Freshwater mussel (Family: Unionidae) survey of Allens Creek and the lower Brazos River.

Submitted by:

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Texas Water Development Board Contract No. 1200011451

Final Report

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Executive Summary

The overall goal of this project was to determine the current status and distribution of freshwater mussels in Allens Creek and the Brazos River from RM 125 to RM 59 and to characterize the habitat at the time of sampling. For Allens Creek, we surveyed twenty-seven sites and collected 28 live individuals representing 4 species. The species composition was dominated by *Quadrula apiculata* (southern mapleleaf) and *Leptodea fragilis* (fragile papershell), and we did not find any evidence of state-threatened species in Allens Creek. The habitat at sites containing mussels was characterized by shallow to moderate water depths, slow to stagnant flows and low near-bed shear stress. Substrate use at those locations was variable, although mussels were frequently found in sand and clay overlain with silt. For the Brazos River, we surveyed 92 sites and collected 2,769 live individuals of 11 species. Mussel species richness and abundance were greatest near the confluence with Allens Creek. Very few live mussels were found in stream segments between Rosenberg, TX, and Brazos Bend State Park. *Lampsilis teres* (yellow sandshell), *Cyrtonaias tampicoensis* (Tampico pearlymussel) and *Leptodea fragilis* (fragile papershell) were the most widely distributed and abundant species. We also observed two species considered candidates for federal listing in the study area: *Quadrula houstonensis* (smooth pimpleback) and *Truncilla macrodon* (Texas fawnsfoot). Overall mussel mesohabitat preference in the Brazos, assessed based on both catch-per-unit-effort and populations densities, was greatest for bank and backwater habitats. The two threatened species, *Q. houstonensis* and *T. macrodon*, mainly occupied bank habitats. The microhabitats most suitable for mussels had moderate water depth, slow to intermediate velocities, and very fine to fine substrates that were firm and compact. Near-bed shear stress at these locations was low, and Froude, Reynolds number, Boundary Reynolds number values indicated that flow at locations occupied by mussels can be generally characterized as smooth and non-turbulent.

Project Overview

Freshwater mussels represent one of the most rapidly declining faunal groups in North America. In the Brazos River basin, 25 mussel species are known to have occurred. Recent mussel surveys by Karatayev and Burlakova (2008) and Randklev et al. (2010), although not exhaustive, documented 14 extant species in the basin, including two federal candidate species (*Quadrula houstonensis* and *Truncilla macrodon*). Karatayev and Burlakova (2008) found that mussel abundance was generally higher in the downstream reaches of the Brazos River, and tributaries of the Brazos River contributed greatly to the diversity of mussels found in the basin. At a site on the Brazos River (near the IH-10 bridge) approximately 13.4 miles upstream from the Allens Creek confluence, these authors collected 63 live mussels representing 6 different species. Despite these observations, the status and distribution of the mussel fauna in the lower Brazos River basin remains largely unknown. Therefore, one of the objectives of this study was to begin evaluating the current distribution of mussels in the lower Brazos River basin by surveying Allens Creek and the Brazos River from RM 125 to RM 59.

Currently, there are plans to impound Allens Creek to meet the long-term water use demands of Houston, Texas, and adjacent coastal basin areas (Osting et al. 2004). Storage volume for the reservoir will primarily be derived from water diverted from the Brazos River. These diversions have the potential to alter habitat for aquatic communities therefore, further information is needed on habitat utilization for biota that are intolerant of flow alteration. For freshwater mussels, or unionids, it is well known that mussel populations downstream from impoundments often experience high mortality, reproductive failure, and low growth rates (Vaughn and Taylor 1999). For many mussel species in Texas, knowledge regarding mussel-habitat associations or responses to river impoundment is either unknown or is at an early stage of development. Thus, a second objective of this study is to collect information on mussel-habitat associations that may be used by the TWDB to assess whether the Allens Creek project will negatively impact mussels populations located in Allens Creek or in the Brazos River downstream from the potential reservoir.

Study Area

Allens Creek

Allens Creek is a third-order intermittent tributary of the lower Brazos River in southern Austin County, Texas. From its headwaters near Sealy, Texas, Allens Creek flows south-southeast and enters the Brazos River 29 km downstream (Gelwick and Li 2002; Osting et al. 2004). Discharge in Allens Creek is highly variable and tends to be intermittent near its headwaters and more perennial in its lower segments due to effluent discharge from the City of Wallis wastewater treatment facility. The dominant land use types in the Allens Creek drainage are agriculture and rangeland, and both have likely degraded water quality through nutrient inputs and fertilizer runoff (Osting et al. 2004). The proposed reservoir site is located immediately upstream of the FM 1458 crossing (Gelwick and Li 2002).

Brazos River

The Brazos River originates in New Mexico and is considered the third longest river in Texas, traveling 1,516 km before emptying in the Gulf of Mexico near Freeport, Texas (Huser 2000). Flow in the Brazos River basin is regulated by several flood control dams and water supply reservoirs (Gelwick and Li 2002; Osting et al. 2004). In the lower Brazos River, where the study is located, the closest on-channel reservoir is Lake Whitney, which is located several hundred kilometers upstream. Land use in the lower Brazos River basin is predominately agricultural and open rangeland.

Storage volume for the proposed reservoir will be obtained by diverting water from the Brazos River (Osting et al. 2004). Pumps will be used for these diversions and tentatively will be located upstream from the confluence of Allens Creek. Impacts from the construction and operation of the impoundment, including the diversion of water from the Brazos, will likely be greatest immediately near the project.

Site Selection

Allens Creek

Survey sites on Allens Creek were selected using a randomized sampling design. Starting at the confluence with the Brazos River, the entire length of Allens Creek was divided into 500 m segments; the bottom of each segment was numbered and georeferenced using ArcGIS 10. Point locations for surveys were chosen from the numbered segments using a random number generator. Additional sites were randomly added to the survey scheme to ensure adequate spatial coverage along the length of Allens Creek. Thirty-three sites were initially selected for surveys; however, inadequate mussel habitat (i.e., stream was dry at time of sampling) or lack of land owner permission precluded us from sampling six of these locations.

Brazos River

Survey sites along the Brazos River were selected using a stratified random sampling design. Initially, the entire length of the Brazos River, from RM 125 to RM 59, was divided into 10 km reaches; seven mesohabitats were then selected per reach. The following mesohabitats were surveyed: 1) shallow bank habitat (SBH), 2) deep bank habitat (DBH), 3) the front (upstream portion) of point bars (FPB), 4) behind (downstream portion) point bars (BPB), 5) backwaters (BW), 6) midchannels (MC), and 7) riffles (R) (Figure 1). Bank habitats were defined by locating the point in the channel where the slope of the bank leveled out. Bank habitats with an average water depth of less than 0.5 m at the point where the bank leveled out to the main channel were consider shallow, whereas those sites with a greater depth were defined as deep. Habitats were identified prior to field sampling using GoogleEarth satellite imagery. The exception were riffle habitats, which were absent or inconsistently identifiable using GoogleEarth for most of the reaches. For reaches where riffle habitat could not be identified prior to sampling, we modified our sampling design by surveying the first riffle that was encountered.

We also surveyed additional sites within an area of the Brazos River known as the 4-Mile Loop, located immediately downstream of the confluence with Allens Creek. Our rationale for performing additional surveys within the 4-Mile Loop is that those stream segments, based on their close proximity to Allens Creek, might be disproportionately impacted by the construction and operation of the proposed project. Therefore, the additional survey information obtained from this area will likely be important for developing baselines to measure future impacts.

Mussel Surveys

Allens Creek

Freshwater mussel data were collected at 27 sites using timed searches (Figure 2). Location of sample sites are listed in Table 1. At each site, surveyors qualitatively searched for mussels 100 m up- and downstream of the GPS location for a minimum of 1 person-hour (p-h). Additional 1 p-h searches were added until no new species were recorded, and the total search effort exerted at each site was then recorded. Effort was made to examine all available habitat types present at each site. Shell material was classified based on condition (i.e., fresh dead, recently dead, or subfossil). Data from the timed searches were analyzed to determine total species richness per site, total abundance per site (number of individuals per timed search), and catch-per-unit-effort (CPUE; number of mussels/total p-h). Field surveys were conducted during low flow conditions to maximize sampling effectiveness.

Brazos River

Qualitative surveys using the timed search method were performed at each randomly selected mesohabitat type (Figure 3; Table 2). Each site (mesohabitat) was surveyed using the same methodology as described for the Allens Creek survey. The resulting data were then used to calculate species richness, CPUE, and total mussel abundance per site. In addition to timed searches, we estimated mussel densities at a subset of sites (Figure 4; Table 2) using a simple random sampling methodology. Specifically, we partitioned each site into a grid of 0.25 m^2 quadrats and randomly selected 15 for mussel sampling and habitat measurements. We excavated each quadrat to a depth of 20 cm. For quadrats where sediment was difficult to excavate, we searched each quadrat for 15 minutes in lieu of excavating to a depth of 20 cm. We separated mussels from the sediment and stored them in mesh bags. Data from the quantitative sampling were then used to calculate species richness and mussel density (mussels/0.25 m^2) for each site. For sites where that were surveyed using timed searches and quantitative sampling, we assessed the correlation between mussel densities and CPUE.

Habitat Sampling

Allens Creek

Habitat measurements were recorded only for sites occupied by live mussels. Point measurements of physical habitat (i.e., depth, dominant substrate, substrate roughness, and near-bed shear stress) were recorded from the vicinity of each live individual. Water depth was measured using a steel ruler touching the stream bottom and set parallel to the flow. Water velocity was measured by setting a steel ruler parallel (D_1) and perpendicular (D_2) to flow. The resulting data were then used to calculate velocity using the following equation: $U = \text{sqrt}(2g))(D_2-D_1)$, where g is the force due to gravity and D is the depth of water (Craig 1987). Substrate composition was subjectively assessed by estimating the dominant substrate at a point location using the following substrate size ranges: pebbles > 2 mm, sand 0.06 – 2 mm, and clay/silt < 0.06 mm. Clay and silt consisted of fine sediments, although the latter was largely unconsolidated, easily disturbed, and had a slippery texture. We also assessed the total amount of silt at each location occupied by a live mussel using a percentage scale from 0 (no silt is present) to 100% (silt is the only substrate type present). Substrate roughness was determined by conforming a chain of known length to the river bottom and then measuring the linear distance between the two ends and then dividing the measured distance by the original length of the chain (Hardison and Layzer 2001). Fliesswasserstammtisch (FST) hemispheres were constructed according to Statzner and Muller (1989) and were used to measure near-bed shear stress. The FST hemisphere numbers correspond to the density of a given hemisphere and not to shear stress therefore, values for the latter were determined using the minimum bottom shear stress values (dyn cm^{-2}) presented by Statzner et al. (1991).

Brazos River

Microhabitats were measured prior to mussel sampling within 15 randomly selected 0.25 m^2 quadrats. All habitat measurements were collected at approximately the center of each quadrat. Water velocity and depth were measured using an electromagnetic flow meter; measurements were collected at the bed surface because flows in this area are most relevant to mussels. Substrate compaction was measured using a soil penetrometer (Humboldt Soil Penetrometer, H-4200). Substrate type was determined by obtaining one sediment core (diameter = 1.5”) to a depth of 15 cm per quadrat. Substrate samples were then taken back to the laboratory and dried for 24 hours at 100°C in a convection oven. Dried samples were then passed through a series of 5, 10, 18, 35, 60, 120 and 230 number sieves (4, 2, 1, 0.5, 0.25, 0.125 and 0.063 mm, respectively), and the sediment in each sieve was weighed. The resulting information was used to create cumulative frequency distribution curves, which were then used to determine the D16, D50, and D84 quantiles. Substrate and hydraulic variables used to describe mussel microhabitat were calculated using the formulae listed in Table 3.

Survey Results – Timed Searches

Allens Creek

Twenty-seven sites were surveyed in Allens Creek, and a total of 68 p-h (person-hour) was spent searching for mussels. We collected 28 live individuals representing 4 species (Table 4). Species richness ranged from 0 to 2 ($\bar{x}$ ± SE; 0.41 ± 0.13) at each site and was generally higher near the confluence with the Brazos River (Figure 5). CPUE ranged from 0.00 to 1.75 mussels/p-h (0.28 ± 0.10) and was greatest in the upper portion of Allens Creek (Figure 5). Overall, the number of live mussels collected at each site was low, ranging from 0 to 7 individuals (1.04 ± 0.38). *Quadrula apiculata* (southern mapleleaf) was the most widely distributed and abundant species, occurring at 6 sites and accounting for 71% of all collected mussels (Figure 6; Table 4). *Leptodea fragilis* (fragile papershell) was the second most abundant species, accounting for 14% of all mussels collected, and occurred at 1 site (Figure 6; Table 4). *Toxolasma texasense* (Texas lilliput) and *Uniomerus tetralasmus* (pondhorn) were the third most abundant species, each accounting for 7% of all mussels collected and occurring at 2 sites each (Figure 6; Table 4). Three additional species, *Amblema plicata* (threeridge), *Lampsilis teres* (yellow sandshell) and *Pyganodon grandis* (giant floater), were found but only as valves (Table 4).

Brazos River

A total of 2,769 live individuals of 11 species were collected after 163 p-h of searching within the Brazos River. Live mussels were observed at 42 of the 92 sites surveyed (Table 5). The number of observed species ranged from 0 to 9 per site (2.35 ± 0.30) and was highest immediately downstream of the 4-Mile Loop and lowest in stream segments downstream of Rosenberg, Texas (Figure 7; Table 5). CPUE showed a similar pattern but decreased in an up to downstream direction from the 4-Mile Loop (Figure 7). Overall, CPUE ranged from 0.00 to 149.50 mussels/p-h (11.16 ± 2.46), and total abundance ranged from 0 to 299 live individuals (30.10 ± 6.41) per site (Table 5). Within the 4-Mile Loop, species richness ranged from 0 to 8 (4.47 ± 0.73), CPUE varied from 0 to 62 mussels/p-h (15.42 ± 4.82), and total abundance ranged from 0 to 186 individuals (48.00 ± 15.15).

Lampsilis teres (38% of all live individuals; occurring at 38 sites), *Cyrtonaias tampicoensis* (Tampico pearlymussel; 29% of all live individuals; occurring at 33 sites) and *L. fragilis* (11% of all live individuals; occurring at 34 sites) were the most abundant species; no other species comprised more than 10% of live individuals that were collected (Figure 8). Two species considered candidates for federal listing were found in the study area: *Quadrula houstonensis* (smooth pimpleback) and *Truncilla macrodon* (Texas fawnsfoot), which are endemic to the Brazos and Colorado Rivers and their tributaries in Central Texas. In the Brazos River, both species sporadically occur throughout the drainage but occur more frequently in stream segments between Waco and Sealy, Texas. In this study, *Q. houstonensis* and *T. macrodon* each accounted for 5% of all live individuals collected and occurred at 16 and 28 sites, respectively; these species mainly occurred within stream segments immediately upstream and downstream of the 4-Mile Loop (Figure 9; Table 5). Overall, CPUE for *Q. houstonensis* and *T. macrodon* ranged from 0.00 to 22.50 (0.60 ± 0.27) and 0.00 to 10.00 (0.61 ± 0.16), respectively.

In the 4-Mile Loop, *Cyrtonaias tampicoensis* was the most abundant species accounting for 43% of all collected mussels and occurring at 11 sites. *Lampsilis teres* was the second most abundant species (accounting for 28% of the collected individuals) and was observed at 11 sites. *Truncilla macrodon* was the third most abundant species (accounting for 11% of all live collected individuals), occurring at 11 sites. No other species accounted for more than 10% of all mussels collected within the 4-Mile Loop.

Survey Results – Quadrat Sampling

Brazos River

We collected 114 live individuals representing 10 species from 35 sampling localities; 15 quadrats were sampled at each site for a total effort of 525 quadrat samples across all sites. Species richness ranged from 0 to 7 (1.11± 0.33) per site and was generally higher in the 4-Mile Loop (Figure 10; Table 6). Densities ranged from 0.00 to 2.13 mussels/0.25 m^2 (0.22 ± 0.09) and showed a spatial pattern similar to that of the species richness (Figure 10; Table 6). Total abundance, ranging from 0 to 32 individuals per site (3.26 ± 1.32), was variable and lower than that observed during the timed searches. *L. teres*, *T. macrodon*, *C. tampicoensis*, and *L. fragilis* were the most abundant species (Figure 11), and *Q. houstonensis* and *T. macrodon* were observed in quadrat samples at densities (mussels/0.25 m^2) ranging from 0.00 to 0.33 (0.02 ± 0.01) and 0.00 to 0.53 (0.05 ± 0.03), respectively.

