Interagency Final Report to the Texas Water Development Board

Final Report for Review

Distributional Survey and Habitat Utilization of Freshwater Mussels (Family Unionidae) in the Lower Brazos and Sabine River basins.

Submitted by:

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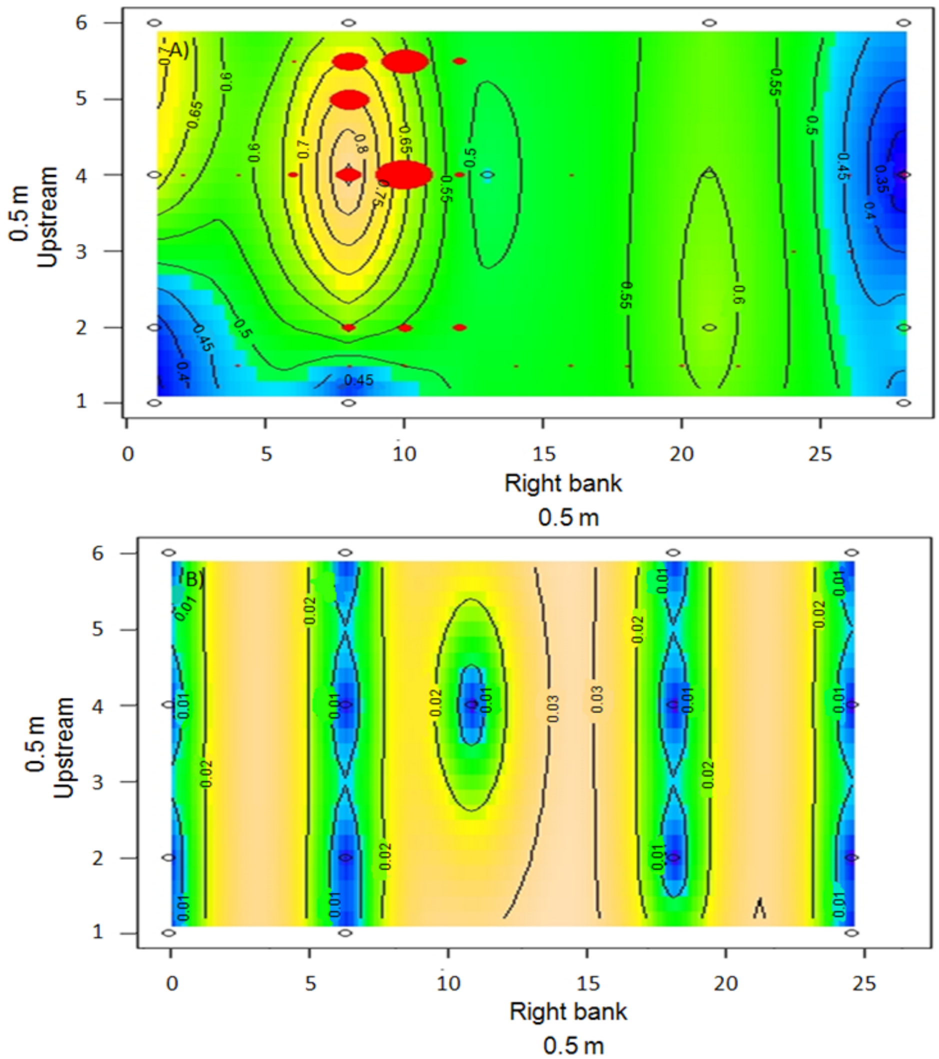
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INTRODUCTION

Freshwater mussels or unionids (Family Unionidae) have experienced a dramatic decline in both numbers and distribution throughout the United States. In fact, it has been estimated that of the 297 species known to occur in North America, 12 % are thought to be extinct and 23 % are considered threatened or endangered (references in Galbraith et al. 2008). Freshwater mussels possess a suite of biological characteristics that render them susceptible to range reductions and extirpations (Vaughn and Taylor 1999). Unionids are long-lived, sedentary organisms that spend a portion of their lives as ectoparasites on fish (Galbraith et al. 2008; Vaughn and Taylor 1999). As a result, anthropogenic impacts such as overharvesting, urban sprawl, stream impoundments, poor agriculture practices, introduction of alien species, and apathetic land-management policies have reduced or eliminated many unionid populations (Bogan 1993; Lydeard et al. 2004; Neck 1982; Strayer 1999a; Vaughn and Taylor 1999; Watters 1999).

This decline is ecologically significant because unionids are often a critical link in nutrient exchange for lotic systems. Unionids remove particles from the water column through suspension or filter feeding, thereby affecting nutrient dynamics through excretion and deposition of faeces and pseudofaeces (Vaughn and Hakenkamp 2001). The resulting enrichment of both the water column and surrounding substratum may lead to increases in primary productivity and local macroinvertebrate diversity (Spooner 2002; Spooner and Vaughn 2006; Strayer et al. 2004; Vaughn and Hakenkamp 2001; Vaughn and Spooner 2006). Unionids may also increase oxygen content in sediment water and release nutrients bound to the substratum during movement and burrowing (Vaughn and Hakenkamp, 2001). The physical presence of unionids can also influence the distribution and abundance of periphyton and benthic organisms by providing stable substrate, refuge from spates and predators and stabilization of surrounding sediments (Beckett et al. 1996; Strayer 1999b; Strayer et al. 2004; Vaughn and Hakenkamp 2001; Zimmerman and de Szalay, 2007).

Despite a general knowledge of unionid ecology little is known regarding the physical habitat necessary to maintain mussel populations. Freshwater mussels are patchy in distribution, existing in multispecies aggregates called mussel beds (Strayer 1999b). Suitable habitat is considered the initial limiting factor for these populations which may explain the patchy distribution of unionids within lotic systems (Strayer 2008). At reach and catchment scales, unionid occurrence is correlated with regional factors such as land use and geology (Arbuckle and Downing 2002; McRae et al. 2004; Strayer 1983; Strayer 1993; Vaughn 1997). However, at local-scales, similar descriptors of habitat have been largely unsuccessful for predicting unioinid occurrence (e.g., Brim Box et al. 2002; Holland-Bartels 1990; Strayer and Ralley 1993). This is because traditional habitat descriptors are often vague, tend to be based on flow conditional measurements, or fail to address the underlying factor responsible for mussel occurrence (Layzer and Madison 1995; Morales et al. 2006; Strayer 1999b; Strayer 2008). Moreover, habitat preferences for many species are based on observations of adults rather than juveniles. Consequently, traditional measurements of habitat may be completely irrelevant to understanding habitat requirements needed to maintain existing mussel beds (Layzer and Madison 1995).

Because mussels are long-lived and relatively sessile they require stable substrate to burrow and anchor. Recent studies have observed that low mussel abundance occurs in portions of a stream with high shear stresses (Hardison and Layzer 2001; Layzer and Madison 1995). High shear stress is problematic for benthic organisms because during episodes of high river discharge the drag force of water (shear stress) may exceed the weight force of gravity holding bed particles in place. For mussels, entrainment of the substratum can result in bed movement, burial, scouring, crushing or dislodgment of juvenile and adult unionids (Hastie et al. 2001; Johnson and Brown 2000; Lorang and Hauer 2003; Strayer 1993; Strayer 1999b). Thus, mussel distribution within lotic systems is thought to reflect portions of a stream that remain stable during periods of high flow. Several studies support this hypothesis (Hastie et al. 2001; Johnson and Brown 2000; Layzer and Madison 1995; Morales et al. 2006; Strayer 1999). Because it is clear that substrate stability plays a role in mussel occurrence, recognizing stable mussel habitats and identifying the degree of stability for known mussel beds is important for maintaining viable unionid populations. As a result, the purpose of this study is to evaluate how mussels are distributed with regards to their physical habitat in the lower Brazos and Sabine River basins.

OBJECTIVES

Task 1: Collect freshwater mussel distribution, habitat utilization and related data in the Sabine and Brazos River basins.

Task 2: Monitor the flow conditions and repeat mapping of the distribution of mussels and habitats at selected sites in the lower Sabine River basin.

Task 3: Monitor the flow conditions and repeat mapping of the distribution of mussels and habitats at selected sites in lower Brazos River basin.

Task 4: Make a GIS of habitat, flow conditions and mussel distributions for selected sites in the Sabine and Brazos River basins.

Task 5: Calculate the shear stress ratio and its relationship with mussel density at selected sites in the lower Sabine River basin and develop a tool to predict mussel beds for other localities within the lower Sabine River basin.

Task 6: Calculate the shear stress ratio and its relationship with mussel density at selected sites in the lower Brazos River basin and develop a tool to predict mussel beds for other localities within the lower Brazos River basin.

MATERIALS AND METHODS

Study sites

Previous studies by Karatayev and Burlakova (*Distributional Survey and Habitat Utilization of Freshwater Mussels, March 2008*) identified potential mussel beds in the lower Brazos River drainage. The focus of our study was to revisit four sites identified in this report for both the lower Brazos and Sabine River basins and monitor habitat under varying flow conditions (Figure 1). Sampling locations for the lower Brazos River drainage included two sites on the Brazos River, one site on Yegua Creek, and one site on the Navasota River.

After preliminary discussions between University of North Texas (UNT) and Sabine River Authority (SRA) personnel it was decided that the occurrence and distribution of freshwater mussels in the lower Sabine was not sufficiently known to choose study sites. In order to increase the probability of identifying potential mussel beds the SRA suggested and received permission from the TWDB for UNT biologists to examine and identify mussel specimens archived in the Tulane University of Natural History (TUMNH). These collections were made during the course of fish surveys conducted by the late Dr. Royal Suttkus from the mid-1960s through the early 1980's. The TUMNH provided evidence that a diverse mussel community was historically present in the lower Sabine and helped identify potential study sites. Ultimately, sample sites were chosen by SRA and UNT scientists based on a combination of factors that included historical records and more recent field surveys. Sampling was performed between July 2008 and May 2009.

Brazos River Basin

The Brazos River originates in New Mexico and is considered the third longest river in Texas, traveling 1516 km before emptying into the Gulf of Mexico near Freeport (Huser 2000). Study sites are located on the lower portion of the Brazos River downstream of Waco, TX, including two major tributaries; Navasota River and Yegua Creek (Figure 1). The following are locations sampled:

- Brazos River at FM 485 crossing (Figure 2); Milam and Robertson Co., TX, sampled on 15 July 2008, 28 September 2008, 5 April 2009, and 13 May 2009

  (WGS84) 14R 0720320 3417211

- Brazos River near SH 105 (Figure 3); Grimes and Washington Co., TX, sampled on 29 September 2008, 4 April 2009, and 27 May 2009

  (WGS84) 14R 0773439 3360660

- Navasota River near SH 105 (Figure 4); Grimes and Washington Co., TX, sampled on 18 July 2008, 27 September 2008, and 4 April 2009

  (WGS84) 14R 0774511 3362672

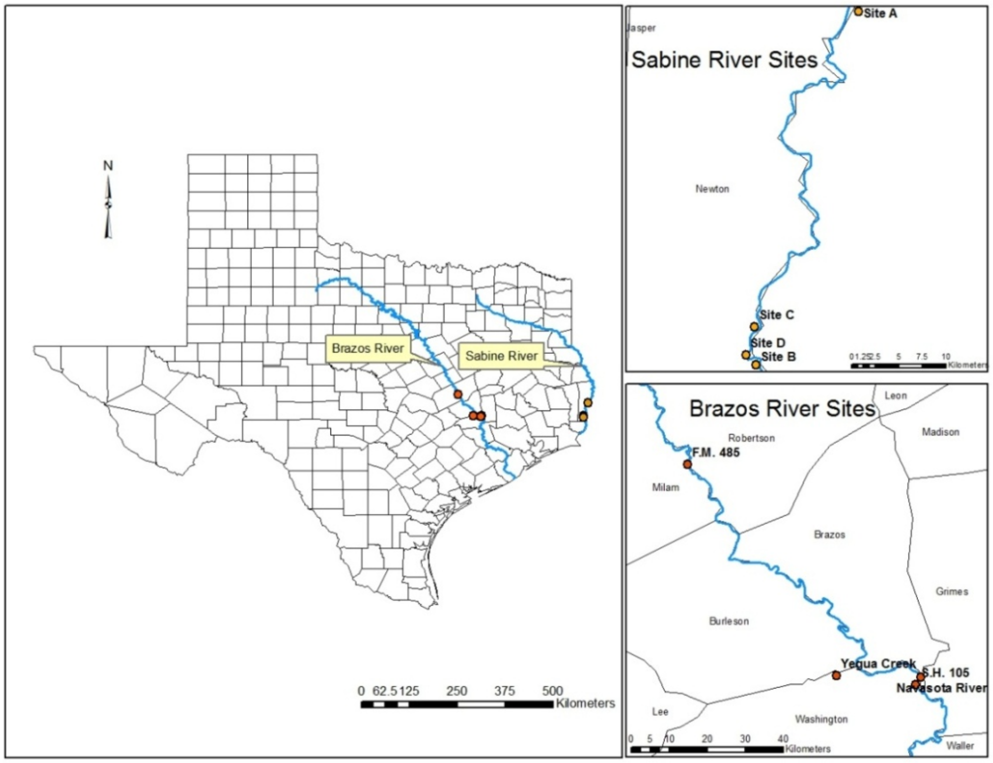

FIGURE 1. Map of sites surveyed on the lower Brazos and Sabine River drainages.

- Navasota River near SH 105 (Figure 4); Grimes and Washington Co., TX, sampled on 18 July 2008, 27 September 2008, and 4 April 2009

  (WGS84) 14R 0774511 3362672

- Yegua Creek at FM 50 (Figure 5); Washington Co., TX, sampled on 17 July 2008, 26 September 2008, 5 April 2009, and 13 May 2009

  (WGS84) 14R 0755388 3362626

Sabine River Basin

The Sabine River arises near Greenville east of Dallas and flows southeast becoming the state line near Logansport, Louisiana (Huser 2000). The Sabine River flows approximately 890 km before joining the Neches in Sabine Lake. The Sabine is impounded by three major dams, two on the main river (Lake Tawakoni and Toledo Bend Reservoir) and one (Lake Fork Reservoir) on Lake Fork Creek a major tributary (Huser 2000). Study sites are located on the Sabine River downstream of Toledo

Bend Reservoir in Newton County, TX (Figure 1). The following are locations sampled; asterisks denote sites that were relocated as a result of low river discharge:

- Site A (Figure 6); Newton Co., TX, sampled on 22 July 2008, 18 October 2008, and 14 February 2009

  (NAD83) 15R 0436959 3392690

- Site B (Figure 7); Newton Co., TX.

  (NAD83) 15R 0427405 3355624 – sampled on 23 July 2008

  (WGS84) 15R 0427402 3355629 – sampled on 16 October 2008 and 12 February 2009

- Site C (Figure 8); Newton Co., TX.

  (NAD83) 15R 0427278 3359587 – sampled on 24 July 2008

  (WGS84) 15R 0427278 3359580 – sampled on 17 October 2008

  (WGS84) 15R 0427245 3359705 – sampled on 13 February 2009

- Site D (Figure 9); Newton Co., TX; sampled on 12 February 2009

  (WGS84) 15R 0427797 3358925

FIGURE 2. Downstream photograph of sample site Br-485 (Brazos River near FM 485, Milam/Robertson Counties).

FIGURE 3. Left bank photograph of sample site Br-105 (Brazos River near SH 105, Grimes/Washington Counties).

FIGURE 4. Left bank photograph of sample site Na-105 (Navasota River near SH 105, Grimes/Washington Counties).

FIGURE 5. Downstream photograph of sample site Yegua Creek (Yegua Creek at FM 50, Washington County).

FIGURE 6. Right bank photograph of sample Site A (Sabine River, Newton County).

FIGURE 7. Right bank photograph of sample Site B (Sabine River, Newton County).

FIGURE 8. Left bank photograph of sample Site C (Sabine River, Newton County).

FIGURE 9. Right bank photograph of sample Site D (Sabine River, Newton County).

Mussel survey techniques

Systematic sampling with three random starts was chosen as the sampling method for quantifying mussel densities, species richness, and relative abundance of mussel beds for the first and last sampling periods. A two hour timed tactile search was used for sites on the Sabine River during the July 2008 sampling period because of a rapid rise in water levels associated with impoundment release. The two hour search time was chosen to ensure that less abundant species were sampled. For both methods, an initial non-timed tactile search was used to determine both the location of live mussels and their greatest densities. The presence of at least two live mussels was used as the criteria for determining transect placement. Once this location was identified a transect not exceeding 400 quadrats (e.g., 10 m x 10 m) was deployed. Transects were marked using four 1.83 m (6 ft) metal studded t-posts, nylon string was attached to demarcate the boundaries of the search area. Additionally, the four corners and the center of the transect were marked using a GPS. At each site, 0.25 m^2 quadrats were marked off within the transect using nylon string. Random numbers were drawn to determine the start location for systematically sampling freshwater mussels. A 0.25 m^2 quadrat made of PVC pipe was used to sample mussels every meter, moving in a horizontal and vertical direction from the starting location. Additionally, ten random quadrats were sampled in each transect to further characterize the association between unionids and their physical habitat. This method was chosen because it was impractical to systematically sample mussels, flow and substrate for four sample sites over four sample periods. The number of quadrats for random sampling was chosen based on a power analysis and concurrent work in the Trinity River. Specimens collected during our study were identified using standard taxonomic references (Howells et al. 1996; Parmalee and Bogan 1998). Average densities for each sample site and variance were calculated following Gilbert (1987). All taxonomy used in this project conforms to standards set by the American Fisheries

Society (Turgeon et al. 1998). A portion of the mussels collected were retained as vouchers. Voucher specimens were preserved in ethanol and deposited in the Joseph Britton Freshwater Mussel Collection, currently housed in the University of North Texas Elm Fork Natural Heritage Museum. Freshwater mussels not retained were carefully returned to the river as close as possible to where they were collected.

Habitat

Substrate

At each sampling site, twenty sediment cores were taken initially to characterize substrate particle size. Sediment cores were sampled every meter along a transect running parallel to the upstream and downstream portion of our search area. Sediment cores were collected using a 24.13 cm (9.5 inch) PVC pipe, 2.54 cm (1 inch) in diameter. The cores were collected by pushing the sampling tubes approximately 20.32 cm (8 inches) into the substrate, end caps were used to prevent loss of sample material while removing the PVC pipe. For the remaining sampling periods ten sediment cores were collected from randomly sampled quadrats (see section above detailing mussel survey techniques). All cores were placed on ice and then frozen upon return to UNT. After thawing, sediment samples were dried for 24 hours at 200 ºC, weighed, and then dry-sieved through a series of sieves (2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.125 mm, 0.0625 mm, 0.004 mm) using a sieve shaker for five minutes. Sediments that were clumped were milled using a mortar and pestle and then shaken for an additional five minutes. For each sample, the median particle size (d_{50}) was calculated by plotting the percentage of sediment in each sieve class using a cumulative arithmetic curve. The median grain size is that which separates 50% of the sample from the other. Grades for each sieve class follow the Wentworth grade scale.

Water velocity

Velocity (m/s) was measured at each sample site following TCEQ (2003) and Gore (2006). To initially characterize instream flow at each sample site a minimum of twenty flow measurements were made following the same sampling protocol as the sediment cores. For the remaining sampling periods 10 flow measurements were taken for each randomly sampled quadrat. When water depth was less than 60 cm, flow measurements were taken at 60% of the depth. Conversely, when water depth exceeded 60 cm, two measurements were made; one at 80% of the total depth and the other at 20% of the total depth.

Hydraulic variables

The effects of flowing water on mussel beds was evaluated using flow measures that describe the complex characteristics of moving water within a river. Froude number (Fr) describes the turbulence close to the water surface and is used to differentiate between streaming or shooting flows (Statzner et al. 1988). Froude number was calculated as:

$$Fr = V/(gD)^{0.5}$$

where V = velocity of flow (m/s), g = the acceleration due to gravity (m/s^2), and D = the depth of water (m). The turbulent structure of free flow is characterized by Reynolds number (Re); conceptually it can be thought of as the prevailing velocity of water passing through an object (Statzner et al. 1988). Reynolds number was calculated as:

$$Re = VD/\eta$$

where V is the velocity of the flow (m/s), D is the depth of water (m), and η is the kinematic viscosity of water (m^2/s). Roughness Reynolds number (Re_*) describes more accurately the flow conditions near the stream bottom and is used to differentiate between hydraulically smooth and rough flows. Roughness Reynolds number was calculated as:

$$Re_* = U_* k/\eta$$

$$\text{Where; } U_* = \sqrt{\frac{\tau_o}{\rho_w}}$$

where U_* is shear velocity, k is height of roughness projections which can be substituted with d_{50} (m), η is the kinematic viscosity of water (m^2/s), τ_o is shear stress (N/m^2), and ρ_w is the density of water (kg/m^3).

Bed stability

When the drag force of flow (shear stress) on an exposed particle exceeds the weight force of gravity holding that particle in place threshold entrainment occurs (*sensu* Lorang and Hauer 2003). Shear stress equations are used to estimate the force exerted by flow on the stream bottom, whereas critical shear stress equations are used to estimate the shear stress required for incipient motion. For this study shear stress (τ_o) was calculated as:

$$\tau_o = gSD\rho_w$$

where g = acceleration due to gravity (m/s^2), S = slope of water surface (dimensionless), D = depth of water (m), and ρ_w = density of water (kg/m^3). Although τ_o applies theoretically to uniform flow conditions it is considered useful for estimating shear stress at a specific locations relative to depth and flow (Lorang and Hauer, 2003).

The Shields (1936) entrainment function (τ_c), estimates the shear stress needed to initiate particle entrainment. Because, the Shields entrainment function was originally tested in flumes using quartz-density spheres of uniform size and controlled increases in flow velocity (Lorang and Hauer, 2003) variance arises when this equation is applied to data collected from natural systems. This is because bed material from a river is neither spherical nor uniform and flow conditions within a stream can be highly variable. To improve estimates of τ_c two derivations of Shield's equation was used to take into account particle size and angles of repose. Critical shear stress was enumerated using the following formulas:

$$\tau_c = \tau *_c \; d_*^{-0.6} g(\rho_s - \rho_w) d \tan\Phi \qquad \text{:For silts and sands}$$

$$\text{Where; } d_* = d_{50}[(G\text{-}1)g/\eta^2]^{1/3}$$

$$\tau_c = \tau *_c \; g(\rho_s - \rho_w) d_{50} \tan\Phi \qquad \text{:For gravels and cobbles}$$

where ρ_s is the density of the substrate particle (2.65 kg/m^3), ρ_w is the density of water (kg/m^3), g is acceleration due to gravity (m/s^2), d_{50} is the median sediment size (m), $\tau *_c$ is dimensionless critical sheer stress (0.25 for silts/sands and 0.06 for gravels and cobbles), Φ is the angle of repose of the particle (angles are given by Julien, 1995), η is the kinematic viscosity of water (m^2/s), and G is the specific gravity of sediment. Fischenich (2001) provides additional information regarding both of these derivations.

