Interagency Final Report to the Texas Water Development Board

FINAL REPORT

Distributional Survey and Habitat Utilization of Freshwater Mussels

Submitted by:

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INTRODUCTION

Freshwater bivalves in family Unionidae are very important components of aquatic ecosystems. They often dominate benthic biomass and production (Negus, 1966; Hanson et al., 1989); impact clarity and quality of water and plankton primary production by removing phytoplankton as well as suspended matter by filtration; affect nutrient dynamics through excretion and biodeposition of faeces and pseudofaeces; release nutrients from the sediment to the water column, and increase water and oxygen content in sediment through bioturbation (reviewed in McMahon and Bogan, 2001; Vaughn and Hakenkamp, 2001; Strayer et al., 2004). Unionid mussels occur in a variety of aquatic environments, however the greatest diversity is found in riverine habitats (Dillon, 2000). They are most abundant in oxygenated, shallow waters of medium to large rivers and occupy a variety of stable substrates including different combinations of silt, sand, gravel, cobble, and boulder (Smith, 2001).

Habitat destruction has been the major cause of unionid decline in the last century (Williams et al., 1993; Bogan, 1993; Richter et al., 1997). The creation of dams and impoundments that change the hydrologic regime of rivers is one form of habitat destruction which results in reduced water flow, increased water level fluctuations, accumulation of silt, interrupted mussel life cycle and dispersal, and a subsequent reduction in mussel fauna (Vaughn and Taylor, 1999; reviewed in Watters, 2000; Richardson et al., 2002). The alteration of flow regimes associated with dam operations has been identified as one of the three leading causes, along with nonpoint source pollution and invasive species, of the imperilment of aquatic animals (Richter et al. 1997; Pringle et al. 2000).

As a result, the family Unionidae is one of the most rapidly declining faunal groups in North America, with 56 endangered species and 70% of unionoideans at some level of imperilment (Turgeon et al., 1998). A variety of life history traits related to their vulnerability include: sensitivity to toxic contaminants in the water due to low selectivity of feeding, long life span, size and mobility limitations, low fertilization rates, high juvenile mortality, and irregular recruitment; unique life cycle including an obligate parasitic larval stage, and the sensitivity of juvenile mussels (Fuller, 1974; Downing et

al., 1993; McMahon and Bogan, 2001). Due to the sensitivity of unionids to water and habitat quality, it is very important to identify the key factors related to habitat destruction and degradation.

Knowledge of the macro- as well as micro-habitat conditions necessary to support unionid assemblages is absolutely imperative in order to counteract additional damage to unionid communities and as well as other benthic invertebrates. The instream flow conditions necessary for viable mussel assemblages is vital information for the successful conservation of unionid bivalves. A river's flow regime is now recognized as the most important driver of variation in many other components of a river system, e.g. fish populations, floodplain forest composition, nutrient cycling, etc. in both direct and indirect ways (reviewed in Richter et al. 2003). The extraordinary species richness and productivity characteristic of freshwater ecosystems is strongly depend upon the natural variability of their hydrological conditions. Instream flow is defined by the Texas Water Development Board as the flow regime adequate to maintain an ecologically sound environment, diversity and productivity of fish and wildlife, including the living resources on which they depend. The ultimate challenge of ecologically sustainable water management is to design and implement a water management program that stores and diverts water for human purposes in a manner that does not cause affected ecosystems to degrade or simplify (Richter et al. 2003).

This study, funded by the Texas Water Development Board (grant # 434135) is only a small part of the overall Texas Instream Flow Program which was established in 2001 during the 77th session of the Texas Legislature. Senate Bill 2 directed the Texas Parks and Wildlife Department, Texas Commission on Environmental Quality, and the Texas Water Development Board to establish a program with the goal of acquiring and evaluating instream flow data. The main goal of the Texas Instream Flow Program is to determine appropriate flow regimes within Texas Rivers which allow for conservation of aquatic ecosystems while still providing necessary beneficial functions to humans. The goal of this research is to provide the Texas Instream Flow Program with data necessary for the successful conservation of unionid bivalves.

OBJECTIVES

Task 1: Collect data on mussel distribution, habitat utilization, and other related data in the Brazos River basin.

Task 2: Collect data on mussel distribution, habitat utilization, and other related data in the San Antonio River basin.

Task 3: Collect data on mussel distribution, habitat utilization, and other related data in the Sabine River Basin.

Task 4: Identify mussels, prepare species lists, and report data.

MATERIAL AND METHODS

Study Sites

The focus of our study was on the San Antonio, Brazos and Sabine drainage basins. Within these basins, a total of 42 locations were sampled including 27 within the Brazos drainage basin, 10 within the San Antonio drainage basin, and 3 within the Sabine drainage basin. Several (from one to five) sites were sampled within each location. In total, we sampled 65 sites: 44 sites on Brazos River drainage basin, 14 sites on San Antonio, and 7 sites on lower Sabine River.

Sampling locations on the Brazos, San Antonio, and Sabine Rivers and tributaries were selected primarily on accessibility from public roads. In some instances canoes or flat bottom aluminum boats were used to reach areas which were inaccessible by road. Sample sites were chosen from the upper, central, and lower reaches of the Brazos and San Antonio Rivers. Sample sites from the Sabine were chosen from sections below Toledo Bend Reservoir along the Texas/Louisiana border. More sampling efforts were initially planned for Brazos River; however, due to extremely wet year, high water and

swift currents, we were not able to survey as conditions were deemed unsafe. Sampling was completed between September 2006 and June 2007.

Brazos River Basin

The headwaters of the Brazos River are located in New Mexico; however the Brazos arises at the confluence of the Double Mountain Fork, and the Salt Fork (33.266940°W, 100.010504°N). The Brazos travels in a southeasterly direction for approximately 840 miles and has a drainage area of approximately 115,600 km^2. The Brazos empties into the Gulf of Mexico near Freeport, TX. The locations sampled on Brazos River basin included the following (Fig. 1):

1) Brazos River at FM 485 crossing; Milam/Robertson Co., TX sampled on 22 September 2006

Site 1: 30.8657°N, -96.6956667°W

Site 2: 30.8657°N, -96.6957000°W

Site 3: 30.86685°N, -96.6959667°W

Site 4: 30.866765°N, -96.695795°W

2) Little River at CR 264 crossing; Milam Co., TX; 22 September 2006 (30.825417°N, -96.743967°W)

3) Brazos River at SH 7 crossing; Falls Co., TX; 23 September 2006

Site 1: 31.288850°N, -96.969817°W

Site 2: 31.289167°N, -96.969833°W

Site 3: 31.288900°N, -96.969517°W

4) Brazos River at U.S. 79 crossing; Milam/Robertson Co., TX; sampled on 23 September 2006 (30.827350°N, -96.650800°W)

5) Little Brazos River at U.S. Hwy 79 crossing; Robertson Co., TX; sampled on 23 September 2006

Site 1: 30.857550°N, -96.608150°W

Site 2: 30.85736667°N, -96.60748333°W

6) Little Brazos River at SH 21 crossing; Brazos Co., TX; sampled on 23 September 2006 (30.640433°N, -96.520850°W)

7) Brazos River at SH 21 crossing; Burleson/Brazos Co., TX; sampled on 24 September 2006 (30.628317°N, -96.543700°W)

8) Yegua Creek at FM 50 crossing; Washington Co., TX; sampled on 24 September 2006

Site 1: 30.368467°N, -96.343650°W

Site 2: 30.36848333°N, -96.343750°W

Site 3: 30.3685°N, -96.343583°W

9) Brazos River near U.S. Hwy 59 crossing; Fort Bend Co., TX; sampled on 6 October 2006 (29.550883°N, -95.638567°W)

10) Brazos River at IH-10 crossing; Austin/Waller Co., TX; sampled on 6 October 2006

Site 1: 29.75791667°N, -96.0305167°W

Site 2: 29.75766667°N, -96.0304667°W

Site 3: 29.757923°N, -96.030945°W

11) Brazos River at SH 159 crossing; Austin/ Waller Co., TX; sampled on 7 October 2006

Site 1: 30.04413°N, -96.11045°W

Site 2: 30.044266°N, -96.11045°W

12) Navasota River at SH 105 crossing; Grimes/Brazos Co., TX; sampled on 7 October 2006

Site 1: 30.36435°N, - 96.141566°W

Site 2: 30.36433°N, - 96.141583°W

Site 3: 30.36435 °N, - 96.141583 °W

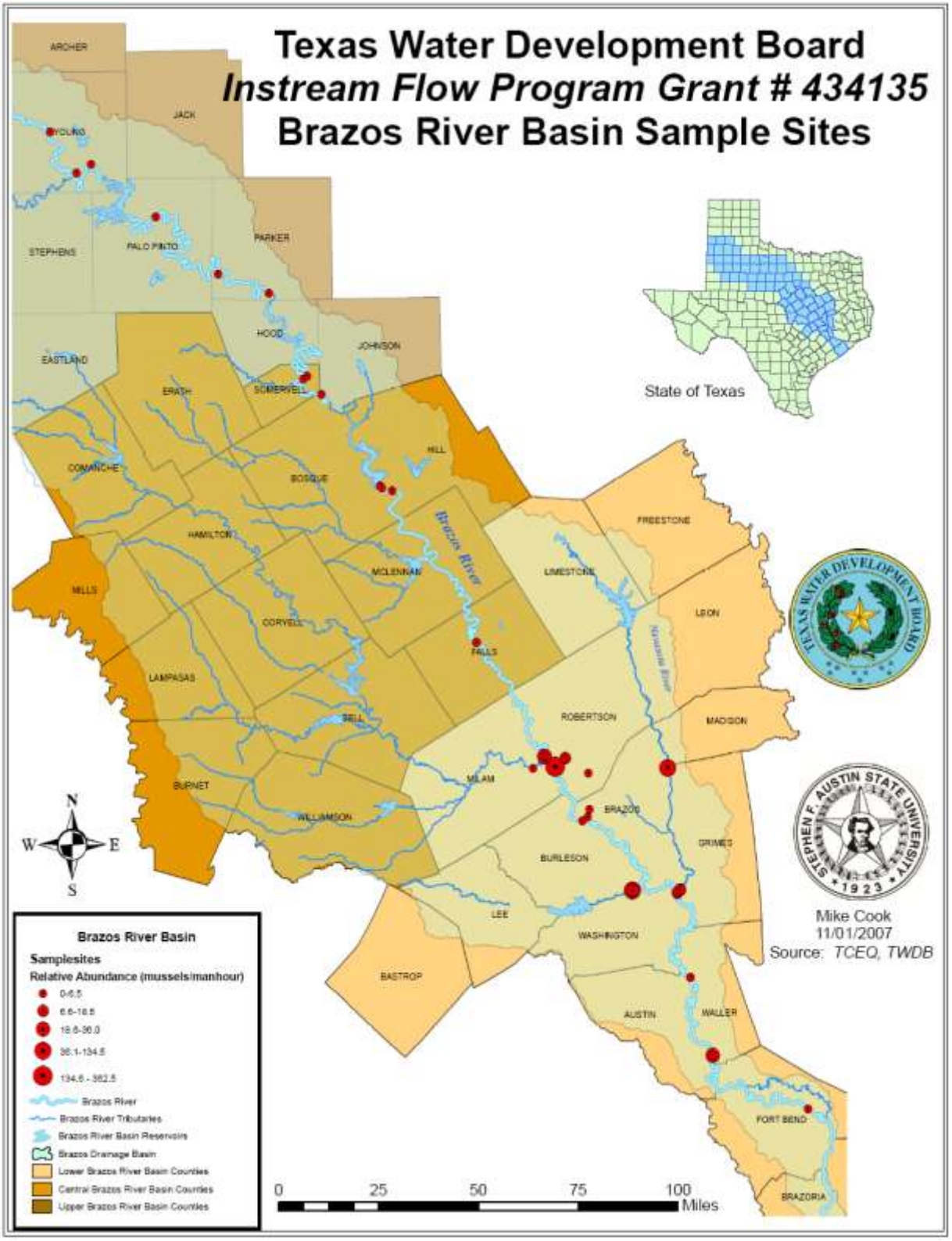

Figure 1. The map of Brazos River basin with sample locations symbols proportional to mussel relative densities.

