A STUDY OF FRESHWATER MUSSELS (PELECYPODA: UNIONIDAE), FISH, AND ASSOCIATED ECOLOGICAL FACTORS IN LAKE CREEK, MONTGOMERY COUNTY, TEXAS

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ABSTRACT

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Approximately 216 of the 297 North American unionid species are extinct, rare, or imperiled. During the last 50 years, freshwater mussel populations throughout the continental United States have declined due to events such as drought, impoundments, sedimentation, dredging, channelization, water pollution, and commercial harvesting. These events have had a direct impact on available mussel habitat and reproductive activities. This study was conducted at 2 locations on Lake Creek, San Jacinto River Basin, Montgomery County, Texas. Characterization of habitat, fish and mussel communities, and water quality parameters are essential as baseline information to determine when changes have occurred, estimation of the resulting impact, and assist in predicting future impacts from human and natural disturbances. Additionally, the physical, chemical, and biological characteristics of an area combined with the habitat requirements of aquatic organisms have a direct relationship to determining presence or absence of a given organism in that habitat. The objective of this study was to determine the abundance and diversity of unionid freshwater mussels at 2 locations on Lake Creek, Montgomery County, Texas and identify those environmental factors that may account for their presence, absence, diversity, and abundance.

About 216 of the 297 North American unionid species are extinct, rare, or imperiled (Williams et al. 1993, Morris and Corkum 1996). Freshwater mussels have long been used for food and as a source of ornamental and economic items by human cultures in North America (Biggins et al. 1995). During the last 50 years, freshwater mussel populations throughout the continental United States have declined due to events such as drought, impoundments, sedimentation, channelization, water pollution, commercial harvesting, and dredging (Biggins et al. 1995). These events have had a direct impact on available mussel habitat and reproductive activities (Neves 1990). In response to a growing concern about the status of freshwater mussels, the Texas Parks and Wildlife Department (TPWD), in January of 1992, initiated statewide unionid population studies. This effort has included a survey of mussel fisheries, statewide population status studies, and mussel host research (Howells 1993, 1994, 1995, 1996a, 1996b, 1997, 1998, Howells et al. 1996, Howells et al. 1997). Still relatively little is known about the distribution, diversity, abundance, and status of freshwater mussels within Texas. This lack of data jeopardizes our understanding of how existing populations may be or have been impacted by urbanization, drought, commercial harvesting, reservoir development, water resource policy, and changes in water quality (Howells et al. 1997).

Biggins et al. (1995) states that ecologically mussels are an important food source for numerous aquatic and terrestrial animals, they improve water quality through filtration of the water column, and can act as indicators of water quality. A certain subset of mussel species have economic value in the cultured pearl industry and as a source of gem quality freshwater pearls (Coker 1919, Howells et al. 1996).

Unionid mussels are relatively immobile, obtain nutrients through filter feeding, have long lifespans, require specific habitat conditions for survival, and reproduce using a glochidia or parasitic larval stage that relies on specific host fish (Coker et al. 1921, Vaughn 1993). These characteristics lead to a patchy distributions and make them vulnerable to habitat disturbances (Bauer et al. 1991, Vaughn 1993). Past and present disturbances such as impoundments, urbanization, and changes in landuse have caused habitat fragmentation and exacerbated the patchy distribution patterns normally associated with unionid mussels (Vaughn 1993, Howells et al. 1996). Their abundance and diversity may be associated with these disturbances as well (Brown 1984).

Habitat fragmentation makes unionid reproduction even more problematic. Reproduction is similar for the majority of species in that males release sperm into the water column and it enters the female during siphoning (Neves 1990). Fertilization and incubation of the eggs takes place in the gills of the female with subsequent growth of glochidia (Neves 1990, Howells et al. 1996). Females use various techniques to trigger release of mature glochidia for attachment to fish gills or scales. Some species indiscriminately release glochidia into the water column while others use mantle adaptations to attract passing fish. The attachment must be to an appropriate host fish if the glochidia are to progress to a viable juvenile stage. Once released from the host fish, juvenile mussels must be deposited in a location possessing the correct habitat requirements for further development (Vaughn 1993).

The objectives of this study were to determine the abundance and diversity of unionid freshwater mussels at 2 locations on Lake Creek, Montgomery County, Texas and identify those environmental factors that may account for their presence, absence, diversity, and abundance.

Methods.

Study Sites.

The study was conducted between June 1997 and June 1998 at 2 locations on Lake Creek. Lake Creek, located in Montgomery County, is part of the San Jacinto River Basin. It is the principal drainage for an 86 km^2 area.

The San Jacinto River Basin is geographically situated between the Trinity and Brazos River basins and is the smallest of the major river basins in Texas. The San Jacinto River Basin has a drainage area of 9330 km^2. The geologic composition consists mostly of sand, silt, gravel, and clay. Figure 1 is a Geographic Information System (GIS) coverage of the basin showing hydrologic systems, land use, and study sites. Figure 2 is an enlarged section of the basin showing the study sites.

Site 1 (Lake Creek-near-Egypt) is located 1.5 km north of the junction of FM 1488 and FM 2978 at N 30° 09' 07.6" latitude and W 95° 20' 49.4" longitude. Site 1 consists of sand, silt, and small gravel substrate with adjacent landuse a combination of forest and residential acreage. Bank slopes are gentle with little erosion. Riparian vegetation consists of grasses, shrubs, and trees. There is a single riffle area, numerous submerged logs, several deep pools, and a few sandbars occurring throughout the site. The site has a variable flow regime relating to precipitation.