For sites where both CPUE and mussel densities were measured, we used Pearson's product moment correlation to test whether species richness in quadrat samples and species richness in timed searches were correlated. We found that both measures were significantly associated ($r(33) = 0.80$, $p < 0.001$) and that more species were observed using the timed-search method compared to quantitative sampling (Figure 12). The most likely reason for this difference is that more mussels were obtained per site using the timed-search method (Tables 5 & 6). Population densities and CPUE were also significantly correlated ($r(33) = 0.90$, $p < 0.001$), although the relationship was more variable, especially for higher densities and CPUE. However, the high degree of correlation between these two variables demonstrates that CPUE is a predictor of actual mussel densities and, at the very least, can be used to relate density and CPUE at an ordinal scale; e.g., sites with low catch rates would be considered to have low densities, whereas those with high rates would be classified as having high densities.

Mussel Habitat Associations

Allens Creek – Microhabitat

A total of 28 point measurements of microhabitat were collected from Allens Creek. Mussels were observed at water depths ranging from 0.08 to 0.62 m ($\bar{x}$ ± SE; 0.43 ± 0.03) and velocities between 0.00 to 0.06 m/s (0.02 ± 0.03) (Table 7). Substrate use was variable, as mussels were found in clay, silt, sand, and pebble (Table 7), but were more frequently found in sand (32% of the point measurements) and clay (29% point measurements) overlain with silt (ranging from 0 to 90%; 35.19 ± 5.39). Bed roughness ranged from 0.75 to 1 (0.93 ± 0.01), which is indicative of sandy bottom streams with very little topography (Table 7). Near-bed shear stress, measured using FST hemispheres, ranged from 0.77 to 1.66 (dyn cm^{-2}) [0.96 ± 0.05], which is equivalent to hemisphere numbers 0 and 5, respectively (Table 7).

Leptodea fragilis was observed at deeper water depths with very little flow and low bottom shear stress and in substrates consisting of silt and sand (Table 8). *Quadrula apiculata*, on average, preferred similar water depths, although this species also occurred in shallow areas along stream banks. Generally, this species was observed at locations with moderate near-bed flow and in clay and sand substrates with silt (Table 8). *Toxolasma texasesnse* was found at moderate water depths, although not as deep as those occupied by *L. fragilis* or *Q. apiculata*, with low flow and near-bed shear stress and in clay and sand substrates with very little silt (Table 8). *Uniomerus tetralamus* was observed at water depths similar to those of *T. texasense*, although flows at those locations were largely stagnant. This species was mainly found in substrates consisting of silt. Overall, bed roughness was generally the same for all four species, indicating that they were all found in areas with similar streambed topography (Table 8).

Brazos River – Mesohabitat

Mesohabitat usage by mussels was examined across all habitat types for both timed searches and quantitative sampling using a permutation test of mean mussel abundance and species richness. Specifically, we calculated the proportion of how many times the permutated differences in the means of these measures were equal or more extreme than the observed differences. Permutation tests were also used to evaluate whether habitat differed among the mesohabitat types; the examined variables are listed in Table 3 and were derived from habitat measurements collected during quantitative sampling. Permutated differences were calculated from randomized trials (N = 10,000) using R software (version 3.02; R Foundation for Statistical Computing, Vienna, Austria), and we considered *p*-values ≤ 0.10 to be significant.

The Strauss Linear Index was used to develop mesohabitat suitability criteria for all mussels and also for *Quadrula houstonensis* and *Truncilla macrodon*. The linear index is the difference in the proportion of species utilization of particular habitat type versus the proportion of its availability. The sampling variance of the linear index allows for a statistical comparison between the calculated value and the null-hypothesis value of zero (Strauss, 1979). P-values less than or equal to 0.05 were considered significant. Suitability values were assigned to each index value using significance tests as follows: 1 = significant positive values; 0.5 = non-significant positive values; 0.2 = non-significant values; and 0 = significant negative values (Persinger et al. 2010). Riffles were not considered in either analysis because the sample size for this habitat category was considerably less than in the other habitat types and not all of the riffle sites were randomly chosen.

For timed searches, mean CPUE for backwater and bank habitats ranged from 14.37 to 23.47 mussels/p-h and was significantly higher than those from behind point bars ($\bar{x}$; 6.93), front of point bars (3.53) and midchannel (1.30) habitats (Figure 13; Tables 9 & 10). Mean species richness was generally the same across all habitat types, although the average number of species found in the midchannel habitats (0.71) was significantly lower compared to shallow bank (3.00), deep bank (3.31), and backwater (2.86) habitats (Figure 13, Tables 9 & 11). CPUE for both *Q. houstonensis* and *T. macrodon* was highest in deep bank habitats (Figure 14; Table 12); however, the difference between the CPUE values for this habitat and those of the other types was not significant (Table 9). For quantitative sampling, habitat usage across all mussel species and for *Q. houstonensis* and *T. macrodon* was similar to that of the timed searches but with fewer significant differences (Figures 13 & 14; Tables 13–16).

Mussel assemblages were generally similar among the various mesohabitat types, with *C. tampicoensis*, *L. teres*, and *L. fragilis* being the dominant species in all habitat types (Table 17). However, there were subtle differences among habitat types for less ubiquitous species. For example, backwater and bank habitats were further characterized by *A. plicata*, *Q. apiculata*, *Q. houstonensis*, and *T. macrodon,* whereas behind point bar habitats were dominated by *P. ohiensis*, *T. parvum*, and *T. texasense* (Table 17). Midchannel and front of point bar habitats also contained *P. ohiensis, Q. houstonensis*, and *T. macrodon* (Table 17), although these species were less abundant in these habitats.

Suitability curves constructed for all species of each mesohabitat type indicate that mussels are primarily using backwater and deep bank habitats (Figure 15a). Suitability values for these habitats were greater than 0.5, indicating optimal habitat conditions. By contrast, suitability values for front of point bar and midchannel areas were 0, indicating that these habitat types are underutilized by mussels. For behind point bar and shallow bank habitats, suitability was 0.2, and 0.5, respectively, indicating that these habitats are usable but not optimal for mussels. Suitability curves for *Q. houstonensis* show that this species prefers deep bank habitats (Figure 15b). Similarly, *T. macrodon* also prefers deep bank habitats but may also utilize backwater and front of point bar habitats (Figure 15c). Suitability values calculated for all mussels using data from the quantitative sampling showed similar results to those derived from the timed searches (Figure 15d).

Boundary Reynolds number, Froude number and FST hemisphere number values were much higher for front of point and mid-channel habitats compared to the other habitats. For habitats with slow-moving water, values for these same variables were much lower, indicative of more laminar flow with less hydraulic stress (Tables 18 & 19). Reynolds number values showed a similar pattern, although the differences were more subtle. Water depth was greatest at backwater habitats and, to a lesser extent, at midchannel habitats (Tables 18 & 20). Velocities were generally low for bank, backwater, and behind point bar habitats but were fast for midchannel habitats (Tables 18 & 20). D50 values were higher for front of point bar and midchannel habitats and lowest for behind point bar, backwater, and bank habitats. Although these habitats were dominated by finer sediments, substrate compaction was greater for these habitat types, particularly for bank habitats, compared to those with coarser substrates (Tables 18 & 20).

Brazos River - Microhabitat

Habitat and abundance data collected using quantitative sampling were combined to develop habitat suitability criteria for all mussels with respect to the water depth and velocity, Froude number, Reynolds number, boundary Reynolds number, shear stress (inferred from FST hemispheres), and substrate type. For continuous variables, non-parametric tolerance limits (Bovee 1986) were used to construct suitability criteria for all mussels. Suitability values derived from this method range from 0 to 1, with 0 indicating underutilization and 1 indicating optimal suitability. The bin widths of the suitability curves were determined using the Sturges (1926) equation. For categorical variables, suitability curves were developed using the Strauss Linear Index as described in the previous section.

Suitability curves for depth and velocity indicate that mussels are using shallow to moderate water depths with slow to intermediate velocities (Figure 16). The optimal substrate for mussels ranges from very fine sand to fine sand, and substrates ranging from very coarse sand to very coarse pebble are considered usable (Figure 16). Criteria for substrate compactness indicate that mussels prefer substrates that are relatively firm (Figure 16). The criteria developed for the boundary Reynolds number show that hydraulically smooth flow is optimal for mussels, and sites with transitional flows are suitable (Figure 17). Suitability criteria based on the Reynolds and Froude numbers indicate that optimal mussel habitat occurs in areas where flow is subcritical and its structure ranges from laminar to turbulent (Figure 17). Suitability curves based on the FST hemispheres indicate that mussels are primarily using areas where shear stress is low (Figure 17).

Discussion

The mussel fauna in Allens Creek is not highly diverse or dense, and the absence of live individuals for several species (i.e., *Amblema plicata* and *Lampsilis teres*) identified by shell material indicates that the fauna is not intact. Hydrologic variability, particularly extremes during high- and low-flow events, can be detrimental to mussels (Di Maio and Corkum, 1995). During the survey, flow at many of the sample sites was extremely low and in some cases reduced to stagnant pools. Persistent low-flow conditions, especially those that result in channel shrinkage, can be detrimental to mussels through decreases in food availability, higher water temperatures, lower concentrations of dissolved oxygen, exposure to concentrated pollutants, and increased rates of predation due to stranding (Golladay et al. 2004). Although circumstantial, the presence of live individuals and shell material of *Uniomerus tetralasmus*, a species known to tolerate periods of intermittency, indicates that portions of Allens Creek are prone to drying (Byrne and McMahon, 1994).

In addition to the observed intermittency, many of the surveyed sites had substrates overlain with a layer of silt and detritus. Mussels can and do occur in silty or muddy areas, although this mainly occurs in places that are stabilized by banks, boulders or trees (Brainwood et al. 2006). In Allens Creek, we did find such microhabitats, although we also observed areas where the entire stream bottom was covered with a thick, loose layer of silt and mud, which may indicate high rates of sedimentation at those locations. Extreme sedimentation events, such as those associated with changes in land use or intensive agriculture and grazing practices, can affect mussels directly by burying adults and juveniles and indirectly by interfering with feeding and respiration (Brim Box and Mossa 1999). These observations combined with our survey results indicate that overall habitat within Allens Creek is marginal to unsuitable for mussels.

Although the samples sizes were too small to draw statistical inferences regarding mussel-habitat associations in Allens Creek, we did observe that live individuals were most often found in areas that were shallow to moderately deep with slow to stagnant flows and had low near-bed shear stresses. Substrate use at those locations was variable, although mussels were more frequently found in sand and clay overlain with silt. We did not find any evidence of habitat partitioning among the four collected species, which is expected especially because all of the collected species are considered habitat generalists. Regardless, there were subtle differences in habitat use among the collected species, although it is unclear whether these differences are ecologically meaningful given our small sample sizes.

The Brazos River, particularly stream segments near the 4-Mile Loop, contains a diverse and abundant mussel fauna, which includes two species being considered for listing under the Endangered Species Act. However, downstream of the 4-Mile Loop, between Rosenberg, TX, and Brazos Bend State Park, we found very few live mussels. Although habitat in this portion of the Brazos appeared similar to that of stream segments where we observed live mussels, nearby land use is slightly different in that the river passes through several small- to medium-size towns. In these stream segments, we observed a number of large canals that appear to drain nearby subdivisions as well as at least one outlet for effluent of an unknown type. Generally, riverine mussels do poorly in urbanized streams because of increased runoff and siltation, altered flow regimes, and nutrient loading (Brim Box and Mossa 1999; Lyons et al. 2007). We did find shell material at several sites within this portion of the Brazos, suggesting that these stream segments may have supported mussel populations in the past. We also observed several in-channel mining operations in this portion of the Brazos and in the 4-Mile Loop. Dredging of sand and gravel can cause changes to the stream channel, which may result in altered habitat versus flow relationships, increased sediment loading, bank erosion, and changes in water quality. The effects of these processes, particularly those that eliminate habitat or disrupt reproductive output, are detrimental to mussels (Kanehi and Lyons, 1992).

We found that mesohabitat type influenced the distribution of mussels. Species richness and abundance were markedly higher in bank and backwater habitats, whereas mussel populations were less dense and diverse at the point bar and midchannel habitats. Physical habitat within these mesohabitats also differed significantly. We found that for bank and backwater habitats, flow was generally more laminar and less turbulent, and near-bed shear stress was much lower compared to front of point bar and midchannel habitats. Substrate compaction, a measure of firmness, was greater for bank habitats and backwater areas; substrates at mid-channel habitats were mainly loose unconsolidated sands. These differences in physical habitats across habitat types indicate that mussel mesohabitat preference may be partly explained in terms of hydraulics. During high flows, bank and backwater habitats are often associated with slow-flowing waters and lower near-bed shear stress, and as a result, the stream bottom remains stable. Under the same discharge, front of point bars and mid-channel habitats tend to experience much higher velocities and shear stresses, which often results in bed mobility. High velocities and near-bottom shear stress and unstable substrates can prevent juvenile settlement, dislodge individuals and prevent both adults and juveniles from burrowing (Di Maio and Corkum 1995; Morales et al. 2006).

Host fish availability and infection strategies may also explain the mesohabitat preferences observed in this study. Freshwater mussels rely on certain fish species for part of their reproductive cycle, and the absence of such fish during critical periods of this reproductive life cycle could result in the absence of mussels even if all other habitat characteristics were ideal (Haag and Warren, 1998). It is well know that fish are able to move out of harm's way during periods of high river discharge to areas that provide protection from scouring flows. Fish encysted with juvenile mussels (i.e., glochidia) during that time could conceivably seed those locations with mussels. If particular refugia was visited by a large number of fish bearing glochidia, then there is a greater likelihood of that population taking hold. These questions were outside of the scope of this project; however, future studies, particularly those evaluating habitat availability during low- and high-flow events, should consider evaluating fish community compositions within these habitat types.

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Table 1. Location, survey date, and presence of live mussels for mussel survey sites on Allens Creek. All sites are located in Austin County. Coordinates are in NAD83, UTM Zone 14N.

Map Number	Site Number	Coordinates		Live mussels
		Northing	Easting	
1	1	3294818	775867	-
2	25	3294375	775981	-
3	2	3293549	776696	-
4	26	3293379	777189	-
5	23	3292906	777354	-
6	3	3292245	777389	Y
7	7	3292148	777386	Y
8	24	3291720	777453	-
9	4	3289629	777658	Y
10	5	3289275	777792	Y
11	27	3288949	777897	Y
12	13	3287527	778752	-
13	11	3286993	779414	Y
14	12	3286801	779397	-
15	14	3285302	780263	-
16	15	3285066	780489	-
17	19	3284408	780530	-
18	18	3284358	780904	-
19	17	3284448	781055	-
20	16	3284159	781462	-
21	20	3284306	782247	-
22	22	3284918	783513	Y
23	21	3285136	783670	-
24	10	3285087	784000	-
25	9	3284899	784249	-
26	8	3284906	785278	Y
27	6	3285128	785467	-

Table 2. Location, survey date, and presence of live mussels for mussel survey sites on the Brazos River. Sites are located in Austin, Brazoria, and Fort Bend Counties. Asterisks denote sites that were sampled using qualitative and quantitative sampling methods. Coordinates are in NAD83, UTM Zone 14N.