Sediment entrainment potential or relative substrate stability (RSS) for a given discharge and substratum profile can be evaluated by comparing τ_o and τ_c (Morales et al. 2006) and was calculated as:

$$\text{RSS} = \tau_o / \tau_c$$

where τ_o is shear stress (defined above) and τ_c is critical shear stress (see derivation listed above). The ratio between τ_o and τ_c integrates water depth, energy gradient or water-surface slope, median sediment-particle size, and critical shear stress. Unlike other hydraulic measures that are flow conditional (e.g., depth, water velocity, shear stress), RSS normalizes shear stress so that entrainment potential can be compared between sample sites and during different flow regimes. Morales et al. (2006) suggest that mussel densities will be greatest at sites where entrainment threshold is less than one and lowest in portions of a stream where RSS values are greater than one. However, critical shear stress is considered, at best, a minimum estimate of sediment entrainment potential therefore we calculated two entrainment thresholds following Elliot (2002):

Partial entrainment threshold (limited movement of d_{50} particles) - $\tau_o = \tau_c$

Complete entrainment threshold (complete movement of d_{50} particles) - $\tau_o = 2\tau_c$

Data analysis

Unless otherwise stated all statistical procedures used in this study were performed with the R statistical package (http://www.R-project.org). Since a number of sampled quadrats contained no live mussels abundance data was converted to presence/absence to control for quadrats that yielded high mussel densities. Because most of the predictor variables were non-normally distributed the non-parametric Kruskal-Wallis test was used to compare differences among measured hydraulic variables for different sampling periods. If a significant difference was found, Kruskalmc, a multiple comparison test, was used to examine which sample sites and sample periods were different. Siegel and Castellan (1988) provide additional information regarding the derivation and mechanics of this multiple comparisons test.   A classification and regression tree (CART) analysis was used to predict observed mussel abundances and absences for quadrats using simple and complex hydraulic measures as explanatory variables. Tree models are formed by splitting observations based on predictor variables to form a complex of nodes and branches; data is split into successive mutually exclusive groups based on decision rules that maximize homogeneity within a group (Zigler et al. 2008). Cross-validation is performed afterwards to determine the prediction error of the model and the appropriate number of groups (Quinn and Keough, 2008). Hydraulic parameters identified as being the most predictive for mussel presence and absence were then analyzed using a logistic regression. Universal Kriging using a spherical model was used for selected sample periods in the lower Brazos and Sabine River basins to visually demonstrate the relationship between Re_* or RSS and mussel distributions. Kriging is a technique of making optimal, unbiased estimates for variables in non-sampled points. Variance associated with estimates for non-sampled points was also calculated and graphed. Acevedo (2005) provides a detailed discussion of the mechanics and theory regarding Kriging. For the Sabine River, ordinary least squares regressions were used to model the relationship between RSS and discharge. It is important to note, because our predictor variable (e.g., discharge) was not fixed but our aim was for prediction model I regressions are considered appropriate (Quinn and Keough 2008).   For lower Brazos River drainage, predictor variables that were non-normally distributed were normalized using Box-Cox transformations. Habitat data from the lower Sabine River were normalized with Box-Cox or square root transformations. Effects for all statistical tests were considered significant a $p <$ 0.05.

RESULTS AND DISCUSSION

Unionid abundance in the lower Brazos and Sabine River drainages

Lower Brazos River drainage

During our survey of the lower Brazos River drainage thirteen unionid species and 1,086 individuals were collected during four sampling periods. The Navasota River near SH 105 had the highest densities of unionids whereas the Brazos River at FM 485 had the lowest (Table 1). The number of species per collection site ranged from 4 for both the Brazos River at FM 485 and the Brazos River at SH 105 to 8 species at the Yegua Creek site (Table 2). Interestingly, the site with the highest diversity also had significantly coarser substratum (χ^2 = 51.8929, p = 1.960e-09, Kruskal-Wallis test, Figure 10) compared to the remaining sampling sites. Recent studies have suggested that bed stability a function of grain size and shear stress is important for both juvenile and adult unionids (Hardison and Layzer 2001; Layzer and Madison 1995; Hardison and Layzer 2001). Strayer (1999b) hypothesized that mussel beds will generally occur in areas where shear stresses during floods with moderately long return periods are too low to displace unionids. Given the substrate composition and high density of unionids (14.11/0.25 m^2) at the Navasota site it is likely this mussel bed represents a refugia from high shear stresses during elevated flows. Also, noteworthy is the near absence of unionids from the the Brazos River at FM 485.   Previous studies at this site reported high mussel diversity (Karatayev and Burlakova 2008). During sampling in July 2008, large numbers of recently dead freshwater mussels indicated that a large die off had occurred prior to this study. There were no obvious changes to the habitat to explain this mortality. Nearby land owners encountered during the survey commented that a number of dead fish were observed recently along the margins of the river.

Two species of unionids were common to most of the sites sampled on the lower Brazos River drainage. *Leptodea fragilis* was documented at both sites on the Brazos River and at Yegua Creek but was absent from the Navasota site; this species was never abundant (Table 2). *Quadrula houstonensis* was documented at all four sampling sites but was most abundant at sites on the Navasota River and Yegua Creek. This species is listed as threatened by the American Fisheries Society (Howells et al. 1997; Williams et al. 1993). *Quadrula houstonensis* is known to occur in the Trinity, Colorado and Brazos Rivers and possibly the San Jacinto River (Howells et al. 1996; Howells et al. 1997). This species has been reported to inhabit substrate consisting of mixed mud, sand, and fine gravel (Howells et al. 1996). During this study *Q. houstonensis* was observed in sand (medium to coarse) and gravel/pebble substrates. Karatayev and Burlakova (2008) found this species in 5 water bodies in the Brazos River basin, suggesting that *Q. houstonensis* was abundant in the Brazos River and its tributaries. However, in general this species seems be declining in distribution throughout most of the Brazos River drainage (reviewed in Howells 2009). Two species considered uncommon were also documented during this survey. *Arcidens confragosus* is widely distributed in north central Texas but is rarely abundant (Howells 1997). This species is generally found in a sand or mud bottom in sluggish waters a few feet deep (references in Mather 1985). *Arcidens confragosus* was documented only at the Navasota River site which has a gravel substratum and sluggish flow. *Truncilla macrodon*, is a rare unionid mussel endemic to the Brazos and Colorado rivers of Central Texas (Howells et al. 1996; Howells et al.1997). Since its original description in the mid-1800s, fewer than 300 specimens have been documented. This species is listed as threatened by the American Fisheries Society (Howells et al. 1997; Williams et al. 1993). Additionally, both *Q. houstonensis* and *T. macrodon* are being petitioned for protection under the Federal Endangered Species Act (WildEarth Guardians 2008). *Truncilla macrodon* was found only at the Brazos River site near SH 105. Individuals collected were observed partially buried (approximately 5 mm to 10 mm) in soft sandy sediment on the left bank of the river. *Truncilla macrodon* was located by observing tracks in the substrate such that one individual, for example, was attached to a conglomeration of sand by proteinaceous threads. Live individuals for this species were collected throughout the duration of this study at our site on the Brazos River near SH 105. Thus, it is unlikely specimens collected were flood deposited between sampling events.

Lower Sabine River drainage

In total, 268 live mussels representing 12 species were documented at our sample sites, including two species considered threatened. The highest mussel densities were found at Site A during the first and second sampling periods, whereas Site D was numerically dominant for the last sampling event (Tables 3 and 4). Species richness was also greatest at Site A for both the July and October sampling periods while Site D had the highest species richness for the last sampling period. Interestingly, Sites A and D had significantly larger median grain sizes (d_{50}) among all other sites/dates sampled; Site B for sample period 12 February 2009 was the only exception ($\chi^2 = 51.015$, $p = 2.941e\text{-}09$, Kruskal-Wallis test, Figure 11). Morales et al. (2006) demonstrated that during high flows bed sediments comprised of small grains sizes (e.g., clay or silt) become unstable sooner than bed sediments comprised of larger grain sizes (e.g., coarse sand or gravel) at comparable water depths. In both their simulation and verification with field data mussel abundance was disproportionately greater in gravel substrates. For the Brazos and Sabine Rivers, high mussel densities consistently occurred at sites with larger median grain size. However, substrate stability is not absolute but instead varies based on level of discharge. For site A, unionid abundance declined following the second sampling

TABLE 1. List of average density (0.25 m^{-2}) and standard deviation ($s(\bar{x})$) for sample sites on the lower Brazos River drainage. Table includes results from systematic and random sampling.

Sample period	Sampling Site	Method of sampling	$\bar{x}$	$s(\bar{x})$	Sampling date
Sample period I	Br-485	Systematic	0.01	0.02	15-VII-2008
	Navasota	Systematic	14.11	1.11	18-VII-2008
	Yegua	Systematic	1.94	1.14	17-VII-2008
Sample period II	Br-105	Systematic	0.07	0.01	29-IX-2008
	Br-485	Random	0.00	0.00	28-IX-2008
	Br-105	Random	0.00	0.00	29-IX-2008
	Navasota	Random	14.50	13.83	27-IX-2008
	Yegua	Random	0.40	0.52	26-IX-2008
Sample period III	Br-485	Random	0.00	0.00	5-IV-2009
	Br-105	Random	0.00	0.00	4-IV-2009
	Navasota	Random	7.3	10.84	4-IV-2009
	Yegua	Random	1.5	2.95	5-IV-2009
Sample period IV	Yegua	Systematic	0.01	0.5	13-V-2009
	Br-485	Random	0.00	0.00	13-V-2009
	Br-105	Random	0.10	0.32	27-V-2009
	Yegua	Random	0.00	0.00	13-V-2009

period (Table 3). The drop in mussel abundance at this site may be a byproduct of our sampling or that bed instability was occurring between sampling periods. To evaluate whether mussels were being dislodged and entrained we surveyed woody debris immediately downstream of Site A. In total, 81 individuals representing 10 different species were collected. Species richness was similar to site A, but abundance was much greater in the woody debris (Table 5). Three species, *Glebula rotundata*, *L. fragilis*, and *Quadrula verrucosa* were found in the woody debris but not at Site A (Table 5). Within the woody debris, most of the collected mussels were partially buried on the downstream side of submerged logs. If these mussels were flood deposited their position within the woody debris suggest that movement occurred following deposition. Additionally, several mussels collected (Figure 12) showed significant loss of the periostracum (outer proteinaceous layer of the mussel shell) which can be an indicator of increased sediment load (Houp 1993; Miller et al. 1993). This also suggests that

TABLE 2. List of mussel species found at sample sites on the lower Brazos River drainage. Counts for species include only live individuals collected during systematic and random sampling except where noted. Asterisks denote mussels collected outside the transect but near the sampling area.

Species name	Common name	Br-485				OT	Br-105			OT	Navasota			Yegua				OT
		1	2	3	4		2	3	4		1	2	3	1	2	3	4	
Amblema plicata	Threeridge					1*					368	101	43	47	1	4	6	1*
Arcidens confragosus	Rock-Pocketbook										3							
Cyrtonaias tampicoensis	Tampico pearlymussel										12	6		10		1		1*
Lampsilis teres	Yellow sandshell										18	3		3			3	1*
Leptodea fragilis	Fragile papershell					1*				2*				2				1*
Megalonaias nervosa	Washboard										10	2	1					
Potamilus ohiensis	Pink papershell					1*												
Quadrula apiculata	Southern mapleleaf										115	16	13	15	1	4	4	
Quadrula houstonensis	Smooth pimpleback	1				12*	1				117	11	14	31	2	6	5	
Quadrula verrucosa	Pistolgrip										38	6	2					
Toxolasma parvus	Lilliput																	1*
Toxolasma texasiensis	Texas lilliput									1*								1*
Truncilla macrodon	Texas fawnsfoot						4		1	11*								
TOTAL		1				15	5		1	14	681	145	73	108	4	15	18	6

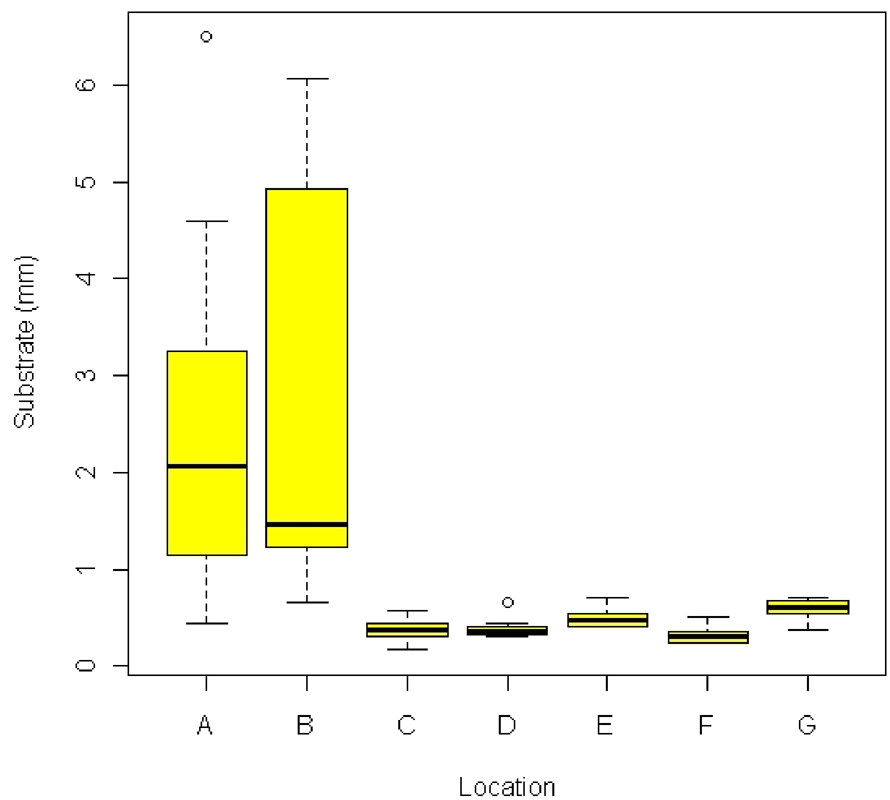

FIGURE 10. Box and whisker plot comparing sediment grain size (d_{50}) for randomly sampled quadrats on the lower Brazos River drainage. Letters denote the following; A) Navasota River-SH105, 4 April 2009; B) Navasota River- SH105, 27 September 2009; C) Brazos River-SH105, 4 April 2009; D) Brazos River-SH105, 29 September 2008; E) Yegua Creek-SH50, 26 September 2008; F) Yegua Creek-SH50, 13 May 2009; G) Yegua Creek-SH50, 5 April 2009.

mussels with signs of scouring were exposed to open channel flows at some point in time. In other words, these mussels did not always inhabit woody debris.

Two species of mussels were common to all sites surveyed on the lower Sabine (Table 4). *Lampsilis teres*, was present in high abundance at sites B, C and D and low abundance at Site A. This species is very mobile and was observed moving several feet towards deeper water following collection and placement near the shoreline. *Lampsils satura* was also found at all four sampling sites but never in abundance. The distribution of this species is reported to occur north and east of the San Jacinto River (Howells et al 1997). This species is reported to occur in small to large rivers with moderate flows on gravel, gravel-sand, and sand bottoms (Howells et al. 1996). During this study, *L. satura* was found inhabiting coarse to medium sand roughly 5 m from the river bank. *Fusconaia askewi*, was collected only at Site A and in woody debris approximately 15 meters downstream of this site. This species is known to

TABLE 3. List of average density (0.25 m^{-2}) and standard deviation ($s(\bar{x})$) for sample sites on the lower Sabine River. Table includes results from timed searches, systematic and random sampling.

Sample period	Sampling Site	Method of sampling	$\bar{x}$	$s(\bar{x})$	Sampling date
Sample period I	Site A	Timed search - 2 hrs	38/hour		21-VII-2008
	Site B	Timed search - 2 hrs	14/hour		23-VII-2008
	Site C	Timed search - 2 hrs	30/hour		24-VII-2008
Sample period II	Site A	Systematic	0.37	0.14	18-X-2008
	Site B	Systematic	0.01	0.01	16-X-2008
	Site C	Systematic	0.13	0.09	17-X-2008
	Site A	Random	0.30	0.48	18-X-2008
	Site B	Random	0.10	0.32	16-X-2008
	Site C	Random	0.20	0.63	17-X-2008
Sample period III	Site A	Systematic	0.04	0.04	14-II-2009
	Site B	Systematic	0.09	0.03	12-II-2009
	Site C	Systematic	0.08	0.03	13-II-2009
	Site D	Systematic	0.30	0.10	12-II-2009
	Site A	Random	0.20	0.63	14-II-2009
	Site B	Random	0.10	0.30	12-II-2009
	Site C	Random	0.00	0.00	13-II-2009
	Site D	Random	0.40	0.70	12-II-2009

occur in southeastern Texas, primarily in the Neches and Sabine (upstream of Toledo Bend reservoir) Rivers (Howells et al. 1997). Previous studies report that this species inhabits substrate consisting of mixed mud, sand, and fine gravel in protected areas associated with fallen trees (Howells et al. 1996). Site A, the only location where *F. askewi* was documented has a substratum comprised of coarse sand and is located in a protected area with several submerged stumps and other woody debris. Both *F. askewi* and *L. satura* are considered threatened by the American Fisheries Society (Howells et al. 1997; Williams et al. 1993).

TABLE 4. List of mussel species found at sample sites on the lower Sabine River. Counts for species include only live individuals collected during systematic and random sampling except where noted. Asterisks denote mussels collected outside the transect but near the sampling area.

Species name	Common name	Site A			Site B			OT	Site C			Site D	OT
		1	2	3	1	2	3		1	2	3	3	
Amblema plicata	Threeridge	1										2	
Fusconaia askewi	Texas pigtoe	6	1	1									
Lampsilis hydiana	Louisiana fatmucket	2	1										1*
Lampsilis satura	Sandbank pocketbook	2		1	2	1		1*	2	5	1	2	
Lampsilis teres	Yellow sandshell	1	7		26	1	8	1*	58	4	5	21	
Leptodea fragilis	Fragile Papershell						1	1*					1*
Plectomerus dombeyanus	Bankclimber												1*
Quadrula apiculata	Southern mapleleaf	4	4							1			
Quadrula mortoni	Western pimpleback	53	22	3						1		1	
Quadrula nobilis	Gulf mapleleaf	7	1										1*
Quadrula verrucosa	Pistolgrip												1*
Villosa lienosa	Little spectaclecase			1									
TOTAL		76	36	6	28	2	9	3	60	11	6	26	5

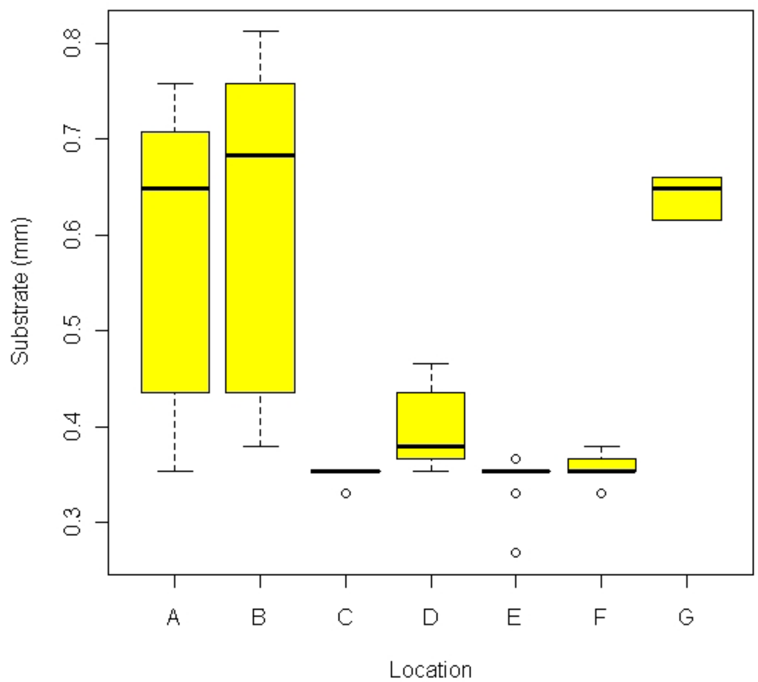

FIGURE 11. Box and whisker plot comparing sediment grain size (d_{50}) for randomly sampled quadrats on the lower Sabine River. Letters denote the following; A) Site A, 18 October 2008; B) Site A, 14 February 2009; C) Site B, 16 October 2008; D) Site B, 12 February 2009; E) Site C, 17 October 2008; F) Site C, 13 February 2009; G) Site D, 12 February 2009.

Historical records from the Tulane University Museum of Natural History

The Tulane University Museum of Natural History (TUMNH) archives collections of freshwater mussels taken in the Sabine River watershed from 1964 to 1982. Historical records from this collection encompass locations upstream and downstream of the Toledo Bend Reservoir. However, most of the preserved specimens and spent valves are from the lower Sabine watershed, either in the main channel or in nearby tributaries (Figure 13). For the lower Sabine River, most of the historical surveys were performed near or within Anacoco Bayou, Beauregard Parish, LA.

In total, 977 individual mussels representing 19 species were identified from specimens curated at the Tulane University Museum of Natural History (Table 6). Historical records from the main channel indicate that 14 mussel species were present on the lower Sabine. Vidrine (1993) reported 20 species along the lower Sabine River in Newton and Orange Counties, TX (Table 7). *Arcidens confragosus*, *Megalonaias nervosa*, *Obliquaria reflexa*, *Obovaria jacksoniana*, *Potamilus amphichaenus*, *Potamilus purpuratus*, *Quadrula nodulata*, *Strophitus undulatus*, *Truncilla truncata* and *Uniomerus declivis* were documented from either TUMNH and/or collections by Vidrine (1993) but were not found during this study. Additionally, *Arcidens confragosus* represents a new record not reported by Vidrine (1993). For Anacoco Bayou, 14 species were documented from TUMNH, while Vidrine (1993) reported 17 unionid species. *Obliquaria reflexa* and *Truncilla donaciformis* were found only in the Tulane mussel collection.

