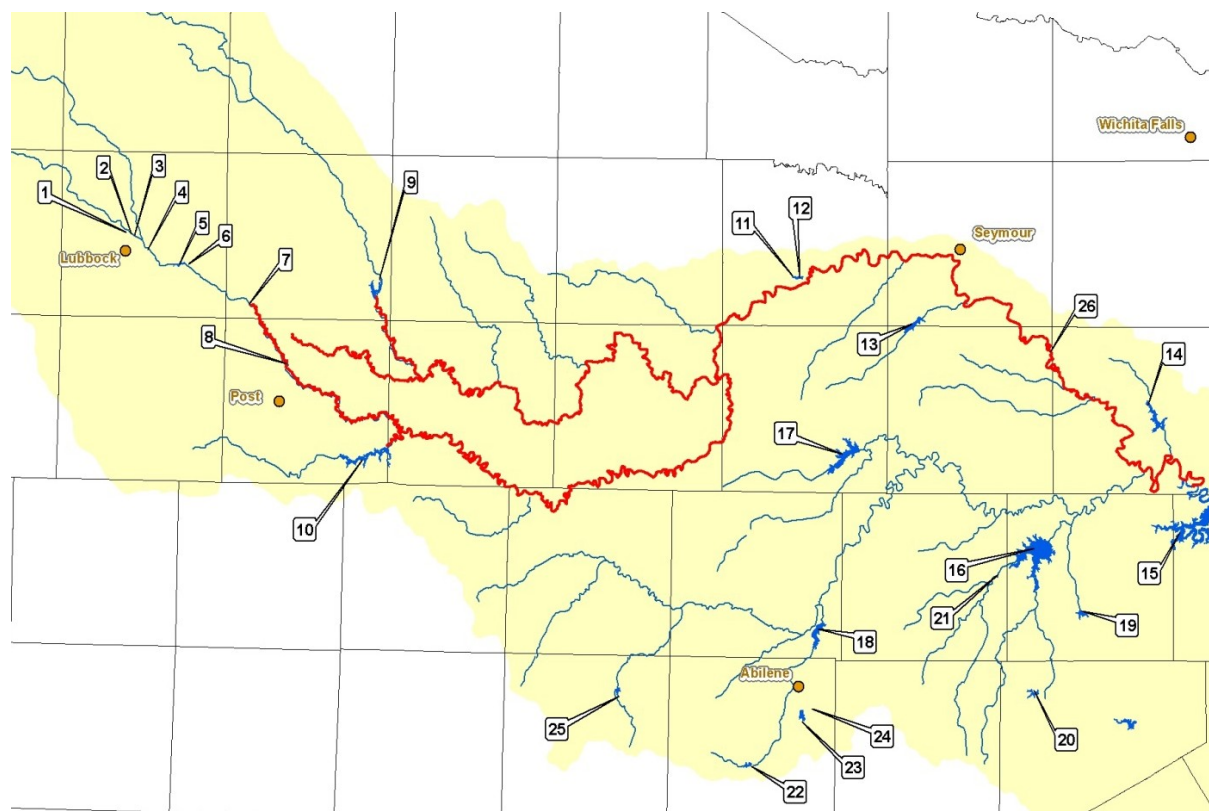


Figure 8. The impoundments, reservoirs, and fish barriers of the upper Brazos River basin. Sharpnose and smalleye shiner occupied habitat shown in red. The impoundments and reservoirs are labeled as follows: 1) Canyon Lake #1, 2) Canyon Lake #2, 3) Canyon Lake #3, 4) Canyon Lake #6, 5) Buffalo Springs Lake, 6) Lake Ransom Canyon, 7) Impounded Area At Janes-Prentice Incorporated's gravel operation, 8) Arock Materials' water diversion, 9) White River Reservoir, 10) Lake Alan Henry, 11) Lake Davis, 12) Lake Catherine, 13) Millers Creek Reservoir, 14) Lake Graham, 15) Possum Kingdom Reservoir, 16) Hubbard Creek Reservoir, 17) Lake Stamford, 18) Lake Fort Phantom Hill, 19) Lake Daniel, 20) Lake Cisco, 21) De LaFosse Lake, 22) Lake Abilene, 23) Kirby Lake, 24) Lytle Lake, 25) Lake Sweetwater, and 26) Pipeline reinforcement structure.

Dams create physical barriers to the movement of fish. Although free-swimming fish and early life-history stages would likely be capable of passing downstream through small fish barriers such as weirs, low-water crossings, and natural or manmade falls, adults and larval stages of sharpnose or smalleye shiners species are not likely capable of passing downstream through most reservoirs large enough to act as water supply or hydroelectric sources. However, due to the small size and limited swimming ability of these species, upstream movement of adults would likely be prohibited by nearly any fish barrier including impoundments (regardless of type or function), weirs, falls, pipeline reinforcements structures, and some low-water crossings. The effect of blocking movement of adult fish limits their ability to seek suitable habitat during drought conditions. Without the ability to migrate upstream as adults, which occurred prior to impoundment of the Brazos River, the downstream drift of their planktonic developmental stages would have eventually carried the population to the Gulf of Mexico, where they would not survive. Fragmented river segments less than 275 km (171 mi) in length will likely result in

the mortality of substantial portions of the reproductive effort (eggs and larvae) of both species. Even in the event ichthyoplanktonic stages of the shiners are capable of passing over a fish barrier, adult fish will remain isolated up and downstream of the barrier.

Alo and Turner (2005, pp. 1144–1146) attribute river fragmentation and associated loss of reproductive effort to downstream fish migration barriers (either through mortality or emigration) as a key factor reducing effective population size in the Rio Grande silvery minnow (*Hybognathus amarus*, another pelagic broadcast spawning fish), potentially leading to loss of genetic diversity and increased potential for extirpation. Bestgen and Platania (1991, pp. 227–228) found that Rio Grande silvery minnows were restricted to a 186 km (116 mi) reach of the Rio Grande River between 1986 and 1989 and that fish were most abundant downstream of diversion dams in this stretch of river. Rio Grande silvery minnows were less abundant in upstream portions of this reach indicating reproductive output passed over diversion dams (Bestgen and Platania 1991, p. 228) and adults were later unable to migrate back upstream, thereby increasing in abundance just below diversion dams. Bestgen and Platania (2005, p. 230) argue that habitat below diversion dams is an important refugium for fish during periods of low flow, but the impediment to upstream migration caused by these diversion dams has a negative impact on population persistence that likely outweighs any positive aspect of refugium creation. The lifespan of sharpnose or smalleye shiners is short enough that two or more successive years of isolation in segments substantially shorter than the estimated 275 km (171 mi) required for population sustainment would likely lead to rapid extirpation of that population.

An example of the isolation and eventual extirpation of one of these species is illustrated by Wilde and Ostrand (1999, p. 208), who documented the collapse of a smalleye shiner population restricted to a short segment (approximately 56 km (35 mi)) of the Double Mountain Fork Brazos River upstream of Lake Alan Henry (impounded in 1993). Prior to impoundment, smalleye shiners could recolonize this stream reach after periods of drying or after flows moved planktonic life stages downstream; however, following impoundment of Lake Alan Henry, shiners isolated upstream of the lake had insufficient stream reach length to support recruitment and could not move downstream to avoid drying conditions. Prior to impoundment of Lake Alan Henry, smalleye shiners comprised as much 26.5 percent of the fish collected in this stream reach (Wilde and Ostrand 1999, p. 206). This species is now extirpated upstream of Lake Alan Henry (Wilde 2011, p. 21).

Dams and impoundments also change flow patterns in rivers. Main channel impoundments, tributary impoundments, and off-channel reservoirs alter the natural flow regime upon which the entire river ecosystem is adapted (Poff *et al.* 1997, p. 772; Bunn and Arthington 2002, p. 492; Richter *et al.* 2003, p. 207). The components of the flow regime include the magnitude, frequency, duration, predictability, and rate of change of hydrologic conditions (Poff *et al.* 1997, p. 770). Impoundments often reduce the magnitude and frequency of high flows leading to channel stabilization and narrowing downstream, alter riparian plant communities, restrict downstream transport of nutrients that support ecosystem development, and alter river substrate (Poff *et al.* 1997, pp. 773–777; Mammoliti 2002, pp. 223–224). Impoundments also store water, reducing the availability of water downstream leading to more frequent lack of flow, channel drying, and pool isolation. However, some reservoir operations provide more stable

base flows in summer months when downstream deliveries are required. Additionally, municipal water sources include several impounded reservoirs that store surface water runoff and groundwater discharge that would have naturally contributed to the flow of the upper Brazos River basin where sharpnose and smalleye shiners persist. The reduction in flows of occupied habitat reduce reproductive success in both of these species, decreasing population resiliency.

Another change in rivers caused by reservoirs is the lowering of water temperatures in the downstream reaches below dams. Reservoirs that release water from the hypolimnion (lake-bottom water) often result in abnormally low water temperatures downstream of impoundments (Edwards 1978, p. 71). The sharpnose and smalleye shiner likely tolerate cool waters for extended periods throughout the winter when mean water temperatures naturally approach 10°C (50°F) (Marks 1999, pp. 86–87). Therefore, hypolimnion releases from impounded Texas reservoirs are not likely to exceed the lowest tolerable thermal limits for these species. However, cool summer-water releases from impounded reservoirs inhibit reproduction and slow the development of spawned eggs and larvae as they drift downstream (Edwards 1978, p. 71; Perkin and Gido 2011, p. 379). Decreased water temperatures slow egg and larval development rates, thereby increasing the minimum river reach length required for successful reproduction and recruitment of juvenile fish as discussed above (Kucharczyk *et al.* 1997, entire; Perkin and Gido 2011, p. 379). Relatively cool water releases during summer months also influence spawning behavior as fish and other aquatic organisms often use the combined cues of day length, temperature, and flow to synchronize important reproductive events (Bunn and Arthington 2002, pp. 497–498). However, in some river systems, distances between impoundments can be sufficient to allow thermal recovery to more natural conditions (Gore and Bryant 1986, p. 341). It is unknown under what climatic and flow conditions thermal recovery of cooler hypolimnetic releases from Brazos River impoundments would occur.

Water releases from large reservoirs, particularly from the hypolimnion, have altered chemical properties compared to more natural, flowing water upstream. Changes in ammonia concentrations, hydrogen sulfide concentrations, oxygenation, conductivity, turbidity, chlorophyll concentrations, nutrient availability, and pH may negatively impact obligate riverine species (Edwards 1978, pp. 71–72). Anderson *et al.* (1983, pp. 83, 85) found that the hypolimnetic water released from Possum Kingdom Lake's Morris Sheppard Dam had lower total dissolved solids, chloride, temperature, and conductivity compared to flowing water upstream of the reservoir. Impacts on fishes from altered water chemistry may not be substantial if conditions remain within tolerable physiological limits.

Another alteration of the river system occurs when dams release sediment-free water downstream that alters the composition of the river substrate. River and stream water velocity slows rapidly where water enters the standing water of reservoirs, resulting in the settlement of suspended sediment within the reservoir (Poff *et al.* 1997, p. 773). Past releases of high-velocity water associated with hydropower generation, which no longer occurs, from Possum Kingdom Lake has scoured the substrate downstream of Morris Sheppard Dam, leaving gravel and rocks rather than the more typical sandy substrate of the Brazos River (Anderson *et al.* 1983, p. 82). Changes to the substrate downstream of Morris Sheppard Dam are obvious to at least 30 km (20 mi), are intermediate out to 57 km (35 mi), and do not return to more natural, sand-dominated

substrate until approximately 121 km (75 mi) (Anderson *et al.* 1983, p. 82, 86). Given that both the sharpnose and smalleye shiner appear to occasionally forage within sandy sediments, the lack of sandy substrate may inhibit their feeding and growth if suspended food sources became scarce. While sharpnose and smalleye shiners can persist in a wide range of turbid conditions, decreased turbidity, resulting from dam releases, provides a competitive advantage to fishes that are not as well adapted to the naturally turbid water of the Brazos River, such as dusky darter (*Percina sciera*), orangethroat darter (*Etheostoma spectabile*), and central stoneroller (*Campestris anomalum*) (Anderson *et al.* 1983, pp. 85–86; Bonner and Wilde 2002, p. 1206). Bonner and Wilde (2002, p. 1205) found that fish adapted to the naturally turbid conditions of the Canadian River are displaced by less-adapted fish that have a competitive advantage in less turbid water released from a main channel reservoir. Therefore, a decrease in turbidity would likely negatively impact sharpnose and smalleye shiners by providing a competitive advantage to other fish species and by reducing the availability of their preferred substrate for foraging.

The reservoirs that are created upstream of dams also drastically alter the riverine habitat. The conversion of shallow lotic (flowing) habitat to deeper lentic (non-flowing) habitat negatively affects species adapted to flowing riverine systems. Sharpnose and smalleye shiners, like other fish poorly adapted to lentic conditions, would likely experience increased mortality from large piscivorous (fish-eating predators) fish in reservoirs (Winston *et al.* 1991, p. 103). Also, as previously discussed, these species spawn semi-buoyant eggs and experience semi-buoyant developmental stages that will settle to the bottom of lentic habitats and be smothered by sediment or predated upon by bottom-dwelling organisms. As such, reservoirs likely act as a sink and reproductive trap for upstream populations (Pringle 1997, pp. 427–428), and no populations of either smalleye or sharpnose shiner are known to be capable of sustaining population growth through successful recruitment in reservoirs.

In addition to the effects above, reduced water velocities upstream from impoundments also increase the likelihood of the establishment of new species or increased abundance of existing species more adapted to the lentic environment (Poff *et al.* 1997, p. 776). Lentic fish species are often top predators and can have negative impacts on smaller, riverine species (Poff *et al.* 1997, p. 777; Mammoliti 2002, p. 223). The loss of seasonal peak flows can also disrupt spawning and larval development (Poff *et al.* 1997, p. 776), which is of concern for broadcast spawning fish such as the sharpnose and smalleye shiner (Durham and Wilde 2009a, p. 25). The middle Brazos River near Waco, Texas, has experienced a 98 percent decrease in the frequency of flood events since impoundment of Possum Kingdom Lake, Lake Granbury, and Lake Whitney and a decrease in mean annual discharge of approximately 20 percent (Bonner and Runyan 2007, p. 9). The lower Brazos River near Houston, Texas, has experienced a 43 percent decrease in the frequency of flood events and an increase in mean annual discharge of approximately 8 percent (Bonner and Runyan 2007, p. 9). Bonner and Runyan (2007, pp. 17–18) indicate that shifts in species assemblage following impoundment of the Brazos River appear to favor fish adapted to these less variable flows over obligate riverine broadcast-spawners, such as the sharpnose and smalleye shiners.

The consequences of impoundments on both upstream and downstream fish assemblages are well documented in many river systems. For example, Taylor *et al.* (2001, pp. 693, 695) indicate that, while species richness within southern Illinois' Kinkaid Creek increased following

impoundment, the upstream and downstream species assemblage shifted from a cyprinid-dominated (minnows) population to that of one dominated by centrarchids (sunfish). The congeneric species, emerald shiner (*N. atherinoides*), appears to have been extirpated from this system following impoundment (Taylor *et al.* 2001, p. 689), while additional, non-native species were introduced to the drainage (Taylor *et al.* 2001, p. 696). In another example from the Solomon River basin of Kansas, Eberle *et al.* (2002, p. 188) discovered that the plains minnow has been extirpated due to conversion of sandy, braided channels to non-sandy, narrow channels following impoundment. The authors also found that 18 species were introduced or immigrated into the altered system, where increased competition from non-native species may have contributed to the decline of native fish species (Eberle *et al.* 2002, p. 182). In a third example from the Canadian River in Texas, the plains minnow and Arkansas River shiner (*N. girardi*) comprised approximately 96 percent of the fish assemblage prior to impoundment of Lake Meredith and less than 1 percent downstream of the dam after impoundment (Bonner and Wilde 2000, pp. 192–193). At least two other cyprinid species have disappeared downstream of Lake Meredith while two others have become much more common and now dominate the assemblage (Bonner and Wilde 2000, p. 193). These three examples indicate the effects impoundments can have on fish species assemblages, including negative impacts to broadcast-spawning minnows native to prairie streams and their potential replacement by other species.

Following impoundment of the middle Brazos River by several dams, eight fish species of the lower Brazos River were identified as having decreasing population trends, including the sharpnose and smalleye shiners, while four species had increasing population trends, thus indicating a shift in fish species assemblage (Bonner and Runyan 2007, p. 11). Anderson *et al.* (1983, p. 84) documented a shift in fish assemblage up to 120 km (75 mi) downstream of Possum Kingdom Lake where five species were present upstream of the lake but not downstream, nine species were present downstream but not upstream, and only four species were present both upstream and downstream of the lake. Of the four species present both upstream and downstream of the lake, most showed substantial differences in abundance between the sites (Anderson *et al.* 1983, p. 84). It should be noted that at least two species were likely misidentified by Anderson *et al.* (1983, entire) as noted by Moss and Mayes (1993, p. 14), although it does not affect their conclusions regarding changes in fish species assemblage.

4.1.2 Potential future dams and impoundments

In addition to the ongoing effects of current dams and impoundments, Texas' 2017 State Water Plan identifies new dams planned for future construction within both species' historical and current ranges over the next 50 years (TWDB 2017, p. 27). According to Texas' 2017 State Water Plan, during drought conditions there is not enough water supply to meet current or projected human water demand (TWDB 2017, p. 7). In an effort to increase water supply, several reservoirs have been identified by the regional water groups as potentially feasible for construction or modification within the Brazos River basin (Table 5, Figure 9). These new reservoirs would have possible impacts to sharpnose or smalleye shiners.

Eight of the twenty reservoir construction or modification projects that the Brazos River regional water groups identified were included as recommended new major reservoirs in Texas' 2012 State Water Plan (Table 5; Figure 9, green circles). Of these eight reservoirs, two would

be impoundments on rivers known to currently be inhabited by both species in the upper Brazos River: Jim Bertram Lake 7 and Post Reservoir.

Table 5. Potentially feasible future reservoirs for construction or modification within the Brazos River basin. Asterisks indicate those projects also recommended by Texas' 2012 State Water Plan (TWDB 2012, p. 191; Figure 9, green circles) (Llano Estacado Regional Water Planning Group [LERWPG], Brazos G Regional Water Planning Group [BGRWPG], and Region H Water Planning Group [RHWPG]).

Impacted River Section	Stream	Project	Reference
Upper Brazos	N. Fork Double Mountain Fork	Jim Bertram Lake 7*	LERWPG 2010, p. 4–184
		Lubbock North Fork Diversion	LERWPG 2010, p. 4–199
		Post Reservoir*	LERWPG 2010, p. 4–214
	Millers Creek & Lake Creek	Millers Creek Reservoir Augmentation*	BGRWPG 2010, p. 4B.7–1
	Clear Fork	Cedar Ridge Reservoir*	BGRWPG 2010, p. 4B.12–5
	North Elm Creek	Throckmorton Reservoir	BGRWPG 2010, p. 4B.12–39
	Brazos River	South Bend Reservoir	BGRWPG 2010, p. 4B.12–21
Middle Brazos	Double Mountain Fork	Double Mountain Fork Reservoir East and West	BGRWPG 2010, p. 4B.12–53
	Palo Pinto Creek	Turkey Peak Reservoir*	BGRWPG 2010, p. 4B.12–81
	Palo Pinto Creek	Lake Palo Pinto Off-channel Reservoir	BGRWPG 2010, p. 4B.13–61
Lower Brazos	Navasota River	City of Groesbeck Off-channel Reservoir	BGRWPG 2010, p. 4B.13–5
		Millican Reservoir	BGRWPG 2010, p. 4B.12–137
	Brushy Creek	Brushy Creek Reservoir*	BGRWPG 2010, p. 4B.12–197
	Little River	Little River Reservoir	BGRWPG 2010, p. 4B.12–99
	Beaver Creek	Little River Off-channel Reservoir	BRWWPG 2010, p. 4B.13–43
	Gibbons Creek	Gibbons Creek Reservoir Expansion	BGRWPG 2010, p. 4B.12–181

Peach Creek	Peach Creek Off-channel Reservoir	BGRWPG 2010, p. 4B.13–25
Cowhouse Creek	Coryell County Off-channel Reservoir*	BGRWPG 2010, p. 4B.13–79
Allens Creek	Allen’s Creek Reservoir*	RHWPG 2010, p. 8–12

The proposed Jim Bertram Lake 7 Reservoir would be a 20,000 acre-foot (26 million cubic meters (mcm)) capacity reservoir on the North Fork Double Mountain Fork Brazos River immediately upstream of Buffalo Springs Lake in Lubbock County, Texas (LERWPG 2015, pp. 5–192). The sharpnose and smalleye shiner have never been recorded in Lubbock County, likely due to a number of impounded reservoirs that support the City of Lubbock; however, additional reservoirs in the upstream reaches of the North Fork Double Mountain Fork Brazos River will reduce the amount of water available downstream in the river and affect shiner habitat there.

