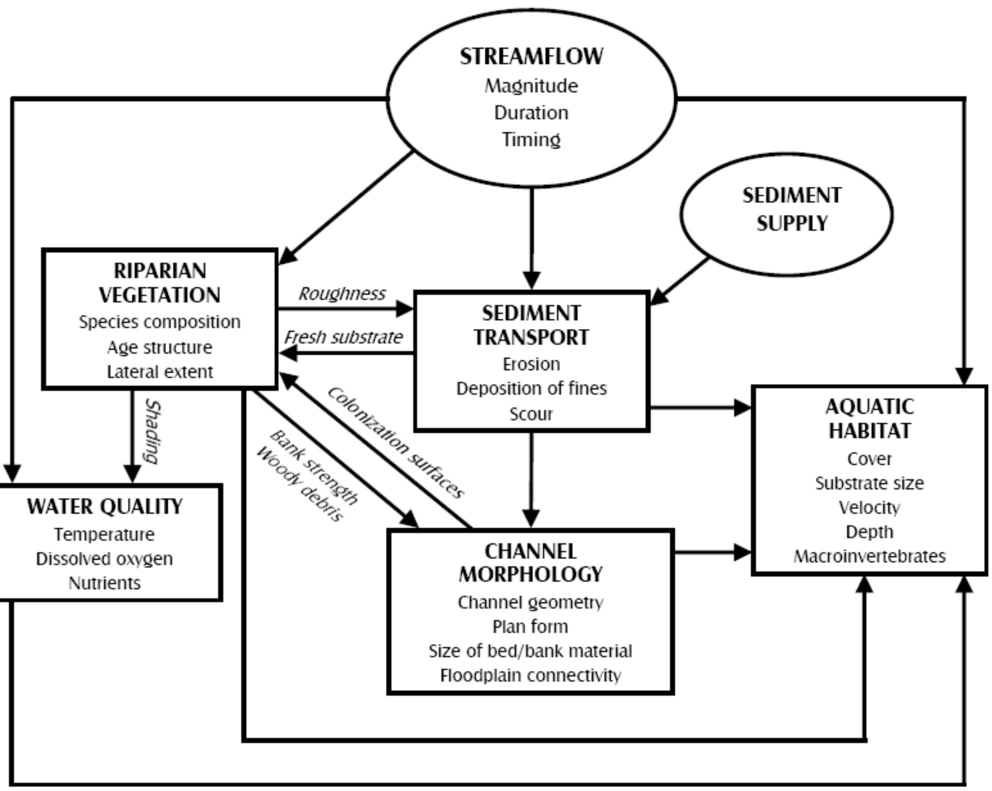
Fluvial Focal Species Summary Report

For the

Sabine/Neches BBEST

Ecological Information to Support Environmental Flow Recommendations



Submitted to:

Sabine/Neches BBEST

Prepared by:

BIO-WEST, Inc.
1812 Central Commerce Court
Round Rock, Texas 78664

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1.0 INTRODUCTION

The magnitude, timing, and duration of instream flows play a key role in the functioning of riverine ecosystems. In 2007, the Texas Legislature passed Senate Bill 3, directing the development of environmental flow recommendations for both an instream flow regime and for a complete freshwater inflow regime to protect a "sound ecological environment" and to maintain the productivity, extent, and persistence of key aquatic habitats in the state (SAC 2009).

This document provides a summary of ecological information on focal aquatic and riparian species within the Sabine River and Neches River watersheds to support instream flow recommendations by the Sabine/Neches Basin and Bay Expert Science Team (BBEST). As noted in SAC (2009), flow regimes largely determine the quality and quantity of physical habitat available to aquatic organisms in rivers and streams as well as the physical and chemical conditions of that environment.

The purpose of this report is to summarize information for select focal species regarding:

- Basic life history and ecological information including environmental requirements for reproduction and recruitment into adult populations and habitats used by various life stages
- Spatial and temporal trends in population abundance or biodiversity within the basins (where available)
- Key relationships between flow variation and the ecology of the species at the individual or population level

Selection of focal species was conducted in conjunction with members of the Sabine/Neches BBEST Biology Subcommittee, as described in Section 2.0. In preparing this document, previous reports on environmental flows were reviewed in addition to a large collection of scientific literature on the Sabine and Neches Rivers and associated watersheds. Much of this information was already compiled in three separate locations: 1) a reference library of pertinent documents compiled and provided by the Sabine-Neches BBEST; 2) an extensive list of documents pertaining to the Neches and Angelina Basins provided by Dr. Matthew McBroom and colleagues from Stephen F. Austin State University (SFASU); and 3) the database compiled to support the ongoing FERC relicensing process at Toledo Bend Dam provided by Sabine River Authority (SRA) of Texas. In addition to these sources, an extensive collection of life history information on the selected focal species was also compiled and reviewed. Information regarding the life history, habitat, and flow requirements of several of the focal species was abundant in the literature, whereas data for others was sparse. Regardless, available data on the life history of each focal species is summarized in Section 3.0. Section 4.0 provides a synthesis of ecology-flow relationships from the 18 focal species identified, along with comments on the temporal and spatial distribution of flows critical for each.

Sabine and Neches River Systems

The Sabine River is formed by the junction of Cowleech Fork, Caddo Fork, and South Fork Creeks in southwestern Hunt County. It flows for approximately 555 miles before emptying into Sabine Lake near Orange, Texas. Average annual rainfall within the basin ranges between 37 inches at its source to 50 inches at its mouth. As a result of the abundant rainfall in this portion of the state, the Sabine discharges more water than any other Texas river. Three major reservoirs have been constructed in the Sabine basin. Lake Tawakoni, which sits at the junction of the South and Cowleech Forks, was completed in 1960 and impounds 936,200 are-feet of water used for municipal, industrial, and irrigation supply. Toledo Bend Reservoir, on the Texas-Louisiana border, was completed in 1969 and has a storage capacity of 4,472,900 acre-feet used for electric generation, recreation, and water supply. Lake Fork, located on Lake Fork Creek in the upper basin, was completed in 1980 for municipal and industrial use, and stores 675,819 acre-feet at conservation pool.

The Neches River, begins in eastern Van Zandt County and flows southeast for approximately 416 miles before emptying into Sabine Lake near Port Arthur, Texas. Two major reservoirs are located on the Neches River. Lake Palestine was completed in 1962, and enlarged in 1972. It has a storage capacity of 411,290 acre-feet. B.A. Steinhagen Reservoir, located between Jasper and Woodville, is used for municipal water supply, flood control, and electric generation. The Angelina River joins the Neches just above B.A. Steinhagen, and drains approximately one-third of the basin area. Sam Rayburn Reservoir is located on the Angelina River, and impounds 3,997,600 acre-feet. It is used for electric generation, municipal, industrial, agricultural, and recreational purposes.

Together the Sabine and Neches Rivers drain almost 20,000 square miles in eastern Texas. The diversity of fishes and aquatic organisms found in this region is higher than anywhere else in the state. Additionally, the rivers, streams, and reservoirs of this region serve important functions by providing water supply, electric generation, and recreational opportunities to local residents.

2.0 FOCAL SPECIES SELECTION

Eighteen riverine focal species were chosen to support environmental flow recommendations of the Sabine/Neches BBEST. The list of focal species was collectively identified by BIO-WEST, Inc. (BIO-WEST) in collaboration and coordination with the Biological Subcommittee of the Sabine/Neches BBEST, and state agency personnel involved in the Texas Instream Flow Program (TIFP). Expert opinion on freshwater mussels was also gathered from researchers at local universities (Dr. Neil Ford, UT-Tyler; and Charles Randklev, University of North Texas). Focal species included 14 fish taxa, two mussel species, and two floodplain vegetation species (**Table 1**). An attempt was made to select species which are known to be flow-dependent, use a variety of habitats, and exhibit multiple feeding and reproductive strategies. Special consideration was given to species of conservation concern, and economically important sport fish.

Table 1. Focal riverine/floodplain species identified to support instream flow recommendations of the Sabine/Neches BBEST.

Common Name	Scientific Name	River/Trib/Floodplain	Unique Distribution in Texas	Species of concern	Sportfish
paddlefish	*Polyodon spathula*	River	Limited	Yes	--
white bass	*Morone chrysops*	River	--	--	Yes
flathead catfish	*Pylodictis olivaris*	River	--	--	Yes
shoal chub	*Macrhybopsis hyostoma*	River	--	--	--
emerald shiner	*Notropis atherinoides*	River	--	--	--
blue sucker	*Cycleptus elongatus*	River	Limited	Yes	--
spotted bass	*Micropterus punctulatus*	River/Tributary	--	--	Yes
dusky darter	*Percina sciera*	River/Tributary	--	--	--
sabine shiner	*Notropis sabinae*	River/Tributary	East TX	--	--
harlequin darter	*Etheostoma histrio*	Tributary	East TX	--	--
freckled madtom	*Noturus nocturnus*	Tributary	East TX	--	--
ironcolor shiner	*Notropis chalybaeus*	Tributary	East TX	Yes	--
alligator gar	*Atractosteus spatula*	River/Floodplain	--	Yes	--
black/ white crappie	*Pomoxis spp.*	River/Floodplain	--	--	Yes
Texas pigtoe	*Fusconaia askewi*	River/Tributary	East TX	Yes	--
pistolgrip	*Tritogonia verrucosa*	River/Tributary	--	--	--
overcup oak	*Quercus lyrata*	Floodplain	East TX	--	--
water tupelo	*Nyssa aquatica*	Floodplain	East TX	--	--

3.0 SABINE-NECHES ESTUARY FOCAL SPECIES

3.1 Fish Focal Species

The magnitude, timing, and duration of flows are critical to the life cycle of riverine fishes. Such species have evolved to natural patterns in flow variability which creates a diversity of hydraulic habitats. Habitat diversity is important given that some species use shallow backwater habitats during larval and juvenile periods, but may shift to occupying swift riffles and runs as adults. Timing of flow related events are also important. Some species require high flows during spawning periods to initiate upstream migration to spawning areas. In contrast, low flows which provide ample amounts of backwater habitats may be important during certain time periods for successful recruitment and growth of juvenile fishes.

This section describes the life histories of the 18 focal species listed above (see Section 2.0), and attempts to elucidate any relationships between the ecology and these species and the magnitude and timing of flow events.

3.1.1 Paddlefish (*Polyodon spathula*)

Paddlefish *Polyodon spathula* were historically distributed throughout the Mississippi River drainage as far north and east as the Great Lakes Region and westward in the Missouri River system to Montana. They also occur in several large Gulf Coast drainages adjacent to the Mississippi, including the Trinity, San Jacinto, Neches, Angelina, Sabine, Cypress, Sulphur, and Red River drainages of eastern Texas. Paddlefish numbers have declined throughout their range over the last century due to overexploitation, river channelization, and reservoir construction which can submerge spawning grounds and block migration routes. In Texas, the species was extirpated from the San Jacinto River by the 1950's, and population declines had been observed in other drainages. As a result, TPWD classified the species as endangered in 1977 (Betsill 1999). The Sabine and Neches Rivers once supported commercial fisheries for paddlefish. However, now paddlefish populations are thought to be limited to the Neches River below B.A. Steinhagen reservoir (Pitman 1991), and an artificially supplemented population in Toledo Bend Reservoir.

Paddlefish typically inhabit deep slow-moving habitats within large rivers (>40 m wide, average depth >1 m) and reservoirs during the majority of the year (non-spawning period). In large rivers, they are often found in deep areas (2-15 m) of backwaters and lakes connected to the main channel which provide current velocity refuges and better feeding opportunities (higher zooplankton densities) (Southall and Hubert 1984). In natural riverine corridors, these habitats are created by deep eddies behind gravel bars and connected oxbows. In modified rivers, paddlefish often use deep eddies and backwaters created by wing dams and other man-made structures (Southall and Hubert 1984). Main channel habitats are typically used only for moving between feeding areas, and for upstream spawning migrations in the spring. Self-sustaining paddlefish populations also occur within some large reservoirs where there is sufficient spawning habitat found in the inflowing rivers (Paukery and Fisher 2001). Within these reservoirs, paddlefish prefer open water over shallow littoral areas.

Large adult paddlefish can obtain weights up to 90 kg (≈200 lbs.) and lengths up to 213 cm (84 in) (Pitman 1991). Females typically weigh more than males due to their large ovaries which can make up 18% of total body weight when ripe (Pitman 1991). Growth is typically fast within the first four years of life and slows thereafter. In northern waters, paddlefish can live up to 55 years, but maximum age is approximately 14 years in southern climates such as Texas (Paukery and Fisher 2001). Paddlefish require 7-10 years to reach sexual maturity (Betsill 1999, Winemiller et al. 2005). Paddlefish feed by filtering zooplankton from the water using their finely spaced gill rakers. The long rostrum is thought to function as a sensory organ to aid in locating food, and as a stabilizer to keep the fish from nosediving due to the drag caused by water entering the open mouth during feeding (Pitman 1991).

Paddlefish spawn over relatively deep silt-free gravel bars of at least one meter deep (>4 m optimum) in rivers from February through June at water temperatures of 12-21˚C (Southall and Hubert 1984, O'Keefe et al. 2007). Fish may migrate long distances upstream (up to 240 km) to reach specific spawning locations. Although annual changes in photoperiod and temperature initiate spawning migrations, actual spawning activity is associated with a sharp rise in flow (Pitman 1991). Spawning often takes place over gravel bars which were previously dry under lower flow conditions. If water levels drop, eggs and larvae can become stranded, and spawning is ceased until another rise in river level occurs (Purkett 1961). Females release demersal eggs into the upper water column which are externally fertilized by nearby males. Fertilized eggs become adhesive and stick to the substrate. Paddlefish eggs hatch in 7-12 days depending on temperature, and larvae drift downstream as they develop. Although male paddlefish are capable of annual spawning, evidence suggests that wild female paddlefish require two or more years to develop mature ova, and therefore, do not spawn every year (Pitman 1991).

Paddlefish are a large-river fish whose life cycle is strongly tied to instream flows. They require deep, slow-moving, zooplankton-rich backwaters, oxbow lakes, or reservoirs in which to feed throughout the year (Pitman 1991). Perhaps even more important from an instream flow perspective are high flow pulses during early spring months (February through April) to stimulate upstream migration and spawning. These pulses should be of significant duration (at least 7 days) to ensure successful hatching of eggs and dispersal of larvae before water levels recede.

