Draft Species Status Assessment Report
For the Sharpnose Shiner (*Notropis oxyrhynchus*)
And Smalleye Shiner (*N. buccula*)

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U.S. Fish and Wildlife Service
Date of last revision: June 28, 2013

EXECUTIVE SUMMARY

This species status assessment reports the results of the comprehensive 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. Sharpnose and smalleye shiners are small minnows currently restricted almost entirely to the contiguous river segments of the upper Brazos River basin in north-central Texas.

In conducting our status assessment we first considered what each of the two shiners need to ensure viability. We generally define viability as the ability of the species to persist over the long term and, conversely, to avoid extinction. We then evaluated whether those needs currently exist and the repercussions to the species when those needs are missing, diminished, or inaccessible. We next consider the factors that are causing the species to lack what it needs, included historical, current, and future factors. Finally, considering the information reviewed, we evaluated the current status and future viability of the species in terms of resiliency, redundancy, and representation. Resiliency is the ability of the species to withstand stochastic events and, in the case of the shiners, is best measured by the extent of suitable habitat in terms of stream length. Redundancy is the ability of a species to withstand catastrophic events by spreading the risk and can be measured through the duplication and distribution of resilient populations across its range. Representation is the ability of a species to adapt to changing environmental conditions and can be measured by the breadth of genetic diversity within and among populations and the ecological diversity of populations across the species range. In the case of the shiners, we evaluate representation based on the extent of the geographical range and the variability of habitat characteristics within their range as indicators of genetic and ecological diversity.

Our assessment found that both species of shiners have an overall low viability (or low probability of persistence) in the near term (over about the next 10 years) and a decreasing viability (or increasing risk of extinction) in the long term future (over the next 11 to 50 years). In this executive summary, we present an overview of the comprehensive status review. A detailed discussion of the information supporting this overview can be found in the following chapters of the assessment.

For the shiners to be considered viable, individual fish need the specific vital resources for survival and completion of their life cycles. Both species need wide, shallow, flowing waters generally less than half a meter deep (1.6 ft) with sandy substrates, which are found in mainstem rivers in the arid prairie region of Texas (Figure ES-1). The most important part of their life history is their reproductive strategies. Both species broadcast-spawn eggs and sperm into open water asynchronously (fish not spawning at the same time) from April through September during periods of low flow and synchronously (many fish spawning at the same time) during periods of elevated streamflow. Their eggs are semi-buoyant and remain suspended one or two days in flowing water as they develop into larvae. Larval fish remain suspended in the flowing water column an additional two to three days as they develop into free-swimming juvenile fish. In the absence of sufficient water velocities, suspended eggs and larvae sink into the substrate and subsequently die.

To sustain populations of the shiners, experimental analysis suggests estimated mean spawning season river flows of 2.61 m^3s^{-1} (92 cfs) and 6.43 m^3s^{-1} (227 cfs) are required for the sharpnose and smalleye shiners, respectively. It is also estimated that populations of shiners require approximately 275 km (171 mi) of unobstructed, flowing water during the breeding season to support a successfully reproductive population. This length of stream allows the eggs and larvae to remain suspended in the water column and survive until they mature sufficiently to swim on their own. In addition, these fish only naturally live for one or two years, making the populations particularly vulnerable when the necessary streamflow conditions for reproduction are lacking for more than one season. Across their range, these species also need unobstructed river lengths to allow for upstream and downstream movements to survive seasons with poor environmental conditions in certain river reaches. Unobstructed river reaches allow some fish to survive and recolonize degraded reaches when conditions improve.

The current conditions of both species indicate that they do not have the necessary resources for persistence even in the short term (Table ES-1). Both species have experienced dramatic range reduction with both fish having lost at least half of their historical range. Both species are now restricted to one population in the upper Brazos River basin (Figure ES-1). As a result, sharpnose and smalleye shiners currently lack redundancy, which is significantly reducing the viability of these species as a whole. In addition, streamflows within their current extant range are insufficient during some years to support successful reproduction, such as occurred in 2011. These fish have been remarkably resilient to past stressors that occur over short durations and their populations appear capable of recovering naturally even when an entire year's reproductive effort is lost. However, without human intervention, given their short lifespan and restricted range, stressors that persist for two or more reproductive seasons (such as a severe drought) severely limit these species' current viability, placing them at a high risk of extinction now.

The two primary factors affecting the current and future conditions of these shiners are river fragmentation by impoundments and alterations of the natural streamflow regime (by impoundments, drought, groundwater withdrawal, and saltcedar encroachment) within their range. Other secondary factors, such as water quality degradation and commercial harvesting for fish bait, likely also impact these species but to a lesser degree. These multiple factors are not acting independently, but are acting together as different sources (or causes), which can result in cumulative effects to lower the overall viability of the species. Figure ES-2 represents the relationship of the multiple causes and effects of activities that decrease viability for the shiners.

Fish barriers such as impoundments are currently restricting the upstream and downstream movement of migrating fish and prevent survival of the semi-buoyant eggs and larvae of sharpnose and smalleye shiners. This is because they cannot remain suspended in the water column under non-flowing conditions in reservoirs or if streamflows cease. Of the area once occupied by one or both species in the Brazos, Colorado, and Wichita Rivers, only two contiguous river segments remain with unobstructed lengths (without dams) greater than 275 km (171 mi): the upper Brazos River (where the fish are extant) and the lower Brazos River (where the fish are functionally extirpated). The effects of habitat fragmentation have occurred and continue to occur throughout the range of both species and are expected to increase if proposed new reservoirs are constructed. Habitat fragmentation is affecting both species at the individual, population, and species levels and puts the species at a high risk of extinction currently and increasingly so into the long-term future.

The historical ranges of both species have been severely fragmented, primarily by large reservoir impoundments, resulting in the isolation of one population of each species in the upper Brazos River basin. The construction of Possum Kingdom Reservoir in 1941, for example, eliminated the ability of these species to migrate downstream to wetter areas when the upper Brazos River experiences drought. There is also a number of existing in-channel structures (primarily pipeline crossings and low-water crossings) within the occupied range of these species, some of which are known to restrict fish passage during periods of low flow. In addition, future fragmentation of the remaining occupied habitat of the upper Brazos River by new impoundments would decrease the contiguous, unfragmented river habitat required by these species for successful reproduction. Texas does not have adequate water supplies to meet current or projected water demand in the upper Brazos River region and additional reservoir construction is likely imminent. As a result, possible new impoundments include the 2012 State Water Plan's proposed Post Reservoir in Garza County, the Double Mountain Fork Reservoir (East and West) in Stonewall County, and the South Bend Reservoir in Young County. Species extirpation is expected to occur in occupied river fragments reduced to less than 275 km (171 miles) in length, so any new structures further fragmenting stream habitats significantly increases the likelihood of species extinction.

The natural flow regime is considered one of the most important factors to which native riverine species, like the shiners, become adapted, and alterations to it can have severe impacts on fishes. A majority of sharpnose and smalleye shiner reproductive output occurs through synchronized spawning during periods of elevated flow associated with storms, although successful reproduction is also possible during periods of low to moderate flow. When streamflows are insufficient, the fish cannot successfully spawn and reproduce. There are several environmental changes that are a source of declining streamflows within the range of the shiners. Downstream of reservoirs, streamflows are lowered and stabilized which has reduced or, in some areas, eliminated successful reproduction in these species. In addition, groundwater withdrawal and depletion will reduce or eliminate the remaining springs and seeps of the Brazos River basin, which will lower river flow. Drought is another obvious source of impact that negatively affects streamflow and has severe impacts on sharpnose and smalleye shiner reproduction. Severe droughts in this region are expected to become more common as a result of ongoing climate change. Finally, saltcedar encroachment is another source of environmental change that not only is affecting streamflows, but also restricts channel width and increases its depth. These stream channel changes reduce the amount of wide channels and shallow waters preferred by sharpnose and smalleye shiners. Flow reduction and an altered flow regime has occurred and continues to occur throughout the range of these species and are expected to impact both species at the individual, population, and species levels.

Within the reduced range of these species in the upper Brazos River basin, there are currently at least thirteen impoundments or other structures affecting (to varying degrees) the amount of stream flow within the occupied range of these species. These reservoirs serve as water supplies for various consumptive water uses and reduce downstream flows available for the fishes. Additional future impoundments, reservoir augmentations, and water diversions are under consideration for construction within the upper Brazos River, which would further reduce flows and fragment remaining habitat. The construction of at least some of these structures to meet future water demand in the region is highly likely to occur within the next 50 years.

Besides impoundments and diversions of water from reservoirs, there are other sources causing reduced stream flows in the upper Brazos River basin. One such source is climate change that is projected to result in warmer temperatures and drier conditions in the upper Brazos River in the future. This trend is already becoming apparent and exacerbates the likelihood of species extinction from loss of river flow. Reductions to river flow and river drying are also expected to increase as groundwater withdrawals negatively impact already reduced spring flows. Saltcedar encroachment also intensifies evaporative water loss along occupied river segments. There are several existing efforts addressing threats to natural flow regimes including the Texas Environmental Flows Program, saltcedar control programs, and groundwater conservation districts. However, these programs and conservation efforts have not alleviated ongoing and future threats negatively affecting water flow in the upper Brazos River.

The effects of reduced stream flows on the shiners were dramatically demonstrated during the summer spawning season of 2011. During this year Texas experienced the worst one-year drought on record and the upper Brazos River went dry. Some individual fish presumably found refuge from the drying river in Possum Kingdom Lake downstream. However, the non-flowing conditions in the river made reproduction impossible and any shiners in the lake would have faced increased predation pressure from large, lake-adapted, piscivorous fish. Fearing possible extinction of these species, State fish biologists from Texas captured sharpnose and smalleye shiners from isolated pools in 2011 prior to their complete drying and maintained a small population in captivity until they were released back into the lower Brazos River the following year. During the 2011 drought, no sharpnose shiner or smalleye shiner reproduction was documented. Given their short lifespan (they typically live only two reproductive seasons), a similar drought in 2012 would have likely led to extinction of both species. However, 2012 fish survey results indicted drought conditions were not as intense as those in 2011, and successful recruitment of sharpnose and smalleye shiners occurred.

As remaining habitat of the shiners becomes more fragmented and drought conditions intensify, the single remaining population of sharpnose shiners and smalleye shiners will become more geographically restricted further reducing the viability of the species into the future. Under these conditions, the severity of secondary threats, such as water quality degradation from pollution and golden alga blooms and legally permitted commercial bait fish harvesting, will have a larger impact on the species. As the shiners become more geographically concentrated, a single pollutant discharge, golden algal bloom, or commercial harvesting or other local event, will severely increase the risk of extinction of both species.

The shiners currently have limited viability and increased vulnerabity to extinction because of their stringent life history requirements of long, 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 a significant range reduction and isolated the one remaining population of both fish into the upper Brazos River. The extant population of each shiner species is located in a contiguous stretch of river long enough to support reproduction, is of adequate size, and is generally considered resilient to local or short-term environmental changes. However, with only one location, the species lacks any redundancy and it is presumed these species lack the genetic and ecological representation to adapt to ongoing threats. Given the short lifespan and restricted range of these species, without human intervention, lack of adequate flows (due to drought and other stressors) persisting for two or more consecutive reproductive seasons would likely lead to species extinction. With human water use and ongoing regional drought, the probability of this happening in the near term (about the next 10 years) is high, putting the species at a high risk of extinction. Over the longer term (the next 11 to 50 years) these conditions will only continue to deteriorate as human water use continues, including possible construction of new dams within the extant range, and enhanced chances of drought due to ongoing climate change. In conclusion, the current condition of both species is at a low viability (low probability of persistence) and their viability is only expected to decline into the future.

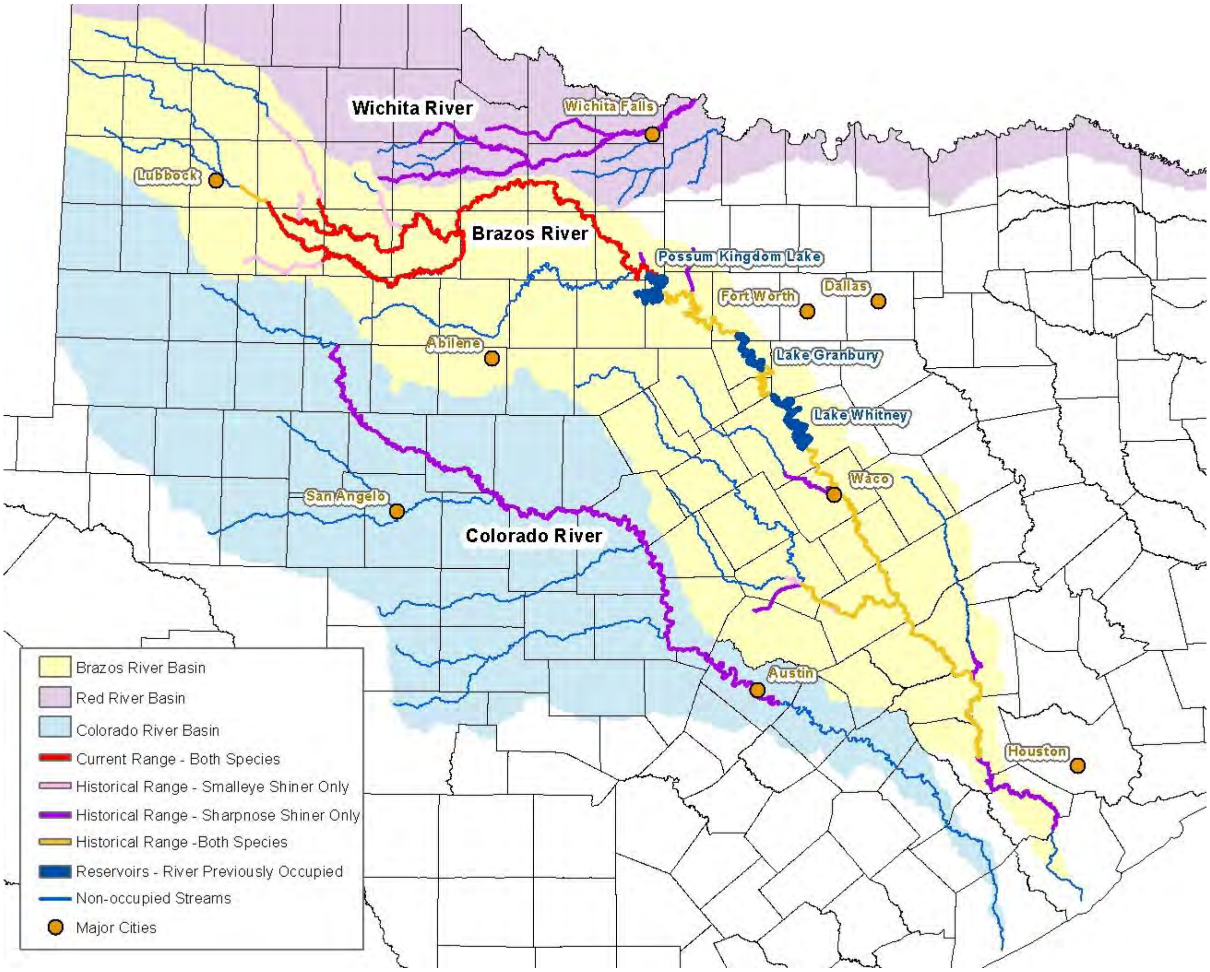

Figure ES-1. An overview map of key points regarding sharpnose and smalleye shiner distributions both historically (pink, purple, and golden lines) and currently (red lines). The Red River basin (pink shading), Brazos River basin (yellow shading) and Colorado River basin (blue shading) are shown with 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.