Map Number	Site Number	Coordinates x	Coordinates y	Date of collection	Live mussels
1	55	788977	3288419	27-Jun-13	Y
2	57	788908	3287821	27-Jun-13	-
3	54	786677	3287860	27-Jun-13	Y
4	56	786435	3287872	26-Jun-13	Y
5	59	785027	3287261	26-Jun-13	-
6	58	785128	3285994	27-Jun-13	-
7*	60	786433	3285613	28-Jun-13	Y
8*	52	786381	3285658	26-Jun-13	Y
9*	51	786585	3285930	27-Jun-13	Y
10*	47	786846	3286224	26-Jun-13	Y
11	42	787971	3286533	10-Jul-13	Y
12*	23	788139	3286245	10-Jul-13	-
13	12	788193	3286163	10-Jul-13	-
14*	10	788613	3285902	11-Jul-13	Y
15*	53	788568	3285843	25-Jun-13	Y
16	34	788882	3285373	10-Jul-13	Y
17*	50	787826	3284662	25-Jun-13	-
18	26	787751	3284640	9-Jul-13	Y
19*	16	787410	3284801	9-Jul-13	Y
20*	49	787261	3284810	25-Jun-13	Y
21*	48	787733	3284051	24-Jun-13	Y
22	5	787850	3283802	24-Oct-12	Y
23	1	788538	3283384	24-Oct-12	Y
24	2	788812	3283058	24-Oct-12	Y
25	3	209980	3281569	24-Oct-12	Y
26	6	212094	3282709	25-Oct-12	Y
27	4	212669	3283052	25-Oct-12	Y
28	13	214084	3283146	26-Oct-12	Y
29	8	215355	3282463	26-Oct-12	Y
30	11	216534	3283665	8-Nov-12	Y
31	7	216738	3284248	9-Nov-12	Y
32	15	218111	3284414	7-Nov-12	Y
33	9	218689	3283536	7-Nov-12	Y
34*	21	219929	3281291	12-Jun-13	Y
35	22	219799	3279757	9-Nov-12	Y
36*	19	219900	3279036	11-Jun-13	Y
37*	25	219978	3277569	11-Jun-13	-
38*	14	221147	3277402	12-Jun-13	-
39*	20	221267	3277737	11-Jun-13	Y

Table 2. Continued

Map Number	Site Number	Coordinates x	y	Date of collection	Live mussels
40*	18	221169	3277769	10-Jun-13	Y
41	17	221188	3277950	9-Nov-12	Y
42	24	221246	3278742	1-Dec-12	Y
43	33	222059	3278700	30-Nov-12	Y
44	31	221922	3278202	30-Nov-12	Y
45	32	222223	3277837	30-Nov-12	Y
46	29	222481	3277711	1-Dec-12	Y
47	27	224222	3277554	1-Dec-12	Y
48	28	225599	3277290	1-Dec-12	Y
49	30	226713	3274714	1-Dec-12	-
50	35	228305	3274251	29-Nov-12	Y
51	38	229095	3274556	29-Nov-12	-
52	41	230617	3275551	29-Nov-12	Y
53	39	229790	3276505	2-Dec-12	Y
54	37	230246	3278226	29-Nov-12	-
55	40	231265	3278715	29-Nov-12	-
56	36	232157	3278663	29-Nov-12	Y
57*	46	232995	3278733	13-Jun-13	-
58*	44	233005	3277196	13-Jun-13	-
59*	85	233114	3275407	13-Jun-13	-
60*	86	235225	3276190	13-Jun-13	-
61*	45	236352	3276143	14-Jun-13	-
62*	43	236417	3276022	14-Jun-13	-
63	87	236891	3274363	14-Jun-13	-
64	88	237463	3274498	14-Jun-13	-
65	89	239262	3274591	14-Jun-13	-
66	90	240217	3275661	14-Jun-13	-
67	91	241668	3274609	14-Jun-13	-
68	92	242846	3273373	14-Jun-13	-
69*	62	243005	3273236	17-Apr-13	-
70*	61	244178	3271886	12-Apr-13	-
71*	63	244732	3271627	12-Apr-13	Y
72*	64	246280	3270207	13-Apr-13	-
73*	65	248202	3269376	13-Apr-13	-
74*	66	248363	3269113	17-Apr-13	-
75*	72	249234	3267617	14-Apr-13	-
76*	70	249228	3266907	14-Apr-13	-
77*	71	249494	3266490	14-Apr-13	-
78*	68	250595	3267406	15-Apr-13	-
79*	67	251283	3266936	15-Apr-13	-
80*	69	252163	3266578	16-Apr-13	-

Table 2. Continued

Map Number	Site Number	Coordinates x	Coordinates y	Date of collection	Live mussels
81	74	252186	3265514	16-Apr-13	-
82	77	253043	3264046	16-Apr-13	-
83	78	253120	3263256	16-Apr-13	-
84	73	253348	3262397	16-Apr-13	-
85	76	254284	3260870	16-Apr-13	-
86	75	254241	3260091	16-Apr-13	-
87	82	252477	3258191	16-Apr-13	-
88	81	252364	3257249	16-Apr-13	-
89	83	252774	3254646	16-Apr-13	-
90	79	251886	3254106	16-Apr-13	-
91	84	250629	3253684	16-Apr-13	-
92	80	250628	3253615	16-Apr-13	-

Table 3. Summary of physical variables measured in the study. U = mean bottom velocity (cm/s), d = water depth (cm), g = acceleration of gravity (980 cm/s), v = kinematic viscosity of water (0.01 cm^2/s), and ρ = density of water (0.998 g/cm^3).

Variable	Formula	Description
Bed roughness (k_s, cm)	3.5 x D_{84}	Topographic variation of the stream bottom
Froude number (Fr, dimensionless)	$\sqrt{\frac{U^2}{gd}}$	Ratio of inertial to gravitational forces
Reynolds number (Re, dimensionless)	$\frac{Ud}{v}$	Ratio of inertial to viscous forces
Boundary Reynolds number (Re_*, dimensionless)	$\frac{U_* k_s}{v}$	Roughness of flow near substrate
Shear stress (τ, $dynes/cm^2$)	Derived from FST hemispheres; see Statzner et al. (1991)	Force of friction on substrate
Shear velocity (U_*, cm/s)	$\sqrt{\frac{\tau}{\rho}}$	Friction velocity

Table 4. Mussel data for sites qualitatively sampled on Allens Creek. Numbers in columns are the total number of live individuals collected during timed-searches. Abbreviations indicate the condition of shell material: LD – Long dead; RD – Recently dead; RRD – Relatively recently dead; SBF – Subfossil.

Map No.		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Species	Common name	Site No.													
		1	25	2	26	23	3	7	24	4	5	27	13	11	12
Subfamily Anodontinae															
Pyganodon grandis	Giant floater	-	-	-	-	-	-	-	-	-	RRD	-	-	-	-
Subfamily Ambleminae															
Amblema plicata	Threeridge	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Quadrula apiculata	Southern mapleleaf	0	0	0	0	0	6	2	0	7	1	2	0	2	0
Uniomerus tetralasmus	Pondhorn	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subfamily Lampsilinae															
Lampsilis teres	Yellow sandshell	-	-	-	-	-	-	-	-	-	RRD	-	-	-	-
Leptodea fragilis	Fragile papershell	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toxolasma texasense	Texas lilliput	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Total individuals		0	0	0	0	0	6	2	0	7	2	2	0	2	0
Time (p-h)		2	2	2	2	2	4	3	2	4	4	3	2	2	2
CPUE		0.00	0.00	0.00	0.00	0.00	1.50	0.67	0.00	1.75	0.50	0.67	0.00	1.00	0.00
Species richness		0	0	0	0	0	1	1	0	1	2	1	0	1	0

Table 4. Continued

Map No.		15	16	17	18	19	20	21	22	23	24	25	26	27
		Site No.												
Species	Common name	14	15	19	18	17	16	20	22	21	10	9	8	6
Subfamily Anodontinae														
Pyganodon grandis	Giant floater	-	-	-	-	-	-	-	-	-	-	-	-	-
Subfamily Ambleminae														
Amblema plicata	Threeridge	-	-	-	-	-	-	-	-	SBF	-	-	-	SBF
Quadrula apiculata	Southern mapleleaf	0	0	0	RD	0	0	0	RD	0	0	0	0	LD
Uniomerus tetralasmus	Pondhorn	0	0	0	RD	0	0	0	1	RD	0	0	1	0
Subfamily Lampsilinae														
Lampsilis teres	Yellow sandshell	-	-	-	-	-	-	-	LD	RRD	-	-	-	RRD
Leptodea fragilis	Fragile papershell	0	0	0	0	0	0	0	4	0	0	0	0	0
Toxolasma texasense	Texas lilliput	0	0	0	0	0	0	0	0	RRD	0	0	1	0
Total individuals		0	0	0	0	0	0	0	5	0	0	0	2	0
Time (p-h)		2	2	2	2	2	2	2	5	2	2	2	4	2
CPUE		0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.50	0.00
Species richness		0	0	0	0	0	0	0	2	0	0	0	2	0

Table 5. Mussel data for sites qualitatively sampled on the Brazos River. Numbers in columns are the total number of live individuals collected during timed-searches. Habitat type acronyms denote the following: DBH – deep bank habitat; SBH – shallow bank habitat; BPB – immediately downstream of point bar; FPB – immediately upstream of point bar; BW – backwater; MC– mid-channel; and R– riffle. Map numbers with asterisks denote sites within the 4-Mile Loop.

Map No.		1	2	3	4	5	6	7*	8*	9*	10*	11*	12*	13*	14*
Species	Common name	Site No./Habitat type													
		55 DBH	57 MC	54 SBH	56 BW	59 FPB	58 BPB	60 DBH	52 BPB	51 R	47 SBH	42 DBH	23 BPB	12 MC	10 BW
Subfamily Anodontinae															
Utterbackia imbecillis	Paper pondshell	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Subfamily Ambleminae															
Amblema plicata	Threeridge	5	-	20	-	-	-	2	-	-	-	-	-	-	9
Quadrula apiculata	Southern mapleleaf	13	-	1	-	-	-	-	-	-	-	-	-	-	1
Quadrula houstonensis	Smooth pimpleback	45	-	10	4	-	-	-	4	8	-	1	-	-	2
Subfamily Lampsilinae															
Cyrtonaias tampicoensis	Tampico pearlymussel	45	-	54	3	-	-	43	2	1	2	-	-	-	26
Lampsilis teres	Yellow sandshell	8	-	32	14	-	-	36	12	3	3	-	-	-	35
Leptodea fragilis	Fragile papershell	3	-	2	5	-	-	2	-	2	-	-	-	-	10
Potamilus ohiensis	Pink papershell	-	-	-	-	-	-	1	1	-	-	1	-	-	3
Toxolasma parvum	Lilliput	-	-	-	-	-	-	3	-	-	-	-	-	-	-
Toxolasma texasense	Texas lilliput	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Truncilla macrodon	Texas fawnsfoot	20	-	6	1	-	-	14	11	7	2	3	-	-	3
Total individuals		139	0	125	27	0	0	101	31	21	7	5	0	0	89
Time (p-h)		2	1	3	2	1	1	4	2	3	2	2	1	1	4
CPUE		69.50	0.00	41.67	13.50	0.00	0.00	25.25	15.50	7.00	3.50	2.50	0.00	0.00	22.25
Species richness		7	0	7	5	0	0	7	6	5	3	3	0	0	8
Length (m)		50	50	50	50	50	50	50	50	50	50	50	50	50	50
Width (m)		8	15	10	15	15	9	5	6	5	6		15		

Table 5. Continued

Map No.		15*	16*	17*	18*	19*	20*	21*	22	23	24	25	26	27	28
Species	Common name	Site No./Habitat type													
		53	34	50	26	16	49	48	5	1	2	3	6	4	13
		FPB	DBH	MC	SBH	FPB	BW	DBH	BW	SBH	FPB	BPB	DBH	MC	BPB
Subfamily Anodontinae															
Utterbackia imbecillis	Paper pondshell	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Subfamily Ambleminae															
Amblema plicata	Threeridge	-	4	-	3	-	9	3	6	1	1	1	-	-	-
Quadrula apiculata	Southern mapleleaf	-	2	-	-	-	-	4	-	1	-	-	-	-	1
Quadrula houstonensis	Smooth pimpleback	3	5	-	-	-	-	14	-	-	2	-	-	2	-
Subfamily Lampsilinae															
Cyrtonaias tampicoensis	Tampico pearlymussel	5	14	-	12	4	134	64	38	32	17	18	9	17	18
Lampsilis teres	Yellow sandshell	1	27	-	15	1	34	34	152	29	23	140	47	5	32
Leptodea fragilis	Fragile papershell	2	1	-	9	3	2	10	43	15	24	20	15	5	12
Potamilus ohiensis	Pink papershell	-	3	-	3	-	-	-	5	3	3	9	8	-	4
Toxolasma parvum	Lilliput	-	-	-	-	-	-	3	2	-	-	1	-	-	24
Toxolasma texasense	Texas lilliput	-	-	-	-	-	-	-	-	-	-	2	-	-	12
Truncilla macrodon	Texas fawnsfoot	7	4	-	-	1	7	19	2	2	10	1	-	1	-
Total individuals		18	60	0	42	9	186	151	248	83	80	193	79	30	103
Time (p-h)		4	3	1	3	2	3	3	3	2	4	5	2	2	3
CPUE		4.50	20.00	0.00	14.00	4.50	62.00	50.33	82.67	41.50	20.00	38.60	39.50	15.00	34.33
Species richness		5	8	0	5	4	5	8	7	7	7	9	4	5	7
Length (m)		50	50	50	50	50	50	50	50	50	50	50	50	50	50
Width (m)		15		15			10	7	15	15	15	15	15	15	8.5

Table 5. Continued

Map No.		29	30	31	32	33	34	35	36	37	38	39	40	41	42
Species	Common name	Site No./Habitat type													
		8 DBH	11 MC	7 SBH	15 FPB	9 BW	21 MC	22 BPB	19 DBH	25 FPB	14 BPB	20 BW	18 SBH	17 SBH	24 FPB
Subfamily Anodontinae															
Utterbackia imbecillis	Paper pondshell	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Subfamily Ambleminae															
Amblema plicata	Threeridge	11	-	6	2	-	-	-	-	-	-	1	-	-	-
Quadrula apiculata	Southern mapleleaf	-	1	3	-	-	-	1	-	-	-	34	-	-	-
Quadrula houstonensis	Smooth pimpleback	19	-	4	-	-	-	-	-	-	-	5	-	-	-
Subfamily Lampsilinae															
Cyrtonaias tampicoensis	Tampico pearlymussel	125	5	80	4	14	-	2	5	-	-	7	-	1	2
Lampsilis teres	Yellow sandshell	98	4	130	8	32	-	13	13	-	-	34	10	13	2
Leptodea fragilis	Fragile papershell	17	1	40	-	4	1	-	3	-	-	7	-	6	4
Potamilus ohiensis	Pink papershell	7	-	3	16	6	-	6	-	-	-	1	-	5	-
Toxolasma parvum	Lilliput	18	-	-	-	-	-	1	-	-	-	-	-	-	-
Toxolasma texasense	Texas lilliput	-	-	2	-	5	-	-	-	-	-	-	-	-	-
Truncilla macrodon	Texas fawnsfoot	4	-	-	2	1	-	-	-	-	-	13	3	1	2
Total individuals		299	11	268	32	62	1	23	21	0	0	102	13	26	10
Time (p-h)		2	4	3	2	2	2	2	2	1	1	3	2	2	2
CPUE		149.50	2.75	89.33	16.00	31.00	0.50	11.50	10.50	0.00	0.00	34.00	6.50	13.00	5.00
Species richness		8	4	8	5	6	1	5	3	0	0	8	2	5	4
Length (m)		53	50	50	50	50	50	50	50	50	50	50	50	50	50
Width (m)		3	15	10	15	12	15	10	6	15	9	14	6	6	15

Table 5. Continued

Map No.		43	44	45	46	47	48	49	50	51	52	53	54	55	56
Species	Common name	Site No./Habitat type													
		33 FPB	31 R	32 BPB	29 BW	27 SBH	28 DBH	30 MC	35 SBH	38 MC	41 FPB	39 R	37 BW	40 BPB	36 DBH
Subfamily Anodontinae															
Utterbackia imbecillis	Paper pondshell	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Subfamily Ambleminae															
Amblema plicata	Threeridge	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Quadrula apiculata	Southern mapleleaf	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Quadrula houstonensis	Smooth pimpleback	-	2	-	-	-	-	-	-	-	-	-	-	-	-
Subfamily Lampsilinae															
Cyrtonaias tampicoensis	Tampico pearlymussel	-	-	-	-	-	1	-	-	-	-	1	-	-	-
Lampsilis teres	Yellow sandshell	-	2	-	1	2	7	-	2	-	1	-	-	-	-
Leptodea fragilis	Fragile papershell	3	15	6	-	1	6	-	4	-	-	-	-	-	-
Potamilus ohiensis	Pink papershell	1	3	2	-	1	2	-	7	-	-	-	-	-	1
Toxolasma parvum	Lilliput	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Toxolasma texasense	Texas lilliput	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Truncilla macrodon	Texas fawnsfoot	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Total individuals		5	22	8	1	4	16	0	14	0	1	1	0	0	1
Time (p-h)		2	3	2	2	2	2	1	4	1	2	2	1	1	2
CPUE		2.50	7.33	4.00	0.50	2.00	8.00	0.00	3.50	0.00	0.50	0.50	0.00	0.00	0.50
Species richness		3	4	2	1	3	4	0	4	0	1	1	0	0	1
Length (m)		50	50	50	50	50	50	50	50	50	50	50	50	50	50
Width (m)								15		15					

Table 5. Continued

Map No.		57	58	59	60	61	62	63	64	65	66	67	68	69	70
Species	Common name	Site No./Habitat type													
		46 FPB	44 MC	85 DBH	86 SBH	45 BPB	43 BW	87 BPB	88 MC	89 DBH	90 FPB	91 BW	92 SBH	62 DBH	61 FPB
Subfamily Anodontinae															
Utterbackia imbecillis	Paper pondshell	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Subfamily Ambleminae															
Amblema plicata	Threeridge	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Quadrula apiculata	Southern mapleleaf	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Quadrula houstonensis	Smooth pimpleback	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Subfamily Lampsilinae															
Cyrtonaias tampicoensis	Tampico pearlymussel	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lampsilis teres	Yellow sandshell	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Leptodea fragilis	Fragile papershell	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Potamilus ohiensis	Pink papershell	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Toxolasma parvum	Lilliput	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Toxolasma texasense	Texas lilliput	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Truncilla macrodon	Texas fawnsfoot	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total individuals		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Time (p-h)		1	1	1	1	1	1	1	1	1	1	1	1	1	1
CPUE		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Species richness		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Length (m)		50	50	50	50	50	50	50	50	50	50	50	50	50	50
Width (m)		15	15	4	4	6	10	9	15	5	15	15	5	4	15