3.1.2 Blue sucker (*Cycleptus elongatus*)

The blue sucker *Cycleptus elongatus* is a large long-lived catostomid native to large rivers of the Mississippi Basin and occurring sporadically in some Western Gulf Slope drainages of Texas including the Sabine and Neches. Commercial harvest records from the Mississippi River indicate that the blue sucker was once abundant; however, they are now considered rare throughout most of their range and have been listed as threatened or endangered by several agencies including TPWD which has listed the species as threatened. Considerable taxonomic changes have occurred within the genus *Cycleptus* in recent years and have resulted in designation of two new species. The southeastern blue sucker *Cycleptus* *meridionalis,* was recently recognized from Eastern Gulf Slope drainages of Alabama, Mississippi, and Louisiana (Burr and Mayden 1999). Additionally, recent molecular analyses have confirmed earlier suspicions based on morphology (Burr and Mayden 1999) that the Rio Grande *Cycleptus* population is divergent from *C. elongatus* populations in the Mississippi River and other western Gulf Slope drainages. A formal species description is currently being conducted for this species (Bessert 2006). Populations in the Sabine and Neches drainages are still recognized as *C. elongatus*.

Due to their specific habitat requirements and resulting collection difficulties, blue suckers are not particularly abundant in fish collections from the Sabine and Neches drainages. However, they have recently been confirmed from both the main-stem Sabine River (SRA et al. 2007) and the main-stem Neches (University of Texas at Tyler collections). Blue suckers are a large river fish which are rarely captured in smaller tributaries. However, blue sucker spawning was observed in the lower portions of Onion Creek, a tributary of the lower Colorado River (BIO-WEST 2007).

Blue suckers occupy deep high-velocity habitats over firm substrates (Rupprecht and Jahn 1980, Vokoun et al. 2003). In the lower Colorado River, Texas, adult blue suckers were fairly common in deep fast rapids over gravel, cobble, boulder, and bedrock substrates. They were most abundant at depths of 2.6 to 4.6 feet, and velocities of 2.0 to 3.3 ft/s. Blue suckers were the only species collected in abundance in these deep high-velocity rapids (BIO-WEST 2008).

Blue suckers feed on aquatic insects, mainly Trichopteran and Dipteran larvae and pupae, and can grow to over 800 mm (31.5 in) total length (Peterson et al. 1999, Moss et al. 1983, Cowley and Sublette 1987). Age and growth studies of blue suckers have yielded varying results. Previous studies using scale-aging have suggested that blue suckers live anywhere from 9-22 years (Rupprecht and Jahn 1980, Moss et al. 1983, Vokoun et al. 2003, Morey and Berry 2003). However, scale-aging is thought to underestimate the ages of large fish, and examination of annuli on opercular bones has suggested that southeastern blue suckers reach ages of 30+ years (Peterson et al. 1999, Burr and Mayden 1999).

Reproduction occurs in the early to late spring at temperatures of 12 – 20˚C when blue suckers migrate to spawning riffles where their adhesive eggs are deposited on the substrate (Moss et al. 1983, Semmens 1985, Peterson et al. 2000, Boschung and Mayden 2003, Mettee et al. 2003, Vokoun et al. 2003). In some instances, these migrations can cover distances of over 150 miles (BIO-WEST 2007). However, in the lower Colorado River, Texas, long migrations were only observed under extremely high-flow conditions. In years with low spring flows, blue suckers spawned on or near their "home riffles" (BIO-WEST 2007).

In the Colorado River study, seven different blue sucker spawning locations were identified from spring 2005 through spring 2007. Spawning was documented at three of these locations in more than one year. Spawning was typically witnessed from early February through early March at temperatures of 14-15˚C. Spawning blue suckers were most common in habitats ranging from 1.0 -2.3 ft deep with velocities of 1.0 – 3.0 ft/s and cobble or bedrock substrates (BIO-WEST 2007). Eggs hatch in about 6 days (Semmens 1985). Although larval blue suckers have occasionally been collected in backwater and off-channel habitats (Fisher and Willis 2000, Adams et al. 2006), information on the ecology of young blue suckers is limited because juveniles are rarely collected (Morey and Berry 2003).

Due to the specific habitat affinities of blue suckers, sufficient instream flow to maintain at least some deep high-velocity rapids throughout the year is important. However, perhaps even more important, especially given recruitment concerns in some areas, is maintenance of adequate amounts of spawning habitat in early spring months. High flow pulses in the January through March period may also be important to stimulate upstream migrations. However, the complex relationship between flow, migration, and recruitment is poorly understood.

3.1.3 Shoal chub (*Macrhybopsis hyostoma*)

The species complex previously known as the speckled chub *Macrhybopsis aestivalis* is distributed throughout the Mississippi River drainage and Gulf Coastal drainages from the Choctawhatchee River in Florida to the Rio San Fernando in Mexico. However, recent analysis has split this complex into five species west of the Mississippi River (Eisenhour 2004). As a result of this work, the species inhabiting the Sabine and Neches Rivers has been reclassified as the shoal chub *M. hyostoma.* Since all *Macrohybopsis* species have similar life histories and exhibit similar habitat utilization, life history information presented herein refers to several species within the *Macrhybopsis* complex.

Shoal chubs are absent from collections taken in large tributaries to the Neches such as Village Creek (Moriarty and Winemiller 1997) and Pine Island Bayou (Kleinsasser and Linam 1987), demonstrating their affinity for large river habitats. They are present in collections from the main-stem Sabine River below Toledo Bend dam (SRA et al. 2007), and are thought to be common in the upper Sabine basin (Bart 2008). They are presumed present in the main-stem portions of the Neches River. However, they were not captured at three sites from the lower Neches sampled between 1999 and 2001 (USGS 2003). Recent analysis by Bonner and Runyan (2007) and Bart (2007) suggest that populations of shoal chubs in the lower Sabine River have declined in recent decades, although neither speculated on the causes of such declines.

M. hyostoma inhabit moderate to swift flowing waters over sandy and gravelly substrates in large rivers. In the Arkansas River basin, they prefer current velocities of 0.2 – 0.4 m/s and substrate composed of 60-90% pea-sized gravel with moderate compaction (Luttrell et al. 2002). In the Brazos River, *M. hyostoma* were most common in waist to chest deep water during the day, and seemed to move shallower at night (C.S. Williams, personal communication).

Shoal chubs are a small, short-lived species which reaches a maximum size of 76 mm over a life span of 1-2 years (Eisenhour 2004, Starrett 1951). They are a benthic-oriented fish which use taste buds located on their head, body, fins, and small barbels to feed along the bottom of turbid rivers. Food consists of aquatic insects, small crustaceans, and some plant material (Robison and Buchanan 1988). Bonner and Wilde (2002) found that *M. tetranema* from the Canadian River were well adapted to feeding under turbid conditions, and that prey consumption was not significantly affected by turbidities ranging from 0-4000

NTU. In the Brazos River, shoal chubs spawn from late March/early April through September/November depending on flows (Williams, in press). Nonadhesive semibouyant eggs (Platania and Altenbach 1998) develop as they drift in the current, hatching in about 25-28 hours (Robison and Buchanan 1988). Spawning is thought to occur during high flow pulses which prevent eggs and weak-swimming larvae from settling to the bottom and becoming buried (Bonner and Wilde 2000). Depending on channel morphology and current velocity, eggs can drift long distances (estimates up to 144 km) before hatching, and therefore, long stretches of unimpounded river may be required for successful reproduction (Platania and Altenbach 1998). A significant reduction in mean annual discharge, reduced frequency of flood events, and decreased turbidity levels seem to have extirpated *M. tetranema* in the Canadian River below Lake Meredith (Bonner and Wilde 2000, Bonner and Wilde 2002).

Studies suggest that perhaps the most important factor influencing *Macrhybopis* populations is maintenance of long stretches of uninterrupted flow in large turbid river systems to allow sufficient time for drifting eggs and larvae to mature. From a timing and magnitude standpoint, pulse events during typically low flow summer months may be important in initiating reproduction. Although maintenance of sand and pea-gravel run habitats are important for the species, this habitat is likely maintained in the Sabine and Neches mainstems under all but extremely low flow conditions.

3.1.4 Sabine shiner (*Notropis sabinae*)

Sabine shiners are a small stream-dwelling cyprinid fish with a somewhat limited distribution found in Gulf Coast drainages from the San Jacinto River of Texas east to the Big Black and Yazoo drainages of Mississippi. A disjunct population also occurs in three rivers in northern Arkansas and southern Missouri (Robison and Buchanan 1988, Williams and Bonner 2006). In the Sabine and Neches drainages, this species is relatively abundant in tributary and main-river habitats, and is known to be common in Village Creek (Neches drainage; Moriarty and Winemiller 1997), Banita Creek and LaNana Bayou (Angelina drainage; Williams and Bonner 2006), and the lower Sabine River (Bart 2008, Bonner and Runyan 2007). Evidently, the species is also found in low numbers in Toledo Bend Reservoir (LDWF). Although Sabine shiners are considered rare or uncommon due to their restricted range in Louisiana, Mississippi, and Arkansas (Williams and Bonner 2007), recent analysis by Bart (2008) suggests that *N. sabinae* populations may actually be increasing in the lower Sabine River and its tributaries.

Sabine shiners are typically collected in shallow flowing water, and are relatively uncommon in backwater and pool areas. Within these shallow runs and riffles there is often segregation among adult and juvenile fish, with juveniles occupying the shallower silty areas along the edges while adults occupy sandier areas near mid-channel. Although not exclusively found over sand, Sabine shiners do exhibit an affinity for sandy substrates (Moriarty and Winemiller 1997, Williams and Bonner 2006, Williams and Bonner 2007).

Sabine shiners obtain a maximum size of approximately 64 mm over a life span of 2.5 years. They are a benthic-oriented species which feeds primarily on detritus and benthic invertebrates (mainly Diptera and Ephemeroptera larvae). Depending on location, spawning occurs from April or May through September or October. Individual females may spawn multiple cohorts of eggs over this extended spawning season. Eggs and larvae are thought to drift downstream as they develop, resulting in higher abundance of age-0 fish in downstream locations. As a result, structures which disrupt stream connectivity and block upstream migrations of juvenile and adult fish may negatively impact this species (Heins 1981, Williams and Bonner 2006, Williams and Bonner 2007).

Maintenance of stream connectivity and natural flow regimes are both identified as important for the conservation of this species (Williams and Bonner 2007). However, no detailed analysis of the instream flow requirements of this species has been conducted. This species does not inhabit particularly deep or swift habitats, and therefore, high flows are likely not crucial from a habitat perspective. However, maintenance of some flow over shallow sandy runs is important to provide habitat for this species, especially during the summer reproductive season. Also, periodic flushing-flows may be important to prevent siltation of sandy run habitats. High flow pulses in winter and spring may serve as stimulus for upstream migration of adults to counteract downstream dispersal of eggs and larvae.

3.1.5 Alligator gar (*Atractosteus spatula*)

The alligator gar is a large, long-lived, predatory fish which ranges throughout the Mississippi River system, as well as coastal rivers of the Gulf of Mexico from Florida to northern Mexico (Buckmeier 2008). In Texas, they occur in coastal streams from the Red River to the Rio Grande (Hubbs et al. 2008). Alligator gar are found in large rivers, reservoirs, oxbow lakes, and coastal bays and estuaries. They are documented in recent collections from the lower mainstem Sabine and Neches Rivers, as well as Village Creek (USGS 2003, SRA et al. 2007). They are most likely absent from smaller tributary streams. Alligator gar populations are declining throughout their range mostly due to fishing pressure and habitat alteration. Along with declining populations a shift in size structure to smaller individuals has been seen. As a result, management regulations have recently been implemented in several Southeastern states, including Texas. TPWD is currently conducting several studies to learn more about Texas alligator gar populations (Ferrara 2001, Buckmeier 2008). The species is listed as vulnerable by the American Fisheries Society.

Alligator gar can grow up to 10ft in length and reach weights exceeding 300 pounds over a life span of 30-50 years (Buckmeier 2008). They are opportunistic predators which feed on fish, invertebrates, and even birds. Due to their large size, adult alligator gar often prey on relatively large fish (>20 cm)(Goodyear 1967). Alligator gar spawn from April to June during spring flooding of vegetated backwater areas, oxbow lakes, and bottomland swamps (Buckmeier 2008, Ferrara 2001). They are non-guarding open substrate spawners with adhesive eggs that stick to plant materials. Larval fish have special cement glands that allow them to attach to plants or other substrate while developing (Simon 1999). Data from the Brazos River suggests that juveniles tend to remain in off-channel spawning areas such as oxbow lakes, while large adults are typically captured from the main river (Robertson et al. 2008). Alligator gar mature at 950-1400 mm total length which takes 10-14 years (Buckmeier 2008, Ferrara 2001).

Preferred habitat of alligator gar is deep slow-moving pools within the main channel of large rivers, as well as backwater areas and oxbow lakes. High flow pulses in spring months are critical to provide a connection between off-channel oxbows and the main river. Such floodplain habitats provide optimum conditions for recruitment and growth of juveniles.

3.1.6 White/black crappie (*Pomoxis annularis* and *P. nigromaculatus*)

Crappie are a widespread and popular gamefish that naturally occurred throughout the central and eastern U.S. including portions of Texas. Due to their popularity as a gamefish, and their high regard as a food fish, crappie have been introduced in ponds and reservoirs throughout North America, greatly expanding their range. There are two species of crappie – white crappie (*Pomoxis annularis*) and black crappie (*Pomoxis nigromaculatus*). White crappie can tolerate higher turbidity, and are thus more widespread in Texas. However, given that the two species occupy similar habitats, and exhibit similar life history traits, they will be treated collectively for this summary. In the Sabine and Neches drainages, both species are common to abundant in oxbow lakes, river mainstems, and lower reaches of major tributaries (Evans and Noble 1979, Kleinsasser and Linam 1987, Linam and Kleinsasser 1987, McCarty 1987, Moriarty and Winemiller 1997, Robbins 2000, USGS 2003, SRA et al. 2007), but are typically absent from smaller tributary streams (Rogers 1994, Kelly 1999, Geeslin 2001). Crappie populations also provide an extremely popular fishery in reservoirs within the Sabine and Neches basins (**Table 2**).

Crappie are most numerous in deep slow-moving pools, backwaters, oxbow lakes, and reservoirs, where they are often associated with submerged trees, brush, aquatic vegetation, or other cover (Edwards et al. 1982). They are typically absent from swift flowing portions of rivers and streams. Adults often suspend in deep water during most of the year, but move shallow to spawn during spring months.

Table 2. Ratings of crappie fisheries in each of the major reservoirs in the Sabine and Neches River basins based on information posted on the TPWD website.

