Evaluation of the influence of various stream substrates on fish communities within Harris County

December 10, 2008

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Acknowledgements:

We would like to thank the Harris County Flood Control District (HCFCD) for funding this project. We would also like to thank Dr. George Guillen, Dianna Ramirez, Mike Franks, Kelli Haskett, Danielle Crossen, Heather Biggs, Heming Bai and for everyone else that helped collect the samples. I would also like to thank my advisor Dr. George Guillen for his guidance. I also would like to thank Dr. Chunlong Zhang for his review and suggestions during the preparation of my proposal and paper.

Abstract

Increasing residential and commercial development in the Harris County, Texas has resulted in the need for more stream modification projects to reduce potential flooding risks. The Harris County Flood Control District (HCFCD) sponsors flood damage reduction projects throughout Harris County. The HCFCD utilizes various engineering strategies to manage flood waters including the use of various substrates (earth, rip rap, concrete, articulated concrete block, and cobble/plastic) during stream channel modification projects (HCFCD 2006). In order to understand the effects of these various substrates on fish, we conducted a study to evaluate the influences of these substrates under varying stream channel configurations on the distribution and abundance of fish organisms. Data collection was made at 13 wadeable streams during three sampling periods (early spring 2007, late spring 2007, and summer 2007). We found that data from electroshocking collections tended to generally support our hypothesis that substrate type does influence fish communities. Higher diversity values and fish abundances were generally associated with higher sediment/substrate values (i.e. more complex substrates). Concrete-lined streams do not appear to support high fish community diversity, richness, and total numbers of fish as well as substrates such as unmodified earthen, earthen, and rip rap given the lack of habitat complexity. These results are in agreement with previous studies that substrate is an essential habitat attribute in aquatic habitats (Bovee et al. 1998). Substrate provides attachment sites for periphyton (Carr et al. 2005) and invertebrates, secondary production of food for fish, refuge from predators, and rest areas for smaller organisms in flowing streams. In contrast, seining collections did not reveal a strong relationship between substrate and fish communities. This may be due to reduced collection efficiency caused by high stream flows and/or debris/snags which caused loss of catch at areas with complex substrate.

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INTRODUCTION

Harris County is located within the Western Gulf Coastal Plain ecoregion (Omernik 1987). Omernik (1987) delineates the ecoregions by areas of relatively homogeneous soils, land use, land surface form, and potential natural vegetation. The Western Gulf Coastal Plain ecoregion is characterized by vertisols soils and potential natural vegetation of bluestem/sacahuista prairie (bluestem, cordgrass). Land surface form in this ecoregion is characterized by flat plains and land use is mostly cropland or some cropland with grazing land. Streams in this ecoregion are sluggish given the relatively flat topography (Platt 2006). These streams have been known to support diverse fish assemblages (Connor and Suttkus 1986) inclusive of estuarine species.

Increasing residential and commercial developments in the Harris County, Texas area has caused the need for more stream modification projects to try to avoid potential flooding issues (HCFCD 2006). Houston, the 4^{th} largest city in the United States, is located in Harris County, Texas (U.S. Census Bureau 2006). The population of Houston is over two million people (U.S. Census Bureau 2006). The population within the Houston Metropolitan Statistical Area, which includes portions of adjoining counties, is approximately 4.6 million (Platt 2006). The population is projected to increase by over one million residents by 2025 (Office of the State Demographer 2006). This continuing increase in population puts increasing demands on drinking water supplies, wastewater treatment, and storm water management.

Freshwater resources and associated services worldwide are rapidly becoming depleted. Rivers and streams are being continually degraded by land use changes driven by changing economic activities and socio-demographics (Carpenter et al. 1998; Naiman and Turner 2000; Nilsson and Berggren 2000). While terrestrial impacts are well understood, less is known about impacts on freshwater streams (Nilsson et al. 2003; Poff et al. 1997). Aquatic environments act as pollution sinks and may be the areas most affected by land use changes (Sala et al. 2000). Inoue et al. (2005) and Walsh et al. (2005) state that increases in urban land cover have resulted in less diverse stream communities composed of more tolerant species. Madejczyk et al. (1998) also notes a reduction in diversity and abundance of riverine fish assemblages associated with human development and urbanization. A survey of a variety of freshwater habitats in Texas indicated that several Texas fishes had become extinct and others were threatened as a result of local habitat disturbances inclusive of alteration of instream flow (Anderson et al. 1995). Hubbs et al. (1991) stated that due to human activities approximately 20% of the native fishes of Texas are in need of targeted conservation efforts. According to Nilsson et al. (2003), species distributions in rivers are not well documented making it difficult to model ecological responses.

Impervious surfaces associated with urbanization have increased the amount of storm water runoff and the amount of areas subject to flooding. Approximately 25% of Harris County was estimated to be located within the 100-year flood zone as of 1980 (Platt 2006). Urban development continues to increase the amount of areas subject to the 100-year flood zone while subsidence due to groundwater extraction has increased the coastal flooding risks.

Traditional storm water management practices included the deepening and straightening of natural streams to increase the velocity and downstream transport of the water during a large storm flow (Riley 1998). Increases in stream velocity cause bank erosion, increased peak flows, and loss of instream habitat (Liscum 2001; Riley 1998; Richter et al. 1996; Strayer et al. 2003). Konrad and Booth (2005) identified four hydrologic changes that result from urban development that have the potential to impact stream ecosystems. These hydrologic changes included: increased frequency of high flows, redistribution of water from base flow to storm flow, increased daily variation in stream flow and a reduction in low flow (Konrad and Booth 2005). Hammer (1972) states that changes in stream flow due to urbanization causes stream channel enlargement. Karr and Dudley (1981) define biological (or biotic) integrity as "the ability to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region". According to Fitzpatrick et al. (2005), the fish index of biotic integrity (IBI) was lower in streams located within urbanized watersheds and also in stream channels that have been enlarged. It has become apparent that new stream restoration methods are necessary for streams that have been historically altered for management of floodwaters. Suggested methods have included the enhancement of the riparian zone, replacement of substrate and woody debris, utilization of terraced stream banks to accommodate stream meandering and creation of artificial meanders to mimic natural riverine geomorphology (Riley 1998; Brierley and Fryirs 2005). However, adjacent riparian land in urban landscapes is not always available for traditional stream restoration activities. This makes it necessary to develop and implement restoration and flood management practices that will meet engineering and flood mitigation goals and also attain instream restoration criteria pursuant to federal and state regulations.