Table 5. Continued

Map No.		71	72	73	74	75	76	77	78	79	80	81	82	83	84
Species	Common name	Site No./Habitat type													
		63 SBH	64 MC	65 BPB	66 BW	72 BW	70 MC	71 BPB	68 DBH	67 FPB	69 SBH	74 DBH	77 BPB	78 BW	73 FPB
Subfamily Anodontinae															
Utterbackia imbecillis	Paper pondshell	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Subfamily Ambleminae															
Amblema plicata	Threeridge	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Quadrula apiculata	Southern mapleleaf	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Quadrula houstonensis	Smooth pimpleback	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Subfamily Lampsilinae															
Cyrtonaias tampicoensis	Tampico pearlymussel	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lampsilis teres	Yellow sandshell	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Leptodea fragilis	Fragile papershell	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Potamilus ohiensis	Pink papershell	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Toxolasma parvum	Lilliput	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Toxolasma texasense	Texas lilliput	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Truncilla macrodon	Texas fawnsfoot	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Total individuals		1	0	0	0	0	0	0	0	0	0	0	0	0	0
Time (p-h)		2	1	1	1	1	1	1	1	1	1	1	1	1	1
CPUE		0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Species richness		1	0	0	0	0	0	0	0	0	0	0	0	0	0
Length (m)		50	50	50	50	50	50	50	50	50	50	50	50	50	50
Width (m)		3	15	7	5	5	15	6	3	8	4.5	4.5	6	7	15

Table 5. Continued

Map No.		85	86	87	88	89	90	91	92
Species	Common name	Site No./Habitat type							
		76 MC	75 SBH	82 BW	81 BPB	83 FPB	79 DBH	84 MC	80 SBH
Subfamily Anodontinae									
Utterbackia imbecillis	Paper pondshell	-	-	-	-	-	-	-	-
Subfamily Ambleminae									
Amblema plicata	Threeridge	-	-	-	-	-	-	-	-
Quadrula apiculata	Southern mapleleaf	-	-	-	-	-	-	-	-
Quadrula houstonensis	Smooth pimpleback	-	-	-	-	-	-	-	-
Subfamily Lampsilinae									
Cyrtonaias tampicoensis	Tampico pearlymussel	-	-	-	-	-	-	-	-
Lampsilis teres	Yellow sandshell	-	-	-	-	-	-	-	-
Leptodea fragilis	Fragile papershell	-	-	-	-	-	-	-	-
Potamilus ohiensis	Pink papershell	-	-	-	-	-	-	-	-
Toxolasma parvum	Lilliput	-	-	-	-	-	-	-	-
Toxolasma texasense	Texas lilliput	-	-	-	-	-	-	-	-
Truncilla macrodon	Texas fawnsfoot	1	-	-	-	-	-	-	-
Total individuals		1	0	0	0	0	0	0	0
Time (p-h)		1	1	1	1	1	1	1	1
CPUE		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Species richness		0	0	0	0	0	0	0	0
Length (m)		50	50	50	50	50	50	50	50
Width (m)		15	2	11	9.6	15	2.5	15	5.5

Table 6. Mussel data for sites quantitatively sampled on the Brazos River. Numbers in columns are the total number of live individuals collected. Habitat type acronyms denote the following: DBH – deep bank habitat; SBH – shallow bank habitat; BPS – immediately downstream of point bar; FPS – immediately upstream of point bar; BW – backwater; MC– mid-channel; and R– riffle. Map numbers with asterisks denote sites within the 4-Mile Loop.

Map No.		7*	8*	9*	10*	12*	14*	15*	17*	19*	20*	21*	34	36	37
		Site No./Habitat type													
Species	Common name	60 DBH	52 BPB	51 R	47 SBH	23 BPB	10 BW	53 FPB	50 MC	16 FPB	49 BW	48 DBH	21 MC	19 DBH	25 FPB
Subfamily Anodontinae															
Utterbackia imbecillis	Paper pondshell	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Subfamily Ambleminae															
Amblema plicata	Threeridge	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Quadrula apiculata	Southern mapleleaf	-	-	-	-	-	-	-	-	-	1	4	-	-	-
Quadrula houstonensis	Smooth pimpleback	-	-	1	-	-	-	1	-	1	-	2	-	-	-
Subfamily Lampsilinae															
Cyrtonaias tampicoensis	Tampico pearlymussel	2	-	1	-	-	-	-	-	-	10	7	-	1	-
Lampsilis teres	Yellow sandshell	3	1	1	-	-	2	-	-	-	2	3	-	4	-
Leptodea fragilis	Fragile papershell	-	-	1	-	-	-	-	-	-	-	6	-	1	-
Potamilus ohiensis	Pink papershell	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Toxolasma parvum	Lilliput	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Toxolasma texasense	Texas lilliput	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Truncilla macrodon	Texas fawnsfoot	-	-	5	-	-	1	1	-	-	1	10	-	1	-
Total individuals		5	2	10	0	0	3	2	0	1	14	32	0	7	0
# of Quadrats		15	15	15	15	15	15	15	15	15	15	15	15	15	15
Density (mussels/0.25m^2)		0.33	0.13	0.67	0.00	0.00	0.20	0.13	0.00	0.07	0.93	2.13	0.00	0.47	0.00
Species richness		2	2	6	0	0	2	2	0	1	4	6	0	4	0
Length (m)		50	50	50	50	50	50	50	50	50	50	50	50	50	50
Width (m)		5	6	5	6	15		15	15		10	7	15	6	15

Table 6. Continued

Map No.		38	39	40	57	58	59	60	61	62	69	70	71	72	73
Species	Common name	Site No./Habitat type													
		14 BPB	20 BW	18 SBH	46 FPB	44 MC	85 DBH	86 SBH	45 BPB	43 BW	62 DBH	61 FPB	63 SBH	64 MC	65 BPB
Subfamily Anodontinae															
Utterbackia imbecillis	Paper pondshell	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Subfamily Ambleminae															
Amblema plicata	Threeridge	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Quadrula apiculata	Southern mapleleaf	-	3	-	-	-	-	-	-	-	-	-	-	-	-
Quadrula houstonensis	Smooth pimpleback	-	5	-	-	-	-	-	-	-	-	-	-	-	-
Subfamily Lampsilinae															
Cyrtonaias tampicoensis	Tampico pearlymussel	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Lampsilis teres	Yellow sandshell	-	11	4	-	-	-	-	-	1	-	-	-	-	-
Leptodea fragilis	Fragile papershell	-	3	-	-	-	-	-	-	-	-	-	-	-	-
Potamilus ohiensis	Pink papershell	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Toxolasma parvum	Lilliput	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Toxolasma texasense	Texas lilliput	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Truncilla macrodon	Texas fawnsfoot	-	8	-	-	-	-	-	-	-	-	-	-	-	-
Total individuals		0	32	4	0	0	0	0	0	2	0	0	0	0	0
# of Quadrats		15	15	15	15	15	15	15	15	15	15	15	15	15	15
Density (mussels/0.25m^2)		0.00	2.13	0.27	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00
Species richness		0	7	1	0	0	0	0	0	2	0	0	0	0	0
Length (m)		50	50	50	50	50	50	50	50	50	50	50	50	50	50
Width (m)		9	14	6	15	15	4	4	6	10	4	15	3	15	7

Table 6. Continued

Map No.		74	75	76	77	78	79	80
Species	Common name	Site No./Habitat type						
		66 BW	72 BW	70 MC	71 BPB	68 DBH	67 FPB	69 SBH
Subfamily Anodontinae								
Utterbackia imbecillis	Paper pondshell	-	-	-	-	-	-	-
Subfamily Ambleminae								
Amblema plicata	Threeridge	-	-	-	-	-	-	-
Quadrula apiculata	Southern mapleleaf	-	-	-	-	-	-	-
Quadrula houstonensis	Smooth pimpleback	-	-	-	-	-	-	-
Subfamily Lampsilinae								
Cyrtonaias tampicoensis	Tampico pearlymussel	-	-	-	-	-	-	-
Lampsilis teres	Yellow sandshell	-	-	-	-	-	-	-
Leptodea fragilis	Fragile papershell	-	-	-	-	-	-	-
Potamilus ohiensis	Pink papershell	-	-	-	-	-	-	-
Toxolasma parvum	Lilliput	-	-	-	-	-	-	-
Toxolasma texasense	Texas lilliput	-	-	-	-	-	-	-
Truncilla macrodon	Texas fawnsfoot	-	-	-	-	-	-	-
Total individuals		0	0	0	0	0	0	0
# of Quadrats		15	15	15	15	15	15	15
Density (mussels/0.25m^2)		0.00	0.00	0.00	0.00	0.00	0.00	0.00
Species richness		0	0	0	0	0	0	0
Length (m)		50	50	50	50	50	50	50
Width (m)		5	5	15	6	3	8	4.5

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Table 7. Mean, standard deviation (SD), and range for physical variables measured at locations where mussels occurred in Allens Creek. Mean substrate was determined based on the most frequently occurring substrate type. The letter N denotes total number of samples per parameter and N/A indicates not available.

Parameter	N	Mean	SD	Range
Depth (m)	28	0.48	0.14	0.78 - 0.62
Velocity (m/s)	28	0.02	0.02	0.00 - 0.06
Substrate	28	sand & clay	N/A	clay, silt, sand, & pebble
Silt (%)	28	25.00	28.50	0.00 - 90.00
Substrate roughness	28	0.94	0.05	0.75 - 1.00
Hemisphere number	28	1	1	0 - 5

Table 8. Habitat summary for species collected in Allens Creek. Mean, standard deviation (SD), and range for physical variables were measured at locations where mussels occurred. Mean substrate was determined based on the most frequently occurring substrate type. The letter N denotes total number of samples per parameter and N/A indicates not available.

Species	Common name	N	Depth (m) Mean	Depth (m) SD	Depth (m) Range	Velocity (m/s) Mean	Velocity (m/s) SD	Velocity (m/s) Range
Subfamily Ambleminae								
Quadrula apiculata	Southern mapleleaf	20	0.45	0.15	0.08 - 0.62	0.03	0.02	0.0 - 0.06
Uniomerus tetralasmus	Pondhorn	2	0.36	0.19	0.23 - 0.49	0.02	0.02	0.01 - 0.03
Subfamily Lampsilinae								
Leptodea fragilis	Fragile papershell	4	0.48	0.02	0.46 - 0.51	0.01	0.00	0.01 - 0.01
Toxolasma texasense	Texas lilliput	2	0.31	0.12	0.23 - 0.40	0.01	0.00	0.00 - 0.01

Species	Common name	N	Substrate Mean	Substrate SD	Substrate Range	Silt (%) Mean	Silt (%) SD	Silt (%) Range
Subfamily Ambleminae								
Quadrula apiculata	Southern mapleleaf	20	clay & sand	N/A	clay, silt, sand & pebble	28.50	25.03	0.00 - 80.00
Uniomerus tetralasmus	Pondhorn	2	silt	N/A	silt	67.50	10.61	60.00 - 75.00
Subfamily Lampsilinae								
Leptodea fragilis	Fragile papershell	4	silt & sand	N/A	silt & sand	60.00	35.59	20.00 - 90.00
Toxolasma texasense	Texas lilliput	2	sand & clay	N/A	sand & clay	20.00	14.14	10.00 - 30.00

Species	Common name	N	Substrate roughness Mean	Substrate roughness SD	Substrate roughness Range	Hemisphere no. Mean	Hemisphere no. SD	Hemisphere no. Range
Subfamily Ambleminae								
Quadrula apiculata	Southern mapleleaf	20	0.93	0.05	0.75 - 1.00	2	2	0 - 5
Uniomerus tetralasmus	Pondhorn	2	0.94	0.05	0.90 - 0.97	0	0	0 - 0
Subfamily Lampsilinae								
Leptodea fragilis	Fragile papershell	4	0.92	0.03	0.89 - 0.95	1	1	0 - 2
Toxolasma texasense	Texas lilliput	2	0.94	0.05	0.90 - 0.97	1	1	0 -1

Table 9. *P*-values from permutation tests comparing CPUE, species richness, CPUE – *Quadrula houstonensis*, and CPUE – *Truncilla macrodon* across all habitat types. Bold numbers indicate significant values.

Habitat type_CPUE	BW	FPB	MC	SBH	DBH
Behind point bar (BPB)	0.16	0.36	0.12	0.29	0.13
Backwater (BW)	-	**0.06**	**0.03**	0.74	0.62
Front of point bar (FPB)	-	-	0.25	**0.09**	**0.06**
Midchannel (MC)	-	-	-	**0.07**	**0.05**
Shallow bank habitat (SBH)	-	-	-	-	0.42

Habitat type_Species richness	BW	FPB	MC	SBH	DBH
Behind point bar (BPB)	0.44	1.00	0.20	0.33	0.23
Backwater (BW)	-	0.39	**0.04**	0.90	0.71
Front of point bar (FPB)	-	-	0.12	0.28	0.20
Midchannel (MC)	-	-	-	**0.02**	**0.02**
Shallow bank habitat (SBH)	-	-	-	-	0.77

Habitat type_CPUE – QH	BW	FPB	MC	SBH	DBH
Behind point bar (BPB)	0.41	0.68	0.73	0.48	0.13
Backwater (BW)	-	0.23	0.23	0.96	0.16
Front of point bar (FPB)	-	-	0.33	0.96	0.17
Midchannel (MC)	-	-	-	0.16	0.13
Shallow bank habitat (SBH)	-	-	-	-	0.16

Habitat type_CPUE – TM	BW	FPB	MC	SBH	DBH
Behind point bar (BPB)	0.57	0.78	0.46	0.88	0.15
Backwater (BW)	-	0.65	**0.07**	0.54	0.27
Front of point bar (FPB)	-	-	**0.04**	0.86	0.17
Midchannel (MC)	-	-	**-**	**0.04**	**0.06**
Shallow bank habitat (SBH)	-	-	-	-	0.14

Table 10. Total (N), mean, standard deviation (SD), and range by habitat type for CPUE (mussels/p-h).

Habitat type	N	Mean	SD	Range
Behind point bar (BPB)	15	6.93	12.92	0.00 - 38.6
Backwater (BW)	14	17.57	26.53	0.00 - 82.67
Front of point bar (FPB)	15	3.53	6.21	0.00 – 20.00
Midchannel (MC)	14	1.30	4.01	0.00 – 15.00
Shallow bank habitat (SBH)	15	14.37	25.04	0.00 - 89.33
Deep bank habitat (DBH)	16	23.47	39.73	0.00 - 149.5
Riffle (R)	3	4.94	3.85	0.00 - 7.33

Table 11. Total (N), mean, standard deviation (SD), and range by habitat type for species richness from timed-searches.

Habitat type	N	Mean	SD	Range
Behind point bar (BPB)	15	1.93	3.15	0 - 9
Backwater (BW)	14	2.86	3.39	0 - 8
Front of point bar (FPB)	15	1.93	2.46	0 - 7
Midchannel (MC)	14	0.71	1.64	0 - 5
Shallow bank habitat (SBH)	15	3.00	2.88	0 - 8
Deep bank habitat (DBH)	16	3.31	3.32	0 - 8
Riffle (R)	3	3.33	2.08	1 - 5

Table 12. Total (N), mean, standard deviation (SD), and range by habitat type for CPUE (mussels/p-h) for *Quadrula houstonensis* (QH) and *Truncilla macrodon* (TM).

Habitat type	N	Mean_QH	SD_QH	Range_QH	Mean_TM	SD_TM	Range_TM
Behind point bar (BPB)	15	0.13	0.52	0.00 - 2.00	0.38	1.42	0.00 - 5.50
Backwater (BW)	14	0.30	0.67	0.00 - 2.00	0.65	1.24	0.00 - 4.33
Front of point bar (FPB)	15	0.08	0.22	0.00 - 0.75	0.48	0.77	0.00 - 2.50
Midchannel (MC)	14	0.07	0.27	0.00 - 1.00	0.04	0.13	0.00 - 0.50
Shallow bank habitat (SBH)	15	0.31	0.90	0.00 - 3.33	0.43	0.65	0.00 - 0.00
Deep bank habitat (DBH)	16	2.43	5.93	0.00 - 22.50	1.54	2.86	0.00 - 10.00
Riffle (R)	3	1.11	1.39	0.00 - 2.67	0.78	1.35	0.00 - 2.30

Table 13. *P*-values from permutation tests comparing mean mussel densities, species richness, densities – *Quadrula houstonensis*, and densities – *Truncilla macrodon* across all habitat types. Bold numbers indicate significant values.

