Variation in Biotic Assemblages and Stream-Habitat Data with Sampling Strategy and Method in Tidal Segments of Highland and March and Bayous, Galveston County, Texas, 2007

By Jeffrey A. Mabe and J. Bruce Moring

In cooperation with the Houston-Galveston Area Council and the
Galveston Bay Estuary Program under the authority of the
Texas Commission on Environmental Quality

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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

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Variation in Biotic Assemblages and Stream-Habitat Data with Sampling Strategy and Method in Tidal Segments of Highland and Marchand Bayous, Galveston County, Texas, 2007

By Jeffrey A. Mabe and J. Bruce Moring

Abstract

The U.S. Geological Survey, in cooperation with the Houston-Galveston Area Council and the Galveston Bay Estuary Program under the authority of the Texas Commission on Environmental Quality (the agency responsible for setting environmental standards for the State of Texas), did a study in 2007 to assess the variation in biotic assemblages (benthic macroinvertebrate and fish communities) and stream-habitat data with sampling strategy and method in tidal segments of Highland Bayou and Marchand Bayou in Galveston County. Data were collected once in spring and once in summer 2007 from four stream sites (reaches) (short names Hitchcock, Fairwood, Bayou Dr, and Texas City) of Highland Bayou and from one reach (short name Marchand) in Marchand Bayou. Only stream-habitat data from summer 2007 samples were used for this report. Additional samples were collected at the Hitchcock, Fairwood, and Bayou Dr reaches (multisample reaches) during summer 2007 to evaluate variation resulting from sampling intensity and location. Graphical analysis of benthic macroinvertebrate community data using a multidimensional scaling technique indicates there are taxonomic differences between the spring and summer samples. Seasonal differences in communities primarily were related to decreases in the abundance of chironomids and polychaetes in summer samples. Multivariate Analysis of Similarities tests of additional summer 2007 benthic macroinvertebrate samples from Hitchcock, Fairwood, and Bayou Dr indicated significant taxonomic differences between the sampling locations at all three reaches. In general, the deepwater samples had the smallest numbers for benthic macroinvertebrate taxa richness and abundance. Graphical analysis of species-level fish data indicates no consistent seasonal difference in fish taxa across reaches. Increased seining intensity at the multisample reaches did not result in a statistically significant difference in fish communities. Increased seining resulted in some changes in taxa richness and community diversity metrics. Diversity increases associated with increased electrofishing intensity were relatively consistent across the two multisample electrofishing reaches (Hitchcock and Fairwood). Differences in the physical characteristics of the Highland and Marchand Bayou reaches are largely the result of the differences in channel gradient and position in the drainage network or watershed of each reach. No trees were observed on the bank adjacent to the five transects at either the Bayou Dr or Texas City reaches. Riparian vegetation at the more downstream Fairwood, Bayou Dr, and Texas City reaches was dominated by less-woody and more-herbaceous shrubs, and grasses and forbs, than at the more upstream Hitchcock and Marchand reaches. The width of the vegetation buffer was variable among all reaches and appeared to be more related to the extent of anthropogenic development in the riparian zone rather than to natural changes in the riparian buffer. Four additional transects per reach were sampled for habitat variables at Hitchcock, Fairwood, and Bayou Dr. Medians of most stream-habitat variables changed with increased sampling intensity (addition of two and four transects to the standard five transects), although none of the differences in medians were statistically significant. All habitat quality index values for the five reaches scored in the intermediate category. Increasing sampling intensity did not change the habitat quality index score for any of the reaches.

Introduction

The tidal zones of rivers and streams are unique environments where freshwater rivers transition into brackish estuarine ecosystems. These areas help to regulate flows of water, nutrients, sediment, and organisms to and from the land, rivers, and the sea. They function as critical habitat that provides nursery grounds for juvenile fish and shellfish and feeding grounds for resident and migratory birds. Economically, coastal ecosystems in Texas provide more than $2 billion in economic benefits annually through recreational fishing and another $260 million from commercial fishing (Houston Advanced Research Center, 2006).

Many of the conditions that threaten tidally influenced ecosystems such as sedimentation, habitat alteration, and altered freshwater inflow patterns are not strictly water-quality issues. Chemical analysis of water samples might not detect these types of alterations to ecosystems, and assessments of biological communities often are necessary to detect ecosystem changes. Biological communities are effective assessment tools because they commonly reflect the cumulative effects of multiple stressors over an extended period of time, and careful consideration of the structure of biological communities can help identify probable causes of impairment (Gibson and others, 2000). However, tidally influenced ecosystems are complex and dynamic environments where the physical and chemical conditions that affect biological communities can vary both spatially and temporally (Odum, 1988; Bulger and others, 1993). Consequently, biological communities in tidal zones generally display a high degree of natural variation in taxa numbers, density, and biomass (McErlean and others, 1972; LaSalle and Bishop, 1987; Montagna and Kalke, 1992; Gelwick and others, 2001). Field sampling methods also can introduce variation or bias into biological assessments in tidal environments (Livingston, 1987).

Changes in tidal-zone biological communities associated with anthropogenic effects can be difficult to detect against background variation. Presently (2008) the Texas Commission on Environmental Quality (TCEQ), the agency responsible for setting environmental standards for the State of Texas, does not have established criteria for evaluating biological data collected from tidal stream segments. Developing suitable criteria for describing anthropogenic changes in tidal streams requires a clear understanding of the natural variation associated with sampling in different locations, at different times of the year, and with different methods or levels of intensity. (Level of intensity in this report generally refer to the number of samples.) Accordingly, the U.S. Geological Survey (USGS), in cooperation with the Houston-Galveston Area Council and the Galveston Bay Estuary Program under the authority of the Texas Commission on Environmental Quality, did a study in 2007 to assess the variation in biotic assemblages (benthic macroinvertebrate and fish communities) and stream-habitat data with sampling strategy and method in tidal segments of Highland Bayou and Marchand Bayou (fig. 1).

Purpose and Scope

This report documents and compares the variation in biotic assemblages (benthic macroinvertebrate and fish communities) and stream-habitat data with sampling strategy and method in tidal segments of Highland Bayou (four sites [reaches]) and Marchand Bayou (one reach) in 2007. Sampling strategies and methods are described. Changes in the structure of benthic macroinvertebrate and fish communities between spring and summer sampling events are assessed using multivariate statistical techniques that compare biotic assemblages between samples. Taxa changes associated with sample variation are described and quantified using diversity and richness metrics. Three of four reaches in Highland Bayou (multisample reaches) were selected for additional sampling to evaluate variation resulting from sampling intensity and location. For those reaches, more than the standard sampling called for in TCEQ protocols (Texas Commission on Environmental Quality, 2007) was done. For those reaches, benthic macroinvertebrate samples collected from three within-reach locations are compared and the between-sample variation is assessed and described taxonomically; variation in fish-community and stream-habitat data associated with sampling intensity is evaluated.

Description of Study Area

Highland Bayou is a tidally influenced stream draining an approximately 100-square-kilometer area in Galveston County on the Texas Gulf Coast (fig. 1). The water course rises near the town of Santa Fe and runs east-southeastward 20 kilometers to Jones Bay. The two upper reaches of Highland Bayou, Highland Bayou at Hitchcock (Hitchcock) and Highland Bayou at Fairwood Road (Fairwood), are riverine in nature with relatively narrow channels, steeply sloping channel sides, and low banks. Private residences line much of each reach, and bank vegetation primarily consists of grasses, trees, and shrubs or maintained lawns. During the study period, salinity (dissolved solids concentration) in the upper reaches ranged from 0.12 to 5.34 parts per thousand (‰) at Hitchcock and 0.19 to 7.35 ‰ at Fairwood (table 1).

The two lower reaches of Highland Bayou, Highland Bayou at Bayou Drive (Bayou Dr) and Highland Bayou at Texas City (Texas City), are more estuarine in nature with relatively broad channels, a sinuate shoreline, and gently sloping channel sides that grade into shallow banks. Channel margins in the lower reaches are less developed and generally are lined with cordgrass that typically extended offshore into shallow water at the time of sampling. During the study period, salinity in the lower reaches of Highland Bayou ranged from 0.50 to 14.25 ‰ at Bayou Dr, and 0.86 to 21.27 ‰ at Texas City (table 1).

Marchand Bayou is a smaller, shallower tributary that joins Highland Bayou near its mid-point (fig. 1) and resembles the upper reaches of Highland Bayou in adjacent land cover and channel form. The Marchand Bayou reach, Marchand Bayou at FM 519 (Marchand), is about 0.4 kilometer upstream from its confluence with Highland Bayou. Salinity at Marchand ranged from 0.07 to 9.48 ‰ (table 1) during the study period.

Climatic conditions in the study area are classified as humid subtropical (Larkin and Bomar, 1983) and characterized by cool temperate winters, long hot summers, and high relative humidity. A National Weather Service station on Galveston Island (Scholes Field, Galveston Island, WBAN 12923) was used to summarize weather conditions during the study period (National Oceanic and Atmospheric Administration, 2007). The overall mean temperature during the 2007 study period was 25.2 degrees Celsius (°C) and monthly mean

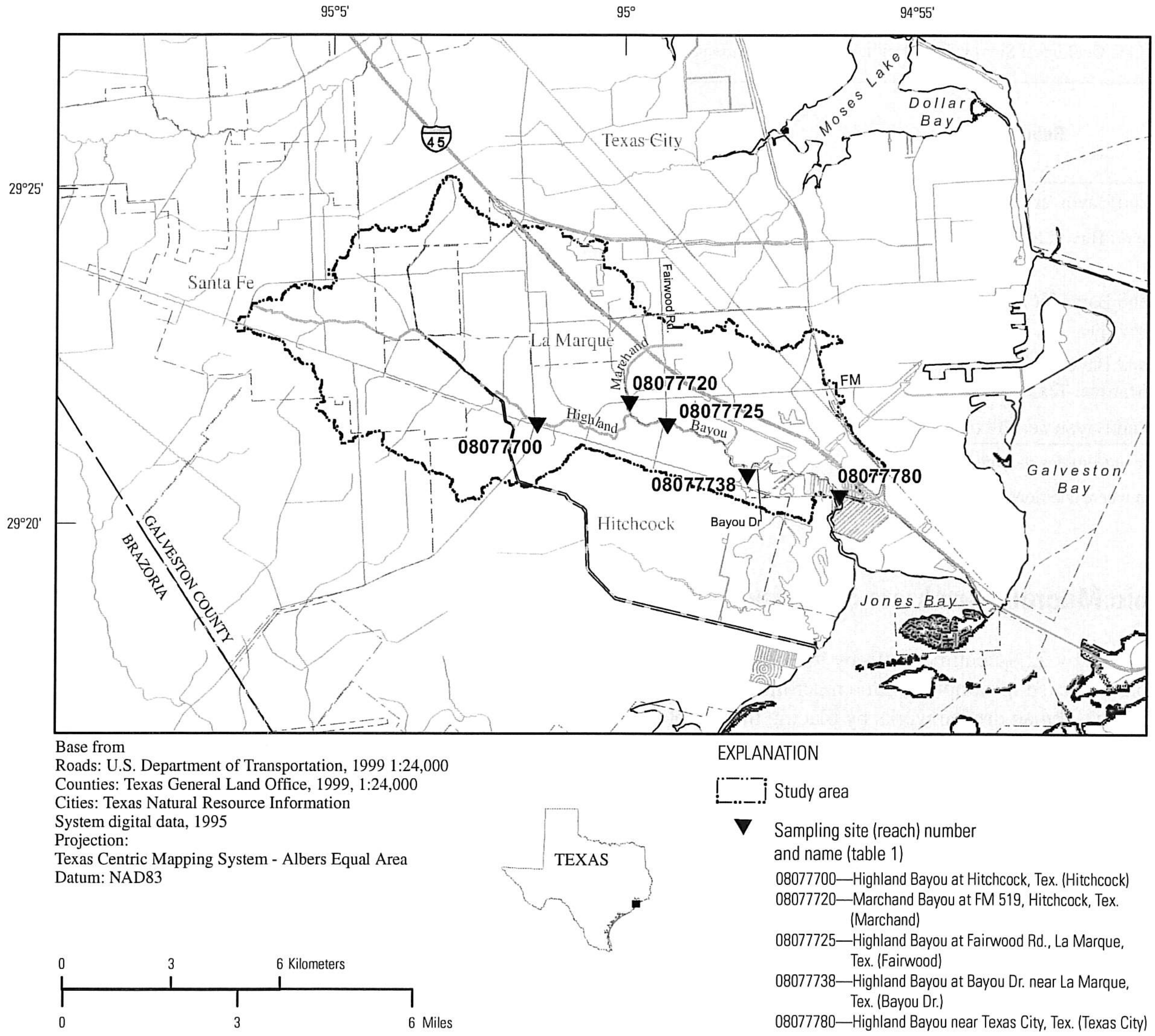


Figure 1. Highland and Marchand Bayou watershed and locations of Highland and Marchand Bayou sampling sites (reaches), Galveston County, Texas.