The Harris County Flood Control District (HCFCD) was created in 1937 and serves as a local partner for the U.S. Corps of Engineers. The HCFCD provides flood damage reduction projects throughout Harris County (HCFCD 2006). Platt (2006) reports that the HCFCD have channelized over 6,000 miles of local streams and bayous in the Houston region. The HCFCD utilizes various engineering strategies to manage flood waters including the use of various substrates (earth, rip rap, concrete, and articulated concrete block) during stream channel modification projects. An earthen lined stream substrate is a modified stream in which no artificial substrates have been installed (i.e. the stream was merely channelized). Rip rap, also known as shot rock, is rock or other material used to stabilize stream banks. Rip rap is usually coarse, angular rock made by crushing or blasting. The use of concrete as a stream substrate involves the placement of a solid concrete lining within a channelized stream in order to stabilize the banks to help prevent bank erosion. Articulated concrete block (ACB) systems are used to provide erosion protection to underlying soil from the hydraulic forces of moving water. An ACB system is comprised of a matrix of individual concrete blocks placed together to form an erosion-resistant revetment with specific hydraulic performance characteristics. The term "articulating" implies the ability of the matrix to conform to minor changes in the subgrade while remaining interconnected with geometric interlock and/or additional system components such as cables. The HCFCD is also implementing substrate types that represent newer approaches to attempt to mimic natural riparian conditions. According to the HCFCD only 6% of the modified channels in Harris County are concrete lined. Information regarding percentages of other substrates used during channel modification was not readily available.

Availability of habitat affects the diversity and richness of fishes within streams (Meador et al. 1990). Substrate is an essential habitat attribute in aquatic habitats (Bovee et al. 1998). Substrate provides attachment sites for periphyton (Carr et al. 2005) and invertebrates, secondary production of food for fish, refuge from predators, and rest areas for smaller organisms in flowing streams. In a study conducted by Buss et al. (2004), it was found that species occurrence of macroinvertebrates in streams was highly dependent on substrate type and to a lesser degree environmental integrity, water quality, and sampling period. In an experiment conducted by Madejczyk et al. (1998), riprapped shorelines had different fish assemblages than river areas that contained only instream artificial rocky structures. Strayer et al. (2003) states that management actions have been introduced to mediate the effects of development on streams, yet little is known about their effectiveness. Madejczyk et al. (1998) states that concurrent examinations of artificial and natural habitat fish preferences have seldom been done.

In order to understand the effect of these various substances on the fish, we conducted a study to determine the influences of these substrates under varying stream channel configurations on the distribution and abundance of fish organisms. As a component of a more expansive project currently being conducted for the HCFCD, we conducted an assessment that documents the suitability and comparative utilization, by fish organisms, of various common substrate materials used by HCFCD for stream modification projects.

<u>Experiment objectives</u>

1) To compare fish communities within streams utilizing substrate types (earth, rip rap, concrete, articulated concrete block, and others) used in stream channel modification projects in Harris County.

2) To characterize fish communities, physical habitat, hydrology, and water quality associated with the substrates used in stream channel modification projects.

Hypothesis

- **Null hypothesis (Ho)** = substrate type does not influence aquatic communities after adjusting for the effects of water quality and hydrology.

- **Alternative hypothesis (H_1)** = substrate type does influence aquatic communities after adjusting for the effects of water quality and hydrology

METHODS

Study Area

Sites were selected based on streams that were of interest to the HCFCD. The streams are all located within an urban environment within Harris, Galveston, or Brazoria Counties. Sites were chosen within the same or similar watershed to reduce or eliminate inter-watershed variability. Sites located further upstream or downstream and containing a different substrate material was evaluated, if available, at each stream. The sites are located in "wadeable" streams that can be sampled under normal base flow conditions without a boat. A total of 13 sites were sampled (Figure 1). Latitude and longitude for each sampling site are provided in Table 1. Stream substrate types at each sampling site are provided in Table 2. At each site, the total study area consisted of a 300-foot long section or reach of the stream with the exception of one site (Coward's Creek at Sunset Lane) which consisted of a 150-foot long section.