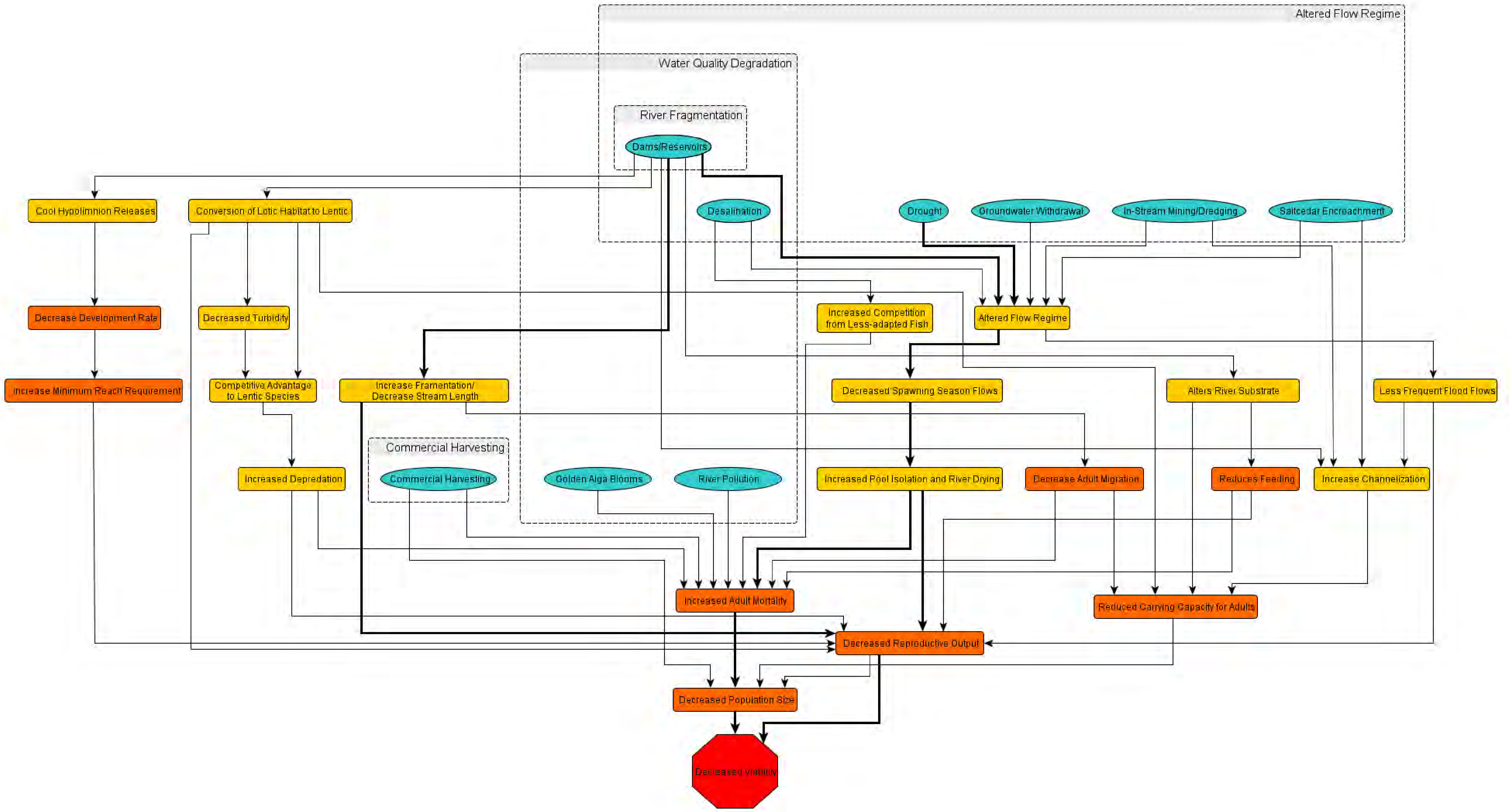

Figure ES-2. An influence diagram illustrating the effects pathway for key threats affecting sharpnose and smalleye shiner viability. Sources of threats are depicted using blue ellipses, the stressor mechanisms are yellow boxes, and the effects on the species are orange boxes. The primary threats have been drawn (dotted lines) to envelope the sources affecting those stressors. The most important effects pathways are drawn with thicker lines.

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

	VITAL NEEDS		CURRENT STATUS			FUTURE STATUS		
Scale	**Resource**	**Function**	**Conditions**	**Causes and Effects**	**Implications for Viability**	**Condition**	**Causes and Effects**	**Implications for Viability**
Individuals	Sandy Substrates and Shallow Channels	Feeding	Presumed adequate within reduced extant range. Some losses of resources have occurred in historical range.	Impoundments; Instream Mining & Dredging; Saltcedar Encroachment	Conditions for individuals 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 quality with physiological tolerances	Feeding/Breeding		Impoundments; Pollution; Golden Algal Blooms			New Impoundments; Pollution; Golden Algal Blooms	
Populations	Minimum spawning season flows	Breeding - *Population Resiliency*	Reduced mean flows from historical conditions in extant range	Impoundments; Groundwater Withdrawal; Severe Drought	Reduced Population Resiliency. Risks to 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	New Impoundments; Increased Groundwater Withdrawal; More Severe Drought due to 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 - *Population Resiliency*	Reduced frequency of flood flows from historical conditions in extant range					
	Unobstructed flowing water greater than 275 km in river length	Breeding & Migration - *Population Resiliency*	One extant length of river remaining in the upper Brazos River					
Rangewide	Larger lengths of unobstructed flowing water in rivers	Migration & Recolonization - *Resiliency, Representation, & Redundancy*	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

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CHAPTER 1. INTRODUCTION

Sharpnose shiners (*Notropis oxyrhynchus*) and smalleye shiners (*Notropis oxyrhynchus*) (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 were made candidates for listing under the Endangered Species Act of 1973, as amended (Act) in 2002 (67 FR 40657). This Species Status Assessment (SSA) Report is one of the first documents of its kind and is serving as a pilot project in the Fish and Wildlife Service's efforts to improve the way our Endangered Species Program works. 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.

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

For the purpose of this assessment, we define **viability** as the ability of a species to persist over the long term, and conversely, to avoid extinction over the long term (next 50 years). Using the SSA framework, we consider what the species needs to maintain viability by characterizing the status of the species in terms of its **resiliency**, **redundancy**, and **representation**.

- **Resiliency** is defined as the ability of the species to withstand stochastic events (arising from random factors). We can measure resiliency based on metrics of population health, for example, birth versus death rates, and population size. 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 able 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 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. This SSA Report provides a thorough assessment of biology and natural history of the 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 (causes and effects) facing the two shiners. For a glossary of other terms used in this SSA Report, reference Appendix A.

CHAPTER 2 – SPECIES NEEDS
BIOLOGY AND BIOGEOGRAPHY

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 resiliency of the shiners. Finally, we briefly consider the rangewide needs for each species in the context of their historical ranges.

A. Biology and Life History

1. Physical Environment

Sharpnose and smalleye shiners are minnows endemic to the Brazos River, Red River, and Colorado River basins that occur within Texas and whose headwaters lie within the semi-arid High Plains region. 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 depend. For ease of reference, the Service has partitioned 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).

The Brazos River headwaters originate in eastern New Mexico and the river and its tributaries extend southeasterly through Texas to the Gulf of Mexico. The climate of the extreme upstream portion of the Brazos River basin is dry, with a mean annual precipitation of 18 inches (46 cm) (LERWPR 2010, pp. 1-6). In this region of the Brazos River basin, uniform topography and gradually sloping terrain restrict the movement of runoff and less than 1 percent of precipitation makes its way into streams and rivers (LERWPG 2010, pp. 1-14, 1-60, 1-63). Groundwater, at least historically, contributed considerable flow to the headwaters and upper Brazos River basin.

The major groundwater supply underlying the headwaters of the Brazos River is the Ogallala Aquifer, which is primarily used for agriculture in this region (LERWPG 2010, pp. ES-12, 1-8). Most of the river segments of the Brazos River basin headwaters have very low flow and are often completely dry during the summer. Currently, very little water leaves the headwaters area as streamflow (LERWPG 2010, p. 1-14), although storms occasionally cause intense flooding of the Brazos River that is carried downstream.

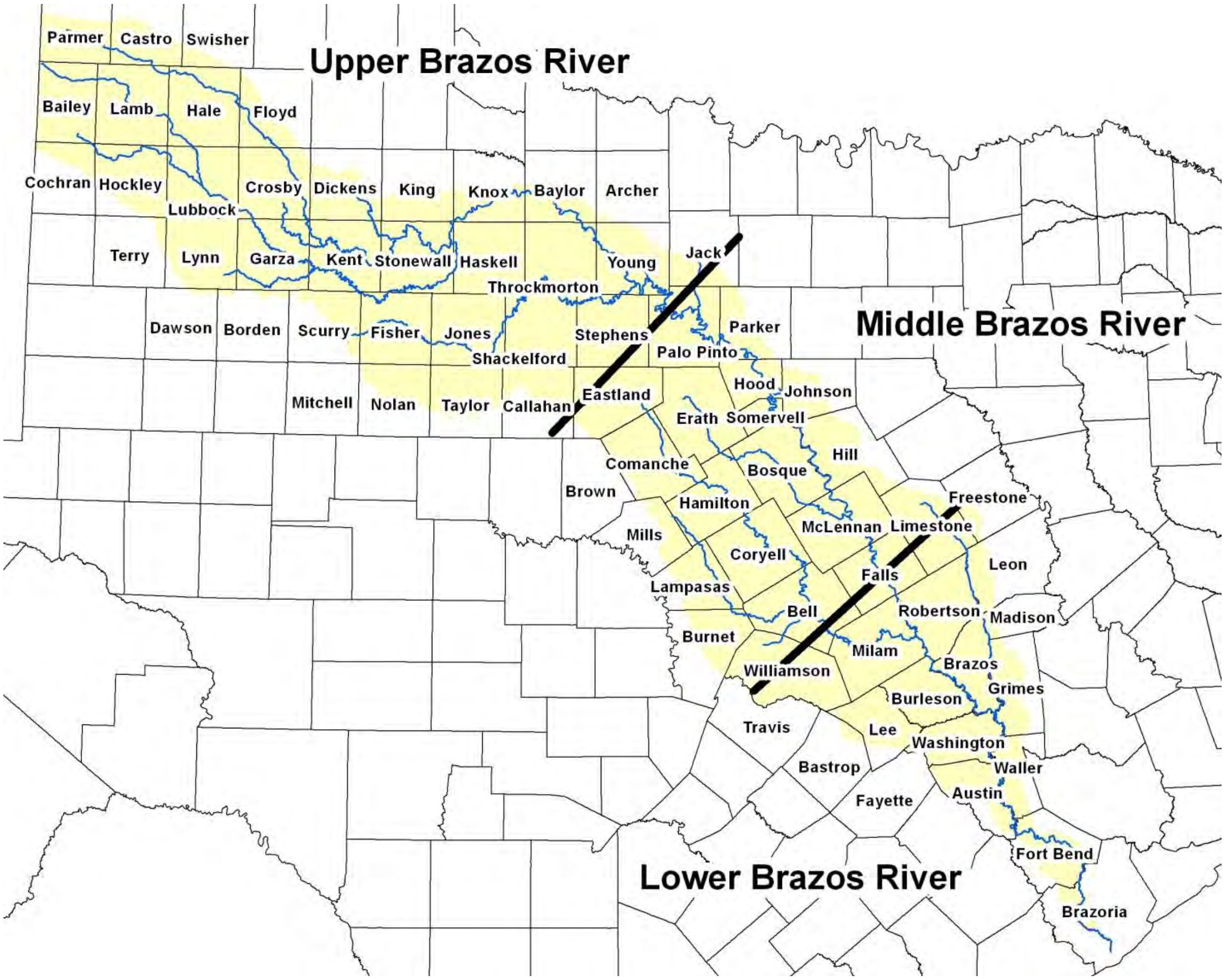

Figure 1. The Brazos River basin (yellow shading) partitioned into the upper, middle, and lower reaches.

The Brazos River basin crosses a considerable portion of Texas and the climate changes significantly from the arid regions at the headwaters to the wetter region at its mouth where 40 to 44 inches (102 to 112 cm) of annual precipitation occurs (BGRWPG 2010, p. 1-11). The upper

Brazos River upstream of the headwaters to 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. During periods of summer drought the upper Brazos River often has intermittent flow resulting in isolated pools as the river runs dry. The variable and harsh conditions of arid prairie streams such as the upper Brazos River are often dominated by small, physiologically tolerant fish species such as sharpnose and smalleye shiners.

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 significantly influenced by the dams and reservoirs. The impoundments of the middle Brazos River effectively isolate the upper, middle, and lower Brazos River from one another by restricting fish migration, restricting flow, and trapping sediments and nutrients. The flow regime and substrates of the highly impacted segments of the middle Brazos River are not typical of what was historically present. The lower Brazos River is much wider and deeper than the upper Brazos River, is not impounded by large reservoirs, and retains many of its natural features; although the flow regime has been altered by the upstream impoundments that regulate flows and minimize downstream flooding. The Brazos River, particularly the upper Brazos River, is typical of the physical environment these species are behaviorally and physiologically adapted to.

2. Taxonomy and Genetics

Sharpnose shiner

The sharpnose shiner (*Notropis oxyrhynchus*) was first collected from the Brazos River in 1938, 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). In contrast, based on cladistic analysis of morphological characteristics, Coburn (1982, p. 166) suggests the sharpnose shiner is more closely associated with *N. jemezanus* (Rio Grande shiner), and belongs to the *N. shumardi* (silverband shiner) group. 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).

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 centimeters (cm) (1.2 to 2.0 inches (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.

<u>Smalleye shiner</u>

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*), silver band shiner (*N. shumardi*), and sand shiner (*N. stramineus*).

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

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 eggs spawned into the pelagic zone (open water not near the river bottom) typically become semi-buoyant within 10 to 30 minutes (Platania and Altenbach 1998, p. 565), allowing them to drift through the water column for one or two days prior to hatching (Platania and Altenbach 1998, p. 565; Perkin *et al.* 2010, p. 3). Pre-larval stages drift in the water column for an additional two to three days post-hatching before developing into a free-swimming juvenile stage (Perkin *et al.* 2010, p. 3; Perkin and Gido 2011, p. 372).

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 2009a, p. 26). 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—floating eggs, larvae, pre-juvenile fish—sink and suffocate in the anoxic sediments and are more susceptible to predation (Platania and Altenbach 1998, p. 565; Perkin and Gido 2011, p. 372).

5. Survival, Growth, and Longevity

Survival rate, growth 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. Growth rate provides an index of development, sexual maturity, and maximal size. 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, growth and longevity is provided below.

Sharpnose shiner

The maximum lifespan for this species is less than three 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 to predation and adverse environmental conditions results in the low observed survival of age-0 fish (Durham 2007, p. 89).

The mean incremental growth rate of second year fish varies seasonally with a mean of 106 micrometers per day (μm/day) over 62 days in early spring (Marks 1999, pp. 50, 68). Spring appeared to be the period of maximal growth for this species although growth rates were not measured throughout summer or fall (Marks 1999, p. 50). Sharpnose shiners display sexual dimorphism with females attaining overall greater lengths and widths (Marks 1999, p. 67).

Smalleye shiner

The maximum life span of the smalleye shiner is less than three 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 environmental conditions results in the low observed survival of age-0 fish (Durham 2007, p. 89).

The mean incremental growth rate of second year fish varies seasonally with a mean of 108 µm/day over a 136-day period through late winter and spring (Marks 1999, pp. 46, 68). Mid to late spring appeared to be the period of maximal growth for this species although growth rates were not measured throughout summer or fall (Marks 1999, p. 46). Smalleye shiners display sexual dimorphism with females attaining overall greater lengths and widths (Marks 1999, p. 67).

B. Individual Needs

1. Microhabitat Requirements

Within the Brazos River system, sharpnose and smalleye shiners are most commonly found in areas that contain the localized habitat features (microhabitat) for which they are best adapted. Sharpnose and smalleye shiners prefer fairly shallow, flowing water, often less than 0.5 m (1.6 feet) deep (Moss and Mayes 1993, pp. 21–22; Marks 1999, p. 86; Ostrand 2000, p. 33). Both species prefer habitats 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.

2. Physiological Tolerances

Sharpnose and smalleye shiners are physiologically adapted to the natural and variable conditions typical of the arid, High Plains streams in which they historically and currently occur. Often, little information is known regarding the physiological limits of rare species; however, recent studies of the sharpnose and smalleye shiners have provided insights into their tolerances to elevated temperature, reduced dissolved oxygen (DO) concentrations, elevated salinity, and turbidity.

Sharpnose shiner

When acclimated to water temperatures of 30 degrees Celsius (°C) (86 degrees Fahrenheit (°F)) in a laboratory setting, sharpnose shiners have an acute critical thermal maximum (the temperature a species can withstand for only brief periods) 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 well below 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), the sharpnose shiner was the least tolerant of elevated temperature.