temperatures ranged from a low of 19.8 °C in March to a high of 29.8 °C in August. Rainfall during the study period totaled 725.2 millimeters with slightly more than 60 percent of the rainfall occurring in March and July. A storm that delivered 118.9 millimeters over 3 days ended 11 days before the March sampling, and another storm that delivered 157.0 millimeters over 6 days ended 2 days before the July sampling.

Sampling Strategies and Methods

Benthic macroinvertebrate, fish, and habitat data were collected from four stream reaches distributed down the length of tidally influenced Highland Bayou (table 1). Data also were collected from a single reach on tidally influenced Marchand Bayou. All five stream reaches were sampled for benthic macroinvertebrates, fish, and stream-habitat data once in spring and once in summer 2007. Only stream-habitat data from summer 2007 samples were used for this report because the summer 2007 habitat dataset was the most complete. Additional benthic macroinvertebrate, fish, and habitat samples were collected at the Hitchcock, Fairwood, and Bayou Dr reaches of Highland Bayou (multisample reaches) during summer 2007 to evaluate variation resulting from sampling intensity and location. The spring sampling occurred March 26–30, and the summer sampling occurred July 9–10 and August 13–14; the gap in summer sampling was because of delays caused by thunderstorms. Sampling methods at individual reaches were consistent across sampling events.

Table 1. Sampling sites (reaches) on Highland and Marchand Bayous, Galveston County, Texas, spring and summer 2007.

[USGS, U.S. Geological Survey; DD, decimal degrees; ‰, parts per thousand; E, electrofishing; S, seine]

Reach name	USGS site number (fig. 1)	Reach short name	Location		Salinity range[1] (‰)	Invertebrate capture method	Fish capture method
			Latitude (DD)	Longitude (DD)			
Highland Bayou at Hitchcock, Tex.[2]	08077700	Hitchcock	29.35361	-95.03028	0.12–5.34	Dredge	E
Marchand Bayou at FM 519, Hitchcock, Tex.	08077720	Marchand	29.35778	-95.00361	.07–9.48	Dredge	S/E
Highland Bayou at Fairwood Rd., La Marque, Tex.[2]	08077725	Fairwood	29.35194	-94.99306	.19–7.35	Dredge	S/E
Highland Bayou at Bayou Dr., near La Marque, Tex.[2]	08077738	Bayou Dr	29.33844	-94.97103	.50–14.25	Dredge	S
Highland Bayou near Texas City, Tex.	08077780	Texas City	29.33222	-94.94500	.86–21.27	Dredge	S

[1]Range of salinities recorded during study.

[2]Reach where additional sampling was done to evaluate variation resulting from sampling location and intensity.

Benthic Macroinvertebrate Sampling

A 22.9- by 22.9-centimeter (9- by 9-inch) Ekman dredge on a pole was used to sample benthic macroinvertebrates at all reaches. The Ekman dredge works by placing the sampler on the streambed and releasing the spring-loaded jaws to collect a sediment sample. An advantage of the Ekman dredge on a pole is that it can be placed precisely to target specific depositional habitats. The Ekman dredge was operated from a boat in all reaches except Marchand Bayou, where it was operated while wading in shallow water. After the jaws were closed to collect a sample, the dredge was brought slowly to the surface where the sample was transferred to a container for transport to shore and eventual processing. All dredge hauls were first washed through a 0.64-centimeter sieve to separate the benthic macroinvertebrates from any large organic debris present in the sample. The general amount of large organic debris in each sample was noted, and the material was discarded after it was inspected for any remaining benthic macroinvertebrates. Samples were then processed through a 0.05-centimeter mesh sieve to separate the benthic macroinvertebrates from the remaining sediment. Processed benthic macroinvertebrate samples were preserved in 80-percent ethanol and submitted to EcoAnalysts, Inc., in Moscow, Idaho, for taxonomic identification and enumeration. Each dredge sample underwent complete sorting and enumeration, and all benthic macroinvertebrates collected were identified to the lowest taxonomic level possible.

TCEQ protocols for a standard Ekman dredge sample in a tidal stream call for four separate dredge hauls (four replicates) from undisturbed soft sediment near mid-channel (Texas Commission on Environmental Quality, 2007). One standard sample following TCEQ protocols was collected from each study reach (table 1) in spring 2007 and one in summer 2007. Two additional samples (four dredge hauls, or replicates, each) were collected in summer 2007 at Hitchcock, Fairwood, and Bayou Dr for evaluation of variation in benthic macroinvertebrate communities associated with sampling location. At each of those three reaches, one sample was collected from soft bottom sediment at a deepwater mid-channel location and one sample at a shallow nearshore location.

Fish Sampling

Two sampling methods, electrofishing and seining, were used to collect fish-community data. Electrofishing methods were used where applicable; however, relatively high salinity common in estuarine environments can make electrofishing ineffective. Seining was used where relatively high salinity precluded effective electrofishing. Because of relatively high salinity, the two downstream reaches of Highland Bayou (Bayou Dr and Texas City) were sampled only by seining. In the upstream reaches where salinity was lower (Marchand and Fairwood), a combination of electrofishing and seining was used. In the uppermost reach of Highland Bayou (Hitchcock), seining was not practical because of steep banks and abundant woody debris that disrupted effective net hauling; therefore only electrofishing was used for fish sampling in this reach.

Electrofishing was done with a Smith-Root 5.0 Generator Powered Pulsator electrofishing system with a maximum power output of 5,000 watts. The electrofishing system was deployed from a boat in the Highland Bayou reaches and from a barge wading unit in the smaller and shallower Marchand Bayou reach. Electrofishing was done over the entire reach and included mid-channel habitat and channel margins. Stunned fish were collected with a net and placed in an aerated holding tank for recovery and transport to the processing station for identification. Captured fish were identified and enumerated on-site and returned to the water.

Seining was done with a 4.6-meter flat-panel seine with a 0.64-centimeter mesh. Seines were deployed about 4 to 6 meters offshore and parallel to the shoreline. Seines were then pulled inland to the shoreline where the lead-line was lifted and the seine pulled onshore. Seine hauls were considered effective only if the lead-line remained on or close to the bottom, and no obstacles were encountered that snagged or otherwise interfered with the smooth progression of the net through the water. On Highland Bayou, where reaches were larger than the Marchand reach, seining was distributed among at least three broadly spaced locations. On the Marchand reach, seining was distributed across the entire reach. In all reaches, seining covered as many nearshore habitat types as possible. Captured fish were removed from the nets, transferred to a container, and transported to shore where they were identified and enumerated on-site and then returned to the water.

Captured fish were identified to the lowest possible taxonomic category (generally species). Individuals of unknown species were preserved in 10-percent buffered formalin and sent to Dr. Dean Hendrickson, Memorial Museum, The University of Texas at Austin, for identification. Voucher specimens (specimens retained for reference) were collected for all taxa at each site. Small taxa were vouchered by preserving a representative specimen in 10-percent buffered formalin, and large taxa were vouchered by photographing a representative specimen.

Fish sampling in the summer had two goals: (1) to collect representative fish-community samples (standard samples) consistent with TCEQ protocols and previous sampling and (2) to evaluate the effects of increased sampling intensity on the structure of the representative fish community captured. Accordingly, sampling intensity varied between spring and summer at the multisample reaches (Hitchcock, Fairwood, and Bayou Dr), and some partitioning of data was necessary to make valid statistical comparisons between spring and summer (table 2).

TCEQ protocol for electrofishing calls for a minimum of 900 seconds (15 minutes) of shocking time covering as many habitat types in a reach as possible for a standard sample (Texas Commission on Environmental Quality, 2007). Shocking (collection) times at the three reaches where electrofishing was done (Hitchcock, Fairwood, and Marchand) averaged 20.6 minutes per reach during spring sampling (table 2). Summer shocking time at the Marchand reach was similar to that for spring, but electrofishing at the Hitchcock and Fairwood reaches involved additional shocking time. Summer electrofishing at the Hitchcock and Fairwood reaches was partitioned into one pass of 15 minutes covering the entire reach and three

Table 2. Description of spring and summer standard samples and the division of summer sampling for evaluation of variation associated with sampling location and intensity, for fish sampling, Highland and Marchand Bayous, Galveston County, Texas, spring and summer 2007.

[--, not applicable]

Reach short name (table 1)	Electrofishing time	Seining
	Spring standard samples	
Hitchcock	21.2 minutes	--
Marchand	22.4 minutes	First 6 effective hauls (entire reach)
Fairwood	18.3 minutes	First 6 effective hauls (2 hauls/3 locations)
Bayou Dr	--	First 10 effective hauls (3 hauls/2 locations and 4 hauls/1 location)
Texas City	--	First 10 effective hauls (3 hauls/2 locations and 4 hauls/1 location)
	Summer standard samples	
Hitchcock	20 minutes (15-minute period and first extra 5-minute period)	--
Marchand	21.7 minutes	First 6 effective hauls (entire reach)
Fairwood	20 minutes (15-minute period and first extra 5-minute period)	First 6 effective hauls (2 hauls/3 locations)
Bayou Dr	--	First 10 effective hauls (3 hauls/2 locations and 4 hauls/1 location)
Texas City	--	First 10 effective hauls (3 hauls/2 locations and 4 hauls/1 location)
	Division of summer sampling in multisample reaches for evaluation of variation	
Hitchcock	One 15-minute period and three 5-minute periods	--
Marchand	--	--
Fairwood	One 15-minute period and three 5-minute periods	18 effective seine hauls distributed among three locations
Bayou Dr	--	18 effective seine hauls distributed among three locations
Texas City	--	--

additional 300-second (5-minute) shocking periods for selective resampling of important fish habitat in the reach. Fish captured during the individual shocking periods were kept separate to allow for assessment of variation with increased sampling intensity. However, to be consistent with spring sampling for statistical comparisons between seasons, summer standard samples for the Hitchcock and Fairwood reaches include only the first 20 minutes (15-minute sample plus the first 5-minute sample) of shocking time.