13) Brazos River at SH 105 crossing; Washington/Brazos Co., TX; sampled on 8 October 2006

Site 1: 30.35753°N, - 96.15423°W

Site 2: 30.3566°N, - 96.15355°W

14) Duck Creek at FM 979 crossing; Robertson Co., TX; sampled on 4 November 2006 (31.19425°N, - 96.45063°W)

15) Deer Creek at CR 320 crossing; Falls Co., TX; sampled on 4 November 2006 (31.279850°N, - 96.97860°W)

16) Spring Creek at SH 6/US 190 crossing; Robertson Co., TX; sampled on 4 November 2006

Site 1: 30.80213°N, - 96.512216°W

Site 2: 30.66905°N, - 96.51213°W

17) Navasota River at CR 101(Democrat Rd) crossing; Brazos/Grimes Co., TX; sampled on 14 October 2006 (30.81035°N, 96.1757°W)

18) Brazos River below Lake Whitney Reservoir; Bosque/Hill Co., TX; sampled on 27 April 2007

Site 1: 31.86497°N, -97.36227°W

Site 2: 31.86137°N, -97.35551°W

Site 3: 31.84719°N, -97.31079°W

19) Brazos River at US Hwy 67 crossing; Somervell Co., TX; sampled on 14 June 2007 (32.27148°N, -97.66431°W)

20) Brazos River at CR 1118 (Brazos Point Rd.); Bosque/ Johnson Co., TX; sampled on 14 June 2007 (32.20465°N, -97.6051°W)

21) Brazos River at FM 2580 crossing; Parker Co., TX; sampled on 14 June 2007 (32.576427°N, -97.821632°W)

22) Brazos River at FM 4 crossing; Palo Pinto Co., TX; sampled on 15 June 2007 (32.86352°N, -98.30344°W)

23) Brazos River at FM 1287 crossing; Young Co., TX; sampled on 15 June 2007 (33.0559°N, -98.58089°W)

24) Brazos River at SH 67 crossing; Young Co., TX; sampled on 15 June 2007 (33.02455°N, -98.64479°W)

25) Brazos River at US Hwy 380; Young Co., TX; sampled on 15 June 2007 (33.175°N, -98.75645°W)

26) Brazos River at IH 20; Parker Co., TX; sampled on 23 June 2007 (32.64898°N, -98.03809°W)

27) Brazos River south of Lake Granbury; Somervell Co., TX; sampled on 24 June 2007 (32.26069°N, -97.68124 °W)

San Antonio River Basin

The San Antonio River originates from small to medium springs located in San Antonio, TX and travels approximately 240 miles south east to it's confluence with the Guadalupe River near Tivoli, TX. Ten sample locations were surveyed on the San Antonio River, ranging from the upper to the lower reaches (Fig. 2).

1) San Antonio River at SH 97 crossing; Wilson Co., TX; sampled on 1 September 2006 (29.110523°N, -98.173183°W)

2) San Antonio River at CR 117 crossing; Wilson Co., TX; sampled on 1 September 2006 (29.16830°N -98.20253°W)

3) Cibolo Creek at FM 537 crossing; Wilson Co., TX; sampled on 1 September 2006 (29.16995°N -97.9947°W)

4) Cibolo Creek at CR 231 crossing; Karnes Co., TX; sampled on 2 September 2006

Site 1: 29.017616°N, -97.920116°W

Site 2: 29.017233°N, -97.919933°W

Site 3: 29.018233°N, -97.920383°W

Site 4: 29.0185°N, -97.92016666°W

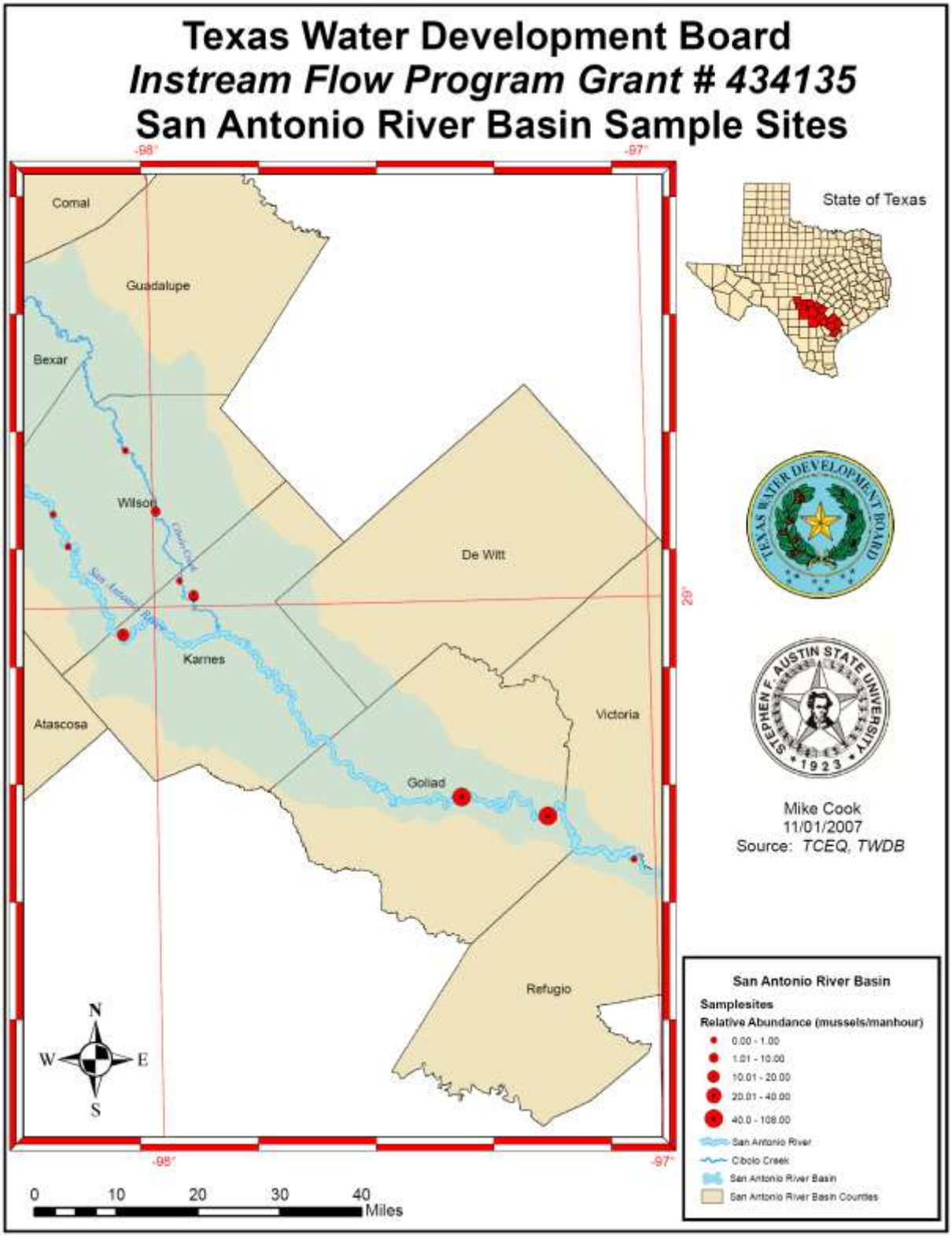

Figure 2. The map of San Antonio River basin with sample locations symbols proportional to mussel relative densities.

Site 5: 29.02°N, -97.91995°W

5) Cibolo Creek at CR 539 crossing; Wilson Co., TX; sampled on 2 September 2006 (29.2797833°N, -98.05315°W)

6) Cibolo Creek at FM 887 crossing; Karnes Co., TX; sampled on 1 June 2007 (29.04607°N, -97.94822°W)

7) San Antonio River at FM 791 crossing; Karnes Co., TX; sampled on 7 June 2007 (28.951363°N, -98.064194°W)

8) San Antonio River at US Hwy 77 crossing; Victoria/Refugio Co., TX; sampled on 8 June 2007 (28.531616°N, -97.04299°W)

9) San Antonio River at FM 2506 crossing; Goliad Co., TX; sampled on 8 June 2007 (28.61291°N, -97.21378°W)

10) San Antonio River at Goliad State Park; Goliad Co., TX; sampled on 8 June 2007 (28.65022°N, -97.38706°W)

Sabine River Basin

The Sabine River arises from several forks located north east of Dallas, TX. The river flows approximately 890 km finally emptying into the Gulf of Mexico. The Sabine is also the primary inflow source to Toledo Bend reservoir located in far east Texas and far west Louisiana. Three sample locations were surveyed below Toledo Bend reservoir to supplement previously collected data on density and distribution as well as the targeted abiotic parameters (Fig. 3).