At 25°C (77°F), sharpnose shiners lose equilibrium at DO concentrations below 2.66 milligrams per liter (mg/L) and were the least tolerant of hypoxic conditions among five Brazos River species tested (Ostrand and Wilde 2001, p. 745). The DO level in isolated pools of the upper Brazos River is known to drop slightly below the laboratory-derived minimum tolerance of this species, although it has not generally resulted in observed fish kills in the wild (Ostrand and Wilde 2001, pp. 745–746). It has been suggested 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 due to a lack of flow, where this species would not survive (Ostrand and Marks 2000, p. 256).

At 25°C (77°F), sharpnose shiners have an LC50 (the concentration at which 50 percent mortality occurs) of approximately 15 parts per thousand (15‰) of sodium chloride (specific conductance of approximately 25 millisiemens per centimeter (mS/cm); Ostrand and Wilde 2001, p. 744). 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‰; 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 of the Brazos River are thought to cause mortality of sharpnose shiners (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 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 extreme turbidity for extended periods.

Of the most common fish species in the upper Brazos River (Red River pupfish (*Cyprinodon rubrofluviatilis*), plains killifish (*Fundulus zebrinus*), plains minnow (*Hybognathus placitus*), mosquitofish (*Gambusia affinis*), smalleye shiner, and sharpnose shiner), based on observations, the sharpnose shiner is the first to succumb to elevated temperature and salinity and low DO in shrinking isolated pools (Ostrand 2000, pp. 53–54).

Sharpnose shiners, like other native fishes of the upper Brazos River, are relatively tolerant of the high temperature, high salinity, high turbidity, and low DO (Table 1). However, environmentally induced mortality resulting from low DO in isolated pools (a natural occurrence) is known to occur, and mortality may also occur from naturally occurring salt plumes.

Table 1. Physiological tolerances of sharpnose and smalleye shiners. See text for additional information.

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

*At 25°C

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 well 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 a slightly higher, although 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 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 in isolated pools along the upper Brazos River, mortality will result (Ostrand and Marks 2000, p. 256).

At 25°C (77°F), smalleye shiners have an LC50 of approximately 18 parts per thousand (18‰) of sodium chloride (specific conductance of approximately 30 mS/cm; Ostrand and Wilde 2001, p. 744). Of the five upper Brazos River fish species analyzed by Ostrand and Wilde (2001, p. 744), the sharpnose 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 18‰; 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 of the Brazos River are thought to cause mortality of sharpnose shiners (Wilde 2012b, pers. comm.).

Although turbidity can be very high in the upper Brazos River (>4002 NTU), 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.

Of the most common fish species in the upper Brazos River (Red River pupfish (*Cyprinodon rubrofluviatilis*), plains killifish (*Fundulus zebrinus*), plains minnow (*Hybognathus placitus*), mosquitofish (*Gambusia affinis*), smalleye shiner, and sharpnose shiner), based on observations, the smalleye shiner is among the first (after the sharpnose shiner) to succumb to elevated temperature and salinity and low DO in shrinking isolated pools (Ostrand 2000, pp. 53–54).

Smalleye shiners, like other native fishes of the upper Brazos River, are relatively tolerant of the high temperature, high salinity, high turbidity, and low DO (Table 1). However, environmentally induced mortality resulting from low DO in isolated pools (a natural occurrence) is known to occur, and mortality may also occur from naturally occurring salt plumes.

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

Sharpnose shiner digestive tract content analysis indicated that up to 90 percent of individuals have empty gut cavities, suggesting that this species likely experiences some level of starvation during the dry summer season, when food becomes scarce (Marks *et al.* 2001, p. 329). 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 (Marks *et al.* 2001, p. 332).

Smalleye shiner

Smalleye shiner digestive tract content analysis indicated that up to 77 percent of individuals have empty gut cavities, suggesting that this species also likely experiences some level of starvation during the dry summer season, when food becomes scarce (Marks *et al.* 2001, p. 329). 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 (Marks *et al.* 2001, pp. 332).

C. Population Needs

1. Abundance

Species' populations require a minimum number of individuals to assure population 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 size may not be a critical measure of species health because the numbers of individuals likely vary widely across seasons and years depending on reproductive success and because the threats these fish face have the ability to cause extinction, regardless of population size. In other words, even when population sizes may be relatively large and robust, if the river segment where the species occurs loses all surface water or is fragmented to the extent it no longer supports reproduction, then the population will be extirpated and the species' will be extinct.

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 continual 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, experimental modeling results estimate a mean summer discharge of approximately 2.61 m^3s^{-1} (92 cfs) is necessary to sustain populations of sharpnose shiners (Durham 2007, p. 110), while a higher mean discharge of 6.43 m^3s^{-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). Population age structure was inferred from length frequency distributions and otolith (inner ear structure) analysis of collected individuals. Age-specific survival was determined by the simple proportion of collected age-1 to age-2 fish for survival of age-1 fish while survival of age-0 fish was solved for algebraically. The survival of age-2 fish was assumed to be zero. Age-specific fecundity was assessed by histological analysis of ovarian tissue and oocyte counts (Durham and Wilde 2009b, p. 668). The discharge factor was fitted to the model by adjusting age-0 survival through multiplication of a term defined as mean daily discharge divided by the discharge factor, where mean daily discharge was based on available stream gage data and the discharge factor was obtained by minimization of residual sum of squares between observed and predicted abundance (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). Until additional data can be gathered and experimentally assessed, the minimum mean discharges during the spawning season of 2.61 m^3s^{-1} (92 cfs) and 6.43 m^3s^{-1} (227 cfs) are the best available estimates 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. It is uncertain if the estimated minimum flow requirements will change when ongoing research adds additional data and models are refined.

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 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 minimum flow requirements to support reproduction, given their diminutive size they likely also have a maximum flow they can tolerate before being transported downstream. 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 feet/s), respectively, indicating that these species will be dispersed downstream at velocities greater than these (Bonner 2004, unpublished data). Fully grown Topeka shiners (*N. topeka*), a similar species, are capable of swimming in water velocities of 0.40 m/s (1.3 feet/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). Given the Topeka, sharpnose, and smalleye shiners belong to the same genus and are similarly sized, it is not surprising these species have similar prolonged swimming capabilities. 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.

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 reproduction 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 have not been experimentally assessed, similar cyprinid species develop a gas bladder 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 rate of 0.3 m/s and temperature of approximately 25°C—a typical early or late spawning season flow rate 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 kilometers (km, 64 miles (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 rates are much higher, and drift distances much greater, when the greatest number of young are produced.

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 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 reproduction 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 experimentally assessed for sharpnose and smalleye shiners, a reach length of greater than 275 km (171 mi) is more appropriate 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 275 km (171 mi) (Wilde and Urbanczyk 2013, p. 3–4). The sicklefin chub (*Macrhybopsis meeki*), another suspected broadcaster spawner, requires river fragments greater than 301 km (187 mi) in length for population persistence (Wilde and Urbanczyk 2013, p. 5). Successful reproduction may occur in river segments shorter than 275 km (171 mi); for instance, when elevated water temperatures decrease larval development time, and when flow rates are low, yet adequate to suspend eggs and larvae. However, under fragmented river conditions, these species are expected to lose a portion of their reproductive effort 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). 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 will be unable to migrate back upstream to suitable habitat as adults. Since eggs and larvae are transported downstream during development, juveniles and adults must migrate back upstream prior to spawning or their populations would eventually be forced into downstream impoundments or the Gulf of Mexico.

Furthermore, during low streamflow conditions sharpnose and smalleye shiners may swim downstream until suitable conditions for survival and reproduction are met, although this has not been experimentally assessed. 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) suggests 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 2010, 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 when favorable conditions returned. Additional studies are needed to fully characterize the potential migratory response of sharpnose and smalleye shiners to intermittent river conditions.

In summary, the primary needs of sharpnose and smalleye populations include a minimum, unobstructed river segment length of greater than 275 km (171 mi) to support development of their early life history stages. Populations of these species also require minimum streamflows to suspend their early life history stages in the water column. It is estimated these average spawning season minimum flow requirements are 6.43 m^3s^{-1} (227 cfs) and 2.61 m^3s^{-1} (92 cfs) for smalleye and sharpnose shiners, respectively. Although sharpnose and smalleye shiners are capable of successfully producing enough offspring to sustain their populations when these minimum flow requirements are met, reproductive activity is increased during elevated streamflow events (such as occur during stormwater runoff), suggesting these elevated flows are likely important to the long term viability of these species.

D. Species Rangewide Needs

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 (1938–2012) 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). The earliest known collection of sharpnose shiners was from the Brazos River (Brazos County) in 1938 (Hubbs and Bonham 1951, p. 95). 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 of the 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.

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
	Hurst Creek Slough	14

References: (1) Moss and Mayes 1993, pp. 19–20; (2) Hendrickson and Cohen 2010; (3) Wilde GR 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; and (15) Winemiller *et al.* 2004, p. 25.

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 of the 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.

We think the sharpnose shiner historically occurred in the Colorado River basin for two reasons. First, several historical, but unpublished, museum records have documented the species from a wide area of the Colorado River. Second, the Brazos River has been hydrologically connected to the Colorado River in the recent 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). The published accounts of this species as a human-mediated, bait-introduced species appear to be based on a single record from the Lake Travis area, near Austin, Texas (Jurgens 1954, p. 155). However, according to museum records from the 1940s and 1950s, very small numbers of sharpnose shiners were also collected from the Colorado River at several locations including an unspecified number near Colorado City in 1940 (Hendrickson and Cohen 2010; Cohen 2012, unpublished data), five near Robert Lee in 1955 (Hendrickson and Cohen 2010), one near San Saba in 1952 (Hubbs *et al.* 2008, p. 23; Hendrickson and Cohen 2010; Cohen 2012, unpublished data), one near Lake Travis in 1954 (Jurgens 1954, p. 155), and an unspecified number near Austin in 1951 (Wang 2004, pp. 28, 127). Although these records occur in museum collections and have not been previously referenced in past published species accounts, the species identifications were recently verified by Cohen (2012, pers. comm.). In addition, an unverified record also exists from 1963 in the San Saba River near Fort McKavett, Menard County, Texas, and another from the Colorado River in 1940 near the City of Wharton, Wharton County, Texas (Hendrickson and Cohen 2010; Cohen 2012, unpublished data).

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 is reasonable to assume 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. 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. 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.

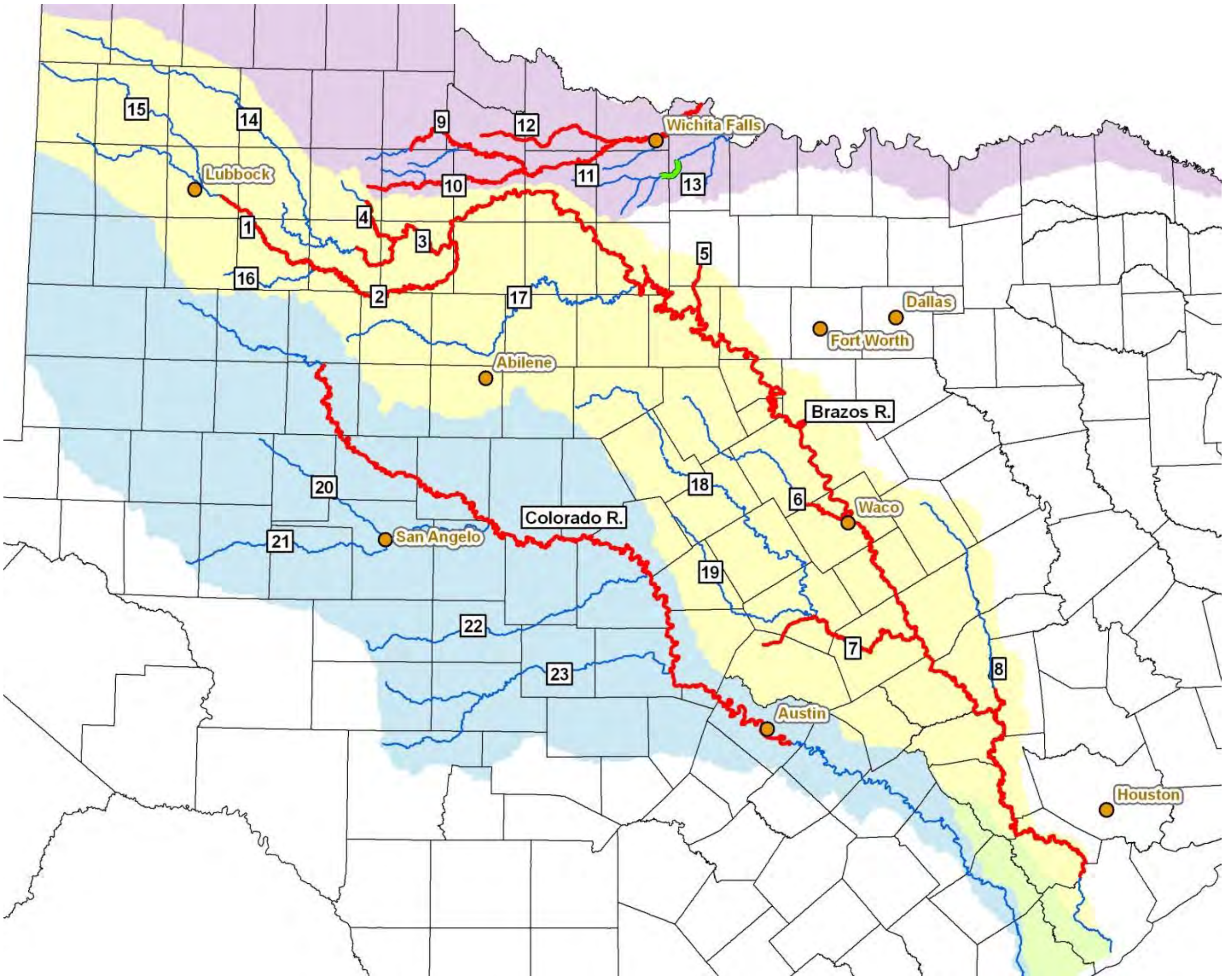

Figure 4. Maximum historical range of the sharpnose shiner, *Notropis oxyrhynchus*. Red lines represent naturally occurring areas while green lines represent areas suspected of human-mediated dispersal. The Red River basin (pink shading), Brazos River basin (yellow shading), Colorado River basin (blue 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 of the Brazos River, 2) Double Mountain Fork of the Brazos River, 3) Salt Fork of the 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) South Fork Double Mountain Fork of the 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.

Smalleye shiner

The natural historical distribution of the smalleye shiner is considered to be limited to the Brazos River basin (Table 3, Figure 5). The earliest known collection of smalleye shiners was from the Brazos River (McLennan County) in 1939 (Hendrickson and Cohen 2010). 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 of the 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
	S. 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 GR 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.

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 this species 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.