Based on the historical records from TUMNH, informal collections by Vidrine (1993) and our study, the presence of 31 species is now recorded for the lower Sabine River.

Table 5. List of unionid species and their relative abundance found within woody debris downstream of Site A.

Species name	Common name	Total number found	Relative abundance
Fusconaia spp.		3	0.04
Fusconaia askewi	Texas pigtoe	7	0.09
Glebula rotundata	Round pearlshell	1	0.01
Lampsilis hydiana	Louisiana fatmucket	2	0.02
Lampsilis satura	Sandbank pocketbook	1	0.01
Lampsilis teres	Yellow sandshell	12	0.15
Leptodea fragilis	Fragile papershell	1	0.01
Quadrula mortoni	Western pimpleback	41	0.51
Quadrula nobilis	Gulf mapleleaf	9	0.11
Quadrula verrucosa	Pistolgrip	1	0.01
Villosa lienosa	Little spectaclecase	3	0.04
TOTAL		81	

FIGURE 12. Picture of live *Quadrula mortoni* collected from woody debris downstream of Site A.

Several species recorded in the TUMNH collection are considered threatened by the American Fisheries Society (Howells et al. 1997; Williams et al. 1993) and are considered extremely rare in Texas. None of these species were collected during our survey. *Obovaria jacksoniana* has been reported to occur in the Neches, Sabine and possibly eastern portions of the Red River and associated tributaries (Howells et al. 1997). This species is currently under petition for protection under the U.S. Endangered Species Act (WildEarth Guardians 2008). Since 2001, no live individuals have been found in Texas (Bordelon and Harrel 2004; Howells 2009). *Obovaria. jacksoniana* was recorded for the lower Sabine and in Anacoco Bayou. *Pleurobema riddellii* historically occurred throughout a number of east Texas Rivers, but habitat degradation is thought to have eliminated many of these populations (Howells et al. 1997). Since 1992, only a few live individuals have been collected and all of them were from the Neches River drainage (Howells 2009). This species was documented only at historical sites within Anacoco Bayou. *Potamilus amphichaenus* is endemic to the Sabine, Neches and Trinity Rivers (Howells et al. 1997; Howells 2009). This species has been collected in the upper Sabine in multiple counties (Howells 2006; Karatyev and Burlakova 2007). The presence of *P. amphichaenus* was recorded for one historical site, located within Toldeo Bend Reservoir. For the lower Sabine, Vidrine (1993) reported collecting this species above Anacoco Bayou.

Habitat and unionid abundance

Lower Brazos River drainage

During our survey of the lower Brazos River drainage sampling events occurred primarily under low flow conditions (Table 8). Overall, mean depth and water velocity were greatest for the Brazos River at FM 485. Both the Navasota and Brazos Rivers near SH 105 had the lowest water velocity whereas Yegua Creek near SH 50 had the lowest mean water depth (Table 8). Substrate for sample sites ranged from pebbles at the Brazos River at FM 485 to medium sand for the Brazos River near SH 105 and Yegua Creek at SH 50. Previous studies in this area observed that mussels were most often collected at shallow depths on soft substrate (Karatayev and Burlakova 2008). During this survey, mussels were collected primarily in habitats with coarse substrate, at shallow depths, and low water velocity (Figure 14). In general these findings agree with previous studies that report unionids are most often found in coarser substrates (e.g., McRae et al 2004; Morales et al. 2006; Strayer 1999b) at shallow to intermediate water depths (e.g., Read and Oliver 1953, Strayer 1981, Strayer 1999b; reviewed in McMahon and Bogan 2001). Despite these preferences, studies linking simple habitat variables such as water depth, grain size, and water velocity with mussel distributions have been largely unsuccessful (Holland-Bartels 1990; Strayer 1981; Strayer and Ralley 1993; Strayer 1999b). Instead, measures that integrate the interactions between substrate and near-bed flow have shown promise for predicting unionid occurrence (Morales et al. 2006; Zigler et al. 2008).

Table 6. Tulane University of Natural history records of unionids for the Sabine River. Sample locations are referred to by collection numbers denoted by the prefix RDS; sampling dates are listed below collection numbers. Mussel species that were represented only by spent valves are denoted with "á", mussel species that what were represented by both spent valves and preserved specimens are indicated by the "b".

Species	Common name	RDS 3529 12 July 1964	RDS 3534 14 July 1964	RDS 4580 23 July 1969	RDS 4581 23 July 1969	RDS 4582 23 July 1969	RDS 4585 24 July 1969	RDS 4587 24 July 1969	RDS 4606 27 August 1969
Amblema plicata	Threeridge	X	X						X[a]
Arcidens confragosus	Rock pocketbook								X[a]
Fusconaia askewi	Texas pigtoe	X	X						X[b]
Lampsilis hydiana	Louisiana fatmucket		X						
Lampsilis satura	Sandbank pocketbook	X	X					X	X[a]
Lampsilis teres	Yellow sandshell	X	X	X	X	X	X		X[a]
Leptodea fragilis	Fragile papershell		X						
Megalonaias nervosa	Washboard		X						X[a]
Obliquaria reflexa	Threehorn wartyback	X							
Obovaria jacksoniana	Southern hickorynut		X						
Plectomerus dombeyanus	Bankclimber		X						
Potamilus amphichaenus	Texas heelsplitter	X							
Potamilus purpuratus	Bleufer		X						
Quadrula mortoni	Western pimpleback	X	X					X	X[b]
Quadrula verrucosa	Pistolgrip	X							

Species	Common name	RDS 4615 29 August 1969	RDS 4616 29 August 1969	RDS 4804 8 August 1970	RDS 4806 9 August 1970	RDS 4807 9 August 1970	RDS 4808 9 August 1970	RDS 4812 20 August 1970	RDS 4813 20 August 1970
Amblema plicata	Threeridge	X	X	X	X		X		X
Fusconaia askewi	Texas pigtoe	X	X	X	X	X	X	X	X
Lampsilis hydiana	Louisiana fatmucket	X	X	X	X	X	X	X	X
Lampsilis satura	Sandbank pocketbook	X	X	X	X	X	X	X	X

Table 6. Continuation of historical records for the Sabine River.

Lampsilis teres	Yellow sandshell	X	X	X	X	X	X	X	
Liguima subrostrata	Pondmussel								X
Obliquaria reflexa	Threehorn wartyback		X				X		X
Obovaria jacksoniana	Southern hickorynut	X		X	X	X		X	X
Pleurobema riddellii	Louisiana pigtoe		X		X				
Potamilus purpuratus	Bleufer			X	X		X		X
Quadrula mortoni	Western pimpleback	X	X	X	X	X	X	X	X
Quadrula verrucosa	Pistolgrip	X	X		X			X	
Truncilla donaciformis	Fawnsfoot								X
Villosa lienosa	Little spectaclecase	X		X	X	X	X	X	X

Table 6. Continuation of historical records for the Sabine River.

Species	Common name	RDS 4816 21 August 1970	RDS 5322 6 October 1972	RDS 8003 19 September 1982	RDS 9998 28 August 1969	RDS 9999* 28 August 1969	RDS 9997* 28 August 1969
Amblema plicata	Threeridge	X	X	X		X[a]	
Fusconaia askewi	Texas pigtoe	X	X	X	X	X[a]	X[a]
Lampsilis hydiana	Louisiana fatmucket	X					
Lampsilis satura	Sandbank pocketbook		X			X[a]	
Lampsilis teres	Yellow sandshell	X	X	X		X[a]	X[a]

Leptodea fragilis	Fragile papershell					X[a]	
Obliquaria reflexa	Threehorn wartyback					X[a]	
Obovaria jacksoniana	Southern hickorynut	X					
Plectomerus dombeyanus	Bankclimber			X		X[a]	X[a]
Potamilus purpuratus	Bleufer					X[a]	
Quadrula mortoni	Western pimpleback	X	X		X	X[a]	
Quadrula nobilis	Gulf mapleleaf					X[a]	
Quadrula verrucosa	Pistolgrip			X			

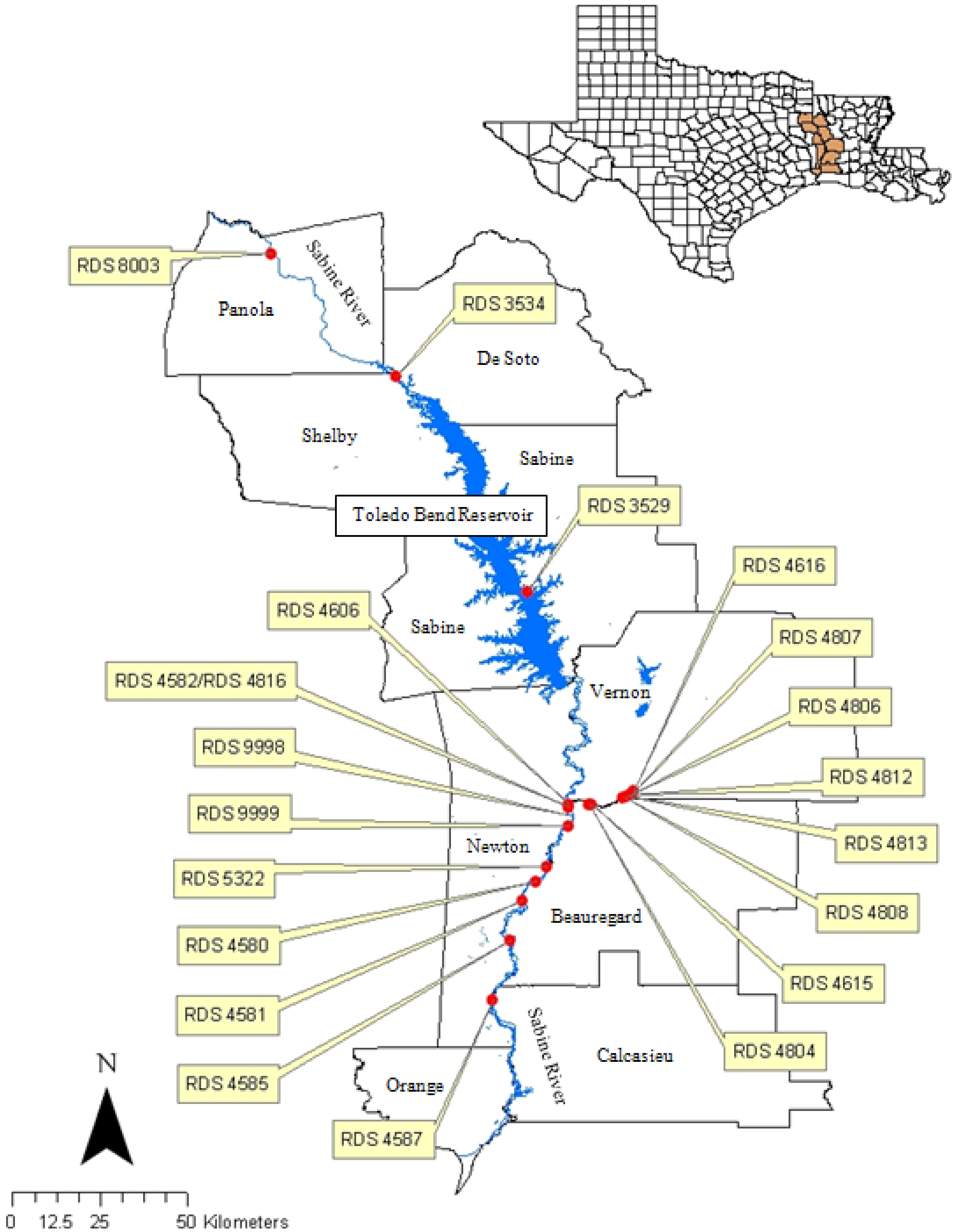

FIGURE 13. Map of historical survey sites on the Sabine River. Sample sites are denoted by red circles and collection numbers are annotated in yellow boxes. RDS 9997 is not plotted because specific location data was not provided.

TABLE 7. Lower Sabine River species richness from previous studies and total number of live individuals collected from present survey. Mussel species that were represented only by spent valves are denoted with the letter S. Asterisks denote species represented by both spent vales and preserved specimens. Total counts include all live individuals from each sample site; this includes mussels found outside but near the sampling stations. *Fusconaia* spp. collected from the woody debris was not included in this total. It is important to note that this table summarizes known unionid records for this basin. It does not evaluate taxonomic turnover.

Species	Common name	TNHM		Vidrine-1993		Present study-lower Sabine River			
		Anacoco	Sabine	Anacoco	Sabine	A	B	C	D
Amblema plicata	Threeridge	X	X*	X	X	1			2
Arcidens confragosus	Rock pocketbook	-	S	-	-	-	-	-	-
Fusconaia askewi	Texas pigtoe	X	X*	X	X	15	-	-	-
Glebula rotundata	Round pearlshell	-	-	-	X	1	-	-	-
Lampsilis hydiana	Louisiana fatmucket	X	X	X	X	5	-	-	1
Lampsilis satura	Sandbank pocketbook	X	X*	X	X	4	4	8	2
Lampsilis teres	Yellow sandshell	X	X*	X	X	20	36	67	21
Leptodea fragilis	Fragile papershell	-	S	-	X	1	2	-	1
Ligumia subrostrata	Pondmussel	X	-	X	-	-	-	-	-
Megalonaias nervosa	Washboard	-	S	-	X	-	-	-	-
Obliquaria reflexa	Threehorn wartyback	X	S	-	-	-	-	-	-
Obovaria jacksoniana	Southern hickorynut	X	X	X	-	-	-	-	-
Plectomerus dombeyanus	Bankclimber	-	S	-	X	-	-	-	1
Pleurobema riddellii	Louisiana pigtoe	X	-	X	X	-	-	-	-
Potamilus amphichaenus	Texas heelsplitter	-	-	-	X	-	-	-	-
Potamilus purpuratus	Bleufer	X	S	X	X	-	-	-	-
Pyganodon grandis	Giant floater	-	-	X	-	-	-	-	-
Quadrula apiculata	Southern mapleleaf	-	-	-	X	8	-	1	-
Quadrula mortoni	Western pimpleback	X	X*	X	X	119	-	1	1
Quadrula nobilis	Gulf mapleleaf	-	S	-	X	17	-	-	1
Quadrula nodulata	Wartyback	-	-	-	X	-	-	-	-
Quadrula verrucosa	Pistolgrip	X	-	X	X	1	-	-	1
Strophitus undulatus	Creeper	-	-	-	X	-	-	-	-
Toxolasma parvus	Lilliput	-	-	X	-	-	-	-	-
Toxolasma texasiensis	Texas lilliput	-	-	X	-	-	-	-	-
Truncilla donaciformis	Fawnsfoot	X	-	-	-	-	-	-	-
Truncilla truncata	Deertoe	-	-	-	X	-	-	-	-
Uniomerus declivis	Tapered pondhorn	-	-	-	X	-	-	-	-
Uniomerus tetralasmus	Pondhorn	-	-	X	-	-	-	-	-
Utterbackia imbecillis	Paper pondshell	-	-	X	-	-	-	-	-
Villosa lienosa	Little spectaclecase	X	-	X	-	4	-	-	-

TABLE 8. Summary of habitat variables measured for sample sites within lower the lower Brazos River drainage; standard deviations (± 1) are listed within brackets. Letters for sediment grade denote the follow; P) Pebble; G) Gravel; VCS) Very coarse sand; CS) Coarse sand; MS) Medium sand.

Sample site	Date sampled	*d50* (*mm*)	Grade	Mean water velocity (*m/s*)	Mean discharge (m^3/s)	Mean depth (*m*)	*RSS*	Fr	Re_*
BR-485	15-VII-2008	4.59	P	0.25 (0.15)	0.08 (0.07)	0.29 (0.12)	0.09	0.15 (0.08)	104.27
BR-485	28-IX-2008	8.57	P	0.85 (0.13)	0.42 (0.14)	0.49 (0.11)	0.08	0.39 (0.04)	248.39
BR-485	5-IV-2009	6.49	P	0.66 (0.17)	0.22 (0.11)	0.32 (0.09)	0.07	0.37 (0.05)	131.72
BR-485	13-V-2009	5.66	P	0.66 (0.17)	0.17 (0.04)	0.25 (0.05)	0.07	0.42 (0.13)	126.85
BR-105	29-IX-2008	0.38	MS	0.01 (0.01)	0.002 (0.002)	0.18 (0.03)	0.36	0.009 (0.01)	5.77
BR-105	4-IV-2009	0.35	MS	0.002 (0.004)	0.001 (0.001)	0.19 (0.11)	0.38	0.001 (0.002)	4.56
BR-105	27-V-2009	0.38	MS	0.42 (0.04)	0.16 (0.03)	0.39 (0.05)	0.84	0.22 (0.02)	10.43
Navasota	18-VII-2008	2.30	G	0.01 (0.01)	0.001 (0.002)	0.19 (0.10)	0.13	0.008 (0.01)	44.76
Navasota	27-IX-2008	2.30	G	0.01 (0.02)	0.002 (0.003)	0.16 (0.08)	0.11	0.01 (0.02)	41.16
Navasota	4-IV-2009	2.00	G/VCS	0.02 (0.04)	0.003 (0.01)	0.17 (0.11)	0.14	0.02 (0.04)	34.40
Yegua	17-VII-2008	0.32	MS	0.17 (0.06)	0.01 (0.01)	0.06 (0.02)	0.20	0.21 (0.08)	3.52
Yegua	26-IX-2008	0.47	MS	0.15 (0.05)	0.01 (0.004)	0.07 (0.02)	0.13	0.19 (0.06)	4.82
Yegua	5-IV-2009	0.62	CS	0.15 (0.06)	0.03 (0.01)	0.18 (0.07)	0.29	0.12 (0.05)	8.17
Yegua	13-V-2009	0.31	MS	0.11 (0.06)	0.05 (0.02)	0.43 (0.08)	1.00	0.42 (0.13)	8.20

CART analysis and logistic regression

To explore how mussels are distributed with regards to their physical habitat survey data was analyzed using CART models. Predictor variables used in our analysis are listed in the methods section; water velocity, discharge, substrate type, and depth were also included. Abundance data was converted to presence/absence because we were interested in the overall relationship between habitat and mussel distribution. Data from the Brazos River at SH 105 for sampling period 27-V-2009 was omitted because sampling occurred under high flow conditions. Our reasoning for doing this was because the predictor variables used in the CART analysis are predicated on discharge (e.g., depth and water velocity), therefore significant differences in flow between sites may confound our ability to construct reliable models for low flow conditions. Also, data for the Brazos River near FM 485 was removed

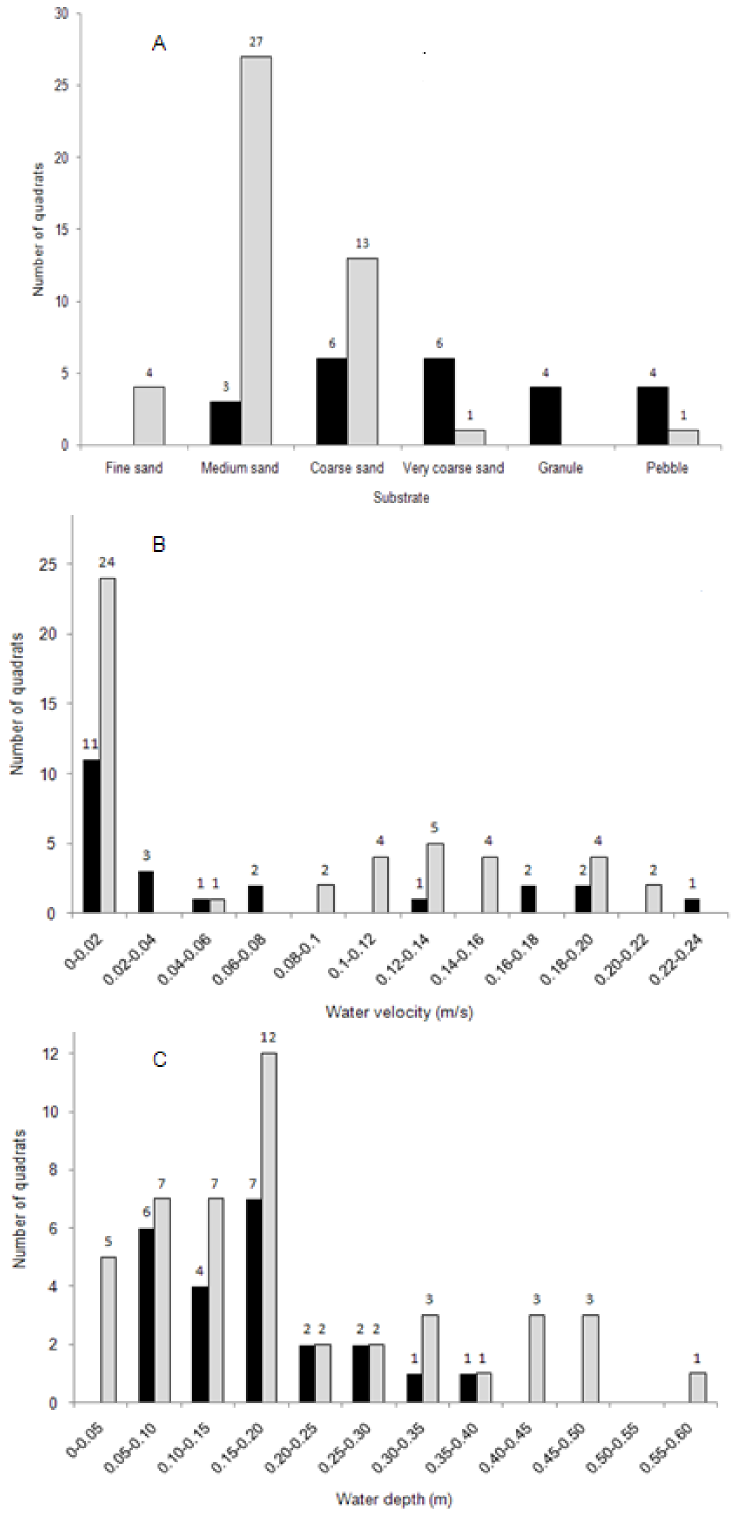

FIGURE 14. Number of quadrats with live mussels for different substrate types (A), water velocities (B), and water depth (C). Black shading denotes quadrats with mussels whereas grey shading represents quadrats without mussels.

because it was unclear whether the absence of mussels from this site was because of sampling methodology, unfavorable habitat, natural senescence, or an unknown environmental contaminant. Logistic regression was then used to build a predictive model for mussel occurrence using the most explanatory variable identified from our CART analysis.