River Basin	Reservoir	Rating	Comments
Angelina	Sam Rayburn	EXCELLENT	Year-round fishery
Neches	B.A. Steinhagen	GOOD	Best in spring
Neches	Palestine	GOOD	-
Sabine	Tawakoni	FAIR	Limited habitat
Sabine	Fork	EXCELLENT	-
Sabine	Toledo Bend	GOOD	Year-round fishery

Crappie have an average life span of 7-9 years, and can attain weights of 2.7 kg (≈6 lbs.). Young crappie (<150 mm) feed mainly on zooplankton and aquatic insects, whereas larger fish (>150 mm) are mostly piscivorous and feed mainly on small gizzard shad (*Dorosoma cepedianum*) (Edwards et al. 1982, Reid 1949, Muoneke et al. 1992). Where there is limited forage in the way of small fish, crappie >150mm will remain planktivorous and insectivorous, resulting in reduced growth rates and stunting of the population (Muoneke et al 1992, Obrien et al 1984). Spawning begins when the water temperature reaches 13-14°C, but peaks at 14-16˚C (Edwards et al 1982, Obrien et al 1984). This usually occurs from February through April in Texas. Males construct and guard nests in calm shallow water protected from the prevailing wind. Nests can be found over a variety of substrates, but usually occur in close proximity to some type of cover such as brush piles, submerged vegetation, or tree roots. Eggs are often attached to submerged vegetation and are closely guarded until hatching.

In the Brazos River system, white crappie were abundant in oxbows, but were uncommon in the main river channel. Periodic flooding resulted in a net movement of fish biomass from the oxbows to the river channel (Winemiller et al. 2004). Results suggest that oxbow lakes provide optimum conditions for crappie recruitment and growth, but that periodic connections with the main river were important for dispersal. Additionally, limited crappie populations in the river provide a source stock for recolonization of oxbows which occasionally dry up during extended periods without significant pulse events. Therefore, periodic connections between river and floodplain habitats such as oxbow lakes are an important component in sustaining crappie populations in lowland rivers.

3.1.7 White bass (*Morone chrysops*)

The white bass is a "true bass" (Family Moronidae) which is widespread throughout the Ohio and Mississippi River drainages of the central U.S. and has been widely introduced into reservoirs throughout Texas (Hubbs et al. 2008). In the Sabine and Neches drainages, white bass are mainly found in the major reservoirs and river segments immediately above or below these reservoirs, where they are a popular gamefish. They were present in low abundance from recent collections in the lower Neches River below B.A. Steinhagen (USGS 2003), and were absent from recent collections in the lower Sabine River (SRA et al. 2007). Table 3-2 summarizes information on white bass fisheries in each of the major reservoirs in the Sabine and Neches basins taken from the TPWD website.

White bass are habitat generalists typically encountered in large schools roaming pelagic areas of reservoirs. They are site feeders (Greene 1962) which feed heavily on shad (*Dorosoma* spp.) and other small fishes (Bonn 1952, Voigtlander and Wissing 1974, Van Den Avyle et al. 1983, Matthews et al. 1992). White bass typically live 4-5 years and reach lengths of 17-20 inches and weights approaching 5 lbs.

Table 3. Ratings of white bass fisheries from each of the major reservoirs in the Sabine and Neches River basins based on data posted on the TPWD website.

River Basin	Reservoir	Rating	Comments
Angelina	Sam Rayburn	FAIR	Limited numbers, but good fishing in spring
Neches	B.A. Steinhagen	POOR	Low numbers, fishery limited to early spring
Neches	Palestine	EXCELLENT	Popular in spring up Neches and Kickapoo Creek
Sabine	Tawakoni	EXCELLENT	Vital to local economy
Sabine	Fork	-	-
Sabine	Toledo Bend	FAIR	-

In spring (February through May in Texas), when water temperature is approximately 12-20˚C, white bass migrate from deep water reservoir habitats into flowing rivers and streams, where they spawn. Males typically migrate before females. Spawning takes place in relatively shallow flowing water (<3 m) and demersal adhesive eggs slowly sink to the bottom. Larvae hatch in 2-3 days (Mettee et al. 1996). If flowing streams are not accessible, white bass will also spawn on wind-swept points within a reservoir (Bonn 1952). In Texas, fishing the white bass "run" is extremely popular during spring months as large numbers of fish migrate into shallow confined areas of rivers and streams to spawn.

White bass are mainly reservoir inhabitants which are not directly affected by instream flows the majority of the year. However, maintaining at least moderate amounts of inflow into reservoirs during spring spawning season is important to provide adequate spawning habitat, and to provide fishing opportunities for anglers. This is especially important in popular fisheries such as Lake Palestine and Lake Tawakoni given the impact to local economies. Additionally, years of high spring inflows, and resulting high water levels in reservoirs, often leads to increased recruitment and growth of young white bass (Bonn 1952).

3.1.8 Dusky darter (*Percina sciera*)

The dusky darter is a fairly widespread species found in moderate to large streams within the Mississippi River drainage as far north as Illinois, Indiana, and Ohio, and in Gulf of Mexico drainages from the Mobile Bay system in Alabama south and west to the Guadalupe River in Texas (Page 1983). In the Sabine and Neches basin it is relatively common, and has been documented by several collections (Evans and Noble 1979, Kleinsasser and Linam 1987, Rogers 1994, Moriarty and Winemiller 1997, Kelly 1999, USGS 2003). Dusky darters are most common in the larger tributary streams, but are also found in main river collections (SRA et al. 2007). They are typically absent from collections in small headwater streams within the Sabine and Neches basins (Geeslin 2001).

Dusky darters usually occur in swift riffles and raceways over gravel substrates, and are often associated with some type of cover such as boulders or logs (Miller and Robison 1973). In the lower Colorado

River, Texas, dusky darters exhibited similar habitat utilization to other riffle-associated species such as: Texas logperch *Percina carbonaria*, suckermouth minnow *Phenacobius mirabilis*, orangethroat darter *Etheostoma spectabile*, central stoneroller *Campostoma anomalum*, burrhead/shoal chub *Macrhybopsis spp.*, and juvenile channel catfish *Ictalurus punctatus* (BIO-WEST 2008).

The dusky darter is a fairly large darter which obtains a maximum size of approximately 110 mm over a life span of 3-4 years. They feed on a variety of aquatic insects including midge, black fly, caddisfly, and mayfly larvae (Page 1983, Robison and Buchanan 1988), and are classified as a benthic invertivore by Goldstein and Simon (1999). In the Colorado River near Austin, Texas, dusky darters spawn from February through June over gravelly substrates (Hubbs 1961). They are classified as a brood hider and lithophil meaning they hide their eggs with benthic larvae beneath stones but do not take care of them. Eggs and larvae of dusky darters can survive at temperatures between 22 and 27˚C (Hubbs 1961).

Due to the preference of this species for shallow riffle habitat, dusky darters are considered flow-sensitive. Specific flow-related requirements of *P. sciera* include maintenance of sufficient flow to create swift riffle habitat over gravel bars and other areas of channel constriction. Maintenance of such habitat may be especially critical during the February through June spawning season.

3.1.9 Flathead catfish (*Pylodictis olivaris*)

The flathead catfish is a large ictalurid native to medium to large rivers and reservoirs in the Mississippi, Ohio, and Missouri River drainages as well as Western Gulf Slope drainages of Texas. They have also been introduced into several locations outside their native distribution, where the resulting impact on native fishes is a major concern (Brown et al. 2005). In the Sabine and Neches Rivers, flathead catfish likely inhabit all the major reservoirs, larger tributaries (Moriarty and Winemiller 1997, Kleinsasser and Linam 1987), and main river segments (SRA et al. 2007).

Habitat utilization by flathead catfish changes considerably as they grow. Young-of-the-year are typically found in swift shallow riffles with large cobble and boulder substrates. Juveniles of 4-16 inches in length distribute among a variety of habitats at intermediate depths. Adults are solitary and are most common in deeper areas around slow to moderate current and heavy cover such as rocks, riprap, or submerged logs (Minkley and Deacon 1959).

Flathead catfish can obtain weights approaching 100 pounds over a life span of approximately 20 years. Sexual maturity is reached in approximately 2-5 years at sizes of 15-20 inches. Small young-of-the-year catfish feed almost exclusively on aquatic insects. However, fish and crayfish gradually become more important in the diet as the fish grow. Large solitary adults feed mainly at night on live fish and crayfish. They are sedentary nocturnal predators which exhibit little movement (Vokoun and Rabeni 2006) and feed by ambushing prey. Spawning occurs in June and July when parents construct a nest in a natural cavity in the bank or under a boulder. Females may lay up to 100,000 eggs which are guarded by the male. After hatching the young catfish form a compact school for a few days before dispersing (Minkley and Deacon 1959, Robison and Buchanan 1988, Munger et al. 1994, Mettee et al. 1996).

Due to their large size and high regard as a food fish, flathead catfish are a popular sport fish in Texas. In fact, they were the preferred sport fish of 30,000 Texas anglers in a 1987 survey (Munger et al. 1994).

Flathead catfish do not make large migrations, and adults have relatively general habitat requirements. The most important flow-related requirement of flathead catfish is maintenance of riffle habitat for juveniles. This is especially important during post-spawn summer and fall months.

3.1.10 Emerald shiner (*Notropis atherinoides*)

Emerald shiners are widely distributed along the Gulf Coast from Alabama to Texas, northward throughout the Mississippi River drainage to the Great Lakes Region, and well into Canada. The Sabine and Neches Rivers are near the southwestern edge of the species' range, which is the Trinity River basin. In the Neches drainage, *N. atherinoides* is commonly collected from the mainstem river as well as the larger tributary streams (Rogers 1994, Kelly 1999, USGS 2003). Although the species has never been particularly abundant in the lower Sabine River, it is absent from recent collection there (SRA et al. 2007), and was categorized as having a declining population trend by Bonner and Runyan (2007). However, Bart (2007) did not list the species as declining in the lower Sabine River.

Most life history information on emerald shiners has been collected in northern waters. In Canada, emerald shiners are found in large schools near the surface water of large open lakes and rivers (Campell and MacCrimmon 1970). They are considered a pelagic species that only occasionally moves inshore. They can live three to five years in northern waters, and reach sizes of 127 mm total length. In northern lakes and reservoirs, they feed mainly on zooplankton, but also consume insects, algae, and plant material. In northern climates, they reach sexual maturity after approximately one year, and broadcast spawn from June through August at temperatures of 20-23˚C over deep water (2-6 m). The nonadhesive eggs sink to the bottom and hatch in 24-36 hours (Fuchs 1967, Dillon and Myers 1990). Little life history information exists from southern riverine populations of *N. atherinoides*.

Given limited life history information, instream flow requirements of emerald shiners are speculative at best. In the southern part of their range, emerald shiners occupy large turbid rivers. Maintenance of deep run and pool habitats, especially during the summer spawning season, are likely important to the species.

3.1.11 Spotted bass (*Micropterus punctulatus*)

The spotted bass (*Micropterus punctulatus*) is native to the Mississippi and Ohio River basins extending east to northwestern Florida (Hubbs et al. 1991). In Texas, spotted bass occur in the eastern half of the state from the Guadalupe River basin northeastward to the Red River basin. In the Sabine and Neches, they are common to widespread in tributaries, and main river habitats, and have adapted well to reservoirs (SRA et al. 2007, ANS 2006, Kelly 1999, Moriarty and Winemiller 1997, Rogers 1994, Kleinsasser and Linam 1987, Evans and Noble 1979). Due to their preference for flowing waters, they are typically not captured in area oxbow lakes (Robbins 2000, Cowan 1998, McCarty 1987) where the closely related largemouth bass (*M. salmoides*) predominates. Based on analysis of lower Sabine River fish community data from 1948 through 2006, Bonner and Runyan (2007) suggested that abundance of spotted bass has increased in recent years.

Spotted bass are most abundant in clear to moderately turbid streams and rivers. Although the young can be captured from a variety of shallow water habitats, adult spotted bass typically inhabit deep runs and pools. They are more common in current than the largemouth bass, which prefers slow pools and other lentic areas (Ryan et al. 1970). Like most centrarchids, spotted bass use aquatic vegetation, submerged logs, rocks, and riprap for cover. They hide in thick cover and ambush prey, which includes aquatic insects, crayfish, and fish (Mettee et al. 1996, Robison and Buchanan 1988, Ryan et al. 1970, Smith and Page 1969).

Although typically smaller than largemouth bass, spotted bass obtain a maximum reported size of approximately 610 mm (24") total length over a life span of up to 11 years. Spawning occurs from April to June with water temperatures ranging from 17.2-25.6°C. Males make shallow nests, usually over rock or gravel substrate and guard them until the fry hatch (Hassan-Williams and Bonner 2009, Simon 1999, Mettee et al. 1996). Spotted bass often select dense cover such as brush piles for nesting (Vogele and Rainwater 1975). Eggs hatch in 2-5 days, and larvae remain in the nest area for 4-8 days (Hassan-Williams and Bonner 2009).

Spotted bass are a popular gamefish in Texas streams and reservoirs which can be very sporting on light tackle. However, they do not have particularly flow-sensitive life history or habitat requirements. Spotted bass often inhabit deep backwaters or eddies beneath swift flowing riffles and runs, where they move into current briefly to feed, and then move back into slack-water refuges. Maintenance of sufficient flow to maintain such habitat complexity is important.

3.1.12 Harlequin darter (*Etheostoma histrio*)

E. histrio is sporadically collected in tributaries of the lower Mississippi River drainage and adjacent Gulf Coastal drainages primarily below the Fall Line (Tsai 1968). In Texas, it occurs in small detritus-laden tributaries of the Cypress, Sabine, Neches, and Trinity Basins (Hubbs et al. 2008). Within collections from the Sabine and Neches drainages, harlequin darters are never particularly abundant, but are somewhat common in tributary streams (Rogers 1994, Moriarty and Winemiller 1997, Kelly 1999) and occasionally collected from main river habitats (SRA et al. 2007).

Although Tsai (1968) described harlequin darters as inhabitants of swift gravel riffles, Hubbs and Pigg (1972) suggested that harlequin darters in Texas and Oklahoma were typically captured over sand and detritus substrates. Although they were found near riffles that contained gravel, Hubbs and Pigg (1972) suggested they were typically captured along the edges over sand and logs and near fallen brush. They have also been described as inhabiting deep riffle detritus habitats (Page 1983).

Harlequin darters obtain a maximum size of 64 mm and live approximately 4 years. Their diet consists of benthic invertebrates such as midge, blackfly, caddisfly, and mayfly larvae. They spawn in February and

March (Hubbs 1985) by attaching adhesive eggs to submerged plants or detritus. Growth is relatively rapid, and females are able to spawn in their first year (Kuhajda and Warren 1989).

Instream flow-related habitat requirements of harlequin darters include maintenance of sufficient flow in tributaries to maintain riffle habitat and acceptable water quality conditions. These fish are not known to migrate long distances, although some authors have suggested that they may move to deep water of large streams during the breeding season (Kuhajda and Warren 1989).