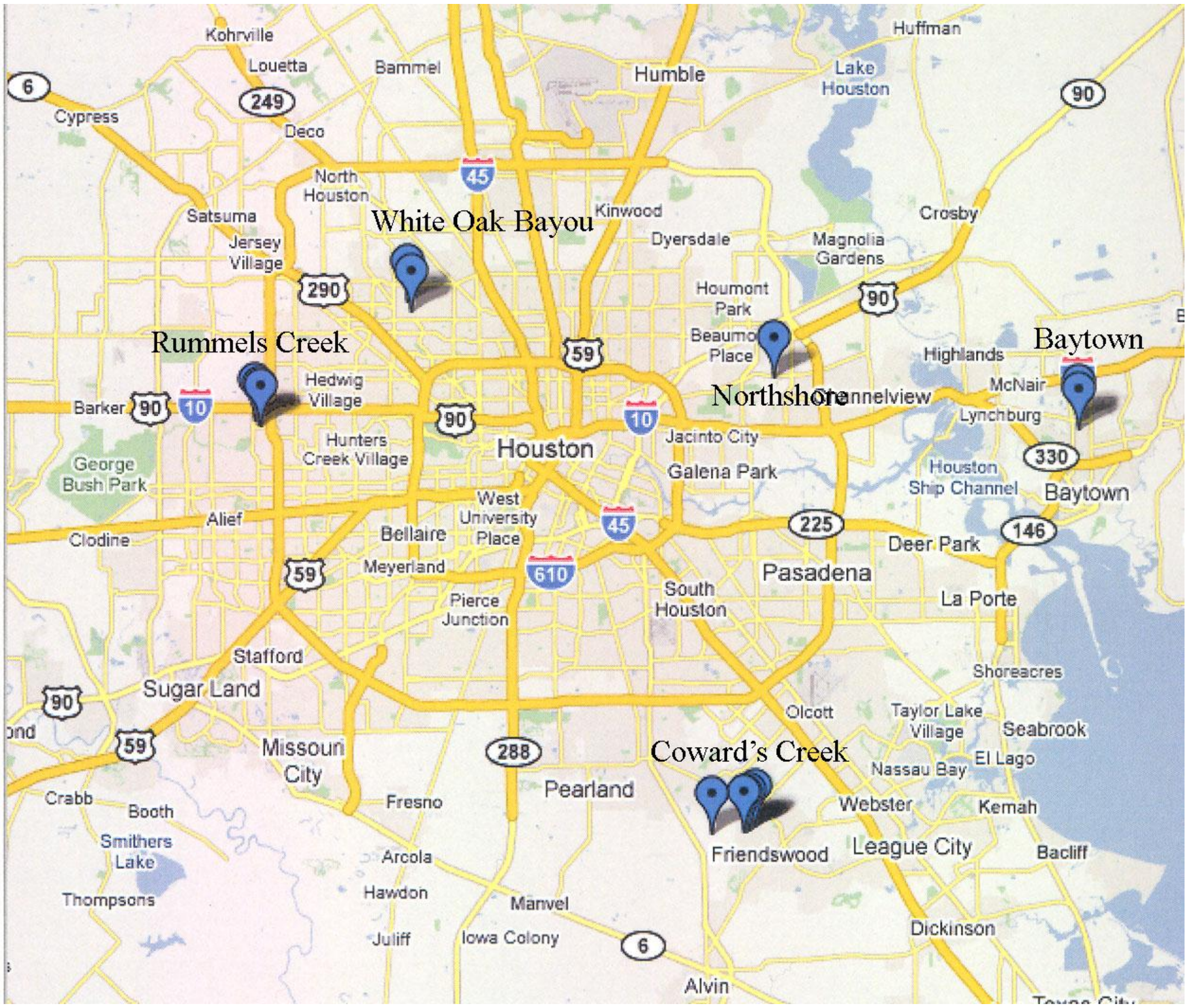

Figure 1: Map showing sampling sites (created with Google Maps).

Table 1: Latitude and Longitude of sampling sites

Sampling Site*	Latitude (N)	Longitude (W)
Northshore [NS]	29.802965	-95.194945
White Oak Bayou at Tidwell Road – upstream [Tid(up)]	29.850434	-95.463037
White Oak Bayou at Tidwell Road – downstream [Tid(down)]	29.84485	-95.459862
Baytown – upstream [Bay(up)]	29.775516	-94.971871
Baytown – downstream [Bay(dn)]	29.770319	-94.971893
Rummels Creek at bird sanctuary [Rum_bd]	29.771232	-95.568416
Rummels Creek at school [Rum_sc]	29.773318	-95.571399
Rummels Creek at houses [Rum_hs]	29.775907	-95.57333
Coward's Creek at Clover Field Airport [Cow_apt]	29.513889	-95.239722
Coward's Creek at control site [Cow_con]	29.514654	-95.216618
Coward's Creek at Linson Lane [Cow_Lin]	29.514803	-95.215287
Coward's Creek at Greenbriar Lane [Cow_Grn]	29.516036	-95.21224
Coward's Creek at Sunset Lane [Cow_sun]	29.519434	-95.207605

* [ ] site name abbreviation used throughout report

Table 2: Stream substrates for the sampling sites

Sampling Site	Substrate
Northshore (tributary of Greens Bayou) [NS]	Unmodified earthen
White Oak Bayou upstream of Tidwell Road – upstream [Tid(up)]	Earthen
White Oak Bayou downstream of Tidwell Road – [Tid(down)]	Concrete-lined
Baytown ditch – upstream [Bay(up)]	Earthen
Baytown – downstream [Bay(dn)]	Rip-rap
Rummels Creek at bird sanctuary [Rum_bd]	Unmodified earthen
Rummels Creek at school [Rum_sc]	Plastic material and cobble
Rummels Creek at houses [Rum_hs]	Rip-rap
Coward's Creek at Clover Field Airport [Cow_apt]	Earthen
Coward's Creek at control site [Cow_con]	Earthen
Coward's Creek at Linson Lane [Cow_Lin]	Articulated concrete block (ACB)
Coward's Creek at Greenbriar Lane [Cow_Grn]	Earthen and rip-rap
Coward's Creek at Sunset Lane [Cow_sun]	Earthen

The experimental design is a repeated measures approach in which replicate measurements of fish community, habitat, hydrology, and water quality are made at each station (treatment) and month (time) combination. Data collections were made during three sampling periods (early spring 2007 [round 1], late spring 2007 [round 2], and summer 2007 [round 3]) (Table 3). The site Cow_apt was only sampled during rounds 1 and 2 and the site Cow_con was only sampled during rounds 2 and 3 because of changes in the sampling strategy.

Table 3. Sampling approach

Treatment	Early Spring 2007	Late Spring 2007	Summer 2007
NS	F Hb H W	F Hb H W	F Hb H W
Tid(up)	F Hb H W	F Hb H W	F Hb H W
Tid(down)	F Hb H W	F Hb H W	F Hb H W
Bay(up)	F Hb H W	F Hb H W	F Hb H W
Bay(dn)	F Hb H W	F Hb H W	F Hb H W
Rum_bd	F Hb H W	F Hb H W	F Hb H W
Rum_sc	F Hb H W	F Hb H W	F Hb H W
Rum_hs	F Hb H W	F Hb H W	F Hb H W
Cow_apt	F Hb H W	F Hb H W	Not sampled
Cow_con	Not sampled	F Hb H W	F Hb H W
Cow_Lin	F Hb H W	F Hb H W	F Hb H W
Cow_Grn	F Hb H W	F Hb H W	F Hb H W
Cow_sun	F Hb H W	F Hb H W	F Hb H W