Overall, correct classification of the data used to build the model for presence/absence of mussels within quadrats was 87 %. Cross-validation success for sampling locations ranged from 90 to 70 % (Table 9). Results from the model indicate that both roughness Reynolds number (Re_*) and Froude

TABLE 9. Cross-validated prediction success of classification tree models of presence/absence of mussels in the lower Brazos River drainage.

Sample site	Date	Prediction success (%)		
		Presence	Absence	Overall
BR105	29-IX-2008	N/A	100	100
BR105	4-IV-2009	N/A	100	100
Navasota	27-IX-2008	89	100	90
Navasota	4-IV-2009	100	67	90
Yegua	26-IX-2008	100	50	70
Yegua	5-IV-2009	67	71	70
Yegua	13-V-2009	N/A	90	90

number (Fr) were the most predictive variables for mussel presence/absence (Figure 15). Moreover, quadrats that had Re_* numbers greater than or equal to 11.01 had a higher occurrence of unionids. For sites with Re_* values less than 11.01, Froude numbers greater than or equal to15.01 were the most predictive for mussel occurrence (Figure 15). As described previously, roughness Reynolds number (Re_*) is used to differentiate between hydraulically smooth and rough flows. Hydraulically smooth flow occurs when Re_* is less than 5, transitional flows occur when Re_* is between 5 and 70, and hydraulically rough flow occurs when $Re_*$is greater than 70 (*sensu* Davis and Barmuta 1989). Roughness Reynolds number for sample sites on the lower Brazos ranged from hydraulically rough (Brazos River at FM 485) to smooth/transitional flows (Yegua Creek and the Brazos River near SH 105). Froude numbers for all sampling periods were less than 1 indicating subcritical flow (*sensu* Davis and Barmuta 1989). Logistic regression between Re_* and mussel presence/absence (Figure 16) was significant ($\chi^2 = 32.85$, $p= 5.11e-09$). The model indicates that 38 % of uncertainty in the presence of unionids in the lower Brazos River drainage can be explained by Re_*. Overall, the model correctly classified 86 % of the presence/absence cases. Additionally, correct classification of mussel occurrence was 65% whereas correct classification of mussel absence was 98 %. The relationship between Re and mussel presence/absence was described as:

$$\text{logit}(p) = -12.218 + 7.158(Re_*)^{0.21}$$

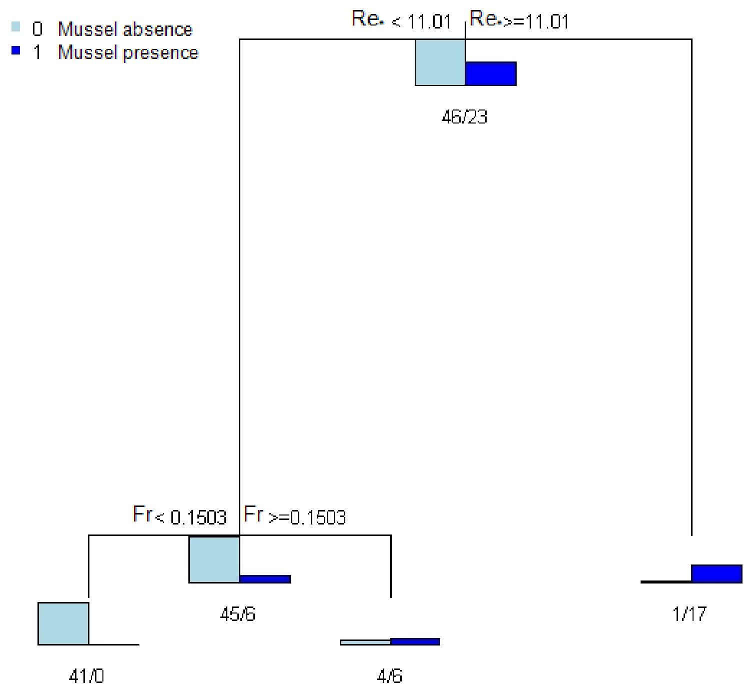

FIGURE 15. Classification tree model of mussel presence and absence in the lower Brazos River drainage. Box plots for each node denote the total number of quadrats with and without mussels; dark blue bars represent mussel presence whereas light blue bars denote mussel absence. Numbers listed below each plot represent the number of quadrats for each category.

For a particle resting on the stream bed the drag and lift forces are partially explained by the roughness Reynolds number (Jowett 2003). Similarly, Re_* values can be used to describe the hydraulic patchiness that occurs near the stream bed as a result of flows moving around and through substrate elements. Davis and Barmuta (1989) noted that benthic organisms living on the upstream side of rocks or boulders should experience greater flows than those on the downstream side during high Re_* situations. They proposed that as Re_* values increase so does the complexity of the micro-flow environment near the stream bed (Davis and Barmuta 1989). Brooks et al. (2005) observed that collector gatherers and scrapers increased in abundance when Re_* values were low, whereas filter feeders were more numerically dominate for mid range Re_* values; they suggested that for high Re_* values the metabolic cost of high flows (i.e., energy needed to maintain position) may limit species richness and abundance. Moreover, several studies have noted the positive correlation between Re_*, species richness, and abundance (Growns and Davis 1994; Jowett 2003; Quinn and Hickey 1994). However, this correlation does break down during periods of high discharge (e.g., Brooks et al. 2005). Steuer et al. (2008) noted that Re_* was the most useful predictor of high mussel densities during low flow. They hypothesized that because Re_* describes turbulence near the stream bed, low Re_* values may indicate stagnant instream conditions during which waste products are not removed. Decreases in velocity and turbulence near the stream bed

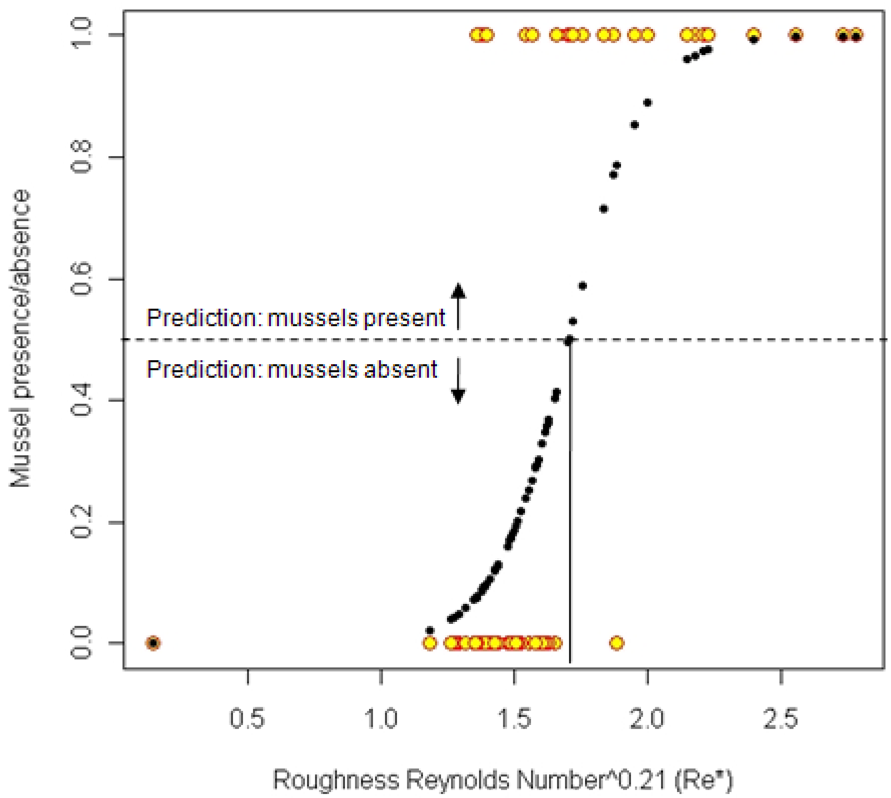

FIGURE 16. Logistic regression between mussel presence/absence and roughness Reynolds number (Re_*). Symbols listed in graph denote the following: continuous line of black circles indicates the probability of mussel occurrence, the horizontal checkered line denotes 50 % probability, and the black vertical line denotes a threshold for roughness Reynolds number and mussel presence.

may also reduce the availability of seston for filter feeders and affect the exchange between surface and interstitial water (Growns and Davis 1994; Quinn and Hickey 1994; Steuer et al. 2008). Because unionids can also obtain food by deposit or pedal-feeding activity, decreases in exchange rates between pore water and surface water may have a deleterious effect on unionid populations. Geist and Auerswald (2007) observed that habitat quality for juvenile mussels was governed by the physical connectivity between free flowing water and the interstitial zone. This suggests, that during low river discharge recruitment success should be low in portions of a stream where this exchange does not occur (i.e., low Re_* conditions). Given the importance of near bed flow for benthic organisms, the results of this study suggest that a minimum Re_* threshold may exist for unionids inhabiting the lower Brazos River drainage. For portions within a stream where Re_* is less than this threshold, near-bed velocities may not meet the physiochemical requirements needed to maintain existing or future mussel populations.

Further work is needed to delineate both species specific and stream specific minimum thresholds. Our model was predictive for the general occurrence of unionids in the lower Brazos River drainage but differences in hydrology and geomorphology for different streams should affect minimum as well as maximum thresholds. For example, substrate at Yegua Creek is primarily coarse to medium sand whereas the substratum for the Navasota is dominated by gravel. Differences in substrate between these sites should certainly influence the flow near the stream bed. Moreover, all of the mussels identified below the minimum threshold value of our model are either from Yegua Creek or the Brazos River near Hwy 105. However, for those sites mussel presence occurred in quadrats with large Re_* values. For example, during the first sampling period on Yegua Creek mussel occurrence and abundance was highest in portions of the stream where Re_* values were greater than 3.98 (Figure 17). Below this value mussel

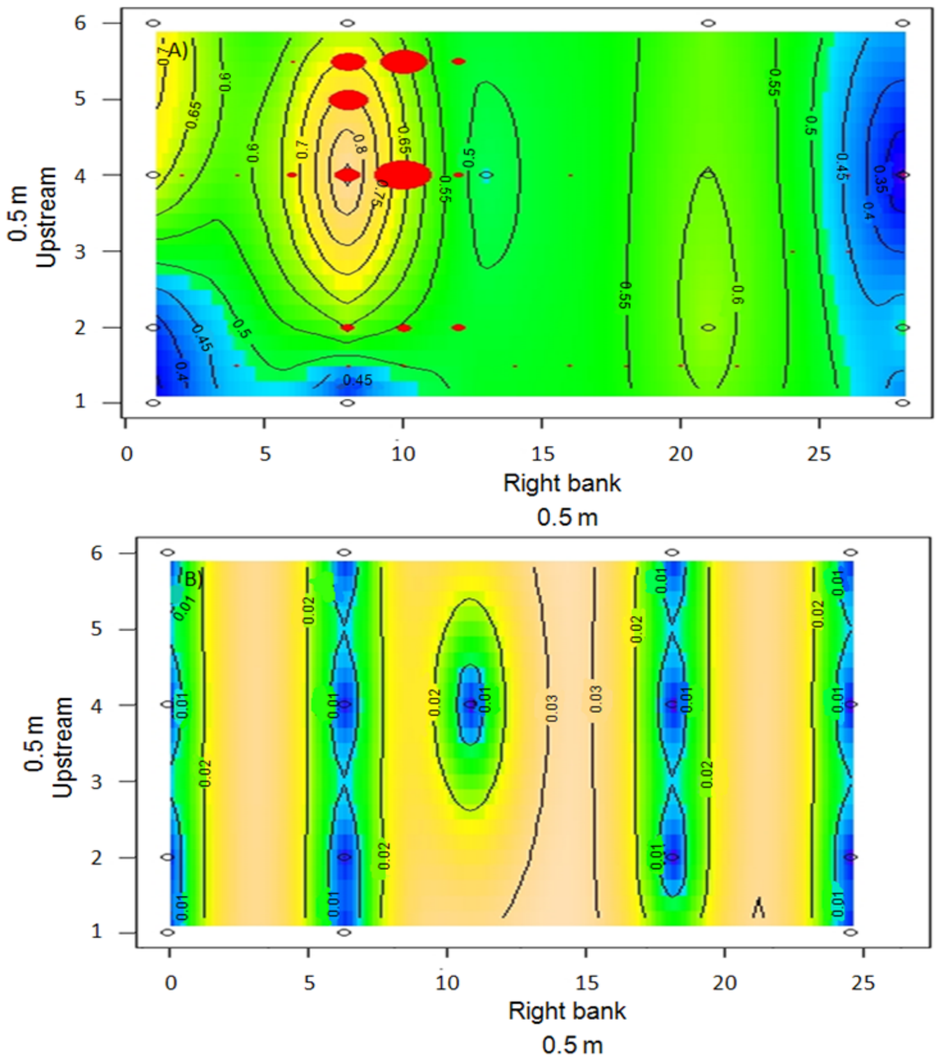

FIGURE 17. Re_* level contours and heat map by Kriging Method for Yegua Creek (17-VII-2008). Red ellipses indicate approximate locations for mussels collected during systematic sampling; ellipse size is constrained by the number of mussels collected. Data was normalized using Log transformations. Estimation variance (sq. Re_*) by Kriging is listed in graph B. In general, the greatest abundance of mussels was found in portions of the stream where Re_* values were greater than 0.6 (or 3.98). The estimation variance was generally low but increased in the middle of the transect which had fewer observations.

abundance and distribution declined. Importantly, while RSS was not predictive for mussel occurrence during low flows, data from Yegua Creek and the Brazos River near SH 105 for the last sampling period indicate that partial bed movement may have been occurring (Table 8). River discharge during this sampling period still appeared low and bed movement was not observed. However, prior to the last study period at Yegua Creek high river discharge did occur, removing more than half of the sand substratum within our sampling area. This probably explains the decline in mussel abundance for this site (Table 1).

Lower Sabine River drainage

During our survey of the lower Sabine River, sampling occurred under both high and low flow conditions (Table 10). River discharge and water depth were greatest at Site B and lowest at Site C during high flows, whereas during low flow discharge and water depth were greatest at Site B and lowest at Site A (Table 9). Substrate grades ranged from coarse sand at sites A and D to medium sand at sites B and C. Because thresholds for entrainment are predicated on grain size, sample sites with larger median particle sizes should be more stable under high flows than sites with smaller median particle sizes (Morales et al. 2006). During the first sampling period entrainment potential increased to more than twice the critical value ($\tau_o = 2\tau_c$) at sites B and C. For Site A, entrainment potential remained below the threshold for complete movement of d_{50} particles (Figure 18). This suggests that the substratum at Site A remained relatively stable compared to sites B and C for similar discharge. It is important to realize that sediment stability is not absolute but varies depending on the stage of water. For Site A, river discharge continued to increase throughout the first sampling period, therefore it is likely that bed instability did occur during these higher flows (Figure 19). Nevertheless, Site A did have the highest abundance of unionids and species richness for the first two sampling periods (Tables 3 and 4). However, mussel abundance did decline for the last sampling event. This decrease in abundance may be partially related to our sampling but also an artifact of increased impoundment release. Thus, areas that have stable sediment for one stage of water may have unstable sediments at another. Because unionids are long-lived and relatively immobile, flood events that are especially intense or too frequent may eliminate existing populations (Strayer, 1999b). Strayer (1999b) observed that higher mussel densities occurred in portions of a stream with low shear stresses during high river discharge and suggested that mussel beds will be generally found in areas where shear stresses during floods with moderately long return periods remain low. Given the episodic nature of discharge for the lower Sabine, it is likely that substantial mussel beds will only occur in areas that remain stable during higher periods of river discharge. Moreover, this highlights the importance of habitat structures, such as woody debris, that increases sediment stability. For sites B and C, low mussel densities are probably related to two factors, substrate instability during high flows and rapid fluctuations in water depth associated during low flows. During the second and third sampling period sites B and C had to be moved to accommodate decreases in river discharge. Recent studies have noted that following a drawdown mussels that are either stranded or reside in shallow waters are exposed to increased predation, harvest, desiccation and temperature extremes

TABLE 10. Summary of habitat variables measured for sample sites within lower the lower Sabine River drainage; standard deviations (± 1) are listed within brackets. Letters for sediment grade denote the follow; CS) Coarse sand and MS) Medium sand.

Sample site	Date sampled	*d50* (*mm*)	Grade	Mean water velocity (*m/s*)	Mean discharge (m^3/s)	Mean depth (*m*)	*RSS*	Fr	Re_*
Site A	22-VII-2008	0.70	CS	0.47 (0.09)	0.35 (0.07)	0.75 (0.15)	1.24	0.18 (0.04)	24.44
Site A	18-X-2008	0.57	CS	0.21 (0.10)	0.06 (0.04)	0.27 (0.06)	0.45	0.12 (0.05)	10.81
Site A	14-II-2009	0.62	CS	0.26 (0.08)	0.10 (0.04)	0.42 (0.07)	0.67	0.13 (0.04)	13.02
Site B	23-VII-2008	0.30	MS	0.35 (0.11)	0.40 (0.20)	1.04 (0.38)	2.36	0.11 (0.03)	11.83
Site B	16-X-2008	0.35	MS	0.32 (0.05)	0.17 (0.04)	0.53 (0.12)	1.14	0.14 (0.04)	9.17
Site B	12-II-2009	0.38	MS	0.23 (0.07)	0.10 (0.04)	0.44 (0.09)	0.87	0.11 (0.03)	8.08
Site C	24-VII-2008	0.35	MS	0.32 (0.12)	0.27 (0.19)	0.74 (0.42)	1.63	0.12 (0.05)	11.55
Site C	17-X-2008	0.35	MS	0.07 (0.05)	0.05 (0.04)	0.70 (0.31)	1.49	0.03 (0.02)	9.89
Site C	13-II-2009	0.35	MS	0.12 (0.05)	0.06 (0.03)	0.48 (0.23)	0.99	0.06 (0.03)	7.56
Site D	12-II-2009	0.66	CS	0.24 (0.07)	0.11 (0.04)	0.42 (0.03)	0.63	0.12 (0.03)	12.56

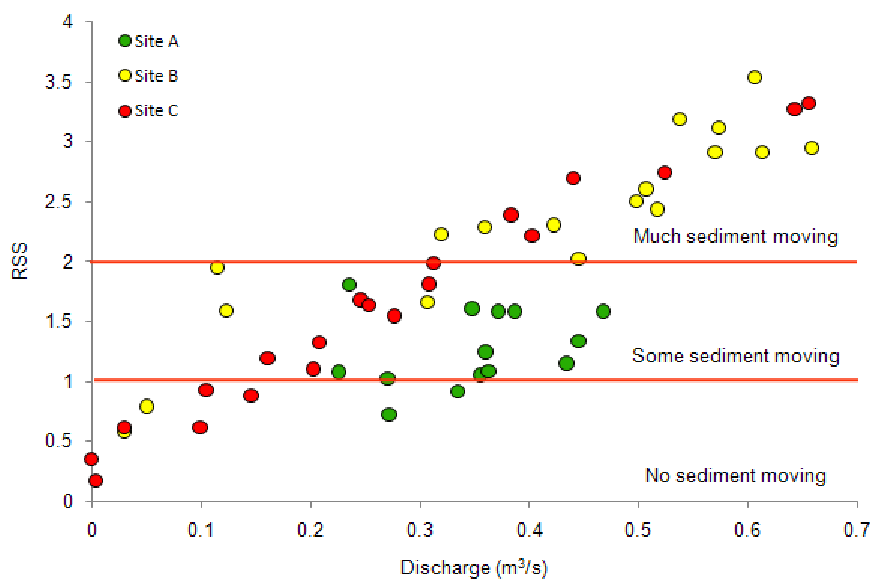

FIGURE 18. Scatter plot of entrainment potential (RSS) for measured discharge under high flow conditions. The top red line denotes complete movement of d_{50} particles ($\tau_o = 2\tau_c$), while the bottom red line indicates partial movement of d_{50} particles ($\tau_o = \tau_c$).

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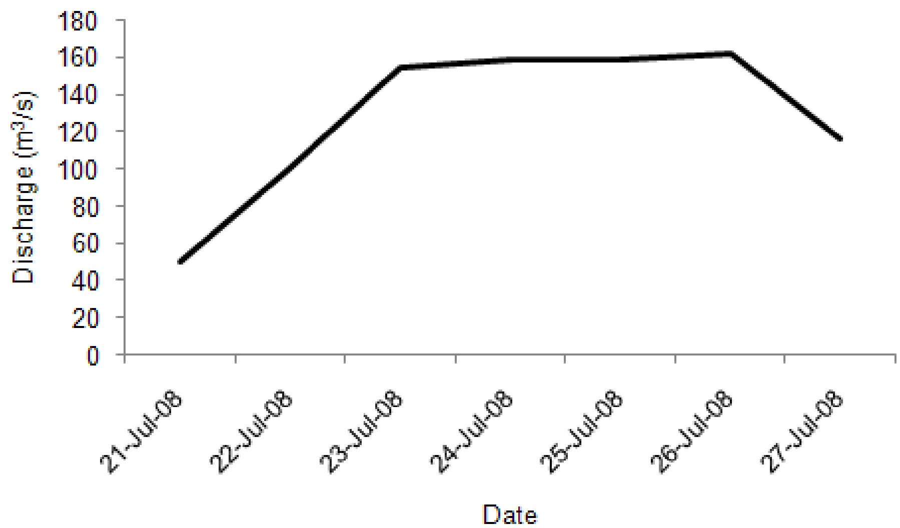

FIGURE 19. Discharge in the Sabine River during the first sampling period (21 to 24 July 2008). Data were collected daily from a USGS gauging station (08028500) located approximately 10 km upstream of Site A.

(Burlakova and Karateyev 2007; Howells et al. 2000). Howells et al. (2000) observed a loss of most of the near shore mussel community following a 3 m drawdown during a 24-48 hour period. This suggests that mussels unlike more mobile aquatic organisms are unable to cope with extreme changes in flow. Correspondingly, river bank morphometry, slope and presence of aquatic vegetation are likely to affect whether mussels can bury or follow receding water lines to escape exposure during low flow river discharge (Howells et al. 2000). Unfortunately, mussel behavior in response to low flow is random resulting in mortality (Layzer and Madison 1995; Howells et al. 2000). For both sites B and C, a large number of spent valves were collected near the exposed shore line. Site A was the only area sampled in the lower Sabine that maintained flow under low river discharge.