The proposed Post Reservoir would be a 57,420 acre-foot (71 mcm) capacity reservoir on the North Fork Double Mountain Fork Brazos River in Garza County, Texas (LERWPG 2015, pp. 5–232). Sharpnose and smalleye shiners inhabit this reach and impacts to both species from the proposed Post Reservoir would likely be substantial both upstream and downstream of the impoundment. The reach south of Lubbock’s Lake Bertram System and north of the proposed Post Reservoir would be approximately 60 km (37 mi) in length and would be too short to support shiner populations into the future. Downstream of the proposed Post Reservoir would remain unobstructed until reaching Possum Kingdom Lake. While this reach would be long enough to support populations of sharpnose and smalleye shiners, it is unclear to what magnitude the impacts to flow regime, water quality, channel morphology, and other factors may negatively affect these species over time in this reach. At the very least, it is likely that a considerable stretch of the river would become less suitable immediately downstream of the impoundment. If downstream spawning season flow drops below that necessary to sustain these species, it could have profound negative impacts to their reproduction and, therefore, long-term viability. Future major reservoirs (including Post Reservoir) on the Brazos River, Salt Fork Brazos River, or North Fork Double Mountain Fork Brazos River upstream of Possum Kingdom Lake within the currently occupied range of these species may impede their ability to survive or recover. Effects from new impoundments could possibly be reduced with placement toward the extreme downstream or, less preferably, upstream portion of the species’ occupied range (to avoid shortening un-impounded segment lengths to less than 275 km (171 mi). Reservoirs upstream of occupied habitat would likely require implementation of well-designed water release strategies to provide flows necessary for survival and reproduction, although such measures have not been proposed, considered, or tested for effectiveness (see discussion in Chapter 6).

The remaining six reservoirs identified in Texas’ 2012 State Water Plan as recommended new major reservoirs in the Brazos River basin would all occur on rivers and tributaries that have not historically been occupied by sharpnose or smalleye shiners. However, each of these may negatively impact the shiners by reducing water availability or modifying flow patterns,

sediment transport, and fish habitat downstream of their dams. Of these six reservoirs proposed for construction in unoccupied habitat, the Millers Creek Reservoir Augmentation and Cedar Ridge Reservoir would capture flow that would otherwise discharge into the occupied segment of the upper Brazos River main stem. The remaining four reservoirs would all occur in the middle or lower Brazos River basin, where these species are not expected to survive long term due to existing habitat conditions. However, middle and lower Brazos River segments may be important for future reintroductions to study these species' biology and to provide temporary redundancy to the species. A continued decline in habitat quality in the middle and lower Brazos River resulting from water management strategies (diversions and impoundments) and other impacts would only further reduce the likelihood of using these reaches as temporary locations for redundant populations.

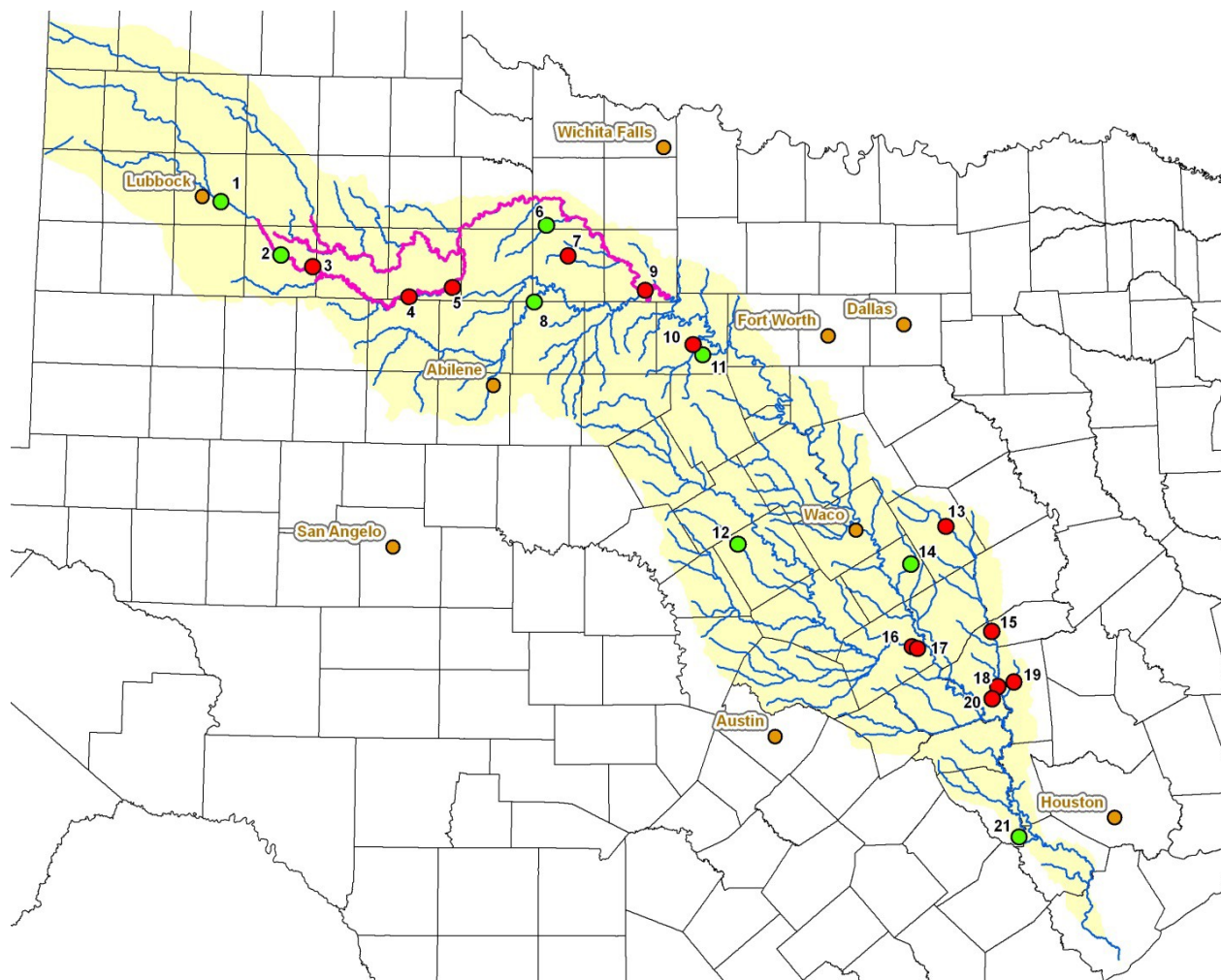


Figure 9. Reservoir projects within the Brazos River basin as determined by Water Planning Regions G, H, and O. Red and green circles represent projects determined to be feasible at the region level; however, only green circles are included in the 2012 Texas State Water Plan. The Brazos River basin (yellow shading) and its rivers and large streams (blue lines) are also shown. Currently occupied sharpnose and smalleye shiner habitat is shown with a pink line. Reservoir projects are labeled as follows: 1) Jim Bertram Lake 7, 2) Post Reservoir, 3) Lubbock North Fork Diversion, 4) Double Mountain Fork Reservoir (West), 5) Double Mountain Fork Reservoir (East), 6) Millers Creek Reservoir Augmentation, 7) Throckmorton Reservoir, 8) Cedar Ridge Reservoir, 9) South Bend Reservoir, 10) Lake Palo Pinto Off-channel Reservoir, 11) Turkey Peak Reservoir, 12) Coryell County Off-channel Reservoir, 13) City of Groesbeck Off-channel Reservoir, 14) Brushy Creek Reservoir, 15) Millican-Bundic Reservoir, 16) Little River Reservoir, 17) Little River Off-channel Reservoir, 18) Millican Reservoir Panther Creek Site, 19) Gibbons Creek Reservoir, 20) Peach Creek Off-channel Reservoir, and 21) Allens Creek Reservoir. See text for additional information.

4.2 Groundwater Withdrawal

Groundwater underlies much of the earth's surface and in many places it is in direct contact with surface-water bodies (Winter 2007, p. 23). Most streams require some contribution from groundwater to provide reliable habitat for aquatic organisms (Winter 2007, p. 15). Within the Brazos, Colorado, and Red River basins of Texas, underlying groundwater (aquifers) often reaches the surface at springs and seeps (Figure 10; Brune 1981, entire) or through groundwater and surface-water interactions at the river bed interface (Sawyer 2011, p. 1). Although natural springs were a primary source of freshwater for Native Americans and early Texas missionaries, groundwater depletion was not particularly damaging until the mid-nineteenth century when Anglo-American settlers discovered wells could be drilled nearly anywhere (Brune 1981, pp. 35–36). In the 1930s, widespread groundwater pumping began for irrigation in Texas (Brune 1981, p. 36). Groundwater withdrawal for irrigation is prevalent in the Llano Estacado Water Planning Region, at the extreme upstream portions of the upper Brazos River basin, where the Ogallala Aquifer is the largest available water source (LERWPG 2015, pp. 3–9). Over 95 percent of this water is used to irrigate agriculture in an otherwise arid landscape (LERWPG 2015, pp. 1–23). Where not governed by a groundwater conservation district, Texas is the only western state that generally allows landowners to remove as much groundwater from beneath their land as is possible without liability (TWDB 2017, p. 122).

The surface-water and groundwater interactions of the upper Brazos River basin are not well understood (Baldys III and Schalla 2011, p. 2). However, springs and seeps once and may still substantially contribute to surface water volume and flow. For example, Running Water Draw, which feeds the White River and ultimately the Salt Fork Brazos River, once contained hundreds of Ogallala-fed springs that kept the draw flowing year round (Brune 1981, p. 38).

Groundwater pumping for irrigation has had substantial impacts on these springs and in 1975 only three small springs along the White River remained flowing (Brune 1981, p. 38). Although the status of these three springs is not known absolutely, a database of Texas springs produced in 2003 indicates the presence of just one spring along the White River (Heitmuller and Reece 2003, entire). In 2010, groundwater stream gains (additional water in the stream that is not accounted for by surface flow, precipitation, etc.) in the Salt Fork Brazos River and Double Mountain Fork Brazos River were attributed to potential contributions from the underlying Dockum, Blaine, Seymour, Ogallala, or Edward-Trinity Aquifers (Baldys III and Schalla 2011, pp. 34–35), suggesting that hydrological connections between groundwater and surface water may still positively contribute to shiner habitat.

The extent to which groundwater depletion has reduced surface flows of streams and rivers that were once, or still remain, inhabited by one or both species is largely unknown; however, the effects may have been substantial as suggested above. Future groundwater depletion may further reduce surface flows of the upper Brazos River basin by reducing groundwater contribution to surface flows. A reduction in surface flows also has implications for water quality since less water is available to dilute potentially harmful pollutants (discussed further in Section 4.7). Under more extreme cases of groundwater withdrawal, groundwater levels may be lowered to the point where Brazos River surface water may infiltrate the river bed and recharge groundwater supplies, further reducing surface water flows. Although groundwater conservation districts manage groundwater resources within their jurisdictional boundaries to

ensure that groundwater will be available for future users, the 2017 Texas State Water Plan indicates statewide groundwater supplies are projected to decrease up to 24 percent by 2070, primarily due to depletion of the Ogallala Aquifer (TWDB 2017, p. 71), which underlies the Llano Estacado Region of the extreme upstream portion of the Brazos River basin and once contributed substantially to the flow of the river. Despite declining availability, groundwater withdrawal and groundwater desalination projects, including within the Brazos River basin, are proposed to remove three times more volume of water in 2060 than in 2010 (TWDB 2012, pp. 73, 194; BGRWPG 2010, p. 4B.19–1; LERWPG 2010, pp. 4–232, 4–239, 4–279). The increased use of water withdrawal from aquifers may have severe, detrimental impacts to surface water availability throughout Texas, including areas supporting sharpnose and smalleye shiners. It is expected that groundwater withdrawal to an extent that decreases surface water flow and volume will reduce the reproductive output of sharpnose and smalleye shiners at the individual, population, and species level. Furthermore, as groundwater is depleted the hydrologic connection between the Brazos River and groundwater will be reduced. Perkin *et al.* (2017, p. 2, 4) analyzed the effects of ground water depletion on fish assemblages in the Great Plains and found a shift in dominance from large-stream fishes to small-stream fishes, and large-stream fish assemblages experienced permanent reduction with increasing depths to ground water in western watersheds. Falke *et al.* (2012, p. 865) found that in Great Plains streams, extinction probability of fishes due to drought increased significantly when the site was not fed by groundwater.

4.3 Climate Change

The terms “climate” and “climate change” are defined by the Intergovernmental Panel on Climate Change (IPCC). “Climate” refers to the mean and variability of different types of weather conditions over time, with 30 years being a typical period for such measurements, although shorter or longer periods also may be used (IPCC 2007a, p. 78). The term “climate change” thus refers to a change in the mean or variability of one or more measures of climate (e.g., temperature or precipitation) that persists for an extended period, typically decades or longer, whether the change is due to natural variability, human activity, or both (IPCC 2007a, p. 78).

Geological records indicate the southern Great Plains, including the upper Brazos River basin, experienced a prolonged period of extreme drought between 6,500 to 4,500 years ago (Johnson and Holliday 1986, p. 44; Meltzer 1999, entire). However, despite extreme drought conditions, archeological and geological records at Lubbock Lake (where the current city of Lubbock, Texas exists) document surface water presence throughout the 2,000 year drought, likely from active springs and seeps (Johnson and Holliday 1986, p. 44). It is not known how much, if any, of the surface water available during this period created measurable flows in the upper Brazos River basin. Fossil pollen records indicate central Texas (through which the Brazos River flows in its middle and lower basin) climate was not different than present time (Bryant 1977, p. 153). As such, central Texas retained surface water and may have acted as a refuge for indigenous people (Johnson and Holliday 1986, p. 48) and for sharpnose and smalleye shiners. The middle and lower Brazos River are currently unable to act as sharpnose and smalleye shiner refuges from drought due to the presence of fish migration barriers (reservoirs and dams) in the middle Brazos River. Additionally, many

springs and seeps of the upstream-most upper Brazos River basin have now gone dry due to groundwater withdrawal or are captured by impoundments. Therefore, sharpnose and smalleye shiners may not have these historical options available to them to overcome future climate conditions, including arid conditions and worsening drought and their consequent effects on riverine habitat.

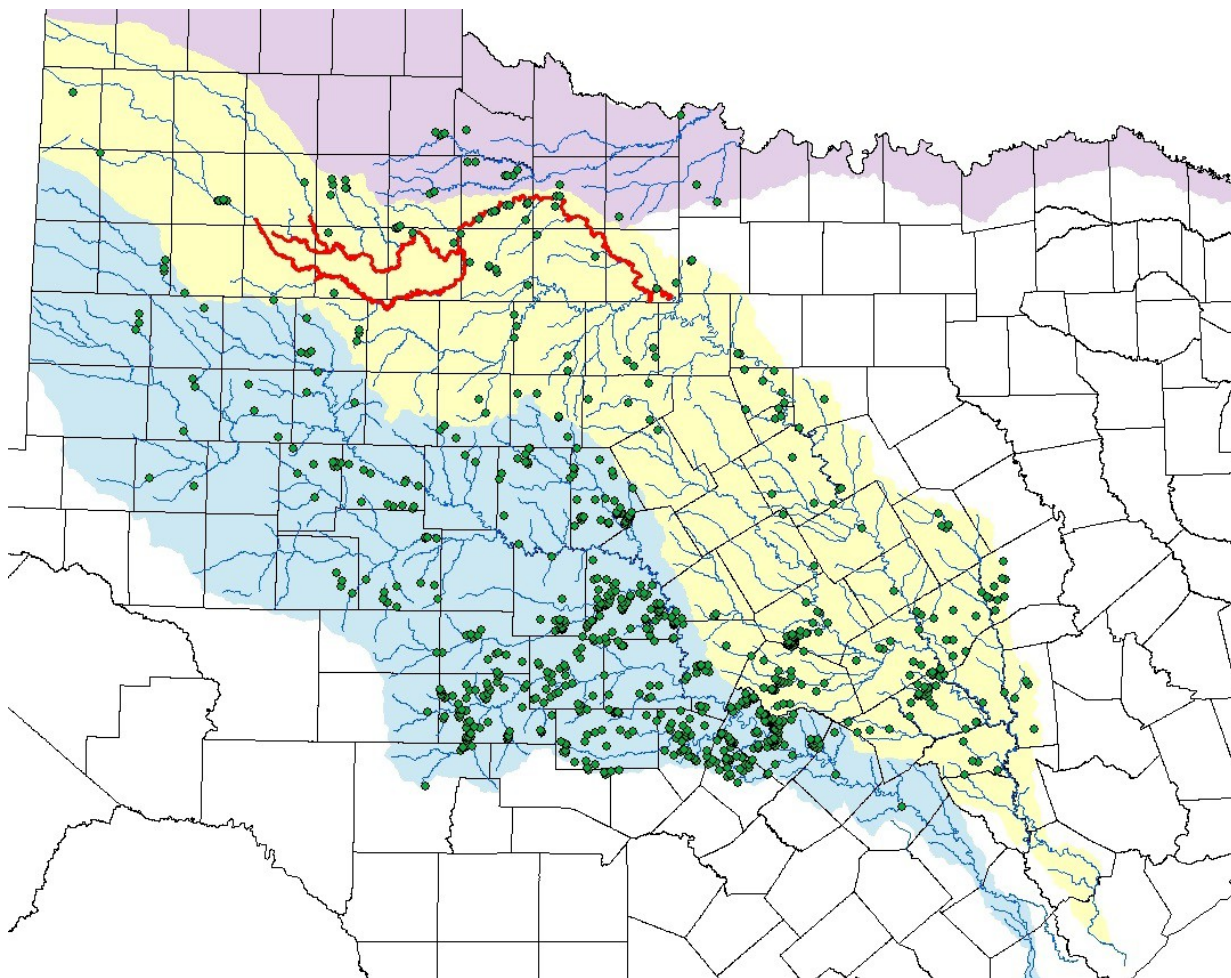


Figure 10. Select springs and seeps (green circles) of the Brazos (yellow), Colorado (blue), and Red River (pink) basins (Heitmuller and Reece 2003, GIS shapefile). The currently occupied habitat of sharpnose and smalleye shiners is shown in red.

Scientific measurements spanning several decades demonstrate that changes in climate are occurring, and that the rate of change has been faster since the 1950s. Based on extensive analyses of global average surface air temperature, the most widely used measure of change, the IPCC concluded that warming of the global climate system over the past several decades is “unequivocal” (IPCC 2007a, p. 2). In other words, the IPCC concluded that there is no question that the world’s climate system is warming. Examples of other changes include substantial increases in precipitation in some regions of the world and decreases in other regions (for these and additional examples, see IPCC 2007a, p. 30; Solomon *et al.* 2007, pp. 35–54, 82–85). Various environmental changes (e.g., shifts in the ranges of plant and animal species, increasing ground instability in permafrost regions, conditions more favorable to the

spread of invasive species and of some diseases, changes in amount and timing of water availability) are occurring in association with changes in climate (see IPCC 2007a, pp. 2–4, 30–33; and Karl *et al.* 2009, pp. 27, 79–88).