3.1.13 Freckled madtom (*Noturus nocturnus*)

The freckled madtom is a small ictalurid distributed throughout the Mississippi basin as well as Gulf Coast drainages from Alabama to Texas. In Texas, they are limited to the eastern half of the state, from the Brazos River east and north to the Red River drainage (Hubbs et al. 1991). Within the Sabine and Neches Rivers, freckled madtoms are relatively common in collections from small to large tributaries, oxbow lakes, and main channel habitats (Evans and Noble 1979, Rogers 1994, Moriarty and Winemiller 1997, Cowan 1998, Kelly 1999, Robbins 2000, Geeslin 2001, USGS 2003, SRA et al. 2007).

Freckled madtoms are typically found in gravel riffles, often in association with complex habitat features such as sticks, root masses, submerged logs, and undercut banks. Individuals often find shelter in beverage cans (Hassan-Williams and Bonner 2009).

Freckled madtoms reach a maximum size of 138 mm standard length over a life span of 4.5 years. They feed on aquatic insect larvae such as mayflies, caddisflies, and midges. They are hole nesters (Simon 1999) which spawn in nests built in holes or cavities along the bank or under submerged debris in areas with some current and depths of 10-15 cm. Spawning takes place from May through July (Hassan-Williams and Bonner 2009).

Freckled madtoms are considered a fluvial specialist with a narrow range of habitat use. They are dependent upon complex riffle habitats. Sufficient instream flow to maintain riffle habitats in tributaries is important for maintaining populations of this species.

3.1.14 Ironcolor shiner (*Notropis chalybaeus*)

Ironcolor shiners are found in acidic lowland streams in parts of the Mississippi River drainage, and along the Gulf and Atlantic coasts from Texas to New York (Robison and Buchanan 1984, Mettee et al. 1996). In Texas, this species is reported as occurring only in far eastern and northeastern Texas streams from the Sabine River to the Red River, except for an isolated population in the headwaters of the San Marcos River (Hubbs et al. 2008). However, Kelly (1999) reported collecting three specimens from Piney Creek, a tributary of the Neches River within the Davy Crockett National Forest. Piney Creek was considered the least impacted stream in the ecoregion, and was the only stream out of ten sampled that contained *N. chalybaeus*. No specific information regarding collections of this species within the Sabine River drainage was located. Hubbs et al. (2008) listed *N. chalybaeus* as a species of "special concern", and it is considered "rare" in the Rare, Threatened, and Endangered Species of Texas Database maintained by TPWD.

Ironcolor shiners are often found in pools with moderate to sluggish current over substrates of sand, mud, silt, or detritus. It is usually associated with aquatic vegetation (Robison 1977). They obtain a maximum size of approximately 53 mm standard length over a life span of about two years. Ironcolor shiners are invertivore (Goldstein and Simon 1999) site feeders which feed on aquatic and terrestrial insects, small crustaceans, and filamentous algae. They spawn from March or April through September or October in Florida (Hassan-Williams and Bonner 2009). Adhesive demersal eggs are broadcast over sluggish pools with sand substrates (Robison and Buchanan 1988).

This species is most likely limited to small, swampy, low-gradient tributary streams within the Sabine and Neches basins and probably only uses mainstem habitats for occasional dispersion. Most of these smaller tributaries are unregulated and, excluding any with wastewater discharges or intense urbanization within the watershed, likely exhibit relatively natural flow regimes. Reproduction and recruitment by this species are probably not strongly affected by pulse flows, and it is speculated that low flows during summer months could potentially enhance recruitment by preventing disturbance of eggs and larvae (Winemiller et al. 2005). As a result of this species life history, watershed management practices which address urbanization, timber harvest, etc. may be more important than instream flow recommendations for preserving this species.

3.2 Freshwater Mussel Focal Species

Freshwater mussels of the family Unionidae occur worldwide. However, North America harbors the greatest number and diversity of these organisms, with nearly 300 species documented (≈51 species known from Texas). However, the combined effects of overharvesting, habitat alteration, and invasive species have made freshwater mussels one of the most endangered groups of organisms in North America (Morales et al. 2006, Howells et al. 1996).

Freshwater mussels are sessile long-lived organisms (30-100 yrs.) exhibiting complex life cycles. They are filter feeders which filter plankton, algae, and detritus from the water as it is circulated via incurrent and excurrent siphons. They are capable of limited movement by extending their muscular "foot" and dragging themselves through or along the substrate. However, dispersal is accomplished mainly through their unique reproductive strategy. To reproduce, males discharge sperm directly into the water. Sperm are inhaled by females during normal feeding and respiration. Fertilization of eggs takes place in brood pouches attached to the gills of the female. Fertilized eggs develop inside the female mussel into a larval stage known as the glochidium. Some individuals may retain glochidia for months, while others release them as soon after they develop. Microscopic glochidia are ultimately released into the water, where they drift in the current, and eventually attach to the fins or gills of fish. Parasitic glochidia may stay attached to fish for anywhere from 7 to 193 days, depending on environmental conditions and species involved. Juvenile mussels, which are often similar in size to glochidia but contain adult structures, then release from fish tissue and drop to the substrate. Juveniles evidently live buried in the substrate until they become sexually mature, when they migrate to the sediment surface. Adults typically remain partially buried, with their incurrent and excurrent siphons exposed to allow for feeding and respiration (Strayer 2008, Morales et al. 2006, Howells et al. 1996).

Mussels exhibit an extremely patchy distribution within the aquatic landscape. They often occur in spatially-limited, dense, multi-species aggregations within a river, whereas they are absent or uncommon from other similar areas. Locations of mussel beds do not seem strongly linked to depth and velocity, since these conditions change with flow rate. Recent studies suggest that mussel beds typically occur in specific areas characterized by low shear-stress even under extremely high-flow conditions. The stable substrates in these areas allow the relatively immobile mussels to persist even under extremely high flow conditions which scour the substrate in other areas (Strayer 2008, Morales et al. 2006, Strayer 1999, Howells et al. 1996).

Two species of mussels [Texas pigtoe (*Fusconaia askewi*) and pistolgrip (*Tritogonia verrucosa*)] were identified for inclusion in the focal species list based on conversations with researchers who had conducted mussel surveys in the Sabine and Neches basins (Dr. Neil Ford, UT-Tyler; and Charles Randklev, UNT). Available life history and habitat information for these two species is summarized below.

3.2.1 Texas pigtoe (*Fusconaia askewi*)

The Texas pigtoe (*Fusconaia askewi*) has been reported from the Brazos, Neches, Sabine, and San Jacinto Rivers of Texas. It was listed as a species of concern by the TPWD Texas Wildlife Action Plan in 2005. Recent surveys in the Sabine and Neches basins confirm that the species is present to abundant in Village Creek and the Sabine River (Bennett 2007, Bordelon and Harrel 2004).

Texas pigtoe reaches a size of approximately 70mm in length (Howells et al. 1996). Although little information is published on habitat, based on conversations with experts, they are typically found in areas of relatively stable substrate such as coarse sand, gravel, or cobble. They were collected in the Sabine River in mixed mud, sand, and fine gravel in protected areas associated with fallen trees or other structures. The small, spineless, elongate-D shaped glochidia were present in specimens found in the Sabine River in July. No reports of host fish have been made for this species (Howells et al. 1996).

3.2.2 Pistolgrip (*Tritogonia verrucosa*)

In Texas, the pistolgrip (*Tritogonio verrucosa*) occurs from the San Antonio River drainage to the north and east. In the Sabine and Neches drainages, it is relatively widespread and has recently been reported from B.A. Steinhagen Reservoir, Village Creek, Sandy Creek, Attoyac Bayou, the Angelina River, the Sabine River, and the Neches River (Bennett 2007, Bordelon and Harrel 2004, Howells et al. 2000, Howells et al. 1996). Although relatively common in the Sabine and Neches drainages, this species is relatively uncommon in other Texas drainages (Howells et al. 1996).

Pistolgrips are reported to at least 170mm shell length in Texas (Howells et al. 1996). They are typically found in oxygen-rich riffles and runs. Although they are considered to be most abundant on stable substrates, they have been reported from a variety of substrates including rock, hard mud, and silt.

Regardless of substrate, they are often buried deeply. Pistolgrips are thought to have a short-term summer spawning season with spawning reported from April through August (Howells et al. 1996). The smallest sexually mature individual identified is an Age-6 female which was 59 mm in shell length. Glochidia are small and smoothly rounded (Howells et al. 1996).

Pistolgrips can produce gem-quality pearls, and therefore, they were heavily harvested in the Caddo Lake area during an early 1900's pearl rush. However, it is not sought after by modern Texas pearlers. Although they were used in the early 1900's by the shell button industry and the cultured pearl industry, they were never significantly harvested in Texas for this purpose (Howells et al. 1996).

3.3 Floodplain Plant Focal Species

Bottomland hardwood forests are the most common type of riverine forested wetlands on the upper coast of Texas and into Louisiana. They are found on the floodplains of rivers and streams where the floodplain soils are constantly renewed by continual sedimentation. The larger rivers of the wet upper coast, such as the Sabine, Neches, Trinity, and Brazos Rivers, have broad floodplains that support extensive forested wetlands.

Overbank river flooding is the primary source of water for forested wetlands. Flooding of these areas along the Sabine and Neches rivers occurs most years from January through April – May and the flooding persists for at least several weeks at a time (USGS, http://waterdata.usgs.gov). Only large rivers have large enough watersheds to maintain this kind of flooding. Most bottomland hardwood forests have flooding periods that range from a few weeks to several months.

Bottomland hardwood forests in the Sabine and Neches watersheds are dominated by willow oak, water oak, overcup oak, cherrybark oak, laurel oak, green ash, red maple, black willow, water tupelo and others. These forests are considered important habitats for birds, reptiles, and small mammals. Many river fishes such as gars, suckers, minnows, shiners, catfishes, bass, and sunfishes use flooded bottomland forests and swamps as feeding and breeding habitats. Bottomland hardwood forests also play an important role in controlling soil erosion, maintaining water quality, recharging groundwater, and preventing flood damage.

Overcup oak (*Quercus lyrata*) and water tupelo (*Nyssa aquatica*) are two tree species commonly found in bottomland hardwood forests of the southeast (**Figure 1**). Both the overcup oak and water tupelo are regarded as tolerant of inundation from overland and flood waters (Coder 1994), and their presence, health and persistence provide an indication of the overall health of bottomland hardwood forests in the Sabine-Neches watershed.

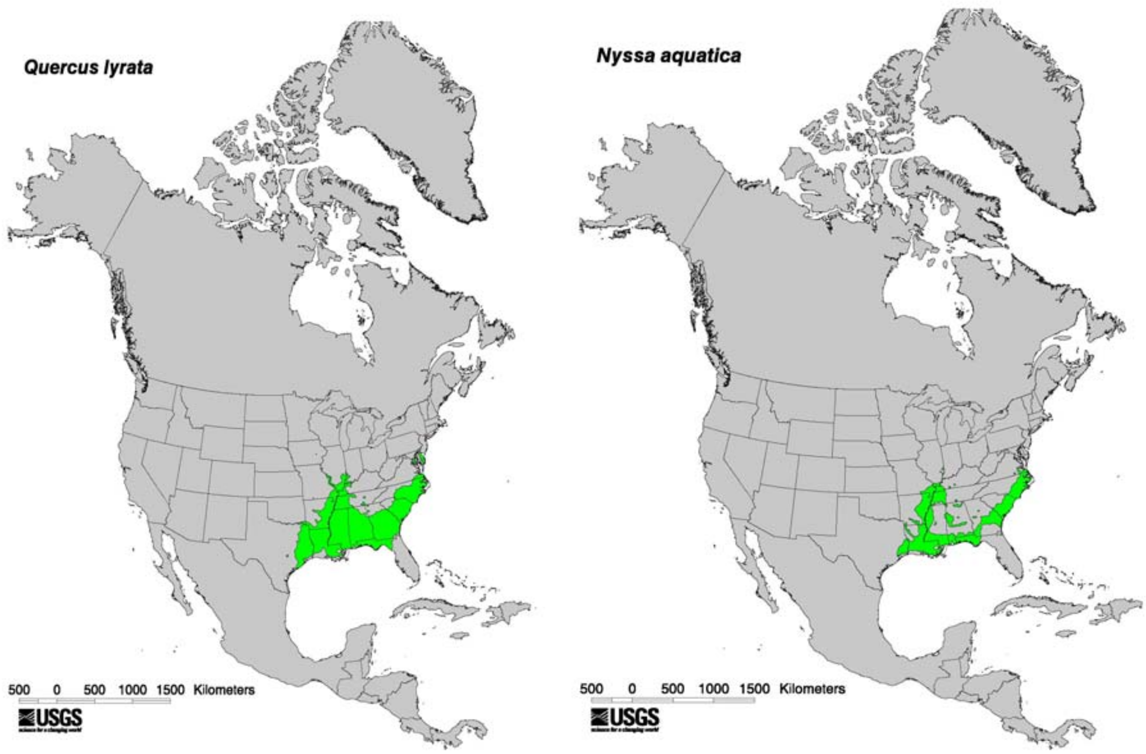

Figure 1. Nationwide distribution map for overcup oak (left) and water tupelo (right) (USGS 1999).

3.3.1 Overcup oak (*Quercus lyrata*)

Overcup oak (*Quercus lyrata*), also called swamp oak, swamp white oak, and water white oak, is a deciduous tree that grows up to 20 meters tall. It is tolerant of flooding (Broadfoot & Williston 1973, McLeod 2000) and grows slowly on poorly drained flood plains and swamp lands of the Southeastern United States (Burns & Honkala 1990). It may take 30 years before overcup oak produces acorns, and seed dispersal is dependent on overflow or flood waters. The acorns are eaten by water fowl and many small mammals. The trees also serve as habitat for wildlife. The quality of the lumber varies greatly and is cut and sold as white oak.

Overcup oak inhabits the wetter sites in bottom lands of the Coastal Plain from Delaware and Maryland south to Georgia and northwestern Florida; west to eastern Texas (**Figure 1**). It grows northward in the Mississippi Valley to southeastern Oklahoma, southeastern Missouri, southern Illinois, southwestern Indiana, and western Kentucky (Little 1979).

Overcup oak is found on poorly drained, alluvial, clayey soils mainly on southern river flood plains (Parker 1949, Putnam 1960). It is most prevalent on low lying clay or silty clay flats in first bottoms and terraces of the larger streams (Sternitzke & Putnam 1956). It is also quite common on the edges of swamps, sloughs, and bayous; in poorly drained depressions or sink holes on ridges; and in shallow swamps and sloughs (Putnam & Bull 1932). Since it leafs out a month or more later than most species; it is better able to endure submergence from late spring floods. In tests, overcup oak survived continuous flooding for at least two growing seasons. In spite of its natural occurrence on wet clay sites, overcup oak grows best on sites with better drainage and soil texture.

The species most commonly associated with overcup oak are water hickory (*Carya aquatica*), willow oak (*Quercus phellos*), Nuttall oak (*Quercus nuttallii*), American elm (*Ulmus americana*), cedar elm (*Ulmus crassifolia*), green ash (*Fraxinus pennsylvanica*), sugarberry (*Celtis laevigata*), waterlocust (*Gleditsia aquatica*), common persimmon (*Diospyros uirginiana*), and red maple (*Acer rubrum*).