CART analysis and linear regression

Classification and regression tree analysis (CART) was used to identify habitat variables that were most predictive for mussel occurrence in the lower Sabine River. Predictor variables used in our analysis are listed in the methods section; water velocity, discharge, substrate type, and depth were also included. Abundance data was converted to presence/absence because we were interested in the overall relationship between habitat and mussel distribution. Data from the first sampling period was omitted because of different sampling methodologies used during high flow conditions. As a result our CART model is predictive for mussel occurrence during low river discharge. Because it was clear that high mussel abundance and species richness was associated with high thresholds for entrainment a regression model was used to build a predictive model for substrate stability using discharge as our predictor variable.

Overall, correct classification of the data used to build the model for presence/absence of mussels within quadrats was 86 %; correct classification for mussel occurrence was 22 % and 95 % for mussel absence. Cross-validation success for sampling locations ranged from 90 to 50 % (Table 11). Results from the model indicate that both RSS and water depth were the most predictive for mussel presence/absence (Figure 20). Moreover, quadrats with RSS numbers less than 0.6027 had a higher occurrence of unionids whereas mussel absence occurred most often in quadrats with RSS values greater than or equal to 0.6027. For quadrats with RSS values less than 0.6027, water depth greater than or equal to 0.335 (m) was the most predictive habitat variable for mussel presence (Figure 20).

TABLE 11. Cross-validated prediction success of classification tree models of presence/absence of mussels in the lower Brazos River drainage.

Sample site	Date	Prediction success (%)		
		Presence	Absence	Overall
Site A	18-X-2008	0	71	50
Site A	14-II-2009	0	100	90
Site B	16-X-2008	0	100	90
Site B	12-II-2009	N/A	100	100
Site C	17-X-2008	0	100	90
Site C	13-II-2009	N/A	100	100
Site D	12-II-2009	67	86	80

In general, the prediction success for this model was low, which we believe is an artifact of the low density of unionids at all sample sites. However, the results from our CART analysis are ecologically meaningful. For sites A and D, all quadrats with mussels had RSS values less than 0.6027 with the exception of one quadrat from Site A during the second sampling period; the latter had an RSS value of 0.98 which is still less than one (Figure 21 A and B; Figure 24 A). Moreover, the remaining two quadrats identified in our model with mussel occurrence were from sites B and C, both of which had RSS values greater than 1, indicating partial bed movement (Figure 22 A; Figure 23 A and B). Overall, species richness ranged from 4 for quadrats with RSS values less than 0.6027 to 2 for quadrats with RSS values greater than or equal to 0.6027. This suggests that unionid abundance and diversity is linked to portions of the stream with low shear stress or high bed stability.

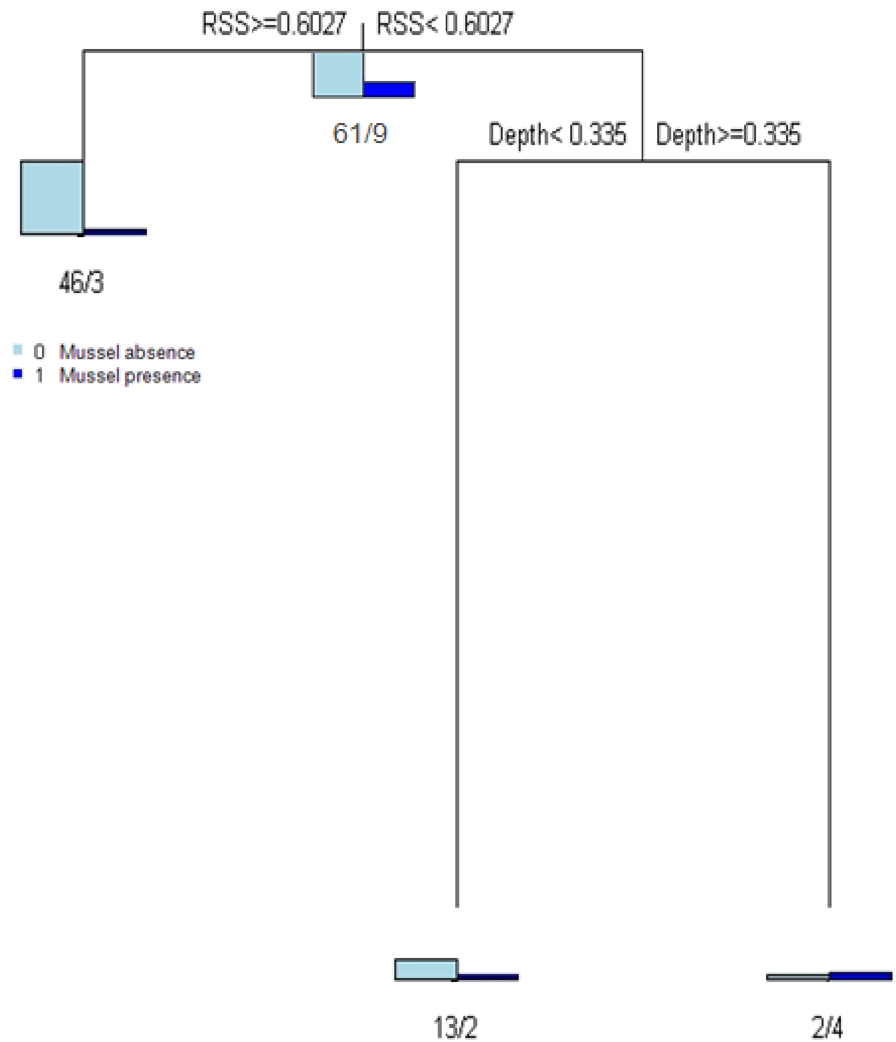

FIGURE 20. Classification tree model of mussel presence and absence in the lower Sabine River. Box plots for each node denote the total number of quadrats with and without mussels; dark blue bars represent mussel presence whereas light blue bars denote mussel absence. Numbers listed below each box plot represent the number of quadrats for each category.

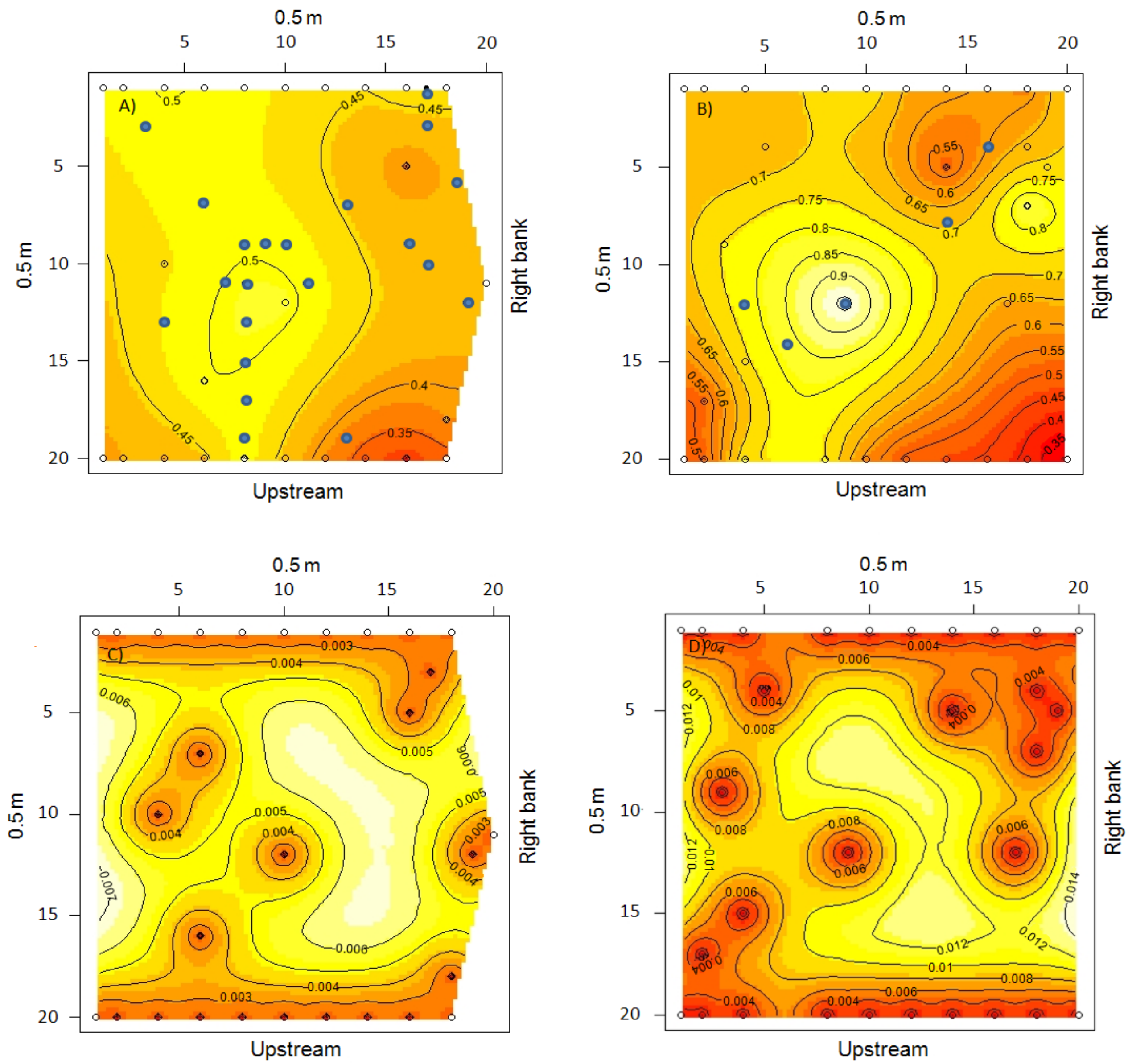

FIGURE 21. RSS level contours and heat map by Kriging Method for Site A. Blue dots indicate approximate locations for mussels collected during systematic and random sampling. Sampling period I was omitted because collection locations for mussels were not recorded due to a rapid increase in water level associated with impoundment release. Letters in the upper left hand corner of each graph denote the following sampling dates: A) 18-X-2008; and B) 14-II-2009. Estimation variance (sq. RSS) by Kriging is listed respectively below each graph; C) for 18-X-2008; and D) for 14-II-2009 . For graph A, most collected mussels were in portions of the stream where RSS was less than 0.5 whereas for graph B, RSS values ranged from 0.6 to 0.9 for collected unionids. The estimation variance was low for both study periods but was greatest in the middle of the transect (area with fewer observations).

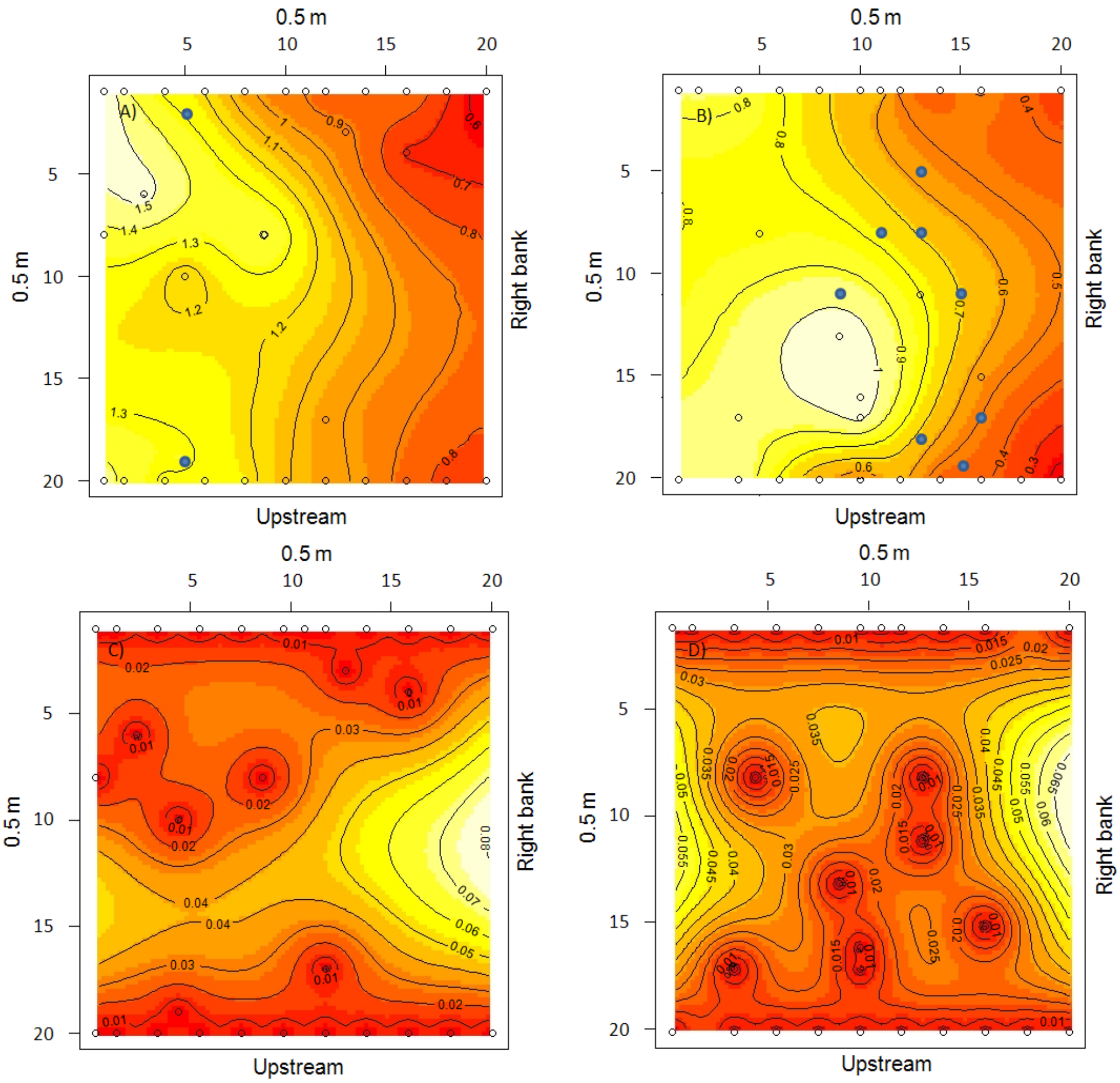

FIGURE 22. RSS level contours and heat map by Kriging Method for Site B. Blue dots indicate approximate locations for mussels collected during systematic and random sampling. Clear and black dots indicate sampling locations for both flow and substrate with a given transect. Sampling period I was omitted because collection locations for mussels were not recorded due to a rapid increase in water level associated with impoundment release. Letters in the upper left hand corner of each graph denote the following sampling dates: A) 16-X-2008; and B) 12-II-2009. Estimation variance (sq. RSS) by Kriging is listed respectively below each graph; C) for 16-X-2008; and D) for 12-II-2009. For graph A, mussels were in portions of the stream where RSS was greater than 1, whereas for graph B most of the mussels were in portions of the stream where RSS values ranged from 0.8 to 0.4. The estimation variance was low for both study periods but was greatest for both the left and right sides of the transect which had fewer observations.

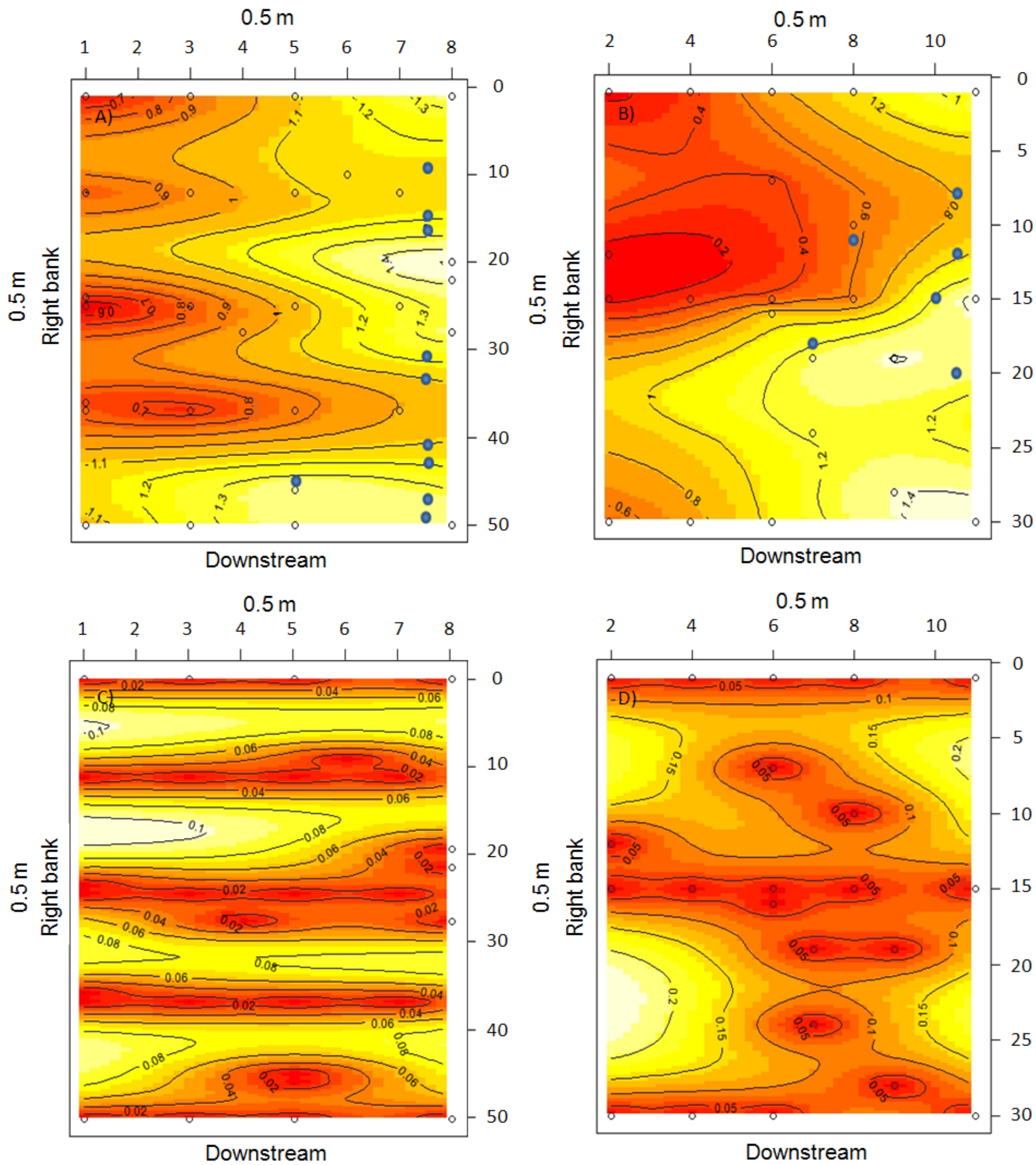

FIGURE 23. RSS level contours and heat map by Kriging Method for Site C. Blue dots indicate approximate locations for mussels collected during systematic and random sampling. Clear and black dots indicate sampling locations for both flow and substrate with a given transect. Sampling period I was omitted because collection locations for mussels were not recorded due to a rapid increase in water level associated with impoundment release. Letters in the upper left hand corner of each graph denote the following sampling dates: A) 17-X-2008; and B) 13-II-2009. Estimation variance (sq. RSS) by Kriging is listed respectively below each graph; C) for 17-X-2008; and D) for 13-II-2009. In general, mussels were collected in portions of the sampling area where RSS values were greater than 1.0 for both sample periods. The estimation variance was relatively high near the right bank for both sampling periods. This was because few measurements were made for both the left and right sides of the sampling area.

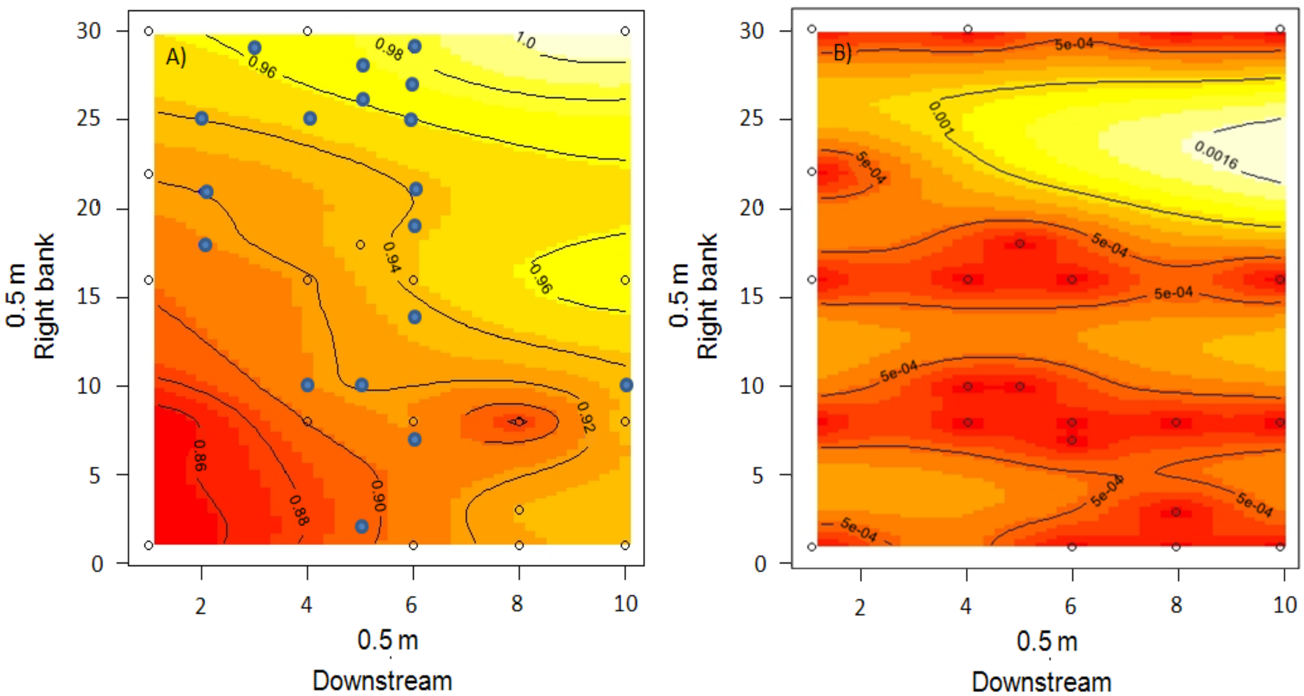

FIGURE 24. RSS level contours and heat map by Kriging Method for Site D (graph A). Blue dots indicate approximate locations for mussels collected during systematic and random sampling. Clear and black dots indicate sampling locations for both flow and substrate with a given transect. Data was normalized using the following transformation; RSS^0.17. Estimation variance (sq. RSS) by Kriging is depicted in graph B. In general, most of the mussels collected were in portions of the sampling area where RSS values were less than 0.96. The estimation variance was highest near the upper right hand corner of the transect.