Scientists use a variety of climate models, which include consideration of natural processes and variability, as well as various scenarios of potential levels and timing of greenhouse gas (GHG) emissions, to evaluate the causes of changes already observed and to project future changes in temperature and other climate conditions (e.g., Meehl *et al.* 2007, entire; Ganguly *et al.* 2009, pp. 11555, 15558; Prinn *et al.* 2011, pp. 527, 529). All combinations of models and emissions scenarios yield very similar projections of average global warming until about 2030. Although projections of the magnitude and rate of warming differ after about 2030, the overall trajectory of all the projections is one of increased global warming through the end of this century, even for projections based on scenarios that assume that GHG emissions will stabilize or decline. Thus, there is strong scientific support for projections that warming will continue through the 21st century, and that the magnitude and rate of change will be influenced substantially by the extent of GHG emissions (IPCC 2007a, pp. 44–45; Meehl *et al.* 2007, pp. 760–764; Ganguly *et al.* 2009, pp. 15555–15558; Prinn *et al.* 2011, pp. 527, 529).

The IPCC reports projections using a framework for treatment of uncertainties (e.g., they define “very likely” to mean greater than 90 percent probability, and “likely” to mean greater than 66 percent probability; see Solomon *et al.* 2007, pp. 22–23). Some of the IPCC’s key projections of global climate and its related effects include: (1) it is virtually certain there will be warmer and more frequent hot days and nights over most of the earth’s land areas; (2) it is very likely there will be increased frequency of warm spells and heat waves over most land areas; (3) it is very likely that the frequency of heavy precipitation events, or the proportion of total rainfall from heavy falls, will increase over most areas; and (4) it is likely the area affected by droughts will increase, that intense tropical cyclone activity will increase, and that there will be increased incidence of extreme high sea level (IPCC 2007b, p. 8, table SPM.2). More recently, the IPCC published additional information that provides further insight into observed changes since 1950, as well as projections of extreme climate events at global and broad regional scales for the middle and end of this century (IPCC 2012, entire).

Although air temperature data from 1900 to 2000 do not support a warming trend across much of Texas (Nielsen-Gammon 2011, p. 2.21), data within the last three decades do support a clear warming trend (Banner *et al.* 2010, p. 8). Climate change models generally project a three to four degree Fahrenheit (1.6 to 2.2 °C) increase in temperature between 2010 and 2050 (Nielsen-Gammon 2011, p. 2.23; Banner *et al.* 2010, p. 8). There are no scenarios in which a general global warming trend is not expected to occur (IPCC 2007b, pp. 5, 12–15). Although climate change models generally project a warming trend, they do not generally agree on the precipitation trends over Texas (Nielsen-Gammon 2011, p. 2.28). The models tend to suggest that Texas weather will become more dry (Banner *et al.* 2010, p. 8), although variation in model projections indicate it is not prudent to assume precipitation will be steady (Nielsen-Gammon 2011, p. 2.30). Even in the event that precipitation increases over Texas, any surface-water gains could be offset by increased evapotranspiration and water demand resulting from increased temperature (Nielsen-Gammon 2011, p. 2.30; Banner *et al.* 2010, p. 10). Wurbs *et al.* (2005, p. 384) modeled the effects of predicted climate change downscaled to the Brazos River

basin on water availability and determined that water availability in the Brazos River would decrease. The decrease in water availability was a result of increased evapotranspiration from increased temperature and a general decrease in precipitation (Wurbs *et al.* 2005, p. 384). Although precipitation increased in some areas of the basin, Wurbs *et al.* (2005, p. 384) found that most of the decreases in precipitation and runoff into the river channel were in the upper basin, where it will be most detrimental to sharpnose and smalleye shiners. Dorman (2003, p. 64) also assessed the impact climate change will have on water availability in the upper Brazos River and estimated that the daily flow of the Brazos River near Seymour, Texas (within occupied habitat) may decrease by 20 percent if atmospheric CO₂ doubles. Overall, drought severity and frequency will likely increase in Texas (Nielsen-Gammon 2011, p. 2.32; Banner *et al.* 2010, p. 9). Projections of future aridity in Texas suggest that each decade between 2040 and 2100 will experience a drought of equal or greater intensity and duration than that of the 1950s, which was the drought of record due to intensity and duration (Banner *et al.* 2010, p. 9) prior to the 2011 drought.

4.4 Drought

Drought conditions in the upper Brazos River basin negatively impact sharpnose shiners and smalleye shiners by reducing the availability and flow rate of river water required to survive, recruit, and reproduce. The drought of 2011 was the worst one-year drought in Texas' history (TWDB 2017, p. 15; NOAA 2011, p. 8). According to annual average discharge data from USGS gage station number 08082500 on the Brazos River main stem at Seymour in Baylor County (a location near the epicenter of persisting sharpnose and smalleye shiners in the upper Brazos River), the average 2011 discharge was $1 \text{ m}^3 \text{ s}^{-1}$ (36.6 cfs), almost half that of the next driest year on record (1998). The greatest monthly mean flow from the sharpnose and smalleye shiner spawning season (April – September) during 2011 was $0.6 \text{ m}^3 \text{ s}^{-1}$ (21.7 cfs) in April, with a maximum daily flow of $1 \text{ m}^3 \text{ s}^{-1}$ (35 cfs) on April 1. The next two driest spawning seasons for which there are monthly data (1963 to 2011) were in 1998 and 1984 with monthly mean peak discharges of $1.8 \text{ m}^3 \text{ s}^{-1}$ (62.2 cfs, July) and $1.7 \text{ m}^3 \text{ s}^{-1}$ (59.1 cfs, August), respectively. A peak daily flow of $13.5 \text{ m}^3 \text{ s}^{-1}$ (478 cfs) was measured at this location on July 5, 1998, and a flow of $12.5 \text{ m}^3 \text{ s}^{-1}$ (443 cfs) was measured on August 29, 1984. For comparative purposes, daily discharges greater than $2.8 \text{ m}^3 \text{ s}^{-1}$ (100 cfs) were recorded throughout the spawning season in 1984 (12 days) and 1998 (17 days), while none were recorded in 2011.

Although the drought of the 1950s was considered the drought of record prior to the 2011 drought, (TWDB 2012, p. 1), USGS daily discharge data dating back to 1924 from the Brazos River at Seymour in Baylor County indicate that, at least at some point during the shiner spawning season of each year during the 1950s, flows were considerably larger than those from 1984, 1998, and 2011. Between 1940 and 2013 (74 years), USGS mean monthly discharge data from the Brazos River at Seymour indicates 25 spawning seasons (more than half of which (13) occurred since 1993) did not meet the estimated minimum mean summer discharge requirement ($6.43 \text{ m}^3 \text{ s}^{-1}$ (227 cfs)) to sustain smalleye shiner population growth while 9 (more than half of which (5) occurred since 1993) did not sustain estimated levels required for sharpnose shiners ($2.61 \text{ m}^3 \text{ s}^{-1}$ (92 cfs)) (Figure 11). Between 1940 and 2013 (74 years), USGS mean monthly

discharge data from the Double Mountain Fork Brazos River at Aspermont (Stonewall County, Texas) indicates 49 spawning seasons (19 of which occurred since 1993) did not meet the estimated minimum mean summer discharge requirement ($6.43 \text{ m}^3 \text{ s}^{-1}$ (227 cfs)) to sustain smalleye shiner population growth while 26 (13 of which occurred since 1993) did not sustain estimated levels required for sharpnose shiners ($2.61 \text{ m}^3 \text{ s}^{-1}$ (92 cfs)) (Figure 11). The frequency of spawning seasons not meeting the estimated minimum mean summer discharge requirements to support sharpnose and smalleye shiner growth appears to be increasing based on the numbers above. With increasing drought there is a projected decrease in surface runoff up to 10 percent by the mid-21st century (Mace and Wade 2008, p. 656; Karl *et al.* 2009, p. 45). As the intensity and frequency of spawning season droughts increase and river flows decrease, shiner survival, reproduction, and recruitment will be reduced.

Due to drought conditions and lack of streamflow in 2011, there was no observed recruitment of juvenile sharpnose or smalleye shiners during sampling efforts of the upper Brazos River during the spawning season of 2011 (Wilde 2012b, pers. comm.). Fearing their possible extinction in the summer of 2011, TPWD and Texas Tech University biologists salvaged more than 1,000 sharpnose and smalleye shiners from the upper Brazos River, where the record drought had confined them to shrinking, non-flowing, isolated pools (Campoy 2011, entire; Mayes 2012, pers. comm.). Approximately 372 surviving individuals of each species were later released into the lower Brazos River in May 2012. Fish survey results of the upper Brazos River in 2012 indicated drought conditions were not as intense as those in 2011 and sharpnose and smalleye shiners persisted; therefore, catastrophic loss of these species did not occur (Wilde 2012a, entire). A highly restricted flow and drying of portions of the river were also documented in the summer of 2018, but no emergency measures were needed (Kevin Mayes, TPWD, pers. comm.).

Prior to impoundment of their native habitat, during drought conditions sharpnose and smalleye shiners could have swum downstream until suitable conditions for survival and reproduction were met. After droughts ended, these fish could recolonize the upstream reaches when favorable conditions returned. Impounded reservoirs often retain water during droughts but sharpnose and smalleye shiners are not well adapted to reproduce in non-flowing habitat because of their broadcast spawning life history requirement suggesting most, if not all, of their reproductive effort under these conditions would not survive. Despite an increased threat of predation, some adult sharpnose and smalleye shiners may temporarily survive drought conditions by finding refuge in impounded reservoirs. The utilization of reservoirs by sharpnose shiners and smalleye shiners during periods of drought is speculative and requires additional investigation. As such, impoundments act as barriers on occupied stream reaches and exacerbate the negative effects of increased duration, frequency, and intensity of drought by preventing these fish from potentially migrating to suitable habitat for increased likelihood of survival and reproduction.

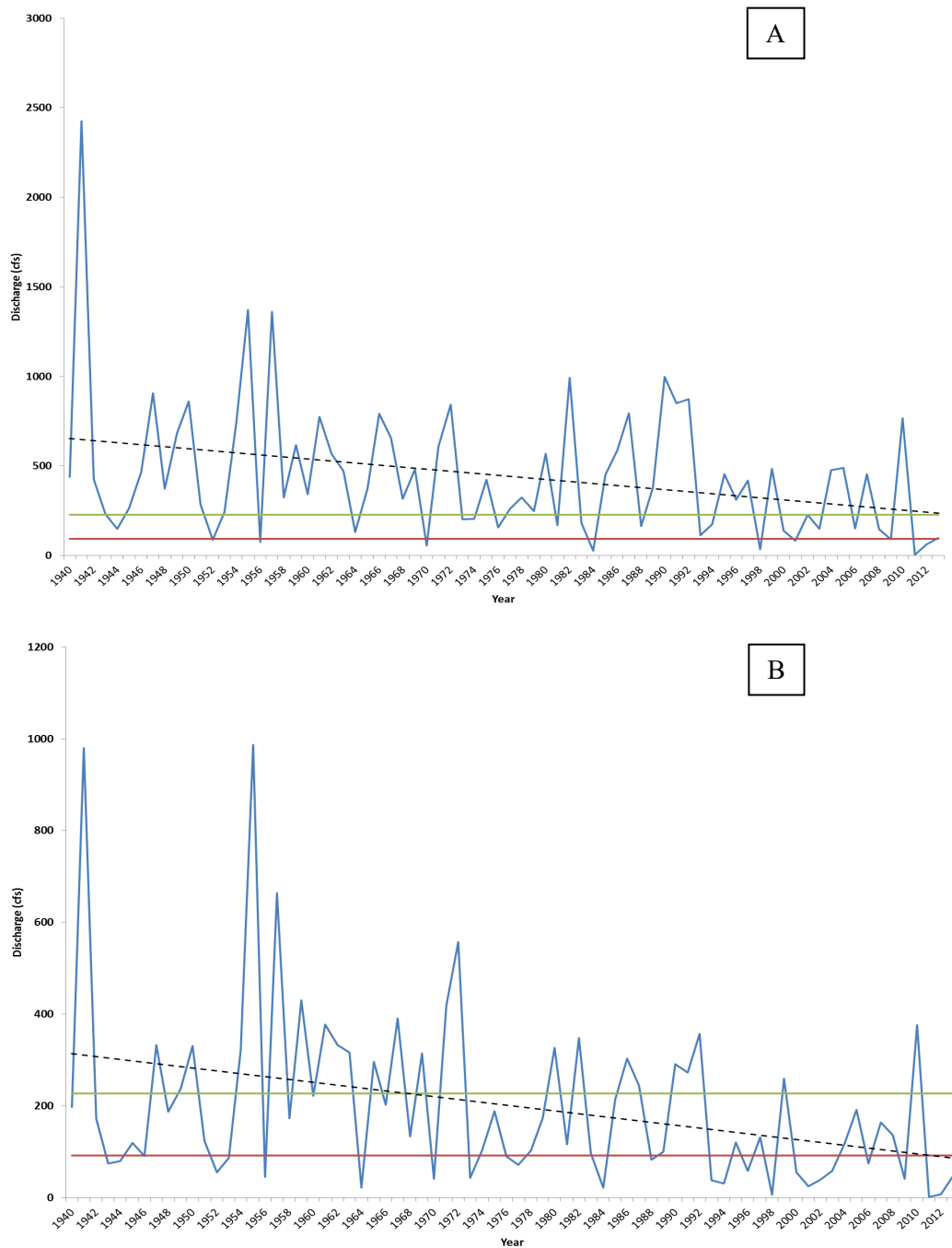


Figure 11. Mean spawning season discharge, calculated as the mean of the monthly discharges from April through September, for the Brazos River near Seymour, Texas (A, Baylor County; blue line) and the Double Mountain Fork Brazos River near Aspermont, Texas (B, Stonewall County; blue line) compared to the estimated minimum required flow required to sustain populations of sharpnose (red line) and smalleye (green line) shiners. Trend in data represented by dotted black line.

During extreme droughts such as the one that occurred in 2011, the upper Brazos River nearly dries out completely, and any remaining water lacks the flow necessary to support successful recruitment in these species. Due to the short lifespan of these species, major drought conditions occurring over two successive years may result in low numbers of remaining individuals or even in local extirpations. However, a study evaluating the 2011 drought concluded that it was an outlier compared to conditions over the past 100 years and not consistent with regional trends (Hoerling *et al.* 2013, entire). Additionally, the drought and heatwave were largely attributed to anomalous sea surface temperatures related to La Niña conditions in the Pacific Ocean, rather than anthropogenic climate change (Hoerling *et al.* 2013, entire).

4.5 Invasive Saltcedar

Saltcedar (*Tamarix* spp.), a non-native deciduous shrub, was likely introduced to North America in the early 1800s through importation from Africa, Asia, and Europe by New England nurseries (Robinson 1965, p. A3). There are several *Tamarix* species that are now well established throughout the southwestern United States, including within the Brazos River basin in Texas (Blackburn *et al.* 1982, p. 298). Saltcedar invaded 18 percent of the upper Brazos River floodplain by 1940, 28 percent by 1950, 30 percent by 1969 (Busby and Schuster 1971, p. 286), more than 57 percent by 1979 (Blackburn *et al.* 1982, p. 299), and presumably even more today, although the current extent of saltcedar is not fully known.

Saltcedar can have negative impacts on riverine ecosystems like the Brazos River. Thick stands of saltcedar along sandbars and channel edges stabilize the sediments and reduce water velocity during flood flows, causing additional sediment accumulation (Blackburn *et al.* 1982, p. 300). As the channel becomes narrower, water flow velocity and channel depth increases (possibly resulting in further drift distances of the semi-buoyant life stages of these species) and saltcedar encroaches further into the channel until the channel is nearly occluded and streamflow is severely reduced (Di Tomaso 1998, p. 328). Between 1941 and 1979 the width of the upper Brazos River channel upstream of Possum Kingdom Lake declined by as much as 71 percent, with an average reduction of nearly 90 m (300 ft) due to excessive sedimentation attributable to saltcedar infestation (Blackburn *et al.* 1982, pp. 299–300). The narrowing, deepening, increased flow velocity, and ultimately the potential occlusion of the Brazos River by saltcedar infestation negatively impacts sharpnose and smalleye shiners because they are associated with the wide, braided, flowing natural conditions historically present. However, the actual extent to which saltcedar-induced sediment trapping and changes in channel morphology affects populations of these shiners is largely unknown.

Saltcedar has historically been suspected of contributing to groundwater depletion and reduction in surface flows due to high transpiration rates and low water-use efficiency (Robinson 1965, p. A10; Busby and Schuster 1971, p. 287; Kerpez and Smith 1987, p. 3; Weeks *et al.* 1987, p. G28; Friederici 1995, p. 45; Di Tomaso 1998, p. 332). However, more recent studies suggest that transpiration rates per leaf area from saltcedar are similar to those of native and naturalized riparian vegetation such as cottonwoods and mesquite (Nagler *et al.* 2003, p. 85; Shafroth *et al.* 2005, p. 234). However, it has been suggested that saltcedar is capable of producing such dense stands that, at a per stand basis (rather than per leaf area),

transpiration rates for saltcedar may be much higher than other riparian vegetation (Di Tomaso 1998, p. 332; Hays 2003, p. 8; Hatler and Hart 2009, p. 309); although Nagler *et al.* (2001, pp. 102–103) found leaf area indices between saltcedar stands and other riparian vegetation (cottonwoods and willows) to be similar and largely overlapping. However, in the upper Brazos River basin historical native riparian vegetation is characterized mostly by grasses and sparse native trees such as cottonwoods, willows, hackberry, mesquite, and a small variety of other woody plant species (Busby and Schuster 1973, entire). Dense stands of saltcedar likely reduce streamflow in the Brazos River basin compared to the transpirational water losses that would have occurred given less dense stands of native, historical vegetation. This streamflow reduction negatively impacts sharpnose and smalleye shiners, although the actual extent of the impact on streamflow and these shiner species is largely unknown. However, at a minimum, dense saltcedar infestation contributes to and acts cumulatively with impoundments, drought, and groundwater depletion to exacerbate water loss from the river channel and restrict the channel width.

4.6 Desalination

The water in the upper Brazos River is highly saline for a freshwater system, as a result of the natural weathering process of groundwater flows in areas surrounding the Salt Fork Brazos River and portions of the Double Mountain Fork Brazos River and Croton Creek watersheds (Wurbs *et al.* 1993, p. 1). Sharpnose and smalleye shiners are presumably adapted to the saline conditions of the Brazos River compared to fish not native to the river, although they appear less tolerant of increased salinity compared to other native fish species common in these reaches (Ostrand and Wilde 2001, p. 744). As such, information is not available to estimate how sharpnose and smalleye shiner populations may react to artificially reduced salt content within the streams where they occur. However, another fish species adapted to saline conditions of arid prairie streams (the Red River pupfish), is competitively excluded by less saline adapted fish in waters containing lower salt content (Echelle *et al.* 1972, entire).

Unintended effects of salt control projects in the form of impoundments and altered hydrology have a far more negative effect on these species than the decrease in salinity. The U.S. Army Corps of Engineers' Brazos River Basin Natural Salt Pollution Control Study recommended plan consisted of three salt control reservoirs on tributaries of the Salt Fork Brazos River: Croton Lake on Croton Creek, Dove Lake on Salt Croton Creek, and Kiowa Peak Lake on North Croton Creek (Wurbs *et al.* 1993, p. 51). These three reservoirs would restrict all upstream runoff with no planned water releases, effectively removing their input of water into the Brazos River system (Wurbs *et al.* 1993, p. 51). The resulting loss of water flow in the Brazos River would likely result in more substantial impacts to these shiners than the decrease in salinity (see **Impoundments** section above). However, the 2017 Texas State Water Plan does not indicate plans to construct salt pollution control reservoirs in the upper Brazos River watershed at this time (TWDB 2017, entire).

Salt pollution control can also be achieved by removing and treating groundwater, thereby removing the volume of highly saline water that enters surface flow. The Llano Estacado Regional Water Planning Group (LERWPG 2010, pp. 4–232) is considering the removal of brackish groundwater from underlying aquifers to treat and supply to the City of Lubbock. The

withdrawal of groundwater from aquifers underlying the Brazos River basin may reduce surface water flows available for sharpnose and smalleye shiner survival and reproduction. The effects of groundwater removal on the shiners were presented in additional detail in the groundwater depletion section of this assessment (see **Groundwater Withdrawal**).