Trees begin bearing seeds about 25 years of age and good seed crops are produced every 3 to 4 years. Late freezes, after the flower buds have started to open have been known to kill the flowers and thus destroy the seed crop. In flooded areas, the acorns remain dormant over winter and germinate in the spring after the surface waters recede, making overcup acorns one of the few of the white oaks that do not germinate until spring. Seed production is prolific, but many young seedlings are killed by inundation during the first few growing seasons. Seeds germinate readily either in the open or in the shade, but because of the tree's relative intolerance to shade, reproduction persists only in openings (Putnam et al. 1960). Seedlings and stump sprouts generally are also able to grow through all competing ground cover except heavy peppervine, which sometimes develops into a tangled mat (Morris 1965). Successful regeneration depends on complete absence of fire and adequate seed.

Growth of seedlings is rated as average but varies greatly with site, soil, and the kind and degree of competition (Putnam et al. 1960). Eight-year-old trees on a backwater flat were found to vary from 12 to 75 mm (0.5 to 3 in) in diameter at groundline (Morris 1965). There is little information on early height growth, but based on site index figures, height growth might be expected to average 45 to 60 cm (18 to 24 in) per year (Broadfoot 1976).

Overcup oak develops a shallow, saucer-shaped root system. The heavy clay soils and wet sites where overcup oak typically grows restrict root development to relatively shallow depths. Although the seedlings initially produce taproots, these are replaced by a lateral root system. The root system of one large tree consisted of many small branching roots with no large main roots.

Seeds germinate profusely beneath complete canopy, but the seedlings invariably succumb or at least die back to the root collar within 3 years unless released. Many stands of overcup oak owe their development to tolerance of early season flooding that kills off earlier flushing species. It is frequently a lack of competition rather than an affinity for the backwater sites that allows this species to dominate.

3.3.2 Water tupelo (*Nyssa aquatica*)

Water tupelo *(Nyssa aquatica),* also called cottongum, sourgum, swamp tupelo, tupelo-gum, and water-gum, is a large, long-lived deciduous tree that grows in southern swamps and flood plains where its root system is periodically under water. It has a swollen base that tapers to a long, clear bole and often occurs in pure stands. A good mature tree will produce commercial timber used for furniture and crates. Many kinds of wildlife eat the fruits and it is a favored honey tree.

Water tupelo trees are also one of the most flood tolerant tree species, surviving continuous flooding for as much as two growing seasons. It commonly grows in areas with saturated soils. Its shallow root system is characterized by morphological and physiological adaptations that are essential to survival and growth. Water tupelo are highly resistant to flooding and can also withstand moderate siltation (Broadfoot & Williston 1973).

Water tupelo grows throughout the Coastal Plain from southeastern Virginia to southern Georgia, and from northwestern Florida along the Gulf of Mexico to eastern Texas (**Figure 1**). It extends up the Mississippi River Valley as far north as the southern tip of Illinois.

Within its range, water tupelo grows in low, wet flats or sloughs and in deep swamps. Some of the better sites are in the sloughs and swamps along Coastal Plain rivers of the Southeast, such as the Roanoke and Santee, and in the large swamps of southwestern Louisiana and southeastern Texas. Surface water may disappear from water tupelo areas in midsummer or fall, but on better sites soil moisture remains at or near saturation level throughout most of the growing season.

In sloughs and moving water, water tupelo usually occupies the deeper parts and with bald cypress along the margins, while in deep, stagnant water the two species occupy much the same depths. Species associated with water tupelo throughout its range are black willow *(Salix nigra),* swamp cottonwood *(Populus heterophylla),* red maple *(Acer rubrum),* waterlocust *(Gleditsia aquatica),* overcup oak *(Quercus lyrata),* water oak *(Q. nigra),* water hickory *(Carya aquatica),* green and pumpkin ash *(Fraxinus pennsylvanica* and *F. profunda),* and sweetgum *(Liquidambar styraciflua).* Swamp tupelo *(Nyssa sylvatica* var. *biflora),* bald cypress *(Taxodium distichum),* and redbay *(Persea borbonia)* are the most common associates in the Southeast.

Water tupelo trees in forested wetland areas initiate seed production in about 30 years or when they are about 20 cm (8 in) in diameter. Stump sprouts have also been documented to seed (Priester 1979). Large trees normally produce a large crop each year with the seeds dispersed mainly by water. Intact fruit will float, and seeds submerged continuously in water may remain viable for over a year.

Seeds do not germinate until water recedes, which may be midway to late in the growing season. Partially shaded, wet, poorly-drained soils provide the best seedbed. Seeds buried 1 to 3 cm (0.5 to 1 in) deep in the soil have a better chance to germinate and establish seedlings than seeds on the soil surface. Seedling survival and development are best in full sunlight and in soil with a pH below 7.0 (Burns & Honkala 1990). Seedling development is better in saturated than in well-drained soil, in moving and aerated rather than stagnant water, and in shallow rather than deep water (Dickson & Broyer 1972, Dickson et al. 1965, Harms 1973). Provided their tops are above water, seedlings can generally survive continuous flooding even if it persists throughout the growing season. Water tupelo is able to survive where it is too wet for most other species because of anatomical and physiological adaptations such as roots that allow for oxidation of the rhizosphere and controlled anaerobic respiration (Hook & Brown

1973). Water tupelo is also a prolific stump sprouter, with the survival and development of sprouts related to timing and duration of flooding.

Water tupelo is classed as intolerant of shade. It will survive codominant but not overtopping competition, and develops in pure, dense stands. Fire is a major enemy of water tupelo. It scorches the thin bark, allowing entrance of rot-causing fungi. The forest tent caterpillar *(Malacosoma disstria)* is a serious enemy in some years and locations, although defoliated trees seldom die but may have lower growth rates than unattacked trees. A foliar disease, *Mycosphaerella nyssaecola,* has caused premature defoliation, but impact has been negligible.

4.0 SUMMARY

Due to the complex nature of river-floodplain ecosystems, the magnitude and timing of certain flow events may benefit some species, while negatively impacting others. For example, Rypel et al. (2009) found that growth of freshwater mussels in southeastern floodplain ecosystems was negatively correlated with annual flood pulse count and May and June discharge, while growth of bald cypress (*Taxodium distichum*) in the same systems was positively correlated with May and June discharge. This demonstrates how seasonal and interannual variability in streamflow can promote diversity in these complex ecosystems. Given the confounding interactions of flow-ecology relationships, synthesizing such relationships for 18 focal species is rather complex. To organize this task, the following section is divided into three sub-sections: 1) effects of flow on habitat of focal species; 2) effects of flow on migration and reproduction; and 3) effects of flow on food supply.

Habitat

A common approach of instream flow studies in diverse warmwater rivers is to combine species which exhibit similar habitat utilization into habitat guilds (BIO-WEST 2008, Austen et al. 1994). This simplifies analysis with the goal of representing the habitat needs at a community level. A recent study on the lower Colorado River, Texas, used a habitat guild approach, and included several of the focal species identified in this report (BIO-WEST 2008). In the Colorado River study, six habitat guilds were identified: Riffles, Shallow Runs, Deep Runs, Shallow Pools/Edge/Backwaters, Deep Pools, and Rapids. Additionally, species specific habitat suitability criteria (HSC) were developed at the lifestage level for spawning blue suckers.

As an example, **Figure 2** and **Figure 3** show the resulting habitat suitability criteria (HSC) for depth and velocity in the Riffles habitat guild. This data was collected and analyzed along with substrate selection for each of the habitat guilds and for spawning blue suckers (BIO-WEST 2008). An example of substrate selection was not provided in this report as it is acknowledged that substrate conditions in the Sabine/Neches system are different from the Colorado River. However, the depth and velocity information for the guilds should be informative for the focal species of the Sabine/Neches. For the Colorado River study, habitat suitability criteria were coupled with a two-dimensional hydrodynamic model at each study site to assess changes in each habitat type relative to discharge (BIO-WEST 2008). **Figure 4** provides an example of the relationship between each habitat type and discharge at the Bastrop study site on the lower Colorado River. Actual discharge values were removed from the figure as they are not applicable to the Sabine/Neches systems.

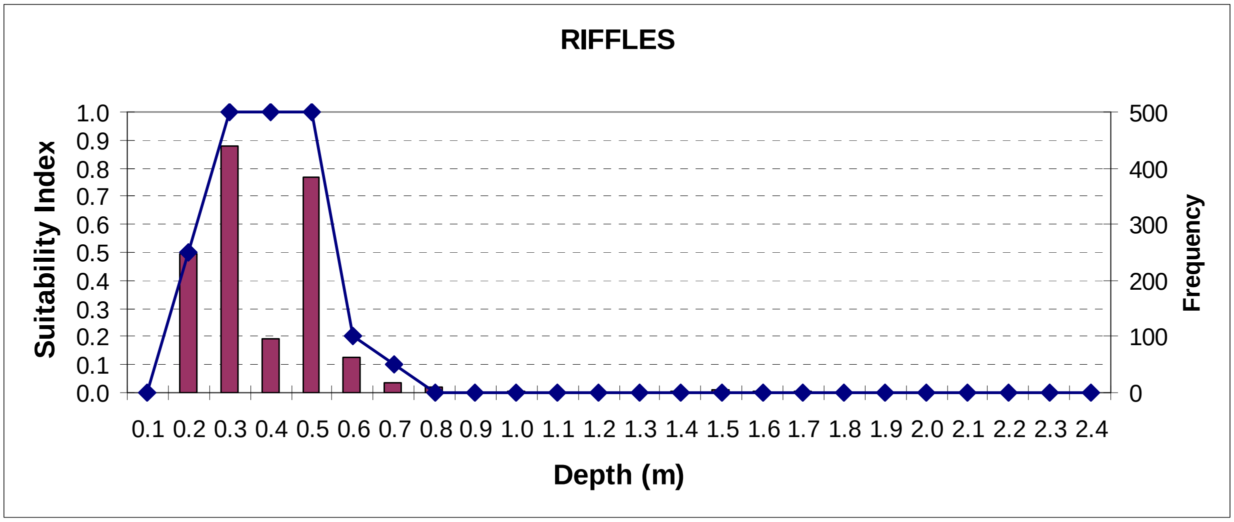

Figure 2. Frequency distribution and depth HSC values for the "Riffles" habitat guild in the lower Colorado River, Texas (BIO-WEST 2008).

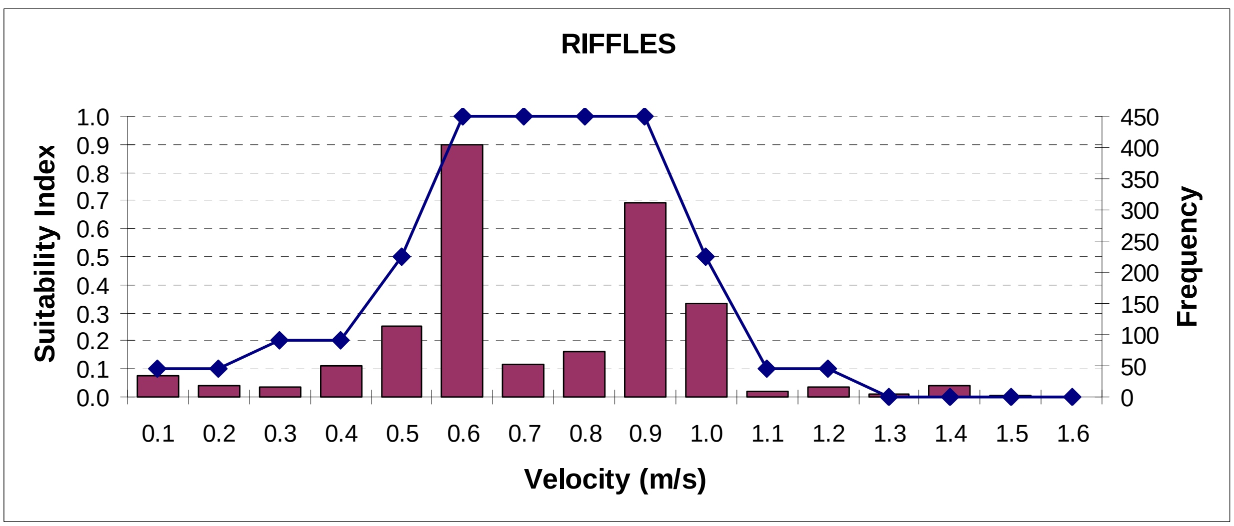

Figure 3. Frequency distribution and velocity HSC values for the "Riffles" habitat guild in the lower Colorado River, Texas (BIO-WEST 2008).

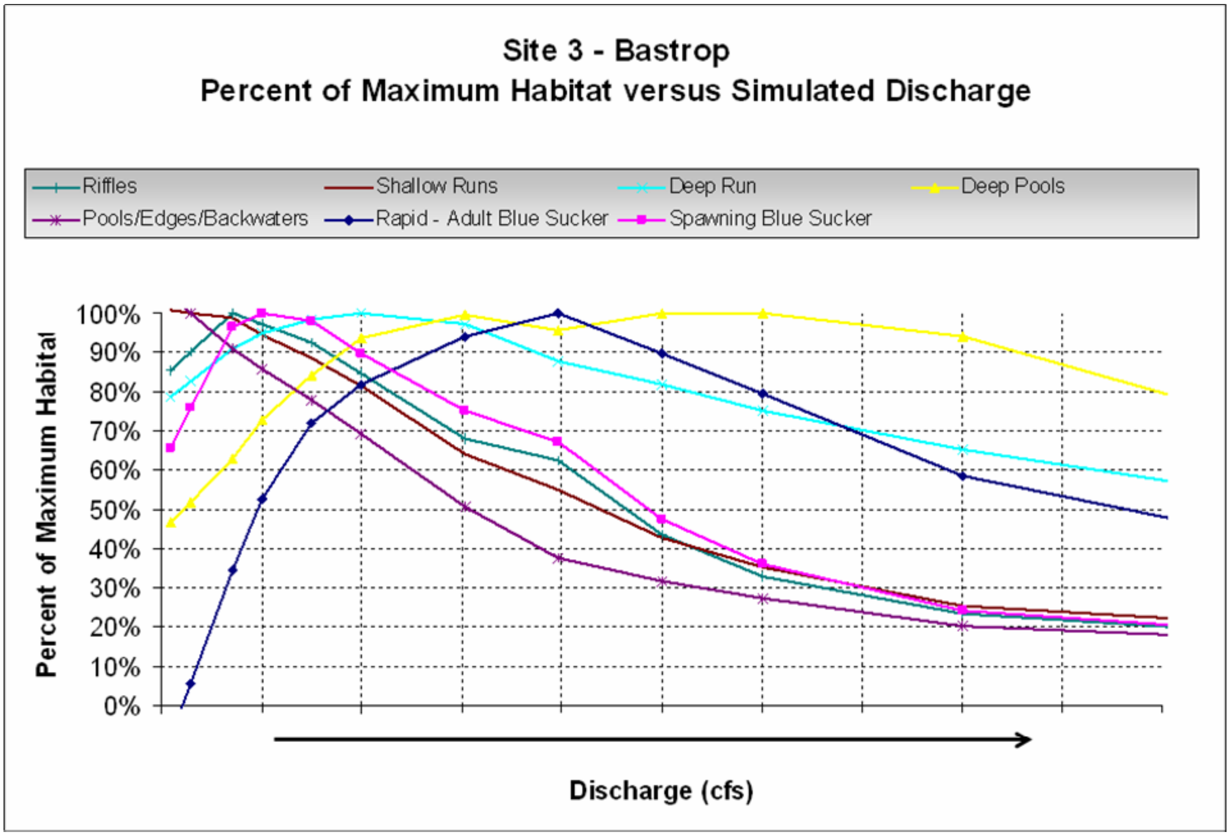

Figure 4. Percent of maximum habitat versus simulated discharge at the Bastrop study site on the lower Colorado River, Texas (BIO-WEST 2008).