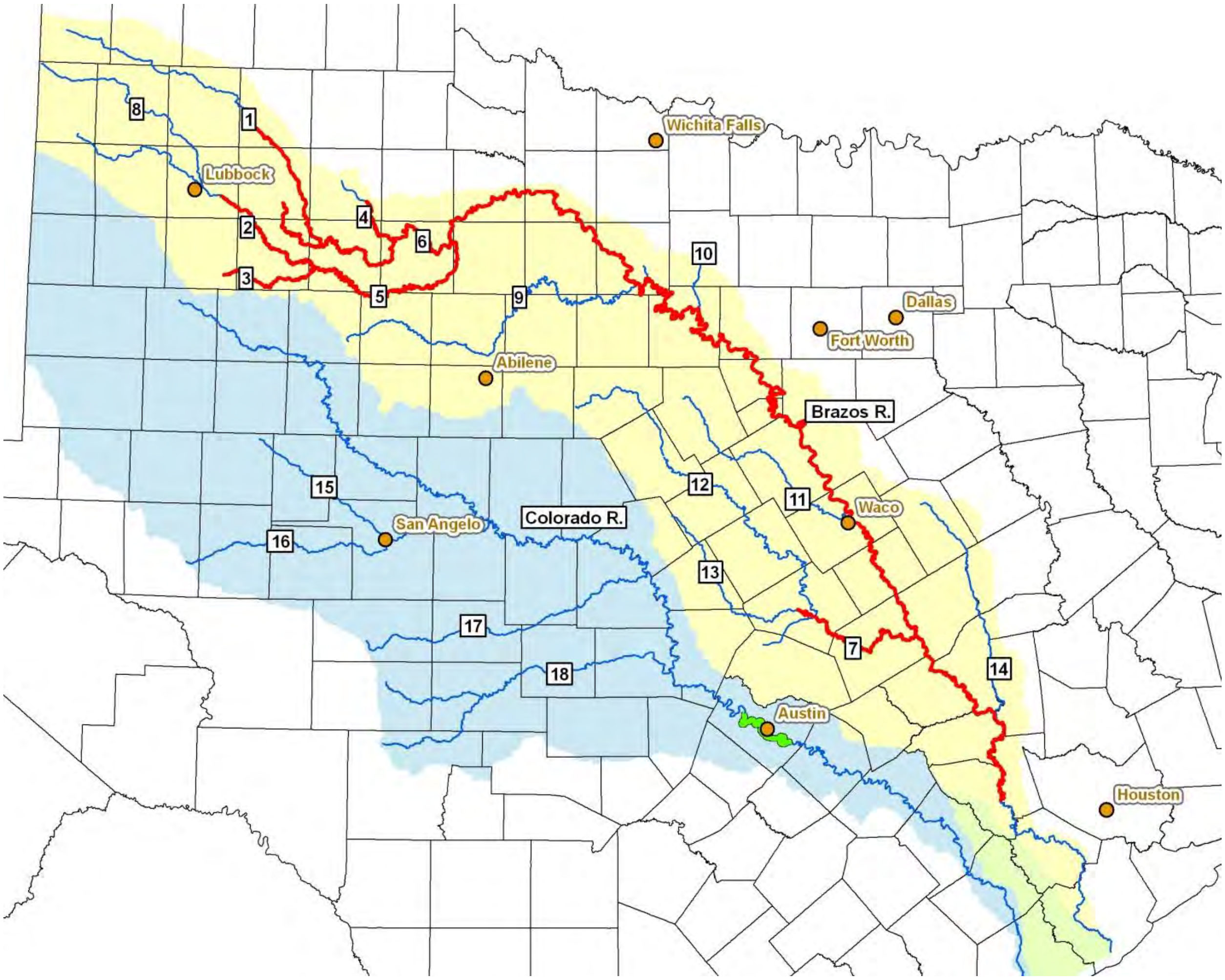

Figure 5. Maximum historical range of the smalleye shiner, Notropis buccula. Red lines represent naturally occurring areas while green lines represent areas suspected of human-mediated dispersal. The Brazos River basin (yellow shading), Colorado River basin (blue shading), Brazos-Colorado River basin (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 of the Brazos River, 3) South Fork Double Mountain Fork of the Brazos River, 4) Croton Creek, 5) Double Mountain Fork of the Brazos River, 6) Salt Fork of the 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. Rangewide Needs

To be viable (to have resiliency, redundancy, and representation adequate to persist long-term), sharpnose and smalleye shiners have specific rangewide needs. Resiliency is defined as the ability to withstand stochastic events and is often represented by having large, healthy populations. There are no estimates of minimum viable population size for these species; however, they are adapted to the highly 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. Following such stochastic events, these fish would recolonize stretches of river that had been uninhabitable.

Refugia from stochastic events provide the redundancy required by these species to withstand catastrophic loss of habitat. Decreasing water availability, increasing drought, and increasing river fragmentation have begun to put unprecedented stress 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. The sharpnose shiner was historically and naturally known to occur in the Brazos River, Colorado River, and Wichita River. The Brazos River population is the primary population and served as a source for the other populations. The Wichita River population was much smaller geographically, is known from only a small number of collections during the early 1950s, and appears to have not been quite as abundant as the population in the Brazos River. The Colorado River population is also known from a very small number of records and the number of fish collected suggests they were never abundant in the Colorado River. In addition, both populations would have been generally isolated historically from the main populations in the Brazos River Basin and completely isolated due to modern impoundments. Therefore, although sharpnose shiners were naturally occurring in the Wichita and Colorado Rivers, because of the small sizes of these populations, we presume they were never important to the historical persistence of the species as a whole.

The smalleye shiner is not known to historically occur naturally outside the Brazos River basin; further suggesting populations of either species outside of the Brazos River basin are not of critical importance. The Brazos River is likely where both the sharpnose and smalleye shiner evolved, and in the case of the sharpnose shiner, radiated from. There is no indication that, historically, populations outside of the Brazos River basin were important to the viability of these species. The Colorado and Wichita Rivers are also fragmented and contain a number of other threats to sharpnose and smalleye shiners (see Chapter 3 below). Therefore, we do not consider Colorado or Wichita River populations necessary for the rangewide redundancy required for sharpnose shiner persistence. It is expected sharpnose and smalleye shiner viability can be addressed by improving conditions within the Brazos River and through the supplementation of either experimental Brazos River populations or captive breeding.

The middle and lower Brazos River also historically supported sharpnose and smalleye shiners. However, the middle Brazos River is now fragmented by four large impoundments and a low-water crossing that restrict the upstream movement of adults and the downstream movement of all life history stages of sharpnose and smalleye shiners (see Chapter 3 below). The habitat characteristics of the lower Brazos River are different than the upper Brazos River and are not likely capable of independently supporting a population of sharpnose or smalleye shiners isolated from the source population inhabiting the upper Brazos River. Sharpnose and smalleye shiners are adapted to conditions of variable headwater river segments; therefore, it is likely the lower Brazos River historically acted as a population sink (a group of individuals not producing enough offspring to maintain itself without constant emigration from other sources). For this reason, we do not think the lower Brazos River would support an isolated, self-sustaining population of sharpnose or smalleye shiners, and, therefore, is not likely a critical need to ensure rangewide persistence of these species.

Ideally, redundancy would be accomplished by providing additional unfragmented river length downstream of, and contiguous with, the occupied range of the upper Brazos River. The middle Brazos River is now fragmented by four large dams (two operated by the Brazos River Authority, and one each by the U.S. Army Corps of Engineers, and the City of Waco), three of which support large reservoirs. These structures are unlikely to be removed, eliminating the possibility of increasing sharpnose and smalleye shiner redundancy and resiliency by permitting the downstream transport of early life history stages and the upstream migration of adults. Given the middle Brazos River does not appear restorable for the purpose of supporting sharpnose and smalleye shiner connectivity with the upper Brazos River, we suggest redundancy of these species may be addressed through captive propagation and experimental populations (See Chapter 6 – Conservation Opportunities). Early captive propagation efforts have shown promise, although the short life span and spawning method of these species makes captive propagation difficult. Experimental populations, including those released in historically occupied river segments not suspected of supporting viable populations of these species long-term, may be important to research efforts and the creation (even if temporary) of redundant populations should environmental conditions lead to the catastrophic loss of the upper Brazos River populations.

Detailed genetic investigation of sharpnose and smalleye shiners has not been performed; however, these species have likely retained a majority of their genetic diversity (genetic representation) despite a considerable reduction in range because, based on historical distribution and abundances, we suspect the remaining population in the upper Brazos River acted as the source for historical populations downstream and in other basins. The upper Brazos River populations appear to have always been of larger size and extent than those in the other river segments. Although these species have likely retained a majority of their genetic diversity, they will be unable to evolve a new reproductive behavior (away from broadcast-spawning) to overcome ongoing and future habitat fragmentation. Adaptation on a grand scale and evolution of a different reproductive strategy would likely occur over tremendously long periods of time, rather than the period of time habitat fragmentation is occurring. Sharpnose and smalleye shiners are already adapted to the variable water conditions of the upper Brazos River (high salinity, high temperature, variable turbidity, variable DO) indicating they may have the genetic variability to further adapt to these conditions. However, prolonged lack of flowing water and habitat fragmentation are beyond the scope of their adaptive ability. Given there is only one remaining potentially viable population of both species in the upper Brazos River, these species do not have representation across differing ecological settings (ecological diversity). Prior to fragmentation of the Brazos River, the lower Brazos River would have provided some ecological diversity; although, now that it is isolated from the upper Brazos River, it is unlikely to support a viable, self-sustaining population of either species.

In summary, given the current status of these species, and the status of these species in a historical context, their rangewide needs revolve around increasing the length of unfragmented habitat contiguous with, and downstream of, currently occupied areas of the upper Brazos River. Unfortunately, restoring the middle Brazos River would involve removing large impoundments that support multi-purpose reservoirs. Removing these structures and restoring river habitat to pre-impoundment conditions is exceedingly unlikely; therefore, prolonged viability of these species (sufficient resiliency, redundancy, representation) may only be attainable by captive propagation or experimental populations that may not be self-sustaining.

E. Summary of Needs

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

Individuals

- Sandy substrates and shallow channels for feeding,
- Adequate prey base, and
- Water 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 m^3s^{-1} (227 cfs) for the smalleye shiner and 2.61 m^3s^{-1} (92 cfs) for the sharpnose shiner to support reproduction and population growth, and
- Elevated streamflow events during the spawning season to support synchronized reproductive efforts.

Rangewide

- Elongation of unfragmented river downstream of, and contiguous with, occupied portions of the upper Brazos River in a manner that provides perpetual refugia from the ongoing threats (particularly drought), or
- Given current habitat conditions, captive bred populations or experimental populations that require continual management because the species will not likely be self-sustaining in captivity or in experimentally released populations.

CHAPTER 3 – CAUSES AND EFFECTS
THREAT ANALYSES

In this chapter we evaluate the past, current, and future stressors that are resulting in the shiners lacking what they need for long-term viability. The most important stressors are related to loss of the specific water resources that individuals and populations need to complete their life history (mainly reproduction) and maintaining resilient populations with sufficient unobstructed stream lengths. 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. We also briefly review other minor factors of concern as well as the concern about the cumulative effects of multiple causes and effects to the species.

In the following section, each of the causes is examined for its historical, current, and potential future effects on shiners' status. It should be noted that current and potential future effects, along with current distribution and abundance, determine present viability and, therefore, vulnerability to extinction. Information about historical causes and effects is included to assist interpretation of historical trends and to inform our assessment of the future responses by the shiners to ongoing and future causes of vulnerability to extinction.

This analysis concentrates on sources of threats to the status of the species and their associated stressors (combined these are the "causes"). The response of the physical resource and species to the stressors, the geographical extent of responses, and the immediacy of the response (combined these are the "effects") are then discussed. The threat analysis concentrates on the upper Brazos River basin because it contains the last remaining potentially viable population of sharpnose and smalleye shiners and likely was the source population for their historical distribution. Although the effects of the analyzed threats 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 threats 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.

A. Impoundments

1. Impacts to fish and the environment

The 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 such as Texas 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, substrates, 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 6 shows the impoundments and reservoirs of the upper Brazos River basin.

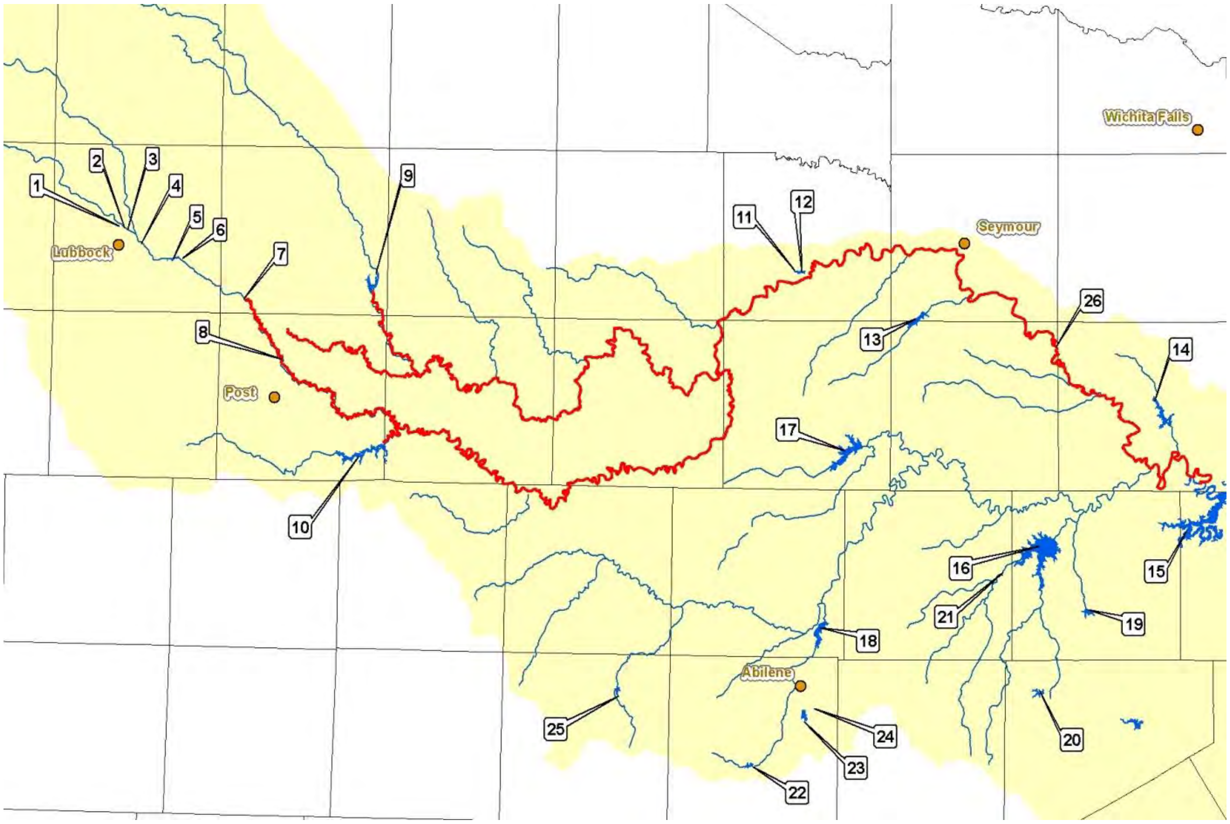

Figure 6. The impoundments, reservoirs, and fish barriers of the upper Brazos River basin. Sharpnose and smalleye shiner occupied habitat as shown in red. The impoundments and reservoirs are labeled as follows: 1) Canyon Lake #1, 2) Canyon Lake #2, 3) Canyon Lake #3, 4) Canyon Lake #6, 5) Buffalo Springs 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 adult fish and larval 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, 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, the downstream drift of their planktonic developmental stages would eventually carry 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 significant portions of the reproductive effort of both species. Even in the event ichthyoplanktonic stages of the shiners are capable of passing over a fish barrier, existing adult fish will remain isolated above and below the barrier. The lifespan of these species is short enough that two or more successive years of isolation in these short, isolated segments would likely lead to 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 South Fork Double Mountain Fork of the upper 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 reproduction and could not move downstream to avoid drought 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). Fragmentation of the remaining occupied habitat of sharpnose and smalleye shiners into segments less than 275 km (171 mi) in length is very likely to result in the extinction of these species (See Chapter 2).

Dams and impoundments also change the nature of 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 bank 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 trap streamflow, reducing the availability of water downstream leading to more frequent lack of flow, channel drying, and pool isolation. The City of Lubbock's municipal water sources include several impounded reservoirs that trap surface water runoff and groundwater discharge that would naturally have contributed to the flow of the upper Brazos River basin where sharpnose and smalleye shiners persist. The reduction in flows of occupied habitat will reduce reproductive success in both of these species and reduce their viability.

One 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 (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 larvae development rates, thereby increasing the minimum river reach length required for successful reproduction and recruitment of juvenile fish as discussed above (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). The resulting release of lower turbidity, high-velocity water 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 conditions until approximately 121 km (75 mi) (Anderson *et al.* 1983, p. 82). 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 provides a competitive advantage to fishes that are not as well adapted to the naturally turbid water of the Brazos River, such as red shiners (*Cyprinella lutrensis*), dusky darters (*Percina sciera*), orangethroat darters (*Etheostoma spectabile*), and stonerollers (*Campostoma 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 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 via semi-buoyant eggs and experience free-floating developmental stages that will settle to the bottom of lentic habitats and be smothered by sediment or predated upon by bottom-dwelling organisms (Perkin and Gido 2011, p. 372). 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 persist 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 shiner.