Habitat type_Densities	BW	FPB	MC	SBH	DBH
Behind point bar (BPB)	0.12	0.80	0.51	0.53	0.14
Backwater (BW)	-	0.12	0.13	0.17	0.85
Front of point bar (FPB)	-	-	0.18	0.67	0.14
Midchannel (MC)	-	-	-	0.53	0.18
Shallow bank habitat (SBH)	-	-	-	-	0.22

Habitat type_Species richness	BW	FPB	MC	SBH	DBH
Behind point bar (BPB)	**0.09**	0.67	0.51	0.73	0.16
Backwater (BW)	-	**0.10**	**0.06**	**0.08**	0.74
Front of point bar (FPB)	-	-	0.19	0.45	0.18
Midchannel (MC)	-	-	-	0.55	0.11
Shallow bank habitat (SBH)	-	-	-	-	0.14

Habitat type_Densities – QH	BW	FPB	MC	SBH	DBH
Behind point bar (BPB)	0.54	0.19	1.00	1.00	0.54
Backwater (BW)	-	0.54	0.51	0.51	0.56
Front of point bar (FPB)	-	-	0.20	0.21	1.00
Midchannel (MC)	-	-	-	1.00	0.52
Shallow bank habitat (SBH)	-	-	-	-	0.50

Habitat type_Densities – TM	BW	FPB	MC	SBH	DBH
Behind point bar (BPB)	0.15	0.53	1.00	1.00	0.19
Backwater (BW)	-	0.24	0.18	0.19	0.86
Front of point bar (FPB)	-	-	0.51	0.51	0.36
Midchannel (MC)	-	-	-	1.00	0.34
Shallow bank habitat (SBH)	-	-	-	-	0.34

Table 14. Total (N), mean, standard deviation (SD), and range by habitat type for mussel densities (mussels/0.25m^2). N/A indicates not available.

Habitat type	N	Mean	SD	Range
Behind point bar (BPB)	6	0.02	0.05	0.00 - 0.13
Backwater (BW)	6	0.57	0.84	0.00 - 2.13
Front of point bar (FPB)	6	0.03	0.06	0.00 - 0.13
Midchannel (MC)	5	0.00	0.00	0.00
Shallow bank habitat (SBH)	5	0.05	0.12	0.00 - 0.27
Deep bank habitat (DBH)	6	0.49	0.83	0.00 - 2.13
Riffle (R)	1	0.67	N/A	N/A

Table 15. Total (N), mean, standard deviation (SD), and range by habitat type for species richness from quantitative sampling. N/A indicates not available.

Habitat type	N	Mean	SD	Range
Behind point bar (BPB)	6	0.33	0.82	0.00 - 2.00
Backwater (BW)	6	2.50	2.66	0.00 - 7.00
Front of point bar (FPB)	6	0.50	0.84	0.00 - 2.00
Midchannel (MC)	5	0.00	0.00	0.00
Shallow bank habitat (SBH)	5	0.20	0.45	0.00 - 1.00
Deep bank habitat (DBH)	6	2.00	2.53	0.00 - 6.00
Riffle (R)	1	6.00	N/A	N/A

Table 16. Total (N), mean, standard deviation (SD), and range by habitat type for mussel densities (mussels/0.25m^2) for *Quadrula houstonensis* (QH) and *Truncilla macrodon* (TM). N/A indicates not available.

Habitat type	N	Mean_QH	SD_QH	Range_QH	Mean_TM	SD_TM	Range_TM
Behind point bar (BPB)	6	0.00	0.00	0.00	0.00	0.00	0.00
Backwater (BW)	6	0.06	0.14	0.00 - 0.33	0.11	0.21	0.00 - 0.53
Front of point bar (FPB)	6	0.02	0.03	0.00 - 0.07	0.01	0.03	0.00 - 0.07
Midchannel (MC)	5	0.00	0.00	0.00	0.00	0.00	0.00
Shallow bank habitat (SBH)	5	0.00	0.00	0.00	0.00	0.00	0.00
Deep bank habitat (DBH)	6	0.02	0.05	0.00 - 0.13	0.12	0.27	0.00 - 0.67
Riffle (R)	1	0.07	N/A	N/A	0.33	N/A	N/A

Table 17. Proportion of mussel community by habitat type using abundance data from timed-searches.

Species	Common name	Proportion of mussel community Habitat type					
		BPB	BW	FPB	MC	SBH	DBH
Subfamily Anodontinae							
Utterbackia imbecillis	Paper pondshell	0.00	-	-	-	-	0.00
Subfamily Ambleminae							
Amblema plicata	Threeridge	0.00	0.03	0.02	-	0.05	0.03
Quadrula apiculata	Southern mapleleaf	0.01	0.05	-	0.02	0.01	0.02
Quadrula houstonensis	Smooth pimpleback	0.01	0.02	0.03	0.05	0.02	0.10
Subfamily Lampsilinae							
Cyrtonaias tampicoensis	Tampico pearlymussel	0.11	0.31	0.21	0.52	0.31	0.35
Lampsilis teres	Yellow sandshell	0.55	0.42	0.23	0.21	0.40	0.31
Leptodea fragilis	Fragile papershell	0.11	0.10	0.23	0.17	0.13	0.07
Potamilus ohiensis	Pink papershell	0.06	0.02	0.13	-	0.04	0.03
Toxolasma parvum	Lilliput	0.07	0.00	-	-	-	0.03
Toxolasma texasense	Texas lilliput	0.04	0.01	-	-	0.01	0.00
Truncilla macrodon	Texas fawnsfoot	0.03	0.04	0.15	0.02	0.03	0.07
Total number of mussels		358	715	155	42	583	872
Total		1.00	1.00	1.00	1.00	1.00	1.00

Table 18. Mean, standard deviation (SD), and range for physical variables measured by habitat type for the Brazos River. 95% CI for the median were calculated using a non-parametric bootstrapping procedure.

Habitat	Parameter	N	Mean	SD	Median	Median_95% CI
BPB	Boundary Reynolds number	90	4.65	2.78	4.34	3.9 - 4.9
	Reynolds number	90	37,033	38,847	23,100	15,550 - 33,150
	Froude number	90	0.06	0.06	0.05	0.03 - 0.06
	Hemisphere no.	90	1.80	1.61	1.00	1.00 – 2.00
	Water depth (m)	90	0.37	0.20	0.33	0.25 - 0.35
	Water velocity (m/s)	90	0.10	0.09	0.08	0.05 - 0.12
	D50 (mm)	90	0.26	0.26	0.23	0.19 - 0.26
	Penetrometer (kg/cm^2)	90	0.10	0.08	0.09	0.06 - 0.11
BW	Boundary Reynolds number	90	6.06	12.69	3.65	2.60 - 4.90
	Reynolds number	90	10,900	22,242	4,600	3,200 - 7,200
	Froude number	90	0.02	0.02	0.01	0.006 - 0.01
	Hemisphere no.	90	0.52	0.90	0.00	N/A
	Water depth (m)	90	0.37	0.31	0.29	0.20 - 0.35
	Water velocity (m/s)	90	0.02	0.03	0.02	0.01 - 0.02
	D50 (mm)	90	0.86	1.26	0.27	0.18 - 0.27
	Penetrometer (kg/cm^2)	90	0.11	0.11	0.06	0.04 - 0.07
FPB	Boundary Reynolds number	90	12.75	12.46	9.47	8.8 - 9.8
	Reynolds number	90	51,200	63,090	25,950	15,800 - 42,600
	Froude number	90	0.05	0.03	0.05	0.05 - 0.06
	Hemisphere no.	90	1.97	1.40	2.00	2.00 - 2.00
	Water depth (m)	90	0.37	0.26	0.29	0.25 - 0.40
	Water velocity (m/s)	90	0.10	0.07	0.09	0.06 - 0.01
	D50 (mm)	90	1.33	1.41	0.59	0.48 - 0.75
	Penetrometer (kg/cm^2)	90	0.08	0.06	0.06	0.04 - 0.07
MC	Boundary Reynolds number	75	9.88	4.92	8.55	7.90 - 10.00
	Reynolds number	75	125,616	68,532	107,500	96,000 - 131,200
	Froude number	75	0.09	0.03	0.09	0.01 - 0.07
	Hemisphere no.	75	4.44	1.59	4.00	4.00 - 4.00
	Water depth (m)	75	0.57	0.16	0.56	0.5 - 0.6
	Water velocity (m/s)	75	0.21	0.08	0.19	0.18 - 0.21
	D50 (mm)	75	0.37	0.16	0.35	0.33 - 0.34
	Penetrometer (kg/cm^2)	75	0.03	0.03	0.03	0.00 - 0.03

Table 18. Continued.

Habitat	Parameter	N	Mean	SD	Median	Median_95% CI
SBH	Boundary Reynolds number	75	3.56	2.11	2.54	2.30 - 3.00
	Reynolds number	75	32,453	35,290	16,800	11,200 - 25,200
	Froude number	75	0.03	0.03	0.03	0.02 - 0.04
	Hemisphere no.	75	1.17	0.95	1.00	1.00 - 1.00
	Water depth (m)	75	0.38	0.18	0.41	0.30 - 0.44
	Water velocity (m/s)	75	0.07	0.06	0.05	0.03 - 0.07
	D50 (mm)	75	0.20	0.10	0.16	0.13 - 0.19
	Penetrometer (kg/cm^2)	75	0.12	0.08	0.09	0.01 – 0.07
DBH	Boundary Reynolds number	90	14.80	56.87	2.02	1.60 - 2.20
	Reynolds number	90	82,923	76,352	60,528	41,800 - 86,800
	Froude number	90	0.04	0.04	0.03	0.02 - 0.03
	Hemisphere no.	90	1.47	2.06	1.00	1.00 - 1.00
	Water depth (m)	90	0.82	0.38	0.78	0.60 - 0.90
	Water velocity (m/s)	90	0.10	0.09	0.08	0.04 - 0.09
	D50 (mm)	90	2.38	7.41	0.13	0.10 - 0.14
	Penetrometer (kg/cm^2)	90	0.11	0.10	0.11	0.06 - 0.13

Table 19. *P*-values from permutation tests comparing hydraulic variables across all habitat types. Bold numbers indicate significant values.

Habitat type_ Re*	BW	FPB	MC	SBH	DBH
Behind point bar (BPB)	0.36	**0.00**	**0.00**	**0.05**	**0.01**
Backwater (BW)	-	**0.00**	**0.00**	0.36	**0.05**
Front of point bar (FPB)	-	-	0.36	**0.00**	**0.00**
Midchannel (MC)	-	-	-	**0.00**	**0.00**
Shallow bank habitat (SBH)	-	-	-	-	0.20

Habitat type_Re	BW	FPB	MC	SBH	DBH
Behind point bar (BPB)	**0.00**	0.70	**0.00**	0.70	**0.00**
Backwater (BW)	-	**0.00**	**0.00**	**0.00**	**0.00**
Front of point bar (FPB)	-	-	**0.00**	0.66	0.28
Midchannel (MC)	-	-	-	**0.00**	**0.01**
Shallow bank habitat (SBH)	-	-	-	-	**0.00**

Habitat type_Fr	BW	FPB	MC	SBH	DBH
Behind point bar (BPB)	**0.00**	0.58	**0.00**	0.20	**0.04**
Backwater (BW)	-	**0.00**	**0.00**	**0.00**	**0.00**
Front of point bar (FPB)	-	-	**0.00**	**0.00**	**0.00**
Midchannel (MC)	-	-	-	**0.00**	**0.00**
Shallow bank habitat (SBH)	-	-	-	-	0.72

Habitat type_Hem	BW	FPB	MC	SBH	DBH
Behind point bar (BPB)	1.00	1.00	**0.00**	1.00	1.00
Backwater (BW)	-	**0.02**	**0.00**	1.00	1.00
Front of point bar (FPB)	-	-	**0.03**	1.00	1.00
Midchannel (MC)	-	-	-	**0.00**	**0.02**
Shallow bank habitat (SBH)	-	-	-	-	1.00

Table 20. *P*-values from permutation tests comparing hydraulic variables across all habitat types. Bold numbers indicate significant values.

Habitat type_Water depth	BW	FPB	MC	SBH	DBH
Behind point bar (BPB)	0.90	0.90	**0.00**	0.52	**0.00**
Backwater (BW)	-	0.93	**0.00**	0.18	**0.00**
Front of point bar (FPB)	-	-	**0.00**	0.35	**0.00**
Midchannel (MC)	-	-	-	**0.00**	**0.00**
Shallow bank habitat (SBH)	-	-	-	-	**0.00**

Habitat type_Water velocity	BW	FPB	MC	SBH	DBH
Behind point bar (BPB)	1.00	1.00	**0.00**	0.90	1.00
Backwater (BW)	-	**0.00**	**0.00**	**0.00**	**0.00**
Front of point bar (FPB)	-	-	**0.00**	0.21	1.00
Midchannel (MC)	-	-	-	**0.00**	**0.00**
Shallow bank habitat (SBH)	-	-	-	-	0.90

Habitat type_D50	BW	FPB	MC	SBH	DBH
Behind point bar (BPB)	0.23	**0.00**	**0.00**	**0.08**	**0.01**
Backwater (BW)	-	**0.00**	0.12	**0.02**	**0.02**
Front of point bar (FPB)	-	-	**0.00**	**0.00**	**0.00**
Midchannel (MC)	-	-	-	**0.00**	**0.00**
Shallow bank habitat (SBH)	-	-	-	-	0.14

Habitat type_Pent	BW	FPB	MC	SBH	DBH
Behind point bar (BPB)	1.00	1.00	**0.00**	1.00	1.00
Backwater (BW)	-	1.00	**0.00**	1.00	1.00
Front of point bar (FPB)	-	-	**0.00**	1.00	1.00
Midchannel (MC)	-	-	-	**0.00**	**0.00**
Shallow bank habitat (SBH)	-	-	-	-	1.00

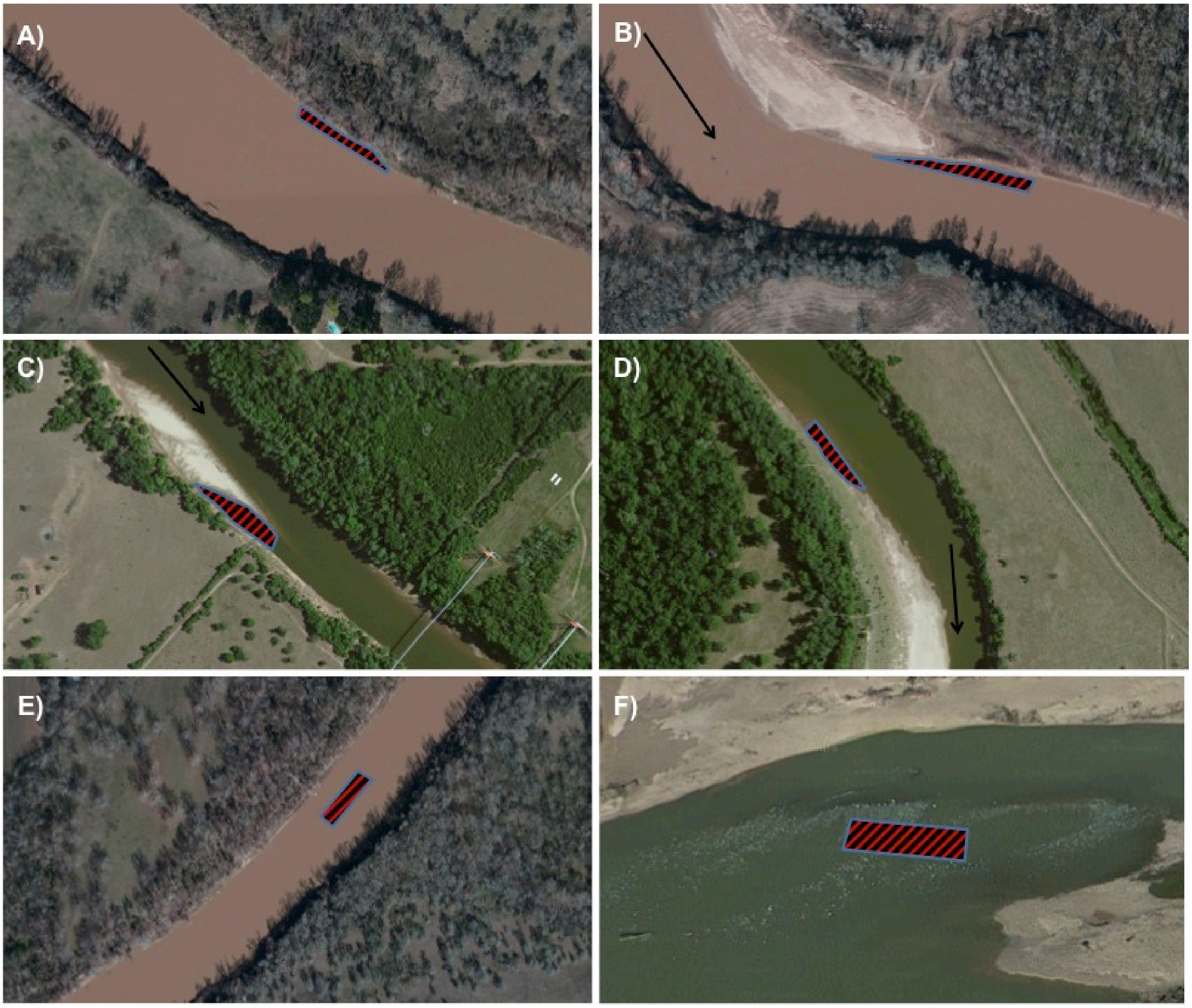

Figure 1. Mesohabitat types sampled on the Brazos River: A) bank habitats, either shallow or deep; B) behind point bars (BPB); C) backwater (BW); D) front of point bars (FPB); midchannel (MC); and riffle (R).