Since relationships between discharge and habitat for each guild were recently described on the lower Colorado River, an attempt was made to assign each of the focal species identified in this report, where applicable, to one of the six habitat guilds based on available habitat and life history information. To include floodplain dependent species, which were not assessed in the Colorado River study, a seventh habitat category was added: Floodplain/Oxbow. **Table 4** provides the guild associations for each of the Sabine/Neches focal species. Freshwater mussel species were not included in this analysis since little information is available on their specific habitat preferences relative to depth and velocity.

Table 4. Habitat utilization guilds based on BIO-WEST (2008), and associated Sabine/Neches riverine focal species.

Habitat Guild	Original Colorado River Species	Sabine/Neches River Focal Species
Riffles	*Percina sciera** *Macrhybopsis spp*.* *Etheostoma spectabile* *Percina carbonaria* *Ictalurus punctatus* (juvenile) *Phenacobius mirabilis* *Campostoma anomalum*	*Percina sciera** *Macrhybopsis hyostoma** *Etheostoma histrio* *Noturus nocturnus* *Pylodictis olivaris* (juvenile)
Shallow Runs	*Notropis volucellus* *Cyprinella lutrensis* *Cyprinella venusta* *Pimephales vigilax* *Micropterus treculli* (juvenile)	*Notropis sabinae* *Notropis chalybaeus* *Notropis atherinoides* *Micropterus punctulatus* (juvenile)
Deep Runs	*Pylodictis olivaris** *Ictalurus punctatus* (adult) *Moxostoma congestum* *Micropterus treculli* (adult) *Carpiodes carpio* *Dorosoma cepedianum*	*Pylodictis olivaris* (adult)* *Micropterus punctulatus* (adult)
Shallow Pools/ Backwaters	*Micropterus salmoides* *Lepomis megalotis* *Lepomis macrochirus* *Lepomis cyanellus* *Cichlasoma cyanoguttatum* *Gambusia affinis* *Poecilia latipinna* *Fundulus notatus*	*Pomoxis* spp.
Deep Pools	*Ictiobus bubalus* *Cyprinus carpio*	*Polyodon spathula* *Atractosteus spatula* *Morone chrysops*
Rapids	*Cycleptus elongatus**	*Cycleptus elongatus**
Floodplain/Oxbow		*Atractosteus spatula* *Pomoxis* spp. *Quercus lyrata* *Nyssa aquatica*

* denotes species common to both studies.

Several caveats should be noted when considering habitat utilization and modeling results from the Colorado River study in the current framework. First, professional judgment was involved in assigning Sabine/Neches focal species to pre-determined habitat guilds. However, based on habitat information from the literature as well as previous fish sampling experience, each species fit well into one or more guilds. Additionally, the geomorphology and associated channel characteristics of the Colorado River are different than the Sabine or Neches rivers, which exhibit considerably more lateral floodplain connectivity. Therefore, specific habitat to discharge relationships in the Sabine/Neches system are likely different. Regardless, general trends in habitat associated with increasing discharge typically remain relatively constant across systems. For example, amounts of shallow riffle, shallow run, and instream backwater habitat peak at lower flows, whereas deep run and deep pool habitat peak at somewhat higher flow levels. Deep fast rapids habitat requires higher discharge and peaks at relatively high flows. Despite the caveats mentioned, this information is still useful. Associating Sabine/Neches focal species with the pre-determined habitat guilds, and assessing general trends in habitat availability to discharge relationships for each guild, should provide useful insight in determining important flow components to maintain habitat for focal species as discussed below.

Discharge-habitat trends for the six habitat guilds used in the Colorado River study at the Bastrop study site are evident in **Figure 4**. Shallow water habitat such as riffles, shallow runs, and shallow pools/backwaters peak under relatively low flows, and then decline under high flow situations. In contrast, deeper habitat types such as deep runs and deep pools peak under moderate flows. Rapids, the deepest and fastest habitat type, peaks under even higher flows. The one habitat type not addressed by **Figure 4** is floodplain/oxbow habitat which is primarily connected to the mainstem by overbanking flows. **Figures 5 and 6** are the compilation the six habitat guilds from the Colorado River (Altair study site) along with a hypothetical example of Floodplain/Oxbow habitat. **Figure 5** is specific to in-channel habitat, whereas **Figure 6** is expanded to show potential trends associated with overbanking flows.

A review of **Figure 5** shows the same trends witnessed in **Figure 4**, with shallow pools/backwater habitat and shallow runs experiencing the highest percentage of maximum habitat at the lower flows. Riffle habitat has a peak at slightly higher flows than shallow runs, but exhibits a rapid decline as discharge increases. Deep run habitat peaks next with Deep Pool and Rapids habitat peaking at considerably higher flows. Even during an in-channel condition, some floodplain/oxbow connectivity is anticipated during high flow pulses when various lower tiers of banks are topped. Yet, the amount of floodplain/oxbow habitat is only maximized at much higher flows when overbanking occurs as hypothetically depicted in **Figure 6**. **Figure 6** also highlights the caution of using instream flow models at higher flows in that predicted shallow run and riffle habitat shows increases in habitat as the banks are overtopped. This phenomenon is at best a very temporary habitat condition and thus the reason for typically separating in-channel vs. overbank habitat conditions.

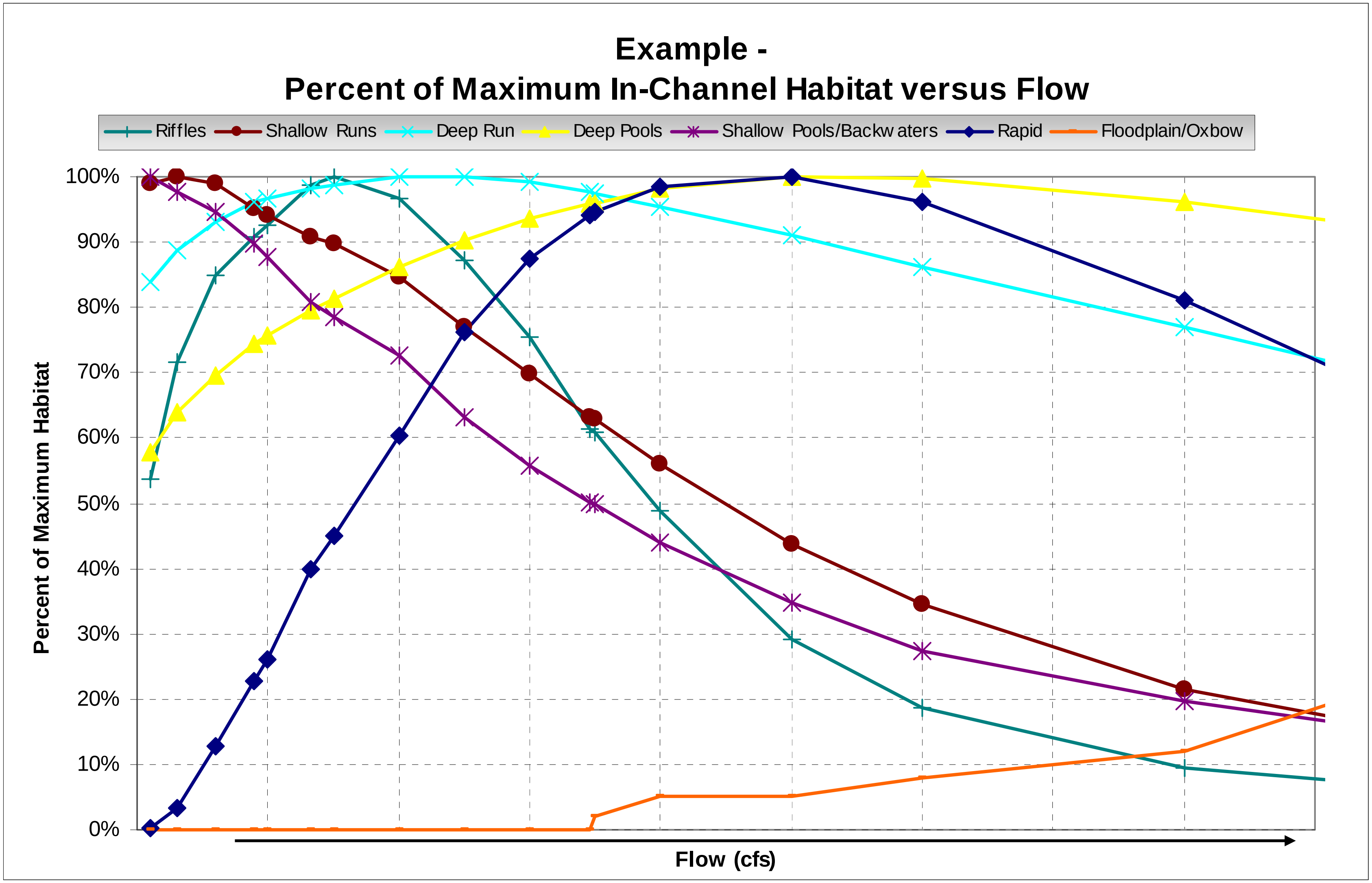

Figure 5. Habitat to discharge relationships for in-channel habitat associated with six habitat guilds on the lower Colorado River, Altair study site, and a theoretical habitat discharge relationship for floodplain/oxbow habitat.

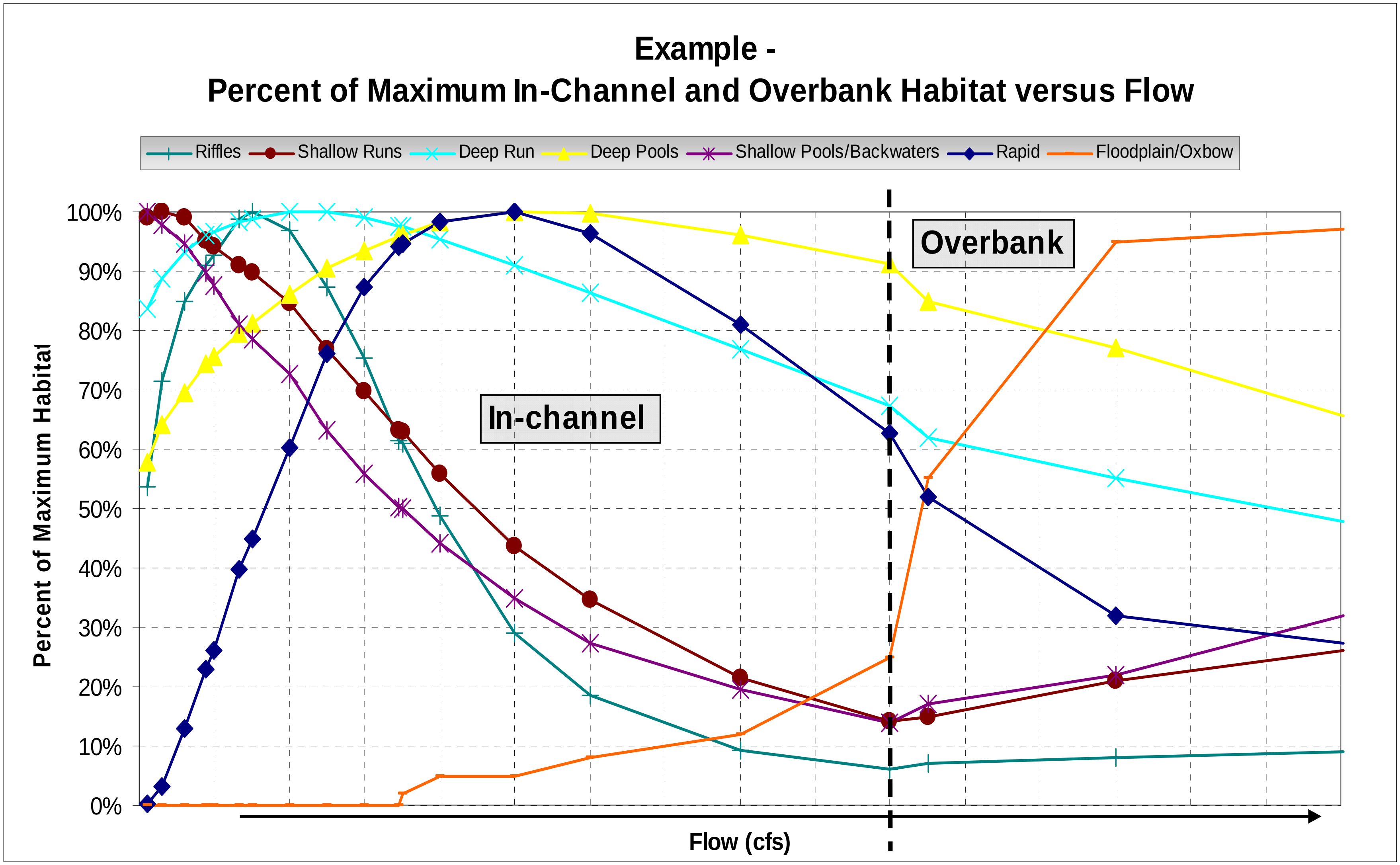

Figure 6. Habitat to discharge relationships associated with in-channel and overbank flows for six habitat guilds on the lower Colorado River, Altair study site, and a theoretical habitat discharge relationship for floodplain/oxbow habitat.

In linking **Figure 6** to **Table 4**, one can start to piece together the effects of changing flow conditions on Sabine/Neches focal species habitat. Lower flow conditions will provide increased habitat conditions for minnow and darter species whereas higher flows provide more habitat for blue suckers, with overbanking flows providing necessary floodplain connectivity for bottomland trees and oxbow habitat for alligator gar and crappie. This highlights the complexity of warmwater fisheries communities and the need for the BBEST to consider a flow regime.