F = fish, Hb = habitat, H = hydrology, W = water quality

Fish collection

Fish were collected during each sampling event using techniques outlined in the TCEQ procedures manual (TCEQ 2005 and TNRCC 1999). Sampling consisted of seining and electro-fishing using a backpack shocker. At each site, a 300-foot stream segment was measured out (except for Cow_sun). Within the stream segment and during each sampling event, ten seine hauls (30-foot segments) were conducted (five seine hauls for Cow_sun) using a 15’ x 4’ seine with a 1/8 inch nylon mesh. A Smith-Root model LR-24 backpack electrofisher using the standard operational parameters of 30 Hz pulsed D.C. electrical current, with a frequency of 105 volts was used to obtain fish from each sample station. All settings including the voltage, watts, type of wave, and amps, from the electrofisher were recorded in a field notebook prior to sampling. Based on current literature and manufacturers recommendations, at conductivities exceeding 1,000 µS electrofishing is ineffective; therefore in these circumstances only seining was used to collect fish (Pusey et al, 1998 & Hill & Willis, 1994). Electro-fishing was conducted along three 100-foot segments for a total of three electro-fishing replicates per site per event. Electro-fishing was not conducted at the Coward’s Creek sites because of the elevated conductivity levels, which were generally greater than 1,000 µS/cm. Table 4 shows the tabulated view of the number of fish collection replicates for this study.

Table 4. Fish collection samples

Treatment	Seining Samples	Electro-fishing samples	Number of sampling events	Total number of samples
NS	10	3	x3	39
Tid(up)	10	3	x3	39
Tid(down)	10	3	x3	39
Bay(up)	10	3	x3	39
Bay(dn)	10	3	x3	39
Rum_bd	10	3	x3	39
Rum_sc	10	3	x3	39
Rum_hs	10	3	x3	39
Cow_apt	10	0	x2	20
Cow_con	10	0	x2	20
Cow_Lin	10	0	x3	30
Cow_Grn	10	0	x3	30
Cow_sun	5	0	x3	15
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Collected fish were euthanized onsite with MS-222 and preserved in 10% formalin. The fish samples were taken back to the laboratory for identification. At the laboratory fish collections were transferred to 40% isopropanol or 70% ethanol for long-term storage prior to identification. Total abundance, abundance of numerically abundant species, Shannon-Wiener's Diversity (H), Pielou's evenness (E), and Richness (Krebs, 1998) were calculated and compared between sites. Shannon-Wiener Diversity (H) is defined as $-\sum P_i(\ln P_i)$ where P_i is the proportion of each species in the sample. Pielou's evenness (E) is defined as H/H_{max} where H is the Shannon-Wiener Diversity, H_{max} is the ln *S*, and *S* is the total number of species in a sample. Richness is a count of the number of species/taxa present in a sample.

Fish IBI (Index of Biotic Integrity) metrics were calculated and compared to regional expected values provided in Linam et al. (2002). The use of IBI metrics is useful for direct biological monitoring because of its strong ecological foundation and flexibility (Miller et al. 1988). In 1987 the U.S. EPA emphasized the need for the development and application of biological monitoring techniques in state monitoring programs in combination with traditional chemical and physical monitoring techniques. A statewide index of numerical criteria for assessing fish assemblages when determining aquatic life uses in small (usually wadeable) Texas streams was proposed by Linam et al. 2002. The criteria for the index was based upon the IBI and was taken from original integrity classes that were developed as a means of assessing fish assemblage degradation in streams located in the midwestern United States. The IBI is comprised of twelve metrics that fall into three broad categories: species composition, trophic composition, and fish abundance and condition. Since the original integrity classes were developed from stream sampling in the midwestern United States, they cannot feasibly be used for other geographic regions. Therefore, Texas, along with other states, developed state IBI indices. However, the use of the statewide IBI for Texas has consistently underestimated the aquatic life use in streams when compared to other methods. Given the diverse nature of habitats and corresponding assemblages within Texas, a regionalized index for Texas was proposed and created (Linam et al. 2002). The sampling sites reside within the Western Gulf Coastal Plain (Ecoregion 34). The individual metrics used in the calculation of the IBI for this ecoregion include: 1) total number of fish species, 2) number of native cyprinid species, 3) number of benthic invertivore species, 4) number of sunfish species, 5) number of intolerant species, 6) % of individuals as tolerant species (excluding western mosquitofish), 7) % of individuals as omnivores, 8) % of individuals as invertivores, 9) number of individuals in sample - (a) number of individuals/seine haul and (b) number of individuals/minute electrofishing, 10) % of individuals as non-native species, and 11) % of individuals with disease or other anomaly. Each metric is then given a score of either 1, 3, or 5 based on the value of the metric. The scores are added together to obtain an IBI/Aquatic Life Use score. For Ecoregion 34 an IBI score of >49 is considered Exceptional, while 39-48 is considered High, 31-38 is considered Intermediate, and <31 is considered Limited.

Physical habitat

During each sampling event, instream and riparian habitat was assessed following protocol outlined in the TCEQ surface water quality monitoring procedures and receiving water assessment manuals (TNRCC 1999; TCEQ 2003; and TCEQ 2005). Physical habitat data was collected at the upstream, middle, and downstream areas of the 300-foot stream segment. Habitat type, measurement and quantification of predominant sediment type and size, submerged and emergent vegetation, stream slope, bank slope, and shading were recorded during each sampling event.

Habitat type

Habitat type was evaluated at each 30 foot increment along the 300-foot stream segment and was categorized into one of three categories: riffle, run, or pool. A riffle is described by TCEQ (2005) as a shallow portion of a stream extending across a stream bed characterized by relatively fast moving turbulent water with a broken water surface. The water column in a riffle is usually constricted and water velocity is fast due to a change in surface gradient. The channel profile in a riffle is usually straight to convex. A run is described as a relatively shallow portion of a stream characterized by relatively fast moving, bank-to-bank, non-turbulent flow. A run is usually too deep to be considered a riffle. The channel profile under a run is usually a uniform flat plane. A pool is a portion of a stream where water velocity is slow and the depth is greater than the riffle or run. Pools often contain eddies with varying directions of flow compared to riffles and runs where flow is nearly exclusively downstream. The water surface gradient of pools is very close to zero and their channel profile is usually concave. In order to characterize available mesohabitat within each stream, percent run, percent riffle, and percent pool were calculated and graphed.