Another form of desalinization that can affect both water quality and quantity is a process known as reverse osmosis (RO). Reverse osmosis technology purifies drinking water by forcing the water across a porous membrane that allows only pure water to pass through, leaving impurities behind in a waste stream. Reverse osmosis has gained popularity among municipalities in west Texas that are struggling to meet increasing demand for drinking water in an arid region with limited supplies. Reverse osmosis is viewed as a viable treatment technology that can purify brackish groundwater and surface water resources in the area, such as Possum Kingdom Lake, that would otherwise not meet drinking water standards; however, disposing of the reject wastewater in an environmentally friendly way has been problematic. When RO wastewater is discharged to nearby waterbodies (natural or human-made), it contains elevated concentrations of potentially harmful constituents such as total dissolved solids, trace metals, selenium, arsenic, and other impurities that are removed from the source water; these impurities can degrade receiving waters and harm aquatic dependent wildlife. The upper Brazos River has received RO wastewater from water treatment plants in the past (City of Seymour; see Pollution) and has been proposed as the receiving stream for wastewater from new RO treatment facilities in the future. The degree to which desalinization activities throughout the upper Brazos River basin affect shiners is unknown and needs further investigation.

4.7 Water Quality Degradation

4.7.1 Pollution

As the human population grows, so do the demands on water resources that support agriculture, industry, recreation, and municipal consumptive uses. These uses adversely affect the water quality and water quantity that is available for wildlife, often resulting in increased competition for scarce water supplies that are increasingly degraded from overutilization. A number of land use practices, activities, and sources of pollution have the potential to impact surface water quality including runoff from irrigated cropland, concentrated animal feeding operations (CAFOs), leaching from municipal solid waste sites, and stormwater runoff from urban areas, often characterized into either point or non-point source pollution. Point sources include so-called end-of-pipe discharges such as municipal or industrial wastewater, while nonpoint source pollution comes from many diffuse sources such as stormwater runoff, atmospheric deposition of mercury from coal-fired power plants, or pesticide drift from croplands. Richter *et al.* (1997, p. 1090) suggests that nonpoint source pollution resulting in nutrient loading of receiving waters is one of the leading threats to freshwater aquatic ecosystems in the United States. Urban areas are also a major source of pollutants that degrade nearby streams, contributing to what scientists call “urban stream syndrome” where a variety of pollutants degrade water quality resulting in lower species richness in urban-impacted waterways (Walsh *et al.* 2005). Although watersheds that hydrologically support the upper Brazos River are generally rural and less populated

compared to other areas of the state, point and non-point sources of pollution exist that are capable of degrading water quality, and consumptive uses are increasing in some areas resulting in reduced surface and groundwater flows.

A spatial review of existing Texas Pollution Discharge Elimination System (TPDES) permits issued by the Texas Commission on Environmental Quality (TCEQ) suggests that a majority of CAFOs located in the extreme upstream portion of the upper Brazos River basin do not occur near the river channel and would therefore presumably have little or no direct impact to water quality. Similarly, there appear to be relatively few non-CAFO TPDES-permitted entities within the upper Brazos River watershed that are located near major surface water channels except near urban areas. These urban areas are also where higher concentrations of municipal and industrial wastewater discharges, municipal solid waste sites (landfills), and other potential sources of environmental contaminants occur. The Brazos River receives treated effluent from both domestic and industrial wastewater sources. Information about these dischargers is available on the Environmental Protection Agency's (EPA) Environmental Compliance History Online (ECHO) database. This database houses permit and environmental compliance information for facilities which are permitted by state and federal agencies.

There are currently no facilities permitted to discharge to either Segments 1238 (Salt Fork Brazos River) or 1241 (Double Mountain Fork Brazos River) (uppermost reaches of the Brazos River), however there are a number of facilities which discharge into streams which flow into Segments 1238 and 1241. Segment 1241A (North Fork of the Double Mountain Fork Brazos River) receives discharge from 5 domestic wastewater facilities, and there are 9 additional permitted entities that discharge treated effluent into Segment 1208 of the Brazos River (downstream of Segments 1238 and 1241 and above Possum Kingdom Lake) (Table 6). Of these 9 permitted dischargers, Luminant Generation Company, LLC (coal-fired power plant) and the City of Seymour (water treatment plant that uses reverse osmosis to treat drinking water) are the only industrial permits while the other 7 are domestic wastewater (i.e., municipal effluent). The City of Graham and Luminant Generation LLC are both considered major permits (i.e., > 1 million gallons per day (MGD)) by the EPA and are permitted to discharge 2.1 MGD and 505.4 MGD, respectively. The remaining entities permitted under the TPDES program to discharge wastewater into Segment 1208 of the Brazos River are the Cities of Throckmorton, Goree, Munday, Knox City, O'Brien, and Seymour (the only entity with both an industrial and domestic discharge).

The combined total daily average discharge allowed from these 14 facilities to the upper Brazos River is 530 MGD. The extent to which these discharges impact water quality varies with changes in weather and as natural flows fluctuate seasonally. Water quality and water quantity are interdependent; as the quantity of natural flows increase (e.g., rainfall), so does the buffering and dilution capacity of the receiving waters, which serves to reduce the concentration of potentially harmful constituents being discharged to a waterbody. The extent to which sharpnose and smalleye shiners are impacted by wastewater flows in the upper Brazos River is unknown, but municipal and industrial effluents are discharged throughout the system and they may comprise the majority of flows near wastewater outfalls during dry weather. Furthermore, municipal effluents are known to contain a variety of persistent, bioaccumulative, and potentially harmful constituents that can adversely impact aquatic life, including elevated nutrients, trace

metals, ammonia, chlorine, coliform bacteria, dissolved solids, trace organic (e.g., pesticides) and inorganic (e.g., copper) pollutants, industrial chemicals, and contaminants of emerging concern such as pharmaceuticals and personal care products (some of which are hormonally active even at low concentrations; Daughton and Ternes 1999). Metabolites and other impurities that form as these pollutants break-down or degrade can also be harmful. The presence of wastewater related contaminants and subsequent changes to the biological, chemical, and physical properties of receiving streams is well established in the scientific literature (Woodling *et al.* 2006, Iwanowicz *et al.* 2009, Stalter *et al.* 2013, Graham *et al.* 2014, Nobles and Zhang 2015). Since point-source discharges occur on a continuous basis, the level of water quality degradation and potential for impacts to aquatic biota varies depending on the type and volume of discharge, and the volume of base flows, among other site-specific variables. Based on this information we can surmise that at a minimum, impacts to the biological community likely occur in the immediate area of wastewater discharges and some distance downstream, particularly during times of low flow, and that risks to aquatic biota increase during dry weather when natural flows are at their lowest or cease to exist.

Table 6. List of facilities permitted by TCEQ to discharge wastewater into the upper Brazos River as of 2016 (Source: TPWD).

TPDES Permit No.	Facility Name	Segment	Daily Avg Flow (MGD)	Major/Minor Permits	Type
10487-001	City of Graham	1208	2.1	Major	Domestic
00551-000	Luminant Generator, LLC	1208	505.4	Major	Industrial
10469-001	City of Throckmorton	1208	0.12	Minor	Domestic
10281-001	City of Seymour WWTP	1208	0.537	Minor	Domestic
04004-000	City of Seymour R.O. Plant	1208	0.20	Minor	Industrial
10102-001	City of Goree	1208	0.55	Minor	Domestic
10228-001	City of Munday	1208	0.20	Minor	Domestic
10416-001	City of Knox City	1208	0.20	Minor	Domestic
13616-001	City of O'Brien	1208	0.02	Minor	Domestic
10788-001	City of Ransom Canyon	1241A	0.225	Minor	Domestic
10353-001	City of Lubbock	1241A	14.5	Major	Domestic
04599-000	City of Lubbock Land Application Site	1241A	3.0	Major	Industrial
10353-011	City of Lubbock Water Reclamation Plant	1241A	3.0	Major	Domestic
10621-001	White River Municipal Water District	1240	0.09	Minor	Domestic

In the area surrounding the extreme upstream portion of the upper Brazos River basin, less than 1 percent of precipitation runs off into streams and rivers and the water quality is generally considered to be good (LERWPG 2010, pp. 1–14, 1–60). In this region, the arid climate, uniform topography, and gradually sloping terrain restrict the movement of runoff into surface waters (LERWPG 2010, pp. 1-63). There are no impaired stream segments in the Brazos River basin north or west of the City of Lubbock (TCEQ 2014a, entire).

The water quality in the upper Brazos River is also generally good (BGRWPG 2010, pp. 1–46), although a number of natural and human-mediated water quality issues have occurred in the past and present that negatively affect sharpnose and smalleye shiners. For example, TCEQ (2008a, pp. 282–283) identified the Salt Fork Brazos River as an impaired stream segment; although the primary impacts are from dissolved chloride, high temperature, and low dissolved oxygen, all of which are natural occurrences in this reach, they can also be influenced and exacerbated by human activity (e.g., groundwater withdrawal). Similarly, portions of the Double Mountain Fork Brazos River were listed as impaired due to the presence of high levels of chloride, bacteria, and total dissolved solids (TCEQ 2008a, p. 292; TCEQ 2010, pp. 477–478), which are also natural occurring constituents in the upper reaches of the Brazos River that can be influenced by human activity. In contrast to naturally occurring water quality issues, the Brazos River above Possum Kingdom Lake and the Double Mountain Fork Brazos River are currently listed as impaired due to the presence of high levels of bacteria (TCEQ 2014a, p. 74 and 83). The North Fork Double Mountain Fork Brazos River has experienced municipal wastewater related impacts including high levels of ammonia, chlorophyll, nitrate, and phosphorus between the City of Lubbock’s reservoir system and its confluence with the Double Mountain Fork Brazos River (TCEQ 2014b, p. 463; TCEQ 2010, pp. 479–480).

In April 2008, elevated levels of mercury were detected in piscivorous fish in Lake Alan Henry on the Double Mountain Fork Brazos River although the source of this neurotoxin is unclear (TDSHS 2010, p. 15; TCEQ 2014a, p. 83). Predatory fish are at the top of the aquatic food chain and are more susceptible to mercury accumulation in their tissues than smaller fish such as shiners that feed on plankton; therefore, mercury contamination in Lake Alan Henry is not believed to pose a risk to riverine species like the sharpnose and smalleye shiners downstream of this impoundment due to their distance from the lake and lower trophic level (i.e., lower position in the food chain). Lastly, oily sheens from unknown sources have been observed in the upper Brazos River and have resulted in fish kills of the sharpnose and smalleye shiner (Wilde 2012b, pers. comm.); potential sources of petroleum are abundant in the area due to active oil and gas production. Further investigations will be required to fully understand the frequency, magnitude, and cause of petroleum contamination and other pollution sources in the upper Brazos River basin. While available information indicates some water pollution issues exist in the upper Brazos River, the extent to which they cause injury or impacts to sharpnose and smalleye shiners is unknown at this time.

Although the upper Brazos River basin has clearly experienced varying levels of water quality from naturally occurring and anthropogenic sources of contamination, the overall impact to sharpnose and smalleye shiners is believed to be less than from other major threats such as impoundment, alterations in flow regime, and drought. Also, most point and many non-point pollution sources are regulated by the Texas Commission on Environmental Quality, which is intended to reduce the impact of permitted discharges to freshwater systems, including those that support sharpnose and smalleye shiners (LERWPG 2010, pp. 1–65). Although unlawful discharges occasionally occur, they, by themselves, are not believed to be a substantial threat to sharpnose and smalleye shiners. Additional information regarding the potential response sharpnose and smalleye shiners may have to historical and existing water quality issues is necessary to further evaluate the impact to these species. Although the effects of pollution on

these species are not well understood, except in the case of extended drought conditions where dilution is low and point-source discharges comprise the majority of base flows, it is expected in the case of point-source pollution that any lethal effects to individuals would be localized to areas near or downstream of outfalls and would not likely affect sharpnose and smalleye shiners at the population or species level. However, non-point source pollution can influence larger areas and could affect shiners beyond the individual level, particularly when the cumulative effects of all sources of pollution in the upper Brazos River are considered. Likewise, should the number, type, volume, and/or locations of point-source discharges in the upper Brazos River increase in the future, cumulative impacts at the population or species level could be possible even absent drought conditions.

4.7.2 Golden Alga

Golden alga (*Prymnesium parvum*) is a non-native yellow-green alga with a now almost world-wide distribution that typically inhabits brackish water and releases the toxin prymnesin, which disrupts normal gill function and can lead to fish kills in affected streams (TPWD 2002, p. 1). In Texas, evidence suggests that golden alga was likely responsible for fish kills as early as the 1960s, although it was not confirmed until 1985 (TPWD 2002, p.1). Small fish such as the sharpnose and smalleye shiner typically succumb to toxic blooms prior to larger species and imperiled species may lack sufficient numbers to recover from such events (Sager *et al.* 2007, p. 4).

Although the exact causes of golden alga blooms are unknown, it appears that toxicity is greatest when nutrients are limited and the algal blooms are in saline conditions (Salleneave 2010, p. 2). In the three large reservoirs of the middle Brazos River basin there is evidence suggesting golden alga blooms and toxicity are most intense during periods of low flow and high salinity, which may be exacerbated by climate change (Roelke *et al.* 2011, p. 252). Fish kills resulting from golden alga blooms have been documented from both the Brazos River and Colorado River basins (TPWD 2002, Appendix I). According to the Brazos River Authority (BRA 2012, unpublished data) the Brazos River and its impoundments have experienced varying levels of golden alga blooms and toxicity since 1981, with fish kills occurring in the upper and middle Brazos River between 1981 and 2012. Although a majority of the golden alga blooms in the Brazos River have occurred within or between the three main reservoirs of the middle basin (Possum Kingdom Lake, Lake Granbury, and Lake Whitney), several blooms—including five resulting in documented fish kills totaling more than 1.3 million fish—have occurred in the upper Brazos River or Double Mountain Fork Brazos River in Stonewall (1981, 1992), Young (1997, 2003), and Knox (2006) Counties where the remaining populations of sharpnose and smalleye shiners occur (TPWD 2002, pp. 2, 14; BRA 2012, unpublished data).

Given the location and highly toxic nature of some golden alga blooms in the Brazos River it is almost certain that impacts to the sharpnose and smalleye shiner have occurred and will continue to occur. However, fish kill monitoring often concentrates on larger sport fish species; therefore, there are currently no documented records of the extent of golden alga fish kills for either shiner species. The conditions continue to exist for golden alga blooms in the upper Brazos River basin where the sharpnose or smalleye shiner have occurred, or still occur. These blooms are a concern in the existing range of the shiners and may negatively impact recovery

options if they occur in river segments proposed for future reintroduction efforts. It is expected that toxicity and lethal impacts to shiners would be to individuals localized to alga bloom locations, although species-wide effects could occur due to the severely restricted range of these species, especially if blooms are widespread or intense.

4.7.3 Sedimentation

Suspended sediments in streams can alter fish habitats in a number of ways. Increased sediment loads in riverine systems block sunlight penetration, thereby reducing phytoplankton and zooplankton production, which negatively affect higher trophic levels such as fish by removing the food base of the aquatic ecosystem (Henley *et al.* 2000, p. 129). Increased sediment loads also settle on the river bottom which can be a problem in some stream systems because the siltation homogenizes the substrate, reduces macroinvertebrate habitat availability, and suffocates fish eggs laid on the substrate (Henley *et al.* 2000, pp. 130, 132). However, prairie streams such as the Brazos River have naturally high sediment loads and turbidity resulting from sediments captured from runoff during intense rainfall events (Marks *et al.* 2001, p. 331; Bonner and Wilde 2002, p. 1203). Sharpnose and smalleye shiners presumably possess adaptations for detecting prey in turbid waters (Marks *et al.* 2001, p. 332), and they broadcast spawn semi-buoyant eggs which remain suspended in the water column avoiding suffocating sediments as long as flowing conditions persist (Durham and Wilde 2009a, p. 21). Therefore, elevated sedimentation loads are not expected to negatively impact sharpnose and smalleye shiners to the degree that may be observed in other fish species. As previously discussed under the impoundment section above (see **Impoundments**), sediment loads decrease from alterations to natural flow regimes and may profoundly impact prairie stream fishes adapted to turbid conditions, by providing a competitive advantage to fish less adapted to turbid conditions (Bonner and Wilde 2002, p. 1203).

4.8 In-stream Gravel Mining and Dredging

In-stream mining involves the excavation of sand and gravel deposits from streambeds by various methods and the processing of those materials. In the lower Brazos River, a single commercial dredging operation can occupy several thousand linear feet of river and remove tens of thousands of cubic yards of river substrate per month. Processing includes screening and grading the deposits using streamwater and discharging the water back into the stream (Meador and Layher 1998, p. 7). In-stream mining alters channel morphology, often creating deeper areas with lower flows (Meador and Layher 1998, p. 8). Deeper areas resulting from in-stream dredging provide support for fish adapted to lentic conditions and may shift fish assemblages from riverine fish to lake-adapted fish (Paukert *et al.* 2008, p. 630). Increased turbidity in downstream areas is often associated with mining activities (Meador and Layher 1998, p. 9), although sharpnose and smalleye shiners are associated with the naturally turbid waters of prairie streams and may not be substantially affected in this regard (see **Sedimentation** section).

Forshage and Carter (1974, pp. 698–699) observed a decrease in minnow species and abundance in the Brazos River at a dredging site downstream of Possum Kingdom Lake. The reduction of minnows was associated with the loss of gravel substrate, increased turbidity, and a

decrease in benthic organisms resulting from the dredging of gravel within the channel (Forshage and Carter 1974, p. 699). However, the original, natural substrate of this portion of the Brazos River prior to construction of Possum Kingdom Lake was probably sand, as occurs upstream, which is the substrate most often associated with sharpnose and smalleye shiner occurrence. Therefore, results from this study may not be indicative of the effects expected from in-stream mining in more natural stream reaches. Forshage and Carter (1974, p. 697) did not detect differences in water temperature, pH, conductivity, DO, free carbon dioxide, silica, chlorides, or hardness between the dredged sites and upstream portions of their Brazos River study area, indicating minimal physiochemical habitat alteration. In-stream dredging is most likely to impact the sharpnose and smalleye shiners when it occurs directly within occupied channels and results in alterations of channel depth and flow regime, and thereby reduces the quality of the stream habitat for use in foraging and reproduction by shiners. In-stream dredging may impact individual shiners directly by localized dewatering or contact with machinery. Large in-stream mining and dredging operations would likely cause widespread and delayed effects to shiners due to substantial channel degradation, increased channel depth, and other effects on hydrologic habitat.

In-stream dredging operations within Texas are required to obtain a sand, shell, and gravel mining permit from TPWD. There are currently three active dredging operations permitted in the Brazos River and all are located in the lower Brazos River in Fort Bend, Brazoria, or Austin Counties (Heger 2017, pers. comm.). It is not known if future dredging operations are planned for additional locations within the Brazos River basin. Although smaller, unpermitted activities do occasionally occur, it is unlikely that they substantially impact the sharpnose or smalleye shiners at the individual, population, or species level. Given the information available, it appears that in-stream dredging and mining could potentially affect sharpnose and smalleye shiners, however, not to the same extent as other threats such as impoundment and drought.

4.9 Overutilization for Commercial and Scientific Purposes

The Service is not aware of any specific information regarding overutilization of sharpnose and smalleye shiners for commercial, recreational, scientific, educational purposes, or any unauthorized collecting activities. Although specimens of both species have been collected and historically preserved for scientific and educational purposes, we are not aware of information indicating that collections for these purposes have any substantial effect on these species. Minnows of the genus *Notropis* are used as bait fishes and are harvested in the commercial bait industry. Commercial bait harvesters are required to obtain an annual non-game fish permit from TPWD that identifies the water bodies from which collections may be made. Currently, TPWD prohibits commercial bait harvest within the critical habitat of the sharpnose and smalleye shiner (McGarritty 2017, pers. comm.). Additional information may be required to fully understand the historical and potential impact commercial bait harvests have on sharpnose and smalleye shiners, but the best available information indicates these collections are a source of concern when collection efforts occur in occupied habitat and are either extensive or occur during periods of drought and range restriction.