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) indicates 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 (*Notropis 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 in 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).

In summary, based on the life history of sharpnose and smalleye shiners and population declines and extirpations directly observed in the South Fork Double Mountain Fork and middle Brazos River, these species have experienced population declines upstream and downstream of impoundments likely as a result of loss of reproductive output from flow stabilization, decreased water temperatures, increased egg/larval settlement, conversion of lotic habitat to lentic habitat, decreased turbidity and nutrient availability, substrate changes, increased predation, and population isolation. The impact of impoundment likely extends for hundreds of kilometers both upstream and downstream of impoundments. Negative impacts to these species may be immediate or occur over long periods of time depending on the scale and location of impoundment.

2. Potential future dams and impoundments

In addition to the ongoing effects of current dams and impoundments, Texas' 2012 State Water Plan identifies new dams are planned for future construction within both species' historical and current ranges over the next 50 years (TWDB 2012, p. 10). According to Texas' 2012 State Water Plan, during drought conditions there is not enough water supply to meet current or projected human water demand (TWDB 2012, p. 4). 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 4, Figure 7). These new reservoirs would have possible impacts to sharpnose or smalleye shiners.

Table 4. 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 7, green circles).

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	Miller's 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
	Double Mountain Fork	Double Mountain Fork Reservoir East and West	BGRWPG 2010, p. 4B.12-53
Middle Brazos	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

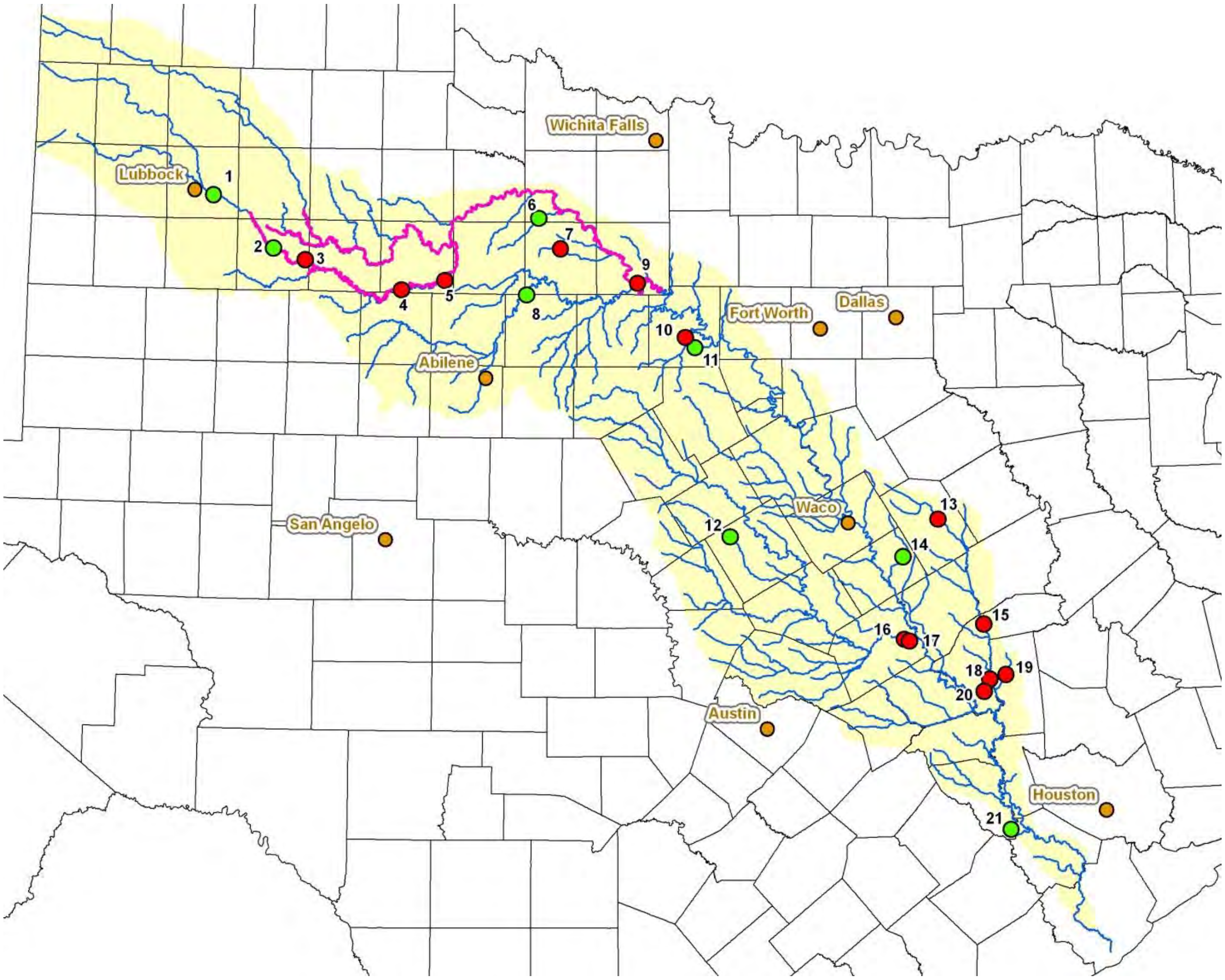

Figure 7. Reservoir projects within the Brazos River basin as determined by Water Planning Regions G, H, and O. Red and green circles represent projects determined to be feasible at the region level; however, only green circles are included in the 2012 Texas State Water Plan. The Brazos River basin (yellow 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.

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 8, 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.

The proposed Jim Bertram Lake 7 Reservoir would be a 20,700 acre-foot (26 million cubic meters (mcm)) capacity reservoir on the North Fork Double Mountain Fork of the Brazos River immediately upstream of Buffalo Springs Lake in Lubbock County, Texas (LERWPG 2010, pp. 4-184–4-186). 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 of the Brazos River will reduce the amount of water available downstream in the river and affect fish habitat there.

The proposed Post Reservoir would be a 57,420 acre-foot (71 mcm) capacity reservoir on the North Fork Double Mountain Fork of the Brazos River in Garza County, Texas (LERWPG 2010, p. 4-214). 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 km) 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 of the Brazos River, or North Fork Double Mountain Fork of the Brazos River upstream of Possum Kingdom Lake within the currently occupied range of these species will likely 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 unimpounded 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 for fish use downstream of their impoundments. Of these six reservoirs proposed for construction in unoccupied habitat, the Millers Creek Reservoir Augmentation would capture flow that would otherwise discharge into the occupied segment of the upper Brazos River main stem. The remaining five 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 (also see Chapter 4). However, middle and lower Brazos River segments may be important for experimental 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 reservoir development would only further reduce the likelihood of successful populations of the sharpnose and smalleye shiner establishing in this portion of their range and potentially limit opportunities for research and population redundancy.

B. 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 8; 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 Planning Region, at the headwaters of the Brazos River, where approximately 97 percent of the region's water supply comes from the Ogallala Aquifer (TWDB 2012, p. 118). Approximately 94 percent of this water is used to irrigate crops in an otherwise arid landscape (TWDB 2012, p. 118). 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 2012, p. 27).

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 of the 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). It is likely that many similar examples exist throughout the Brazos, Colorado, and Red River basins. In 2010, groundwater stream gains (additional water in the stream that is not accounted for by surface flow, precipitation, etc.) in the Salt Fork and Double Mountain Fork of the 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. Although groundwater conservation districts manage groundwater resources within their jurisdictional boundaries to ensure that groundwater will be available for future users, the 2012 Texas State Water Plan indicates statewide groundwater supplies are projected to decrease up to 30 percent by 2060, primarily due to depletion of the Ogallala Aquifer (TWDB 2012, p. 3), which underlies the headwaters of the Brazos River and once contributed significantly 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 coupled with the presence of an unsustainably declining groundwater supply 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. Falke *et al.* (2012, p. 865) found that, in Great Plains streams, extinction probability of fishes increased significantly from drought when the site was not fed by groundwater.

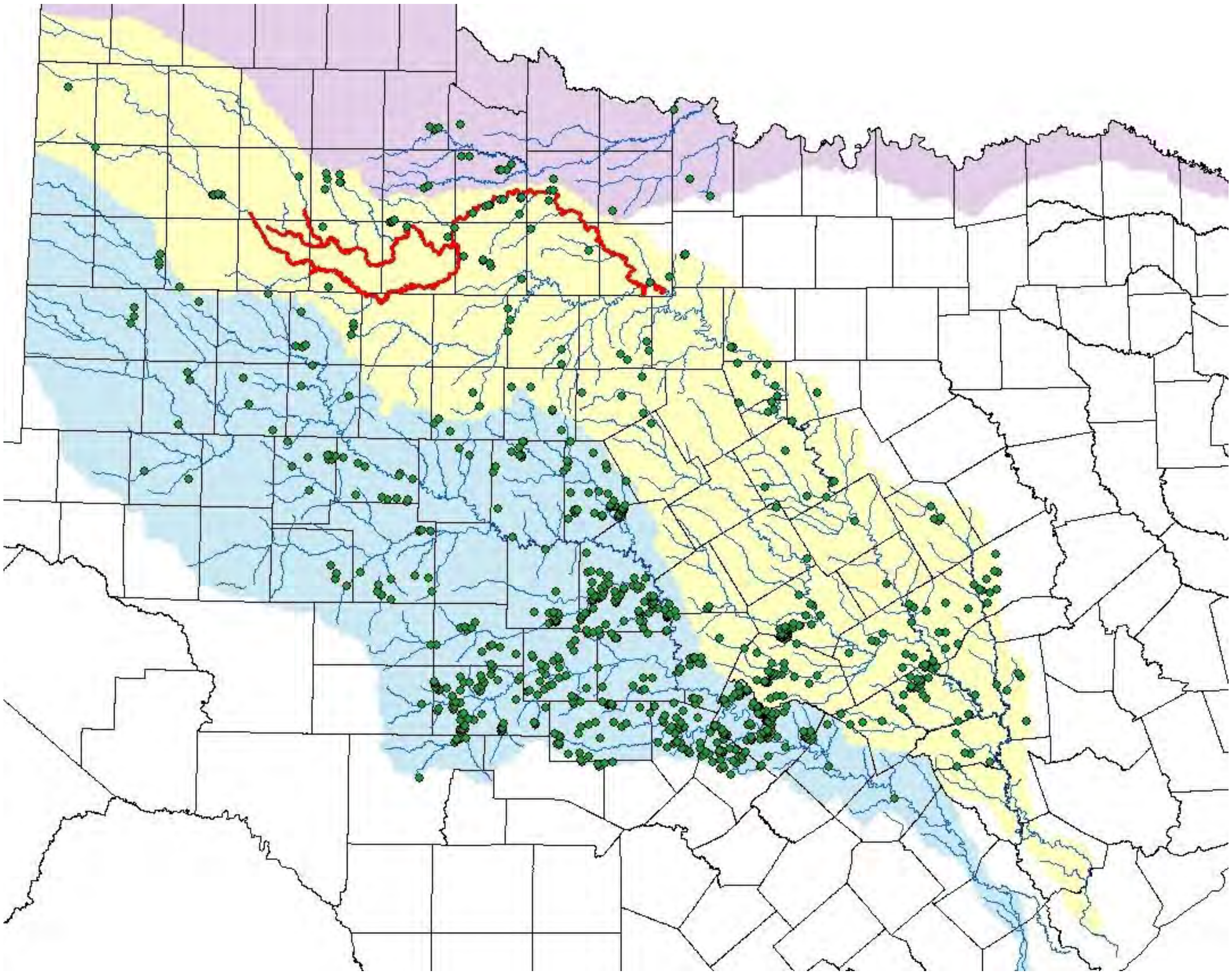

Figure 8. Select springs and seeps (green circles) of the Brazos (yellow), Colorado (blue), and Red River (pink) basins (Heitmuller and Reece 2003, GIS shapefile). The currently occupied habitat of sharpnose and smalleye shiners is shown in red.

C. Climate Change and Drought

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).

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).

In addition to basing their projections on scientific analyses, 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 does 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 will be offset by increased evapotranspiration and water demand resulting from increased temperature (Nielsen-Gammon 2011, p. 2.30; Banner *et al*. 2010, p. 10). 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 is currently considered the drought of record due to intensity and duration (Banner *et al*. 2010, p. 9).

The drought of 2011 was the worst one-year drought in Texas' history (TWDB 2012, p. 14; NOAA 2011, p. 8). According to yearly average discharge data from the USGS station 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 m^3s^{-1} (36.6 cfs), almost half that of the next driest year on record (1998). The peak monthly mean flow from the sharpnose and smalleye shiner spawning season (April – September) during 2011 was 21.7 cfs (0.6 m^3s^{-1}) in April, with a peak daily flow of 35 cfs (1 m^3s^{-1}) 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 62.2 (1.8 m^3s^{-1}, July) and 59.1 cfs (1.7 m^3s^{-1}, August), respectively. A peak daily flow of 478 cfs (13.5 m^3s^{-1}) was measured at this location on July 5, 1998, and a flow of 443 cfs (12.5 m^3s^{-1}) was measured on August 29, 1984. For comparative purposes, daily discharges greater than 100 cfs (2.8 m^3s^{-1}) 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 is generally considered the drought of record due to intensity and duration (TWDB 2012, p. 1), USGS daily discharge data dating back to 1924 from the Brazos River at Seymour in Baylor County indicates 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 1964 and 2011 (48 years), USGS mean monthly discharge data indicates twenty spawning seasons did not meet the estimated minimum mean summer discharge requirement (227 cfs (6.43 m^3s^{-1})) to sustain smalleye shiner population growth while six did not sustain estimated levels required for sharpnose shiners (92 cfs (2.61 m^3s^{-1})) (Figure 9). 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.

With increasing drought there is a projected decrease in surface runoff (which is the primary source of flow in the upper Brazos River) up to 10% by the mid-21st century (Mace and Wade 2008, p. 656; Karl et al. 2009, p. 45). 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 CO_2 doubles. As the intensity and frequency of spawning season droughts increase and river flows decrease, shiner survival and reproduction will be reduced.

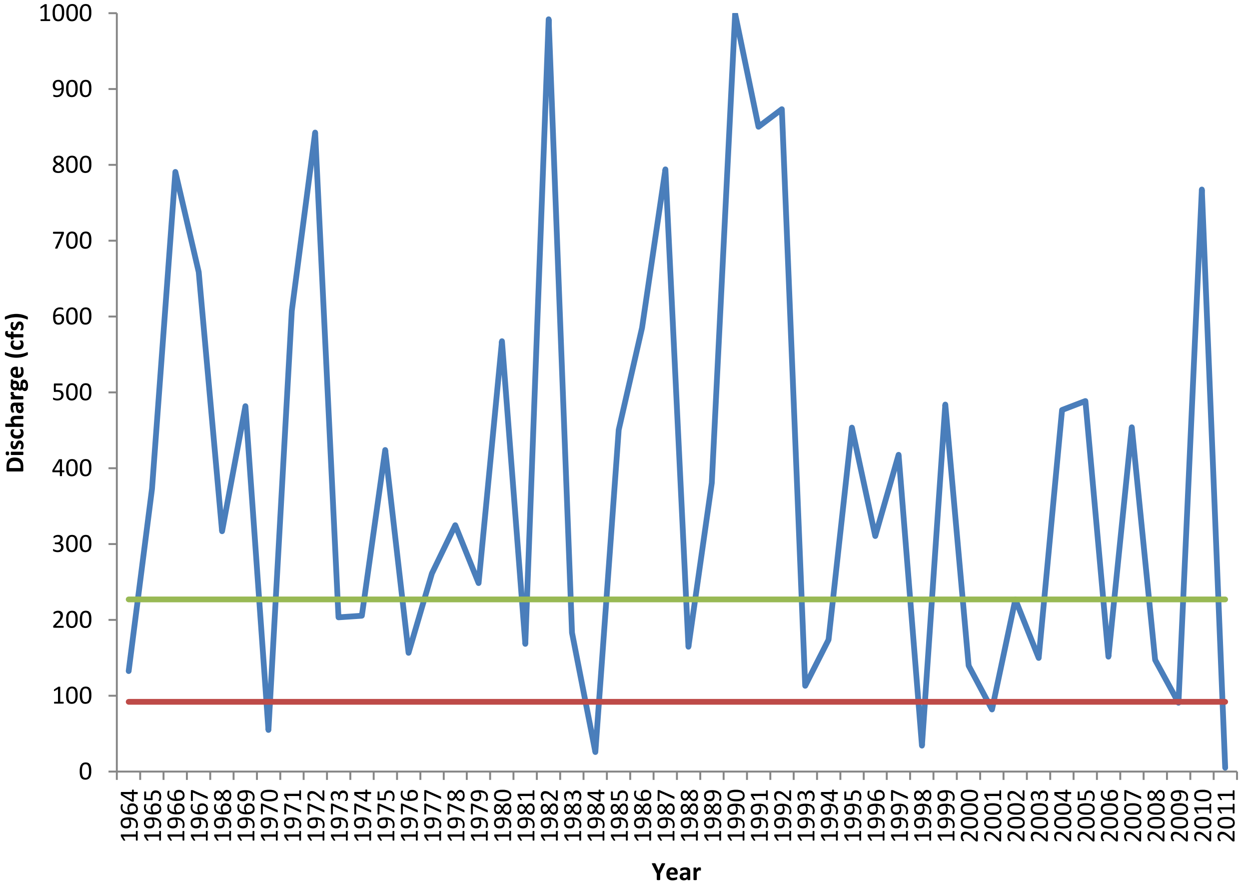

Figure 9. Mean spawning season discharge, calculated as the mean of the monthly discharges from April through September, for the Brazos River near Seymour, Texas (Baylor County; blue line) compared to the estimated minimum required flow required to sustain populations of sharpnose (red line) and smalleye (green line) shiners.