Site 2 (Lake Creek-at-FM 149) is located 2.7 kilometers north of the junction of FM 1488 and FM 149 at N 30° 09' 53.2" latitude and W 95° 25' 18.7" longitude. The site consists predominately of hard packed clay and limited sand and silt substrate areas. The site is used by cattle as a drinking water source and bed substrates in low water areas have been compressed by wading. Bank slopes are gentle with erosion caused by transiting cattle. Riparian vegetation consists of grasses, shrubs, and trees. There is a single riffle area, partly exposed logs, a deep pool, and a sandbar occurring in the site. The site has a variable flow regime relating to precipitation.

Habitat Survey.

The habitat survey followed the protocol described by Meador et al. (1993b) and was conducted on September 19, 1997 at Site 1 and May 6, 1997 at Site 2. All surveys were done with the aid of a Sokia Lietz Set 4A

Total Station survey instrument. Upstream and downstream boundaries, 4 transects, wetted channel structure, edge of waters, bars, and thalwegs were surveyed and data points recorded for each site. Linear reach length, curvilinear reach length, sinuosity, reach slope, number and type of in-channel structures, channel width, mean channel depth, and wetted channel width were calculated from the surveyed data points for each site (see Analytical Methods section). Velocity readings were taken using a Price AA velocity meter at the upstream boundary thalweg, the downstream boundary thalweg, and each of the 4 transect thalwegs and a mean velocity value was determined for each site. Survey data points were used to create planometric maps of each site and an Eagle Global Map Sport Global Positioning System (GPS) was used to determine the site latitude and longitude for inclusion into an U. S. Geological Survey Geographic Information System (GIS) basin coverage.

Water Quality Data.

Dissolved oxygen, pH, water temperature, conductivity, and Secchi disk values were recorded on September 19, 1997 at Site 1 and May 6, 1997 at Site 2 at approximately 7:00 A.M. and 4:00 P.M. Readings of the various water quality parameters were taken using a YSI Model 50B Dissolved Oxygen (DO) meter, an ATI Orion Model 230A pH meter, an ATI Orion Model 128 temperature and conductivity meter, and a standard Secchi disk.

Fish Community Sampling.

Fish community sampling followed the protocol described by Meador et al. (1993a) and was conducted on September 19, 1997 at Site 1 and May 6, 1997 at Site 2. A Smith-Root electrofishing barge unit (pulsed DC, 500 volts) and a 6-m bag seine with a square mesh size of 6.4-mm were used to collect the fishes. Each fish was identified to species. Voucher specimens were preserved on site in 10% formalin. Sampling effort consisted of 2 upstream direction electrofishing passes the full length of the site and 2 seining passes of pools and riffles. Scientific names are based on Robins et al. (1991). Identification was done with the aid of a fish key by Hubbs et al. (1991).

Unionid Community Sampling.

Sampling was conducted at Site 1 on April 25, 1998 and at Site 2 on May 23, 1998. Unionids at each site were hand sampled using a 0.25 m^2 quadrat (Figure 4) and a random search method. Ten quadrat samples were taken at each site. Deep pools were sampled with a 24-tooth bull rake with a length of 0.6-m, height of 0.2-m, and a width of 0.3-m (Figure 4) and a transect search method. The bull rake is used in New England and the Mid-Atlantic regions of the United States as one method of harvesting marine clams and oysters. The depth that a bull rake can be used is theoretically only limited by the length of its handle but normally is not used past a depth of 8-m. The area sampled at Site 1 was 220 m^2. The sampling effort consisted of 10 random quadrat samples and 6 bull rake transect samples. The area sampled at Site 2 was 174 m^2. The sampling effort consisted of 12 random quadrat samples and 15 bull rake transect samples. Data collected for each specimen included species identification, length (largest distance from posterior margin to anterior margin), and width (largest distance from dorsl margin to ventral margin). Voucher specimens were retained for confirmation of species identification. Identification of mussels was based on Howells et al. (1996). Nomenclature used for family, genus, and species is based on Turgeon et al. (1988).

Analytical Methods.

Habitat.

The calculation for the length of the hypotenuse of a right triangle was used to compute linear reach length using the upstream and downstream edge of water data points. Curvilinear reach length was determined by creating an ESRI ARC/INFO version 7.0 GIS coverage of the recorded left or right edge of water data points and having the GIS system calculate the length of the line. Sinuosity, a value useful in comparing habitat conditions among sites, is the ratio between linear reach length and curvilinear reach length. Reach slope was calculated using the slope function in Microsoft's Excel 97 spreadsheet software with upstream and downstream edge of waters as the data points. Mean channel width, mean right bank height, mean left bank height, mean wetted channel width, and mean channel depth were calculated using the appropriate surveyed point values. Mean velocity was calculated using velocities from the upstream, downstream, and 4 transect thalwegs.

Fish and Mussel Communities.