TCEQ protocol for seining calls for a minimum of six effective seine hauls (six replicates) for a standard sample (Texas Commission on Environmental Quality, 2007). However, there is no limit on the number of seine hauls that can be used for a given research objective. Fish sampling in the two downstream reaches of Highland Bayou, where seining was the only capture method, comprised 10 effective seine hauls for the standard sample. In contrast, in the upstream reaches where electrofishing was used with seining, only six effective seine hauls were done for the standard sample.

Additional seining was done at Fairwood and Bayou Dr to assess variation associated with increased sampling intensity. Eighteen effective seine hauls were done in each of the two reaches during the summer sampling event. At each reach seining was distributed among three broadly spaced within-reach sampling locations (six hauls each), and the data were partitioned to reflect the fish catch as if the seine hauls were done in blocks of two at each location. The result is such that, for each reach, the dataset of six seine hauls consists of the first two seine hauls from each of the three within-reach locations; the dataset of 12 seine hauls consists of the first four seine hauls from each of the three within-reach locations; and the dataset of 18 seine hauls consists of the entire six seine hauls from each of the three within-reach locations. Thus, the analysis of increased sampling intensity reflects the difference between two, four, or six seine hauls at each of the three within-reach locations.

Stream-Habitat Measurement

TCEQ has not developed protocols for assessing physical habitat conditions in tidally influenced streams. Therefore stream-habitat assessment procedures in the Highland Bayou reaches, which were generally not wadeable, were modified from TCEQ protocols for non-wadeable streams (Texas Commission on Environmental Quality, 2007), and reach lengths were computed to include at least one river bend. Stream-habitat conditions in the Marchand reach, which was wadeable, were assessed using TCEQ protocols for wadable streams, and the reach length was computed as 40 times the mean channel width. Measurements of stream-habitat variables were recorded along five uniformly spaced transects perpendicular to the channel at all reaches. The stream-habitat variables for this report are

- Stream width
- Stream depth
- Bank slope
- Bank erosion
- Dominant substrate
- Instream cover
- Tree canopy
- Riparian trees
- Riparian shrubs
- Riparian grasses and forbs
- Width of vegetation buffer
- Habitat quality index (HQI)

These variables are described in "Surface Water Quality Monitoring Procedures," volume 2 (Texas Commission on Environmental Quality, 2007).

TCEQ protocols for assessing stream-habitat conditions call for data collection from a minimum of five transects in wadeable streams and a minimum of six transects in non-wadeable streams. However, the standard sample for the non-wadeable Highland Bayou reaches was modified to reflect the general physical homogeneity of tidally influenced environments (Diaz, 1994) and involved data collection from only five transects. Stream-habitat data collection at the Hitchcock, Fairwood, and Bayou Dr reaches included four additional transects, distributed among the five standard transects, to evaluate the effects of increased sampling intensity on stream-habitat data. Additional transects were treated in the same manner as the standard transects, and the same stream-habitat variables were measured.

Data Analysis

Benthic macroinvertebrate and fish data were analyzed to evaluate differences in community composition among reaches, sampling seasons, and within-reach sampling locations. Changes in community composition with increased sampling intensity also were assessed. The analysis of stream-habitat data emphasized a comparison among reaches of transect-derived habitat data to help understand the basic differences in physical channel features and aquatic-habitat conditions and the effects of increased sampling intensity, particularly on the HQI.

Data Treatment

Benthic macroinvertebrate data from the four separate dredge hauls at each benthic macroinvertebrate sampling location were combined to form one composite sample (total of five samples in March and 11 samples in July/August). In some cases, the separate dredge hauls (replicates) were analyzed independently to provide sufficient data replication for statistical analysis.

Results from analysis of benthic macroinvertebrate data can be misleading if the taxonomic resolution of samples is inconsistent. Therefore, benthic macroinvertebrate data were analyzed at the genus level. Individuals identified to a lesser degree of resolution (family or lower) were distributed among their corresponding children (higher taxonomic resolution such as genus) according to their proportions in the samples. Individuals identified at a lesser taxonomic resolution with no corresponding children were left at their respective taxonomic level. Fish-community data from electrofishing and seining standard samples were combined into one standard sample for reaches where both capture methods were used (Marchand and Fairwood).

Species identification is less problematic with fish than with benthic macroinvertebrates, and all individuals except juveniles of the genus *Brevoortia* were identified to the species level. Therefore the fish data were analyzed at the species level except for juvenile *Brevoortia*, which was analyzed at the genus level (*Brevoortia* sp.).

Statistical Analysis

Benthic macroinvertebrate and fish data were formatted and imported into the statistical software package Plymouth Routines In Multivariate Ecological Research (PRIMER) version 6 for summation and analysis (Clarke and Warwick, 2001). PRIMER is designed to use data on community structure (abundance data for a set of taxa) to perform a wide array of univariate, graphical, and multivariate statistical procedures on sets of samples.

Multidimensional Scaling (MDS) was used to compare taxa assemblages between reaches and samples. MDS is an ordination technique that uses multidimensional taxa abundance information to construct a two-dimensional plot reflecting the similarities between samples (Clarke and Warwick, 2001). Samples close to one another on the plot are more similar in taxonomic composition than samples farther away from one another. Similarities between each pair of samples are calculated using the Bray-Curtis similarity coefficient (Bray and Curtis, 1957). The Bray-Curtis similarity coefficient (S) between the *j*th and *k*th samples is defined as

$$S_{jk} = 100\left\{1 - \frac{\sum_{i-1}^{p}\left|y_{ij} - y_{ik}\right|}{\sum_{i-1}^{p}\left(y_{ij} + y_{ik}\right)}\right\}, \quad (1)$$

where

y_{ij} = the abundance of the *i*th taxa in the *j*th sample, and
y_{ik} = the abundance of the *i*th taxa in the *k*th sample.

The Bray-Curtis coefficient ranges from 1 if samples are exactly similar (same taxa in same abundance) to 0 if samples are completely dissimilar (no taxa in common).

Ordinations such as MDS attempt to fit distances between samples in the ordination to match corresponding dissimilarities in community structure. However, because the data are multidimensional there is no single unique arrangement of samples, and MDS ordinations should be considered exploratory rather than definitive. The average dissimilarity between samples or sets of samples that appear to be dissimilar in the MDS can be tested with an Analysis of Similarities (ANOSIM) test (Clarke and Warwick, 2001). The ANOSIM test is based on the Bray-Curtis similarity matrix underlying the MDS ordination. Bray-Curtis similarities between samples are ranked and then used to compute a test statistic (R) defined as

$$R = \frac{\left(\bar{r}_B - \bar{r}_W\right)}{\frac{1}{2}M}, \quad (2)$$

where

M = n(n-1)/2; n is the total number of samples;
$\bar{r}_W$ = the average of rank similarities among replicates *within* sites; and
$\bar{r}_B$ = the average of rank similarities among replicates *between* sites.

The value of R will be close to 1 if all within-reach replicates are more similar to each other than to any replicates from other reaches. R will be close to zero if all within-reach replicates are more similar to replicates from other reaches than to each other. The test statistic R can be calculated in the global sense (Global R) where similarities between all sites are compared, or, if enough data replication exists at individual sites, R can be calculated between individual sites (Pairwise R). The statistical significance of R is then evaluated against a null distribution of potential values for R developed from a random sampling of all possible sample groupings. If the actual value of R is outside the calculated null distribution of R values, it is likely not a result of chance variation and statistically significant at a level defined by the number of possible simulated sample groupings, which is computed as

$$(t+1)/(T+1), \quad (3)$$

where

T = the number of simulated values of R, and
t = the number of simulated values greater than the actual value of R.

The Bray-Curtis dissimilarity coefficient (δ) can be used to identify taxa that account for the dissimilarity between groups of samples with the PRIMER SIMilarity PERcentages (SIMPER) routine (Clarke and Warwick, 2001). Bray-Curtis dissimilarity is the reciprocal of Bray-Curtis similarity:

$$(\delta = 100 - S). \quad (4)$$

The SIMPER routine averages δ_{jk} (*i*) for individual taxa (*i*) across all pairs of samples (*j*,*k*) to calculate the individual contribution of the *i*th taxa to the dissimilarity between groups of samples.

Several commonly used measures of taxa richness and diversity were calculated to assist in comparing changes in biological assemblages with an increase in sampling intensity or between different sampling methods. Total individuals collected and total taxa collected were computed for each sample. Margalef's richness index (d), defined as

$$d = (S-1)\ln N, \qquad (5)$$

where

S = the number of taxa, and
N = the number of individuals,

standardizes the number of taxa collected against the total number of individuals collected to give a relative measure of taxa richness (Zar, 1998). Shannon's diversity index (H'), defined as

$$H' = -\sum_{i=1}^{S} p_i \log_e p_i, \qquad (6)$$

where

S = the number of taxa, and
p_i = the proportion of observations in taxa i,

is based on information theory and provides information on the degree of heterogeneity in a community (Zar, 1998). Peilou's evenness index (J'), defined as

$$J' = H' / H'_{max}, \qquad (7)$$

where

H'_{max} = the maximum possible value of Shannon's diversity index,

provides an indication of how evenly the individuals in the community are distributed among the different taxa (Zar, 1998).

Nonparametric summary statistics (medians and 25th and 75th percentiles) were used to describe differences in stream-habitat variables among reaches. Kruskal-Wallis multiple comparison tests were used to compare medians of stream-habitat variables among reaches to indicate significant differences. All statistical analyses of stream-habitat data were done using Statistica Version 7 (StatSoft, 2006).