4.10 Disease, Predation, and Hybridization

The Service is not aware of any specific information regarding the potential threat that disease, predation, and hybridization may have on sharpnose or smalleye shiners. The Asian tapeworm (*Bothriocephalus acheilognathi*) is known to infect other shiner species and can result in reduced growth and possible decreased survival of host fish (Koehle 2006, p. 21; Bean and Bonner 2009, pp. 386–387); however, although it occurs in Texas (Bean and Bonner 2010, p. 183), it is not known if it occurs in the Brazos River basin. As such, it is not currently considered a concern to the sharpnose or smalleye shiner.

Impoundment of riverine habitat alters the hydrologic regime and often supports large, piscivorous fish species that might not normally occur in un-impounded prairie streams. These fish, including fish stocked by TPWD such as striped bass (*Morone saxatilis*), Florida largemouth bass (*Micropterus salmoides floridanus*), largemouth bass (*Micropterus salmoides salmoides*), smallmouth bass (*Micropterus dolomieu*), and channel catfish (*Ictalurus punctatus*) (Howell and Mauk 2011, pp. 11–12), may predate upon sharpnose and smalleye shiners, which are not associated with lentic environments. The precise magnitude of effects from predation on sharpnose and smalleye shiner abundance is not well understood, although we assume that predation of adults, juveniles, and planktonic larval stages would increase in lentic conditions due to the presence of these predatory fish species. The non-indigenous Gulf killifish (*Fundulus grandis*) has become established in the middle Brazos as a result of bait releases and there is one record within the Upper Brazos River within Possum Kingdom Lake (TNSC 2011). During laboratory testing, this species predaes both sharpnose and smalleye shiners (Wilde 2016, pers. comm.).

Although hybridization of freshwater fish is known to occur, including within *Notropis* (Hubbs 1955, p. 10), it has not been observed in sharpnose or smalleye shiners; therefore, it does not represent a current threat to these species. Currently, there is no evidence suggesting disease, predation, and hybridization pose a substantial concern to the viability of either species.

4.11 Cumulative Effects

The stressor sources discussed above rarely affect sharpnose and smalleye shiners independently; rather they act in a cumulative nature that increases the magnitude of effects. As such, it is important to identify these cumulative interactions where the effects are known or can be anticipated. Several threat sources produce a similar stress on the environmental resources upon which these fish rely. Where several threat sources produce a similar effect on the environment they will produce an effect of greater magnitude or duration than any single source would otherwise. A good example of this is the combined effects of in-channel impoundment, off-channel impoundment, groundwater depletion, saltcedar encroachment, drought, and desalination (i.e., the threat sources) on flow regime by decreasing surface water flows and availability (i.e., the stressor). Each of these sources has the potential to alter flow regime by decreasing surface water availability for fish use.

The summer of 2011 provided an example of adverse effects to these species when water availability was reduced by in-channel impoundments (water withheld for municipal use in the

upper Brazos River basin), continued groundwater depletion (particularly for agricultural use in the upper Brazos River basin), saltcedar encroachment, and severe drought (2011 being Texas' worst one-year drought on record). When these factors acted together the upper Brazos River dried up over much of its length and a complete lack of reproduction and recruitment occurred for these species. The impoundment of Possum Kingdom Lake also exacerbated the impact of flow regime alteration to these species by blocking the downstream movement of these fish to areas with suitable conditions for survival and reproduction, as may have historically occurred during extreme circumstances. Negative effects were likely also exacerbated by increased predation pressure on adult sharpnose and smalleye shiners seeking refuge in Possum Kingdom Lake by larger, lentic-adapted piscivorous fish species.

Although the most important impact to these species appears to be from sources that alter the flow regime and fragment habitat, it cannot be discounted that the effects of overutilization of the species, water quality issues, disease, and predation –while alone not being of primary importance– may have profound impacts on these species. For example, while a rare golden alga bloom or a contaminants release might not result in species level effects under normal conditions, both species could have temporarily restricted ranges due to the cumulative effect of fragmentation and flow reductions, making them particularly vulnerable even to such short-term or localized events.

4.12 Summary

The two key factors influencing the current and future status of the sharpnose and smalleye shiners by affecting both individual and population-level survival and reproduction are the fragmentation of riverine habitat and alterations to flow regime. Fragmentation of riverine habitat occurs primarily through fish barrier construction (reservoir construction, chloride control dams, impoundments, low-water crossing, falls, etc.). Impoundments, groundwater depletion, mining or dredging, saltcedar invasion, alteration of channel morphology, and drought all have the potential to alter flow regimes. Together these factors have likely been the main reasons for the large range reduction by both species and heightened risk of extirpation within their remaining ranges in the upper Brazos River basin.

Secondary factors affecting both species include sources of pollution such as CAFOs, industrial discharges, municipal discharges, urban runoff, and agricultural runoff. These factors may potentially reduce sharpnose and smalleye shiner survival, especially when considered together and in conjunction with other threats. Although golden alga-related fish kills are of concern, the causes of golden alga blooms are not well understood.

CHAPTER 5 – FUTURE VIABILITY

We have considered what the sharpnose shiner and smalleye shiner need for viability (Chapter 2), the current condition of those needs (Chapter 3), and the historical and current influences on viability (Chapter 4). We now consider future conditions of the species by forecasting the availability of resources, needs, and current and future stressors. We apply our future forecasts to the concepts of resiliency, redundancy, and representation to describe the future viability of the shiners under various scenarios.

5.1 Introduction

Both species of shiner have declined significantly in overall distribution and abundance, with the sharpnose shiner and smalleye shiners currently occupying approximately less than 30% and 49% of their historical range respectively. The resulting remnant population of both species occupies shorter reaches compared to documented historical populations, with both species restricted to the upper Brazos River basin. The primary reason for this reduction in range for both species was reservoir construction in the middle Brazos River basin and reservoirs constructed in the Wichita and Colorado River basins for the sharpnose shiner.

Prior to reservoir development, both species occurred over a larger range in the Brazos River increasing resiliency to stochastic events such as extirpation of populations by drought by allowing recolonization from downstream surviving populations. This connectivity would have made for a highly resilient species overall. However, under current conditions, restoring that connectivity throughout the Brazos River is not feasible due to large reservoirs.

Currently the viability of both species of shiner has been reduced (or low probability of persistence) in the near term (over about the next 10 years) largely because of the existing limitations of their life history requirements of long, wide, flowing rivers to complete their reproductive cycle. With a short life span allowing only one or two breeding seasons and the need for long, unobstructed flowing river reaches during the summer, both species are at a high risk of extirpation when rivers are fragmented by fish barriers and flows are reduced from human use and drought-enhanced water shortages. These conditions have already resulted in substantial range reduction and isolated the one remaining population of both fish to the upper Brazos River basin. The extant population of each shiner species is located in a contiguous stretch of river long enough to support recruitment, is of adequate size, and is generally considered resilient to local or short-term environmental changes. However, with only one location, redundancy is limited and these species may lack the genetic and ecological representation to adapt to ongoing threats.

As a consequence of these current conditions, the viability of both shiner species now primarily depends on the resiliency of the remaining Upper Brazos River populations and increasing redundancy within the historical range. Given the current condition of both shiner species is characterized by low viability as well as significant uncertainty pertaining to future stream flows, water quality impairment, and impoundment construction, we have forecasted what the sharpnose shiner and smalleye shiner may have in terms of resiliency, redundancy, and representation under five plausible future scenarios. These scenarios forecast resources, needs,

and shiner persistence over the next 50 years. We chose 50 years because it is within the range of the available hydrological and climate change model forecasts (Mace and Wade 2008, entire; Texas Water Development Board 2008, entire; and Wurbs *et al.* 2005, p. 384). Temperature projections over the next 50 years for the upper Brazos River basin consistently predict increasing temperatures with increasing evaporation and water demand (Nielsen and Gammon 2011, p. 2.30; Wurbs *et al.* 2005, p. 384; and Banner *et al.* 2010, p. 10). Within the middle and lower Brazos River basin, increasing temperatures are predicted as well, but with less severity (Jiang and Yang 2012, pp. 235 and 241). Considerable uncertainty exists concerning future precipitation within the basin, thus making accurate predictions of available suitable stream length impossible, but flows in the upper Brazos River have declined over the last 50 years based on USGS stream data and overall the southwest is predicted to become more arid over the next 50 years (Seager *et al.* 2007, entire; IPCC 2014, p.61). The Upper Brazos River Restoration scenario evaluates the condition of both species with minimum risks to their populations, combined with habitat restoration efforts throughout the basin. The other four scenarios evaluate the response of the species to changes in those risks and potential reintroduction efforts. For each scenario we describe the stressors that are anticipated to occur to each species.

5.2 Sharpnose Shiner Future Viability Scenarios

(1) Upper Brazos River Basin Restoration

- The current population is maintained throughout the currently occupied range (1,002 km [623 m] of the Double Mountain Fork and its major tributaries, Salt Fork and its major tributaries, and main stem of the Brazos River).
- Conservation efforts to improve fish passage by removing minor barriers, and improve habitat by controlling saltcedar and protecting water quality, continue to be implemented within the occupied range. Work with stakeholders to develop groundwater and surface water management strategies as well as potential water release strategies in the upper Brazos River basin to provide adequate surface flows.

(2) Upper Brazos River Basin Restoration and Lower Brazos River Reintroduction

- The current population is maintained throughout the currently occupied range (1,002 km [623 mi] of the Double Mountain Fork and its major tributaries, Salt Fork and its major tributaries, and main stem of the Brazos River).
- Conservation efforts to improve fish passage by removing minor barriers, and improve habitat by controlling saltcedar and protecting water quality, continue to be implemented within the occupied range. Work with stakeholders to develop groundwater and surface water management strategies as well as potential water release strategies in the upper Brazos River basin to provide adequate surface flows.
- Habitat conditions within the historical range of the sharpnose shiner in the lower Brazos River (421 km [262 mi] un-impounded river segment from the Marlin low water crossing to the Brazoria County line) improve, enabling the establishment of a second population through reintroduction efforts.

(3) Post Reservoir on the Double Mountain Fork and Lower Brazos River Reintroduction

- The population is maintained throughout the Salt Fork and main stem of the Brazos River currently occupied range (642 km [399 mi]). Post Reservoir is constructed on the North Fork Double Mountain Fork, reducing the population to 142 km (88 mi) within the Double Mountain Fork and its major tributaries.
- Habitat conditions within the historical range of the sharpnose shiner in the lower Brazos River (421 km [262 mi] un-impounded river segment from the Marlin low water crossing to the Brazoria County line) improve, enabling the establishment of a second population through reintroduction efforts.

(4) Double Mountain Fork and Salt Fork Range Contraction and Lower Brazos River Reintroduction

- Limitations on water availability reduce the range of the existing population to the main stem of the Brazos River and the lower portions of the Salt Fork and Double Mountain Fork.
- Habitat conditions within the historical range of the sharpnose shiner in the lower Brazos River (421 km [262 mi] un-impounded river segment from the Marlin low water crossing to the Brazoria County line) improve, enabling the establishment of a second population through reintroduction efforts.

(5) Double Mountain Fork and Salt Fork Range Loss with Reintroductions in the Lower Brazos River and Colorado River

- Major limitations on water availability reduce the existing population to the main stem of the Brazos River. Habitat conditions within the historical range of the sharpnose shiner improve in the lower Brazos River (421 km [262 mi] un-impounded river segment from the Marlin low water crossing to the Brazoria County line), and Colorado River basin (between O.H. Ivie Reservoir and Lake Buchanan requiring the removal of a single fish passage barrier (275 km [171 mi]), or between Austin and the Altair Dam (285 km [177 mi]), enabling the establishment of a second and third population through reintroduction efforts.

We examine the resiliency, representation, and redundancy of the sharpnose shiner under each of these five plausible scenarios. Resiliency of sharpnose shiner depends on suitable future water quality, availability of flowing water meeting the needs for all life stages, and un-impounded stream lengths greater than 275 km (171 mi). We expect the sharpnose shiner population to experience changes to these aspects of their resource needs in different ways under the different scenarios. We projected the expected future resiliency of the 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 condition categories (described in Table 7) for the sharpnose shiner population (Table 8). For these projections, populations in high condition are expected to have high resiliency at that time period; i.e., they have sufficient resources to support life history needs, are reproducing successfully, and they occupy habitat of sufficient size to allow upstream and downstream dispersal within the population.

Habitat characteristics of populations in high condition are stream lengths greater than twice the length necessary (>550 km [>342 mi]) for recruitment possessing suitable substrates with sufficient water quantity and quality to accommodate all life stages combined with pulse flows during the spawning season (April – September) in two of three consecutive years. Populations in high condition are better suited to persist into the future, beyond 50 years, and more able to withstand stochastic events that may occur. Populations in moderate condition have lower resiliency than those in high condition. Habitat characteristics of populations in moderate condition are stream lengths greater than one and a half to twice the length necessary (413 – 550 km [257 – 342 mi]). Finally, habitat characteristics of populations in low condition are the minimum to one and a half the length necessary (275 – 413 km [171 – 257 mi]) for successful recruitment. A population in this condition would have low resiliency and is not necessarily able to withstand stochastic events and as a result, is less likely to persist over the next 50 years. A summary of the 3Rs for each scenario is provided in Table 9.

Table 7. Habitat Elements projected for High, Moderate, and Low condition categories for sharpnose shiner population and species resiliency in Table 8.

Condition Category	Habitat Elements
High	Un-impounded stream greater than twice the length (>550 km [>342 mi]) necessary for successful recruitment possessing suitable substrates with adequate water quantity and quality to accommodate all life stages combined with pulse flows during the spawning season (April – September) in two out of three consecutive years.
Moderate	Un-impounded stream greater than one and a half to twice the length (413 – 550 km [257 – 342 mi]) necessary for successful recruitment possessing suitable substrates with adequate water quantity and quality to accommodate all life stages combined with pulse flows during the spawning season (April – September) in two out of three consecutive years.
Low	Un-impounded stream meeting the minimum to one and a half the length (275 – 413 km [171 – 257 mi]) necessary for successful recruitment possessing suitable substrates with adequate water quantity and quality to accommodate all life stages combined with pulse flows during the spawning season (April – September) in two out of three consecutive years.
Ø	Stream segment does not meet minimum length for recruitment.

5.2.1 Scenario 1 – Upper Brazos River Basin Restoration

Under this scenario, groundwater extraction and climatic conditions influencing the sharpnose shiner population continue at current rates. These effects are already occurring, resulting in reduced streamflow throughout the upper Brazos River basin since the 1940s based on USGS streamflow data (source: <https://waterdata.usgs.gov>). To offset these sources of stream flow loss, targeted restoration actions implemented throughout the upper Brazos River basin would be necessary. Restoration actions would include the following: 1) removal of invasive species (e.g.,

saltcedar); 2) restoration of native stream bank plant communities; 3) protection of water quality, outreach to stakeholders, and enhanced TPDES permit review for proposed wastewater discharges to the upper Brazos River; 4) water release strategies to aid fish reproduction/recruitment during the spawning season; 5) restoration of fish passage upstream of Possum Kingdom Reservoir through removal of barriers; and 6) implementation of groundwater and surface water management strategies in the upper Brazos River basin to provide adequate surface water flows.

Resiliency

Conservation actions would be expected to improve habitat quality, reduce impediments to fish migration, and therefore enhance reproductive success. With the improvement of fish passage throughout the current range of the sharpnose shiner, dispersal and recruitment would improve over the current condition. The effects of primary stressors (such as severe drought) would be reduced. Under this scenario, we expect that resiliency would improve above the current condition.

Redundancy

Due to the existence of only a single population of sharpnose shiner, all of the potential effects to this population may affect the species as a whole and place the entire species at risk of extinction. Therefore under this scenario, the sharpnose shiner lacks redundancy (i.e., multiple populations) by which to survive a catastrophic event in the Upper Brazos River basin. Any future event or action that extirpates the populations in the Upper Brazos River basin may result in the extinction of the species.

Representation

In the absence of definitive genetic information, it is not known to what extent, if any, genetic variability has been lost due to range contraction. The sharpnose shiner has limited ecological diversity, given the persistence of only a single population of the sharpnose shiner restricted to the upper Brazos River basin. Thus, the species has limited representation in this scenario.



Figure 12. Sharpnose and smalleye shiner Scenario 1 - Upper Brazos River Basin Restoration.

5.2.2 Scenario 2 – Upper Brazos River Basin Restoration and Lower Brazos River Reintroduction

Under this scenario, groundwater extraction and climatic conditions influencing the sharpnose shiner population are the same, as well the conservation actions in Scenario 1 – Upper Brazos River Basin Restoration. This scenario differs with the development of a captive propagation and reintroduction program, resulting in a second population of the sharpnose shiner established within its historical range in the lower Brazos River basin downstream of the Marlin Falls low water crossing.

Resiliency

Stream flow conditions and the impact of conservation actions targeting water conservation throughout the basin would be the same as in Scenario 1 – Upper Brazos River Basin Restoration. As a result, improved habitat quality and stream connectivity would be expected to enhance reproductive success. With the restoration of fish passage throughout the current range of the sharpnose shiner, dispersal and recruitment would improve over the current condition. The effects of primary stressors (such as severe drought) would be reduced. Under this scenario, we expect that resiliency would improve above the current condition. With the development of a captive propagation program, a second population could be established in the lower Brazos River

basin. Given the possible differences in habitat conditions between the upper Brazos River basin and the lower Brazos River and available un-impounded stream length, this population would likely need to be sustained through captive bred releases.

Redundancy

Although isolated from one another by the middle Brazos River, two populations of the sharpnose shiner would exist. Redundancy would be improved beyond the species' current condition.

Representation

The range of the sharpnose shiner would be expanded from the arid prairie region of north Texas to ecoregions less susceptible to the risks of climate change and drought. Using ecological diversity as a measure of species representation, this scenario improves sharpnose shiner representation in comparison to the current condition.



Figure 13. Sharpnose and smalleye shiner Scenario 2 – Upper Brazos River Basin Restoration and Lower Brazos River Reintroduction.

5.2.3 Scenario 3 – Post Reservoir on the Double Mountain Fork and Lower Brazos River Reintroduction

Under this scenario, groundwater extraction and climatic conditions influencing the sharpnose shiner population are the same, as well the conservation actions in Scenarios 1 and 2. This scenario differs in that the presence of Post Reservoir would create a fish passage barrier and impound habitat on the North Fork Double Mountain Fork, as well as render the stream segment upstream of Post Reservoir too short to accommodate all of the species life stages. It would also eliminate adequate stream flows capable of sustaining all life stages of the sharpnose shiner in the Double Mountain Fork upstream of the confluence of Rough Creek (Fisher County). The confluence at Rough Creek was chosen as it functions as a large tributary contributing to streamflow downstream of this river segment. With the development of a captive propagation and reintroduction program, a second population of the sharpnose shiner is established within its historical range in the lower Brazos River basin downstream of the Marlin Falls low water crossing.

Resiliency

Stream flow conditions and the impact of conservation actions targeting water conservation in the Salt Fork Brazos River basin would be the same as in Scenario 1 – Upper Brazos River Basin Restoration and Scenario 2 – Upper Brazos River Basin Restoration and Lower Brazos River Reintroduction. The presence of Post Reservoir would function as a fish passage barrier to almost the entirety of the North Fork Double Mountain Fork Brazos River and preclude access to the remainder of the North Fork Double Mountain Fork and the Double Mountain Fork Brazos River upstream of the confluence of Rough Creek due to diminished stream flows. The loss of stream habitat, barrier to movement, and reduction in water availability would result in reduced reproductive success, ultimately leading to extirpation of the sharpnose shiner above the confluence of the Double Mountain Fork and Rough Creek. As a result, the current range of the sharpnose shiner could be reduced by approximately 218 km (135 mi), thereby reducing the species resiliency from its current condition. With the development of a captive propagation program, a second population could be established in the lower Brazos River basin. Given the possible differences in habitat conditions between the upper Brazos River basin and the lower Brazos River, this population would likely need to be sustained through captive bred releases.

Redundancy

Although isolated from one another by the middle Brazos River, two isolated populations of the sharpnose shiner would exist. Thus, redundancy would be improved beyond the species' current condition.