<u>Regression model for substrate stability and discharge</u>

Linear regression between RSS and discharge was significant for all three sample sites (Table 12). In general, the relationship between these habitat measures appears to be linear; indicating that bed instability increases with discharge (Figure 25). Because sediment composition is often heterogeneous, areas that are comprised of smaller grain sizes will have lower thresholds for entrainment. Substratum for sites A and B included areas with very fine sand and fine sand, therefore bed instability will occur in these portions of the stream during lower discharges (Figure 26 A and B). For site C, sampling period two was omitted because of the irregularities in flow associated with sampling in a depositional area. For mussels located in these areas, bed instability will be non-linear. In these cases, increased water depth and low discharge should result in unstable substrate and thus unsuitable habitat for unionids (Figure 26C). This is because shear stress integrates slope, water depth, and the density of water, therefore if water velocity is low relative to water depth shear stress values will remain high. Nevertheless, our model does indicate a general linear relationship between RSS and discharge (Figure 25). This suggests that portions of the stream that are comprised of small median grain sizes are probably poor habitats for mussels because these areas are not stable during high flows. Previous studies for this drainage have suggested that the lower Sabine River is poor habitat for unionids because of the sand substrate and fluctuating river discharge. We agree that substratum comprised of sand can be poor habitat for unionids during episodes of impoundment release. However, our results suggest that differences in grain size will have profound implications on whether or not bed substratum remains stable during both low (Figures 21 – 24) and high flows (Figure 18). Undoubtedly, other factors influence unionid distribution but we feel that without stable substrate colonization and subsequent recruitment are not likely to occur.

Table 12. Summary of linear regression models for RSS against discharge.

Model	*n*	Intercept	*p* - value	95 % C.I. for intercept	Slope	*p*- value	95 % C.I. for slope	R^2
Site A	33	0.45626	5.56e-12	0.37363 to 0.53099	1.07136	2.78e-12	0.88373 to 1.27082	0.79
Site B		0.40479	2.14e-11	0.31922 to 0.48092	1.71098	2.0e-16	1.57227 to 1.86520	0.93
Site C		0.23990	6.97e-4	0.12382 to 0.36728	1.85294	2.4e-15	1.62698 to 2.02618	0.89

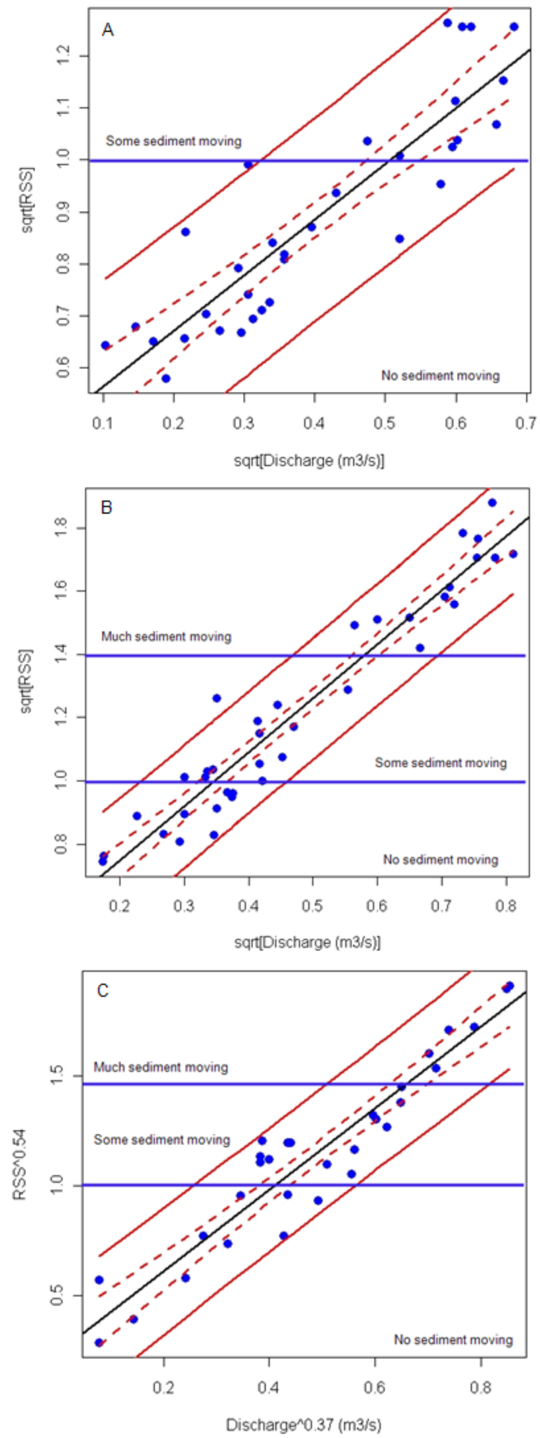

FIGURE 25. Linear regression between RSS and point measurements of discharge. Red dashed lines denote 95 % confidence bounds on the mean values, solid red lines indicate 95 % confidence bounds on future predicted values. Sample sites are denoted by letters in the upper left hand corner of each graph.

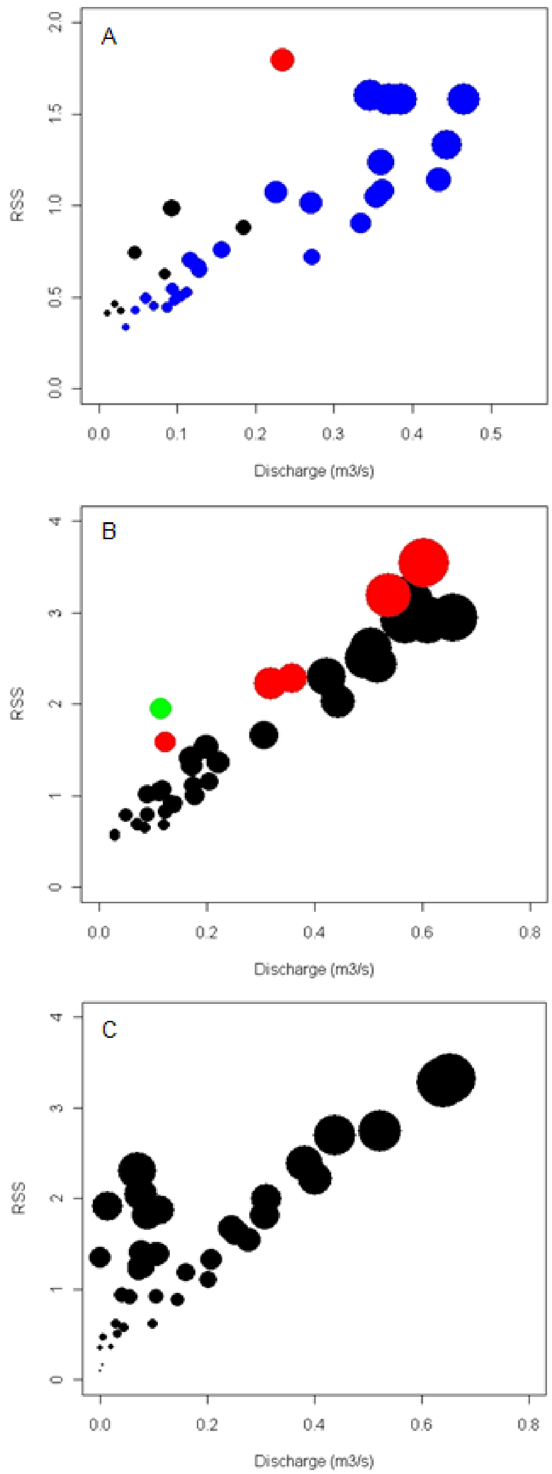

FIGURE 26. Scatter plot of RSS against point measurements of discharge constrained by depth. Green circles denote very fine sand, red circles indicate fine sand, black circles depict medium sand, and blue circles denote coarse sand. Circle size indicates water depth; thus large circles indicate measurements at greater water depth. Sample sites are denoted by letters in the upper left hand corner of each graph.

CONCLUSIONS

1. During this survey, we sampled four sites on both the lower Brazos and Sabine River drainages. For the lower Brazos River drainage, sample sites were on Yegua Creek near SH 50, the Navasota River near SH105, the Brazos River near FM 485, and the Brazos River near SH 105. Sampling locations on the Sabine River were between HWY 190 and HWY 12 in Newton County. Sampling on the lower Sabine River occurred under both high and low river discharge, whereas sampling on the lower Brazos River drainage occurred primarily under low flows.

2. In total, thirteen unionid species and 1,086 individuals were collected during four sampling periods in the lower Brazos River drainage. The Navasota River and Yegua Creek had the highest densities (14.11/0.25 m^2 and 1.94/0.25 m^2 respectively) and species richness (8 and 6 respectively) compared to the other sample sites. The low diversity of unionids at the study site on the Brazos River near FM 485was unexpected. It is unclear whether the absence of mussels from this site was the result of, changes in habitat, natural senescence, or an unknown environmental contaminant.

3. For the lower Sabine River, 268 live mussels representing 12 species were documented within our sampling sites. Sampling sites A and Site D (0.37/0.25 m^2 and 0.30/0.25 m^2 respectively) had the highest densities and species richness (9 and 4 respectively) compared to sites B and C. Our survey of the lower Sabine River and records from the Tulane Museum of Natural History, suggests that the lower Sabine (downstream of Toledo Bend Reservoir) is more diverse than previously reported.

4. The results of this study on the lower Brazos River drainage suggests that a minimum Re_* threshold may exist for mussel populations during low river discharge. During this study mussel occurrence was positively correlated with sites that had high Re_* numbers. This suggests that portions of a stream with near bed flows below this minimum threshold may not meet the physiochemical requirements needed to maintain existing mussel populations. Additionally, these results highlight the need to better understand not only maximum thresholds but also minimum thresholds for unionid populations. Given the preponderance of low flow in this drainage we feel that understanding both will strengthen instream flow programs designed to maintain healthy unionid populations.

5. Based on analysis of survey data from the lower Sabine River, unionid abundance and species richness were highest at sites with low shear stress during both low and high river discharge. Additionally, statistically significant differences were measured in median grain size between sites with high mussel densities and those with low densities. Substratum at Sites A and D were comprised of coarse sand whereas substratum at sites B and C were comprised of medium sand grains. During high flows, coarser substrate will remain more stable during high flows compared to substrates with finer grain sizes. Given the intensity of flow within the Sabine it is likely that sites A and D will become unstable during large impoundment releases. However, our survey of woody debris downstream of Site A suggests that unionids may passively use these habitat

structures for refuge during high river discharge. Further sampling in the lower Sabine is needed to evaluate the role of woody debris as flow refugia for unionids.

6. *Quadrula houstonensis* was documented at all four sampling sites on the lower Brazos River drainage but was most abundant at sites on the Navasota River and Yegua Creek. This species is listed as threatened by the American Fisheries Society (Williams *et al*., 1993; Howells *et al*., 1997). Previous reports in the Brazos have reported this species as being quite abundant in the Brazos River and its tributaries. However, in general this species seems be declining in distribution throughout most of Brazos River drainage (reviewed in Howells 2009).

7. The results of this study indicate that the application of the habitat criteria proposed by Morales *et al.* (2006) is promising regarding mussel occurrence and low shear stresses. For the lower Sabine sample sites with high RSS values (Sites B and C) had low species richness and unionid densities, whereas sites with low RSS values (Sites A and D) had high species richness and unionid densities. Also important to note, is that a number of species found at Sites A and D were either absent or in low abundance at high shear stress sites. This suggests that shear stress thresholds do exist and are probably species specific. What is unclear is whether an RSS value of 1 is the threshold separating high and low density sites. The data from this report suggests this might not be the case. RSS values measured during the first sampling event at Site A exceeded the threshold recommended by Morales *et al.* (2006). As a result, using an RSS value of 2 is probably a better approach given that estimates of critical shear stress are considered, at best, a minimum estimate of sediment entrainment potential. However, further studies assessing the relationship between shear stress and mussel occurrence for variety stream types are needed to test this hypothesis. Given the number of flow competence equations, flume studies are needed to calibrate RSS values recorded in the field. Recent studies have suggested that these equations may be context dependent (see Lorang and Hauer 2003). Finally, it is important to reiterate that low shear stress was predictive for mussel occurrence on the lower Sabine. What is unclear is the threshold separating high and low density sites and whether changes in community structure observed during this study were in response to high and low shear stresses.

8. The first population of a *Truncilla macrodon* was found in the Brazos River near SH 105. Individuals for this species were collected during all sampling periods therefore it is unlikely they were flood deposited between sampling periods. Since its original description in the mid-1800s, perhaps fewer than 300 specimens have been documented. This species is listed as threatened by the American Fisheries Society (Williams *et al*., 1993; Howells *et al*., 1997). Additionally, both *Q. houstonensis* and *T. macrodon* are being petitioned for protection under the Federal Endangered Species Act (WildEarth Guardians, 2008).

9. *Fusconaia askewi* a rare East Texas mussel was found during our survey of the lower Sabine River. This species was found only at Site A and in nearby woody debris. This species is listed as threatened by the American Fisheries Society (Williams *et al*., 1993; Howells *et al*., 1997).

10. *Lampsils satura* another rare unionid was found during our sampling of lower Sabine River. This species is listed as a species of special concern by the American Fisheries Society (Williams *et*

al., 1993; Howells *et al*., 1997). Little is known about the distribution, spawning or host fish for this species. *Lampsilis satura* was found at all four sample sites but never in abundance.

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Appendix A. Descriptive statistics for grain size analysis from study sites on the lower Brazos River drainage. The “Grid number” column denotes a given quadrat where sediment was sampled.

Site	Date	Grid number	Median (phi)	Mean (phi)	D95 (phi)	D84 (phi)	D75 (phi)	D25 (phi)	D16 (phi)	D5 (phi)	SD (phi)	Skewness (phi)	Kurtosis (phi)	Number of live mussels
Navasota	18-VII-2008	1,16	-1.00	-1.27	0.80	0.60	0.40	-2.80	-3.40	-4.10	1.74	-0.23	0.63	-
Navasota	18-VII-2008	Corner C	0.20	-1.27	2.50	0.80	0.65	-3.00	-4.80	-7.00	2.84	-0.65	1.07	-
Navasota	18-VII-2008	4,28	0.40	-0.30	3.20	2.70	2.40	-2.70	-4.00	-5.60	3.01	-0.34	0.71	-
Navasota	18-VII-2008	2,24	-1.00	-0.80	2.90	2.30	1.40	-3.00	-3.70	-4.60	2.64	0.07	0.70	-
Navasota	18-VII-2008	Corner B	0.10	-0.67	3.20	2.50	2.00	-3.30	-4.60	-6.20	3.20	-0.33	0.73	-
Navasota	18-VII-2008	4,8	-1.60	-1.47	2.30	1.10	0.50	-3.30	-3.90	-4.50	2.28	0.11	0.73	-
Navasota	18-VII-2008	4,24	-2.10	-1.43	3.10	2.10	1.25	-3.70	-4.30	-5.00	2.83	0.30	0.67	-
Navasota	18-VII-2008	6,8	-1.10	-0.97	2.90	2.10	1.60	-3.20	-3.90	-4.80	2.67	0.05	0.66	-
Navasota	18-VII-2008	Corner A	0.00	0.07	3.10	2.40	1.90	-1.80	-2.20	-2.70	2.03	0.06	0.64	-
Navasota	18-VII-2008	1,8	-3.10	-2.63	2.40	1.10	1.10	-5.20	-5.90	-6.90	3.16	0.19	0.93	-
Navasota	18-VII-2008	2,8	-2.60	-2.43	2.70	1.50	0.50	-5.20	-6.20	-7.40	3.46	0.06	0.73	-
Navasota	18-VII-2008	4,16	-1.60	-1.03	3.40	2.30	1.60	-3.20	-3.80	-4.50	2.72	0.27	0.67	-
Navasota	18-VII-2008	4,1	0.30	0.03	2.90	2.40	2.00	-1.90	-2.60	-3.40	2.20	-0.17	0.66	-
Navasota	18-VII-2008	2,16	-2.10	-1.43	2.70	1.70	0.00	-3.40	-3.90	-4.50	2.49	0.35	0.87	-
Navasota	18-VII-2008	6,16	-1.80	-1.07	3.40	2.60	2.00	-3.40	-4.00	-4.70	2.88	0.31	0.61	-
Navasota	18-VII-2008	1,24	1.40	0.67	3.60	2.90	2.60	-1.70	-2.30	-3.10	2.32	-0.38	0.64	-
Navasota	18-VII-2008	6,24	-1.35	-0.78	3.50	2.70	2.00	-3.10	-3.70	-4.45	2.80	0.24	0.64	-
Navasota	18-VII-2008	2,28	-1.55	-0.42	3.50	2.50	1.80	-1.80	-2.20	-2.60	2.10	0.69	0.69	-
Navasota	18-VII-2008	Corner D	0.20	0.00	3.10	2.40	2.00	-2.00	-2.60	-3.40	2.23	-0.11	0.67	-
Navasota	18-VII-2008	2,1	0.00	-0.07	2.80	2.40	2.10	-2.10	-2.60	-3.30	2.17	-0.06	0.60	-
Navasota	27-IX-2008	1,15	-0.50	-0.03	3.55	2.60	1.80	-1.80	-2.20	-2.70	2.15	0.29	0.71	16
Navasota	27-IX-2008	3,16	-2.45	-1.98	1.80	1.10	-0.30	-4.00	-4.60	-5.30	2.50	0.22	0.79	18
Navasota	27-IX-2008	1,24	-2.60	-2.27	2.10	1.30	0.35	-4.80	-5.50	-6.50	3.00	0.12	0.68	6
Navasota	27-IX-2008	2,1	-0.30	-0.53	1.95	1.40	1.10	-2.10	-2.70	-3.30	1.82	-0.16	0.67	1
Navasota	27-IX-2008	6,5	-0.40	-0.47	3.00	1.80	1.40	-2.20	-2.80	-3.50	2.13	0.00	0.74	0
Navasota	27-IX-2008	3,14	-2.30	-1.87	1.90	1.20	-0.40	-4.00	-4.50	-5.20	2.50	0.21	0.81	17
Navasota	27-IX-2008	3,24	0.60	-0.67	3.50	1.90	1.60	-3.20	-4.50	-6.00	3.04	-0.49	0.81	26
Navasota	27-IX-2008	3,17	-1.60	-1.18	2.20	1.50	1.10	-2.90	-3.45	-4.10	2.19	0.23	0.65	14
Navasota	27-IX-2008	3,19	0.40	-0.13	2.10	1.70	1.50	-2.00	-2.50	-3.20	1.85	-0.37	0.62	46
Navasota	27-IX-2008	4,3	-0.60	-0.80	2.70	1.70	1.30	-2.70	-3.50	-4.40	2.38	-0.09	0.73	1

Appendix A. Continuation of grain size analysis for study sites on the lower Brazos River drainage.