Biotic Assemblages

Benthic Macroinvertebrates

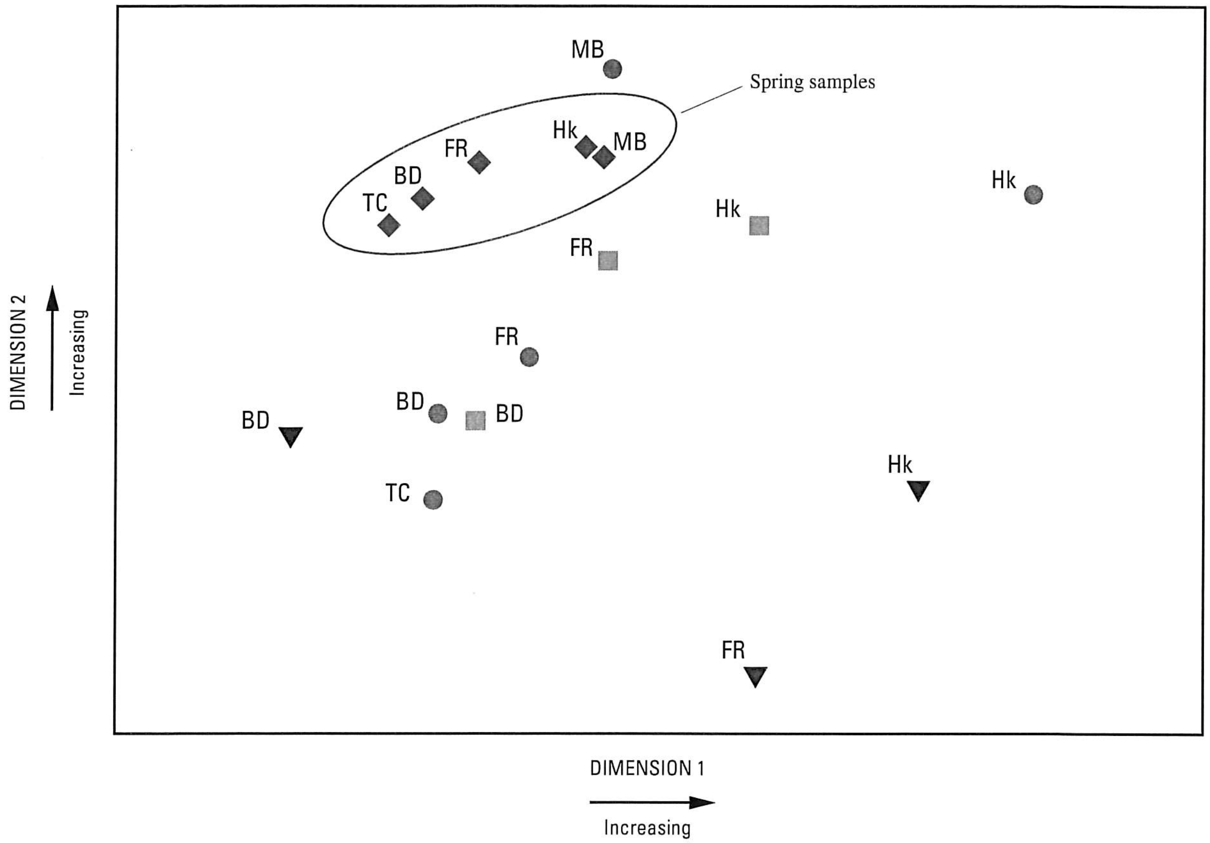
Sixteen benthic macroinvertebrate samples were collected in Highland Bayou and Marchand Bayou in spring and summer 2007 (table 3). Mean depths for standard Ekman samples ranged from 0.67 to 1.14 meters; depths for the deepwater and the nearshore locations ranged from 1.37 to 1.68 meters and 0.30 to 0.53 meter, respectively. The amount of organic debris collected in dredge samples generally was higher in the upper reaches of Highland Bayou (Hitchcock and Fairwood), although the Marchand Bayou samples contained little organic debris. The deepwater samples consistently contained relatively little organic debris, and the nearshore samples generally contained relatively medium-to-high amounts of organic debris.

Influence of Seasons and Reaches

The separation between spring and summer standard samples in the MDS plot of the combined genus level benthic macroinvertebrate data indicates that there are taxonomic differences between the spring and summer samples (fig. 2). The apparent differences are confirmed by an ANOSIM test comparing the replicates from the spring and summer standard samples (Global R = .436, p-value = .0001). The distribution of samples on the plot indicates that the similarity between reaches in the spring was (1) much higher than the similarity in the summer and (2) generally higher than the similarity between different sampling locations within the same reach in the summer.

In the standard samples, benthic macroinvertebrate taxa richness and abundance were considerably larger in the spring than in the summer (table 4). The single exception was Bayou Dr; there, although abundance was much higher in the spring, taxa richness was slightly smaller in the spring.

The major taxonomic groups that account for the dissimilarity between spring and summer samples, identified by the SIMPER analysis, are the Dipteran insect family Chironomidae (non-biting midges), and the annelid worm class Polychaeta (polychaete worms). Chironomids of the genera *Chironomus* and *Tanypus* were found in 100 percent of the spring samples and averaged 303 and 116 individuals per sample, respectively (appendix 1). In the summer samples, the genus *Chironomus* was found in 18 percent of samples and averaged four individuals per sample, whereas the genus *Tanypus* was found in 64 percent of samples and averaged five individuals per sample. Another chironimid genus, *Dicrotendipes*, was relatively abundant in the uppermost reach of Highland Bayou (Hitchcock) and Marchand in the spring samples (average of 44 individuals per sample) and greatly reduced in the summer samples (average of 1.5 individuals per sample). Two species of polychaetes, *Streblospio benedicti* and *Amphicteis floridus*, also were found in 100 percent of the spring samples with an average number of individuals per sample of 93 and 62, respectively. Summer sampling yielded *Streblospio benedicti* and *Amphicteis floridus* in only 64 percent of samples with an average number of individuals per sample of 11 and six, respectively. Although the chironomids and polychaetes were the dominate contributors to dissimilarity, other organisms were important at specific reaches. The



EXPLANATION

Sample

- ▼ Summer deep water sample (SuDW)
- ■ Summer nearshore sample (SuNS)
- ◆ Spring standard sample (SpS)
- ● Summer standard sample (SuS)

Reach

TC	08077780 (Highland Bayou nr Texas City)
BD	08077738 (Highland Bayou at Bayou Drive)
FR	08077725 (Highland Bayou at Fairwood Road)
MB	08077720 (Marchand Bayou at FM 519)
Hk	08077700 (Highland Bayou at Hitchcock)

Dimensions and units are arbitrary. Samples close to one another are more similar in taxonomic composition than samples farther away from one another.

Figure 2. Multidimensional scaling plot of benthic macroinvertebrate community data for Highland and Marchand Bayous, Galveston County, Texas, spring and summer 2007.

largest contributor to dissimilarity between seasons at the Texas City reach was the amphipod genus Ampelisca, which composed 54 percent of the spring sample and only 6 percent of the summer sample. At Marchand, a species of bivalve *Mytilopsis leucophaeata* composed 23 percent of the spring sample but was absent from the summer sample. Also at Marchand, the mayfly genus *Caenis* composed only 2 percent of the spring sample but 30 percent of the summer sample.

Although the spring and summer datasets are taxonomically dissimilar, both datasets indicate a gradient in the benthic macroinvertebrate community associated with reaches (fig. 2) that is likely caused by increases in salinity with downstream distance toward Jones Bay (fig. 1). The lowermost reaches, Texas City and Bayou Dr, where salinity generally is highest, are on the left side of the plot and have benthic macroinvertebrate communities dominated by highly tolerant freshwater organisms such as the chironomids *Chironomus* and *Tanypus* as well as common estuarine organisms such as amphipods, isopods, Nemertea (ribbon worms), and polychaetes. The uppermost reaches, Hitchcock and Marchand, where salinity generally is lower, are on the right side of the plot and are characterized by more diverse chironomid communities, a

Table 3. Summary of benthic macroinvertebrate sampling from Highland and Marchand Bayous, Galveston County, Texas, spring and summer 2007.

[SpS, spring standard; SuS, summer standard; SuDW, summer deepwater; SuNS, summer nearshore]

Reach short name (table 1)	Date	Sample type	Sample location	Mean depth (meters)
		Spring		
Hitchcock	03/27/2007	SpS	Mid-channel	0.91
Marchand	03/27/2007	SpS	Mid-channel	.76
Fairwood	03/27/2007	SpS	Mid-channel	.91
Bayou Dr	03/26/2007	SpS	Mid-channel	1.14
Texas City	03/26/2007	SpS	Mid-channel	.67
		Summer		
Hitchcock	07/09/2007	SuS	Mid-channel	.84
Hitchcock	07/09/2007	SuDW	Deepwater	1.37
Hitchcock	07/09/2007	SuNS	Nearshore	.30
Marchand	08/14/2007	SuS	Mid-channel	1.07
Fairwood	07/10/2007	SuS	Mid-channel	1.14
Fairwood	07/10/2007	SuDW	Deepwater	1.68
Fairwood	07/10/2007	SuNS	Nearshore	.53
Bayou Dr	07/10/2007	SuS	Mid-channel	.99
Bayou Dr	07/10/2007	SuDW	Deepwater	1.37
Bayou Dr	07/10/2007	SuNS	Nearshore	.37
Texas City	08/13/2007	SuS	Mid-channel	.76

general absence of amphipods, isopods, and Nemertea, and the presence of freshwater organisms such as Oribatei (water mites) and *Caenis* mayflies. The middle reach, Fairwood, is in the middle of the plot and contained a mixture of taxa from the upper and lower reaches.

The taxa identified in this report are similar to taxa in other tidal freshwater systems. Odum (1988) reports that benthic invertebrate communities in tidal freshwater marshes (salinities less than 0.5 ‰) on the East Coast generally are dominated by chironomid larvae, oligocheate worms, freshwater snails, and some amphipods. The more saline zones (salinities between 18.0 and 35.0 ‰) generally are dominated by polychaetes, crustaceans (for example, isopods, amphipods, and crabs), and bivalves (Odum, 1988).

The seasonal variation in the benthic macroinvertebrate community documented in this report (decreases in taxa richness and individual taxa abundance from spring to summer) is similar to seasonal variation reported by other researchers (LaSalle and Bishop, 1987; Livingston, 1987; Crumb, 1997). LaSalle and Bishop (1987) reported that benthic macroinvertebrates in tidal marshes in Mississippi peaked in abundance in the spring and declined to seasonal lows in the summer after the metamorphosis and emergence of adults. Crumb (1997), on the basis of work in the tidal segment of the Delaware River, reported a similar seasonal pattern in oligocheate worms (Tubificidae) that do not undergo metamorphosis and attributed the pattern to a temperature-mediated reproductive pattern where large numbers of juveniles were present in the spring. In contrast, researchers studying Guadalupe Bay on the Texas Coast in Calhoun County (about 200 kilometers southwest of the study area) found a sharp decrease in benthic macroinvertebrate densities at a tidal freshwater station in July, but they attributed the decrease to a large inflow event rather than a seasonal pattern (Montagna and Kalke, 1992).

Rainfall occurred before the summer sampling event in the study reported here, which likely increased streamflow in Highland and Marchand Bayous. However, data collected for this report are not sufficient for determining whether the observed variation in the benthic macroinvertebrate community is the result of high flows, seasonal factors, or other factors.

Influence of Sampling Locations

Benthic macroinvertebrate communities in the three reaches at which multiple samples were collected (Hitchcock, Fairwood, and Bayou Dr) differed among the three within-reach sampling locations (standard, deepwater, and nearshore).

Table 4. Summary of richness and diversity metrics for benthic macroinvertebrate samples from Highland and Marchand Bayous, Galveston County, Texas, spring and summer 2007.

[SpS, spring standard; SuS, summer standard; SuDW, summer deepwater; SuNS, summer nearshore]

Reach short name (table 1)	Sample type	Taxa richness	Abundance	Margalef's richness	Pielou's evenness	Shannon's diversity
			Spring			
Hitchcock	SpS	20	703	2.90	0.401	1.200
Marchand	SpS	25	598	3.75	.728	2.344
Fairwood	SpS	20	928	2.78	.584	1.750
Bayou Dr	SpS	11	968	1.45	.394	.944
Texas City	SpS	18	1,068	2.44	.528	1.525
			Summer			
Hitchcock	SuS	5	16	1.44	.865	1.392
Hitchcock	SuDW	6	7	2.57	.976	1.748
Hitchcock	SuNS	15	140	2.83	.764	2.068
Marchand	SuS	23	201	4.15	.736	2.309
Fairwood	SuS	11	123	2.08	.757	1.816
Fairwood	SuDW	6	7	2.57	.976	1.748
Fairwood	SuNS	16	298	2.63	.658	1.824
Bayou Dr	SuS	13	73	2.80	.866	2.222
Bayou Dr	SuDW	5	24	1.26	.490	.789
Bayou Dr	SuNS	12	66	2.63	.844	2.096
Texas City	SuS	10	33	2.57	.845	1.946

Global ANOSIM tests indicated that taxonomic differences among the three sampling locations were statistically significant at the .05 level at all reaches (table 5). Pairwise results, however, were not consistent across all reaches. All three sampling locations were significantly different from each other only at the most downstream multisample reach (Bayou Dr). The Bayou Dr reach also yielded the highest Global R value (.847), indicating that many of the replicates from each sampling location (for example, nearshore) are more similar to each other than to any replicates from other sampling locations. Standard samples and deepwater samples from the Hitchcock reach were not significantly different largely because of the very low numbers of benthic macroinvertebrates collected in these samples.