Sediment type and size

At the upstream, middle, and downstream areas of the 300-foot stream segment, the stream sediment size composition was visually assessed by obtaining a grab sample by hand at the left and right banks and at midstream. Predominant stream sediment type was given a numeric code based on its size (Table 5). The Wentworth scale for characterizing sediment/substrate was used to describe substrates at the sites. The scale uses sediment size to characterize substrate materials. The scale was modified to include sediment/substrates not normally included in the traditional Wentworth scale including concrete lined and irregular hardpan clay and articulated concrete bricks.

Table 5. Sediment size distributions (modified from Fitzpatrick et al. 1998)

Substrate/sediment type	Size	Numeric code
Concrete-lined	---	0
Clay/silt	<0.059 mm	1
Sand	0.06 – 1 mm	2
Gravel	2 – 15 mm	3
Pebble	16 – 63 mm	4
Cobble	64 – 256 mm	5
Boulder, Articulate Concrete Block, irregular hardpan clay	>256 mm	6

Submerged and emergent vegetation

Percent of the bottom covered by submerged and emergent vegetation at the upstream, middle, and downstream areas of the 300-foot stream segment was characterized during each sampling event. Any additional instream cover types such as undercut banks, logs or snags, overhanging vegetation, leaf packs, and artificial covers (i.e. tires, etc) was noted.

Stream slope and bank slope

Bank slopes were determined using a clinometer at the upstream, middle, and downstream sections of the 300-foot stream segment during each sampling event.

Shading

Percent shading was determined at the upstream, middle, and downstream sections of the 300-foot stream segment during each sampling event. Shading was determined using a convex spherical densitometer following the methods outline in TNRCC 1999.

Hydrology

During each sampling event, hydrological conditions were assessed following protocol outlined in the TCEQ surface water quality monitoring procedures and receiving water assessment manuals (TNRCC 1999; TCEQ 2003; and TCEQ 2005). Stream velocity, depth, and width were determined at the upstream, middle, and downstream sections of the 300-foot stream segment during each sampling event. Stream velocity at the upstream transect was determined at ten cross sections and averaged to calculate a stream flow. Depth and velocity was determined using a top-setting wading rod and an attached electronic or mechanical price pygmy velocity meter. Depth measurements were collected from the thalweg, or center portion of the deepest channel, at each transect. Stream velocity measurements were taken at 60 percent of the depth according to TCEQ and USGS protocol.

Water quality

Environmental and water quality measurements were collected during each sampling event at the upstream section of each 300-foot stream segment. Measurements included air temperature, water temperature, conductivity, pH, dissolved oxygen, secchi disk turbidity, turbidity (NTU), phosphorous, ammonia-nitrogen, nitrate-nitrogen, nitrite-nitrogen, total suspended solids (TSS), alkalinity, hardness (Mg and Ca), chlorine residual, and chlorophyll-a. Turbidity (NTU), alkalinity, phosphorous, nitrate-nitrogen, nitrite-nitrogen, hardness (Mg and Ca), TSS, and chlorophyll-a samples were collected onsite and measured at the laboratory. Turbidity was measured using a nephelometer. TSS was measured by gravimetric means and chlorophyll-a by spectophotometric techniques. All samples were analyzed either in the field or in the laboratory. Analysis methods to be used are listed below in Table 6.

Table 6. Water quality variables monitored and sampling method (APHA 1998 and Hach Method Manual)

Parameter	**Type of kit, meter, and/or method**
Temperature (°C)	Thermometer
Conductivity (mS)	Oakton Instruments: EC Testr
pH	Oakton Instruments: pH Testr 2
Dissolved oxygen (mg/L)	LaMotte Test kit Model EDO code 7414
Hardness (mg/L Mg and Ca)	Hach method 8030
Turbidity (cm & ntu)	Secchi Tube and Scientific Inc. Turbidimeter
Orthophosphate (mg/L PO_4)	Phosphorus, reactive Method 8048 using a Hach DR/890 Colorimeter (filtered with 47mm filter paper) (detection limit 2.50 mg/L)
Ammonia-nitrogen (mg/L NH_3-N)	Hach Kit Midrange Model NI-8 (detection limit 3 mg/L)
Nitrate-nitrogen (mg/L NO_3-N)	Nitrate, low-range Method 8192 using a Hach DR/890 Colorimeter (detection limit 0.50 mg/L)
Nitrite-nitrogen (mg/L	Hach method 8507

NO_2-N)	
Total suspended solids (mg/L)	APHA 2540
Alkalinity (mg/L $CaCO_3$)	LaMotte Kit Model WAT-DR code 49-DR
Chlorine residual (mg/L)	Hach methods 8021 and 8167
Chlorophyll-a (mg/m^3)	APHA 10200

Data analysis

The experimental design used for this experiment employs a repeated measures approach in which replicate measurements of various traits (fish abundance and community composition, habitat, hydrology, and water quality) are made at each station (treatment) and season (time) combination.

All fish were identified to the lowest taxonomic level possible. In most cases specimens were identified to species level to facilitate comparisons between individual species abundances. This identification was also used for further calculation of number of fish species, fish diversity indices and IBI metrics. The identified fish were counted to determine the total number of each species, as well as the total number of fish collected in the study. Regional taxonomic guides and keys were used to aid in identification (Hubbs et al. 1991 and Thomas et al. 2007).

The standard length (mm) of a subsample of each species/taxa, not to exceed ten fish per species per site, was measured. Computations of the number of species and individuals and community diversity indices were conducted for use in later calculations. Diversity indices were standard indices modified to describe fish communities. The indices used were Shannon-Wiener's Diversity (H\`), Pielou's evenness (E), and Richness (Krebs 1998). Given data gaps, a one-way ANOVA was used to analyze seine and electrofishing replicate measurements. One-way ANOVA analyses and associated box plots were done for the sites for: total numbers of fish, Shannon-Wiener diversity, Pielou's Evenness, and richness. Given the non-normal data, Kruskal-Wallis analyses were conducted across the various substrate types identified in Table 2. The Kruskal-Wallis test is a nonparametric alternative to a one-way ANOVA. The test does not require the data to be normal, but instead uses the rank of the data values rather than the actual data values for the analysis. This test performs a hypothesis test of the equality of population medians for a one-way design (two or more populations). The Kruskal-Wallis test looks for differences among the populations' medians.