From analysis of **Figures 5 and 6**, it is evident that substantial flow variation is necessary to maintain acceptable habitat conditions for all of the focal species/habitat guilds. Citing the importance of this variation, the SAC (2009) adopted the same framework for instream flow recommendations currently used by the TIFP, which identifies a regime of instream flow components including subsistence flows, base flows, high flow pulses, and overbank flows. Subsistence flows are infrequent periods of low flow that occur during drought, and are aimed mainly at maintaining water quality criteria and thus preventing loss of organisms due to high temperatures or low dissolved oxygen. Base flows provide a range of average flow conditions, not including significant rainfall or runoff events. They are meant to provide adequate amounts of instream habitat to maintain the diversity of biological communities. High flow pulses represent short-duration, high flow events that naturally occur following significant precipitation events. They move accumulated fine silts and sediments, and can provide important life cycle cues for some species. Overbank flows are infrequent extremely high-flow events that exceed channel banks and result in floodplain connectivity. These flows are important in providing sediments and nutrients to riparian areas, and providing habitat and connectivity for floodplain dependent organisms. **Figure 7** provides a conceptual overlay of the four TIFP instream flow components. Recommendations inclusive of all four components should provide a range of habitat for all of the habitat guilds. This biological overlay of habitat guilds per instream flow component may prove helpful to the BBEST in evaluating the hydrological HEFR output.

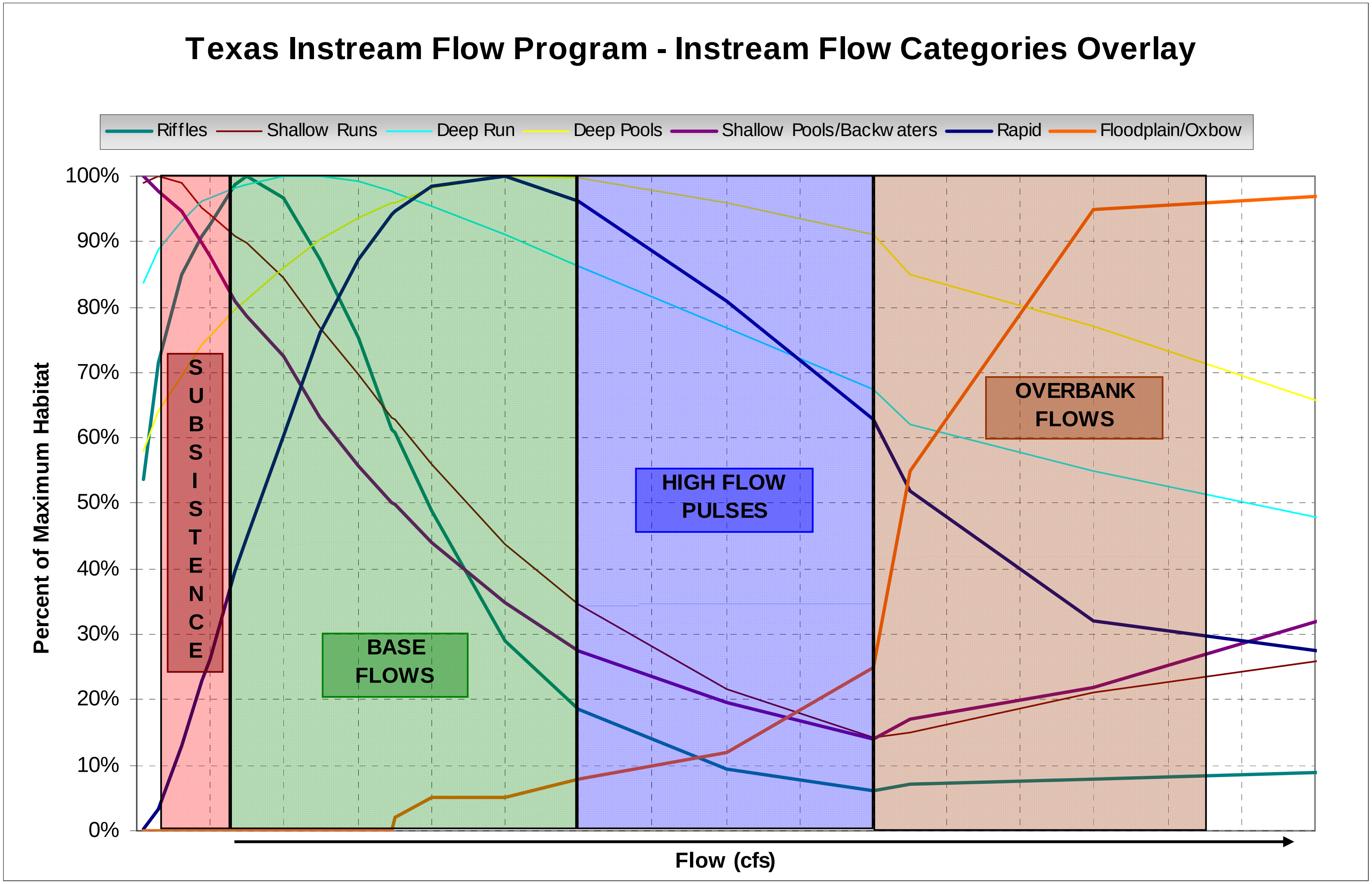

Figure 7. TIFP instream flow categories overlaid on an example of flow-habitat trends.

Migration and Reproduction

In addition to maintaining habitat, timing and magnitude of instream flows are also important reproductive cues for many species, including several of the focal species. For example, reproduction of paddlefish is strongly tied to high spring flows. Paddlefish often make long migrations upstream to specific spawning grounds. However, actual spawning is not initiated until a sharp rise in river level occurs. Additionally, if the river level suddenly drops, eggs and larvae can become stranded. As a result, spring (February through May) high flow pulses of at least 7 days in length may be important to ensure successful recruitment of this species.

Blue suckers have also been known to exhibit large spawning migrations which are evidently initiated by high flows. In the Colorado River, blue suckers spawn in February and March at temperatures of 14-15˚C. Although spawning habitat has been documented, little is known about factors affecting recruitment in this species.

White bass are a popular game fish in reservoirs within the Sabine and Neches Basins, which typically exhibit upstream spawning migrations in spring months. Maintenance of sufficient spring flows in river and tributary segments upstream of reservoirs likely benefits this species, as well as the anglers who seek them.

Shoal chub reproduction is also thought to be linked to high flow pulses which prevent eggs and larvae from settling to the bottom and becoming buried. Shoal chubs spawn multiple clutches of eggs over an extended spawning season lasting from April through September. Therefore, this species may respond favorably to maintenance of occasional high flow pulses during typically low flow summer months.

Overbank floodplain connectivity during spring months appears important for several species. Overcup oak and water tupelo both benefit from spring flooding of floodplain areas and the resulting influx of water and nutrients. However, neither actually germinates until water recedes. Connectivity to floodplain aquatic habitats such as oxbows also seems to benefit alligator gar and crappie. Young of both of these species are typically more common in floodplain pools and oxbows than in the main river channel.

Food Supply

Focal species identified in this study use a variety of feeding strategies. For example, paddlefish are planktivores which filter microscopic organisms from the water column. Freshwater mussels are also filter feeders. Many of the fish species identified feed on aquatic invertebrates (e.g., blue sucker, sabine shiner, shoal chub, dusky darter). Others are invertivores when young, but switch to piscivory as adults (e.g., flathead catfish, white bass, alligator gar, crappie). Maintenance of range of flows and timing of flows which promote healthy plankton and invertebrate communities are important for maintaining an adequate and diverse food supply for the focal species.

In conclusion, there is no question as to the high level of complexity in the fluvial environment of the Sabine/Neches system. As such, we feel that the focal species approach taken by the Sabine/Neches BBEST is appropriate for the SB3 objectives. We also feel that a detailed evaluation of the HEFR output or alternative Flow-regime prescription focusing on the flow-ecology relationships, migration and reproduction patterns, and food supply components for the selected species (as presented above) will prove valuable to the BBEST for the establishment of instream flow recommendations associated with SB3.

5.0 LITERATURE CITED

Adams, S. R., M. B. Flinn, B. M. Burr, M. R. Whiles, and J. E. Garvey. 2006. Ecology of larval blue sucker (*Cycleptus elongatus*) in the Mississippi River. Ecology of Freshwater Fish 15:291-300.

[ANS] Academy of Natural Sciences of Philadelphia. 2006. 2003 Neches River Biological Survey near Beaumont, Texas for Mobil Oil Corporation, DuPont Beaumont and Lower Neches Valley Authority. Report No. 14-15F.

Bart, H. L. 2008. Extraction, analysis, and summary of fish community data from the Sabine River System (Louisiana, Texas). Final Report to Sabine River Authority of Texas. July 8, 2008.

Bennett, D. L. 2007. Diversity and distribution of freshwater unionid bivalves in Texas. Master's Thesis, Stephen F. Austin State University.

Bessert, M. L. 2006. Molecular systematic and population structure in the North American endemic fish genus Cycleptus (Teleostei: Catostomidae). Dissertation, University of Nebraska – Lincoln.

Betsill, R. K. 1999. Statewide Fisheries Research: Project 77. Assessment of Paddlefish Stockings in the Neches, Trinity, Angelina, and Sabine River Systems. TPWD Report, Federal Aid Grant F-31-R-25.

BIO-WEST. 2007. Blue Sucker Life History Studies – Summary Report. Colorado River Flow Relationships to Aquatic Habitat and State Threatened Species: Blue Sucker. Technical report prepared for the Lower Colorado River Authority and San Antonio Water System. October 2007.

BIO-WEST. 2008. Lower Colorado River, Texas Instream Flow Guidelines. Colorado River Flow Relationships to Aquatic Habitat and State Threatened Species: Blue Sucker. Technical report prepared for the Lower Colorado River Authority and San Antonio Water System. March 2008.

Bonn, E. W. 1952. The food and growth rate of young white bass (*Morone chrysops*) in Lake Texoma. Transactions of the American Fisheries Society 82:213-221.

Bonner, T., and D. T. Runyan. 2007. Fish assemblage changes in three Western Gulf Slope drainages. Final Report to the Texas Water Development Board (2005-483-033). Submitted July 31, 2007.

Bonner, T. H., and G. R. Wilde. 2002. Effects of turbidity on prey consumption by prairie stream fishes. Transactions of the American Fisheries Society 131:1203-1208.

Bonner, T. H., and G. R. Wilde. 2000. Changes in the Canadian River fish assemblage associated with reservoir construction. Journal of Freshwater Ecology 15(2):189-198.

Bordelon, V. L., and R. C. Harrel. 2004. Freshwater mussels (Bivalvia: Unionidae) of the Village Creek drainage basin in southeast Texas. Texas Journal of Science 56(1):63-72.

Boschung, H. T., and R. L. Mayden. 2003. Fishes of Alabama. Smithsonian Books, Washington, D. C.

Broadfoot, W. M. 1976. Hardwood suitability for and properties of important midsouth soils. USDA Forest Service, Research Paper SO-127. Southern Forest Experiment Station, New Orleans, LA. 84 p.

Broadfoot, W. M., and H. L. Williston. 1973. Flooding effects on southern forests. Journal of Forestry 71(9):584-587.

Brown, J. J., J. Perillo, T. J. Kwak, and R. J. Horwitz. 2005. Implications of *Pylodictis olivaris* (flathead catfish) introduction into the Delaware and Susquehanna drainages. Northeastern Naturalist 12(4):473-484.

Buckmeier, D. L. 2008. Life history and status of alligator gar *Atractosteus spatula*, with recommendations for management. TPWD Inland Fisheries Report, Heart of the Hills Fisheries Science Center.

Burns, Russell M., and Barbara H. Honkala, tech. coords. 1990. Silvics of North America: 1. Conifers; 2. Hardwoods. Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, DC. vol.2, 877 p.

Burr, B. M., and R. L. Mayden. 1999. A new species of *Cycleptus* (Cypriniformes: Catastomidae) from Gulf Slope drainages of Alabama, Mississippi, and Louisiana, with a review of the distribution, biology, and conservation status of the genus. Bull. Alabama Mus. Nat. Hist. 20:19-57.

Campbell, J. S., and H. R. MacCrimmon. 1970. Biology of the emerald shiner *Notropis atherinoides* Rafinesque in Lake Simcoe, Canada. Journal of Fish Biology 1970(2), 259-273.

Coder, K. D. 1994. Flood Damage to Trees. University of Georgia Extension Forest Resources Publication FOR94-61.

Cowan, D. C. 1998. A survey of the fishes of three oxbow lakes in eastern Texas and Louisiana. Master’s Thesis, Stephen F. Austin State University.

Dickson, R.E. and T.C. Broyer. 1972. Effects of aeration, water supply and nitrogen source on growth and development of tupelo-gum and baldcypress. Ecology 53(4):626-634.

Dickson, R.E., J.F. Hosner and N.W. Hosley. 1965. The effects of four water regimes upon the growth of four bottomland species. Forest Science 11(3):299-305.

Dillon, J. C., and D. Myers. 1990. Emerald shiner introduction to Brownlee Reservoir: Evaluation of Proposal. Idaho Fish and Game Fishery Research Publication. Volume 076, Article 10.

Edwards, E. A., D. A. Krieger, G. Gebhart, and O. E. Maughan. 1982. Habitat suitability index models: white crappie. U.S.D.I. Fish and Wildlife Service. FWS/OBS-82/10.7. 22 pp.

Eisenhour, D. J. 2004. Systematics, variation, and speciation of the *Macrhybopsis aestivalis* complex west of the Mississippi River. Bull. Alabama Mus. Nat. Hist. 23:9-48.

Evans, J. W., and R. L. Noble. 1979. The longitudinal distribution of fishes in an east Texas stream. The American Midland Naturalist 101(2):333-343.

Ferrara, A. M. 2001. Life-history strategy of Lepisosteidae: Implications for the conservation and management of alligator gar. Dissertation, Auburn University.

Fisher, S. J., and D. W. Willis. 2000. Observations of age-0 blue sucker, *Cycleptus elongatus* utilizing an Upper Missouri River backwater. Journal of Freshwater Ecology 15(3):425-427.

Fuchs, E. H. 1967. Life history of the emerald shiner, *Notropis atherinoides*, in Lewis and Clark Lake, South Dakota. Transactions of the American Fisheries Society 96(3):247-256.

Geeslin, P. D. 2001. An ichthyological study of fish communities in six streams in the Angelina National Forest, Texas. Master's Thesis, Stephen F. Austin State University.

Goldstein, R.M., and T.P. Simon. 1999. Toward a united definition of guild structure for feeding ecology of North American freshwater fishes. pp. 123-202 *in* T.P. Simon, editor. Assessing the sustainability and biological integrity of water resources using fish communities. CRC Press, Boca Raton, Florida.