Species diversity refers to the number of species that are in a quantifiable area of a habitat (Collins and Glenn 1991, Cox 1996). species diversity was calculated using the Shannon-Weiner functions (Krebs 1994). The calculated H value is an expression of species richness and the J value is an expression of species evenness.

$$H = -\Sigma\,(p_i)(\log_2 p_i)$$

where

p_i = proportion of total sample belonging to the i^{th} species

Density, relative density, and frequency where calculated for each sample using the following methods:

$$\text{Density} = \frac{\text{total number of specimens collected at a site}}{\text{area sampled } (m^2)}$$

$$\text{Relative Abundance (\%)} = \frac{\text{number of species A collected at a site}}{\text{total number of all species collected at a site}} \times 100$$

$$\text{Frequency (\%)} = \frac{\text{number of samples a species occurred in at a site}}{\text{total number of samples taken at a site}} \times 100$$

Density is a measure that defines the number of individuals of a species collected per unit area of a site. Relative abundance for an individual species expresses the percent of the total number of individuals collected at that site that is contributed by a species at a site. Frequency measures how common a species is within a site.

Results.

Table 1 is a summary of the physical parameters measured at Sites 1 and 2. Figure 3 is a planometric map that graphically indicates wetted channel structures and general habitat characteristics. Sites 1 and 2 are similar in their linear lengths but differ in curvilinear lengths due to more meandering in site 1. Reach slopes differ greatly from site to site. Site 2 differs from Site 1 in mean channel and wetted channel widths. Site 2 shows a greater degree or erosion than Site 1. Bank heights, channel depths, and velocities were similar among sites.

Water quality parameters are similar with the exceptions of Secchi disk and conductivity readings (Table 2). Water clarity was greater and conductivity was lower at Site 1 as compared to Site 2.

Each site had a total of 18 fish species present (Table 3). The sites had 14 species in common. Site 1 was dominated by three species (79%; *Pimephales vigilax*, *Lepomis megalotis*, and *Cyprinella venusta*). Site 2 was dominated by three species (71%; *Lepomis megalotis, Lepomis macrochirus*, and *Cyprinella venusta*).

Forty-four mussel specimens representing four species were collected from site 1 which was dominated by *Quadrula apiculata* (Table 4). The density of unionid mussels at Site 1 was 0.2 mussels/m^2. No unionid mussels were found at Site 2.

Fish species richness and evenness at Sites 1 and 2 are similar (Table 5). Site 1 has low unionid evenness (Table 5).

Species Account.

Family: UNIONIDAE

Plectomerus dombeyanus (Valenciennes, 1827)

Figure 5.

Common Names: White-eye, ridge-runner, mudskipper, washboard (Howells et al. 1996).

Distribution in Texas: *Plectomerus dombeyanus* occurs from the San Jacinto River into basins to the north and east (Howells et al. 1996).

Shell Measurements of Specimens:

Length: Range = 29.9 – 101.3 mm; mean = 65.6 mm

Width: Range = 22.3 – 68.1 mm; mean = 45.2 mm

Fish Hosts: No hosts are reported for this species (Howells et al. 1996).

Remarks: The specimens were found in a silt and sand substrate.

Fusconaia askewi (Marsh, 1896)

Figure 6.

Common Names: Texas pigtoe, pigtoe, Askew's pigtoe (Howells et al. 1996).

Distribution in Texas: *Fusconaia askewi* has been reported from the Brazos, Neches, Sabine, and San Jacinto River systems (Howells et al. 1996).

Shell Measurements for Specimens:

Length: Range = 48.5 – 54.8 mm; mean = 51.6 mm

Width: Range = 32.2 – 39.6 mm; mean = 35.9 mm

Fish Hosts: No hosts are reported for this species (Howells et al. 1996).

Remarks: The specimens were found in a sand and gravel substrate.

Lampsilis teres (Rafinesque, 1820)

Figure 7.

Common Names: Yellow sandshell, bank creeper, sandshell, tiger tooth (Howells et al. 1996).

Distribution in Texas: *Lampsilis teres* is found in all major Texas river systems (Howells et al. 1996).

Shell Measurements of Specimens:

Length: Range = 80.1 – 83.7 mm; mean = 81.9 mm

Width: Range = 42.5 – 42.6 mm; mean = 42.55 mm

Fish Hosts: Probable hosts sampled include *Lepomis cyanellus*, *Lepomis gulosus*, and *Micropterus salmoides* (Howells et al. 1996).

Remarks: The specimens were found in a sand and gravel substrate.

Quadrula apiculata (Say, 1829)

Figure 8.

Common Names: Southern mapleleaf, greenie, mapleleaf (Howells et al. 1996).

Distribution in Texas: *Quadrula apiculata* is found in all major drainage systems in Texas (Howells et al. 1996).

Shell Measurements of Specimens:

Length: Range = 29.0 – 62.4 mm; mean = 45.7 mm

Width: Range = 21.3 – 48.1 mm; mean = 34.7 mm

Fish Hosts: No hosts are reported for this species (Howells et al. 1996).

Remarks: The specimens were found in a sand and gravel substrate.

Discussion.

The San Jacinto River Basin has experienced a decline in unionid populations due to urbanization, impoundments, and channelization (Howells 1997). Characterization of habitat, fish and mussel communities, and water quality parameters are essential as baseline information to determine when changes have occurred, estimation of the resulting impact, and assist in predicting future impacts from human and natural disturbances (Meador et al. 1993b, Morris and Corkum 1996). Additionally, the physical, chemical, and biological characteristics of an area combined with the habitat requirements of aquatic organisms have a direct relationship to determining presence or absence of a given organism in that habitat (Meador et al. 1993b).