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.). Given these species at most survive for two reproductive seasons, severe drought conditions during consecutive spawning seasons may result in local extirpations or complete extinction unless recovery actions are implemented. Fearing their possible extinction in the summer of 2011, TPWD 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)

Prior to impoundment of their native habitat, during drought conditions sharpnose and smalleye shiners could have potentially swam downstream until suitable conditions for survival and reproduction were met. After droughts ended, these fish could recolonize the upstream reaches when favorable conditions returned. Although impounded reservoirs often retain water during droughts, sharpnose and smalleye shiners are not adapted to survive or reproduce in non-flowing habitat because of the broadcast spawning life history requirement. Despite an increased threat of predation, some adult sharpnose and smalleye shiners may temporarily survive drought conditions by finding refuge in impounded reservoirs; although successful reproduction would not be possible and predation from lentic piscivorous fish would increase. 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 survival and reproduction.

There is no question the world's climate system is warming, and the Texas climate is generally expected to become hotter and drier. The drought of 2011 was the worst one-year drought in Texas' history, and, as a result, despite extensive survey effort there was no observed recruitment of juvenile sharpnose or smalleye shiners that spawning season. 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 reproduction in these species. Under these circumstances, reproduction fails and no new juvenile fish are recruited into the population. Given the short lifespan of these species, if a major drought occurs in two successive years, there is a high likelihood these species will go extinct in the wild. Continuing climate change is expected to result in less water availability within the upper Brazos River basin by the mid-21st century which will negatively impact shiner reproduction and survival at the population and species level.

D. 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 unknown.

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 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 has declined by as much as 71 percent, with an average reduction of nearly 90 meters (300 feet) 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 adapted to 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 to be similar and largely overlapping. If dense stands of saltcedar do reduce streamflow in the Brazos River basin, this would negatively impact sharpnose and smalleye shiners, although the actual extent of the impact on streamflow and these shiner species is unknown. However, at a minimum, saltcedar infestation contributes to and acts cumulatively with impoundments, drought, and groundwater depletion to exacerbate water loss from the river channel.

E. Desalination

The water in the upper Brazos River is highly saline as a result of the natural process of groundwater emission 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). Upper Brazos River water is often unusable for municipal needs without desalinization (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.

Unintended effects of salt control projects in the form of impoundments and altered flow regimes 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 of the 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 **Dams and Impoundment** section above). However, the 2012 Texas State Water Plan does not indicate plans to construct salt pollution control reservoirs in the upper Brazos River watershed at this time (TWDB 2012, entire), suggesting they may not be implemented in the near future. The Red River Chloride Control Project has implemented temporary and permanent weirs, dikes, dams, and pumps to divert saline water in the historically occupied Wichita River to brine retention ponds, reducing the natural salinity and flow of this river system (Wilde *et al.* 2008, p. 2).

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, p. 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**).

F. Water Quality Degradation

1. Pollution

A number of practices and sources have the potential to impact surface water quality including runoff from concentrated animal feeding operations (CAFOs), municipal solid waste sites, and urban areas; point sources such as municipal wastewater discharges and industrial discharges; and nonpoint sources such as atmospheric deposition and pesticide treatment. Richter *et al.* (1997, p. 1090) suggests that nonpoint pollution resulting in nutrient loading is one of the leading threats to freshwater aquatic ecosystems in the United States.

A spatial review of existing Texas Pollution Discharge Elimination System (TPDES) permits suggests that a majority of CAFOs in the headwaters of the Brazos River basin do not occur near the river channel. Similarly, there appear to be relatively few non-CAFO TPDES-permitted entities within the Brazos River, Red River, and Colorado River basins that are located near major surface water channels except near urbanized areas around Lubbock, Dallas-Fort Worth, Waco, Bryan, Austin, and Houston. These urbanized areas are also where concentrations of municipal and industrial wastewater discharges and municipal solid waste sites occur.

In the area surrounding the headwaters of the Brazos River, 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, p. 1-63). There are no impaired stream segments in the Brazos River basin north or west of the City of Lubbock (TCEQ 2008a, entire).

The water quality in the upper Brazos River is also generally good (BGRWPG 2010, p. 1-46), although a number of natural and human-mediated water quality issues negatively affecting sharpnose and smalleye shiners are present. For example, TCEQ (2008a, pp. 282–283) identifies the Salt Fork of the 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. Similarly, the Double Mountain Fork of the Brazos River was listed as impaired due to the presence of high levels of chloride and total dissolved solids (TCEQ 2008a,

p. 292; TCEQ 2010, pp. 477–478)—also a natural occurrence in upper reaches of the Brazos River. In contrast to naturally occurring water quality issues, the North Fork Double Mountain Fork of the Brazos River has experienced high levels of ammonia, chlorophyll, nitrate, and bacteria since 2006 between the City of Lubbock's reservoir system and its confluence with the South Fork Double Mountain Fork of the Brazos River (TCEQ 2008a, pp. 294–295; TCEQ 2010, pp. 479–480). In April 2008, elevated levels of mercury were discovered in piscivorous fish in Lake Alan Henry on the South Fork Double Mountain Fork of the Brazos River although it is unclear if this is from natural or manmade causes (TDSHS 2010, p. 15). These top predators are more susceptible to mercury accumulation in their tissues than fish such as the shiners; therefore, it is not thought that mercury contamination of Lake Alan Henry is negatively affecting sharpnose and smalleye shiners downstream of this impoundment due to their distance from this lake and position in the food chain (non-top predators). Finally, oil slicks 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.). While available information indicates some water pollution issues in the upper Brazos River, the actual extent of any impacts to sharpnose and smalleye shiners is unknown at this time. Further investigations will be required to understand the frequency, magnitude, and cause of petroleum contamination and other pollution sources in the upper Brazos River basin.

The middle Brazos River is experiencing water quality issues, in part, due to non-point source pollution activity attributed to a high concentration of CAFOs in the Bosque River drainage that discharge into the Brazos River near Waco (BGRWPG 2010, p. 1-47). The Bosque River contains high levels of nitrate and fecal coliform as it enters Lake Waco, which also has high levels of chlorophyll (TCEQ 2008a, pp. 359–260, 215; TCEQ 2010, p. 671). High concentrations of herbicides or nutrient loads have also been identified entering the Brazos River near Hillsboro, the Leon River watershed, and Salado Creek, likely as a result of agricultural practices (BGRWPG 2010, p. 1-47, 1-48; TCEQ 2008a, pp. 154, 328). The Brazos River basin near Brazos County and the Yegua Creek watershed near Burleson County also experience high discharges of nutrients into surface waters due to agricultural activities (BGRWPR 2010, p. 1-48). High nutrient and bacterial loads throughout the middle Brazos River may be partially responsible for lower dissolved oxygen levels in portions of the lower Brazos River (BGRWPR

2010, p. 1-51). Despite the presence of water quality issues in the middle Brazos River basin, we do not think that this is the primary cause of the extirpation of sharpnose and smalleye shiners in these reaches because the middle Brazos river segments are highly fragmented and much shorter than the estimated minimum reach length requirement for successful reproduction in these species.

The lower Brazos River near the Gulf Coast is characterized by elevated nutrients, dissolved minerals, and fecal coliform (RHWPG 2010, p. 1-22). The Navasota River contains elevated levels of nutrients and bacteria (TCEQ 2008a, pp. 79, 82–83; TCEQ 2010, pp. 127–128). Allen's Creek in Austin County has had recorded instances of high nutrient and fecal coliform discharges coupled with low dissolved oxygen in the recent past (TCEQ 2008a, p. 10; TCEQ 2010, p. 17). The Leon River downstream of Lake Belton, the San Gabriel River, and the Little River have all had reported elevated nutrient and fecal coliform loads (TCEQ 2008a, pp. 126, 131, 135, 137, 154). Fish survey data and museum collections show a decline in the abundance of sharpnose and smalleye shiners in the lower Brazos River over time, although we do not have a perfect understanding of the reason for the decline. It cannot be discounted that water quality issues may have played a role in these species' declines in the lower Brazos River. However, effects of pollution on sharpnose and smalleye shiners in the lower Brazos River were probably not the primary cause of their decline given these species could not likely survive (even under historical, natural conditions as discussed in Chapter 4) in the different ecological setting of the lower Brazos River without constant emigration from an upstream source.

The Wichita River system of the Red River basin also suffers from a number of water quality issues where the sharpnose shiner once occurred. The North and Middle Forks of the Wichita River have elevated levels of selenium (TCEQ 2008c, pp. 78, 87). The South Fork of the Wichita River has elevated levels of chloride and ammonia (TCEQ 2008c, pp. 109–110), although high levels of chloride are likely natural in this reach. The Wichita River downstream of Diversion Lake has high nutrient loads and fecal coliform (TCEQ 2008c, pp. 64–66). Despite the presence of water quality issues in the Wichita River, it is not believed that this is the primary cause (i.e., river fragmentation) of the extirpation of sharpnose shiners in these reaches.

The Colorado River downstream of Lake J.B. Thomas has elevated nutrient and *E. coli* levels (TCEQ 2008b, pp. 142, 145) and E.V. Spence Reservoir has elevated sulfates, dissolved solids, and nutrients, and has had golden algae blooms resulting in fish kills (TCEQ 2008b, pp. 126, 128). The Colorado River downstream of E.V. Spence Reservoir has suffered from low dissolved oxygen and elevated chlorides, dissolved solids, and nutrients (TCEQ 2008b, pp. 279–280). The Colorado River downstream of O.H. Ivie Reservoir also has records of elevated nutrients (TCEQ 2008b, p. 119). Lower Pecan Bayou, which empties into the Colorado River upstream of Lake Buchanan contains elevated nutrient levels and *E. coli* bacteria (TCEQ 2008b, pp. 206–207). Downstream of Lake Buchanan and continuing through the City of Austin, the Colorado River and its impoundments and tributaries continue to display signs of water quality degradation. Despite the presence of water quality issues in the Colorado River basin, it is not believed that this is the primary cause (i.e., river fragmentation) of the extirpation of sharpnose and smalleye shiners in these reaches.

Although the Brazos, Wichita, and Colorado River basins clearly have experienced varying levels of water quality degradation and pollution, the impact to sharpnose and smalleye shiners is not likely as substantial as from other major threats such as impoundment, alterations in flow regime, and drought. Also, many point and non-point pollution sources are regulated by the Texas Commission on Environmental Quality, which may reduce the potential impact to freshwater systems that support sharpnose and smalleye shiners (LERWPG 2010, p. 1-65). Although unlawful discharges occasionally occur, they, by themselves, are not likely 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, it is expected that any lethal effects to individuals would be localized to contaminated areas and would not likely affect sharpnose and smalleye shiners at the population or species level.

2. Golden Alga

Golden alga (*Prymnesium parvum*) is a yellow-green alga 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 were 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 rare 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 most likely in saline conditions (Sallenave 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– have occurred in the upper Brazos River or Double Mountain Fork of the 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, p. 14; BRA 2012, unpublished data).

The Colorado River and Red River basins have also experienced golden alga blooms in areas historically occupied by sharpnose and smalleye shiners, although these species were already extirpated at the time these blooms were documented. In the Colorado River basin, documented fish kills have occurred in the main channel in Runnels (1989, 2001, 2009) and Coke (1989, 2009) Counties, E.V. Spence Reservoir (2001, 2008, 2009, 2010), and Lake Colorado City (2009) (TPWD 2002, p. 14; TPWD 2012, entire). Additional blooms without documented fish kills were recorded in E.V. Spence Reservoir (2007, 2008, 2009, 2010, 2011), Lake Colorado

City (2007, 2008, 2009, 2010, 2011), and a number of other smaller tributaries and impoundments (TPWD 2012, entire).

In the Red River basin, Lake Diversion fish kills were documented in 2001 (TPWD 2002, p. 14) and additional blooms without fish kills have been documented from Lake Diversion (2007, 2008, 2009, 2010, 2011, 2012) and Kemp Lake (2008) (TPWD 2012, entire).

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 Brazos, Colorado, and Wichita River basins 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 future recovery options if they occur in river segments proposed for experimental release of shiner populations and 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.

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 naturally have 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 that would not be subject to suffocating sediments under flowing conditions (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 load decreases from alterations to flow regime may have a more profound impact on 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).

G. 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 adapted to 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 that the sharpnose and smalleye shiner appear to prefer. 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 changes in flow regime and channel depth.

In-stream dredging operations within Texas are required to obtain a dredge permit from the TPWD. There are currently four 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 2012, pers. comm.). It is not known if future dredging operations are planned for additional locations within the Brazos River basin. Dredging operations in the extreme downstream portion of the Brazos River may not be as likely to affect sharpnose and smalleye shiners as these species do not currently inhabit much, if any, of this reach. Also, given the planktonic nature of these species' pre-adult life stages and the estimated minimum reach length required to sustain populations of these fish, much of the reproductive output in the extreme lower reach of the Brazos River is likely carried into the Gulf of Mexico. The only permitted operation in the Colorado River channel since 2007 was a one-time permit for a railroad bridge repair in Matagorda County in 2012 (Heger 2012, pers. comm.). Sharpnose and smalleye shiners have never been recorded from the Colorado River in Matagorda County. There have been no permitted activities in the Wichita River since 2007. 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. Considerably more permitted activities occur on smaller tributaries of these drainages (Heger 2012, pers. comm.); however, impacts to sharpnose and smalleye shiners from dredging of these smaller tributaries is not likely unless they are occupied by the shiners. Given the information available, it appears that in-stream dredging and mining will not affect sharpnose and smalleye shiners to the same extent as other threats such as impoundment and drought.

H. 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, or educational purposes. 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. According to TPWD's 2012 records, there are seven active permits in the Colorado River basin and eight in the Brazos River basin (Cook-Hildreth 2012, pers. comm.). Although TPWD also indicates that active permits also occur in the Red River basin, there are no currently permitted activities occurring in areas known to historically contain sharpnose shiners. At least one active permit allows for collection of bait from the upper Brazos River basin in Stonewall, Throckmorton, and Fisher Counties, Texas, where sharpnose and smalleye shiners still persist. TPWD permits to collect and sell non-game fish do not provide collection limits, nor do they require reporting to the species level. Therefore, it is not known if commercial bait harvesting in the upper Brazos River has, or continues to be, a substantial concern to the viability of sharpnose or smalleye shiners.