Site	Date	Grid number	Median (phi)	Mean (phi)	D95 (phi)	D84 (phi)	D75 (phi)	D25 (phi)	D16 (phi)	D5 (phi)	SD (phi)	Skewness (phi)	Kurtosis (phi)	Number of live mussels
Navasota	4-IV-2009	24,8	1.20	0.00	2.00	1.70	1.60	-2.00	-2.90	-4.10	2.07	-0.76	0.69	0
Navasota	4-IV-2009	4,4	-0.20	-0.70	1.90	1.50	1.10	-2.50	-3.40	-4.50	2.19	-0.32	0.73	1
Navasota	4-IV-2009	10,3	-1.60	-1.47	2.10	1.50	1.00	-3.60	-4.30	-5.20	2.56	0.04	0.65	4
Navasota	4-IV-2009	28,5	-1.30	-1.03	1.95	1.50	1.10	-2.70	-3.30	-3.90	2.09	0.14	0.63	34
Navasota	4-IV-2009	22,1	-2.70	-1.80	3.40	2.20	1.60	-4.10	-4.90	-5.90	3.18	0.35	0.67	18
Navasota	4-IV-2009	9,8	-2.20	-1.90	2.00	1.30	0.35	-4.10	-4.80	-5.60	2.68	0.13	0.70	0
Navasota	4-IV-2009	16,4	-1.70	-1.40	1.80	1.20	0.50	-3.20	-3.70	-4.40	2.16	0.16	0.69	7
Navasota	4-IV-2009	10,1	-0.70	-0.67	1.90	1.40	1.00	-2.20	-2.70	-3.30	1.81	0.01	0.67	6
Navasota	4-IV-2009	2,1	0.30	-0.23	2.60	1.70	1.40	-2.00	-2.70	-3.60	2.04	-0.31	0.75	0
Navasota	4-IV-2009	22,6	-0.75	-0.68	2.10	1.60	1.25	-2.40	-2.90	-3.60	1.99	0.02	0.64	3
Yegua	17-VII-2008	2,1	1.60	1.57	3.10	2.60	2.30	0.90	0.50	-0.15	1.02	-0.06	0.95	-
Yegua	17-VII-2008	4,1	2.30	2.05	3.55	2.90	2.70	1.60	0.95	0.00	1.03	-0.34	1.32	-
Yegua	17-VII-2008	Corner A	1.40	1.57	2.90	2.50	2.20	1.10	0.80	0.30	0.82	0.22	0.97	-
Yegua	17-VII-2008	4,8	1.55	1.45	3.00	2.50	2.25	0.80	0.30	-0.70	1.11	-0.18	1.05	-
Yegua	17-VII-2008	Corner B	1.60	1.62	2.90	2.45	2.20	1.10	0.80	0.30	0.81	0.02	0.97	-
Yegua	17-VII-2008	2,28	1.75	1.78	2.90	2.60	2.30	1.20	1.00	0.30	0.79	-0.03	0.97	-
Yegua	17-VII-2008	2,21	1.40	1.37	3.00	2.30	1.90	0.70	0.40	-0.30	0.98	-0.04	1.13	-
Yegua	17-VII-2008	4,21	1.50	1.52	2.90	2.25	2.00	1.10	0.80	0.20	0.77	0.04	1.23	-
Yegua	17-VII-2008	2,13	1.60	1.53	3.20	2.60	2.30	0.90	0.40	-1.20	1.22	-0.18	1.29	-
Yegua	17-VII-2008	Corner D	2.50	2.43	3.80	3.20	3.00	2.00	1.60	0.30	0.93	-0.19	1.43	-
Yegua	17-VII-2008	6,8	2.25	2.08	3.70	2.90	2.70	1.50	1.10	0.00	1.01	-0.25	1.26	-
Yegua	17-VII-2008	6,13	2.00	1.90	3.05	2.70	2.50	1.30	1.00	-0.20	0.92	-0.27	1.11	-
Yegua	17-VII-2008	1,8	1.30	1.25	3.10	2.30	1.90	0.50	0.15	-1.00	1.16	-0.10	1.20	-
Yegua	17-VII-2008	1,21	1.40	1.33	3.00	2.30	2.00	0.70	0.30	-0.50	1.03	-0.09	1.10	-
Yegua	17-VII-2008	1,13	1.20	1.18	3.20	2.15	1.80	0.50	0.20	-0.65	1.07	0.01	1.21	-
Yegua	17-VII-2008	Corner C	1.90	1.93	4.10	3.00	2.70	1.20	0.90	-0.10	1.16	0.05	1.15	-
Yegua	17-VII-2008	2,8	0.70	0.78	2.00	1.45	0.90	0.40	0.20	-0.05	0.62	0.23	1.68	-
Yegua	17-VII-2008	6,21	2.00	1.85	3.20	2.70	2.50	1.30	0.85	0.30	0.90	-0.21	0.99	-
Yegua	17-VII-2008	4,13	1.50	1.33	3.40	2.70	2.40	0.40	-0.20	-2.00	1.54	-0.23	1.11	-
Yegua	17-VII-2008	4,28	2.30	2.17	3.30	2.90	2.70	1.60	1.30	0.30	0.85	-0.29	1.12	-

Site	Date	Grid number	Median (phi)	Mean (phi)	D95 (phi)	D84 (phi)	D75 (phi)	D25 (phi)	D16 (phi)	D5 (phi)	SD (phi)	Skewness (phi)	Kurtosis (phi)	Number of live mussels
Yegua	26-IX-2008	2,17	1.30	1.23	1.95	1.70	1.60	0.95	0.70	0.20	0.52	-0.23	1.10	1
Yegua	26-IX-2008	3,24	1.20	0.95	1.95	1.70	1.60	0.70	-0.05	0.00	0.73	-0.33	0.89	1
Yegua	26-IX-2008	4,4	0.90	0.90	1.90	1.60	1.40	0.40	0.20	-0.10	0.65	0.00	0.82	0
Yegua	26-IX-2008	5,10	0.80	0.83	1.80	1.50	1.30	0.40	0.20	0.00	0.60	0.09	0.82	0
Yegua	26-IX-2008	3,4	1.10	1.07	1.95	1.70	1.50	0.60	0.40	0.00	0.62	-0.10	0.89	0
Yegua	26-IX-2008	6,16	1.30	1.20	2.00	1.70	1.60	0.80	0.60	0.10	0.56	-0.27	0.97	0
Yegua	26-IX-2008	5,19	1.30	1.25	1.90	1.75	1.65	1.00	0.70	0.10	0.54	-0.24	1.13	0
Yegua	26-IX-2008	4,24	1.10	1.05	1.90	1.65	1.50	0.60	0.40	0.10	0.59	-0.12	0.82	1
Yegua	26-IX-2008	4,10	0.90	0.93	1.90	1.60	1.40	0.45	0.30	0.05	0.61	0.08	0.80	1
Yegua	26-IX-2008	5,17	0.50	0.12	1.40	0.95	0.80	0.10	-1.10	-0.10	0.74	-0.18	0.88	0
Yegua	5-IV-2009	22,4	0.90	0.93	1.90	1.60	1.40	0.40	0.30	0.00	0.61	0.06	0.78	0
Yegua	5-IV-2009	3,3	0.50	0.50	1.85	1.30	1.00	0.10	-0.30	-2.50	1.06	-0.19	1.98	9
Yegua	5-IV-2009	24,4	0.75	0.92	3.10	1.80	1.40	0.40	0.20	0.00	0.87	0.41	1.27	0
Yegua	5-IV-2009	5,2	0.70	0.88	3.10	1.75	1.30	0.30	0.20	-0.10	0.87	0.43	1.31	4
Yegua	5-IV-2009	17,1	1.10	1.20	3.70	2.10	1.70	0.60	0.40	0.10	0.97	0.31	1.34	0
Yegua	5-IV-2009	17,4	0.55	0.57	1.90	1.05	0.90	0.20	0.10	-0.20	0.56	0.17	1.23	0
Yegua	5-IV-2009	27,3	0.60	0.73	3.00	1.40	0.90	0.35	0.20	0.10	0.74	0.49	2.16	0
Yegua	5-IV-2009	15,3	0.50	0.53	2.50	0.90	0.80	0.30	0.20	0.00	0.55	0.37	2.05	2
Yegua	5-IV-2009	16,1	0.70	1.20	3.90	2.70	1.90	0.35	0.20	-2.00	1.52	0.34	1.56	0
Yegua	5-IV-2009	4,4	1.40	1.50	3.45	2.70	2.40	0.60	0.40	-2.00	1.40	-0.06	1.24	0
Yegua	13-V-2009	9,2	2.05	2.05	3.80	2.90	2.40	1.40	1.20	0.60	0.91	0.05	1.31	0
Yegua	13-V-2009	19,3	1.40	1.38	2.95	2.10	1.80	0.90	0.65	0.30	0.76	0.07	1.21	0
Yegua	13-V-2009	4,4	1.00	0.30	3.50	2.00	1.70	-0.10	-2.10	-2.80	1.98	-0.36	1.43	0
Yegua	13-V-2009	10,6	1.50	1.60	3.50	2.30	1.90	1.15	1.00	0.40	0.79	0.26	1.69	0
Yegua	13-V-2009	16,3	1.65	1.92	4.20	2.90	2.10	1.35	1.20	1.05	0.90	0.54	1.72	0
Yegua	13-V-2009	29,3	1.90	2.08	5.10	3.35	3.05	1.30	1.00	0.50	1.28	0.31	1.08	0
Yegua	13-V-2009	26,6	1.55	1.65	3.90	2.90	2.50	0.70	0.50	0.20	1.16	0.20	0.84	0
Yegua	13-V-2009	16,1	1.70	2.02	4.30	3.10	2.70	1.40	1.25	1.00	0.96	0.54	1.04	0
Yegua	13-V-2009	12,3	2.10	2.17	4.05	3.10	2.80	1.50	1.30	1.00	0.91	0.19	0.96	0
Yegua	13-V-2009	11,1	2.10	2.20	4.50	3.20	2.80	1.50	1.30	0.80	1.04	0.23	1.17	0

Appendix A. Continuation of grain size analysis for study sites on the lower Brazos River drainage.

Site	Date	Grid number	Median (phi)	Mean (phi)	D95 (phi)	D84 (phi)	D75 (phi)	D25 (phi)	D16 (phi)	D5 (phi)	SD (phi)	Skewness (phi)	Kurtosis (phi)	Number of live mussels
Br-105	29-IX-2008	6,20	1.50	0.80	3.40	2.70	2.35	-0.20	-1.80	-3.25	2.13	-0.45	1.07	-

Appendix A. Continuation of grain size analysis for study sites on the lower Brazos River drainage.

Br-105	29-IX-2008	1,24	1.70	1.80	3.10	2.50	2.20	1.40	1.20	1.00	0.64	0.28	1.08	-
Br-105	29-IX-2008	6,34	1.70	1.80	3.20	2.60	2.20	1.30	1.10	-3.10	1.33	-0.16	2.87	-
Br-105	29-IX-2008	1,32	1.70	1.77	3.25	2.50	2.20	1.30	1.10	-2.00	1.15	-0.13	2.39	-
Br-105	29-IX-2008	Corner A	1.90	2.00	3.50	2.80	2.50	1.50	1.30	1.10	0.74	0.27	0.98	-
Br-105	29-IX-2008	1,8	1.75	1.87	3.15	2.55	2.25	1.40	1.30	1.10	0.62	0.32	0.99	-
Br-105	29-IX-2008	1,28	1.60	1.70	3.30	2.40	2.00	1.30	1.10	-2.40	1.19	-0.09	3.34	-
Br-105	29-IX-2008	Corner B	1.50	1.00	3.60	2.70	2.05	1.00	-1.20	-3.90	2.11	-0.41	2.93	-
Br-105	29-IX-2008	1,34	1.60	1.70	3.20	2.30	2.00	1.30	1.20	1.00	0.61	0.36	1.29	-
Br-105	29-IX-2008	1,16	1.60	1.63	3.10	2.10	1.90	1.30	1.20	1.05	0.54	0.29	1.40	-
Br-105	29-IX-2008	3,1	1.70	1.83	3.50	2.60	2.10	1.30	1.20	1.00	0.73	0.36	1.28	-
Br-105	29-IX-2008	6,32	1.60	1.73	3.40	2.50	2.00	1.25	1.10	-4.00	1.47	-0.11	4.04	-
Br-105	29-IX-2008	6,28	1.70	1.77	3.20	2.40	2.00	1.35	1.20	1.00	0.63	0.27	1.39	-
Br-105	29-IX-2008	6,24	1.60	1.67	3.10	2.30	2.00	1.30	1.10	0.00	0.77	0.07	1.81	-
Br-105	29-IX-2008	1,20	1.70	2.02	4.00	3.10	2.30	1.40	1.25	1.05	0.91	0.54	1.34	-
Br-105	29-IX-2008	6,5	1.60	1.70	3.60	2.90	2.10	1.20	0.60	-2.60	1.51	-0.11	2.82	0
Br-105	29-IX-2008	5,19	1.30	0.33	2.10	1.80	1.60	-0.90	-2.10	-3.40	1.81	-0.73	0.90	0
Br-105	29-IX-2008	1,22	1.60	1.63	3.25	2.10	1.90	1.30	1.20	1.00	0.57	0.29	1.54	0
Br-105	29-IX-2008	4,10	1.60	1.72	3.25	2.40	2.00	1.30	1.15	0.80	0.68	0.31	1.43	0
Br-105	29-IX-2008	5,24	1.45	1.42	2.00	1.80	1.70	1.20	1.00	-3.00	0.96	-0.45	4.10	0
Br-105	29-IX-2008	3,24	1.50	1.47	2.05	1.80	1.70	1.20	1.10	-2.00	0.79	-0.44	3.32	0
Br-105	29-IX-2008	3,28	1.20	1.13	2.20	1.80	1.60	0.60	0.40	0.10	0.67	-0.10	0.86	0
Br-105	29-IX-2008	3,25	0.60	0.67	1.85	1.20	1.00	0.30	0.20	0.00	0.53	0.28	1.08	0
Br-105	29-IX-2008	1,32	1.70	1.93	3.60	2.90	2.30	1.30	1.20	0.00	0.97	0.23	1.48	0
Br-105	4-IV-2009	24,8	1.20	1.18	3.30	1.85	1.75	0.70	0.50	0.20	0.81	0.16	1.21	0
Br-105	4-IV-2009	9,8	0.80	0.27	2.00	1.60	1.40	-0.10	-1.60	-2.70	1.51	-0.49	1.28	0
Br-105	4-IV-2009	13,16	1.00	0.92	1.90	1.65	1.50	0.40	0.10	-2.30	1.02	-0.37	1.56	0
Br-105	4-IV-2009	11,1	2.60	2.52	4.30	3.45	3.30	1.80	1.50	1.20	0.96	-0.02	0.85	0
Br-105	4-IV-2009	22,1	1.80	2.07	3.70	3.10	2.60	1.40	1.30	1.10	0.84	0.45	0.89	0
Br-105	4-IV-2009	13,3	1.70	2.03	4.25	3.20	2.70	1.35	1.20	0.00	1.14	0.35	1.29	0

Site	Date	Grid number	Median (phi)	Mean (phi)	D95 (phi)	D84 (phi)	D75 (phi)	D25 (phi)	D16 (phi)	D5 (phi)	SD (phi)	Skewness (phi)	Kurtosis (phi)	Number of live mussels
Br-105	4-IV-2009	24,13	1.40	0.67	3.10	1.90	1.70	1.00	-1.30	-3.30	1.77	-0.58	3.75	0
Br-105	4-IV-2009	4,4	1.50	1.50	3.40	1.90	1.80	1.25	1.10	0.40	0.65	0.13	2.24	0
Br-105	4-IV-2009	5,10	1.30	1.27	2.00	1.80	1.60	1.00	0.70	0.15	0.56	-0.17	1.26	0
Br-105	4-IV-2009	22,4	1.50	1.53	3.55	1.90	1.80	1.30	1.20	1.00	0.56	0.38	2.09	0
Br-105	27-V-2009	10,6	1.40	1.37	2.00	1.80	1.70	1.10	0.90	0.40	0.47	-0.18	1.09	0
Br-105	27-V-2009	19,7	1.20	1.17	2.00	1.75	1.60	0.80	0.55	0.20	0.57	-0.10	0.92	0
Br-105	27-V-2009	2,6	1.10	1.07	1.95	1.70	1.50	0.70	0.40	0.20	0.59	-0.05	0.90	0
Br-105	27-V-2009	12,5	1.30	1.27	3.60	1.90	1.70	0.80	0.60	0.20	0.84	0.14	1.55	0
Br-105	27-V-2009	4,3	1.00	1.02	1.90	1.65	1.50	0.55	0.40	0.15	0.58	0.03	0.75	0
Br-105	27-V-2009	9,2	1.50	1.50	3.50	1.90	1.80	1.20	1.10	0.60	0.64	0.19	1.98	0
Br-105	27-V-2009	10,7	1.50	1.50	4.20	1.95	1.80	1.20	1.05	0.60	0.77	0.25	2.46	0
Br-105	27-V-2009	7,4	1.50	1.52	2.05	1.85	1.75	1.30	1.20	1.00	0.32	0.06	0.96	0
Br-105	27-V-2009	21,8	1.30	1.20	1.95	1.70	1.60	0.80	0.60	0.20	0.54	-0.26	0.90	1
Br-105	27-V-2009	16,1	1.50	1.53	3.80	1.90	1.80	1.30	1.20	1.00	0.60	0.39	2.30	0
Br-485	15-VII-2008	4,20	-2.60	-2.25	1.70	0.60	-0.70	-4.15	-4.75	-5.45	2.42	0.20	0.85	-
Br-485	15-VII-2008	8,10	-3.90	-3.75	1.50	-0.75	-1.70	-5.90	-6.60	-7.60	2.84	0.13	0.89	-
Br-485	15-VII-2008	1,10	-2.10	-1.73	1.90	1.10	-0.10	-3.60	-4.20	-4.80	2.34	0.20	0.78	-
Br-485	15-VII-2008	10,10	-2.00	-1.73	1.70	0.70	-0.10	-3.40	-3.90	-4.50	2.09	0.18	0.77	-
Br-485	15-VII-2008	8,1	-2.70	-2.73	1.75	0.70	0.00	-5.30	-6.20	-7.45	3.12	-0.02	0.71	-
Br-485	15-VII-2008	12,10	-2.05	-1.85	1.80	0.20	-0.70	-3.30	-3.70	-4.20	1.88	0.22	0.95	-
Br-485	15-VII-2008	4,10	-2.45	-2.15	1.80	0.40	-1.00	-3.90	-4.40	-5.00	2.23	0.22	0.96	-
Br-485	15-VII-2008	16,10	-2.10	-1.63	2.10	0.80	-0.60	-3.20	-3.60	-4.10	2.04	0.34	0.98	-
Br-485	15-VII-2008	2,20	-2.70	-2.50	1.70	-0.10	-1.30	-4.20	-4.70	-5.30	2.21	0.19	0.99	-
Br-485	15-VII-2008	Corner A	-2.00	-1.53	2.20	1.30	0.10	-3.40	-3.90	-4.50	2.32	0.26	0.78	-
Br-485	15-VII-2008	Corner D	-1.90	-1.57	2.50	0.40	-0.80	-2.80	-3.20	-3.60	1.82	0.36	1.25	-
Br-485	15-VII-2008	Corner C	-2.40	-2.10	1.70	0.20	-1.10	-3.70	-4.10	-4.60	2.03	0.26	0.99	-
Br-485	15-VII-2008	Corner B	-2.80	-2.50	1.80	0.50	-0.90	-4.50	-5.20	-5.90	2.59	0.18	0.88	-
Br-485	15-VII-2008	16,1	-2.40	-1.93	3.10	1.20	-0.30	-4.00	-4.60	-5.25	2.72	0.28	0.92	-
Br-485	15-VII-2008	12,20	-1.60	-1.47	3.30	1.30	0.40	-3.40	-4.10	-4.80	2.58	0.14	0.87	-
Br-485	15-VII-2008	16,20	-1.10	-1.27	1.80	0.90	0.50	-2.90	-3.60	-4.30	2.05	-0.08	0.74	-

Appendix A. Continuation of grain size analysis for study sites on the lower Brazos River drainage.

Site	Date	Grid number	Median (phi)	Mean (phi)	D95 (phi)	D84 (phi)	D75 (phi)	D25 (phi)	D16 (phi)	D5 (phi)	SD (phi)	Skewness (phi)	Kurtosis (phi)	Number of live mussels
Br-485	28-IX-2008	6,7	-2.50	-2.27	1.70	0.30	-0.90	-4.05	-4.60	-5.30	2.29	0.17	0.91	0
Br-485	28-IX-2008	3,16	-2.50	-2.50	0.70	-1.00	-1.45	-3.60	-4.00	-4.40	1.52	0.13	0.97	0

Appendix A. Continuation of grain size analysis for study sites on the lower Brazos River drainage.

Br-485	28-IX-2008	18,10	-4.00	-4.03	-1.20	-1.90	-2.50	-5.60	-6.20	-6.90	1.94	-0.02	0.75	0
Br-485	28-IX-2008	16,5	-3.00	-3.00	-1.00	-1.60	-1.90	-4.00	-4.40	-4.90	1.29	0.01	0.76	0
Br-485	28-IX-2008	5,12	-2.90	-2.90	1.30	-1.00	-1.60	-4.30	-4.80	-5.40	1.97	0.13	1.02	0
Br-485	28-IX-2008	6,16	-2.60	-2.73	2.10	-0.80	-0.80	-4.20	-4.80	-5.60	2.17	0.06	0.93	0
Br-485	28-IX-2008	12,16	-2.30	-1.93	2.00	1.00	-0.60	-3.90	-4.50	-5.20	2.47	0.20	0.89	0
Br-485	28-IX-2008	4,10	-2.20	-2.13	1.60	-0.60	-1.20	-3.20	-3.60	-4.05	1.61	0.21	1.16	0
Br-485	28-IX-2008	1,1	-3.90	-3.40	1.70	0.30	-1.60	-5.90	-6.60	-7.45	3.11	0.22	0.87	0
Br-485	28-IX-2008	17,3	-4.40	-4.45	-0.80	-2.10	-2.70	-6.20	-6.85	-7.60	2.22	0.01	0.80	0
Br-485	5-IV-2009	10,11	-2.20	-2.03	0.70	-0.20	-1.00	-3.30	-3.70	-4.20	1.62	0.16	0.87	0
Br-485	5-IV-2009	3,4	-3.40	-3.23	1.50	0.10	-1.20	-5.60	-6.40	-7.30	2.96	0.10	0.82	0
Br-485	5-IV-2009	10,13	-2.00	-1.83	1.00	-0.10	-0.90	-3.00	-3.40	-3.90	1.57	0.19	0.96	0
Br-485	5-IV-2009	18,18	-3.30	-3.30	0.00	-1.40	-1.90	-4.70	-5.20	-5.80	1.83	0.07	0.85	0
Br-485	5-IV-2009	16,5	-3.20	-3.18	1.40	-1.30	-1.80	-4.60	-5.05	-5.70	2.01	0.15	1.04	0
Br-485	5-IV-2009	1,1	-2.80	-2.67	1.70	0.50	-0.40	-4.90	-5.70	-6.60	2.81	0.07	0.76	0
Br-485	5-IV-2009	8,9	-2.40	-2.13	1.80	0.50	-0.50	-3.95	-4.50	-5.20	2.31	0.18	0.83	0
Br-485	5-IV-2009	10,6	-2.60	-2.17	3.00	1.00	-0.80	-4.25	-4.90	-5.60	2.78	0.26	1.02	0
Br-485	5-IV-2009	16,13	-2.50	-2.38	1.80	-0.40	-1.20	-3.80	-4.25	-4.80	1.96	0.20	1.04	0
Br-485	5-IV-2009	16,4	-3.10	-2.97	1.80	-0.70	-1.50	-4.60	-5.10	-5.80	2.25	0.19	1.00	0
Br-485	13-V-2009	6,16	-3.60	-3.57	0.60	-1.30	-1.90	-5.20	-5.80	-6.50	2.20	0.10	0.88	0
Br-485	13-V-2009	20,11	-2.20	-2.17	2.20	-1.00	-1.40	-3.10	-3.30	-3.70	1.47	0.27	1.42	0
Br-485	13-V-2009	7,4	-2.80	-2.73	2.50	-0.60	-1.30	-4.20	-4.80	-5.50	2.26	0.19	1.13	0
Br-485	13-V-2009	4,10	-2.30	-1.77	2.90	1.30	-0.50	-3.80	-4.30	-5.00	2.60	0.30	0.98	0
Br-485	13-V-2009	8,13	-2.20	-1.97	2.70	0.00	-1.00	-3.30	-3.70	-4.20	1.97	0.30	1.23	0
Br-485	13-V-2009	3,4	-3.30	-3.23	2.60	-0.50	-1.50	-5.20	-5.90	-6.70	2.76	0.15	1.03	0
Br-485	13-V-2009	4,4	-2.30	-2.07	2.40	0.10	-0.90	-3.50	-4.00	-4.50	2.07	0.27	1.09	0
Br-485	13-V-2009	1,1	-2.50	-2.00	2.70	1.10	-0.90	-4.10	-4.60	-5.30	2.64	0.28	1.02	0
Br-485	13-V-2009	5,17	-2.20	-1.83	2.60	0.90	-0.40	-3.70	-4.20	-4.80	2.40	0.26	0.92	0

Appendix B. Descriptive statistics for grain size analysis from study sites on the lower Sabine River. Grid number denotes quadrat within sample

Site	Date	Grid number	Median (phi)	Mean (phi)	D95 (phi)	D84 (phi)	D75 (phi)	D25 (phi)	D16 (phi)	D5 (phi)	SD (phi)	Skewness (phi)	Kurtosis (phi)	Number of live mussels
Site A	22-VII-2008	4,20	0.35	0.30	1.90	0.95	0.75	-0.15	-0.40	-0.85	0.75	0.01	1.25	-
Site A	22-VII-2008	Corner A	0.40	0.38	1.55	0.90	0.75	0.10	-0.15	-0.80	0.62	-0.03	1.48	-

area where sediment was sampled.