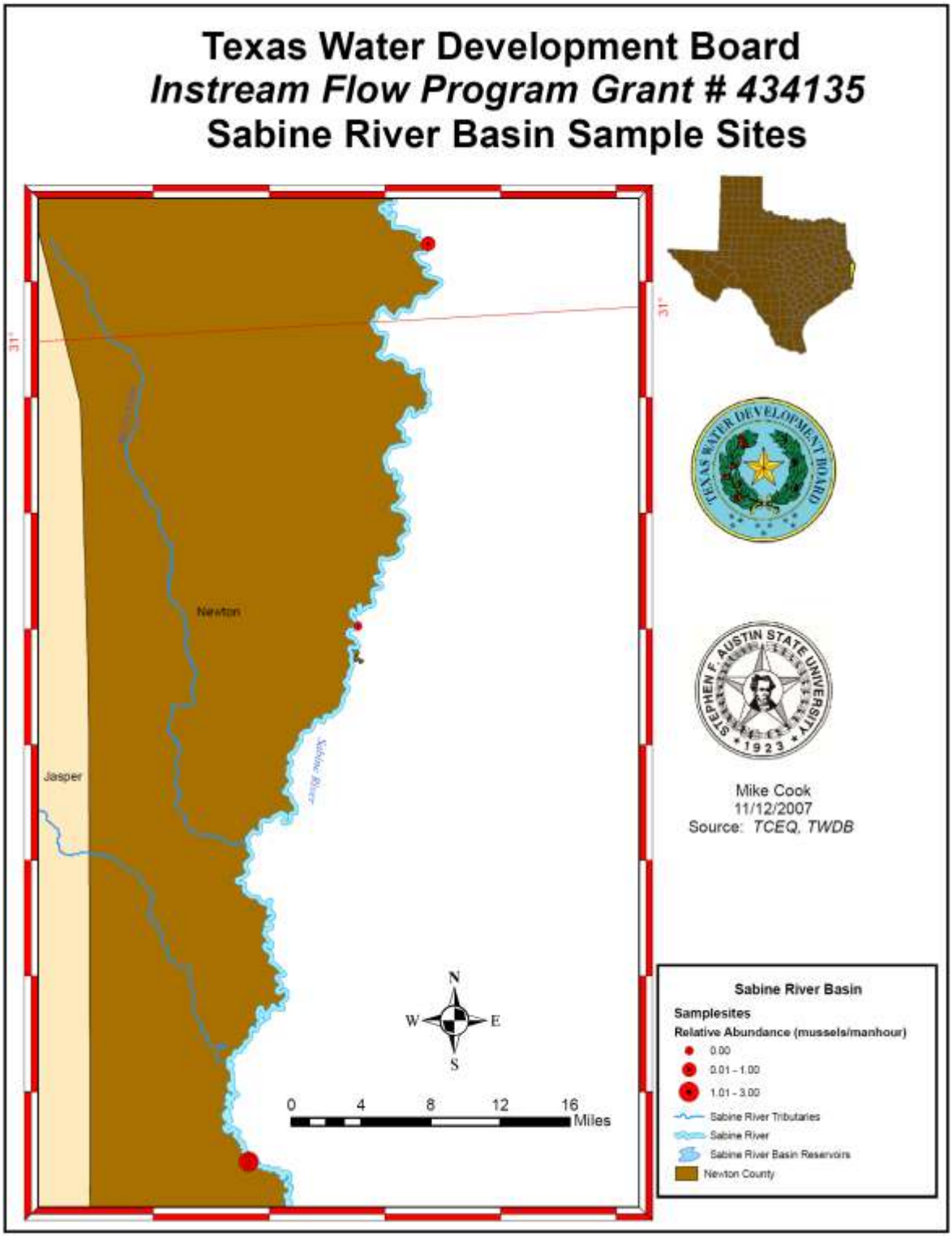

Figure 3. The map of the lower Sabine River Basin with sample locations symbols proportional to mussel relative densities.

1) Sabine River at SH 63 crossing; Newton Co., TX; sampled on 15 September 2006 (31.063583°N, -93.51845°W)

2) Sabine River at US Hwy 190 crossing; Newton Co., TX; sampled on 15 September 2006 (30.746567°N, -93.6085 °W)

3) Sabine River at SH 12 crossing; Newton Co., TX; sampled on 16 September 2006

Site 1: 30.303283°N, -93.743583°W

Site 2: 30.30315 °N, -93.74363°W

Site 3: 30.303267°N, -93.7436167°W

Site 4: 30.30315°, -93.7435667°

Site 5: 30.30335°, -93.7435500°

Unionid Sampling and Identification

Sample sites were chosen through coordination between Texas State Agencies including: Texas Parks and Wildlife Department, Texas Water Development Board (TWDB), River Authorities, and Stephen F. Austin State University (SFASU) on the basis of geographic location (i.e. upper, central, or lower reaches) of each river basin as well as the level of accessibility to the waterbody. Sampling was completed via hand collection of both live and dead unionids. Snorkeling equipment was employed to aide in the search for mussels. Once live mussels were located (either alone or within assemblages) the elapsed time was recorded to determine the time search to be used to calculate relative (semi-quantitative) density (number of mussels per man hour effort, mussels mh^{-1}). When live mussels were found during time searches, we used quantitative (quadrat) sampling to estimate mussel density per unit of area. We used a 0.25 m^2 quadrat made of white PVC and filled with sand. Specimens were identified using published taxonomic keys ("*Freshwater Mussels of Texas"* by R. Howells, R. Neck, and H. Murray). Live mussels and dead shells were identified and measured; live mussels were released back on the same site, and voucher specimens were deposited into the A. Karatayev and L. Burlakova freshwater mussel collection (located currently in Buffalo State College, Buffalo, NY).

Abiotic Data

Water Chemistry

Water chemistry data (temperature (^{o}C), dissolved oxygen (mg/L and % saturation), pH, total dissolved solids (g/L), specific conductivity (mS/cm), and turbidity (NTU)) was recorded using a HACH Quanta Hydrolab®.

Water Velocity

Water velocity (cm/s) was measured at each site which contained either single mussels or assemblages. Water velocity measurements were also taken when we failed to find live mussels after extensive searching. Water velocity data were recorded using a SonTek FlowTracker Handheld ADV® coupled with a top setting wading rod. When water depth was greater than 2.5 feet, two measurements were required; one at 80% of the total depth and the other at 20% of the total depth (Receiving Water Assessment Procedures Manual, [TNRCC] 1999). Once these values were obtained they were averaged to determine the flow rate at 60% of the total site depth. When the water depth was less than 2.5 feet, only a 60% depth velocity recording was necessary. We will refer later in the text to the velocity measured by standard method as velocity 60%.

In addition to 60% velocity readings, we recorded velocity at two inches above the substrata (velocity 2") in order to obtain a better depiction of flow rates at mussel assemblages.

Substrate Determination

We recorded substrate type using the standard classification (Receiving Water Assessment Procedures Manual, 1999). To classify substrate types for the data analysis, we used a coded array of substrates by increasing particle size (from 1 to 17): fine organics, clay, silt/clay, silt, silt/sand, sand/clay, sand, sand/organics, sand/gravel, gravel, rubble, cobble, small rocks/gravel, medium rocks/gravel, large rocks, large rocks with sand, and large rocks with gravel.

Data Analysis

Since a number of sites surveyed yielded no live mussels (density = 0), we used non-parametric Kruskal-Wallis test to analyze the primary data. Effects were considered statistically significant at $P < 0.05$. Analysis was performed using Statistica software (STATISTICA version 6, StatSoft, Inc. 2001) and PRIMER 5 for Windows (version 5-2-9, PRIMER-E Ltd).

As some of our parameters correlated (e.g., velocity at 2 inches and at 60%, pH and TDS, TDS and turbidity), we used Forward Stepwise Ridge Regression (lambda = 0.10, Tolerance = 0.0001). To analyze binary presence/absence data, we applied Logistic regression on presence/absence of live mussels with one independent variable – water velocity at 2 inches. Discriminant analysis was used to explore the possibility of prediction of unionid presence based on habitat data.

Biodiversity and Tolerance Indices

Taxa richness (S) was calculated as total number of unionid species in each location. The Shannon Diversity index (H′) is commonly used to calculate aquatic and terrestrial biodiversity (Krebs, 1999) and measures the order/disorder in a particular system. This order is characterized by the number of individuals found for each species/category in the sample. As the number and distribution of taxa within the community increases, so does the value of H′. Base 2 of logarithm was used to calculate H′.

Pielou's evenness was used as a measure of equitability ($J' = H'/\text{Log } S$), or how evenly the individuals are distributed among the different species. Simpson's diversity index ($1-\lambda$) is the probability that two randomly selected individuals belong to two different species/categories (Clarke and Warwick, 2001). This index places relatively little weight on rare species and more weight on common species (Krebs, 1999). Its values range from 0, indicating a low level of diversity, to a maximum of 1-(1/S).

Multivariate Analysis

Multivariate procedures are effective tools to reduce the dimensionality of data set and to extract a set of correlated variables. They show greater promises for detecting and understanding the spatial and temporal trends in benthic fauna (Norris and Georges, 1993). The presence of natural grouping in recorded abiotic parameters was analyzed using Cluster and ordination methods on square root transformed standardized data (PCA). Hierarchical Cluster analysis (Complete Linkage) was performed on normalized Euclidean distances (abiotic factors) and on Bray-Curtis similarity matrices (biological data) on log-transformed standardized data. Principal Component Analysis (PCA) was performed on log-transformed normalized data.

The parameters included in the abiotic data analyses were depth, substrate type, temperature, turbidity, conductivity, dissolved oxygen concentration, pH, percent of organic matter in the substrate, and coded habitat type. We intentionally excluded latitude and longitude as they strongly influenced the locations.

Biological data included relative density (live mussels found per man hour of time search, mussels mh^{-1}), and number of species found.

Species Analysis

To estimate the contribution of particular species to the average similarity within the communities, we used PRIMER SIMPER routine (Clarke and Warwick, 2001). The more abundant was a species in a community, the more it contributed to the intra-community similarity.

Analysis of similarities among communities

To find differences among abiotic parameters of sites with and without unionids, we used 2-way crossed Analysis of Similarities (ANOSIM) on log-transformed density and biomass data. The analysis is used permutation/randomization methods on similarity matrix.

Relationship among biotic and abiotic parameters

To link the biotic and abiotic parameters, we used BVSTEP procedure, which selects environmental variables "best explaining" community pattern, by maximizing a rank correlation between their respective similarity matrices. The abiotic parameters used were depth, substrate type (coded), habitat type, temperature, dissolved oxygen, conductivity, velocity 2", velocity 60%, and pH. We used log-transformation of abiotic data and Normalized Euclidean distance as similarity measure, and Bray-Curtis similarity matrix on log-transformed density and biomass data.

Roles of any personnel involved in the project

Lyubov Burlakova – grant management, data collection design, execution, unionid identification, data analysis, reports writing, budget and all technical questions supervision.

Alexander Karatayev – data collection design, execution, analysis, final report writing, grant supervision.

Michael Cook - data collection, data analysis, final report writing, providing GIS maps.

Bobbi Cook, Daniel Bennett - data collection.

RESULTS AND DISCUSSION

Unionid species richness and abundance in sampled waterbodies

In total, we found 463 live mussels belonging to 12 species in Brazos River and its tributaries, 221 mussels (4 species) in San Antonio River and its tributaries, and 5 live mussels all belonging to one species in lower Sabine River (Table 1). The total number of live mussels, density and species richness varied among river basins (Fig. 4, 5). The highest relative unionid density and diversity was found in Brazos River, and the lowest – in lower Sabine River below Toledo Bend (Fig. 5). Densities of unionids varied from 2.8 to 19.2 mussel m^{-2} (Table 2). The highest densities of unionids were found in Yegua Creek, Navasota River, lower San Antonio River and in the Brazos River (Fig. 6, Table 2).

Brazos River and its tributaries (Navasota River and Yegua Creek) had the highest species diversity among all other sampled river basins (Tables 1, 3, 4).