Goodyear, C. P. 1967. Feeding habits of three species of gars, *Lepisosteus*, along the Mississippi gulf coast. Transactions of the American Fisheries Society 96:438-449.

Greene, G. N. 1962. White bass feeding: scent or sight. Transactions of the American Fisheries Society 91(3):326.

Hassan-Williams, C., and T. H. Bonner. 2009. Texas Freshwater Fishes Website. Texas State University – San Marcos. http://www.bio.txstate.edu/~tbonner/txfishes/index.htm

Harms, W.R. 1973. Some effects of soil type and water regime on growth of tupelo seedlings. Ecology 54:188-193.

Heins, D. C. 1981. Life history pattern of Notropis sabinae (Pisces: Cyprinidae) in the lower Sabine River drainage of Louisiana and Texas. Tulane Studies Zool. Bot. 22:67-84.

Hook, D. and C.L. Brown. 1973. Root adaptations and relative flood tolerance of five hardwood species. Forest Science 19:225-229.

Howells, R. G., C. M. Mather, and J. A. M. Bergmann. 2000. Impacts of dewatering and cold on freshwater mussels (Unionidae) in B. A. Steinhagen Reservoir, Texas. Texas Journal of Science 52(4):93-104.

Howells, R. G., R. W. Neck, and H. D. Murray. 1996. Freshwater Mussels of Texas. Texas Parks and Wildlife Press, Austin, Texas.

Hubbs, C. 1961. Developmental temperature tolerances of four Etheostomatine fishes occurring in Texas. Copeia 1961(2):195-198.

Hubbs, C., and J. Pigg. 1972. Habitat preferences of the harlequin darter, *Etheostoma histrio*, in Texas and Oklahoma. Copeia 1972(1):193-194.

Hubbs, C. 1985. Darter reproductive seasons. Copeia 1985(1):56-68.

Hubbs, C., R. J. Edwards, and G. P. Garrett. 2008. An annotated checklist of the freshwater fishes of Texas, with keys to identification of species. The Texas Journal of Science 43(4):Supp., Second Edition July 2008.

Hubbs, C., R. J. Edwards, and G. P. Garrett. 1991. An annotated checklist of the freshwater fishes of Texas, with keys to identification of species. The Texas Journal of Science 43(4):Supp.

Kelly, J. P. 1999. An ichthyological survey of the Davy Crockett National Forest, Texas. Texas Journal of Science 51(2):115-126.

Kleinsasser, L. J., and G. W. Linam. 1987. Fisheries Use Attainability Study for Pine Island Bayou (Segment 0607). TPWD Resource Protection Division, River Studies Report No. 6.

Kuhajda, B.R., and M.R. Warren, Jr. 1989. Life history aspects of the harlequin darter, Etheostoma histrio, in Western Kentucky. ASB Bull. 36(2):66-67.

Linam, G. W., and L. J. Kleinsasser. 1987. Fisheries Use Attainability Study for Hillebrandt Bayou. TPWD Resource Portection Division, River Studies Report No. 1.

Little, Elbert L., Jr. 1979. Checklist of United States trees (native and naturalized). U.S. Department of Agriculture, Agriculture Handbook 541. Washington, DC. 375 p.

Luttrell, G. R., A. A. Echelle, and W. L. Fisher. 2002. Habitat correlates of the distribution of *Macrhybopsis hyostoma* (Teleostei: Cyprinidae) in western reaches of the Arkansas River basin. Transactions of the Kansas Academy of Science 105(3-4):153-161.

Matthews, W. J., F. P. Gelwick, and J. J. Hoover. 1992. Food and habitat use by juveniles of species of *Micropterus* and *Morone* in a southwestern reservoir. Transactions of the American Fisheries Society 121:54-66.

McCarty, C.E. 1987. Fish populations of six oxbow lakes within the Angelina and Neches River Basins, Texas. Master's Thesis, Stephen F. Austin State University.

McLeod, K.W. 2000. Species selection trials and silvicultural techniques for the restoration of bottomland hardwood forests. Ecological Engineering 15:S35-S46.

Mettee, M. F., P. E. O'Neil, and J. M. Pierson. 1996. Fishes of Alabama and the Mobile Basin. Oxmoor House, Inc., Birmingham, Alabama.

Mettee, M. F., T. E. Shepard, P. E. O'Neil, S. W. McGregor, and W. P. Henderson, Jr. 2003. Biology of a spawning population of *Cycleptus meridionalis* in the Alabama River. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 57:59-67.

Miller, R. J., and H. W. Robison. 1973. The Fishes of Oklahoma. Oklahoma State University Press, Stillwater, Oklahoma.

Minckley, W. L., and J. E. Deacon. 1959. Biology of flathead catfish in Kansas. Transactions of the American Fisheries Society 88:344-355.

Morales, Y., L. J. Weber, A. E. Mynett, and T. J. Newton. 2006. Effects of substrate and hydrodynamic conditions on the formation of mussel beds in a large river. Journal of the North American Benthological Society 25(3):664-676.

Morey, N. M., and C. R. Berry, Jr. 2003. Biological characteristics of the blue sucker in the James River and the Big Sioux River, South Dakota. Journal of Freshwater Ecology 18(1):33-41.

Moriarty, L. J., and K. O. Winemiller. 1997. Spatial and temporal variation in fish assemblage structure in Village Creek, Hardin County, Texas. Texas Journal of Science 49:85-110.

Morris, Robert C. 1965. Overcup oak (*Quercus lyrata* Walt.). In Silvics of forest trees of the United States. p. 600-602. H. A. Fowells, comp. U.S. Department of Agriculture, Agriculture Handbook 271. Washington, DC.

Moss, R. E., J. W. Scanlan, and C. S. Anderson. 1983. Observations on the natural history of the blue sucker (*Cycleptus elongatus* Le Sueur) in the Neosho River. The American Midland Naturalist 109(1):15-22.

Munger, C. R., G. R. Wilde, and B. J. Follis. 1994. Flathead catfish age and size at maturation in Texas. North American Journal of Fisheries Management 14:403-408.

Muoneke, M. I., C. C. Henry, and O. E. Maughan. 1992. Population structure and food habits of white crappie Pomoxis annularis Rafinesque in a turbid Oklahoma reservoir. Journal of Fish Biology (1992) 41, 647-654.

O'Brien, W. J., B. Loveless, and D. Wright. 1984. Feeding ecology of young white crappie in a Kansas Reservoir. North American Journal of Fisheries Management 4:341-349.

O'Keefe, D. M., J. C. O'Keefe, and D. C. Jackson. 2007. Factors influencing paddlefish spawning in the Tombigbee Watershed. Southeastern Naturalist 6(2):321-332.

Page, L. M. 1983. Handbook of Darters. T.F.H. Publications, Inc., Neptune City, New Jersey.

Parker, J. 1949. The effects of flooding on the transpiration and survival of some southeastern forest tree species. Plant Physiology 25:453-460.

Paukert, C. P., and W. L. Fisher. 2001. Characteristics of paddlefish in a southwestern U.S. reservoir, with comparisons of lentic and lotic populations. Transactions of the American Fisheries Society 130:634-643.

Peterson, M. S., L. C. Nicholson, D. J. Snyder, and G. L. Fulling. 1999. Growth, spawning preparedness, and diet of *Cycleptus meridionalis* (Catostomidae). Transactions of the American Fisheries Society 128:900-908.

Peterson, M. S., L. C. Nicholson, G. L. Fulling, and D. J. Snyder. 2000. Catch-per-unit-effort, environmental conditions and spawning migration of *Cycleptus meridionalis* Burr and Mayden in two coastal rivers of the northern Gulf of Mexico. The American Midland Naturalist 143:414-421.

Pitman, V. M. 1991. Synopsis of Paddlefish Biology and Their Utilization and Management in Texas. Special Report of TPWD Inland Fisheries Branch.

Platania, S. P., and C. S. Altenbach. 1998. Reproductive strategies and egg types of seven Rio Grande Basin cyprinids. Copeia 1998:559-569.

Priester, D. S. 1979. Stump sprouts of swamp and water tupelo produce viable seeds. Southern Journal of Applied Forestry 3(4):149-151.

Purkett, C. A., Jr. 1961. Reproduction and early development of the paddlefish. Transactions of the American Fisheries Society 90(2):125-129.

Putnam, John A., and Henry Bull. 1932. The trees of the bottomlands of the Mississippi River Delta Region. U.S. Forest Service, Occasional Paper 27. Southern Forest Experiment Station, New Orleans, LA. 207 p.

Putnam, John A., George M. Furnival, and J. S. McKnight. 1960. Management and inventory of southern hardwoods. U.S. Department of Agriculture, Agriculture Handbook 181. Washington, DC. 102 p.

Reid, G. K., Jr. 1949. Food of the black crappie *Pomoxis nigromaculatus* (LeSueur), in Orange Lake, Florida. Transactions of the American Fisheries Society 79:145-154.

Robbins, M. W. 2000. An ichthyological survey of an oxbow lake of the Angelina River near Nacogdoches, Texas. Master's Thesis, Stephen F. Austin State University.

Robison, H. W., and T. M. Buchanan. 1988. Fishes of Arkansas. The University of Arkansas Press, Fayetteville, Arkansas.

Robertson, C. R., S. C. Zeug, and K. O. Winemiller. 2008. Associations between hydrological connectivity and resource partitioning among sympatric gar species (Lepisosteidae) in a Texas river and associated oxbows. Ecology of Freshwater Fish 2008: 17: 119-129.

Rogers, G. L. 1994. Fish communities of three streams in the Sabine National Forest and their relationship to petroleum exploration. Master's Thesis, Stephen F. Austin State University.

Rupprecht, R. J., and L. A. Jahn. 1980. Biological notes on blue suckers in the Mississippi River. Transactions of the American Fisheries Society 109:323-326.

Ryan, P. W., J. W. Avault, Jr., and R. O. Smitherman. 1970. Food habits and spawning of the spotted bass in Tchefuncte River, southeastern Louisiana. The Progressive Fish-Culturist 32(3):162-167.

Rypel, A. L., W. R. Haag, and R. H. Findlay. 2009. Pervasive hydrologic effects on freshwater mussels and riparian trees in southeastern floodplain ecosystems. Wetlands 29(2):497-504.

[SAC] Senate Bill 3 Science Advisory Committee for Environmental Flows. 2009. Essential Steps for Biological Overlays in Developing Senate Bill 3 Instream Flow Recommendations. July 31, 2009.

Semmens, K. J. 1985. Induced spawning of the blue sucker (*Cycleptus elongatus*). Progressive Fish Culturist 47(2):119-120.

Simon, T. P. 1999. Assessment of Balon's reproductive guilds with application to Midwestern North American freshwater fishes. Pages 97-121 in Simon, T. P., editor. Assessing the sustainability and biological integrity of water resources using fish communities. CRC Press, New York.

Smith, P. W., and L. M. Page. 1969. The food of spotted bass in streams of the Wabash River drainage. Transactions of the American Fisheries Society 1969(4):647-651.

Southall, P. D., and W. A. Hubert. 1984. Habitat use by adult paddlefish in the Upper Mississippi River. Transactions of the American Fisheries Society 113:125-131.

[SRA] Sabine River Authority of Texas, Texas Commission on Environmental Quality (TCEQ), Texas Parks and Wildlife Department (TPWD), and Texas Water Development Board (TWDB). 2007. Baseline Fish Collections Lower Sabine River Priority Instream Flow Study. Report submitted under TWDB Research and Planning Fund Research Grant, Contract No. 0604830567. February 28, 2007.

Starrett, W. C. 1951. Some factors affecting the abundance of minnows in the Des Moines River, Iowa. Ecology 32(1):13-24.

Sternitzke, H. S., and John A. Putnam. 1956. Forests of the Mississippi Delta. USDA Forest Service, Survey Release 78. Southern Forest Experiment Station New Orleans LA. 42 pp.

Strayer, D. L. 1999. Use of flow refuges by unionid mussels in rivers. Journal of the North American Benthological Society 18(4):468-476.

Strayer, D. L. 2008. Freshwater Mussel Ecology: A Multifactor Approach to Distribution and Abundance. University of California Press.

Tsai, C. 1968. Distribution of the harlequin darter, *Etheostoma histrio*. Copeia 1968(1):178-181.

[USGS] United States Geological Survey. 2003. Baseline Assessment of Fish Communities, Benthic Macroinvertebrate Communities, and Stream Habitat and Land Use, Big Thicket National Preserve, Texas, 1999-2001. Water-Resources Investigations Report 03-4270.

Van Den Avyle, M. J., B. J. Higginbotham, B. T. James, and F. J. Bulow. 1983. Habitat preferences and food habits of young-of-the-year striped bass, white bass, and yellow bass in Watts Bar Reservoir, Tennessee. North American Journal of Fisheries Management 3:163-170.

Vogele L.E., W.C. Rainwater. 1975. Use of Brush Shelters as Cover by Spawning Black Basses (*Micropterus*) in Bull Shoals Reservoir. South Central Reservoir Investigations. U.S. Fish and Wildlife Service. Fayetteville, Arkansas.

Vokoun, J. C., and C. F. Rabeni. 2006. Summer diel activity and movement paths of flathead catfish (Pylodictis olivaris) in two Missouri streams. American Midland Naturalist 155:113-122.

Vokoun, J. C., T. L. Guerrant, and C. F. Rabeni. 2003. Demographics of a spawning aggregation of blue sucker (*Cycleptus elongatus*) in the Grand River, Missouri, USA. Journal of Freshwater Ecology 18(4):567-575.

Voigtlander, C. W., and T. E. Wissing. 1974. Food habits of young and yearling white bass, *Morone chrysops* (Rafinesque), in Lake Mendota, Wisconsin. Transactions of the American Fisheries Society 1:25-31.

Williams, C. S., and T. H. Bonner. 2007. Threatened fishes of the world: *Notropis sabinae* (Jordan and Gilbert 1886) (Cyprinidae). Environmental Biology of Fishes 80:7-8.

Williams, C. S., and T. H. Bonner. 2006. Habitat associations, life history and diet of the Sabine shiner *Notropis sabinae* in an east Texas drainage. American Midland Naturalist 155:84-102.

Winemiller, K. O., A. Chin, S. E. Davis, D. L. Roelke, L. M. Romero, and B. P. Wilcox. 2005. Summary Report Supporting the Development of Flow Recommendations for the Stretch of Big Cypress Creek below Lake O' the Pines Dam.

Winemiller, K. O., F. P. Gelwick, T. Bonner, S. Zeug, and C. Williams. 2004. Response of oxbow lake biota to hydrologic exchanges with the Brazos River channel. Final Project Report submitted to Texas Water Development Board (2003-483-493, 2003-483-003).