Site A	22-VII-2008	Corner B	0.20	0.15	1.00	0.75	0.60	-0.30	-0.50	-0.90	0.60	-0.14	0.87	-
Site A	22-VII-2008	13,10	0.60	0.63	2.30	1.20	0.90	0.30	0.10	-0.30	0.67	0.20	1.78	-
Site A	22-VII-2008	8,1	0.60	0.73	2.50	1.40	0.95	0.30	0.20	0.00	0.68	0.43	1.58	-
Site A	22-VII-2008	17,20	2.20	0.42	3.20	2.85	2.70	-1.20	-3.80	-7.10	3.22	-0.81	1.08	-
Site A	22-VII-2008	10,10	0.30	0.23	2.60	1.00	0.80	-0.20	-0.60	-1.70	1.05	-0.03	1.76	-
Site A	22-VII-2008	13,1	0.60	0.90	2.75	2.20	1.10	0.10	-0.10	-1.10	1.16	0.25	1.58	-
Site A	22-VII-2008	8,20	0.40	0.38	2.50	1.05	0.80	0.00	-0.30	-1.00	0.87	0.08	1.79	-
Site A	22-VII-2008	4,1	0.50	0.47	2.05	0.90	0.80	0.10	0.00	-0.70	0.64	0.01	1.61	-
Site A	22-VII-2008	17,10	0.65	1.08	2.80	2.40	2.10	0.30	0.20	0.00	0.97	0.56	0.64	-
Site A	22-VII-2008	9,10	0.45	0.43	1.00	0.80	0.70	0.20	0.05	-0.40	0.40	-0.14	1.15	-
Site A	22-VII-2008	13,20	0.60	0.95	2.75	2.15	0.80	0.30	0.10	-0.30	0.97	0.46	2.50	-
Site A	22-VII-2008	Corner D	0.60	1.02	2.85	2.40	2.10	0.20	0.05	-7.40	2.14	-0.01	2.21	-
Site A	22-VII-2008	1,10	0.30	0.20	0.90	0.70	0.60	-0.10	-0.40	-0.85	0.54	-0.29	1.02	-
Site A	18-X-2008	4,10	0.40	0.37	1.80	1.10	0.80	-0.10	-0.40	-0.90	0.78	-0.01	1.23	0
Site A	18-X-2008	17,3	0.80	0.83	2.40	1.70	1.40	0.25	0.00	-1.00	0.94	0.00	1.21	1
Site A	18-X-2008	1,1	0.70	0.77	1.90	1.50	1.20	0.30	0.10	-0.30	0.68	0.12	1.00	0
Site A	18-X-2008	18,18	1.20	-0.50	2.40	1.80	1.60	-2.40	-4.50	-6.90	2.98	-0.78	0.95	0
Site A	18-X-2008	19,12	1.50	1.50	2.40	1.90	1.75	1.20	1.10	-0.60	0.65	-0.20	2.24	1
Site A	18-X-2008	20,11	1.45	1.42	2.00	1.80	1.70	1.20	1.00	-2.80	0.93	-0.45	3.93	0
Site A	18-X-2008	6,16	0.55	0.55	1.80	1.20	1.00	0.10	-0.10	-2.90	1.04	-0.23	2.14	0
Site A	18-X-2008	10,12	0.50	0.40	1.80	1.30	1.00	0.00	-0.60	-5.50	1.58	-0.40	2.99	0
Site A	18-X-2008	16,5	0.50	0.50	2.00	1.50	1.20	-0.10	-0.50	-2.40	1.17	-0.16	1.39	0
Site A	18-X-2008	6,7	0.40	0.33	1.70	1.00	0.80	-0.10	-0.40	-1.00	0.76	-0.09	1.23	1
Site A	14-II-2009	3,9	0.60	0.70	1.80	1.30	1.05	0.30	0.20	-0.10	0.56	0.27	1.04	0
Site A	14-II-2009	14,5	0.40	0.37	1.40	0.90	0.80	0.05	-0.20	-0.80	0.61	-0.09	1.20	0
Site A	14-II-2009	19,5	0.50	0.48	1.70	1.10	0.85	0.10	-0.15	-0.70	0.68	-0.02	1.31	0
Site A	14-II-2009	4,15	1.20	1.13	1.90	1.70	1.55	0.70	0.50	0.20	0.56	-0.17	0.82	0
Site A	14-II-2009	5,4	0.30	0.25	1.20	0.85	0.70	-0.20	-0.40	-0.95	0.64	-0.14	0.98	0

Site	Date	Grid number	Median (phi)	Mean (phi)	D95 (phi)	D84 (phi)	D75 (phi)	D25 (phi)	D16 (phi)	D5 (phi)	SD (phi)	Skewness (phi)	Kurtosis (phi)	Number of live mussels
Site A	14-II-2009	2,17	0.50	0.50	1.70	1.20	1.00	0.10	-0.20	-1.00	0.76	-0.06	1.23	0
Site A	14-II-2009	17,12	1.10	-0.33	2.10	1.70	1.55	-0.80	-3.80	-7.70	2.86	-0.79	1.71	0

Site A	14-II-2009	9,12	1.40	1.30	3.25	1.85	1.70	1.00	0.65	0.00	0.79	-0.06	1.90	2
Site A	14-II-2009	18,4	0.30	0.22	1.20	0.80	0.70	-0.20	-0.45	-1.00	0.65	-0.19	1.00	0
Site A	14-II-2009	18,7	1.30	1.15	2.00	1.75	1.60	0.70	0.40	-0.40	0.70	-0.38	1.09	0
Site B	23-VII-2008	18,20	3.10	3.00	4.90	3.60	3.40	2.50	2.30	2.00	0.76	0.01	1.32	-
Site B	23-VII-2008	8,1	2.20	2.20	3.10	2.90	2.60	1.70	1.50	1.20	0.64	-0.03	0.87	-
Site B	23-VII-2008	12,20	2.40	2.38	3.10	2.85	2.70	2.10	1.90	1.40	0.50	-0.11	1.16	-
Site B	23-VII-2008	Corner A	2.20	2.17	3.10	2.80	2.65	1.70	1.50	1.20	0.61	-0.06	0.82	-
Site B	23-VII-2008	14,1	2.00	2.03	3.10	2.70	2.50	1.60	1.40	1.15	0.62	0.10	0.89	-
Site B	23-VII-2008	8,20	1.70	1.77	2.80	2.30	2.00	1.40	1.30	1.10	0.51	0.25	1.16	-
Site B	23-VII-2008	6,20	1.70	1.80	3.10	2.40	2.00	1.40	1.30	1.10	0.58	0.34	1.37	-
Site B	23-VII-2008	18,1	2.60	2.55	4.00	3.35	3.20	2.00	1.70	1.30	0.82	-0.03	0.92	-
Site B	23-VII-2008	4,1	1.60	1.62	2.60	2.00	1.90	1.30	1.25	1.10	0.41	0.20	1.02	-
Site B	23-VII-2008	12,1	1.50	1.53	2.10	1.90	1.80	1.30	1.20	1.10	0.33	0.17	0.82	-
Site B	23-VII-2008	4,20	1.60	1.58	2.70	1.95	1.80	1.30	1.20	1.10	0.43	0.15	1.31	-
Site B	23-VII-2008	14,20	1.60	1.58	2.60	1.95	1.80	1.30	1.20	1.10	0.41	0.13	1.23	-
Site B	23-VII-2008	2,20	1.60	1.57	2.30	1.90	1.80	1.30	1.20	1.10	0.36	0.01	0.98	-
Site B	23-VII-2008	Corner C	1.60	1.80	4.00	2.50	2.00	1.40	1.30	1.10	0.74	0.58	1.98	-
Site B	23-VII-2008	10,1	1.50	1.50	2.00	1.80	1.70	1.30	1.20	1.10	0.29	0.06	0.92	-
Site B	23-VII-2008	10,20	1.50	1.50	1.95	1.80	1.70	1.30	1.20	1.10	0.28	0.03	0.87	-
Site B	23-VII-2008	Corner D	1.60	1.60	3.40	2.00	1.90	1.30	1.20	1.10	0.55	0.28	1.57	-
Site B	23-VII-2008	Corner B	1.60	1.67	2.70	2.20	2.00	1.30	1.20	1.00	0.51	0.25	1.00	-
Site B	16-X-2008	10,20	1.50	1.53	2.10	1.90	1.80	1.30	1.20	1.10	0.33	0.17	0.82	0
Site B	16-X-2008	3,6	1.60	1.65	2.60	2.10	1.90	1.30	1.25	1.10	0.44	0.25	1.02	0
Site B	16-X-2008	13,3	1.60	1.57	2.20	1.90	1.80	1.30	1.20	1.10	0.34	-0.03	0.90	0
Site B	16-X-2008	1,8	1.50	1.50	2.00	1.80	1.70	1.30	1.20	1.10	0.29	0.06	0.92	0
Site B	16-X-2008	16,4	1.50	1.50	2.00	1.80	1.70	1.30	1.20	1.10	0.29	0.06	0.92	0
Site B	16-X-2008	12,17	1.50	1.50	1.90	1.80	1.70	1.30	1.20	1.10	0.27	0.00	0.82	0
Site B	16-X-2008	5,19	1.50	1.50	1.90	1.80	1.70	1.30	1.20	1.10	0.27	0.00	0.82	1

Appendix B. Continuation of grain size analysis for study sites on the lower Sabine River.

Site	Date	Grid number	Median (phi)	Mean (phi)	D95 (phi)	D84 (phi)	D75 (phi)	D25 (phi)	D16 (phi)	D5 (phi)	SD (phi)	Skewness (phi)	Kurtosis (phi)	Number of live mussels
Site B	16-X-2008	11,1	1.50	1.50	2.00	1.80	1.70	1.30	1.20	1.00	0.30	0.00	1.02	0
Site B	16-X-2008	9,8	1.50	1.50	1.90	1.80	1.70	1.10	1.20	1.00	0.29	-0.06	0.61	0

Site B	16-X-2008	5,10	1.50	1.50	2.00	1.80	1.75	1.30	1.20	1.10	0.29	0.06	0.82	0
Site B	12-II-2009	1,1	1.10	1.07	2.00	1.70	1.50	0.60	0.40	0.15	0.61	-0.05	0.84	0
Site B	12-II-2009	8,9	1.50	1.52	2.10	1.90	1.75	1.30	1.15	0.90	0.37	0.03	1.09	0
Site B	12-II-2009	10,13	1.20	1.13	1.90	1.70	1.55	0.70	0.50	0.20	0.56	-0.17	0.82	0
Site B	12-II-2009	13,5	1.50	1.48	2.00	1.80	1.70	1.30	1.15	1.00	0.31	-0.04	1.02	0
Site B	12-II-2009	4,10	1.40	1.33	1.90	1.80	1.65	1.10	0.80	0.30	0.49	-0.29	1.19	0
Site B	12-II-2009	4,4	1.40	1.43	1.90	1.80	1.70	1.20	1.10	0.90	0.33	0.07	0.82	0
Site B	12-II-2009	5,10	1.45	1.43	1.90	1.80	1.70	1.20	1.05	0.60	0.38	-0.19	1.07	0
Site B	12-II-2009	20,11	1.40	1.40	1.90	1.80	1.70	1.10	1.00	0.40	0.43	-0.17	1.02	0
Site B	12-II-2009	13,13	1.20	1.13	1.90	1.70	1.60	0.80	0.50	0.20	0.56	-0.17	0.87	1
Site B	12-II-2009	6,16	1.40	1.37	2.00	1.80	1.70	1.10	0.90	0.40	0.47	-0.18	1.09	0
Site C	24-VII-2008	4,1	1.50	1.57	2.10	1.90	1.80	1.40	1.30	1.10	0.30	0.27	1.02	-
Site C	24-VII-2008	8,20	1.50	1.53	2.10	1.90	1.80	1.30	1.20	1.10	0.33	0.17	0.82	-
Site C	24-VII-2008	16,20	1.50	1.50	1.95	1.80	1.70	1.30	1.20	1.05	0.29	0.00	0.92	-
Site C	24-VII-2008	20,1	1.50	1.50	2.00	1.80	1.70	1.30	1.20	1.10	0.29	0.06	0.92	-
Site C	24-VII-2008	1,1	1.50	1.50	2.00	1.80	1.70	1.30	1.20	1.10	0.29	0.06	0.92	-
Site C	24-VII-2008	2,1	1.50	1.50	2.00	1.80	1.70	1.30	1.20	1.10	0.29	0.06	0.92	-
Site C	24-VII-2008	16,1	1.50	1.50	2.00	1.80	1.70	1.30	1.20	1.10	0.29	0.06	0.92	-
Site C	24-VII-2008	1,20	1.50	1.50	2.00	1.80	1.70	1.30	1.20	1.10	0.29	0.06	0.92	-
Site C	24-VII-2008	2,20	1.50	1.50	1.95	1.80	1.70	1.30	1.20	1.10	0.28	0.03	0.87	-
Site C	24-VII-2008	14,1	1.50	1.53	2.10	1.90	1.80	1.30	1.20	1.00	0.34	0.12	0.90	-
Site C	24-VII-2008	10,1	1.50	1.47	2.00	1.80	1.70	1.20	1.10	0.70	0.37	-0.19	1.07	-
Site C	24-VII-2008	20,20	1.45	1.45	2.00	1.80	1.70	1.20	1.10	0.60	0.39	-0.11	1.15	-
Site C	24-VII-2008	6,20	1.50	1.53	2.10	1.90	1.80	1.30	1.20	1.10	0.33	0.17	0.82	-
Site C	24-VII-2008	6,2	1.50	1.50	2.00	1.80	1.70	1.30	1.20	1.00	0.30	0.00	1.02	-
Site C	24-VII-2008	10,20	1.50	1.53	2.05	1.90	1.75	1.30	1.20	1.10	0.32	0.15	0.87	-
Site C	24-VII-2008	12,20	1.50	1.53	2.05	1.90	1.80	1.30	1.20	1.05	0.33	0.12	0.82	-
Site C	24-VII-2008	4,20	1.50	1.52	2.00	1.85	1.75	1.30	1.20	1.05	0.31	0.06	0.87	-

Appendix B. Continuation of grain size analysis for study sites on the lower Sabine River.

Site	Date	Grid number	Median (phi)	Mean (phi)	D95 (phi)	D84 (phi)	D75 (phi)	D25 (phi)	D16 (phi)	D5 (phi)	SD (phi)	Skewness (phi)	Kurtosis (phi)	Number of live mussels
Site C	24-VII-2008	8,1	1.50	1.52	2.00	1.85	1.70	1.30	1.20	1.05	0.31	0.06	0.97	-
Site C	24-VII-2008	14,20	1.50	1.50	2.00	1.80	1.75	1.30	1.20	1.10	0.29	0.06	0.82	-
Site C	24-VII-2008	12,1	1.50	1.50	1.95	1.80	1.70	1.30	1.20	1.00	0.29	-0.03	0.97	-

Appendix B. Continuation of grain size analysis for study sites on the lower Sabine River.

Site C	17-X-2008	20,1	1.45	1.42	2.40	1.90	1.80	1.10	0.90	0.30	0.57	-0.10	1.23	0
Site C	17-X-2008	50,4	1.50	1.53	2.45	2.00	1.80	1.30	1.10	0.90	0.46	0.17	1.27	0
Site C	17-X-2008	28,1	1.90	1.93	2.90	2.60	2.40	1.50	1.30	1.00	0.61	0.06	0.87	0
Site C	17-X-2008	45,4	1.50	1.50	2.20	1.90	1.80	1.25	1.10	0.90	0.40	0.04	0.97	2
Site C	17-X-2008	22,1	1.45	1.42	2.30	1.90	1.80	1.10	0.90	0.40	0.54	-0.10	1.11	0
Site C	17-X-2008	10,3	1.60	1.63	2.60	2.10	1.90	1.30	1.20	1.10	0.45	0.22	1.02	0
Site C	17-X-2008	28,5	1.50	1.50	2.00	1.80	1.70	1.30	1.20	1.00	0.30	0.00	1.02	0
Site C	17-X-2008	36,8	1.50	1.52	2.00	1.85	1.80	1.30	1.20	1.10	0.30	0.09	0.74	0
Site C	17-X-2008	46,4	1.50	1.47	1.90	1.80	1.70	1.20	1.10	0.80	0.34	-0.21	0.90	0
Site C	17-X-2008	24,8	1.50	1.53	2.10	1.90	1.80	1.30	1.20	1.00	0.34	0.12	0.90	0
Site C	13-II-2009	24,5	1.60	1.57	2.30	1.90	1.80	1.30	1.20	1.10	0.36	0.01	0.98	0
Site C	13-II-2009	19,5	1.50	1.53	2.10	1.90	1.80	1.30	1.20	1.00	0.34	0.12	0.90	0
Site C	13-II-2009	16,6	1.50	1.50	2.00	1.80	1.70	1.30	1.20	1.00	0.30	0.00	1.02	0
Site C	13-II-2009	19,3	1.50	1.47	2.00	1.80	1.70	1.20	1.10	0.90	0.34	-0.12	0.90	0
Site C	13-II-2009	29,3	1.50	1.50	2.00	1.80	1.70	1.30	1.20	1.10	0.29	0.06	0.92	0
Site C	13-II-2009	10,4	1.50	1.50	1.95	1.80	1.70	1.30	1.20	1.10	0.28	0.03	0.87	0
Site C	13-II-2009	7,6	1.50	1.50	1.95	1.80	1.70	1.30	1.20	1.10	0.28	0.03	0.87	0
Site C	13-II-2009	12,10	1.40	1.42	1.90	1.80	1.70	1.20	1.05	0.65	0.38	-0.07	1.02	0
Site C	13-II-2009	1,2	1.40	1.37	1.90	1.80	1.70	1.10	0.90	0.50	0.44	-0.20	0.96	0
Site C	13-II-2009	28,3	1.45	1.45	1.90	1.80	1.70	1.20	1.10	0.80	0.34	-0.09	0.90	0
Site D	12-II-2009	16,6	0.70	0.77	1.70	1.30	1.00	0.40	0.30	0.10	0.49	0.23	1.09	0
Site D	12-II-2009	7,6	0.70	0.80	1.80	1.40	1.10	0.40	0.30	0.10	0.53	0.28	1.00	1
Site D	12-II-2009	10,4	0.65	0.70	1.70	1.20	1.00	0.35	0.25	0.10	0.48	0.24	1.01	1
Site D	12-II-2009	24,1	0.60	0.67	1.70	1.15	0.90	0.35	0.25	0.10	0.47	0.30	1.19	0
Site D	12-II-2009	3,8	0.60	0.58	1.50	0.95	0.80	0.30	0.20	0.00	0.41	0.07	1.23	0
Site D	12-II-2009	10,5	0.60	0.60	1.60	1.00	0.90	0.30	0.20	0.10	0.43	0.17	1.02	2
Site D	12-II-2009	22,1	0.70	0.75	1.80	1.30	1.00	0.40	0.25	0.10	0.52	0.22	1.16	0

Site	Date	Grid number	Median (phi)	Mean (phi)	D95 (phi)	D84 (phi)	D75 (phi)	D25 (phi)	D16 (phi)	D5 (phi)	SD (phi)	Skewness (phi)	Kurtosis (phi)	Number of live mussels
Site D	12-II-2009	17,5	0.70	0.80	1.80	1.40	1.20	0.40	0.30	0.10	0.53	0.28	0.87	0

Appendix B. Continuation of grain size analysis for study sites on the lower Sabine River.

Site D	12-II-2009	19,5	0.60	0.70	1.80	1.20	1.00	0.40	0.30	0.10	0.48	0.37	1.16	0
Site D	12-II-2009	18,5	0.60	0.60	1.50	1.00	1.00	0.35	0.20	0.10	0.41	0.14	0.88	0

Appendix C. Historical and daily average flow data for sample sites on the lower Brazos River drainage. Flow data was collected from USGS gages near sampling localities. For Yegua Creek historical data was omitted because USGS gages are located either above or immediately below Somerville Reservoir.

Sample site	Date sampled	USGS Gage #	Years of data	Daily mean flow (cfs)	Median flow (cfs)	10%-ile flow (cfs)
BR-485	15-VII-2008	08098290	42-43	117	947	289
BR-485	28-IX-2008	08098290	42-43	629	656	130
BR-485	5-IV-2009	08098290	43	248	1,870	321
BR-485	13-V-2009	08098290	43	308	2,880	288
BR-105	29-IX-2008	08111500	69-70	493	1,400	478
BR-105	4-IV-2009	08111500	70	696	3,850	719
BR-105	27-V-2009	08111500	70	970	7,550	1,180
Yegua	17-VII-2008			2		
Yegua	26-IX-2008			2		
Yegua	5-IV-2009			1		
Yegua	13-V-2009			1		
Navasota	18-VII-2008	08110800	11-12	40	46	17
Navasota	27-IX-2008	08110800	11-12	23	21	9.9
Navasota	4-IV-2009	08110800	11-12	37	367	78

Appendix D. Historical and daily average flow data for sample sites on lower Sabine River. Flow data was collected from USGS gages near sampling localities.

Sample site	Date sampled	USGS Gage #	Years of data	Daily mean flow (cfs)	Median flow (cfs)	10%-ile flow (cfs)
Site A	22-VII-2008	08028500	47-48	3,550	4,540	734
Site A	18-X-2008	08028500	48-49	878	967	367
Site A	14-II-2009	08028500	48-49	974	10,500	937
Site B	23-VII-2008	08030500	47-48	3,060	4,920	1,180
Site B	16-X-2008	08030500	48-49	981	1,270	524
Site B	12-II-2009	08030500	48-49	993	11,200	2,000
Site C	24-VII-2008	08030500	47-48	4,640	5,270	1,050
Site C	17-X-2008	08030500	48-49	1,200	1,410	545
Site C	13-II-2009	08030500	48-49	1,020	10,800	2,190
Site D	12-II-2009	08030500	48-49	993	11,200	2,000