Cluster analysis of the species community data was conducted to determine the similarity of sites and dates in terms of overall community composition. Squared Euclidean Distance and Ward's Linkage method were used for cluster determination. In addition, Clustan was used to determine the final number of group clusters. Clustan uses a variance reduction algorithm and then replicates the best cut to determine how many clusters are significant, therefore determining where the classification tree should be cut (Wishhart 2006).

A principal components analysis (PCA) was used to determine how the environmental and biological components of the study were interrelated and which factors, including substrate, appear to influence fish species composition. PCA is an ordination technique that reduces numerous variables into explanatory principal components that can be used to predict interrelationships between variables and observations (Tabachnick & Fidell 1989). Scatter plots and correlation analyses were conducted for seine and electroshocking collections to compare substrates types with principal components versus fish abundance, Shannon-Wiener diversity, Pielou's Evenness, and richness.

RESULTS

During this study we collected physical, hydrological, water quality and biological data from 13 sites, over a six month period extending from March to August 2007.

Physical Site Characterization

The stream width was significantly different ($p=0.00$, $R^2= 81.02$) amongst collections particularly the White Oak Bayou sites (Tid(up) and Tid(down)) versus the majority of the other sites. The average stream width for the sites was between five feet and 47 feet. Figure 2 illustrates the stream width (ft) per site for each round of sampling (early spring – round 1, late spring – round 2, and summer – round 3). Bay(up) and Bay(dn) had the lowest average stream widths amongst sites. Tid(up) and Tid(down) had the highest average stream widths for all of the sites because they are larger order streams/bayous.

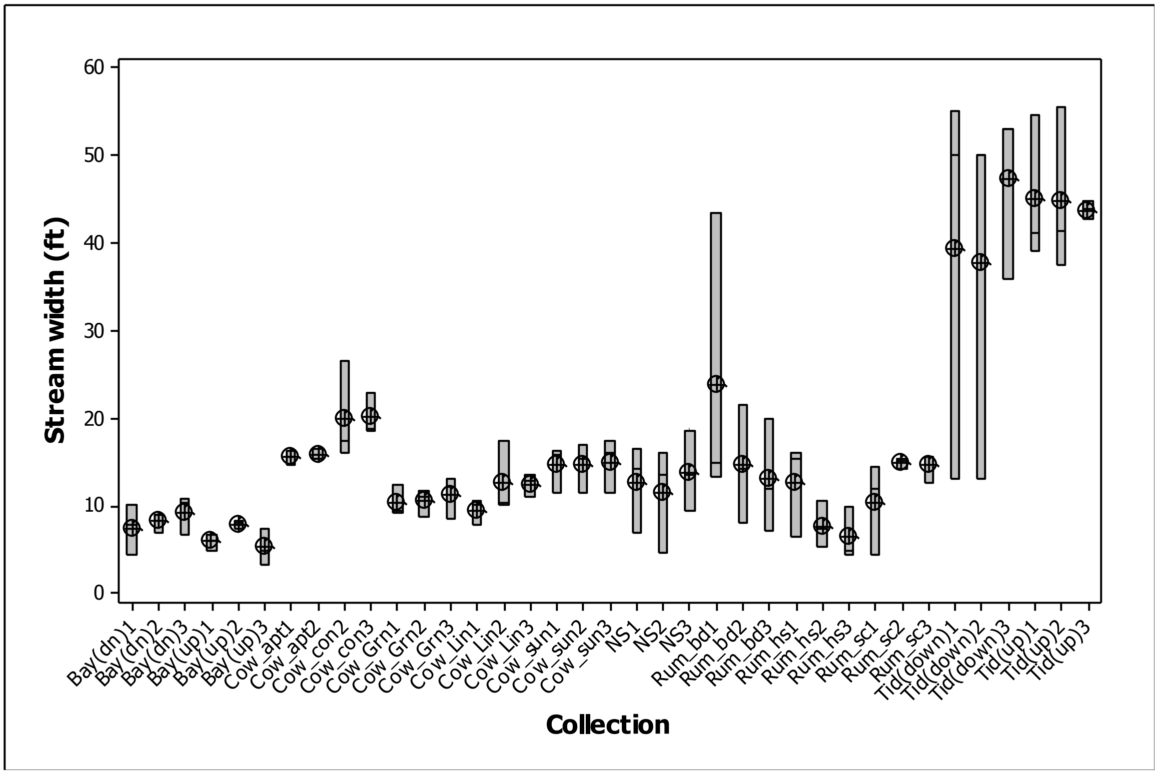

Figure 2: Stream width (ft) upstream, midstream, and downstream combined per collection. Boxplots of interquartile range with median line. ANOVA (p=0.000, R^2=81.02). 1 = early spring 2007, 2 = late spring 2007, 3 = summer 2007.

The stream thalweg depth (center portion of the deepest channel) was significantly different between collections (p=0.000, R^2=67.25) likely due to the differences in stream orders (Figure 3). The stream thalweg depth for the sites was between 0.45 and five feet. Bay(dn) had the shallowest average stream thalweg depth amongst sites. Cow_sun (summer) had the deepest average stream thalweg depth. For many of the sites, the depths increased from early spring through the summer because of rainfall events.