The summer benthic macroinvertebrate samples from different locations showed strong differences in taxa richness, abundance, and diversity (table 4). Values for taxa richness and abundance were smallest in the deepwater samples. In contrast, two of the three multisample reaches (Hitchcock and Fairwood) had the largest values for these variables in the nearshore samples. Values for taxa richness and abundance were largest in the standard sampling location only at the most downstream of the three multisample reaches (Bayou Dr).

Values for Margalef's richness and Shannon's diversity (table 4) varied as those of taxa richness and were largest for the reaches where taxa richness was largest—that is, at the nearshore sampling locations at Hitchcock and Fairwood and at the standard sampling location at Bayou Dr. Values for Pielou's evenness for the Bayou Dr reach also varied similar to values of taxa richness and were largest for the standard sampling location. The deepwater samples from the two upper reaches, however, contained few taxa with most represented by a single individual (appendix 1). As a result, Pielou's evenness at these reaches was largest for the deepwater samples (table 4).

Patterns in taxa distribution were evident between summer sampling locations. The nearshore sites tended to have a larger diversity of chironomids and larger numbers of annelid worms (polychaetes and oligocheates) (appendix 1). Arthropods showed no clear pattern but were the most diverse and abundant at the primary sampling location at the most downstream multisample reach (Bayou Dr).

Although determining the reasons for observed differences in community composition among sampling locations was beyond the scope of this study, noting the differences among sampling locations might provide insight into the observed community patterns: The nearshore sampling locations were (1) close to emergent vegetation and woody debris, (2) close to the surface where water movement and diffusion likely increase dissolved oxygen, and (3) characterized by

Table 5. Global and pairwise results for Analysis of Similarities (ANOSIM) tests comparing the taxonomic structure of benthic macroinvertebrate communities from three different within-reach sampling locations in three separate reaches on Highland Bayou, Galveston County, Texas, summer 2007.

[R, ANOSIM test statistic; p, p-value; S, standard sample; DW, deepwater sample; NS, nearshore sample]

Highland Bayou at Hitchcock			Highland Bayou at Fairwood			Highland Bayou at Bayou Dr		
Statistical test	**R**	**p**	**Statistical test**	**R**	**p**	**Statistical test**	**R**	**p**
Global test	.299	.003	Global test	.316	.002	Global test	.847	.001
Pairwise tests			Pairwise tests			Pairwise tests		
S, DW	.26	.114	S, DW	.375	.029	S, DW	.969	.029
S, NS	.552	.029	S, NS	.198	.171	S, NS	.781	.029
DW, NS	.281	.029	DW, NS	.339	.057	DW, NS	.948	.029

a firmer and less anoxic mud substrate compared to that of the deepwater and standard sampling locations. Greater taxa diversity in the nearshore samples might be a result of one or all of those factors, or other factors.

Fish

Fish-community samples were collected at the four Highland Bayou reaches and the Marchand Bayou reach in spring and summer 2007 (table 6). In standard samples, 4,980 individuals representing 29 taxa were collected (appendix 2). In standard and nonstandard samples, electrofishing accounted for 1,991 individuals and 21 taxa (appendix 3), and seining accounted for 3,928 individuals and 21 taxa (appendix 4).

Influence of Seasons and Reaches

The grouping of standard samples in the MDS plot of species-level fish data indicates no consistent seasonal difference in fish taxa across reaches (fig. 3). Results of an ANOSIM test comparing the standard spring catch with the standard summer catch (Global R = .13, p-value = .168) supports this conclusion. The MDS plot does, however, indicate that the spring standard samples in the two upper reaches (Hitchcock and Marchand) are more similar to each other than to their corresponding summer standard samples. The summer dissimilarity between these two reaches, as indicated by the SIMPER analysis, primarily is because of the abundance of juvenile *Brevoortia* sp. collected at Hitchcock in the summer and the absence of this genus from the Marchand collection.

The SIMPER analysis also indicated that the spring-to-summer changes in abundance of one species, *Leiostomus xanthurus*, were consistent across standard samples. *Leiostomus xanthurus* accounted for 17.9 percent of the standard fish collection across all reaches in the spring, but only 0.35 percent of the summer standard collection (appendix 2). Spring-to-summer changes in the upper reaches generally involved an increase in the abundance of freshwater taxa such as *Micropterus salmoides* and most sunfish species (*Lepomis macrochirus*, *Lepomis megalotis*, and *Lepomis gulosus*) and a decrease in the abundance of some euryhaline taxa such as *Menidia beryllina*, *Mugil cephalus*, and *Brevoortia* sp. The Hitchcock reach was a notable exception where juveniles of the euryhaline genus *Brevoortia* sp. accounted for 86 percent of the total fish catch in the summer. Spring-to-summer changes in the lower reaches involved a general decrease in abundance of most of the common euryhaline species with the exception of *Menidia beryllina*, which increased by 127 percent at the Bayou Dr reach and 1,625 percent at the Texas City reach.

The lack of fish-sample replication within a given sampling period did not allow statistically valid ANOSIM tests to be done on the fish communities at individual reaches between seasons. However, the amount of separation between spring and summer standard samples in the MDS plot (fig. 3) at some reaches indicates that some seasonal taxa differences were locally important. The amount of separation between the Marchand standard samples is caused by spring-to-summer decreases in abundance of 92 percent of the euryhaline taxa and increases in abundance of 100 percent of the freshwater taxa (appendix 2). In the Fairwood reach, the abundance of three tolerant euryhaline taxa, *Poecilia latipinna*, *Gambusia affinis*, and *Cyprinodon variegatus*, increased from spring to summer by 3,117, 6,100, and 600 percent, respectively. Five taxa not found at Fairwood in the spring were captured there in the summer; these taxa comprised three other euryhaline taxa (*Lucania parva*, *Fundulus pulvereus*, and *Microgobius gulosus*) and two freshwater taxa (*Micropterus salmoides* and *Lepomis macrochirus*). Salinities in the upper reaches of Highland Bayou measured during the study were lowest in July and might account for the increased presence of freshwater taxa in the July samples.

The MDS plot of the species-level fish data (fig. 3) indicates a fish-community gradient in Highland Bayou. The two lower reaches of Highland Bayou (Bayou Dr and Texas City) are in the lower middle of the plot, whereas the higher reaches (Hitchcock and Marchand) grade into the upper right of the

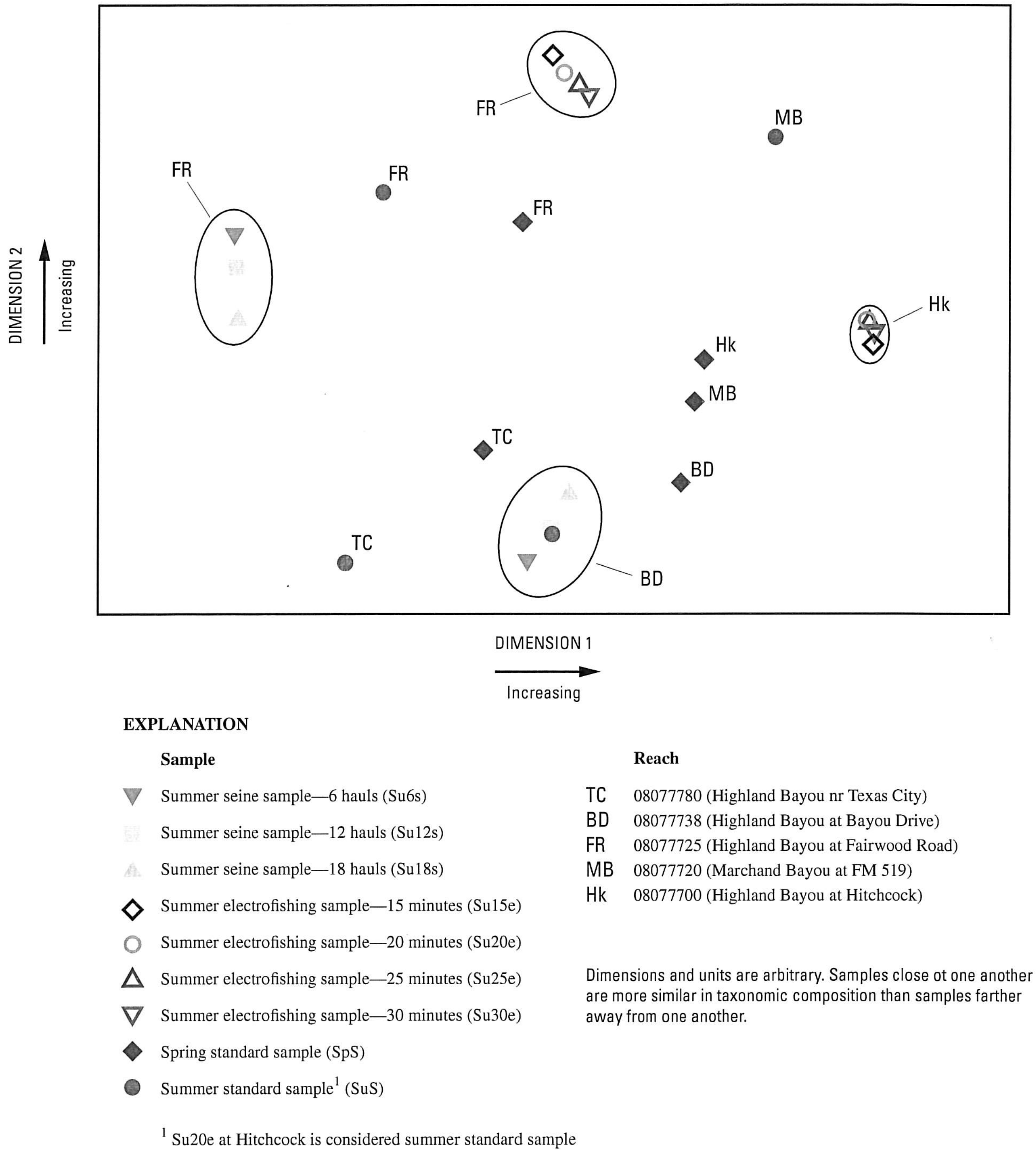


Figure 3. Multidimensional scaling plot of fish-community data for Highland and Marchand Bayous, Galveston County, Texas, spring and summer 2007.

plot. The ANOSIM test comparing fish catch in the standard samples supports the conclusion that the fish communities at the different reaches of Highland Bayou are different from one another (Global R = .53, p-value = .007). The gradient in the MDS plot primarily is related to the lack of freshwater taxa in the lower reaches of Highland Bayou and a mix of euryhaline and freshwater taxa in the upper reaches of Highland and Marchand Bayous. Samples from the middle reach (Fairwood) are above this gradient, to the left, on the MDS plot. The SIMPER analysis indicated that the separation of the Fairwood samples is because of a decreased abundance in the Fairwood samples of some euryhaline taxa found in the lower reaches

Table 6. Summary of fish-community sampling from Highland and Marchand Bayous, Galveston County, Texas, spring and summer 2007.