Table 1. Unionid diversity of sampled waterbodies.

Sample	River Basin	Sites sampled	Live mussels found	Number of species	Pielou's evenness	Shannon's diversity index (log e)	Simpson's diversity index
Brazos River	Brazos	29	233	9	0.651	1.431	0.717
Deer Creek	Brazos	1	0	0	n.c.**	0	n.c.
Duck Creek	Brazos	1	0	0	n.c.	0	n.c.
Little Brazos	Brazos	3	22	5	0.626	1.008	0.506
Little River	Brazos	1	1	4	0.876	1.215	0.923
Navasota River	Brazos	4	159	8	0.639	1.329	0.596
Spring Creek	Brazos	2	11	1	n.c.	0	0
Yegua Creek	Brazos	3	37	7	0.782	1.522	0.715
San Antonio River	San Antonio	6	210	4	0.493	0.684	0.402
Cibolo Creek	San Antonio	8	11	2	0.845	0.586	0.546
Sabine River	Sabine	7	5	1	n.c.	0	0

** not calculated.

Table 2. Average densities of unionids (from quadrat samples).

River	Crossing	Site	Average density, mussels m^{-2}
Brazos	FM 485	1	3.2
Brazos	FM 485	4	12.8
Brazos	190/79	1	5.6
Yegua Creek	Hwy 50	1	19.2
Brazos	Hwy 10	1	6.4
Navasota	Hwy 105	1	2.8
Navasota	Hwy 105	2	6.7
Navasota	Hwy 105	1	8.4
Brazos	CR 101	1	13.2
Sabine	Hwy 63	2	6.4

All three locations were we found relatively abundant unionid communities in the San Antonio River were at the mid- and lower reaches (close to Falls City and at Goliad); in contrast, very low densities were found on upper San Antonio and its tributary Cibolo Creek (0.29 ± 0.12 mussel mh^{-1}).

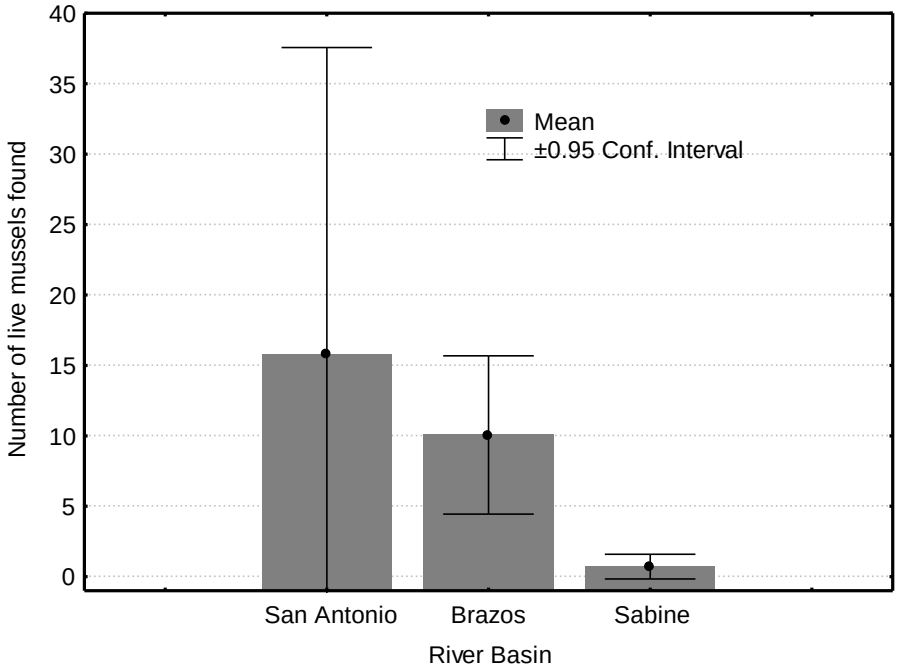

Figure 4. The average number of live mussels collected during the survey, grouped by river basins.

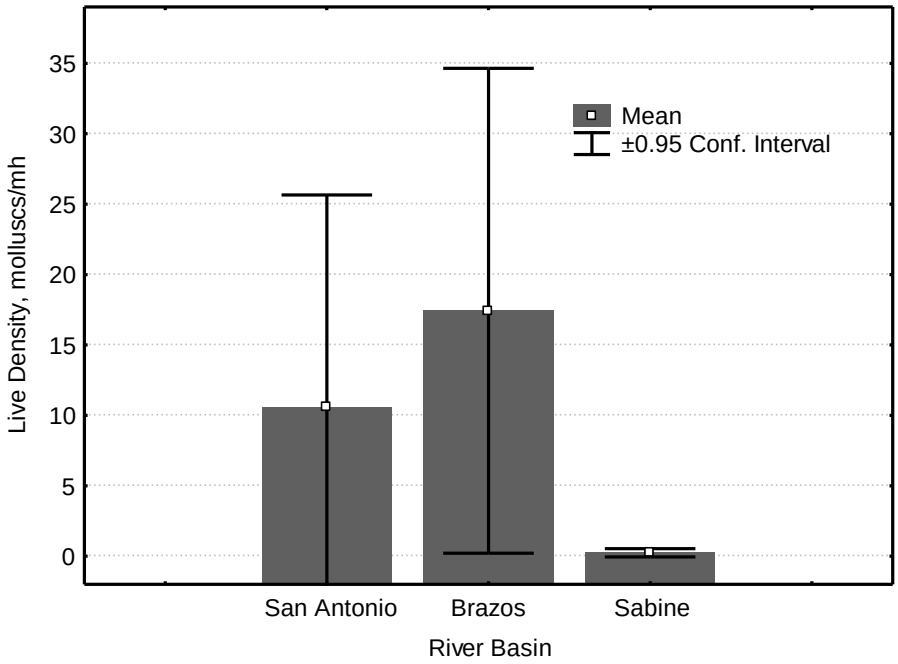

Figure 5. Density of unionids (mussels mh^{-1}) in sampled waterbodies grouped by river basins.

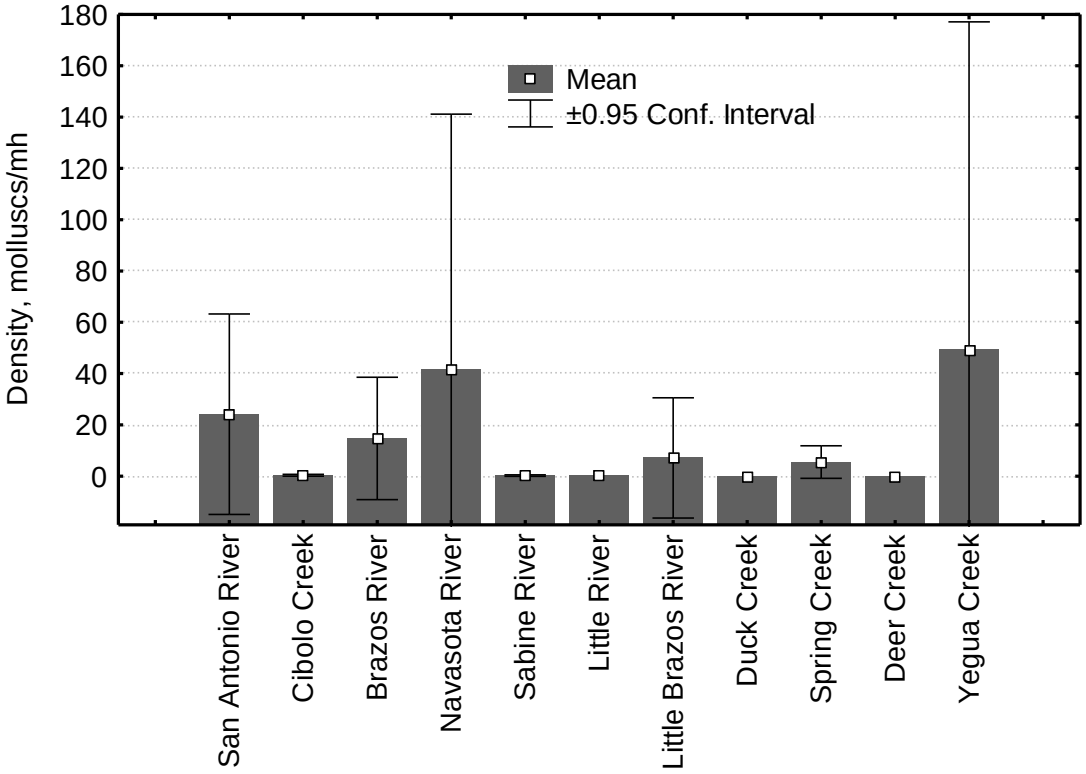

Figure 6. Density of unionid collected during the survey grouped by sampled waterbodies.

Table 3. List of unionid species and their relative density (mussels mh^{-1}, only live mussels counted) collected from the sampled waterbodies on Brazos, San Antonio and lower Sabine River in 2006-2007. No live mussels were found in Deer and Duck Creek (Brazos River basin).

Latin name	Common name	Brazos River	Little Brazos	Little River	Navasota River	Spring Creek	Yegua Creek	Sabine River	Cibolo Creek	San Antonio River
Ablema plicata	Threeridge	3.99	0.67	1.20	14.27	0.00	12.00	0.00	0.13	0.61
Arcidens confragosus	Rock-pocketbook	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00
Cyrtonaias tampicoensis	Tampico pearlymussel	5.70	0.00	1.60	0.76	0.00	2.67	0.00	0.00	0.15
Lampsilis teres	Yellow sandshell	1.54	0.44	0.40	1.25	0.00	22.67	0.24	0.33	17.89
Leptodea fragilis	Fragile papershell	0.08	0.00	0.00	0.00	0.00	4.00	0.00	0.00	0.00
Megalonaias nervosa	Washboard	0.00	5.00	0.00	2.59	0.00	0.00	0.00	0.00	0.00
Potamilus ohiensis	Pink papershell	0.06	0.00	0.00	0.00	0.00	1.33	0.00	0.00	0.00
Quadrula apiculata	Southern mapleleaf	0.36	0.33	0.00	1.51	0.00	2.67	0.00	0.00	0.00
Quadrula aurea	Golden orb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.53
Quadrula houstonensis	Smooth pimpleback	2.20	0.67	0.40	1.76	0.00	4.00	0.00	0.00	0.00
Quadrula verrucosa	Pistolgrip	0.00	0.00	0.00	0.83	0.00	0.00	0.00	0.00	0.00
Truncilla macrodon	Texas fawnsfoot	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Utterbackia imbecillis	Paper pondshell	0.02	0.00	0.00	0.00	5.50	0.00	0.00	0.00	0.00

Table 4. List of unionid species and their relative abundance (mussels mh^{-1}, only live mussels counted) collected from the sampled waterbodies on Brazos, San Antonio and lower Sabine River (combined) in 2006-2007. Average density, standard error and maximum abundance are given.