The baseline data collected during this survey appears to support the relationship between the organism's habitat requirements and those physical, chemical, and biological characteristics present in the habitat area. Bottom sediments at Site1 are generally made up of sand, sand and silt mixtures , and small gravel which would, in general, provide appropriate substrate for colonization by freshwater mussels. Site 1 does though have a few areas of shifting sand that are not appropriate habitat for freshwater mussels. Site 2 has hard packed clays throughout the majority of the channel which would not provide the appropriate substrate for colonization for the majority of freshwater mussels (Coker 1919, Howells 1995). Channel sinuosity calculations, as discussed in

Meador et al. (1993b), indicate that Site 1 has a low channel gradient, asymmetrical cross sections, bank pools on outside of meanders, and a greater diversity of habitat available as compared to Site 2. Site 1 has a reach slope of 0.6 indicating low channel gradient while Site 2 has a reach slope of –4.2 indicating a steeper channel gradient. Both sites have similar bank composition consisting of a sandy soil. The difference in channel morphology between Sites 1 and 2, as indicated by the difference in mean channel and wetted channel widths, is due to differences in land use practices and channel gradients.

Water quality measurements are similar at both sites with the exceptions of conductivity and water clarity. Higher conductivity at Site 2 most likely is due to a greater amount of total dissolved solids (TDS) from bank erosion and disturbance by cattle. TDS values were not measured during the study. Due to the higher level of channel disturbances occurring at Site 2 from cattle activity, the site most likely has a higher level of suspended solids in the water column as evidenced by the lower Secchi disk readings. Visual estimation riparian vegetation at each site indicated that Site 2 has a lower proportion of riparian vegetation than Site 1 primarily as a result of cattle disturbances. The increase in sediment load may be a cause for the absence of unionids due to impaired light penetration and disruption of phototaxic responses as well as possible interference with siphoning activities (Morris and Corkum 1996).

The diversity of unionid mussels depends on several factors. The appropriate host fish must be present in the habitat area; the host fish must be infected with the glochidia; the glochidia must progress to the juvenile stage; and the glochidia must be deposited in an appropriate habit for survival. Fourteen of the 22 total fish species collected exist in both locations but only Site 1 contained unionids. Known fish hosts exist at both sites and the possibility exists that some of the other fish species are in fact hosts, though currently unreported, for those unionid species recorded during the study. Then why were there no unionids recorded at Site 2 ? One possibility is that the channel substrate at Site 2, which is generally hard packed clay, is inappropriate habitat for the majority of unionid species (Coker 1919, Howells 1995). Another possibility is that the disturbances caused by cattle using the creek as a source of water precludes habitation by unionids (Watters 1997).

Brown (1984) and Neck (1989) discussed drawdowns of water levels due to impoundments and water management policies as a possible reason for low mussel species diversity. Even though not affected by impoundments, mussel populations in Lake Creek may be negatively impacted by low water levels. The majority of in-stream flow in Lake Creek is from runoff, with a small portion of the water budget coming from groundwater. During times of low precipitation or drought, mussel survival and host fish distribution would be difficult. Alternatively, Brown (1984) suggests low species diversity can occur because the study area is outside of the distribution range of many of the species and this may explain the absence of unionids at Site 2.

Future efforts in studying not only the presence or absence of freshwater mussels at a site but those physical, chemical, biological, and habitat parameters that exist at the site should be consolidated by a single entity. As the database increases, correlations may surface that will assist in determining impacts caused by human and natural disturbances and possibly allow for proactive instead of reactive environmental practices.

TABLE 1. Summary of physical parameters measured at Sites 1 and 2. Linear and curvilinear lengths are calculated from surveyed edge of water points. Sinuosity is the ratio between linear length and curvilinear length. Reach slope was calculated from the upstream and downstream edge of water surveyed points using the slope function in Microsoft's Excel 97 software. All other calculations are arithmetic means derived from the appropriate surveyed points within the reach.

	Site 1	Site 2
Linear Length (m)	132.7	133.5
Curvilinear Length (m)	215.7	159.6
Sinuosity	1.6	1.1
Reach Slope	0.6	-4.2
Mean Channel Width (m)	59.7	93.1
Mean Right Bank Height (m)	3.6	4.1
Mean Left Bank Height (m)	2.6	4.2
Mean Wetted Channel Width (m)	6.2	11.1
Mean Channel Depth (m)	0.7	0.9
Mean Velocity (m/sec)	0.2	0.1

TABLE 2. Summary of water quality parameters taken at Sites 1 and 2. Site 1 parameters measured on September 19, 1997 and Site 2 parameters measured on June 6, 1997.

	Site 1		Site 2	
	7:00 AM	4:00 PM	7:00 AM	4:00 PM
Dissolved Oxygen (ppm)	5.3	5.6	5.4	5.9
pH	6.7	6.9	7.2	7.5
Conductivity ($\mu S\ cm^{-1}$)	195	193	298	301
Secchi Disk (cm)	41.5	35.0	29.0	26.0
Temperature (C°)	26.0	26.9	25.3	26.6

TABLE 3. Summary of fish community parameters collected at Sites 1 and 2. Total sample (N) represents the combined samples from both electrofishing and seining. T = less than1. Percentages rounded to the nearest decimal. Scientific names in accordance with Robbins et al. (1991).