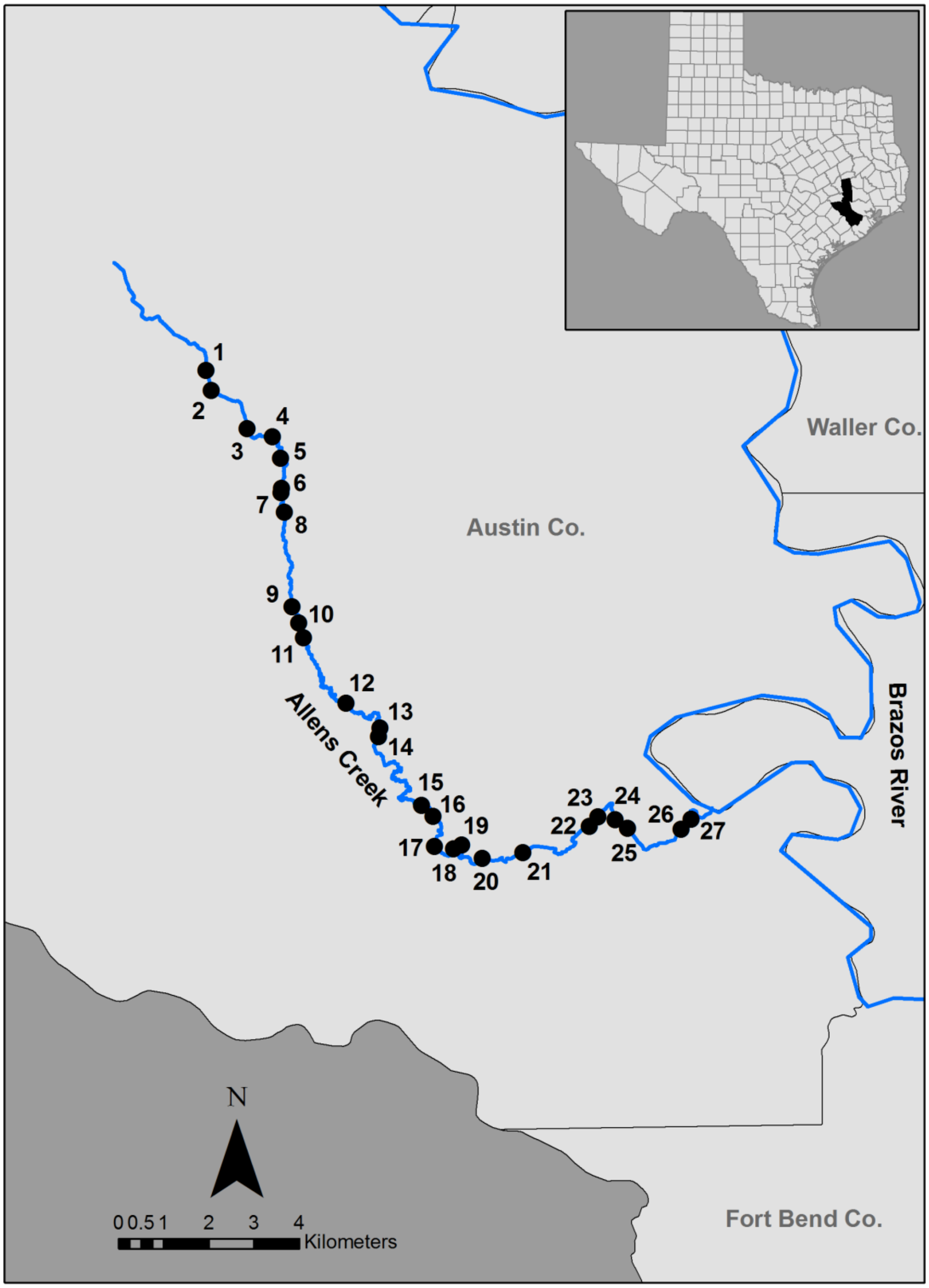

Figure 2. Sites sampled in Allens Creek. Sites codes are listed in Table 1.

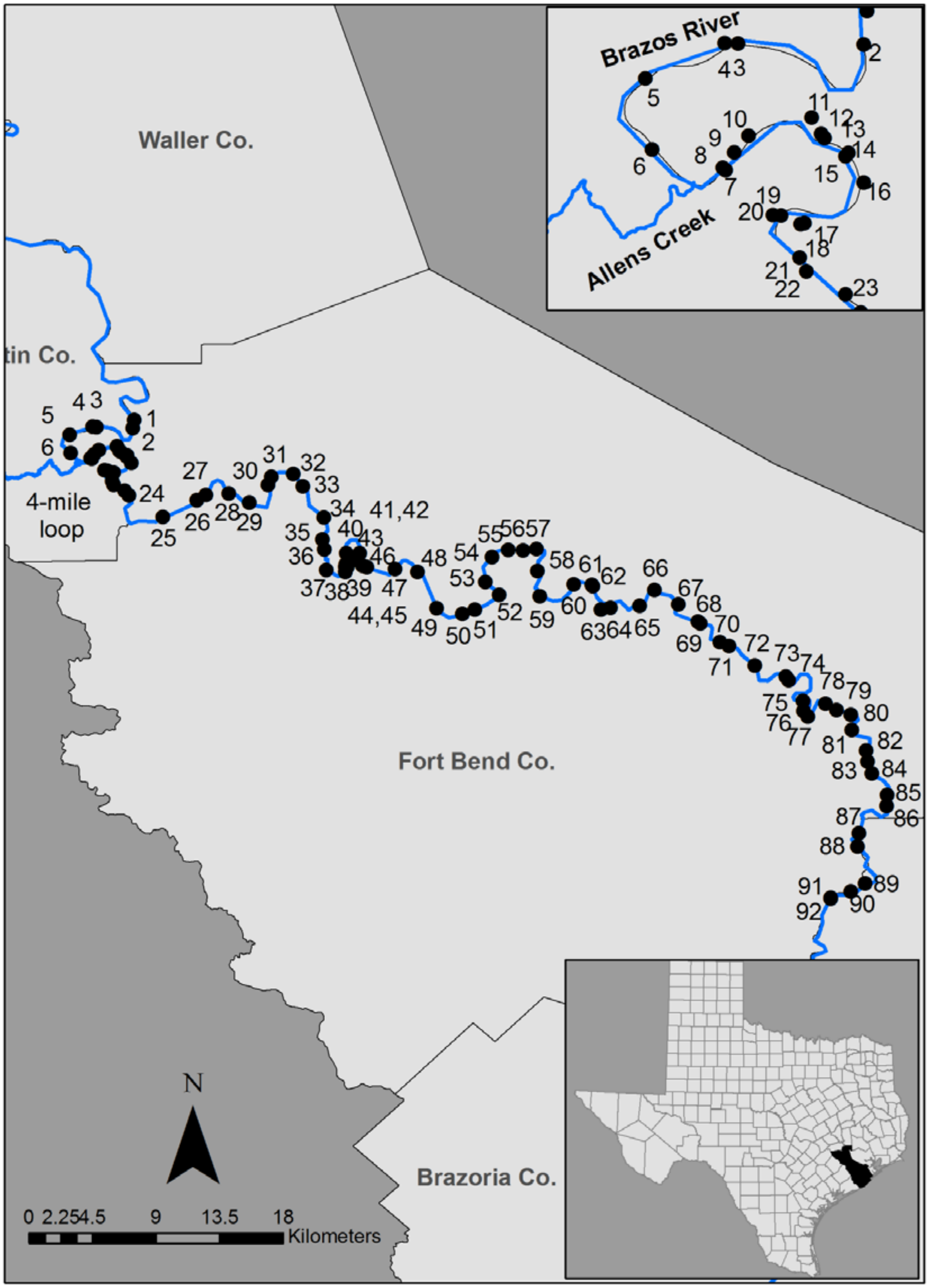

Figure 3. Sites in the Brazos River that were sampled qualitatively. Sites codes are listed in Table 2. A detailed few of the 4-Mile Loop is provided in the upper right hand corner of the map.

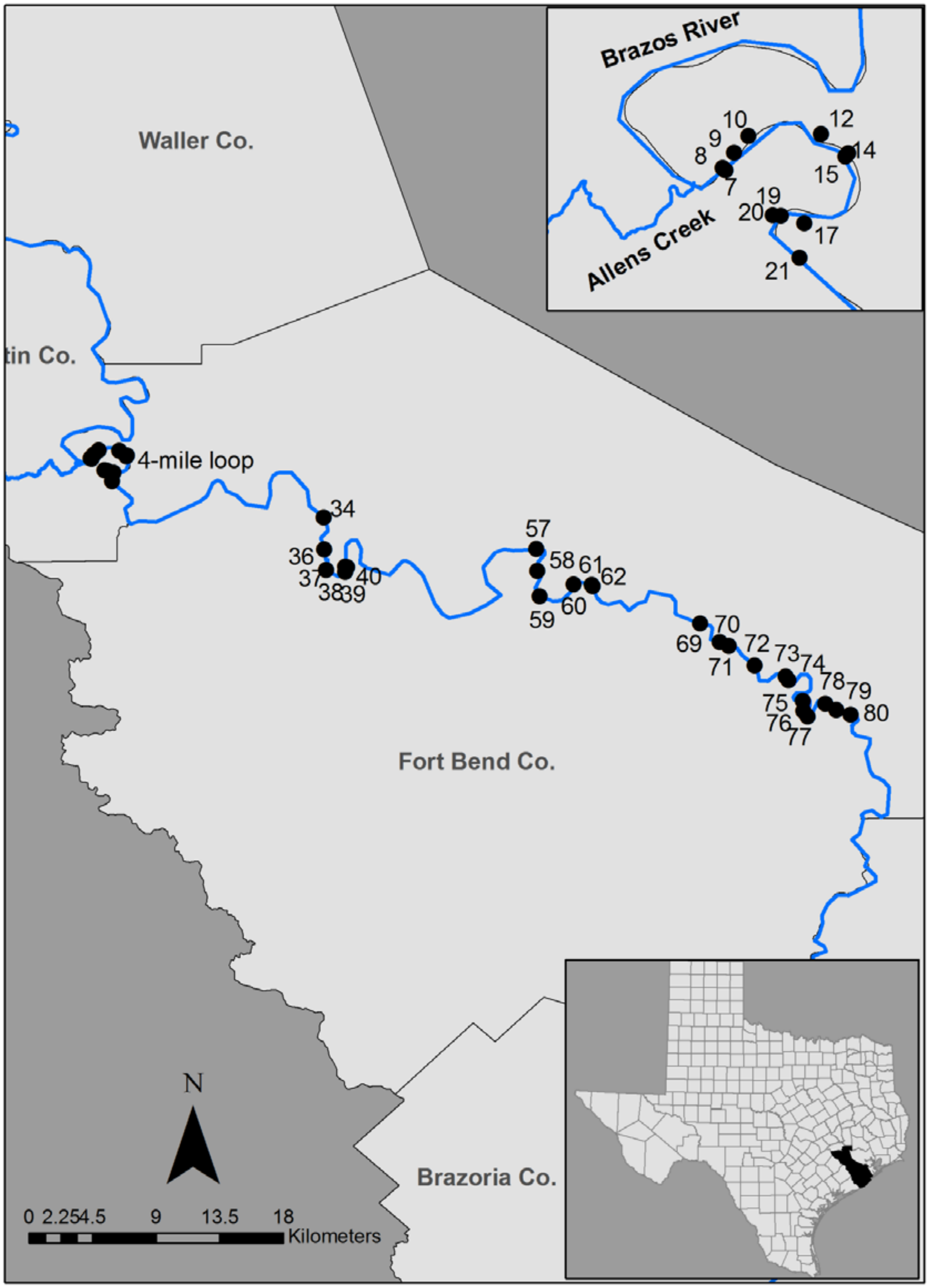

Figure 4. Sites in the Brazos River that were sampled quantitatively. Sites codes are listed in Table 2. A detailed few of the 4-Mile Loop is provided in the upper right hand corner of the map.

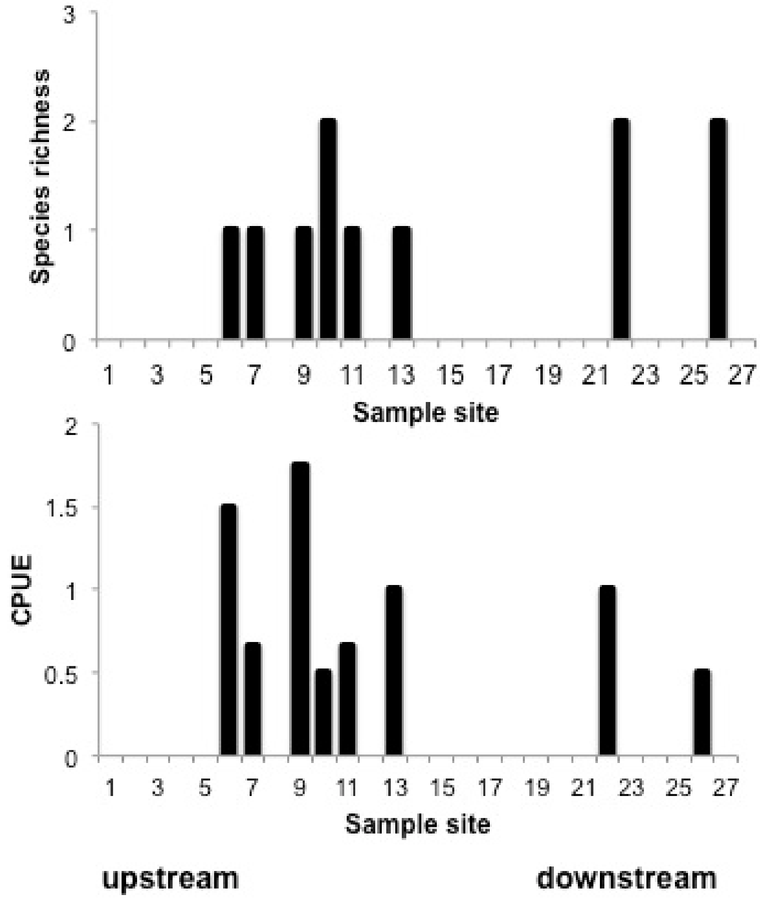

Figure 5. Species richness (top) and CPUE [catch-per-unit effort; mussels/p-h] (bottom) from timed-searches for collection sites on Allens Creek. Sites codes denote map numbers provided in Table 1 and are listed in longitudinal sequence from upstream to downstream.

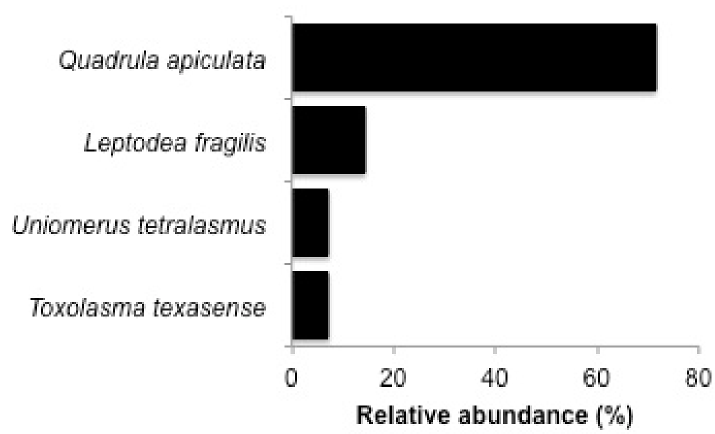

Figure 6. Relative abundance of mussel species in Allens Creek.