Latin name	Common name	Average relative density, mussels mh^{-1}	Number of sites where the species was present	Standard error	Maximum relative density, mussels mh^{-1}
Ablema plicata	Threeridge	8.4	15	3.6	53.6
Arcidens confragosus	Rock-pocketbook	0.3	1		0.3
Cyrtonaias tampicoensis	Tampico pearlymussel	14.7	13	12.9	168.8
Lampsilis teres	Yellow Sandshell	10.2	23	4.7	91.3
Leptodea fragilis	Fragile papershell	3.7	4	2.8	12.0
Megalonaias nervosa	Washboard	5.2	5	2.3	14.0
Potamilus ohiensis	Pink papershell	2.0	3	1.0	4.0
Quadrula apiculata	Southern Mapleleaf	2.7	10	0.6	6.3
Quadrula aurea	Golden Orb	16.6	2	15.2	31.8
Quadrula houstonensis	Smooth Pimpleback	6.5	14	3.2	43.8
Quadrula verrucosa	Pistolgrip	1.7	2	0.3	2.0
Truncilla macrodon	Texas Fawnsfoot	0.6	1		0.6
Utterbackia imbecillis	Paper Pondshell	8.4	15	3.6	53.6

The lowest densities and diversity of unionids were found in the lower Sabine River below Toledo Bend Reservoir. Only 8 species, mostly those typical for impoundments, were found in the Toledo Bend Reservoir. In contrast, the upper Sabine River is known to support one of the most abundant and diverse (with at least 28 species) unionid communities in Texas. Lower Sabine River also had significantly higher velocity of water among all other rivers sampled (P = 0.011, Kruskal-Wallis test, Fig. 7) at the time of sampling. We hypothesize that these elevated water currents in combination with the prevalent substrate type (pure sand) may result in a very unstable habitat for mussels – shifted sand, where unionids cannot anchor themselves well enough and, as a result, get dislodged by water releases from upstream or storm events. Mussels are able to survive in areas where shear stresses are low and sediments are stable during flooding (Layzer and Madison 1995, Strayer 1999b, Hastie et al. 2001). However, other factors could be responsible for the low abundance of unionids in the area during our study, e.g. a massive fish and mussel kill after the Hurricane Rita in 2005. The results of this snap-shot study on a small number of sites do not allow us to make certain conclusions, and more research is needed to explain the low diversity and abundance of unionids in the lower Sabine River.

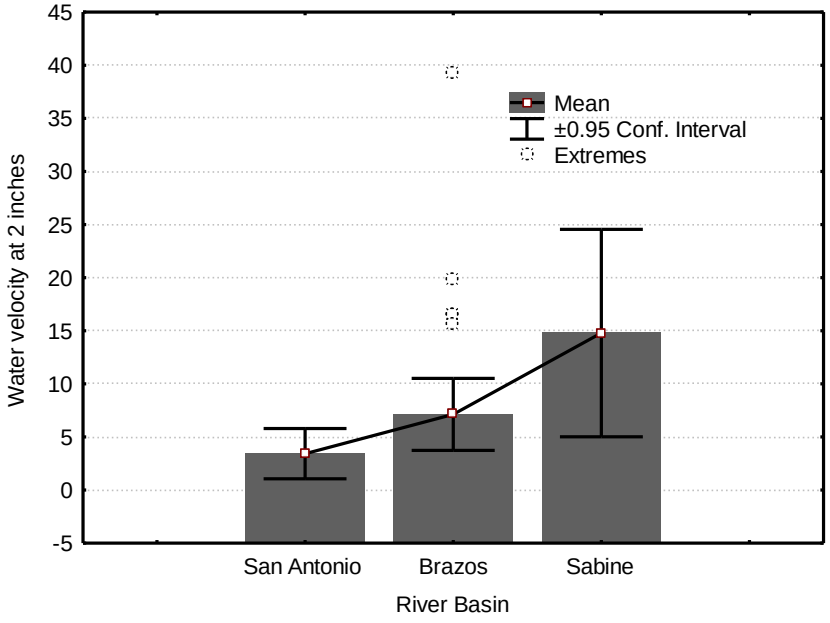

Figure 7. Average water velocity measurements (at 2 inches) recorded in the sampled river basins; the difference in velocity among river basins was significant (P = 0.011, Kruskal-Wallis test).

Effect of water velocity

To test the effect of water current on unionid abundance, we plotted the relative mussel densities against water velocity measured by standard methods (at 60 % depth) and directly above the mussels – at 2 inches above the bottom (Figs. 8, 9). The ratio between these measurements (Velocity at 60% depth/Velocity at 2 inches above the bottom) was 2.0±0.17 (mean ± 95% confidence level). No mussels were found at water velocities greater than 30 cm/s (measured at 60%) and 16 cm/s (measured at 2 inches above the bottom) during our sampling conditions.

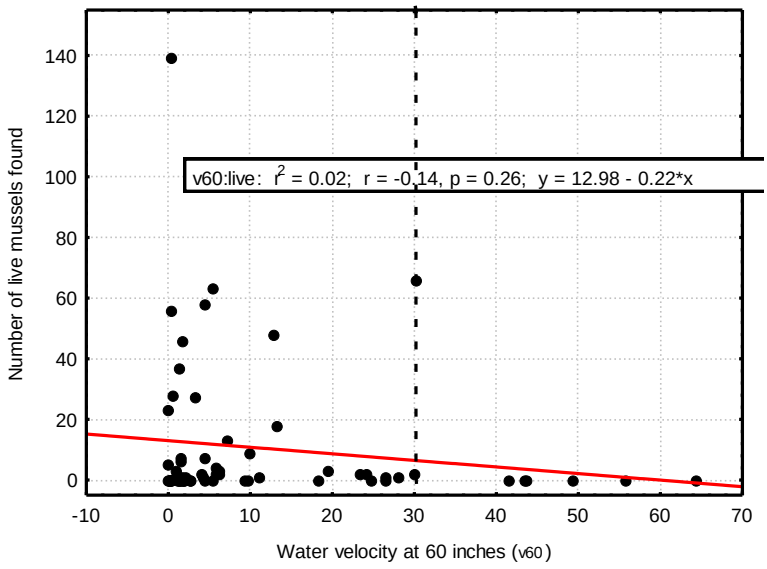

Figure 8. Number of live mussels found at different water velocities measured by standard procedure (at 60 % depth, cm/s) in all sampled waterbodies.

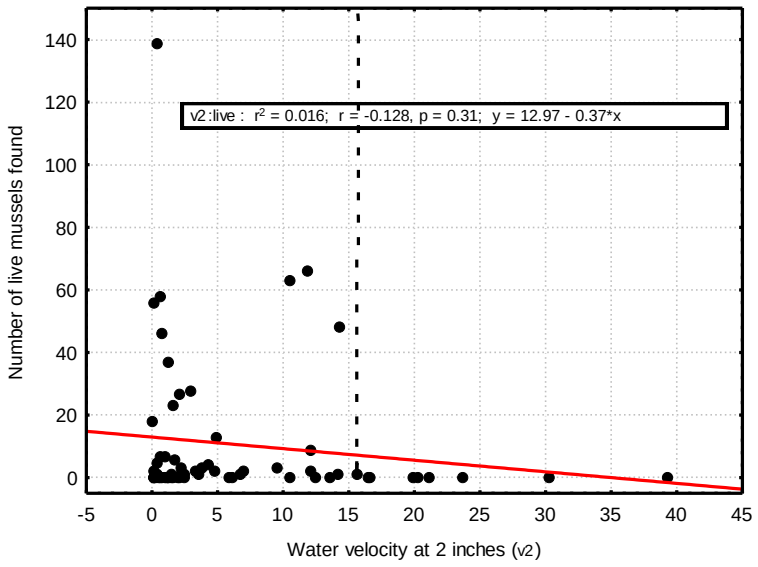

Figure 9. Number of live mussels found at different water velocities (cm/s) measured at 2 inches above the bottom in all sampled waterbodies.

Most often live mussels were found at velocities < 3 cm/s, and no live mussels was found at velocities higher than 16 cm/s (Fig. 9). These velocities fit in the transportation/deposition zones in Hjulstrom's diagram (Fig. 10), considering that the highest densities and diversity of unionids at our sampled sites were found on mixtures of fine sediments (silt/clay, silt, silt/sand, sand/clay, and sand), and maximum on silt and sand (see chapter below, Fig. 12, 13). Therefore, the optimal velocities for unionids situated below the erosion (upper) line on Hjulstrom's diagram (depending on the type of substrate), and will be lower for in areas with fine substrates and higher in areas with gravel (Fig. 10).

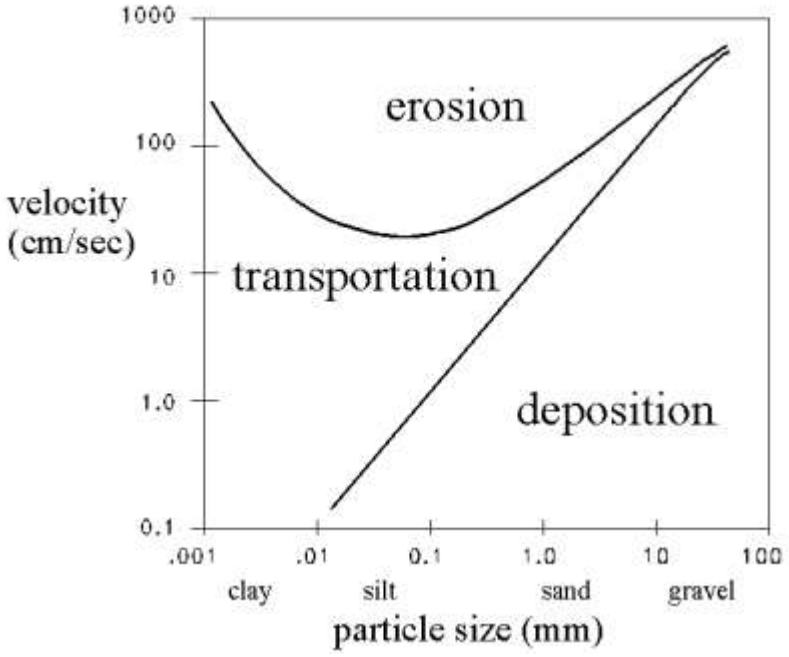

Figure 10. Hjulstrom's diagram, mean flow velocity required to initiate movement on a flat, uniform bed, for flow depth of 1 meter. The diagram shows the velocity a stream needs to pick up (erode), carry (transport), or drop (deposit) a clast or grain in flowing water.

Our results correspond well with similar study on the upper Mississippi River (Holland-Bartels, 1990) where mussels were found mostly on sand at velocities 0 - 34 cm/s (al low discharge that similar to most our sampling conditions) and were most abundant at currents 15 – 20 cm/s (standard measurement at 60% depth).

To explore the effect of measured abiotic parameters on mussel abundance, presence/absence and species richness, we applied several statistical procedures: multiple linear regression analysis, logistic regression, discriminant analysis, and multivariate analysis. As the sampling effort was different across sites, multiple regression analysis was performed on two dependent variables: density of live mussels (mussels mh^{-1}), and the number of species found per man hour (live mussels only). Independent variables used in the analysis were: water velocity 2", velocity 60%, turbidity, substrate type, pH,

TDS, depth, and percent of organic matter in the substrate. All variables were log-transformed, except the pH; the percent of organic was arcsine-transformed.