	Site 1		Site 2	
Species Name	N	Relative Density (%)	N	Relative Density (%)
Lepisosteus oculatus	0	0	1	T
Dorosoma cepedianum	4	2	1	T
Cyprinella venusta	48	18	34	15
Notropis stramineus	3	1	7	3
Pimephales vigilax	81	31	15	7
Moxostoma poecilurum	7	3	2	1
Ictalurus punctatus	1	T	1	T
Noturus gyrinus	2	1	0	0
Noturus nocturnus	1	T	0	0
Aphredoderus sayanus	1	T	3	1
Fundulus notatus	1	T	8	4
Gambusia affinis	1	T	11	5
Labidesthes sicculus	0	0	1	T
Lepomis cyanellus	1	T	1	T
Lepomis gulosus	0	0	3	1
Lepomis macrochirus	3	1	29	13
Lepomis megalotis	80	30	92	42
Lepomis microlophus	3	1	0	0
Lepomis punctatus	0	0	1	T
Micropterus salmoides	9	3	6	3
Percina sciera	17	6	3	1
Aplodinotus grunniens	1	T	0	0
Total Individuals	264		219	
Total Species	18		18	

TABLE 4. Summary of unionid community parameters collected at Site 1. No specimens were collected at Site 2. Total sample (N) represents the combined samples from both hand and bull rake.

	Site 1		
Species	N	Frequency (%)	Relative Density (%)
Plectomerus dombeyanus	4	13	10
Fusconaia askewi	2	6	4
Lampsilis teres	2	6	4
Quadrula apiculata	36	75	82
Total Individuals	44		

TABLE 5. Species diversity parameters for mussels and fishes collected at Sites 1 and 2. Base 2 was used for all Shannon-Wiener calculations.

	Site 1		Site 2	
	Mussels	Fish	Mussels	Fish
Richness	0.957	2.630	0	2.815
Evenness	0.478	0.631	0	0.675

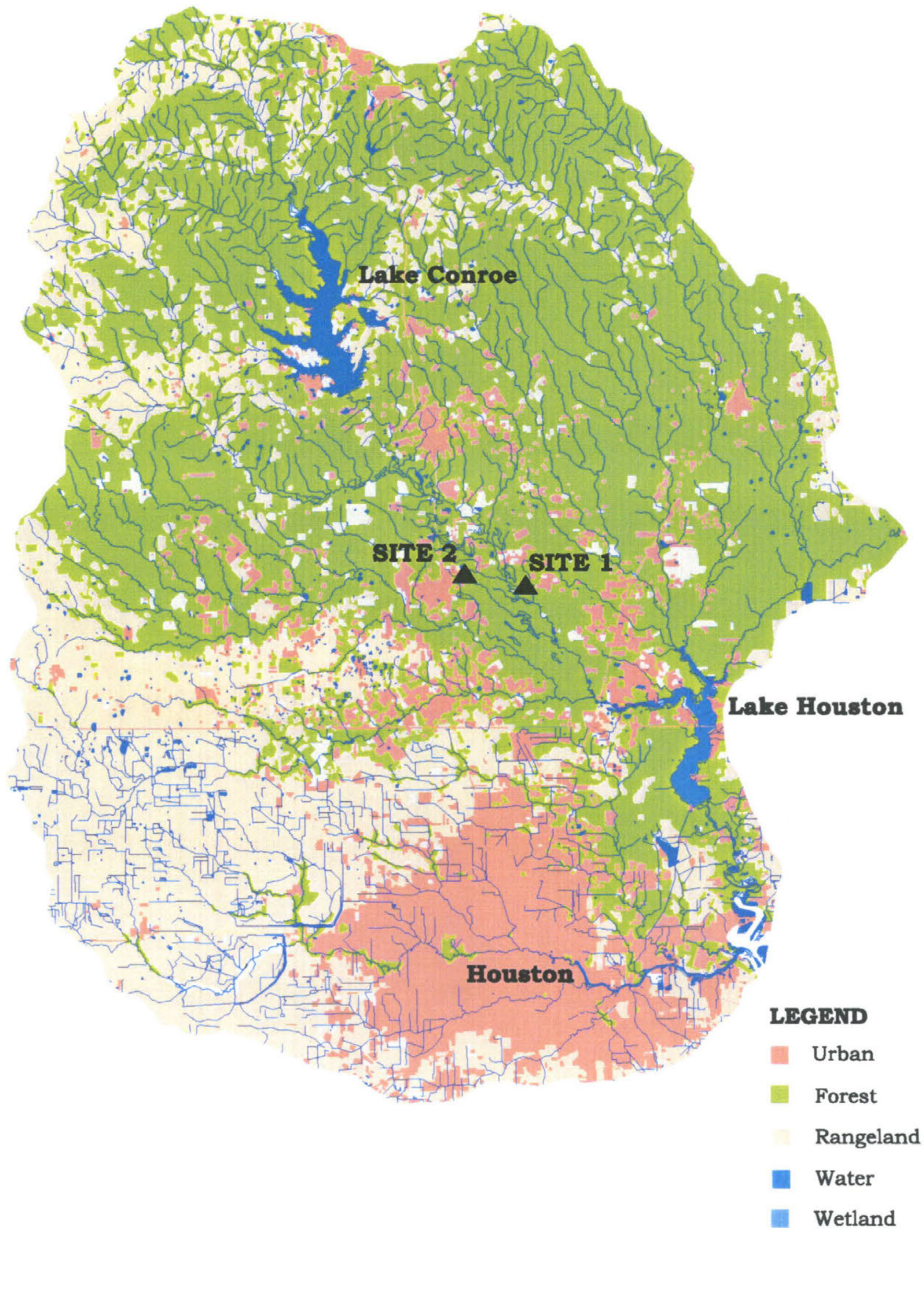

FIGURE 1. The San Jacinto River Basin showing hydrologic systems, landuse, and study sites.