[SpS, spring standard; E, electrofishing; S, seining; Suxe, summer nonstandard and x minutes of electrofishing; SuS, summer standard; Suxs, summer nonstandard and x seine hauls]

Reach short name (table 1)	Date	Sample type	Meth-od	Sample intensity
		Spring		
Hitchcock	03/27/2007	SpS	E	Standard
Marchand	03/28/2007	SpS	S/E	Standard
Fairwood	03/27/2007	SpS	S/E	Standard
Bayou Dr	03/26/2007	SpS	S	Standard
Texas City	03/26/2007	SpS	S	Standard
		Summer		
Hitchcock	07/11/2007	Su15e	E	15 minutes
Hitchcock	07/11/2007	Su20e/SuS[1]	E	20 minutes
Hitchcock	07/11/2007	Su25e	E	25 minutes
Hitchcock	07/11/2007	Su30e	E	30 minutes
Marchand	08/13/2007	SuS	S/E	Standard
Fairwood	07/12/2007	SuS	S/E	Standard
Fairwood	07/12/2007	Su6s	S	6 hauls
Fairwood	07/12/2007	Su12s	S	12 hauls
Fairwood	07/12/2007	Su18s	S	18 hauls
Fairwood	07/12/2007	Su15e	E	15 minutes
Fairwood	07/12/2007	Su20e	E	20 minutes
Fairwood	07/12/2007	Su25e	E	25 minutes
Fairwood	07/12/2007	Su30e	E	30 minutes
Bayou Dr.	07/11/2007	SuS	S	Standard
Bayou Dr.	07/11/2007	Su6s	S	6 hauls
Bayou Dr.	07/11/2007	Su12s	S	12 hauls
Bayou Dr.	07/11/2007	Su18s	S	18 hauls
Texas City	08/13/2007	SuS	S	Standard

[1]Summer standard sample consists of first 20 minutes of electrofishing.

(*Menidia beryllina*, *Anchoa mitchilli*, and *Brevoortia* sp.) and a decreased abundance or absence in the Fairwood samples of some of the freshwater taxa found in the upper reaches (*Lepomis macrochirus*, *Lepomis megalotis*, and *Lepomis gulosus*). In addition, the summer sample at the Fairwood reach contained an abundance of several tolerant euryhaline taxa such as *Poecilia latipinna*, *Cyprinodon variegatus*, and *Gambusia affinis* that are only found in low numbers at the other reaches. Although comparison of community assemblages to environmental variables was not done for this report, the gradient in the fish community likely is caused by changes in salinity. Fish communities structured by salinity levels are common in estuarine environments (Hackney and others, 1976; Bulger and others, 1993) and have been documented on the Texas coast (Gelwick and others, 2001).

Apparent differences in fish communities might be related to the different methods of fish capture used in the reaches. The lower reaches of Highland Bayou were sampled by seining, and the upper reaches were sampled by electrofishing or a combination of electrofishing and seining. Samples collected using different capture methods are not strictly comparable. Although it seems intuitive that the salinity gradient in Highland Bayou would produce a concurrent gradient in the fish community based on salinity tolerance, confounding effects of different capture methods on results is a possibility.

Influence of Sampling Intensity

Increased seining intensity at the multisample reaches (Hitchcock, Fairwood, and Bayou Dr) did not result in a statistically significant difference in fish communities. The ANOSIM analysis indicated no significant differences in fish communities between samples of 6, 12, and 18 seine hauls at either Fairwood (Global R = -.02, p-value = .566) or Bayou Dr (Global R = -.03, p-value = .639) (table 7).

Increased seining for fish resulted in some changes in taxa richness and community diversity metrics (table 8). The largest changes were at the Bayou Dr reach where an increase from six seine hauls to 12 seine hauls added an additional eight taxa and increased taxa richness by 114 percent and Margalef's richness by 111 percent. Community diversity as measured by Shannon's diversity index was minimally affected by this taxa increase, but Pielou's evenness decreased by 28 percent. Shannon's diversity index was stable because none of the new taxa were collected in great numbers, and the numerically dominate taxa continued to be collected in abundance. The decrease in Pielou's evenness can be attributed to the increased collection of juvenile *Brevoortia* sp., which constituted the majority of the catch at one sampling location. An increase in the seining intensity at Bayou Dr from 12 seine

Table 7. Global results for Analysis of Similarities (ANOSIM) tests comparing the taxonomic structure of fish communities collected with different levels of seining intensity at three different within-reach locations in two separate reaches on Highland Bayou, Galveston County, Texas, summer 2007.

[R, ANOSIM test statistic; p, p-value]

Highland Bayou at Fairwood			Highland Bayou at Bayou Dr		
Statistical test	R	p	Statistical test	R	p
		Seining intensity			
Global test	-.02	.566	Global test	-.03	.639
		Seining location			
Global test	.46	.001	Global test	.26	.007

Table 8. Summary of taxa richness and community diversity metrics for fish samples from Highland and Marchand Bayous, Galveston County, Texas, spring and summer 2007.

[SpS, spring standard; Suxe, summer nonstandard and x minutes of electrofishing; SuS, summer standard; Suxs, summer nonstandard and x seine hauls]

Reach short name (table 1)	Sample type	Taxa richness	Abundance	Margalef's richness	Pielou's evenness	Shannon's diversity index
			Spring			
Hitchcock	SpS	15	666	2.15	0.39	1.06
Marchand	SpS	12	430	1.81	.50	1.24
Fairwood Rd	SpS	10	244	1.64	.43	.99
Bayou Dr	SpS	6	1,286	.70	.53	.96
Texas City	SpS	9	285	1.42	.66	1.45
			Summer			
Hitchcock	Su15e	9	789	1.20	.20	.45
Hitchcock	Su20e/SuS[1]	11	833	1.49	.26	.62
Hitchcock	Su25e	11	862	1.48	.28	.68
Hitchcock	Su30e	11	905	1.47	.31	.74
Marchand	SuS	12	88	2.46	.80	1.98
Fairwood	SuS	14	419	2.15	.69	1.82
Fairwood	Su6s	12	326	1.90	.55	1.38
Fairwood	Su12s	12	467	1.79	.61	1.51
Fairwood	Su18s	13	642	1.86	.62	1.59
Fairwood	Su15e	6	52	1.27	.70	1.26
Fairwood	Su20e	9	66	1.91	.70	1.53
Fairwood	Su25e	9	80	1.83	.67	1.47
Fairwood	Su30e	9	93	1.77	.67	1.48
Bayou Dr	SuS	13	572	1.89	.48	1.24
Bayou Dr	Su6s	7	354	1.02	.64	1.25
Bayou Dr	Su12s	15	683	2.15	.46	1.26
Bayou Dr	Su18s	16	1,097	2.14	.47	1.30
Texas City	SuS	6	184	.96	.47	.84

[1] Summer standard sample consists of first 20 minutes of electrofishing.

hauls to 18 seine hauls added one additional taxon but only resulted in marginal changes to the calculated metrics.

Increased seining intensity at the Fairwood reach generally resulted in increased values for calculated metrics but changes were marginal. The first set of six seine hauls collected 12 of the 13 taxa found at the reach. Shannon's diversity index for six seine hauls increased 15 percent for 18 seine hauls (table 8). Margalef's richness for six seine hauls actually decreased 5.8 percent for 12 seine hauls because the additional seining increased taxa abundance without adding additional taxa. The increased taxa abundance associated with the additional seine hauls at the Fairwood reach decreased the cumulative dominance of the two most abundant taxa.

ANOSIM tests indicated significant differences in fish communities among the three within-reach sampling locations at Fairwood (Global R = .46, p-value = .001) and Bayou Dr (Global R = .26, p-value = .007) (table 7). The SIMPER analysis indicated most of the dissimilarity among sampling locations at both reaches was accounted for by differences in the abundance of common taxa. For example, at the Bayou Dr reach, *Brevoortia* sp. was either sparse or not found at the first and second sampling locations but composed 67 percent of the catch at the third sampling location (appendix 4). Taxa accounting for dissimilarities among sampling locations at Fairwood included *Poecilia latipinna*, *Cyprinodon variegatus*, and *Gambusia affinis*.

The lack of valid replicates within the different levels of electrofishing intensity make ANOSIM tests invalid; therefore changes in fish-community data between levels of electrofishing intensity were analyzed only by comparing the values of metrics. Diversity increases associated with increased electrofishing intensity were relatively consistent across the two multisample electrofishing reaches (Hitchcock and Fairwood). Total taxa richness, Margalef's richness, and Shannon's diversity index for both reaches increased with an increase in electrofishing time from 15 minutes to 20 minutes. The 5-minute increase in electrofishing time at the Hitchcock reach increased taxa richness by 22 percent (table 8) and added one sunfish (*Lepomis microlophus*) and one livebearer (*Poecilia latipinna*) (appendix 3). Taxa richness at the

Fairwood reach was increased 50 percent and contributed two important game species (*Micropterus salmoides* and Sciaenops ocellatus) to the taxa list. The 5-minute increase in electrofishing time increased Shannon's diversity index 38 percent at the Hitchcock reach and 21 percent at the Fairwood reach. Pielou's evenness was increased 30 percent at the Hitchcock reach but was unchanged at the Fairwood reach. Additional electrofishing at Hitchcock tended to increase the abundance of all taxa, whereas additional electrofishing at Fairwood tended to increase the abundance of only the most abundant taxa. Additional sampling beyond 20 minutes added no new taxa and produced only small changes in diversity metrics, which were related to changes in taxa abundance.

Stream-Habitat Data

The analysis of stream-habitat data from summer 2007 emphasized a comparison among reaches of transect-derived habitat data and the effects of increased sampling intensity on the stream-habitat variables, particularly on the HQI. Stream-habitat data collected for this report are in appendix 5, and HQI data calculated for this report are in appendix 6.

Physical Characteristics

The Marchand reach is the smallest in terms of length and stream width, and the Texas City reach is the largest (table 9). Median stream width of the Marchand reach was significantly smaller than that of the downstream Bayou Dr and Texas City reaches (fig. 4). Median stream depth was relatively uniform among the five reaches, ranging from 0.87 meter at the Texas City reach to 2.22 meters at the Fairwood reach (table 9). Median bank slope of the Marchand reach was several times larger than that of the Hitchcock, Bayou Dr, and Texas City reaches, and median percentage bank erosion at the Marchand reach was higher than that at the Hitchcock and Texas City reaches. Surficial streambed substrate was dominated by silt or clay at all reaches (table 9). Clay was the dominant bed material at the Marchand Bayou reach, and silt was dominant at the other four reaches. Instream cover was low (quartile values 0–10 percent) at all reaches and generally higher at the upstream reaches, which were characterized by more woody debris, emergent and submergent vegetation, and other instream structure.