Forward stepwise multiple linear Ridge regression on density of live mussels was significant ($P < 0.002$), however it explained only 25% of variation ($R = 0.50$). Parameters left on step 4 were: pH, velocity 2", turbidity and TDS; the only significant parameter was the water velocity (partial $R = -0.29$; $P = 0.02$). The negative sign indicate that mussels tend to be more abundant in areas with lower flows. The relationship among mussel relative density and abiotic parameters was described as:

$$\text{Log } \textit{Density} = 2.05(\pm 1.73) - 0.24(\pm 0.19) \times \textit{pH} - 0.42(\pm 0.18) \times \text{Log } \textit{Velocity} + 0.52(\pm 0.27) \times \text{Log } \textit{Turbidity} - 0.85(\pm 0.61) \times \text{Log } \textit{TDS}$$

Forward stepwise multiple linear Ridge regression on the number of species per effort was also significant ($P < 0.0002$), and explained 30% of variation ($R = 0.55$). The same parameters were selected on step 4 (pH, velocity 2", turbidity and TDS); water velocity was again significant ($R = -0.26$, partial $R = -0.30$; $P = 0.03$), as well as turbidity (partial $R = -0.27$; $P = 0.046$).

Therefore, water velocity, among few other parameters (e.g. pH, turbidity and TDS) impacts the mussel abundance; however the regression has low explanatory power. The reasons for the low percentage of explained variability in density could be: non-linear relationship of the parameters, non-normality of distribution, and large amount of noise in the data. Although we transformed all the abiotic parameters, and checked their normality and distribution of residuals, density data, that yielded zero values, was very hard to normalize. Similarly, Holland-Bartels (1990) concluded that although total mussel abundance in upper Mississippi River varied significantly as a function of sediment and current, these parameters were poor predictors of abundance.

To analyze binary data on mussel presence/absence, we applied Logistic regression on presence/absence of live mussels with one independent variable – water velocity at 2 inches. The regression was significant ($\chi^2 = 4.4$, $P = 0.035$; Odds ratio in cases classification was 2.1; 78% of cases with mussel presence and 38% on absence were predicted correctly). Logistic regression that included all other parameters (velocity, substrate type, pH, turbidity, percent organics) was also significant (χ^2=24.7, P

= 0.0004) and explained 86 and 76% of presence and absence of mussels correctly (odds ratio = 19.5).

Multivariate analysis

We applied non-parametric methods in PRIMER software that are based on randomization and permutation techniques and therefore do not require the data to be normally distributed. Using ANOVA of Similarities, a non-parametric analog of ANOVA that tests for the difference among resemblance matrices, we found that the groups of sites with and without mussels were significantly different by their abiotic parameters (Global R > 0.22; P = 0.001, ANOSIM). Water velocity at 2 inches was the most important parameter contributing to the group of sites without mussels (18.3% contribution to group similarity), and contributed 11% to the group similarity of sites with mussels. Water velocity also contributed 14% to dissimilarity among the sites with and without mussels, with higher percentage of contribution from conductivity, substrate type, and depths (range 14.1 - 15.4%).

First three PC axes explained 65% of variation in abiotic data. The most important correlates with first PC were pH (r = -0.61) and conductivity (-0.51). Velocity 2" (-0.52), substrate type (-0.53) and percent of organics in the substrate (-0.54) contributed the most to the second PC. Third PC had strong negative correlation with turbidity (r = -0.72). Most of the sites where unionids were found were concentrated in upper right part of the plane (Fig. 11), indicating that they are found in areas with higher pH and conductivity, and lower velocities. However, due to the high variability in velocity data (as a result of sampling in different seasons and at different water conditions (at high and low water)), and variability in other parameters, the division among sampling sites was not very well defined (Fig. 11).

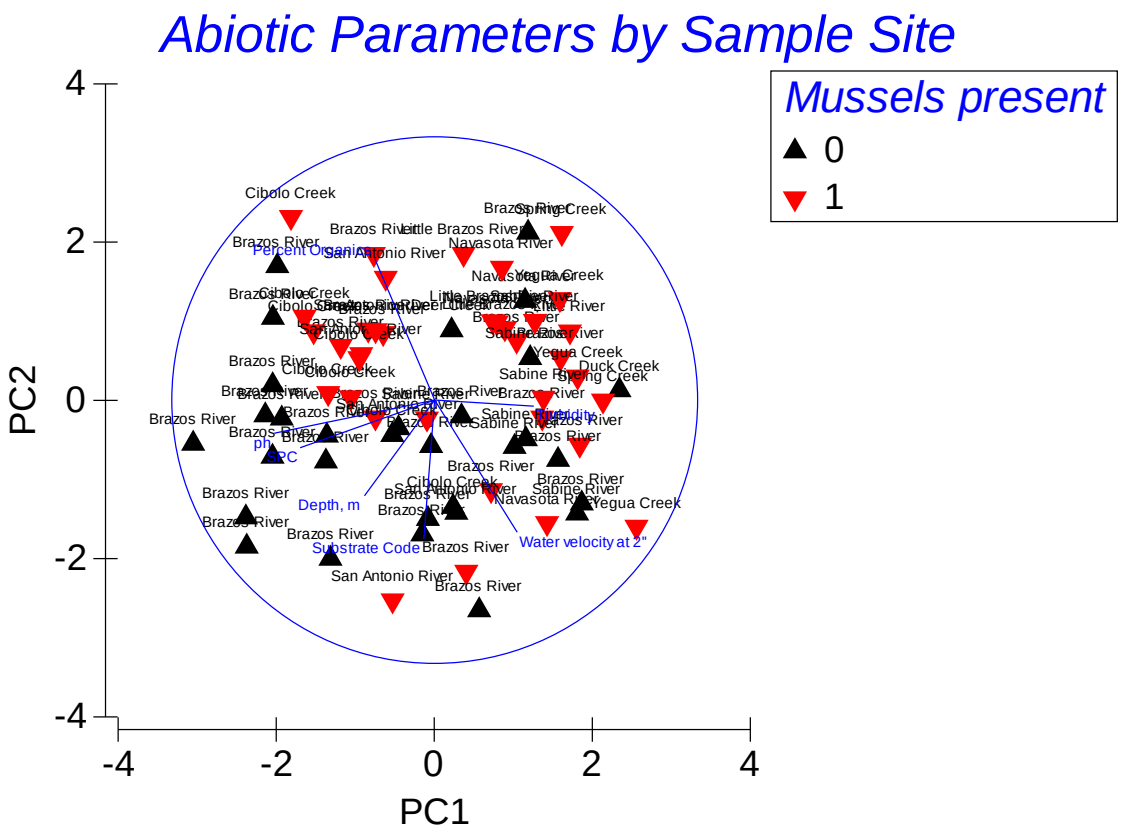

Figure 11. PCA plot of abiotic parameters of sites with (red symbols) and without (black) mussels.

Various chemical parameters may play an important role in unionid density and distribution. Unionid shells are composed of three major layers; the epidermis, the prismatic layer, and the nacre (reviewed in McMahon and Bogan, 2001). Additionally, a fourth layer known as the hypostracum can be found at the attachments of the major muscles. The prismatic layer is composed of calcium carbonate ($CaCO_3$) in the calcite form, while the nacre or mother of pearl layer is composed of $CaCO_3$ in the form of calcite or aragonite. Therefore, due to unionid dependence on $CaCO_3$, the probability of dense mussel appendages in mineral poor waters is unlikely (reviewed in McMahon and Bogan, 2001).

The formation of $CaCO_3$ crystals requires the release of protons (H^+) to maintain the high pH (7.4-8.3) required for the deposition of $CaCO_3$ (reviewed in McMahon and

Bogan, 2001). However, ambient pH does not greatly limit the distribution of freshwater bivalves though most species prefer alkaline waters with a pH above 7.0 (reviewed in McMahon and Bogan, 2001). Acidic waters may etch the older portions of unionid shells penetrating the innermost layer, causing the mussel to repair the damage (Neck, 1982).

The concentration of dissolved oxygen at various sites within a waterbody limits the distribution of unionid mussels. Some species may be capable of surviving in hypoxic and anoxic conditions for short periods of time. Horne and McIntosh (1979) found that low dissolved oxygen concentrations (i.e. 0-0.5 mgO_2/L) proved lethal to 47% of mussels tested over a seven day period. Other studies have determined that dissolved oxygen levels which fall below 20% saturation can adversely affect unionid populations (reviewed in McMahon and Bogan, 2001). However, as most of our sites were in running water, usually well saturated with oxygen, and its concentration was apparently not limiting mussel distribution.

The best set of abiotic parameters explaining species composition among sampling sites were: water velocity 2", substrate type, and specific conductivity (Spearman R: 0.236, P = 0.0001, BVSTEP).

The low predictive power of water chemistry in explaining mussel distribution and abundance is not surprising. Historically, explanations for the location of mussel beds focused on simple physical variables such as sediment grain size, current speed, water chemistry, but these explanations have largely failed when tested critically (Strayer and Ralley 1993; Strayer et al 2006), and explanatory power of such correlations was always low (Holland-Bartels, 1990).

The type of substrate was important in determining mussel density and diversity ($P < 0.025$, Kruskal-Wallis test) (Fig. 12, 13). The highest density (from 2 to 22 mussels mh^{-1}) and number of species (from 1.8 to 2) were found on substrates coded from 3 – 7 (silt/clay, silt, silt/sand, sand/clay, and sand) and maximum on #5 (silt and sand, in average, 45 mussel mh^{-1} and 2.8 species).

Substrate preference of unionids may be one of the most influential factors which dictates the distribution and density of mussels (reviewed in Bauer, 2001). Diversity becomes greater in major rivers and morphometrically irregular lakes due to the

variability of substrata contained within these waterbodies (Harman, 1972). Similarly, active habitat selection most likely corresponds with high substrate heterogeneity (Huehner, 1987).