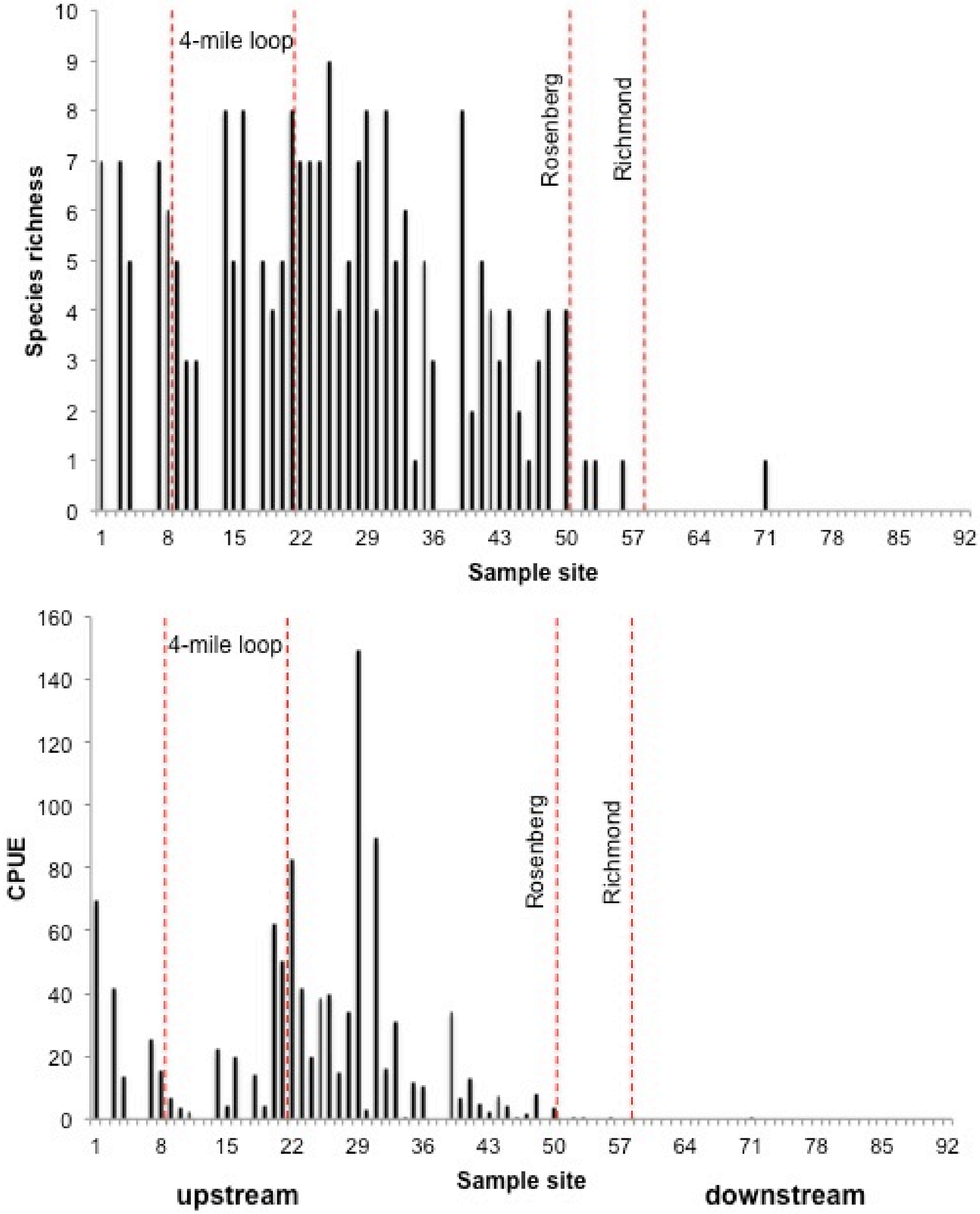

Figure 7. Species richness (top) and CPUE [catch-per-unit effort; mussels/p-h] (bottom) from timed-searches for collection sites on the Brazos River. Sites codes denote map numbers provided in Table 2 and are listed in longitudinal sequence from upstream to downstream.

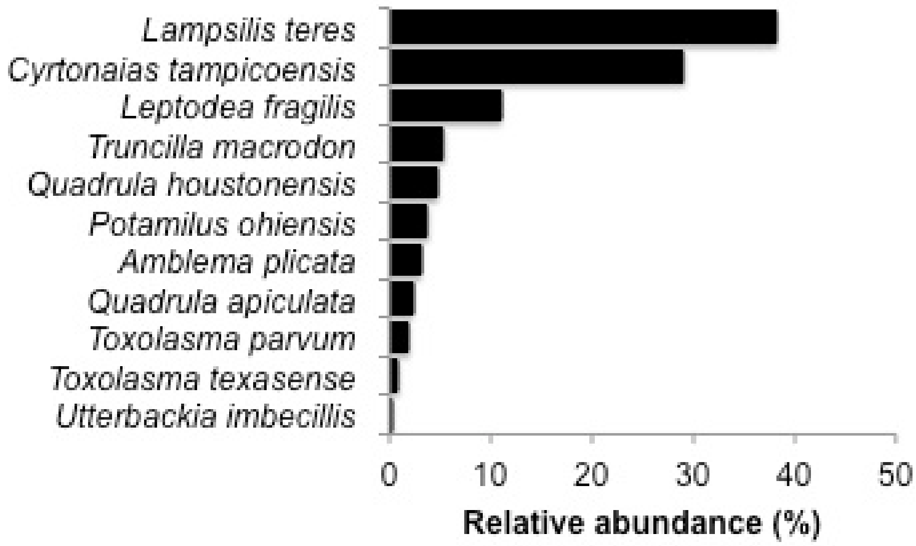

Figure 8. Relative abundance of mussel species in the Brazos River; abundance data are from timed-searches.

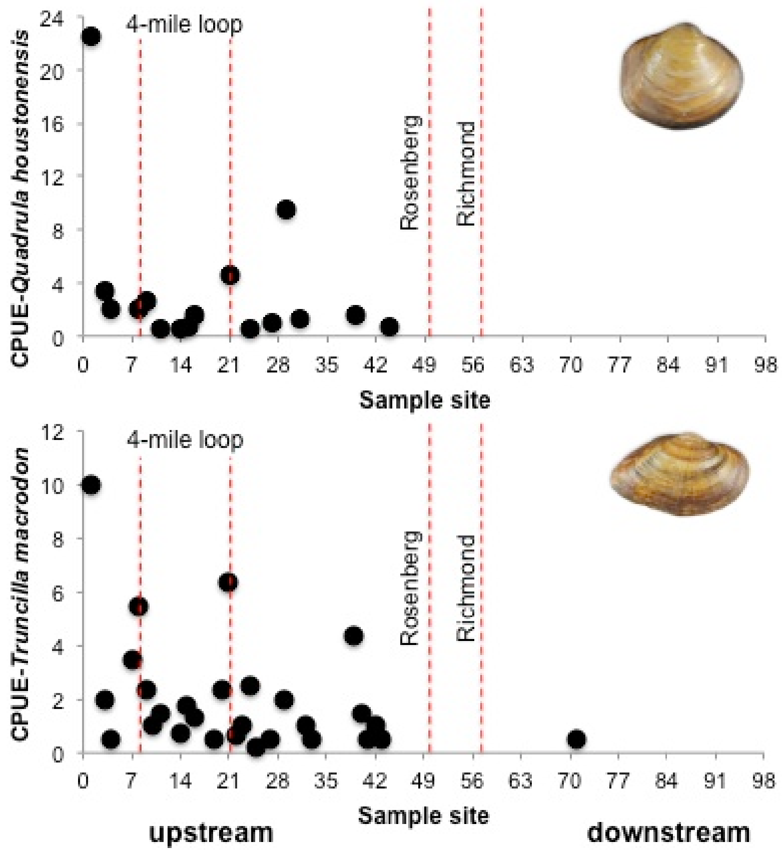

Figure 9. CPUE (mussels/p-h) for *Quadrula houstonensis* (top) and *Truncilla macrodon* (bottom) from timed-searches for collection sites on the Brazos River.

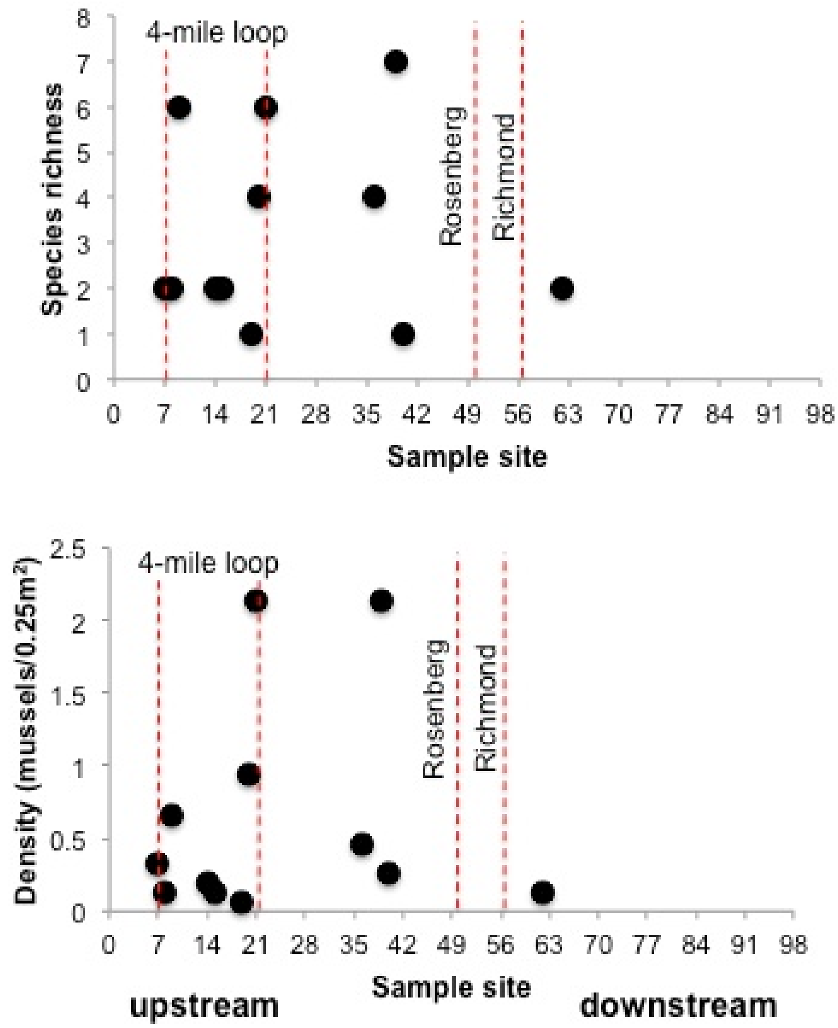

Figure 10. Species richness (top) and population densities (bottom) in the Brazos River.

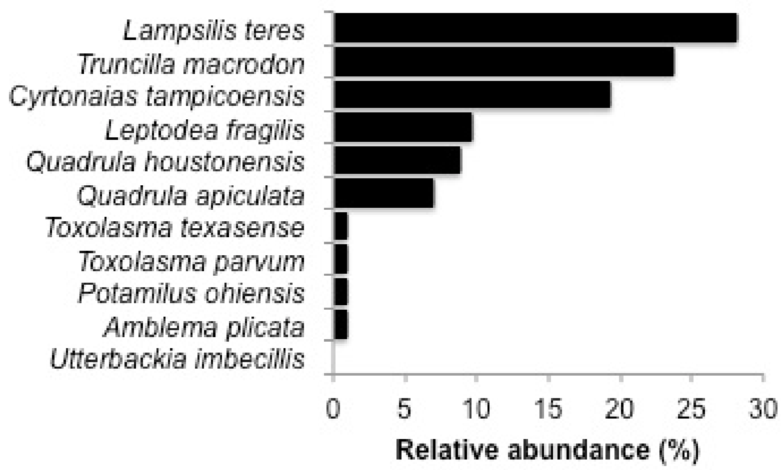

Figure 11. Relative abundance of mussel species in the Brazos River; abundance data are from quantitative sampling.

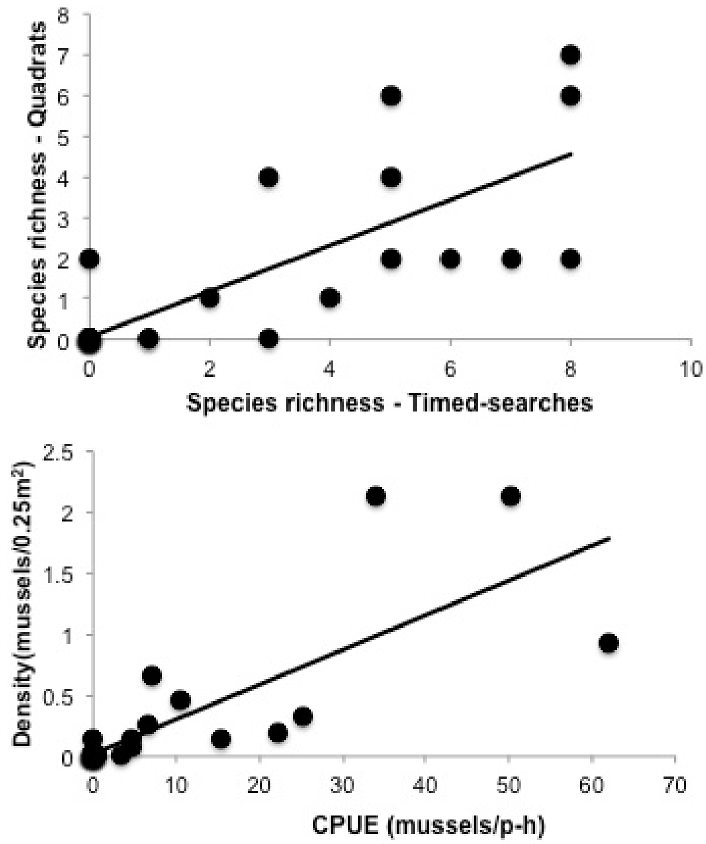

Figure 12. Relationship between species richness from timed-searches and quantitative sampling (top) and CPUE in timed-searches and population density from quantitative sampling (bottom).

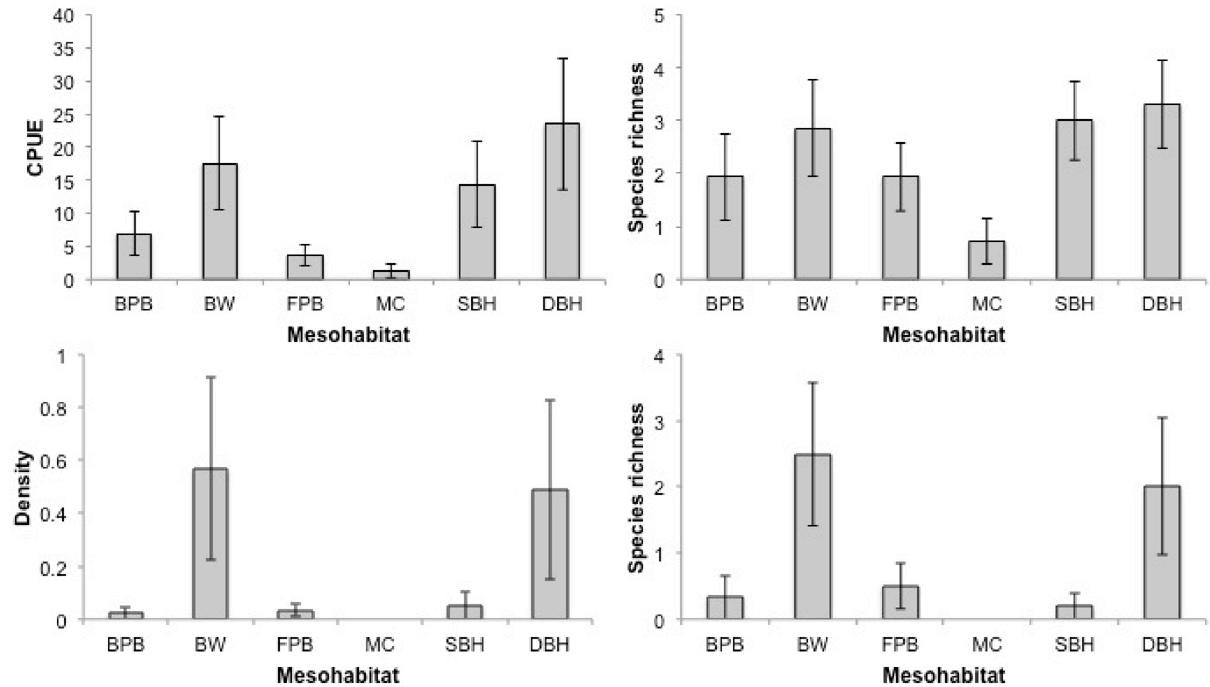

Figure 13. Mean CPUE and species richness (top) and mussel densities and richness (bottom) from timed-searches and quantitative sampling, respectively, by mesohabitat type. Error bars = ± 1 SE and acronyms for each habitat type correspond to the following: (DBH) deep bank habitat; (SBH) shallow bank habitat; (BPB) behind point bar; (BW) backwater; (FPB) front of point bar (FPB); and (MC) midchannel.