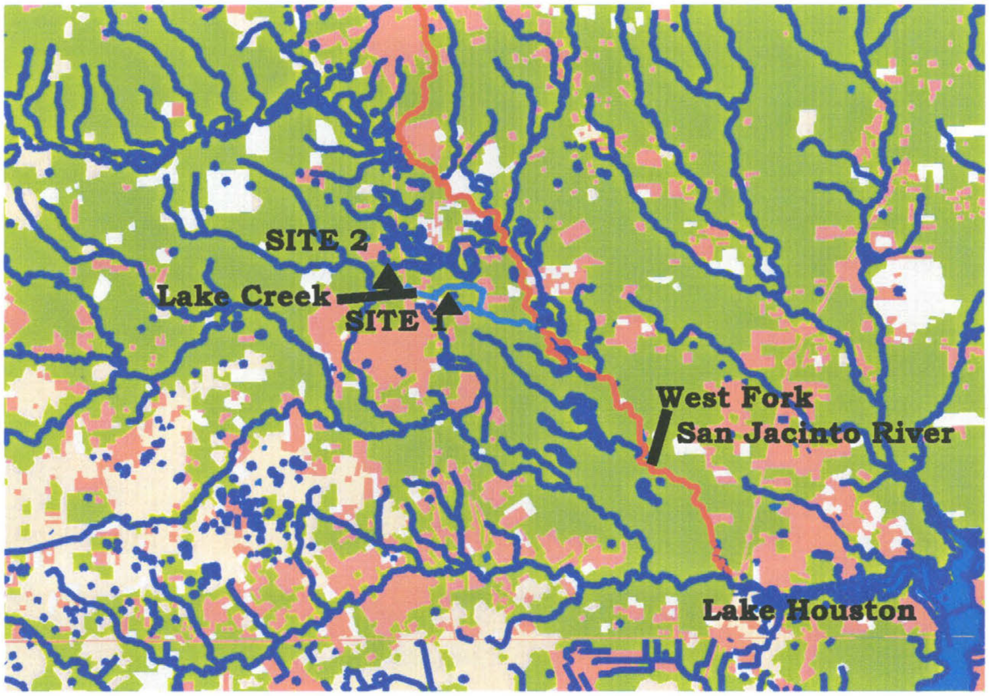

FIGURE 2. Location of Lake Creek, West Fork San Jacinto River, Lake Houston, and study sites.