Representation

The range of the sharpnose shiner would be expanded from the arid prairie region of north Texas to ecoregions with higher rates of precipitation and less susceptibility to drought. Using ecological diversity as a measure of species representation, this scenario improves sharpnose shiner representation in comparison to the current condition.

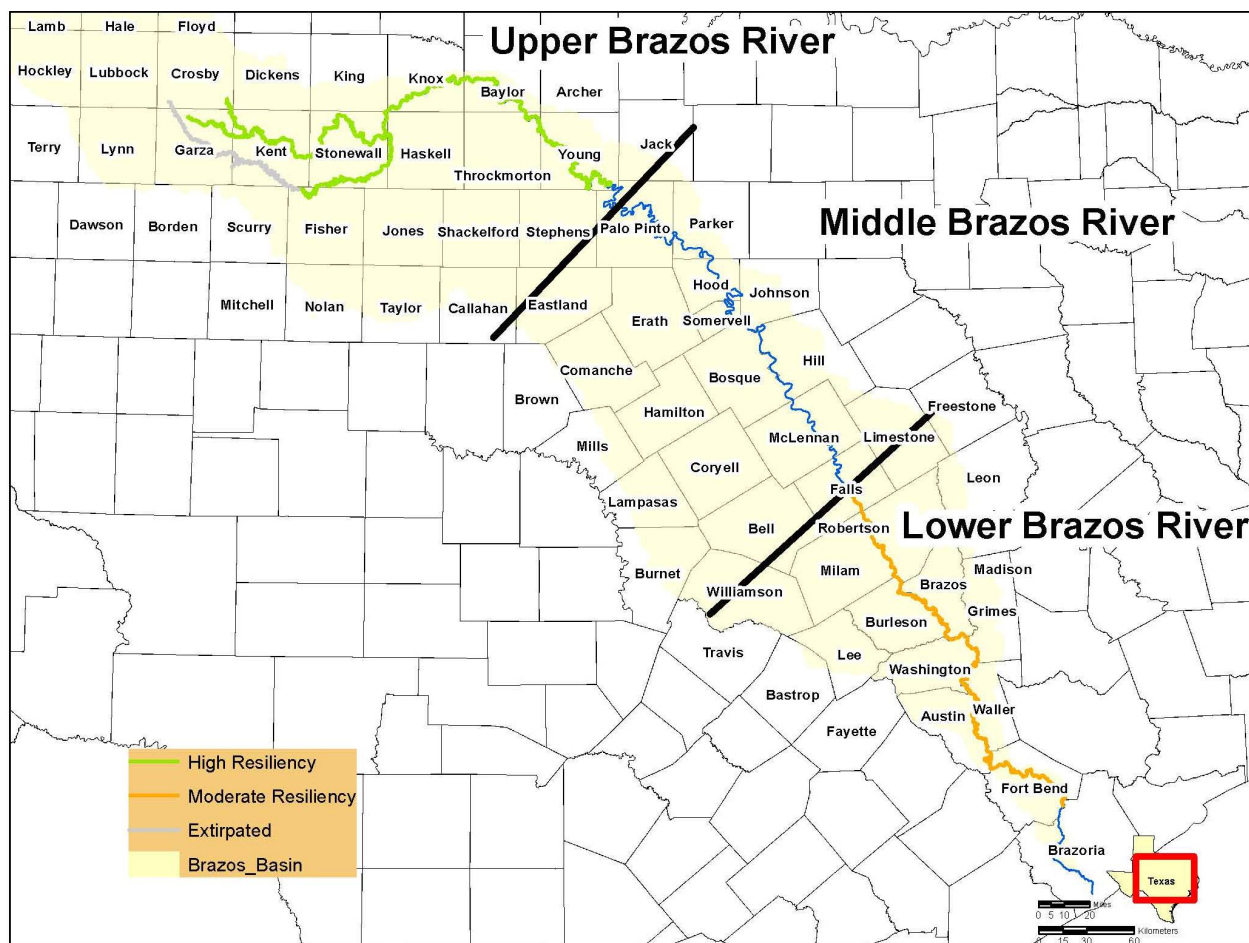


Figure 14. Sharpnose and smalleye shiner Scenario 3 – Post Reservoir on the Double Mountain Fork and Lower Brazos River Reintroduction.

5.2.4 Scenario 4 – Double Mountain Fork and Salt Fork Range Contraction and Lower Brazos River Reintroduction

Under the Double Mountain Fork and Salt Fork Range Contraction and Lower Brazos River Reintroduction scenario, risks associated with reduced stream flow occur, although the severity of the impact is challenging to predict. In this scenario, adequate stream flows capable of sustaining all life stages of the sharpnose shiner no longer occur with the necessary frequency in the Double Mountain Fork upstream of the confluence of Rough Creek and in the Salt Fork upstream of the confluence of Croton Creek. The confluences at Rough and Croton Creeks were chosen as they function as large tributaries that contribute to downstream flows of these river segments. With the development of a captive propagation and reintroduction program, a second population of the sharpnose shiner is established within its historical range in the lower Brazos River basin downstream of the Marlin Falls low water crossing.

Resiliency

Stream flows in the upstream portions of the upper Brazos River basin are reduced due to the effects of climate change, groundwater withdrawal, and drought. The reduction in water availability would result in reduced reproductive success, ultimately leading to extirpation of the

sharpnose shiner above the confluence of the Double Mountain Fork and Rough Creek as well as the portion of the Salt Fork above its confluence with Croton Creek. As a result, the current range of the sharpnose shiner could be reduced by approximately 416 km (259 mi), thereby reducing species resiliency from its current condition. With the development of a captive propagation program, a second population could be established in the lower Brazos River basin. Given the possible differences in habitat conditions between the upper Brazos River basin and the lower Brazos River, this population would likely need to be sustained through captive bred releases.

Redundancy

Two populations of the sharpnose shiner would exist, isolated from one another by the middle Brazos River. Redundancy would be improved beyond the species' current condition.

Representation

The range of the sharpnose shiner would be expanded from the arid prairie region of north Texas to ecoregions less susceptible to the risks of climate change and drought. Using ecological diversity as a measure of species representation, this scenario improves sharpnose shiner representation in comparison to the current condition.



Figure 15. Sharpnose and smalleye shiner Scenario 4 – Double Mountain Fork and Salt Fork Range Contraction and Lower Brazos River Reintroduction.

5.2.5 Scenario 5 – Double Mountain Fork and Salt Fork Range Loss with Reintroductions in the Lower Brazos River and Colorado River

Under the Double Mountain Fork and Salt Fork Range Loss with Reintroductions in the Lower Brazos River and Colorado River scenario, risks associated with reduced stream flows have extreme effects throughout the upper Brazos River basin, although the severity of the impact is challenging to predict. In this scenario, adequate stream flows capable of sustaining all life stages of the sharpnose shiner no longer occur with the necessary frequency in the entire Double Mountain Fork and Salt Fork. With the development of a captive propagation and reintroduction program, two populations of the sharpnose shiner are established within its historical range in the lower Brazos River basin downstream of the Marlin Falls low water crossing and the Colorado River.

Resiliency

The effects of climate change, groundwater withdrawal, drought and upstream reservoir construction result in diminished streams incapable of supporting all life stages of the sharpnose shiner. As a result, approximately 644 km (400 mi) of currently occupied stream may no longer function as suitable habitat, restricting the sharpnose shiner to the 327 km (203 mi) main stem of the Brazos River. Resiliency would be considerably reduced compared to its current condition. With the development of a captive propagation program, two populations could be established in the lower Brazos River basin and in the Colorado River. Given the possible differences in habitat conditions between the upper Brazos River basin and the lower Brazos River, this population would likely need to be sustained through captive bred releases. Within the Colorado River basin, only two stream segments may meet or exceed the necessary requirements for all life stages of the sharpnose shiner. The segment between O.H. Ivie Reservoir and Lake Buchanan would require an improvement to fish passage due to an existing barrier, resulting in a length of 275 km (171 mi). The segment between Austin and the Altair Dam is 285 km (177 mi). Due to the length of both of these river segments, we would expect a population in either location to have limited resiliency.

Redundancy

Three populations of the sharpnose shiner would exist, although they are isolated from one another and two are limited in resiliency with the potential for extirpation. Redundancy may not be substantially improved beyond the species' current condition, depending on the resiliency of the reintroduced populations.

Representation

The range of the sharpnose shiner would be expanded from the arid prairie region of north Texas to ecoregions less susceptible to the risks of climate change and drought. Another population would be established in the historical range of the species within the Colorado River basin. Using ecological diversity as a measure of species representation, this scenario improves sharpnose shiner representation in comparison to the current condition.

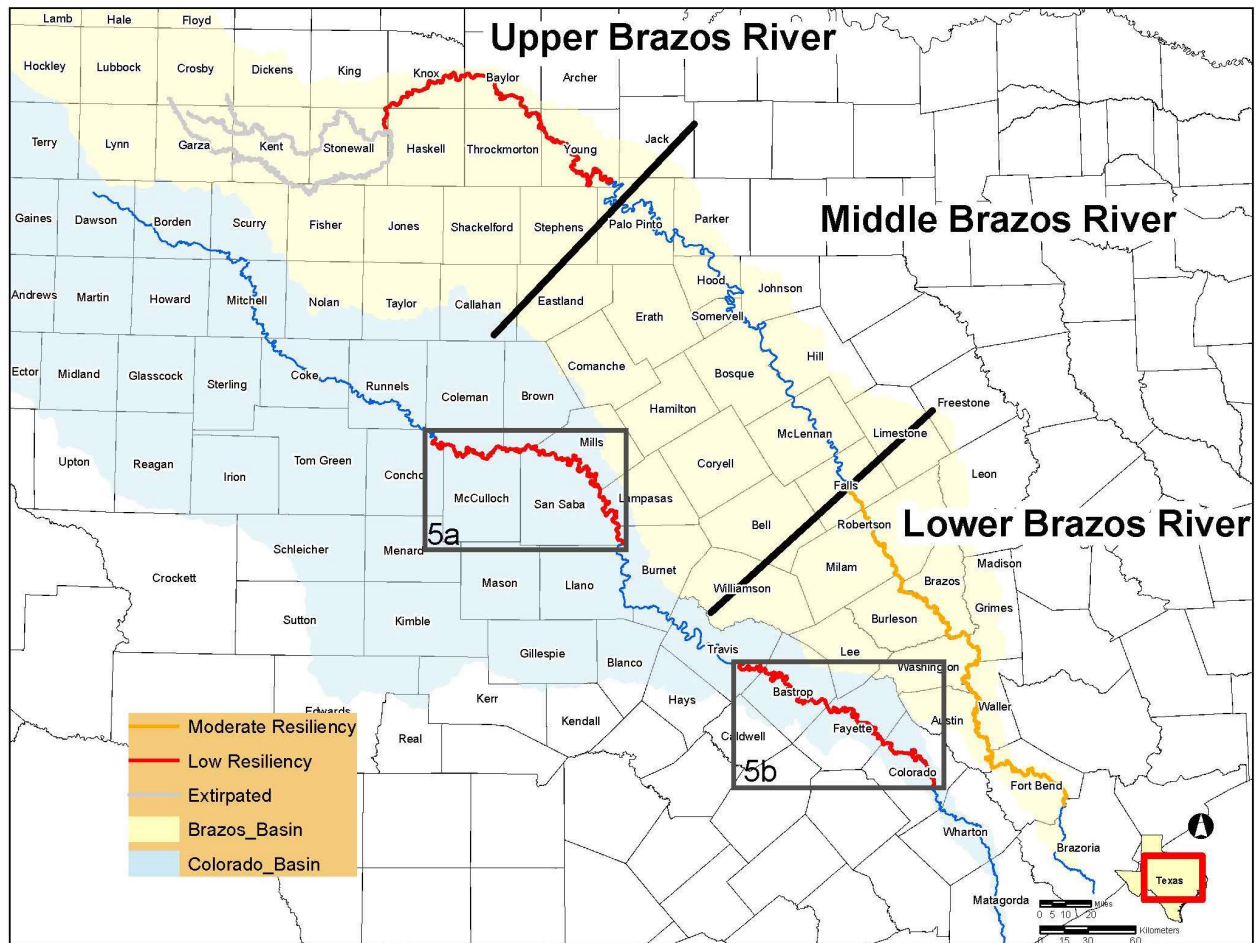


Figure 16. Sharpnose shiner Scenario 5 – Double Mountain Fork and Salt Fork Range Loss with Reintroductions in the Lower Brazos River and Colorado River.

Table 8. Sharnose shiner future viability scenarios.

Scenario		Population Resiliency	Species Viability
1	Double Mountain Fork and its major tributaries to Brazos River – 360 km (224 mi)	High (1,002 km[623 mi])	High
	Salt Fork and its major tributaries to Brazos River – 315 km (196 mi)		
	Main stem Brazos River to Possum Kingdom Laker – 327 km (203 mi)		
2	Double Mountain Fork and its major tributaries to Brazos River – 360 km (224 mi)	High (1,002 km [623 mi])	High
	Salt Fork and its major tributaries to Brazos River – 315 km (196 mi)		
	Main stem Brazos River to Possum Kingdom Lake – 327 km (203 mi)		
	Lower Brazos River below Marlin low water crossing and Brazoria County – 421 km (262 mi)	Moderate (421 km [262 mi])	
3	Double Mountain Fork below Rough Creek to Brazos River – 142 km (88 mi)	High (784 km [487 mi])	High
	Salt Fork and its major tributaries to Brazos River – 315 km (196 mi)		
	Main stem Brazos River to Possum Kingdom Lake – 327 km (203 mi)		
	Lower Brazos River below Marlin low water crossing and Brazoria County – 421 km (262 mi)	Moderate (421 km [262 mi])	
4	Double Mountain Fork below Rough Creek to Brazos River – 142 km (88 mi)	High (554 km [344 mi])	High
	Salt Fork below Croton Creek to Brazos River – 85 km (53 mi)		
	Main stem Brazos River to Possum Kingdom Lake – 327 km (203 mi)		
	Lower Brazos River below Marlin low water crossing and Brazoria County – 421 km (262 mi)	Moderate (421 km [262 mi])	
5	Double Mountain Fork	Ø	Low
	Salt Fork	Ø	
	Main stem Brazos River to Possum Kingdom Lake – 327 km (203 mi)	Low (327 km [203 mi])	
	Lower Brazos River below Marlin low water crossing and Brazoria County – 421 km (262 mi)	Moderate (421 km [262 mi])	
	Colorado River from O.H. Ivie Reservoir to Lake Buchanan – 275 km (171 mi)	Low (275 or 285 km [171 or 177 mi])	
	or Colorado River below Austin to the Altair Dam – 285 km (177 mi)		

Table 9. Summary of the sharpnose shiner resiliency, redundancy and representation under each scenario.

Scenario	Change in Resiliency, Redundancy and Representation from Current Condition
1 – Upper Brazos River Basin Restoration	Resiliency – Improved Redundancy – Unchanged, continues to lack redundancy Representation – Unchanged, continues to lack representation
2 – Upper Brazos River Basin Restoration and Lower Brazos River Reintroduction	Resiliency – Improved Redundancy – Improved with addition of second population Representation – Improved with increased ecological diversity
3 – Post Reservoir on the Double Mountain Fork and Lower Brazos River Reintroduction	Resiliency – Reduced Redundancy – Improved with addition of second population Representation – Improved with increased ecological diversity
4 – Double Mountain Fork and Salt Fork Range Contraction and Lower Brazos River Reintroduction	Resiliency – Reduced Redundancy – Improved with addition of second population Representation – Improved with increased ecological diversity
5 – Double Mountain Fork and Salt Fork Range Loss with Reintroductions in the Lower Brazos River and Colorado River	Resiliency – Reduced Redundancy – Unchanged due to potential for extirpation in Upper Brazos River Basin Representation – Improved with increased ecological diversity

5.3 Smalleye Shiner Future Viability Scenarios

(1) Upper Brazos River Basin Restoration

- Water availability remains stable allowing the current population to continue to occupy the current range (1,002 km [623 mi] of the Double Mountain Fork and its major tributaries, Salt Fork and its major tributaries, and main stem of the Brazos River).
- Conservation efforts to improve fish passage by removing minor barriers, and improve habitat quality by controlling saltcedar and protecting water quality, continue to be implemented within the occupied range. Work with stakeholders to develop groundwater and surface water management strategies as well as potential water release strategies in the upper Brazos River basin to provide adequate surface water flows.

(2) Upper Brazos River Basin Restoration and Lower Brazos River Reintroduction

- The current population has sufficient resource needs to be resilient throughout the currently occupied range (1,002 km [623 mi] of the Double Mountain Fork and its major tributaries, Salt Fork and its major tributaries, and main stem of the Brazos River).
- Conservation efforts to improve fish passage by removing minor barriers, and improve habitat quality by controlling saltcedar and protecting water quality, continue to be implemented within the occupied range. Work with stakeholders to develop groundwater and surface water management strategies as well as potential water release strategies in the upper Brazos River basin to provide adequate surface water flows.
- A second population is established within the historical range of the

smalleye shiner in the lower Brazos River (421 km [262 mi] un-impounded river segment from the Marlin low water crossing to the Brazoria County line) through reintroduction efforts.

(3) Post Reservoir on the Double Mountain Fork and Lower Brazos River Reintroduction

- The population is maintained throughout the Salt Fork and main stem of the Brazos River currently occupied range (642 km [399 mi]). Post Reservoir is constructed on the North Fork Double Mountain Fork, reducing the population to 142 km (88 mi) within the Double Mountain Fork and its major tributaries.
- Habitat conditions within the historical range of the smalleye shiner in the lower Brazos River (421 km [262 mi] un-impounded river segment from the Marlin low water crossing to the Brazoria County line) improve, enabling the establishment of a second population through reintroduction efforts.

(4) Double Mountain Fork and Salt Fork Range Contraction and Lower Brazos River Reintroduction

- Limitations on water availability reduce the range of the existing population to the main stem of the Brazos River and the lower portions of the Salt Fork and Double Mountain Fork.
- Habitat conditions within the historical range of the smalleye shiner in the lower Brazos River (421 km [262 mi] un-impounded river segment from the Marlin low water crossing to the Brazoria County line) improve, enabling the establishment of a second population through reintroduction efforts.

(5) Double Mountain Fork and Salt Fork Range Loss with Reintroductions in the Lower Brazos River

- Major limitations on water availability reduce the range of the existing population to the main stem of the Brazos River.
- A second population is established within the historical range of the smalleye shiner in the lower Brazos River (421 km [262 mi] un-impounded river segment from the Marlin low water crossing to the Brazoria County line) through reintroduction efforts.

We examine the resiliency, representation, and redundancy of the smalleye shiner under each of these five plausible scenarios. Resiliency of smalleye shiner depends on suitable future water quality and quantity sufficient to meet the needs for all life stages, and un-impounded stream lengths greater than 275 km (171 mi). We expect the smalleye shiner population to experience changes to these aspects of their resource needs in different ways under the different scenarios. We projected the expected future resiliency of the population based on the events that may 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 the smalleye shiner population (Table 10).

For these projections (Table 11), populations in high condition are expected to have high resiliency at that time period; i.e., they are reproducing successfully, and they occupy habitat of sufficient size to allow upstream and downstream dispersal within the population. Habitat characteristics of populations in high condition are stream lengths greater than twice the length necessary (>550 km [>342 mi]) for successful recruitment possessing suitable substrates with adequate water quantity and quality to accommodate all life stages combined with pulse flows during the spawning season (April – September) in two out of three consecutive years. Populations in high condition are better suited to persist into the future, beyond 50 years, and more able to withstand stochastic events that may occur. Populations in moderate condition have less resiliency than those in high condition. Habitat characteristics of populations in moderate condition are stream lengths greater than one and a half to twice the length necessary (413 – 550 km [257 – 342 mi]) for successful recruitment. Finally, habitat characteristics of populations in low condition are the minimum to one and a half the length necessary (275 – 413 km [171 – 257 mi]) for successful recruitment. A population in this condition would have low resiliency and is not necessarily able to withstand stochastic events and as a result, they are less likely to persist 50 years. A summary of the 3Rs for each scenario is provided in Table 12.