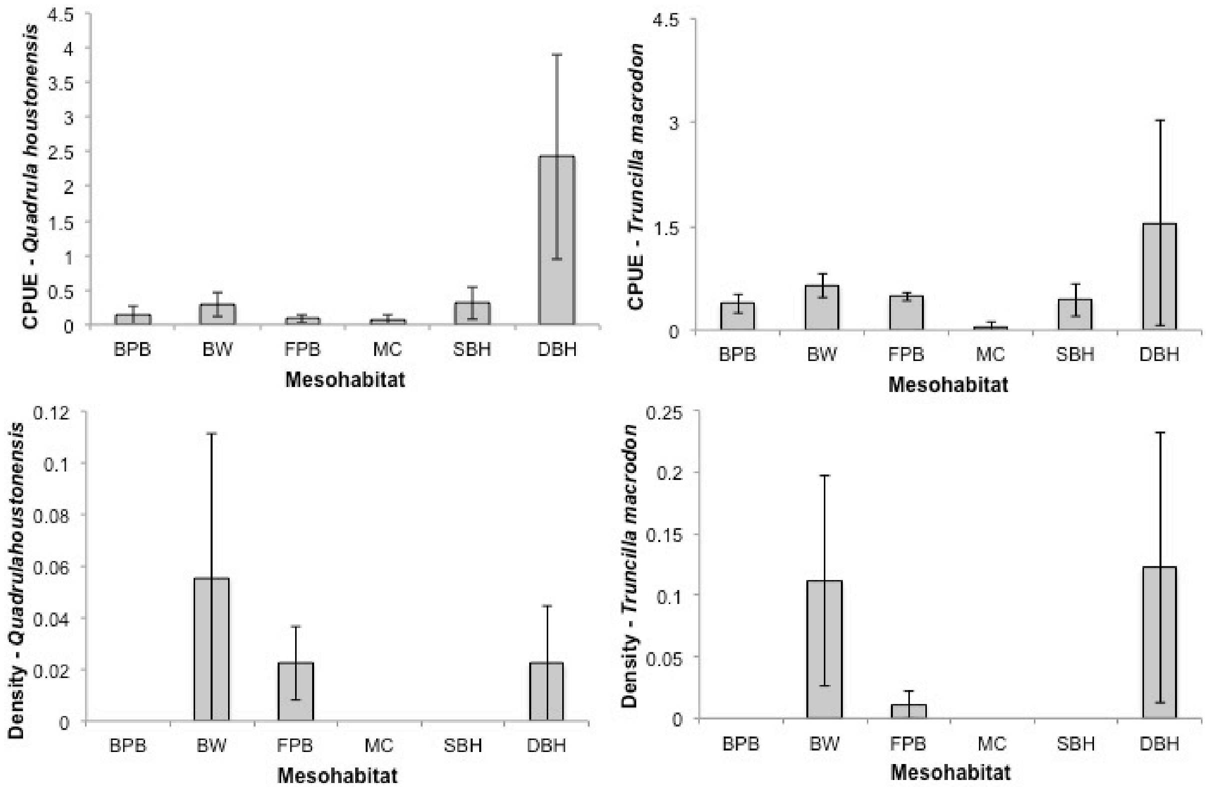

Figure 14. Mean CPUE (top) and mussel densities (bottom) from timed-searches and quantitative sampling, respectively, by mesohabitat type for *Quadrula houstonensis* and *Truncilla macrodon*. Error bars = ± 1 SE and acronyms for each habitat type correspond to the following: (DBH) deep bank habitat; (SBH) shallow bank habitat; (BPB) behind point bar; (BW) backwater; (FPB) front of point bar (FPB); and (MC) midchannel.

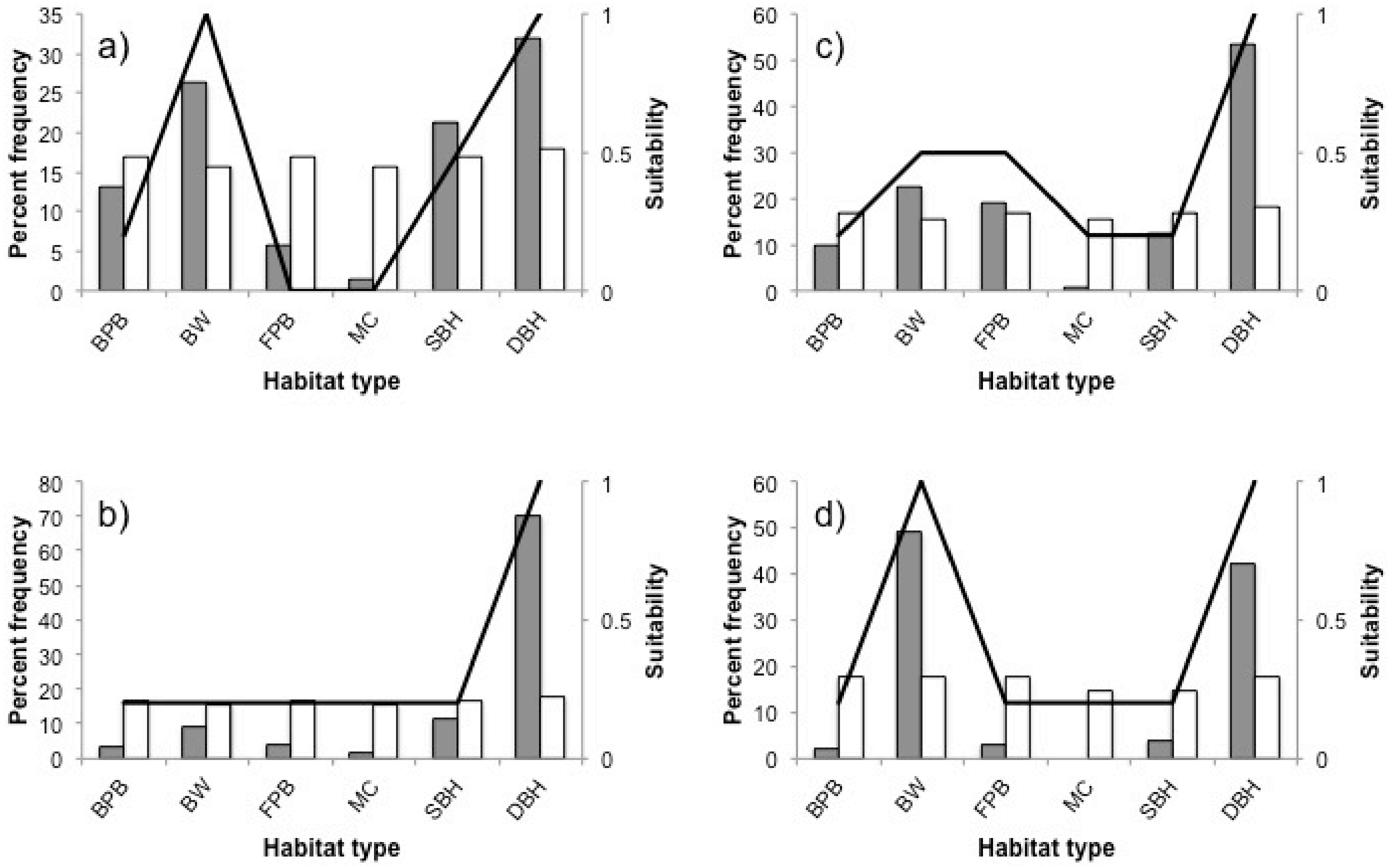

Figure 15. Percent frequency of occurrence (grey bars), habitat availability (white bars), and Strauss linear index values (black line) for mesohabitats. Suitability criteria are shown for (a) all mussels, (b) *Quadrula houstonensis*, and (c) *Truncilla macrodon*. Panels (a), (b), and (c) are based on abundance data from the timed-searches. Panel (d) shows habitat suitability for all mussels using abundance data from quantitative sampling. The number of observations used were: N = 2,725 (a), N = 120 (b), N = 142 (c), and N = 104 (d). Acronyms for each habitat type correspond to the following: (DBH) deep bank habitat; (SBH) shallow bank habitat; (BPB) behind point bar; (BW) backwater; (FPB) front of point bar (FPB); and (MC) midchannel.

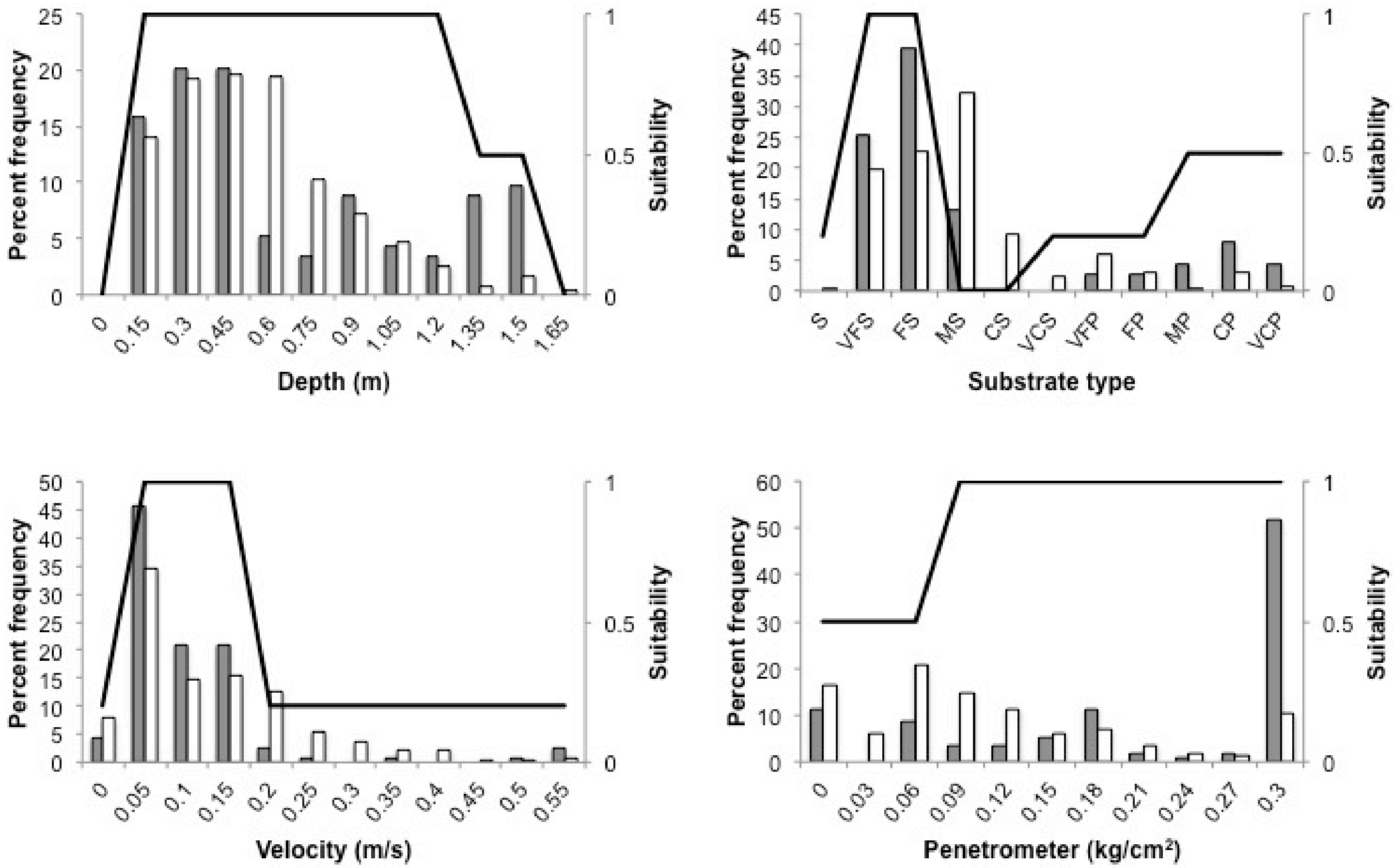

Figure 16. Percent frequency of occurrence (grey bars), habitat availability (white bars), and Strauss linear index values (black line) for water depth, velocity, substrate type, and compactness (Penetrometer). Suitability criteria are shown only for all mussels and are based on abundance data from quantitative sampling. The number of observations used were: N = 114. Acronyms for each substrate type correspond to the following: (S) silt (< 0.063 mm); (VFS) very fine sand (0.063 – 0.124 mm); (FS) fine sand (0.125 – 0.249 mm); (MS) medium sand (0.250 – 0.499 mm); (CS) coarse sand (0.500 – 0.999 mm); (VCS) very coarse sand (1.00 - 1.99 mm); (VFP) very fine pebble (2.00 – 3.99 mm); (FP) fine pebble (4.00 – 7.99 mm); (MP) medium pebble (8.00 – 15.99 mm); (CP) coarse pebble (16.00 – 31.99 mm); and (VCP) very coarse pebble (32.00 mm ≥).

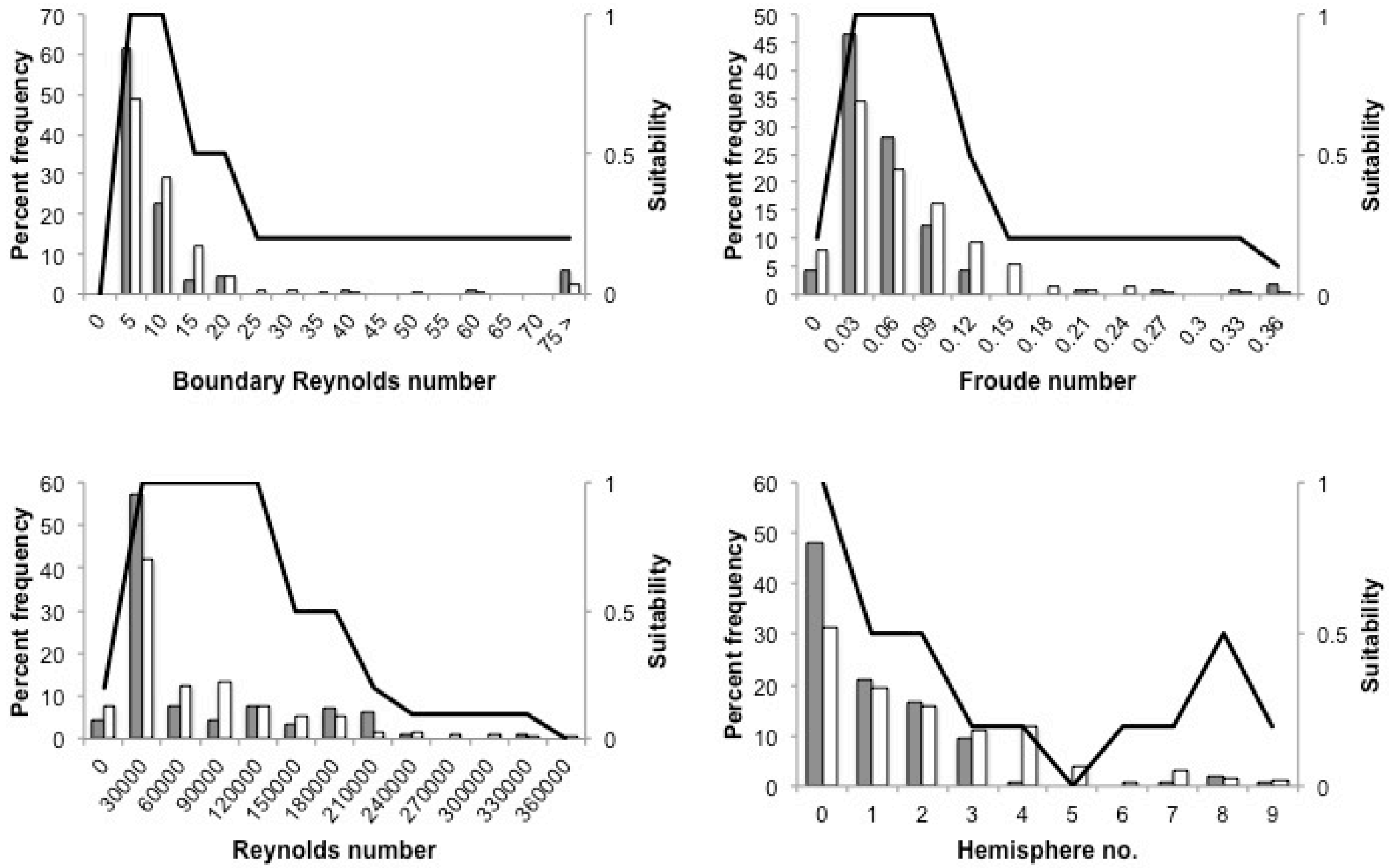

Figure 17. Percent frequency of occurrence (grey bars), habitat availability (white bars), and Strauss linear index values (black line) for Boundary Reynolds number, Reynolds number, Froude number, and FST hemisphere no. Suitability criteria are shown only for all mussels and are based on abundance data from quantitative sampling. The number of observations used were: N = 114.