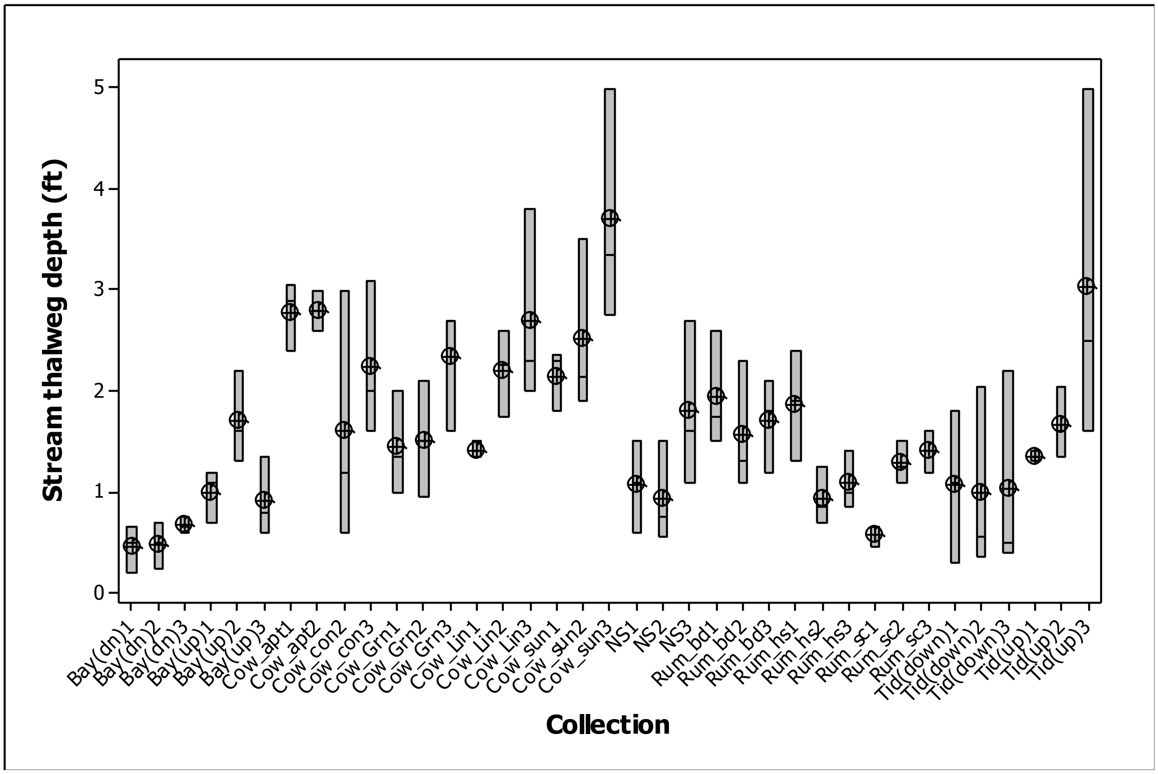

Figure 3: Stream thalweg depth (ft) upstream, midstream, and downstream combined per collection. Boxplots of interquartile range with median line. ANOVA (p=0.000, R^2=67.25). 1 = early spring 2007, 2 = late spring 2007, 3 = summer 2007.

The percent of the stream that was classified as a run is illustrated in Figure 4. The sites Tid(down) and Cow_apt consistently had 100 percent run for all rounds sampled. Bay(up), Rum_bd, and Rum_hs (all collections) had the lowest percentage of runs (0 to 20%). Bay(dn) had the highest percentage of riffle areas (60%) when compared to the other sites (Figure 5). Tid(up) had percentage riffle ranges from 30-40% while Tid(down) had no riffle areas. During two sampling events NS pool area percentages were 90% (Figure 6). During early spring Bay(up) contained 100% pool area. Coward's Creek sites showed low to medium ranges for percent pool areas (0-60%). Pool areas were absent during all sampling periods, at Tid(up), Tid(down), and Cow_apt.

Habitat complexity, which was estimated using an index that was computed as the variance of pool riffle run scores, represented the distribution of pool, riffle, run complexes within the stream. This index could not be analyzed using ANOVA due to small sample size (Figure 7). In general, the greater the habitat complexity index value the greater the variation in habitat within a stream location. Tid(down) and Cow_apt sites both had 0 values for the habitat complexity, indicating these sites exhibited no variation in stream morphology. Tid(down) had been modified with a concrete-lined stream bottom. Both of these sites were channelized and only had runs throughout our sampling segment as seen in Figure 4. The habitat complexity scores varied from 0.32 to 1.03 for the rest of the sites throughout the study.

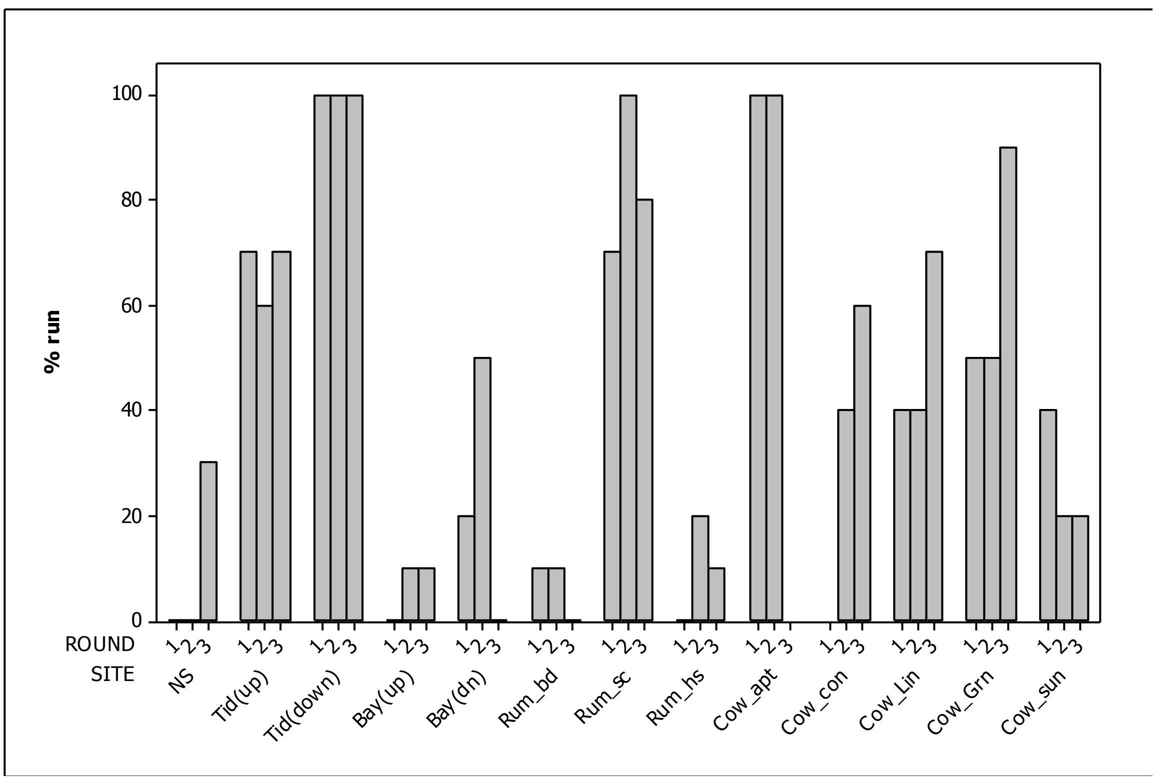

Figure 4: Percent of stream that was a run area. 1 = early spring 2007, 2 = late spring 2007, 3 = summer 2007.