Given the prevalence of sharpnose and smalleye shiners in the upper Brazos River main stem, Salt Fork, and Double Mountain Fork, it is likely that any permitted harvest activities in these areas will result in their capture. Impacts to sharpnose and smalleye shiners are expected to be localized at the harvest location and would not likely extend to the whole population unless a large number of individuals (thousands of fish, with a significant portion of sharpnose and smalleye shiners) were collected. Commercial bait harvest permits are also active for the middle and lower Brazos River, Navasota River, Colorado River, and San Saba River where one or both species have occurred historically. Given the current status of both species in these areas (either extirpated or nearly so), ongoing collections for commercial use are not likely to impact the status of either species, although future harvests may impact recovery efforts. Additional information may be required to fully understand the historical, current, and potential impact commercial bait harvests have on sharpnose and smalleye shiners, but the best available information does not indicate these collections are a major source of concern.

I. 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, Colorado, or Red River basins. 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 unimpounded prairie streams. These fish, including fish stocked by state fishery biologists 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 well adapted to 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.

Although hybridization of freshwater fish is known to occur, including within the genus *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.

J. 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. Figure 10 provides an influence diagram that demonstrates some of the relationships among the sources (or causes), stressors (changes environment), and the effects on the species that influence viability.

The summer of 2011 provided an example of what happens to these species when water availability is reduced by in-channel impoundments (water withheld for municipal use in the headwaters of the Brazos River), continued groundwater depletion (particularly for agricultural use in the headwaters of the Brazos River), salt cedar encroachment (particularly in the downstream portion of the upper Brazos River), 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 was observed 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 given their currently degraded status. For example, while commercial harvesting, a 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.

K. 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, salt cedar 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 why both species are at a heightened risk of extirpation within their remaining ranges in the upper Brazos River basin.

Secondary factors, but still important ones, affecting both species include commercial bait harvesting and 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.

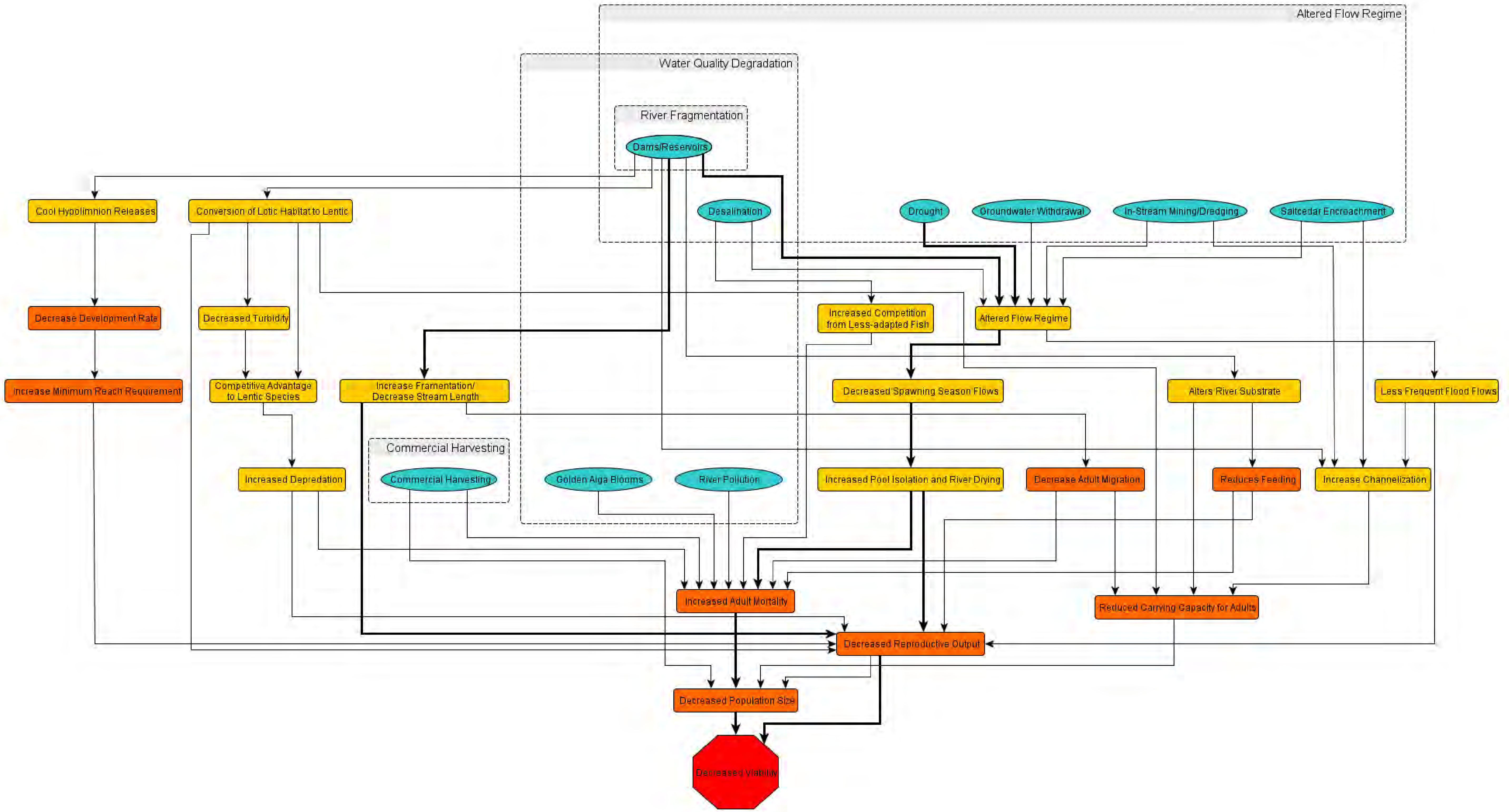

Figure 10. An influence diagram illustrating the effects pathway for key threats affecting sharpnose and smalleye shiner viability. Sources of threats are depicted using blue ellipses, the stressor mechanisms are yellow boxes, and the effects on the species are orange boxes. The primary have been drawn (dotted line) to envelope the threats affecting those stressors. The most important effects pathways are drawn with thicker lines.

CHAPTER 4 – SPECIES CURRENT CONDITIONS

In this chapter we review the current conditions of these species in terms of the conditions of individuals, populations, and each species rangewide. We look at the limited 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. We conclude that the current conditions of the shiners, rangewide, fall well short of what the species need to maintain long-term viability.

The sharpnose and smalleye shiner have experienced a substantial reduction in their ranges. The 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 1,009 km (627 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 range and conditions are discussed below.

A. Condition of Individuals

Although specific information is limited, microhabitat needs such as substrate, food resources and prey availability, and water quality conditions generally appear to be adequate to support sharpnose and smalleye shiners in the upper Brazos River where the species is currently extant. Some limitations in these conditions are discussed in Chapter 3 – Cause and Effects.

B. Condition of Populations

1. Current Abundance

In recent years, the sharpnose shiner has become less abundant in the Salt Fork and North and South Fork Double Mountain Fork of the upper Brazos River basin (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 of the Brazos River (5 sites, 8 surveys each), 284 from the North Fork Double Mountain Fork of the Brazos River (2 sites, 8 surveys each), and none from the South Fork Double Mountain Fork of the Brazos River (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 fall of 2011, only 12 sharpnose shiners were collected in the Salt Fork of the Brazos River (6 sites, 8 surveys each), 42 from the North Fork Double Mountain Fork of the Brazos River (3 sites, 8 surveys each), and none from the South Fork Double Mountain Fork of the Brazos River (2 sites, 8 surveys each), representing a 95 percent, 85 percent, and zero percent decrease in abundance over approximately 10 years, respectively (Wilde 2011, p. 21). They remain relatively abundant in the Double Mountain Fork and main stem of the upper Brazos River, with 1,106 and 4,669 individuals collected between 2008 and 2011, respectively (Wilde 2011, p. 21).

The smalleye shiner has also become less abundant in the Salt Fork, North Fork, and South Fork Double Mountain Fork of 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 of the Brazos River, 1451 from the North Fork Double Mountain Fork of the Brazos River, and 28 from the South Fork Double Mountain Fork of the Brazos River (Ostrand 2000, p. 34). Using similar sampling effort between the spring of 2008 and fall of 2011, only 379 smalleye shiners have been collected from the Salt Fork, 720 from the North Fork Double Mountain Fork, and zero from the South Fork Double Mountain Fork of the Brazos River, representing a 60 percent, 50 percent, and 100 percent decrease in abundance, respectively (Wilde 2011, p. 21). They remain relatively abundant in the Double Mountain Fork and main stem of the upper Brazos River, with 1,588 and 4,218 individuals collected between 2008 and 2011, respectively (Wilde 2011, p. 21). Available data suggest the only sharpnose and smalleye shiners possibly remaining in the Brazos River downstream of Possum Kingdom Lake are the fish released by the Texas Parks and Wildlife Department (TPWD) in May 2012. However, given the age of the released fish and the previous decline of these species in the lower Brazos River, it is unlikely successful reproduction occurred, and both species are presumed extirpated from this river segment.

2. Streamflows

An estimated mean spawning season flow of 6.43 m^3s^{-1} (227 cfs) and 2.61 m^3s^{-1} (92 cfs) is required to sustain populations of smalleye and sharpnose shiners, respectively. Between 1964 and 2011 (48 years), in the upper Brazos River, twenty spawning seasons did not meet the estimated minimum mean summer discharge requirement to sustain smalleye shiner population growth while six did not sustain estimated levels required for sharpnose shiners. Drought conditions coupled with anthropogenic factors have reduced streamflow in the upper Brazos River beyond that which has normally occurred in this reach. The drought of 2011 was the worst single-year drought on record (TWDB 2012, p. 14) 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.

3. Stream Reach Length

The substantial reduction in the occupied range of sharpnose and smalleye shiners and a decrease in their abundance in parts of their current range suggest a number of their habitat requirements are not currently being met. The estimated minimum unobstructed reach length required to meet reproductive needs of individuals and populations as a whole ($\geq$ 275 km (171 mi)) occurs in only two geographically separate locations within the confirmed, maximum historical range of both species. Table 5 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.

Table 5. Important river segment lengths 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 and the only reaches to be currently occupied, although the lower Brazos River population is not expected to sustain itself long-term. Segment lengths do not account for occasional fish movement barriers such as low-water crossings. Double asterisks indicate segments from which historical sharpnose and smalleye records do not exist. † indicates additional information in text.

Brazos River

Segment (Upstream to Downstream)	**Length**
Upper Brazos†	
Double Mtn Fork → Possum Kingdom Lake	673 km*
Salt Fork → Possum Kingdom Lake	601 km*
Middle Brazos	
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
Lower Brazos	
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 → OH Ivie Reservoir	135 km

OH 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

Only two separate river segments with confirmed historical records of sharpnose and smalleye shiners retain the minimum unobstructed length required for the successful reproduction 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. A segment of the Colorado River downstream of the City of Austin is also greater than 275 km (171 mi) in length; however, there are no records of sharpnose or smalleye shiners from this reach. Although it is suspected that this reach may have once contained sharpnose shiners after historic flood events connected the Colorado and Brazos River basin it is unclear if, like the lower Brazos River, they would survive here without constant emigration from more suitable habitat.

The upper Brazos River is currently inhabited by both species and has the only viable populations remaining. A previously exposed pipeline crossing the Brazos River in Throckmorton County, approximately 130 river km (80 mi) upstream of the downstream portion has been reinforced with a concrete protective mat capable of acting as a fish barrier during periods of moderate and low flow (Label 26 on Figure 6). This site was visited on February 27, 2013, at which time it appeared to be a barrier to upstream fish movement. Given the flow conditions on the day of the visit, it is estimated the pipeline reinforcements will act as a fish barrier more than 40 percent of the time. Given historical flow data, in 2011 and 2012 it likely acted as a fish barrier 73 to 79 percent of the time, respectively. These estimates are conservative because it is unknown exactly what, if any, flow conditions are needed before it would not act as a fish barrier. If the pipeline reinforcement remains unchanged and acts (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 of the Brazos River having the potential to occasionally impact upstream fish migration depending on water depth and flow. The South Fork Double Mountain Fork of the Brazos River has a road crossing approximately 0.25 miles 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. The North Fork Double Mountain Fork has one low-water crossing and one unknown structure having the potential to occasionally impact upstream fish migration depending on water depth and flow. The Salt Fork of the Brazos River has two low water crossings and one unknown 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 makes it difficult to access the river channel to assess the potential impacts of these structures.

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 regime 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 unimpounded. 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 (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. The lower Brazos River differs from the upper portion by being deeper, having more rapid current, having less sandy substrate, having more stable flows, and likely differs in water chemistry measures such as salinity, DO, and temperature. 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 sink. Given the historical decline and disappearance of both species in the lower Brazos River, the May 2012 reintroduction effort 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 reproduction 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.

C. Condition 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 11; 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). 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 south of Possum Kingdom Lake (Durham and Wilde 2009a, p. 21; Labay 2010, pp. 35–54; Wilde 2000 & 2001, unpublished data), it cannot be discounted that a very small number of individuals 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. The lower Brazos River is much wider and deeper, likely has a lower salinity, supports lentic-adapted piscivorous fish, and historically experienced more intense floods 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 wildlife biologists. These fish were collected from 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 severe decline of this species in the lower Brazos River prior to their reintroduction, and that released individuals were nearing their maximum life expectancy, substantial reproductive output is unlikely to be generated nor do we 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 both 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.; Figure 11), 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. The ongoing and future threat of increased fragmentation and decreasing flows in the upper Brazos River further reduce the viability of this species.

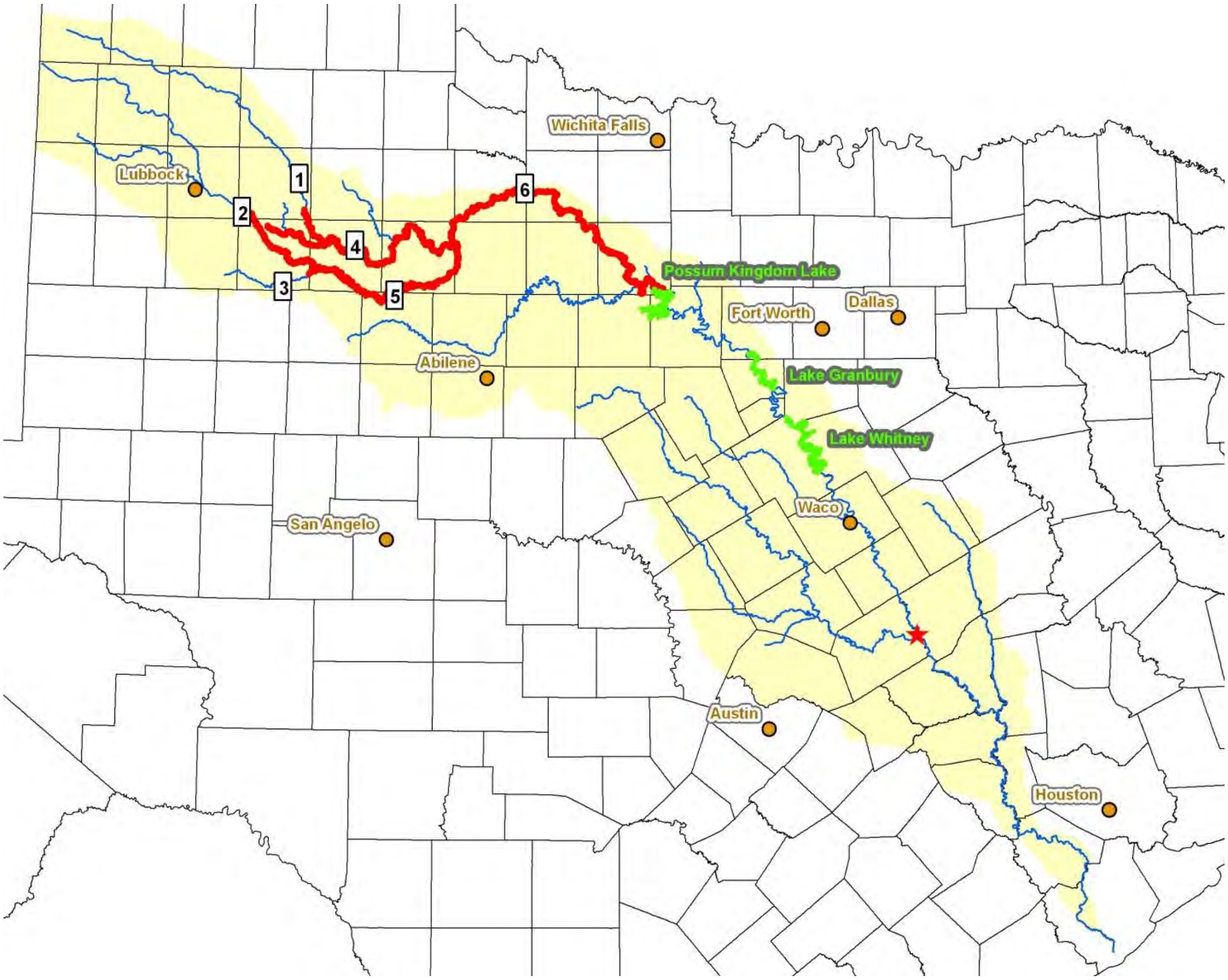

Figure 11. The current range of the sharpnose shiner, *Notropis oxyrhynchus*. The Brazos River basin (yellow shading) and the three main channel reservoirs (green) of the middle Brazos River are also shown. The red star indicates the location of sharpnose shiner release in May of 2012. Occupied segments of sharpnose shiner habitat are labeled as follows: 1) White River, 2) North Fork Double Mountain Fork of the Brazos River, 3) South Fork Double Mountain Fork of the Brazos River, 4) Salt Fork of the Brazos River, 5) Double Mountain Fork of the Brazos River, 6) Brazos River.