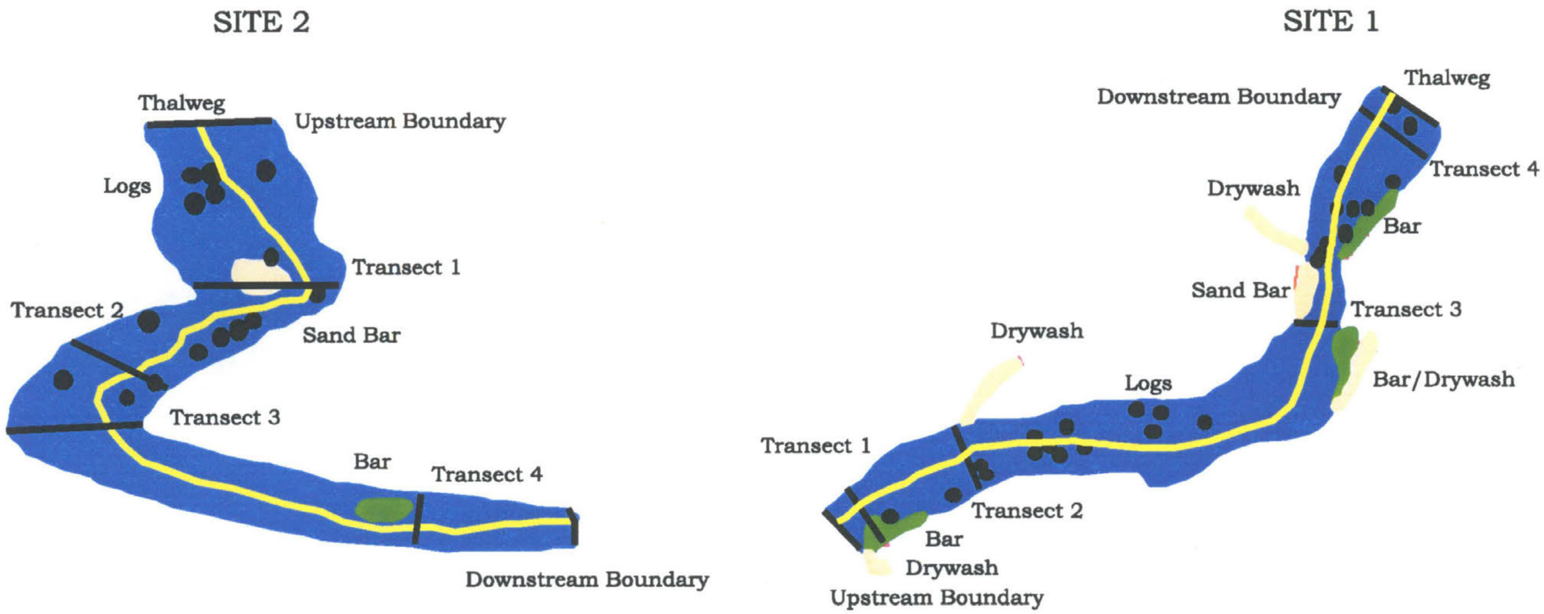

FIGURE 3. Lake Creek, Montgomery County, Texas showing channel features of sites 1 and 2.

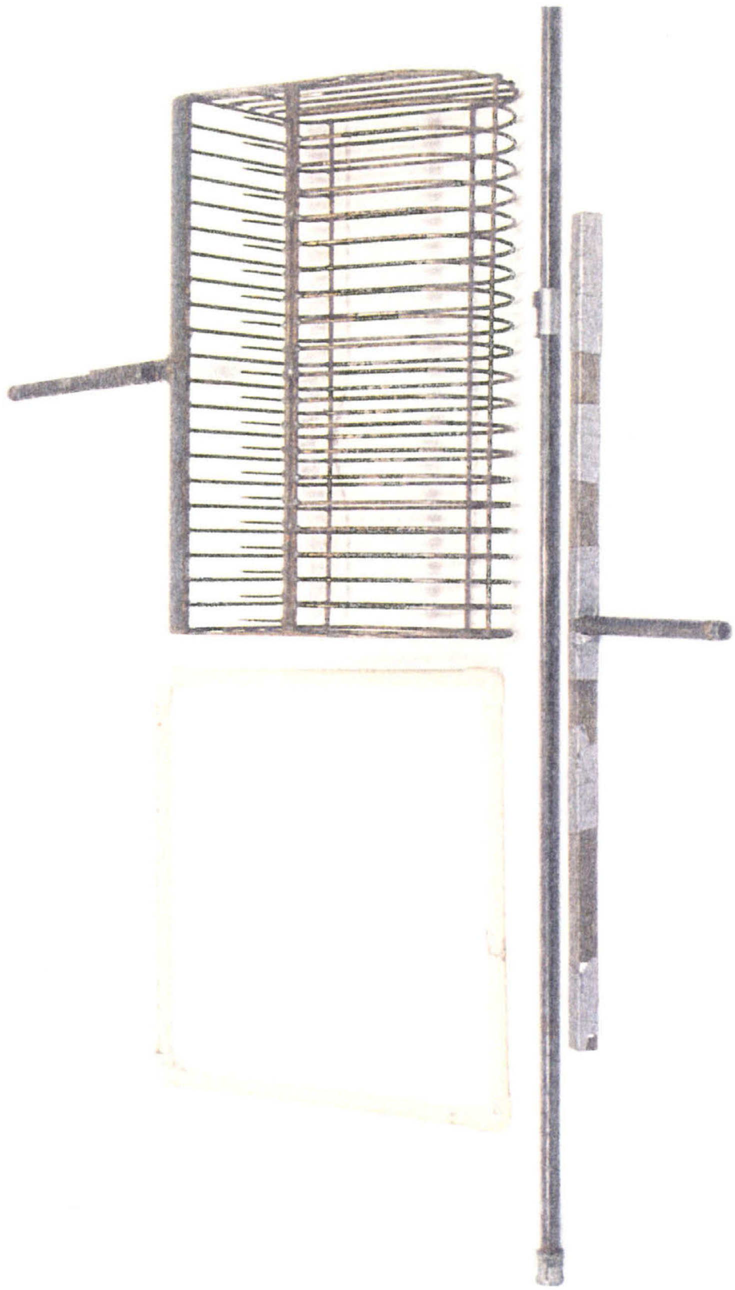

FIGURE 4. Quadrat and bull rake used for unionid sampling.

FIGURE 5. Picture of *Plectomerus dombeyanus*.

Texas Pigtoe
Fusconaia askewi

FIGURE 6. Picture of *Fusconaia askewi*.

Yellow Sandshell
Lampsilis teres

FIGURE 7. Picture of *Lampsilis teres*.

FIGURE 8. Picture of *Quadrula apiculata*.

Literature Cited.

Bauer, G. S., S. Hochwald, and W. Silkenat. 1991. Spatial distribution of freshwater mussels: the role of host fish and metabolic rate. Freshwater Biology 26:377-386.

Biggins, R. G., R. J. Neves, and C. K. Dohner. 1995. National strategy for the conservation of native freshwater mussels (Draft). U.S. Fish and Wildlife Service, Washington, D.C.

Brown, J. H. 1984. On the relationship between abundance and distribution of species. American Naturalist 124:253-279.

Coker, R. E. 1919. Freshwater mussels and mussel industries of the United States. U.S. Bureau of Fisheries Bulletin, Document 685.