Differences in the physical characteristics of the Highland and Marchand Bayou reaches are largely the result of the differences in channel gradient and position in the drainage network or watershed of each reach. The relatively high-gradient upstream reaches (Hitchcock and Marchand), characterized by narrower channels, steeper banks, and greater bank erosion than the downstream Bayou Dr and Texas City reaches are relatively more riverine; the relatively low-gradient downstream reaches, characterized by wider channels, more gently sloping banks, and smaller bank erosion, are relatively more estuarine.

Riparian/Bank Vegetation

Tree canopy over a stream channel can moderate or lower water temperature and reduce primary productivity (Platts and others, 1987). At the Marchand reach, tree canopy was greater than 50 percent; at all other reaches, it was less than 20 percent (fig. 4, table 9). The large difference between Marchand and the other reaches likely is primarily related to the relatively narrow Marchand Bayou channel width. No riparian trees were observed adjacent to the five transects at either the Bayou Dr or Texas City reaches. The median percentage of riparian trees was significantly different only between the Hitchcock and Bayou Dr reaches. The median percentage of riparian trees was 10 and 15 percent at the Hitchcock and Marchand reaches, respectively.

Riparian vegetation at the more downstream Fairwood, Bayou Dr, and Texas City reaches was dominated by less-woody and more-herbaceous shrubs, and grasses and forbs, than at the more upstream Hitchcock and Marchand reaches. Grasses and forbs accounted for 35 and 93 percent of riparian vegetation at the Bayou Dr and Texas City reaches, respectively. The median percentage of grasses and forbs was significantly different only between the Marchand and Texas City reaches (fig. 4).

The width and composition of the natural buffer of riparian vegetation adjacent to a stream channel can influence the rate, volume, and quality of runoff that reaches the channel during a rain event. Carbon in the form of throughfall such as leaves and small, particulate organics, and overhanging and in-channel vegetation can influence stream temperature and provide habitat for aquatic biota (Wente, 2000). The median width of the natural buffer of riparian vegetation varied from 3.4 meters at the Texas City reach to 91.4 meters at the Bayou Dr reach (table 9). The width of the vegetation buffer was variable among all reaches, particularly the more upstream Hitchcock, Marchand, and Fairwood reaches, and the median was significantly different only between the Bayou Dr and Texas City reaches (fig. 4). The variability in buffer width appeared to be more related to the extent of anthropogenic development in the riparian zone rather than to natural changes in the riparian buffer.

Four additional transects per reach were sampled for habitat variables at multisample reaches Hitchcock, Fairwood, and Bayou Dr, the same reaches where additional benthic macroinvertebrate and fish samples were collected. Habitat variable medians were computed for sample sizes of seven and nine transects per reach, in addition to the standard five transects per reach (table 10). Medians changed for the majority of habitat variables with the addition of two and four transects, although none of the differences in medians were statistically significant based on results of Kruskal-Wallis tests. The variables most affected by a change in transect sample size were those associated with riparian vegetation. The medians of percentages of trees, shrubs, and grasses and forbs for each of the three reaches varied considerably with transect sample size.

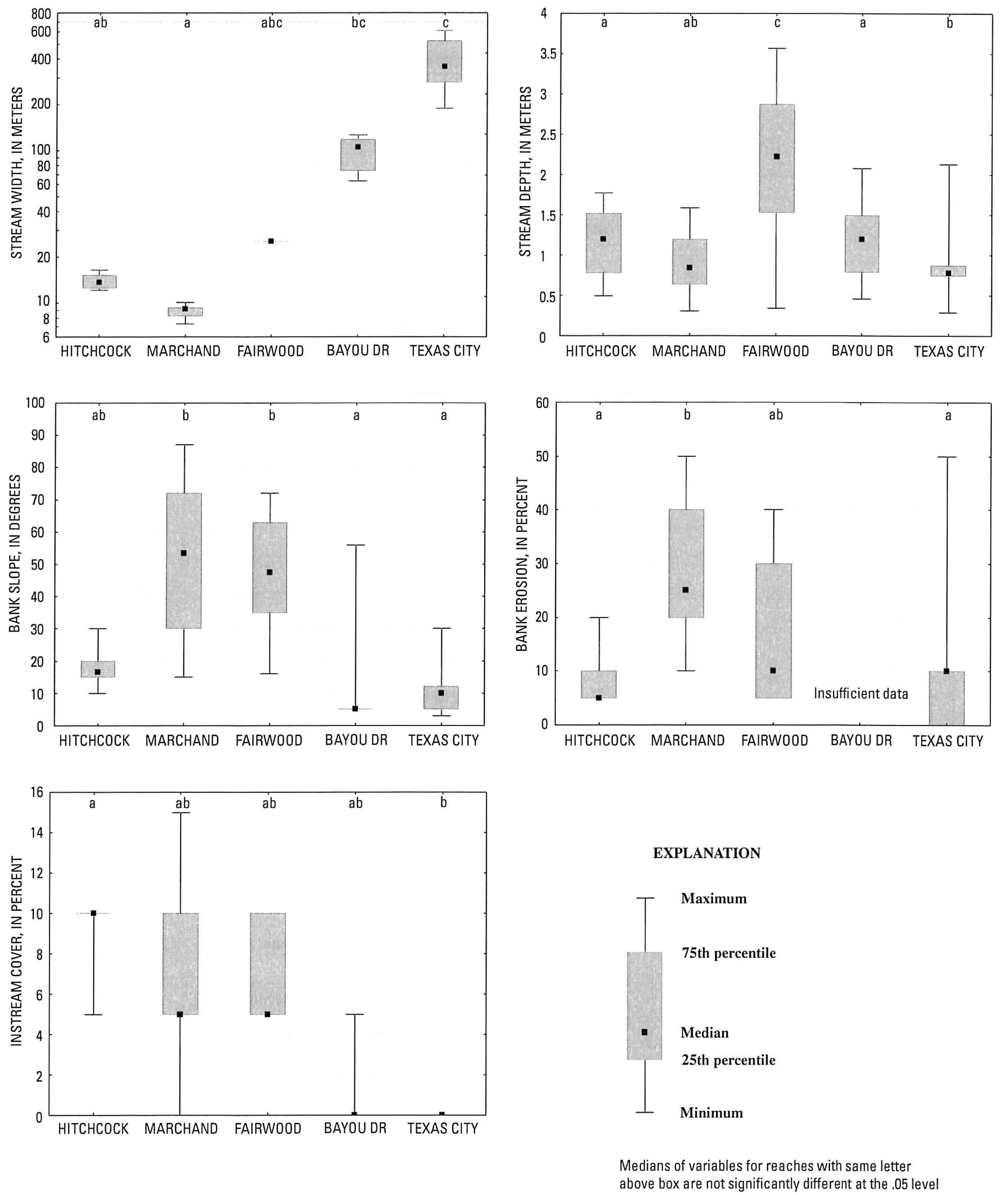


Figure 4. Stream-habitat variables by reach for Highland and Marchand Bayous, Galveston County, Texas, summer 2007.

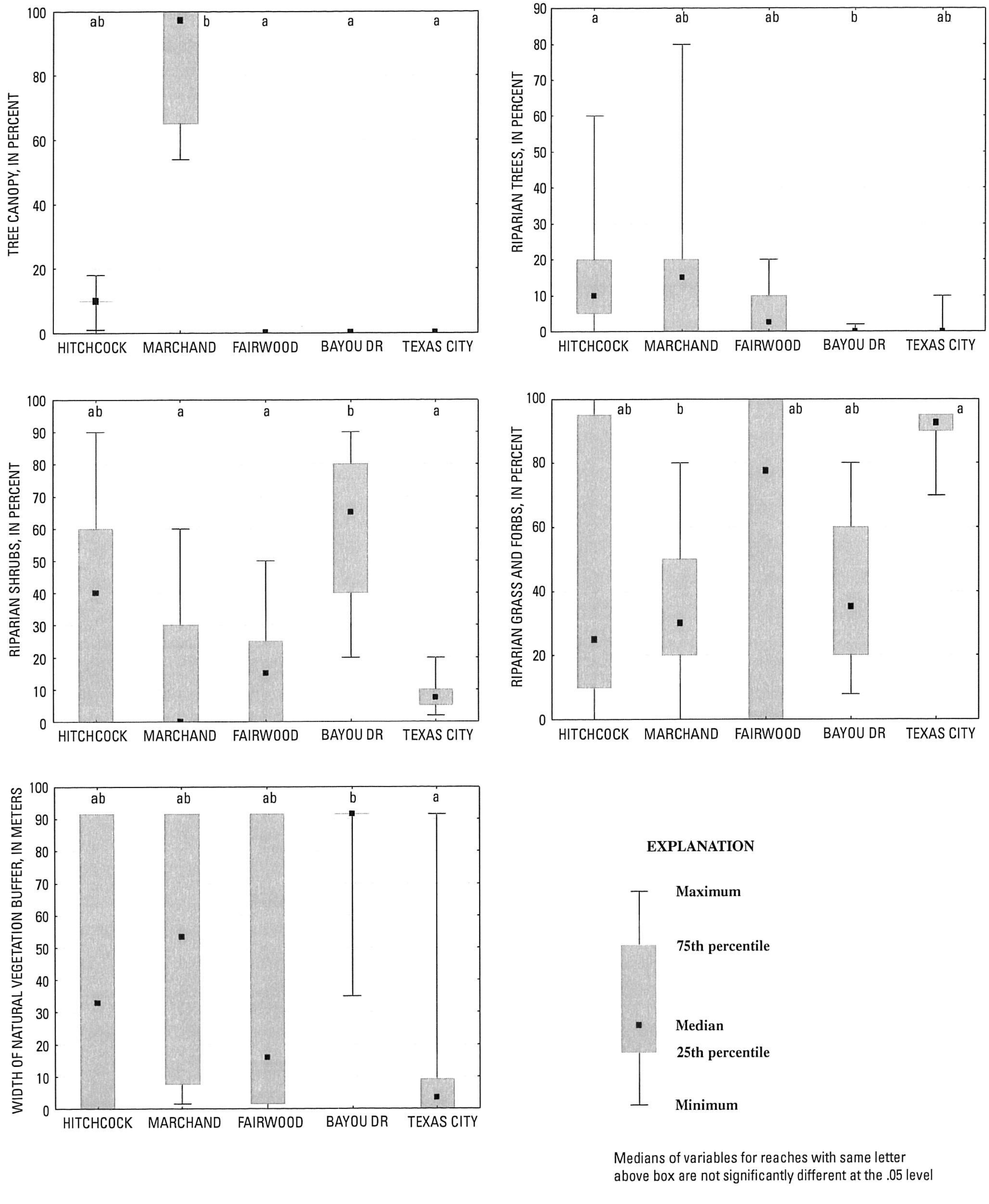


Figure 4.—Continued.

Table 9. Summary statistics for stream-habitat variables from reaches on Highland and Marchand Bayous, Galveston County, Texas, summer 2007.