Table 10. Habitat elements projected for High, Moderate, and Low condition categories for smalleye shiner population and species resiliency in Table 11.

Condition Category	Habitat Elements
High	Un-impounded stream greater than twice the length (>550 km [>342 mi]) necessary for successful recruitment possessing suitable substrates with adequate water quantity and quality to accommodate all life stages combined with pulse flows during the spawning season (April – September) in two out of three consecutive years.
Moderate	Un-impounded stream greater than one and a half to twice the length (413 – 550 km [257 – 342 mi]) necessary for successful recruitment possessing suitable substrates with adequate water quantity and quality to accommodate all life stages combined with pulse flows during the spawning season (April – September) in two out of three consecutive years.
Low	Un-impounded stream meeting the minimum to one and a half the length (275 – 413 km [171 – 257 mi]) necessary for successful recruitment possessing suitable substrates with adequate water quantity and quality to accommodate all life stages combined with pulse flows during the spawning season (April – September) in two out of three consecutive years.
Ø	Stream segment does not meet minimum length for successful recruitment.

5.3.1 Scenario 1 – Upper Brazos River Basin Restoration

Under this scenario, groundwater extraction and climatic conditions influencing the smalleye shiner population continue at current rates. These effects are already occurring, resulting in reduced streamflow throughout the upper Brazos River basin since the 1940s based on USGS streamflow data (source: <https://waterdata.usgs.gov>). To offset these sources of stream flow loss, targeted restoration actions implemented throughout the upper Brazos River basin would be necessary. Working with stakeholders to develop and implement conservation actions throughout the upper Brazos River basin is vital. Restoration actions would include the following: 1) removal of invasive species (e.g., saltcedar); 2) restoration of native stream bank plant communities; 3) protection of water quality, outreach to stakeholders, and enhanced TPDES permit review for proposed wastewater discharges to the upper Brazos River; 4) water release strategies to aid fish reproduction during the spawning season; 5) restoration of fish passage upstream of Possum Kingdom Lake through removal of barriers; and 6) implementation of groundwater and surface water management strategies in the upper Brazos River basin to provide adequate surface water flows (see Figure 12 for map of Scenario 1).

Resiliency

Conservation actions would be expected to improve habitat quality and reduce impediments to

fish migration, and therefore, enhance reproductive success. With the improvement of fish passage throughout the current range of the smalleye shiner, dispersal and recruitment would improve over the current condition. The effects of primary stressors (such as severe drought) would be reduced. Under this scenario, we expect that resiliency would improve above the current condition.

Redundancy

Historically, the smalleye shiner has lacked redundancy, being limited to a single population. Therefore under this scenario, redundancy for the smalleye shiner remains the same as current conditions. Any future event or action that extirpates the populations in the upper Brazos River basin may result in the extinction of the species.

Representation

In the absence of definitive genetic information, it is not known to what extent, if any, genetic variability has been lost due to range contraction. The smalleye shiner has limited ecological diversity given the persistence of only a single population of the smalleye shiner restricted to the upper Brazos River basin. Thus, the species has limited representation in this scenario.

5.3.2 Scenario 2 – Upper Brazos River Basin Restoration and Lower Brazos River Reintroduction

Under this scenario, groundwater extraction and climatic conditions influencing the smalleye shiner population are the same, as well the conservation actions in Scenario 1 – Upper Brazos River Basin Restoration. This scenario differs with the development of a captive propagation and reintroduction program, resulting in a second population of the smalleye shiner established within its historical range in the lower Brazos River basin downstream of the Marlin Falls low water crossing (see Figure 13 for map of Scenario 2).

Resiliency

Stream flow conditions and the impact of conservation actions targeting water conservation throughout the basin would be the same as in Scenario 1 – Upper Brazos River Basin Restoration. As a result, improved habitat quality and stream connectivity would be expected to enhance reproductive success. With the restoration of fish passage throughout the current range of the smalleye shiner, dispersal and recruitment would improve over the current condition. The effects of primary stressors (such as severe drought) would be reduced. Under this scenario, we expect that resiliency would improve above the current condition. With the development of a captive propagation program, a second population could be established in the lower Brazos River basin. Given the possible differences in habitat conditions between the upper Brazos River basin and the lower Brazos River and available un-impounded stream length, this population would likely need to be sustained through captive bred releases.

Redundancy

Two populations of the smalleye shiner would exist isolated from one another by the middle Brazos River. Redundancy would be improved beyond the species' current condition.

Representation

The range of the smalleye shiner would be expanded from the arid prairie region of north Texas to ecoregions less susceptible to the risks of climate change and drought. Using ecological diversity as a measure of species representation, this scenario improves smalleye shiner representation in comparison to the current condition.

5.3.3 Scenario 3 – Post Reservoir on the Double Mountain Fork and Lower Brazos River Reintroduction

Under this scenario, groundwater extraction and climatic conditions influencing the smalleye shiner population are the same, as well the conservation actions in Scenarios 1 and 2. This scenario differs in that the Post Reservoir creates a fish passage barrier and impounds habitat on the North Fork Double Mountain Fork, while also eliminating adequate stream flows capable of sustaining all life stages of the smalleye shiner in the Double Mountain Fork upstream of the confluence of Rough Creek. The confluence at Rough Creek was chosen as it functions as a large tributary to this river segment. With the development of a captive propagation and reintroduction program, a second population of the smalleye shiner is established within its historical range in the lower Brazos River basin downstream of the Marlin Falls low water crossing (see Figure 14 for map of Scenario 3).

Resiliency

Stream flow conditions and the impact of conservation actions targeting water conservation in the Salt Fork basin would be the same as in Scenario 1 – Upper Brazos River Basin Restoration and Scenario 2 – Upper Brazos River Basin Restoration and Lower Brazos River Reintroduction. The presence of Post Reservoir would function as a fish passage barrier to almost the entirety of the North Fork Double Mountain Fork and preclude access to the remainder of the North Fork Double Mountain Fork and the Double Mountain Fork upstream of the confluence of Rough Creek due to diminished stream flows. The loss of stream habitat, barrier to movement, and reduction in water availability would result in reduced reproductive success, ultimately leading to extirpation of the smalleye shiner above the confluence of the Double Mountain Fork and Rough Creek. As a result, the current range of the smalleye shiner could be reduced by approximately 218 km (135 mi), thereby reducing the species resiliency from its current condition. With the development of a captive propagation program, a second population could be established in the lower Brazos River basin. Given the possible differences in habitat conditions between the upper Brazos River basin and the lower Brazos River, this population would likely need to be sustained through captive bred releases.

Redundancy

Two populations of the smalleye shiner would exist isolated from one another by the middle Brazos River. Redundancy would be improved beyond the species' current condition.

Representation

The range of the smalleye shiner would be expanded from the arid prairie region of north Texas to ecoregions with higher rates of precipitation and less susceptibility to drought. Using ecological diversity as a measure of species representation, this scenario improves smalleye shiner representation in comparison to the current condition.

5.3.4 Scenario 4 – Double Mountain Fork and Salt Fork Range Contraction and Lower Brazos River Reintroduction

Under the Double Mountain Fork and Salt Fork Range Contraction and Lower Brazos River Reintroduction scenario, risks associated with reduced stream flow occur, although the severity of the impact is challenging to predict. In this scenario, adequate stream flows capable of sustaining all life stages of the smalleye shiner no longer occur with the necessary frequency in the Double Mountain Fork upstream of the confluence of Rough Creek and in the Salt Fork upstream of the confluence of Croton Creek. The confluences at Rough and Croton Creeks were chosen as they function as large tributaries to these river segments. With the development of a captive propagation and reintroduction program, a second population of the smalleye shiner is established within its historical range in the lower Brazos River basin downstream of the Marlin Falls low water crossing (see Figure 15 for map of Scenario 4).

Resiliency

Stream flows in the upstream portions of the upper Brazos River basin are reduced due to the effects of climate change, groundwater withdrawal, and drought. The reduction in water availability would result in reduced reproductive success, ultimately leading to extirpation of the smalleye shiner above the confluence of the Double Mountain Fork and Rough Creek as well as the portion of the Salt Fork above its confluence with Croton Creek. As a result, the current range of the smalleye shiner could be reduced by approximately 416 km (259 mi), thereby reducing the species resiliency from its current condition. With the development of a captive propagation program, a second population could be established in the lower Brazos River basin. Given the possible differences in habitat conditions between the upper Brazos River basin and the lower Brazos River, this population would likely need to be sustained through captive bred releases.

Redundancy

Two populations of the smalleye shiner would exist isolated from one another by the middle Brazos River. Redundancy would be improved beyond the species' current condition.

Representation

The range of the smalleye shiner would be expanded from the arid prairie region of north Texas to ecoregions less susceptible to the risks of climate change and drought. Using ecological diversity as a measure of species representation, this scenario improves smalleye shiner representation in comparison to the current condition.

5.3.5 Scenario 5 – Double Mountain Fork and Salt Fork Range Loss with Reintroductions in the Lower Brazos River

Under the Double Mountain Fork and Salt Fork Range Loss with Reintroductions in the Lower Brazos River scenario, risks associated reduced stream flows have extreme effects throughout the upper Brazos River basin although the severity of the impact is challenging to predict. In this scenario, adequate stream flows capable of sustaining all life stages of the smalleye shiner no longer occur with the necessary frequency in the entire Double Mountain Fork and Salt Fork. With the development of a captive propagation and reintroduction program, a second population

of the smalleye shiner is established within its historical range in the lower Brazos River basin downstream of the Marlin Falls low water crossing.

Resiliency

The effects of climate change, groundwater withdrawal, drought, and upstream reservoir construction result in diminished streams incapable of supporting all life stages of the smalleye shiner. As a result, approximately 644 km (400 mi) of currently occupied stream may no longer function as suitable habitat, restricting the smalleye shiner to the 327 km (203 mi) main stem of the Brazos River. Resiliency would be considerably reduced compared to its current condition. With the development of a captive propagation program, a second population could be established in the lower Brazos River basin. Given the possible differences in habitat conditions between the upper Brazos River basin and the lower Brazos River, this population would likely need to be sustained through captive bred releases.

Redundancy

Two isolated populations of the smalleye shiner would exist, although they are isolated from one another and both in low condition with the potential for extirpation. Redundancy would not be substantially improved beyond the species' current condition.

Representation

The range of the smalleye shiner would be expanded from the arid prairie region of north Texas to ecoregions less susceptible to the risks of climate change and drought. Using ecological diversity as a measure of species representation, this scenario improves smalleye shiner representation in comparison to the current condition.

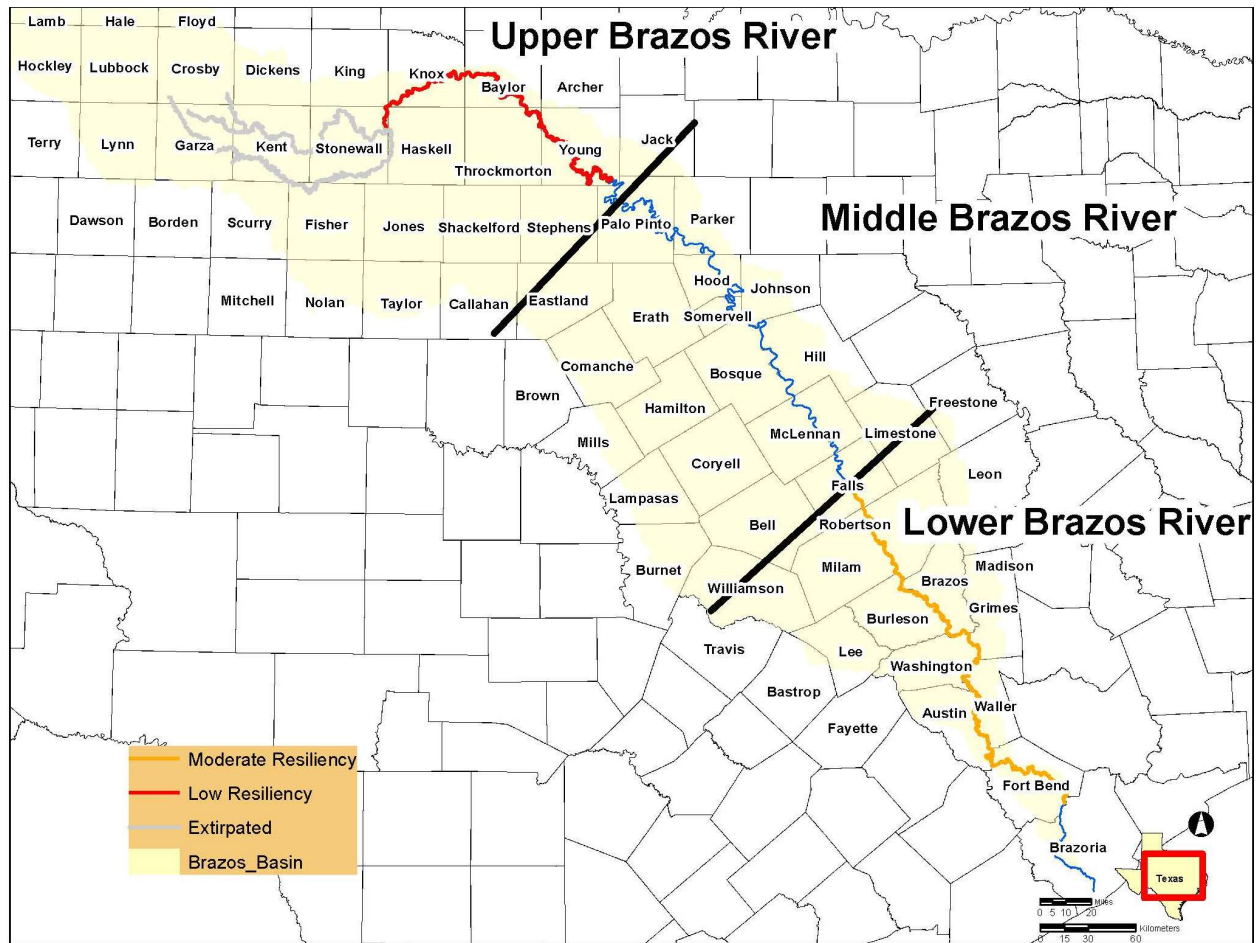


Figure 17. Smalleye shiner Scenario 5 – Double Mountain Fork and Salt Fork Range Loss with Reintroductions in the Lower Brazos River.

Table 11. Smalleye shiner future viability scenarios

Scenario		Population Resiliency	Species Viability
1	Double Mountain Fork and its major tributaries to Brazos River – 360 km (224 mi)	High (1,002 km [623 mi])	High
	Salt Fork and its major tributaries to Brazos River – 315 km (196 mi)		
	Main stem Brazos River to Possum Kingdom Lake – 327 km (203 mi)		
2	Double Mountain Fork and its major tributaries to Brazos River – 360 km (224 mi)	High (1,002 km [623 mi])	High
	Salt Fork and its major tributaries to Brazos River – 315 km (196 mi)		
	Main stem Brazos River to Possum Kingdom Lake – 327 km (203 mi)		
	Lower Brazos River below Marlin low water crossing and Brazoria County – 421 km (262 mi)	Moderate (421 km [262 mi])	
3	Double Mountain Fork below Rough Creek to Brazos River – 142 km (88 mi)	High (748 km [487 mi])	High
	Salt Fork and its major tributaries to Brazos River – 315 km (196 mi)		
	Main stem Brazos River to Possum Kingdom Lake – 327 km (203 mi)		
	Lower Brazos River below Marlin low water crossing and Brazoria County – 421 km (262 mi)	Moderate (421 km [262 mi])	
4	Double Mountain Fork below Rough Creek to Brazos River – 142 km (88 mi)	High (554 km [344 mi])	High
	Salt Fork below Croton Creek to Brazos River – 85 km (53 mi)		
	Main stem Brazos River to Possum Kingdom Lake – 327 km (203 mi)		
	Lower Brazos River below Marlin low water crossing and Brazoria County – 421 km (262 mi)	Moderate (421 km [262 mi])	
5	Double Mountain Fork	Ø	Low
	Salt Fork		
	Main stem Brazos River to Possum Kingdom Lake – 327 km (203 mi)	Low (327 km [203 mi])	
	Lower Brazos River below Marlin low water crossing and Brazoria County – 421 km (262 mi)	Moderate (421 km [262 mi])	

Table 12. Summary of smalleye shiner resiliency, redundancy and representation under each scenario.

Scenario	Change in Resiliency, Redundancy and Representation from Current Condition
1 – Upper Brazos River Basin Restoration	Resiliency – Improved Redundancy – Unchanged, continues to lack redundancy Representation – Unchanged, continues to lack representation
2 – Upper Brazos River Basin Restoration and Lower Brazos River Reintroduction	Resiliency – Improved Redundancy – Improved with addition of second population Representation – Improved with increased ecological diversity
3 – Post Reservoir on the Double Mountain Fork and Lower Brazos River Reintroduction	Resiliency – Reduced Redundancy – Improved with addition of second population Representation – Improved with increased ecological diversity
4 – Double Mountain Fork and Salt Fork Range Contraction and Lower Brazos River Reintroduction	Resiliency – Reduced Redundancy – Improved with addition of second population Representation – Improved with increased ecological diversity
5 – Double Mountain Fork and Salt Fork Range Loss with Reintroductions in the Lower Brazos River	Resiliency – Reduced Redundancy – Unchanged due to potential for extirpation in Upper Brazos River Basin Representation – Improved with increased ecological diversity

CHAPTER 6 – CONSERVATION OPPORTUNITIES

The reduced range and the reproductive strategy of the smalleye and sharpnose shiners, combined with the current and future threats to these species, have severely limited their viability. However, there are a number of conservation opportunities that can be implemented to help minimize threats and improve the status of these species. A number of potential conservation strategies are discussed below.

6.1 Improve Redundancy and Resiliency

Given only a single suitable river segment (the upper Brazos River) within the historical distribution, redundancy may need to be addressed through a number of alternative means. Three possible means of increasing redundancy in these species are (1) a captive propagation and/or refugia program to ensure that the species are not lost due to catastrophic loss of their only populations; (2) reintroducing these species within their historical ranges and monitoring to determine their success and if minimum requirements have been correctly assessed; and (3) removal of existing fish barriers and restoration of the Brazos River, where feasible and appropriate, to provide additional river length and suitable stream flow in which sharpnose and smalleye shiners could seek refuge from severe droughts and other catastrophic events.

Captive breeding of the Rio Grande silvery minnow, another broadcast spawning cyprinid species, has been successful in a number of facilities and the fish reared have been used to supplement the natural population (Service 2007, pp. 38–40). Rio Grande silvery minnow releases are partly responsible for the increased abundance of this species in the wild observed in 2004 and 2005 (NMDGF (pub. date unknown), p. 2). Augmentation of the natural Rio Grande silvery minnow population with hatchery raised fish is the only available option to prevent extinction until habitat conditions can be improved (Archdeacon and Remshardt 2013, p. 20). However, the positive effects of repatriation efforts for the much more range-restricted Rio Grande silvery minnow suggests repatriation efforts for the sharpnose and smalleye shiner may not need to occur as often and will be equally or more successful in avoiding population declines and extinction. Early laboratory captive breeding efforts on sharpnose and smalleye shiners have already proven to be successful, suggesting these species will be capable of hatchery rearing (Wilde 2016, pers.comm.).

6.2 Minimize Impacts from Impoundments

The need for new reservoirs could be minimized to the greatest extent possible by adopting rigorous water conservation strategies. However, without new reservoirs, even rigorous water management strategies would not be adequate to meet the future needs of Texans during a severe drought (TWDB 2012, p. 18). Reservoir water management strategies have normally been implemented to maintain steady, dependable water supplies and to minimize impacts to humans from floods and droughts. This often results in a complete departure from the historical conditions upon which the natural flora and fauna of many rivers depend (Richter *et al.* 2003, p. 207). Richter *et al.* (2003, pp. 208–222) outlined six steps to accomplish ecological sustainability with new reservoir construction: estimate ecosystem flow requirements,

determine human influences on the flow regime, identify incompatibilities between human and ecosystem needs, collaboratively search for solutions to incompatibilities, test uncertainties using scientific methods, and design an adaptive management plan. Although reservoirs may be constructed in a manner that minimizes impacts to the environment, the restricted range and current status of these species makes them vulnerable to even slight changes to their remaining occupied habitat.