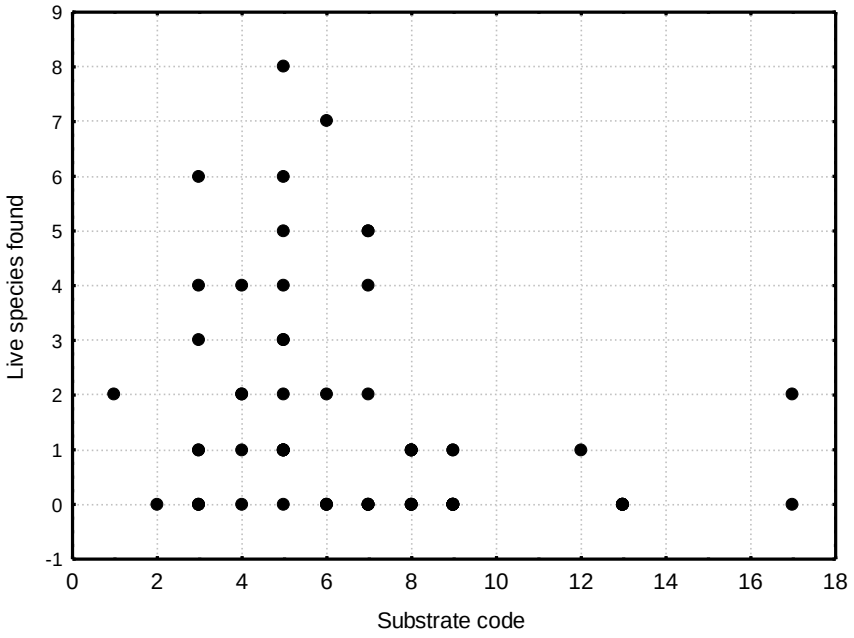

Figure 12. The diversity of unionid depending on the type of substrate.

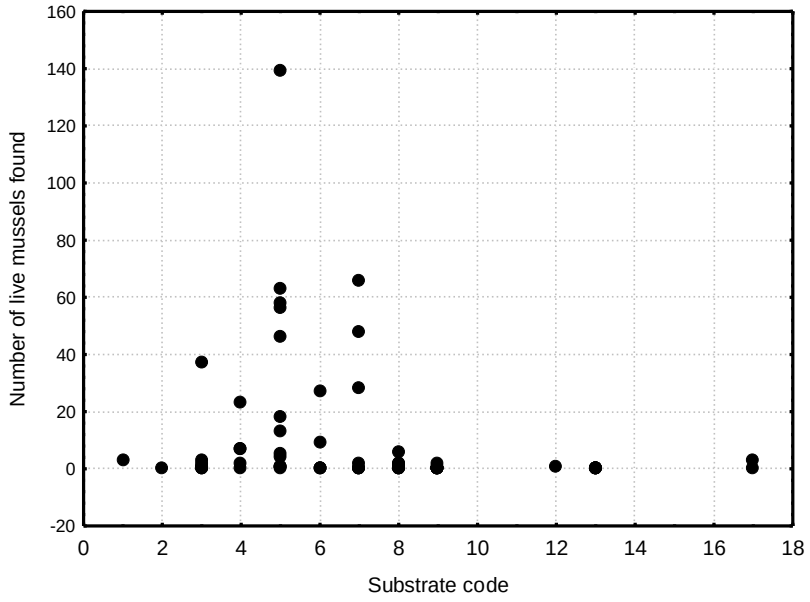

Figure 13. Unionid density on different substrate types.

Deep shifting sand and deep soft silt are among the most limiting bottom types for mussels. Likewise, bedrock, heavy boulder, and cobble bottoms are often poorly populated (reviewed in McMahon and Bogan, 2001). Sand and gravel, and combinations of these, are often the most heavily populated substrates (Morales et al. 2006). Different mussel species show variable tolerances of substrate types; however, many species were shown to be statistically less abundant at sites with finer sediment (Holland-Bartels, 1990). Fine sediments, such as silt, may result in the loss of light penetration which in turn causes diminished algal abundance, which is an important food source for mussels (Watters, 1999). Silt deposition can also smother mussels by interfering with gill functions necessary for respiration. The ability of different species of mussels to survive in variable silt levels may be dependent on their morphology (i.e. shell shape and thickness). Mussel shells with large thin surface areas may be able to survive on the surface of silt deposits. In contrast, mussels with thicker shells may sink into deep silt deposits. Silt may also affect the efficiency of filter feeding. Silt deposition onto substrates such as sand, gravel, and cobble may cause a change in the density of mussels as well as a shift in the species composition (Burkhead et al., 1992; Layzer et al., 1993; Williams et al., 1992).

A study of the upper Mississippi River found that the sand-gravel substrata of areas adjacent to the main channel supported nearly twice the mussel density of either silted lentic areas or homogenous sands of the main channel (Duncan and Thiel, 1983). It has been hypothesized that the correlations between distribution of mussel communities and substrate type may be subject to substrate stability and the habitat it provides rather than it particle size (Strayer, 1993). The apparent difference in substratum preference may be associated with species specific differences in optimal water velocities (reviewed in McMahon and Bogan, 2001).

Analysis of selected locations

Water velocity is extremely variable parameter, and can change in matter of hours depending on weather conditions. Therefore, to test the difference in water current at sites with and without mussels, ideally one has to measure the velocity on many sites simultaneously, or at very similar conditions. However, our sampling was done

throughout the year, starting in an extremely dry late summer and early fall of 2006 and was finished in extremely wet summer 2007. Therefore, the effect of velocity on mussel presence was tested by direct comparison of sites with and without mussels at the same locations. For this analysis we selected only the locations where several measurements of water velocity were done (on sites with and without mussels), or in the same waterbody at the same sampling event.

Water velocity in sites where live mussels were found was significantly lower than in areas free of mussels (4.7±0.9 vs. 13.6±3.1 cm/s, mean and standard error here and elsewhere; P = 0.04, Kruskal-Wallis test) (Fig. 14). The maximum velocity at sites with mussels was over 2 times lower than at sites devoid of unionids (15.7 vs. 39.3 cm/s).

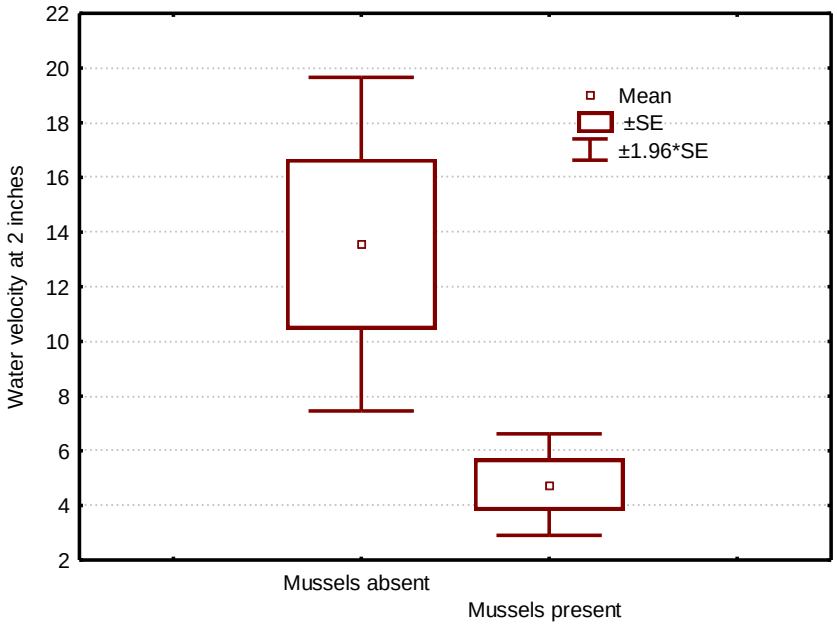

Figure 14. Average (± standard error) water velocity measured at 2 inches above the bottom on sites with and without mussels. The difference was significant (P = 0.04, Kruskal-Wallis test).

Water velocity measured by standard technique (at 60% depth) was also lower at sites with mussels (7.8±1.7 vs. 22.8±5.9 cm/s), but the difference was not significant (P = 0.15, Kruskal-Wallis test). Maximum recorded velocity was also lower at mussel sites

(29.9 vs. 64.3 cm/s). Therefore, recording water velocity close to the bottom is more important in explaining mussel distribution.

Most often, "pockets" of mussels were found along river shores, and in pools, where the water current is much slower, and substrates are not scored as in runs and riffles. Our analysis has shown that unionids were more often found on shallower depths ($P = 0.02$) and on softer substrates (marginal significance, $P = 0.06$) with higher percentage of organics ($P = 0.09$). The presence of soft substrates in areas inhabited by mussels also indicates the lower currents that otherwise will wash away the silts and detritus. Other chemical and habitat parameters were not significantly different between sites with and without mussels ($0.75 > P > 0.14$).

Most species of unionids prefer shallow water habitats (Machena and Kaustsky, 1988; Salmon and Green, 1983; Way et al., 1989; reviewed in McMahon and Bogan, 2001) and are rarely found in deeper portions of lakes and rivers (Neck, 1982). A study of unionids in the St. Croix River in Minnesota and Wisconsin revealed that unionid density and species richness was highest at depths of 2.0 meters (Hornbach et al., 1996). Decreasing water depth may expose unionids to increased predation, harvest, desiccation, and exposure to temperature extremes (Howells et al., 2000; Burlakova and Karatayev, 2006).

Forward stepwise Ridge regression on density of live mussels and velocity, depth, turbidity, pH, substrate type, conductivity, and habitat type was significant, but explained only 35% of variation ($R = 0.59$, $P < 0.001$). Among the parameters tested, only velocity, pH and turbidity were significant ($P < 0.04$; partial $R = -0.35$; -0.33, and 0.34 respectively). Thus, correlation coefficients become higher when we run the test on selected locations (where the velocity was measured simultaneously) and therefore removed some "noise" from the data.

Forward stepwise Ridge regression on the number of live species found per man hour was also significant and explained 25% of variance ($R = 0.50$, $P < 0.035$); the most important parameters were turbidity and velocity. Discriminant function analysis on mussels presence/absence with all the abiotic parameters we recorded was only marginally significant (Wilks' lambda 0.72, $P < 0.10$).

Logistic regression between unionid presence/absence and velocity at 2 inches was significant (χ^2 = 9.6, P = 0.002) (Fig. 15). The model explained 88% and 53% cases of mussel presence and absence correctly. Similarly, logistic regression between unionid presence/absence and velocity at 60 % was also significant (χ^2 = 7.8, P = 0.005) (Fig. 16), and explained 88% and 47% cases of mussels presence and absence correctly.

Unionid mussels are found both in lentic and lotic waters. Most unionid species do not coexist well with high flow velocities, and are often found at intermediate current speeds (Strayer and Ralley, 1993). During floods, currents may damage organisms or wash them downstream, as the stream bottom itself often moves, potentially crushing, burying, or sending downstream the organisms that live there (Strayer, 1999). Substrate stability may also be adversely affected by high flow velocities. The shear stress (i.e. the parallel force applied by water current against the substrate) acting on the river bottom increases as a function of increasing flow rates (Morales et al., 2006). During low flow conditions (i.e. around 566 m^3/s) there is not enough shear stress acting on the substrate to cause significant movement. During high flow conditions (i.e. up to 3,965 m^3/s) the shear stress acting on the river bottom is great enough to cause significant movement of substrate (Morales et al., 2006).