[M, median (50 percent); 25, lower quartile (25 percent); 75, upper quartile (75 percent); --, insufficient data
Dominant substrate category: 1, clay; 2, silt; 8, other]

Reach short name (table 1)	Reach length (meters)	Quartile	Stream width (meters)	Stream depth (meters)	Bank slope (degrees)	Bank erosion (percent)	Dominant subtrate category	Instream cover (percent)	Tree canopy (percent)	Riparian trees (percent)	Riparian shrubs (percent)	Riparian grasses and forbs (percent)	Width of vegetation buffer (meters)	Habitat Quality Index (HQI)
Hitchcock	490	M	13.7	1.19	17	10	2	10	10	10	40	25	32.8	19
		25	12.5	.78	15	5.0	2	10	10	5.0	0	10	0	
		75	15.2	1.52	20	10	2	10	10	20	60	95	91.4	
Marchand	220	M	9.1	.79	54	25	1	5.0	97	15	0	30	53.3	15
		25	8.2	.58	30	20	1	5.0	65	0	0	20	62.9	
		75	9.3	1.02	72	40	1	10	100	20	30	50	91.4	
Fairwood	470	M	25.3	2.22	48	10	2	5.0	0	2.5	15	78	16.0	15
		25	25.3	1.52	35	5.0	2	5.0	0	0	0	0	1.5	
		75	25.3	2.87	63	30	2	10	0	10	25	100	91.4	
Bayou Dr	540	M	105.5	1.19	5.0	--	2	0	0	0	65	35	91.4	19
		25	73.8	.79	5.0	--	2	0	0	0	40	20	91.4	
		75	118.9	1.49	5.0	--	8	0	0	0	80	60	91.4	
Texas City	640	M	354.2	.87	10	10	2	0	0	0	7.5	93	3.4	15
		25	280.4	.72	5.0	0	2	0	0	0	5.0	90	0	
		75	523.3	.93	12	10	8	0	0	0	10	95	9.1	

Table 10. Medians for stream-habitat variables based on different transect sample sizes at multisample reaches on Highland Bayou, Galveston County, Texas, summer 2007.

[Variable medians for number of transects (sample size n = 5, 7, 9) per reach; --, insufficient data; mean ranks associated with sample sizes of 5, 7 and 9 were not significantly different at the .05 level; dominant substrate categories: 2=silt, 5=cobble, 8=other]

Reach short name (table 1)	Sample size	Stream width (meters)	Stream depth (meters)	Bank slope (degrees)	Bank erosion (percent)	Dominant subtrate category	Instream cover (percent)	Tree canopy (percent)	Riparian trees (percent)	Riparian shrubs (percent)	Riparian grasses and forbs (percent)	Width of vegetation buffer (meters)	Habitat Quality Index (HQI)
Hitchcock	5	13.7	1.19	17	10	2	10	10	40	25	25	32.8	19
	7	13.7	1.18	15	10	2	10	10	10	50	20	107.5	19
	9	13.7	1.22	17	10	2	10	10	10	50	20	37.5	19
Fairwood	5	25.3	2.22	48	5.0	2	5.0	0	2.5	15	78	16.0	15
	7	25.3	2.23	50	18	2	10	0	5.0	23	60	12.5	15
	9	25.3	1.87	41	18	2	10	0	5.0	23	60	12.5	15
Bayou Dr.	5	105.5	1.19	5.0	--	8	0	0	0	35	35	91.4	19
	7	105.5	1.24	5.0	--	2	0	0	0	70	25	300.0	19
	9	105.5	1.01	5.0	--	5	0	0	0	60	40	300.0	19

Habitat Quality Index

The HQI is a dimensionless measure of stream-habitat quality that is based on scoring values for bank and instream habitat variables between 1 and 3 and summing the individual values to yield an HQI score for the reach (Texas Commission on Environmental Quality, 2007). The HQI scores are grouped into four quality categories: limited, intermediate, high, and exceptional based on ranges of scores assigned by TCEQ to each category.

All HQI values for the five reaches (table 9) scored in the intermediate category (scores ranging from 14 through 19). The Hitchcock and Bayou Dr reaches scored 19, and the other three reaches each scored 15. The higher HQI values for the Hitchcock and Bayou Dr reaches resulted from larger scores for bank stability and riparian vegetation that can be attributed to little or no anthropogenic development along these reaches.

In addition to habitat-variable medians, HQIs were computed for sample sizes of seven and nine transects per reach for Hitchcock, Fairwood, and Bayou Dr, as well as the standard five transects per reach (table 10). The addition of two and four transects did not change the HQI score for any of the reaches.

Summary

The tidal zones of rivers and streams are unique environments where freshwater rivers transition into brackish estuarine ecosystems. Many of the conditions that threaten tidally influenced ecosystems such as sedimentation, habitat alteration, and altered freshwater inflow patterns are not strictly water-quality issues. Biological communities are effective assessment tools to help identify probable causes of impairment. However, biological communities in tidal zones generally display a high degree of natural variation, and changes in tidal-zone biological communities associated with anthropogenic effects can be difficult to detect against background variation. Developing suitable criteria for describing anthropogenic changes in tidal streams requires a clear understanding of the natural variation associated with sampling in different locations, at different times of the year, and with different methods or levels of intensity (level of intensity generally refers to number of samples). Accordingly, the U.S. Geological Survey (USGS), in cooperation with the Houston-Galveston Area Council and the Galveston Bay Estuary Program under the authority of the Texas Commission on Environmental Quality (the agency responsible for setting environmental standards for the State of Texas), did a study in 2007 to assess the variation in biotic assemblages (benthic macroinvertebrate and fish communities) and stream-habitat data with sampling strategy and method in tidal segments of Highland Bayou and Marchand Bayou in Galveston County.

Highland and Marchand Bayous flow east-southeastward to the Texas Coast and drain an approximately 100-square-kilometer area. Marchand Bayou is a smaller, shallower tributary that joins Highland Bayou near its mid-point. Benthic macroinvertebrate, fish, and stream-habitat data were collected from four stream sites (reaches) (short names Hitchcock, Fairwood, Bayou Dr, and Texas City) distributed down the length of Highland Bayou and from one reach (short name Marchand) in Marchand Bayou. All five stream reaches were sampled once in spring and once in summer 2007. Additional samples were collected at the Hitchcock, Fairwood, and Bayou Dr reaches during summer 2007 to evaluate variation resulting from sampling intensity and location. Only stream-habitat data from summer 2007 samples were used for this report because the summer 2007 habitat dataset was the most complete.

A 22.9- by 22.9-centimeter (9- by 9-inch) Ekman dredge on a pole was used to sample benthic macroinvertebrates at all reaches. One standard sample following TCEQ protocols was collected from each study reach in spring 2007 and one in summer 2007. Two additional samples were collected in summer 2007 at Hitchcock, Fairwood, and Bayou Dr for evaluation of variation in benthic macroinvertebrate communities associated with sampling location.

Two sampling methods, electrofishing and seining, were used to collect fish-community data. All reaches that were electrofished (Hitchcock, Marchand, Fairwood) were sampled following TCEQ protocols regarding shocking time to obtain standard samples, one in spring 2007 and one in summer 2007. Additional electrofishing was done in summer 2007 at the Hitchcock and Fairwood reaches to assess variation associated with increased sampling intensity. All reaches that were seined (Marchand, Fairwood, Bayou Dr, Texas City) were done following TCEQ protocols regarding number of seine hauls to obtain standard samples, one in spring 2007 and one in summer 2007. Additional seining was done at Fairwood and Bayou Dr to assess variation associated with increased sampling intensity.

Measurements of stream-habitat variables were recorded along five uniformly spaced transects perpendicular to the channel at all reaches, which generally follows TCEQ protocols for the Highland Bayou (non-wadeable) reaches and follows TCEQ protocols for the Marchand (wadeable) reach. Stream-habitat data collection at the Hitchcock, Fairwood, and Bayou Dr reaches included four additional transects, distributed between the five standard transects, to evaluate the potential for changes in computed habitat quality with additional data.

Changes in benthic macroinvertebrate and fish-community structure between seasons, within-reach locations, and sampling intensity were analyzed with a multivariate ordination technique (multidimensional scaling [MDS]) and univariate diversity metrics. Nonparametric summary statistics (medians and 25th and 75th percentiles) were used to describe differences in stream-habitat variables among reaches. Kruskal-Wallis multiple comparison tests were used to compare medians of stream-habitat variables among reaches to indicate significant differences.

The separation between spring and summer standard samples in the MDS plot of the combined genus level benthic macroinvertebrate data indicates that there are taxonomic differences between the spring and summer samples. Seasonal differences in benthic macroinvertebrate communities primarily were related to decreases in the abundance of chironomids and polychaetes in summer samples. Although the spring and summer datasets are dissimilar, both datasets indicate a gradient in the benthic macroinvertebrate community associated with reaches that is likely caused by increases in salinity with downstream distance toward Jones Bay.

Multivariate Analysis of Similarities (ANOSIM) tests of additional summer 2007 benthic macroinvertebrate samples from Hitchcock, Fairwood, and Bayou Dr indicated significant taxonomic differences between the sampling locations at all three reaches. In general, the deepwater samples had the smallest numbers for benthic macroinvertebrate taxa richness and abundance. The nearshore samples had the largest numbers for all sites except Bayou Dr.

The grouping of standard samples in the MDS plot of species-level fish data indicates no consistent seasonal difference in fish taxa across reaches. Increased seining intensity at the multisample reaches (Hitchcock, Fairwood, and Bayou Dr) did not result in a statistically significant difference in fish communities. Increased seining resulted in some changes in taxa richness and community diversity metrics. The largest changes were at the Bayou Dr reach where an increase from six seine hauls to 12 seine hauls added an additional 8 taxa and increased taxa richness by 114 percent and Margalef's richness by 111 percent.

Diversity increases associated with increased electrofishing intensity were relatively consistent across the two multisample electrofishing reaches (Hitchcock and Fairwood). Total taxa richness, Margalef's richness, and Shannon's diversity index for both reaches increased with an increase in electrofishing time from 15 minutes to 20 minutes.

The Marchand reach is the smallest in terms of length and stream width, and the Texas City reach is the largest. Median stream depth was relatively uniform among the five reaches. Median bank slope of the Marchand reach was several times larger than that of the Hitchcock, Bayou Dr, and Texas City reaches, and median percentage bank erosion at the Marchand reach was higher than that at the Hitchcock and Texas City reaches. Surficial streambed substrate was dominated by silt or clay at all reaches. Instream cover was low (quartile values 0–10 percent) at all reaches. Differences in the physical characteristics of the Highland and Marchand Bayou reaches are largely the result of the differences in channel gradient and position in the drainage network or watershed of each reach.

The large difference in tree canopy between Marchand (greater than 50 percent) and the other reaches (all less than 20 percent) likely is primarily related to the relatively narrow Marchand Bayou channel width. No trees were observed on the bank adjacent to the five transects at either the Bayou Dr or Texas City reaches. Riparian vegetation at the more downstream Fairwood, Bayou Dr, and Texas City reaches was dominated by less-woody and more-herbaceous shrubs, and grasses and forbs, than at the more upstream Hitchcock and Marchand reaches. The width of the vegetation buffer was variable among all reaches, particularly the more upstream Hitchcock, Marchand, and Fairwood reaches. The variability in buffer width appeared to be more related to the extent of anthropogenic development in the riparian zone rather than to natural changes in the riparian buffer.

Four additional transects per reach were sampled for habitat variables at Hitchcock, Fairwood, and Bayou Dr. Medians changed for the majority of habitat variables with the addition of two and four transects to the standard five transects, although none of the differences in medians were statistically significant.

All habitat quality index (HQI) values for the five reaches scored in the intermediate category. In addition to habitat-variable medians, HQIs were computed for sample sizes of seven and nine transects per reach, as well as the standard five transects per reach. The addition of two and four transects did not change the HQI score for any of the reaches.

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