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 12). 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). 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 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).

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 wildlife biologists (Figure 12; Mayes 2012, pers. comm.). These fish were collected from 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 and habitat fragmentation from drought and other threats appear to be negatively affecting smalleye shiner abundance. The ongoing and future threat of increased fragmentation and decreasing flows in the upper Brazos River further reduce the viability of this species.

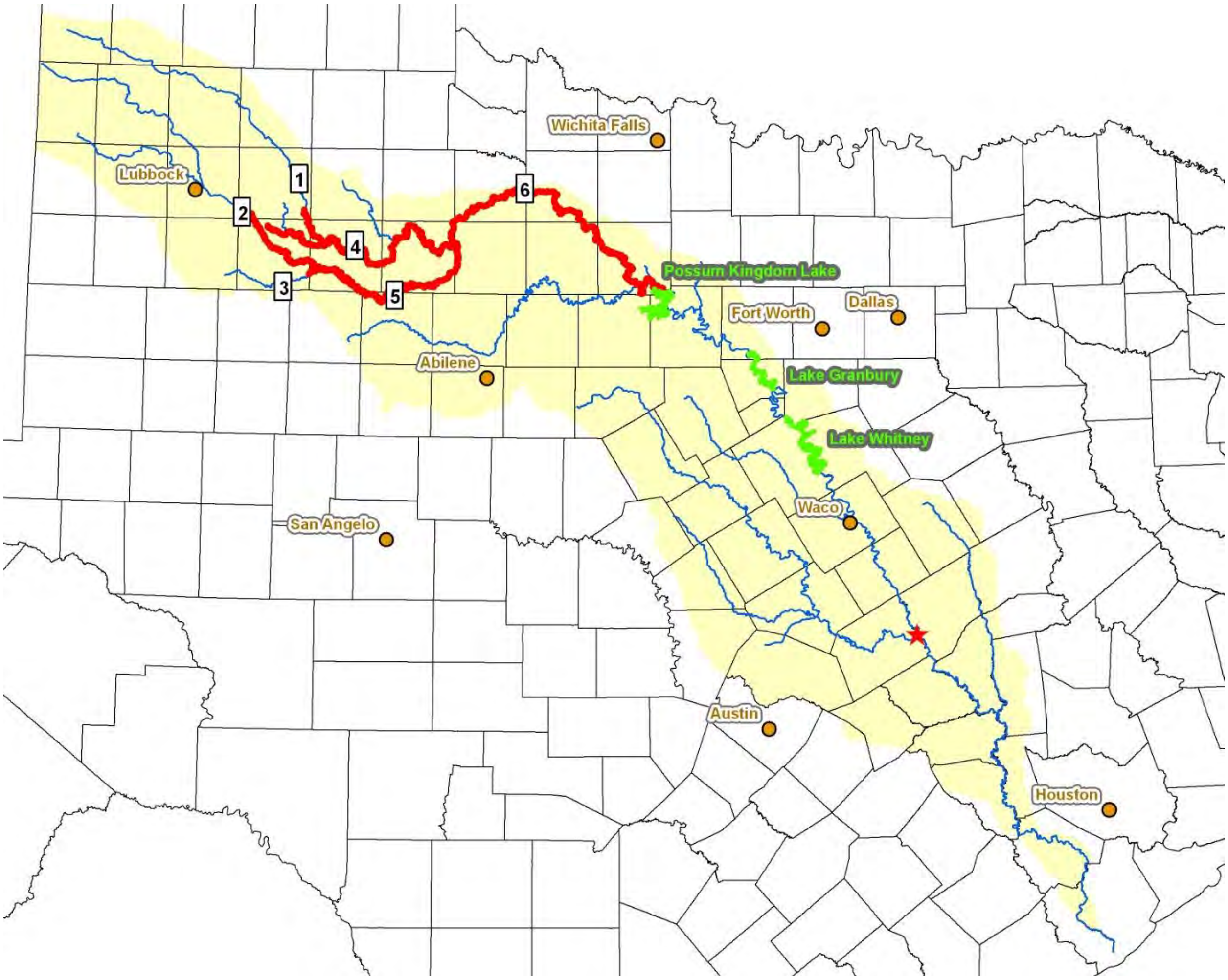

Figure 12. The current range of the smalleye shiner, *Notropis buccula*. The Brazos River basin (yellow shading) and the three main channel reservoirs (green) of the middle Brazos River are also shown. The red star indicates the location of smalleye shiner release in May of 2012. Occupied segments of smalleye shiner habitat are labeled as follows: 1) White River, 2) North Fork Double Mountain Fork of the Brazos River, 3) South Fork Double Mountain Fork of the Brazos River, 4) Salt Fork of the Brazos River, 5) Double Mountain Fork of the Brazos River, 6) Brazos River.

D. Summary of Needs Currently Being Met or Unmet

Sharpnose and smalleye shiners have a number of individual, population, and rangewide needs to ensure they have the resiliency, redundancy, and representation required to sustain their viability long-term. At the individual level, both species require sandy substrates and shallow channels supporting an adequate prey base and water conditions within their physiological tolerances. Currently, both species are primarily restricted to the upper Brazos River basin, where occupied river segments retain the shallow channels with sandy substrates preferred by 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. The populations of both species in the upper Brazos River basin appear to be healthy, and it is likely they are representative of the species' historical genetic variability.

At the population level, both species require unobstructed flowing water greater than 275 km (171 mi) in river length to support successful reproduction. Occupied portions of the upper Brazos River reach up to 673 river kilometers (418 mi). Although occupied segments of the upper Brazos River do not currently contain large, main channel impoundments, there are a number of 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 reproduction that was once occupied by both species. However, the lower Brazos River naturally has different flow characteristics and channel morphology than the upper Brazos River. These species are not 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 reproduction of these shiners, both species are extirpated or functionally extirpated from the lower Brazos River. Therefore, these species completely lack redundancy and are currently restricted to the upper Brazos River basin.

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.

It is currently estimated sharpnose and smalleye shiners require a minimum mean spawning season flow of 2.61 m^3s^{-1} (92 cfs) and 6.43 m^3s^{-1} (227 cfs), respectively. 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 due to climate change further reduce streamflow of occupied segments of the upper Brazos River. Although intermittent flow is a natural occurrence in the upper Brazos River, and these species are adapted to 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.

In summary, sharpnose and smalleye shiners are currently each restricted to one potentially viable population in the upper Brazos River, which has become isolated from downstream river segments by several impoundments. Although the upper Brazos River retains a sufficient length to support reproduction of these species, existing impoundments limit the ability of individuals to seek refuge from receding water levels during periods of drought and to recolonize river segments upon the return of favorable habitat conditions. Increased water capture by upstream reservoirs, spring flow reduction due to groundwater withdrawal, and increasing drought due to climate change have reduced the availability of streamflow such that it no longer reliably supports sharpnose and smalleye shiner reproduction.

CHAPTER 5 – SPECIES VIABILITY

Species viability, or the ability to survive long term, is related to the species' ability to withstand catastrophic population and species-level events (redundancy), the ability to adapt to changing environmental conditions (representation), and the ability to withstand disturbances of varying magnitude and duration (resiliency). The viability of species is also dependent on the likelihood of new or continued threats now and in the future that act to reduce a species' redundancy, representation, and resiliency.

A. Resiliency

Sharpnose and smalleye shiners are adapted to the variable and harsh conditions of arid prairie streams. As such, they are relatively tolerant of variation in water quality parameters such as 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 and by acting as barriers to fish migration during and after severe environmental perturbations. Prior to impoundment, sharpnose and smalleye shiners may have potentially moved downstream during poor environmental conditions. Downstream individuals would also be capable of migrating upstream when favorable flow conditions returned to recolonize lost habitats. This life history strategy presumably provided a high level of resiliency historically 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 lost, 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 lessened.

Over longer terms greater than a few years, both species have naturally limited resiliency because their life span is usually 2 years or less. Therefore, impoundments and other stressors (such as groundwater withdrawals) affect the flow regime to the extent that the minimum streamflows necessary for successful reproduction and population growth in these species may not be maintained. As a result, any stressors in the upper Brazos River basin precluding successful reproduction that 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 viable 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 change, which has increased the probability of severe droughts in this region. The resiliency of these species (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.

B. Redundancy

Currently sharpnose and smalleye shiners are each essentially restricted to single populations in the upper Brazos River upstream of Possum Kingdom Lake, due primarily to habitat fragmentation and flow regime alteration in other river segments where they historically occurred but have been extirpated. 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 and place the entire species at risk of extinction. 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. 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 extinction from inadequate flows 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 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, having more rapid current, having less sandy substrate, having more stable flows, and likely differs 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 likely 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 sink.

Redundancy (the ability of a species to withstand rare destructive events occurring suddenly).is lacking in both sharpnose and smalleye shiners because both species are limited to a single population within the contiguous river segments of the upper Brazos River basin. As such, a catastrophic drought affecting the last remaining occupied habitat of these species could result in their extinction.

C. Representation

The genetic ability of sharpnose and smalleye shiners to adapt to environmental conditions is not well understood. As of 2012, 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, 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 harsh prairie stream environments in which they evolved. It is highly unlikely 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 for reproduction 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. In the absence of definitive genetic information, it is often useful to use ecological diversity as a surrogate for genetic diversity. However, there is no indication that sharpnose or smalleye shiners historically occupied riverine habitats of obviously different ecological settings. Therefore, the use of ecological diversity as a surrogate for genetic diversity for these species may not be appropriate. Regardless, given the persistence of only a single population of both species restricted to the upper Brazos River basin, there is no ecological diversity, nor may there ever have been.

Sharpnose and smalleye shiners lack the representation (the ability of to adapt to changing environmental conditions) necessary to overcome the impacts of habitat fragmentation and loss of river flow because it would likely require adapting their reproductive strategy. The evolution of a different reproductive strategy (away from broadcast spawning) or the extensive adaption of their existing strategy (e.g., by increasing egg/larval development rate) would not be expected to occur within a time period rapid enough to avoid being overcome by their threats.

D. Summary

In summary, as of 2012, sharpnose and smalleye shiners have no redundancy to cope with catastrophic events. However, it appears the remaining populations of both species have retained enough genetic variability for long term survival in the prairie stream habitats for which they are well adapted, although they do not have the genetic capability to adapt to habitat fragmentation or persistent loss of river flow. Sharpnose and smalleye shiners appear remarkably resilient to short term (less than two spawning seasons) natural variation of conditions in naturally functioning prairie streams, although they will not be able to withstand a high magnitude combination of anthropogenic and natural stressors occurring across two or more reproductive seasons.

The Texas 2012 State Water Plan indicates that water demand in Texas will continue to increase while water supplies will continue to decrease, creating the need for additional reservoir construction, groundwater exploitation, and desalination. Likewise, in-stream gravel mining and dredging, pollution, saltcedar invasion, golden alga blooms, commercial fish harvest, and drought will likely continue into the future. Therefore, it is likely threats to the sharpnose and smalleye shiners will continue and increase in the future. A conceptual model of threats to sharpnose and smalleye shiners and their effect on the viability of these species is presented in Figure 10. Given the continuation and increase of threats to the species, the species' reproductive needs and life histories, the current status of the species, and the near extirpation of their populations in the upper Brazos River during the drought of 2011, it seems clear the viability of these species will decrease into the future. If drought severity in Texas continues or increases (as currently projected by climate change models), this will significantly reduce water availability and fragment remaining habitat to the extent that survival of these species over the near term (next 10 years) will be significantly reduced. If additional reservoirs are constructed in the upper Brazos River basin (as currently planned as part of the State Water Plan), it will add to the threats of reduced water availability and fragmentation and further reduce viability over the longer term (next 11 to 50 years). A summary of the current status of sharpnose and smalleye shiner needs and their impact on viability is presented in Table 6.

Table 6. Summary of the status of vital resource needs of Brazos River shiners and implications for viability.

	VITAL NEEDS		CURRENT STATUS			FUTURE STATUS		
Scale	**Resource**	**Function**	**Conditions**	**Causes and Effects**	**Implications for Viability**	**Condition**	**Causes and Effects**	**Implications for Viability**
Individuals	Sandy Substrates and Shallow Channels	Feeding	Presumed adequate within reduced extant range. Some losses of resources have occurred in historical range.	Impoundments; Instream Mining & Dredging; Saltcedar Encroachment	Conditions for individuals 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 quality with physiological tolerances	Feeding/Breeding		Impoundments; Pollution; Golden Algal Blooms			New Impoundments; Pollution; Golden Algal Blooms	
Populations	Minimum spawning season flows	Breeding - *Population Resiliency*	Reduced mean flows from historical conditions in extant range	Impoundments; Groundwater Withdrawal; Severe Drought	Reduced Population Resiliency. Risks to loss of one extant population puts both species at high risk of extinction under current conditions.	Flows and unobstructed river length will likely be further reduced	New Impoundments; Increased Groundwater Withdrawal; More Severe Drought due to 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 - *Population Resiliency*	Reduced frequency of flood flows from historical conditions in extant range					
	Unobstructed flowing water greater than 275 km in river length	Breeding & Migration - *Population Resiliency*	One extant length of river remaining in the upper Brazos River					
Rangewide	Larger lengths of unobstructed flowing water in rivers	Migration & Recolonization - *Resiliency, Representation, & Redundancy*	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

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.

A. Improve Redundancy

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 potential means. Three possible means of increasing redundancy in these species are: (1) a captive propagation program to ensure that the species are not lost due to catastrophic loss of their only populations; (2) introduction of experimental populations throughout their historical range that would be monitored to determine their success and to determine if minimum requirements for these species 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 in which sharpnose and smalleye shiners could seek refuge from severe droughts and other catastrophic events.

B. 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 m^3s^{-1} (92 cfs) necessary to sustain populations of the sharpnose shiner and 6.43 m^3s^{-1} (227 cfs) for the smalleye shiner. Since the impoundment of Lake Alan Henry on the South Fork Double Mountain Fork of the Brazos River in 1992, mean summer discharge of the Brazos River at Seymour in Baylor County has 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). 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 m^3s^{-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 2009, p. 25). Where available, historical streamflow data should be reviewed and reservoir discharges should be planned during the shiners' spawning season in a manner 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). 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 pulse flows. 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 smalleye 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 smalleye 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.

Despite planning and managing to accommodate the needs of sharpnose and smalleye 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, or alteration of the natural flow regime. Although proper siting, design, and management of future reservoirs in the upper Brazos River basin may minimize impacts to sharpnose and smalleye shiners, the restricted range and current status of these species makes them vulnerable to even slight changes to their remaining occupied habitat.

C. 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 salt cedar 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). Although saltcedar control efforts are ongoing, they have been inadequate to eliminate this highly invasive plant from the Brazos River basin and saltcedar continues to encroach on the Brazos River channel.

D. 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 drip irrigation 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.

E. 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 meters (m) (16.4 to 98.4 feet (ft)) 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 in much of the proposed 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 extensive due to the aridity of the area, 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.

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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

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

Headcutting- the erosion of rock and soil from a stream at its headwaters or origin in the opposite direction that the stream flows

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

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

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 paths 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 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 male 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

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 materials 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 plants 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