Durham (2007, p. 110) calculated a minimum flow of $2.61 \text{ m}^3 \text{ s}^{-1}$ (92 cfs) necessary to sustain populations of the sharpnose shiner and $6.43 \text{ m}^3 \text{ s}^{-1}$ (227 cfs) for the smalleye shiner. Since the impoundment of Lake Alan Henry on the Double Mountain Fork Brazos River in 1993, mean summer discharge of the Brazos River at Seymour in Baylor County has been reduced by approximately 14 percent and exceeded minimum spawning season flow requirements for the sharpnose and smalleye shiner in 85 percent and 57 percent of the years, respectively (Durham 2007, p. 110; Durham and Wilde 2009b, p. 671). In the 28 years prior to impoundment, mean summer discharge exceeded the minimum flow requirements of these species in 93 percent and 79 percent of the years, respectively. This reduction in adequate spawning flows illustrates how off-channel and tributary impoundments may impact these shiners through altered flow regimes, rather than by acting directly as fish barriers. Based on available information, water releases from new and existing reservoirs that provide a minimum mean discharge exceeding $6.43 \text{ m}^3 \text{ s}^{-1}$ (227 cfs) in occupied downstream habitat during the shiners' spawning season (April – September) may minimize impacts to both species. Sharpnose and smalleye shiners are known to synchronize spawning during elevated streamflow events (Durham and Wilde 2009a, p. 25). Where available, historical streamflow data should be reviewed and reservoir discharges should be planned during the shiners' spawning season to provide peak pulse high flow events representative of historical flows prior to impoundment.

Senate Bill 3 of the 2007 Texas Legislature established the Texas Environmental Flows Program to establish environmental flow standards for Texas river basins to support a sound ecological environment. One method of environmental flow standard implementation is through reservoir management of dam releases (NRC 2005, p. 112). In March 2012, The Brazos River and Associated Bay Estuary System Basin and Bay Expert Science Team (BBEST) provided flow recommendations to the Brazos River and Associated Bay and Estuary System Stakeholder Committee (BBASC) for the Brazos River, including the upper Brazos River inhabited by the sharpnose and smalleye shiner (BBEST 2012, pp. 5-3 to 5-13). The BBEST environmental flow recommendations were developed using a hydrology-based environmental flow regime methodology that interprets subsistence flows, base flows, high flow pulses, and overbank flows and assesses their effectiveness in maintaining a sound ecological environment through analyses of water quality, aquatic and riparian biota, and channel geomorphology (BBEST 2012, p. 3.2).

The BBASC evaluated the BBEST report and in September 2012, produced its Environmental Flow Regime Recommendations Report for the Texas Commission on Environmental Quality (TCEQ), who implements flow standards for the state. The BBEST flow recommendations would provide a number of high flow pulses in the upper Brazos River basin during the spawning season that would likely support synchronized sharpnose and smalleye shiner reproduction. However, the BBASC recommendations to TCEQ for the upper Brazos River do not follow the recommendations of the BBEST report and provide much fewer high flow

pulses. The minority opinion report submitted as Appendix E of the BBASC report indicates the proposed regime “is neither adequate to protect a sound ecological environment nor necessitated by water supply considerations” (BBASC 2012, p. 100). The minority report also indicates that the level of environmental flow protection recommended for the upper Brazos River by the BBASC would “severely harm and, quite likely, extirpate the two candidate shiner species found in these river reaches” (BBASC 2012, p. 87). If flow regimes of the upper Brazos River are not carefully managed, particularly if additional reservoirs are created or existing reservoirs are expanded, sharpnose and smallmouth shiner reproduction could be negatively impacted, leading to their possible extinction.

If feasible, future impoundments should also be designed in a manner as to avoid releasing hypolimnetic water that is not representative of the river water upstream of manmade reservoirs. In addition, locating future impoundments as off-channel reservoirs or on small, non-occupied tributaries would likely impact sharpnose and smallmouth shiners to a lesser degree than large reservoirs on occupied reaches or river main stems. If reservoir construction within occupied habitat occurs, impacts to shiners may be minimized by constructing impoundments at the extreme downstream portion of the occupied range, where the alterations of downstream flow regime would impact shiner populations to a lesser degree and may reduce the effects of fragmentation on the species. Impoundments located in the extreme upstream portion of the species’ ranges will also minimize fragmenting remaining habitat but will likely reduce river flow within the occupied range. Impoundments in the middle of the occupied range will impact flow regimes and substantially fragment remaining habitat. The construction of fish migration passages has rarely been tested for small-bodied fish but there is some indication from testing with the Rio Grande silvery minnows that feasible passage construction may be possible (Bestgen *et al.* 2010, entire), although the relatively large size of Brazos River impoundments may preclude their use. Furthermore, the lack of field collected samples of sharpnose and smallmouth shiners below Possum Kingdom Lake despite their relative abundance upstream indicates they are incapable of traversing downstream through the lake even as adults, suggesting a reduced need for upstream migration passageways.

Despite planning and managing to accommodate the needs of sharpnose and smallmouth shiners to the greatest extent possible, future reservoirs within the upper Brazos River basin will negatively impact these species. Depending on the location, design, and management of future reservoirs within the upper Brazos River basin, expected impacts would include at least one or more of the following: decreased water volume in occupied sections of the river, fragmentation or shortening of occupied river segments, changes in water quality, conversion of occupied riverine habitat to lentic habitat, alteration of river channel substrate and sediment transport, altered hydraulic habitat, or alteration of the natural flow regime. Although siting, design, and management of future reservoirs in the upper Brazos River basin could be realized in a way that may reduce adverse impacts to sharpnose and smallmouth shiners, the restricted range and current status of these species makes them vulnerable to even slight changes to their remaining occupied habitat.

6.3 Minimize Impacts from Saltcedar Encroachment

In scenarios where saltcedar control is implemented and revegetation is not conducted,

increases in surface water availability can be as high as 82 percent, although as native vegetation or saltcedar regrows, water use by riparian vegetation may rise to previous levels (Hatler and Hart 2009, pp. 312–315). Saltcedar control efforts should be concentrated on dense stands that can be replaced by native vegetation with a lower leaf area—potentially including native forbs, grasses, and cottonwood trees—to maximize the potential for water salvage without eliminating important riparian vegetation communities (Shafroth *et al.* 2005, p. 240). The salvage of any groundwater or surface water runoff that can elevate streamflow within occupied shiner habitat would benefit these species by supporting necessary flows for survival and successful reproduction. Chemical control of saltcedar is typically performed using imazapyr-based compounds, which are unlikely to be toxic to fish or aquatic invertebrates (USEPA 2006, pp. 17– 18; BASF 2012a, p. 2; BASF 2012b, p. 2). TPWD, in cooperation with USFWS, has initiated a saltcedar control program focusing on the Upper Brazos basin. This program is free to participating landowners and involves participation at two levels: herbicide treatment only or herbicide treatment combined with monitoring to determine efficacy of treatment. In 2016 and 2017, approximately 286 river km (6,700 acres) of the Double Mountain Fork of the Brazos were treated for saltcedar and will be monitored for efficacy. It is expected that the program will be an ongoing multi-year effort targeting saltcedar throughout the watershed. Although saltcedar control efforts are ongoing, the spatial coverage has been limited to the Double Mountain Fork to date. Substantially more coverage, retreatments, and management will be needed to eliminate this highly invasive plant from the Brazos River basin and stop saltcedar encroachment on the Brazos River channel.

6.4 Implement General Water Conservation Strategies

The improvement and implementation of general water conservation strategies could have a profound impact on streamflow of the upper Brazos River. Improvements to agricultural, municipal, and industrial water use efficiency would decrease water demand and put less pressure on the already strained surface and groundwater resources of the upper Brazos River basin. These conservation measures (including but not limited to the use of high-efficiency household appliances and fixtures, optimization of commercial and industrial water uses, and improved irrigation efficiencies for agriculture) could reduce the need for additional reservoir development, increase groundwater contribution to streamflow, and allow existing reservoirs to release more stormwater runoff than occurs currently. These benefits from general water conservation would likely increase streamflow within occupied sharpnose and smalleye shiner habitat, improving their likelihood for survival and successful reproduction.

6.5 Conserve Native Vegetation Adjacent to Occupied Habitat

Riparian vegetation adjacent to riverine habitat filters surface water runoff and is important in maintaining instream water quality. Fischer and Fischenich (2000, p. 8) suggest a riparian width of 5 to 30 m (16.4 to 98.4ft) is generally sufficient to protect the water quality of adjacent streams. The ability of riparian buffers to filter surface runoff is largely dependent on vegetation density, type, and slope, with dense, grassy vegetation and gentle slopes facilitating filtration. Due to a lack of dense, grassy vegetation throughout much of the designated critical habitat, a 30-m (98-ft) buffer may be most appropriate to maintain proper runoff filtration.

Fischer and Fischenich (2000, p. 8) suggest a riparian width of 30 to 500 m (98 to 1,640 ft) to provide wildlife habitat. However, the riparian zone of the upper Brazos River may never have been extensively or diversely vegetated due to the aridity of the area (Busby and Schuster 1973, entire), and the terrestrial insect prey base of the shiners would likely persist at even the thinnest recommended width. A riparian width of 30 m (98 ft) beyond the bankfull width of the river should be sufficient to provide the water quality and food base required by sharpnose and smalleye shiners. Bankfull width is indicated by marked changes in vegetation, topographic breaks, and substrate changes (Leopold 1994, p. 133) and occurs approximately every one to two years (Gordon *et al.* 1992, p. 305). While the stream beds are owned and managed by the State because they are navigable-in-fact or navigable-by-statute, areas beyond the bankfull width are primarily privately owned (Riddell 2004, entire; Kennedy 2007, p. 3). As such, much of the riparian vegetation conservation would likely occur on privately owned land. However, the conservation of native riparian vegetation along the banks of occupied sharpnose and smalleye shiner river segments is not generally expected to negatively impact farming or ranching activities, nor would it require restricting landowner access to these buffer areas. Allowing cattle access to the river might help remove vegetation that would otherwise have been removed by seasonal floods that are now reduced by upstream impoundments, thereby reducing the likelihood occupied river segments will become further channelized by encroaching vegetation. Regardless, there is no scientific evidence suggesting cattle access to occupied river segments or the riparian buffers is currently a threat to either sharpnose or smalleye shiners.

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APPENDIX A – GLOSSARY

Acute thermal maximum- the maximum temperature a species can withstand for brief periods

Acute thermal minimum- the minimum temperature a species can withstand for brief periods

Age-0, age-1, age-2 fish- Age-0 fish are those fish less than one year old, age-1 fish are those greater than one year old but less than two years old, and age-2 fish are those greater than two years old but less than three years old

Algal bloom- rapid increase in the population of algae

Anal Fin- the unpaired fin situated between the anus and tail of a fish

Anoxic- absence of oxygen

Anterior- nearer to the head

Anthropogenic activities- caused or resulting from the influence of humans on the environment

Aquifer- a formation of permeable rock that stores and transmits groundwater

Asynchronous spawning- fish spawning that occurs when multiple fish spawn intermittently, but not all at the same time

Basin- see river basin

Bloom- see algal bloom

Braided channel- a river channel consisting of a network of smaller channels often separated by small and temporary islands and bars

Broadcast spawn- sperm and eggs are released into the water column where fertilization occurs

Catastrophic event- a rare destructive natural event or episode involving many populations and occurring suddenly

Centrarchid- small carnivorous fish belonging to the sunfish family (Centrarchidae)

Channel morphology- the shape and dimensions of the cross-section of a river channel

Chronic upper thermal limit- the maximum temperature a species can withstand for extended periods

Cladistic analysis- An analysis to classify organisms according to the proportion of measurable characteristics they have in common

Climate- prevailing mean weather conditions and their variability for a given area over a long period of time

Climate change- a change in one or more measures of climate that persists over time, whether caused by natural variability, human activity, or both

Conductivity- the degree to which electricity is passed through a material, in the instance of water it often signifies the amount of dissolved salt

Confluence- the junction of two rivers

Congeneric- a species belonging to the same genus as another

Contiguous- next together in sequence and touching

Cumulative effects- when several seemingly separate effects combine to have an effect greater than their individual effects

Cyprinid- a fish of the minnow family (Cyprinidae)

Demographic stochasticity- the variability of population growth rates arising from related random events such as birth rates, death rates, sex ratio, and dispersal, which may increase the risk of extirpation in small populations

Desalination- the removal of salt from water

Detritus- non-living organic material suspended in water, typically including dead organisms, decaying vegetable matter, fecal material, etc.

Discharge- the volume rate of streamflow

Disjunct- two or more populations that are widely separated from each other geographically, usually by large expanses of unsuitable habitat

Dissolved Oxygen (DO)- the amount of oxygen dissolved in water

Dorsal- toward the back of an organism

Dorsal fin- the unpaired fin on the back of a fish

Dredge- to scrape the substrate and vegetation from the bottom of a water body

Drought- a prolonged period of abnormally low precipitation

Dynamic processes- flooding, inundation, drought, and the resulting changes (expansion and contraction) in the extent and location of floodplains, river channels, and riparian vegetation

Ecological diversity- the variation in the types of environmental settings inhabited by an organism

Egg stage- spawning to hatching

Eddy- a small whirlpool

Endemic- belonging exclusively to an area and nowhere else

Environmental diversity- see ecological diversity

Environmental stochasticity- the variation in birth and death rates from one season to the next in response to weather, disease, competition, predation, or other factors external to the population

Evapotranspiration- the loss of water to the atmosphere from the combined effects of evaporation and transpiration

Extant- still in existence; persisting; surviving

Extinction- the process of completely ceasing to exist rangewide

Extirpation- the loss of a population or a species from a particular geographic region

Falcate- curved; hooked

Fecundity- the number of gametes an organism can produce; a measure of reproductive output

Flow regime- the manner in which water flows through a river including mean flow and its variation

Fluvial processes- the movement of sediment from erosion or deposition that is associated with rivers and streams

Forage- to search for food

Fragmentation- the state of being broken into separate parts

Gas bladder- an air-filled structure in fish that maintains buoyancy

Generalist feeder- an organism capable of ingesting and digesting different food types

Genetic diversity (genetic variability)- the genetic measure of a tendency of individual organisms of the same species to differ from one another

Golden alga- any of a group of algae belonging to the class Chrysophyceae. In the case of those pertinent to sharpnose and smalleye shiners, they also produce toxins called prymnesins capable of killing fish

Greenhouse gas- any gas that traps the sun's warmth in the Earth's atmosphere by absorbing infrared radiation

Groundwater- water held underground in the soil or in rock crevices and pores

Hybridization- the act of mixing different species to produce a new hybrid species

Hydrology- the movement or distribution of water on the surface and underground, and the cycle involving evaporation, precipitation, and flow

Hypolimnion- the lower (typically cooler) layer of water in a stratified lake

Ichthyoplankton- fish eggs and larva that float in the water column

Impoundment- a structure blocking river flow and trapping water behind it to form a reservoir

Incremental growth rate- the rate at which something grows over a given period of time

Intermittent flow- river flow that is not continuous, often stopping during the dry season

Invasive species- a species capable of causing environmental harm by rapidly spreading, colonizing, and reproducing, often to the detriment of other organisms. Invasive species are often non-native and competitively replace other native organisms

Invertebrate- an Animal with a backbone

Juvenile stage- completion of fin-ray development to attainment of sexual maturity.

Individuals that have reached the juvenile stage of development generally resemble small adults. The stage ends with the attainment of sexual maturity.

Lambda (λ)- the eleventh letter of the Greek alphabet. In population modeling it symbolizes rate of population growth

Larvae stage-hatching to complete absorption of yolk sac and fin-ray development.

Lateral- toward the side

LC50- the concentration of a substance at which 50 percent of a sample of organisms is expected to die

Lentic- still, non-flowing water

Lotic- flowing water

Low-water crossing- a man-made river crossing which allows some water to flow over the path's surface under certain flow conditions

Macroinvertebrate- invertebrates which are visible to the naked eye

Mean- the central tendency or average of a collection of numbers, calculated by the sum of the numbers divided by the size of the collection

Melanophore- pigment-containing cells

Microhabitat- an area of habitat that differs (often slightly) from the more extensive surrounding habitat

Minimum viable population- the minimum number of individuals a population requires to survive

Monophyletic—originating from a common ancestor

Monotypic—in taxonomy, a genus with only a single species.

Morphological—the structure or form of an organism

Notropid- any fish belonging to the shiner genus *Notropis*

Oblique- slanted

Off-channel reservoir- a reservoir built on a smaller tributary rather than on the main river channel, avoiding fragmentation of the main river channel by impoundment. Often these reservoirs require water pumped from the main river channel to maintain their water levels.

Otolith- a small bonelike structure of the inner ear

Pelagophils- an open-water spawner that produce numerous buoyant eggs

Pharyngeal teeth- teeth in the pharyngeal arch of the throat in fish otherwise lacking oral teeth

Phytoplankton- plankton consisting of microscopic plants (algae)

Piscivorous- feeding on fish

Planktonic- relating to the small and microscopic organisms drifting and floating in water

Population dynamics model- a mathematical description of a population designed to simulate its growth, often in response to some predictive variables

Population sink- a group of individuals not producing enough offspring to maintain itself without constant emigration from other sources

Posterior- toward the rear

Recruitment- the survival of developing young fish to the adult stage

Redundancy- the ability of a species to survive catastrophic events, usually through sustaining a number of viable populations distributed over a larger landscape

Refugia or refugial areas- an area that has remained relatively unchanged compared to surrounding areas

Representation- the ability of a species to adapt to changing environmental conditions, accomplished by having sufficient genetic or ecological diversity

Reproductive effort- the resources an organism devotes to reproduction, often simply measured as the number of offspring produced

Resiliency- the ability of a species to withstand stochastic events, often determined by the size and health of existing populations

River basin- the land area drained by a river and its tributaries where all runoff is ultimately conveyed to the same river

Riverine- of or related to a river

Saline- containing significant concentration of salt

Salinity- the measurement of salt content

Saltcedar- any one of several plants of the genus *Tamarix*, primarily native to the Mediterranean region and invasive in the southwestern United States

Seep- a location where water slowly oozes from the ground at a rate less than 0.028 liters per second

Semi-buoyant- partially buoyant; having nearly the same buoyancy as water. In the case of fish developmental stages it refers to eggs and larvae that float when subjected to adequate water flow and sink in still water

Sexual dimorphism- a distinct difference in size or appearance of males and females of the same species

Sink population- a breeding group of a species that does not produce enough offspring to maintain itself without constant emigration from other sources

Slackwater- an area of a river generally unaffected by the predominant current

Source- the human-produced or natural origins of a stressor; the mechanism of an impact or benefit to a species

Source population- a stable population that contributes individuals that immigrate to other subpopulations (including sink populations)

Spawn- to release eggs and sperm

Spawning Season- the period of time during which a fish species reproduces

Specific conductance- the measurement of a material's ability to conduct electricity; in the instance of water it often signifies the amount of dissolved salt

Spring- a location where water oozes from the ground at a rate more than 0.028 liters per second

Standard length- the measurement of fish length referring to the distance between the tip of the snout to the base of the caudal (posterior most) fin

Stochastic events- arising from random factors such as weather, flooding, or fire

Stressor- Any physical, chemical, or biological alteration of the environment that can lead to an adverse response by individuals or populations of a species

Substrate- the material comprising the river bed

Subterminal- near but not precisely at the end

Synchronized spawning- fish spawning that occurs when many fish spawn at the same time, often in response to some environmental cue

Taxon- a group of organisms classified by their natural relationships or genetics

Taxonomic- pertaining to the classification of animals and plants

Transpiration- the loss of water to the atmosphere through a plant's leaf openings

Turbidity- the suspension of sediment and other particles in water

Viability- the ability to survive, grow, and reproduce normally

Ventral- toward the abdomen or underside of an organism

Weir- a low dam built across a river

Young-of-year fish- fish less than one year old

Zooplankton- plankton consisting of small animals and the microscopic developmental stages of larger animals