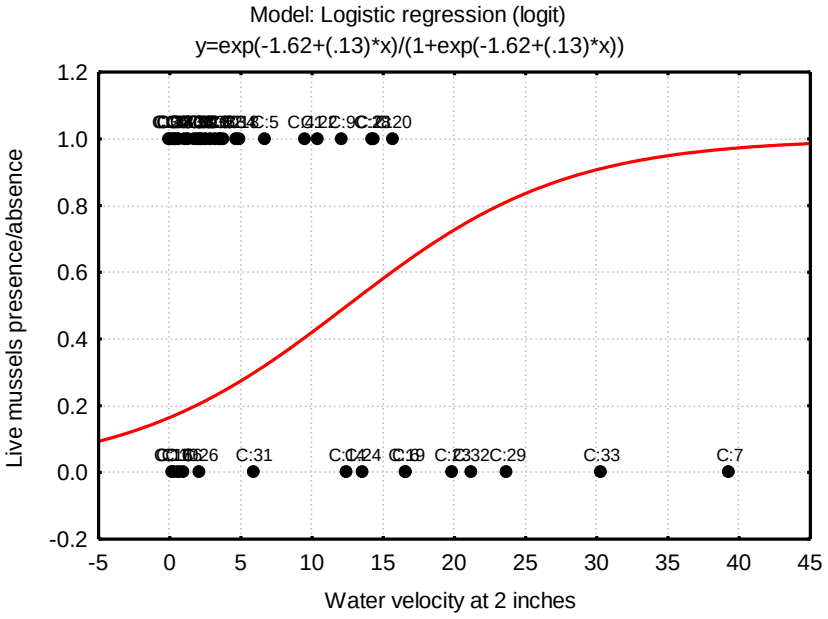

Figure 15. Logistic regression between mussel presence and water velocity at 2 inches. Upper points: mussels absent, lower – present.

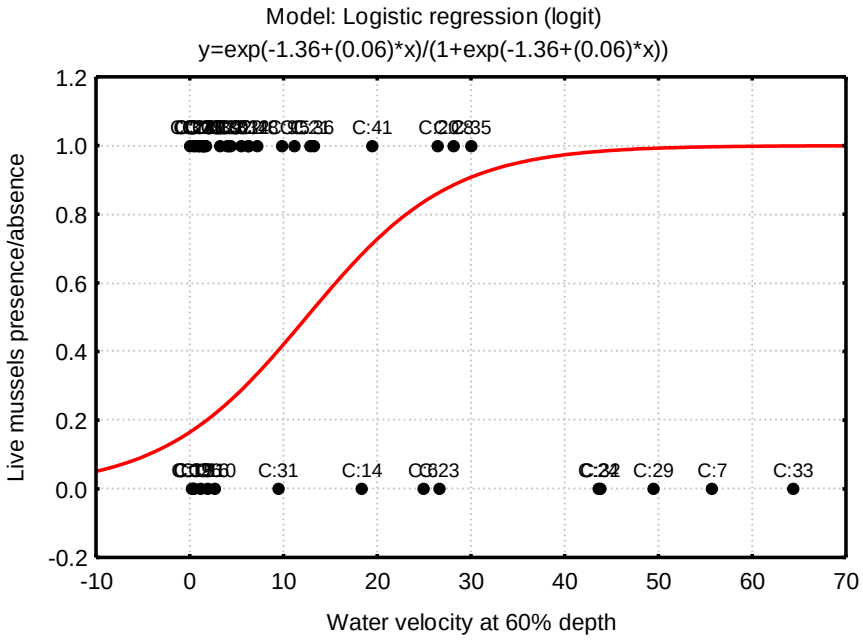

Figure 16. Logistic regression between mussel presence and water velocity at 60% above bottom. Upper points: mussels absent, lower – present.

Varying flow regimes may effect mussel habitat selection depending on the life or reproductive stage of mussels during particular flow conditions. Low discharge and associated low water velocity may enhance fertilization success by allowing sperm released into the water by males to be drawn into the mantle cavities of nearby females instead of being carried rapidly downstream (Payne and Miller, 2000; Downing and Downing, 1992). Changes in the flow rates may also affect the abundance, distribution, and movements of fishes which are required as hosts to the parasitic glochidial larvae of mussels (Hardison and Layzer, 2001). Additionally, juvenile mussels when detaching from their fish host are approximately 0.2 mm in size, so they are unlikely to be able to settle in areas where substrate particles ≥ 0.25 mm are actively transported with flow, which may directly affect the availability of suitable microhabitat for juvenile mussels (Morales et al., 2006; Hardison and Layzer, 2001; Holland-Bartels, 1990). Low flow conditions will likely deposit juvenile mussels near the edge of a waterbody, while high

flow conditions will likely prevent the settlement of juveniles (Morales et al., 2006). The affect of annual peak flows on juvenile settlement may be an explanation for the variability mussel distribution (Morales et al., 2006). The use of flow refuges by mussels may provide at least a partial explanation of how unionids are able to persist in river substrates which are randomly unpredictably subjected to severe disturbance (Strayer, 1999). Strayer (1999) suggests that mussel beds will generally be found only in areas where shear stresses during floods with moderately long return periods (e.g., 3-30y) are too low to displace unionids or the substrate in which they are bedded.

Unionids live partially or completely buried in the sediments of rivers, and therefore substrate and hydrodynamic conditions have a profound effect on community structure, and are critical for mussel survival. Mussels require appropriate substrate to anchor and burrow, and both water velocities and substrate stability affect their distribution and abundance. Many studies, including the present study, were dedicated to find the relationship between these abiotic factors (e.g. substrate type, depth, water current etc) to mussel abundance in rivers, however it was proven hard to find strong relationships when the factors were studied separately. The reason may be due to interconnection of these factors, i.e. in the substrate stability. Modifications of flow patterns that increase flow velocities may preclude recruitment of young individuals and hinder the long-term survival of otherwise healthy mussel beds. Morales et al. (2006) proposed to use a dimensionless parameter (shear stress ratio) that combines shear force and substrate type. Shear stress ratio may be used across varying flow regimes and sediment types in systems ranging from a 4th-order stream to large rivers. This parameter is a measure of substrate stability that we would suggest to apply in future studies to identify suitable habitats and flow regimes necessary for mussel survival.

Status of rare and endemic species

This survey allowed us to update the status of several Texas endemic species: *Quadrula houstonensis, Q. aurea,* and *Truncilla macrodon.*

Quadrula houstonensis

Texas endemic *Quadrula houstonensis* (Smooth Pimpleback) is native to the Brazos and Colorado drainage basins of central Texas. According to Howells (2006), *Q. houstonensis* populations persist at sites in the Brazos River (between Possum Kingdom Reservoir dam and the mouth of the Navasota River), the Little Brazos River, and the Leon River. This species was considered reduced in distribution and abundance in recent decades in the Colorado River Drainage to few sites (Howells, 2002).

During our survey, we found this species being very abundant in Brazos River drainage basin, at average relative densities 6.5±3.2 mussels mh^{-1} (maximum densities 44). Densities in quadrats were from 0.4 to 4.8 mussel m^{-2}, in average 1.3 (±1.5 STDS) mussel m^{-2}. It was found in 5 waterbodies in the Brazos River basin, on 14 sites. Therefore, this species is still quite abundant in Brazos River and its tributaries.

Truncilla macrodon

Truncilla macrodon (Texas Fawnsfoot) is a very rare Central Texas endemic (Howells et al., 1996). Only about 200 specimens have been documented since it was described in 1859, and only five living (moribund) and a number of recently dead shells have been found in recent decades (R. Howells, personal communication). The American Fisheries Society considers this species endangered (Williams et al. 1993), and its conservation status by NatureServe is G2 (Imperiled).

We found a single live *T. macrodon* in the lower Brazos River, at IH 10 (Austin Co), at very low water in the fall 2006. Recently to long dead shells of the species were found at three more locations: at HWY 105, at S. Granbury Road, and at CR 320 crossing. Therefore, this species should be still considered as very rare, and requires special attention. To our knowledge, this species currently does not have even a state rank (not ranked to date).

Quadrula aurea

Central Texas endemic *Quadrula aurea* (Golden orb) is native to the Colorado, Guadalupe-San Antonio, and Nueces-Frio drainage basins (Howells et al., 1996). Dewatering during droughts and habitat loss and modification during floods has reduced this species to only five known locations: two sites in the Guadalupe River upstream of Gonzales, the lower San Marcos River, one small area in the Guadalupe River at Kerrville, and in Lake Corpus Christi (Howells, 2006).

We found large amounts of dead shells of *Q. aurea* at locations in the upper San Antonio River. At some sites it was the dominant species, however no live mussels were found on these upper sites. We found *Q. aurea* in mid- and lower San Antonio River locations on 2 sites: at FM 2506 and at Goliad State Park (Goliad Co.), at relative densities 1.3 and 31.9 mussels mh^{-1}. Apparently, this species still persists in lower San Antonio River.

CONCLUSIONS

1. During this survey, we sampled 11 rivers and creeks belonging to three major river basins in Texas: Brazos, San Antonio and Sabine River basin. Sixty seven sites were sampled on 42 locations: 44 sites (27 locations total) were surveyed on Brazos River drainage basin, 14 sites (10 locations) on San Antonio, and 7 sites (3 locations) on lower Sabine River.
2. In total, we found 463 live mussels belong to 12 species in Brazos River and its tributaries, 221 mussels belong to 4 species in San Antonio River basin, and 5 live mussels belong to one species in lower Sabine River.
3. The Brazos River and its tributaries (Navasota River and Yegua Creek) had the highest unionid diversity (9, 8 and 7 species respectively) and densities (with 233, 159 and 37 mussels found) among all other basins sampled.
4. Abundant unionid communities in San Antonio River were found only at mid- and lower riches (close to Falls City and at Goliad); in contrast, very low densities were found on upper San Antonio and its tributary Cibolo Creek (0.29 ± 0.12 mussels mh^{-1}).
5. The lowest densities and diversity of unionids were found in lower Sabine River below Toledo Bend Reservoir (only 5 specimens of *Lampsilis teres* in all three locations (7 sites) sampled). In contrast, upper Sabine River is known to support one of the most abundant and diverse (with at least 28 species) unionid communities in Texas. Lower Sabine River also had the highest velocity of water among all other rivers sampled. More research is needed to explain the low diversity and abundance of unionids in the lower Sabine River.
6. Based on our data on unionid presence and water currents, no mussels were found at water velocities greater than 30 cm/s (measured at 60 % of depth) and 16 cm/s (measured at 2 inches above the bottom). Mussel densities and species richness both significantly negatively correlated with water velocity at 2 inches indicating that unionids are more abundant in areas with lower flows. However regression analyses explained low amount of variation in mussel abundance and diversity.

7. Central Texas endemic *Quadrula houstonensis* was found at high densities, in 5 waterbodies (at 14 sites) in the Brazos River basin. Therefore, this species is still quite abundant in Brazos River and its tributaries.

8. In contrast, only single live specimen of another very rare Central Texas endemic *Truncilla macrodon* was found in lower Brazos River, and dead shells were found at three more locations on Brazos River. Therefore, this species should be still considered as very rare, and certainly requires special attention.

9. Large quantities of dead shells of Texas endemic *Quadrula aurea* were found in upper San Antonio River; at some sites it was apparently the dominant species, however no live mussels were found on upper sites. We found live *Q. aurea* at two sites in mid- and lower San Antonio River.

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