Coker, R. E., A. F. Shira, H. W. Clark, and A. D. Howard. 1921. Natural history and propagation of freshwater mussels. U.S. Bureau of Fisheries Bulletin (Document 893) 37:75-181.

Collins, S. L. and S. M. Glenn. 1991. Importance of spatial and temporal dynamics in species regional abundance and distribution. Ecology 72:654-664.

Cox, G. W. 1996. Laboratory manual of general ecology, 7th ed. W. C. Brown Publishers, Chicago, Illinois.

Howells, R. G. 1993. Preliminary survey of freshwater mussel harvest in Texas. Texas Parks and Wildlife Department, Management Data Series Number 100, Austin.

Howells, R. G. 1994. Preliminary distributional surveys of freshwater bivalves in Texas: progress report for 1992. Texas Parks and Wildlife Department, Management Data Series Number 105, Austin.

Howells, R. G. 1995. Distributional surveys of freshwater bivalves in Texas: progress report for 1993. Texas Parks and Wildlife Department, Management Data Series Number 119, Austin.

Howells, R. G. 1996a. Distributional surveys of freshwater bivalves in Texas: progress report for 1994. Texas Parks and Wildlife Department, Management Data Series Number 120, Austin.

Howells, R. G. 1996b. Distributional surveys of freshwater bivalves in Texas: progress report for 1995. Texas Parks and Wildlife Department, Management Data Series Number 125, Austin.

Howells, R. G. 1997. Distributional surveys of freshwater bivalves in Texas: Progress Report for 1996. Texas Parks and Wildlife Department, Management Data Series Number 144, Austin.

Howells, R. G. 1998. Distributional surveys of freshwater bivalves in Texas: Progress Report for 1997. Texas Parks and Wildlife Department, Management Data Series Number 147, Austin.

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

Howells, R. G., C. M. Mather, and J. A. M. Bergmann. 1997. Conservation status of selected freshwater mussels in Texas. The Conservation and management of freshwater mussels II: Initiatives for the future. Symposium proceeding. Upper Mississippi River Conservation Commission.

Hubbs, C., R. J. Edwards, and G. P. Garrett. 1991. An annotated checklist of the freshwater fishes of Texas, with keys to identification of species. The Texas Journal of Science 43:1-56.

Krebs, C. J. 1994. Ecology. 4th ed. Harper-Collins, New York, New York.

Meador, M. R., T. F. Cuffney, and M. E. Gurtz. 1993a. Methods for sampling fish communities as part of the National Water-Quality Assessment Program. U.S. Geological Survey, Open File Report 93-104, Raleigh, North Carolina.

Meador, M. R., C. R. Hupp, T. F. Cuffney, and M. E. Gurtz. 1993b. Methods for characterizing stream habitat as part of the National Water-Quality Assessment Program. U.S. Geological Survey, Open File Report 93-408, Raleigh, North Carolina.

Morris, T. J. and L. D. Corkum. 1996. Assemblage structure of freshwater mussels (Bivalvia: Unionidae) in rivers with grassy and forested riparian zones. Journal of the North American Benthological Society 15:576-586.

Neck, R. W. 1989. Freshwater bivalves of Medina Lake, Texas: Factors producing a low-diversity fauna. The Texas Journal of Science 41:319-325.

Neves, R. J. 1990. Biology and ecology of mollusks in streams. Pages 8-9 *in* Ecology and assessment of warmwater streams: Workshop synopsis. U.S. Department of the Interior, Fish and Wildlife Service, Biological Report 90, Washington, D.C.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1991. Common and scientific names of fishes from the United States and Canada. American Fisheries Society, Special Publication 20, Bethesda, Maryland.

Turgeon, D. D., A. E. Bogan, E. V. Coan, W. K. Emerson, W. G. Lyons, W. L. Pratt, C. F. E. Roper, A. Scheltema, F. G. Thompson, and J. D. Williams. 1991. Common and scientific names of aquatic invertebrates from the United States and Canada: Mollusks. American Fisheries Society, Special Publication 16, Bethesda, Maryland.

Vaughn, C. C. 1993. Can biogeographic models be used to predict the persistence of mussel populations in rivers? Pages 117-121 *in* K.S. Cummings, A.C. Buchanan, and L.M. Koch, eds. Conservation and management of freshwater mussels. (Proceedings of a symposium held 12-14 October 1992 in St. Louis, Missouri) Upper Mississippi River Conservation Committee, Rock Island, Illinois.

Watters, G. T. 1993. Mussel diversity as a function of drainage area and fish diversity: Management implications. Pages 113-116 *in* K.S. Cummings, A.C. Buchanan, and L.M. Koch, eds. Conservation and management of freshwater mussels. (Proceedings of a symposium held 12-14 October 1992 in St. Louis, Missouri) Upper Mississippi River Conservation Committee, Rock Island, Illinois.

Watters, G. T. 1997. Freshwater mollusks and water quality: effects of hydrologic and instream habitat alterations. *In* Freshwater mollusks as indicators of water quality: a workshop. Fernbank Museum of Natural History, Atlanta, Georgia.

Williams, J. D., M. L. Warren, Jr., K. S. Cummings, J. L. Harris, and R. J. Neves. 1993. Conservation status of freshwater mussels of the United States and Canada. American Fisheries Society, Fisheries 18(9):6-22.

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