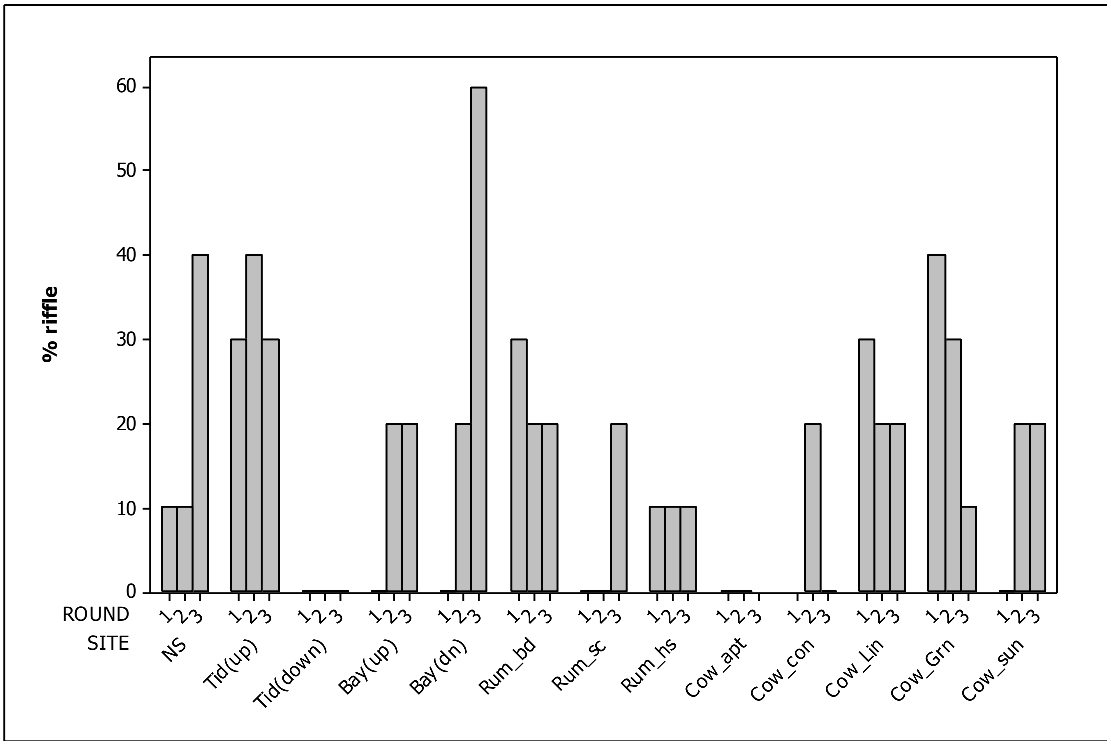

Figure 5: Percent of stream that was a riffle area. 1 = early spring 2007, 2 = late spring 2007, 3 = summer 2007.

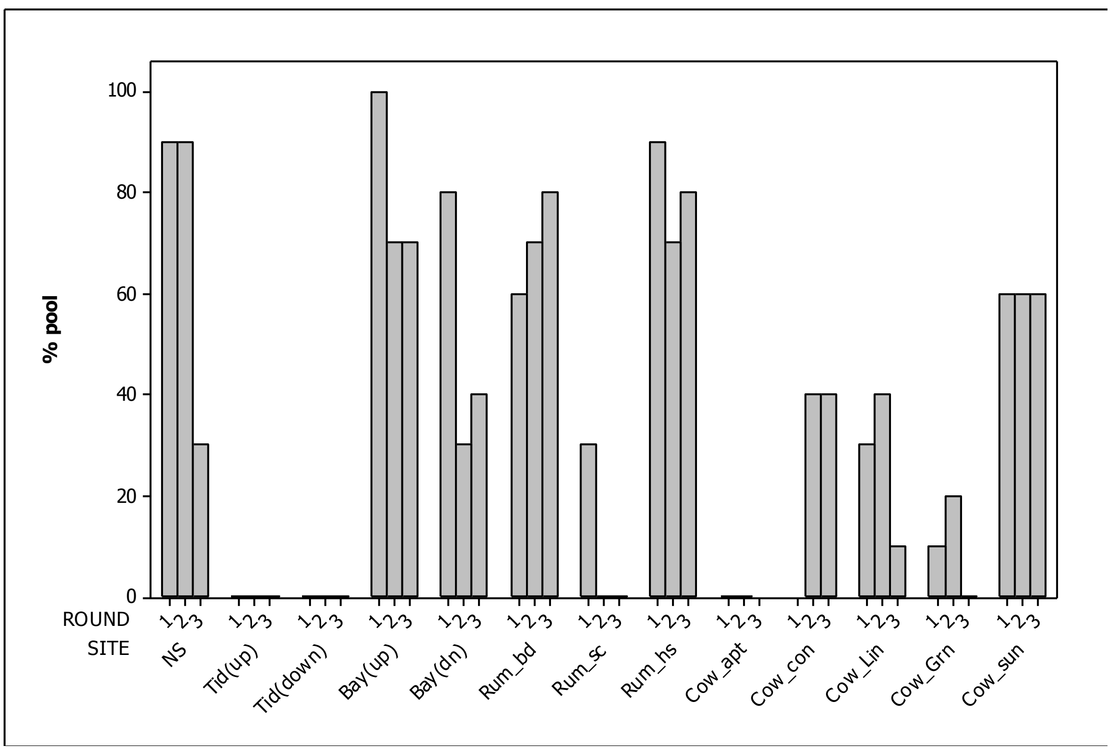

Figure 6: Percent of stream that was a pool area. 1 = early spring 2007, 2 = late spring 2007, 3 = summer 2007.

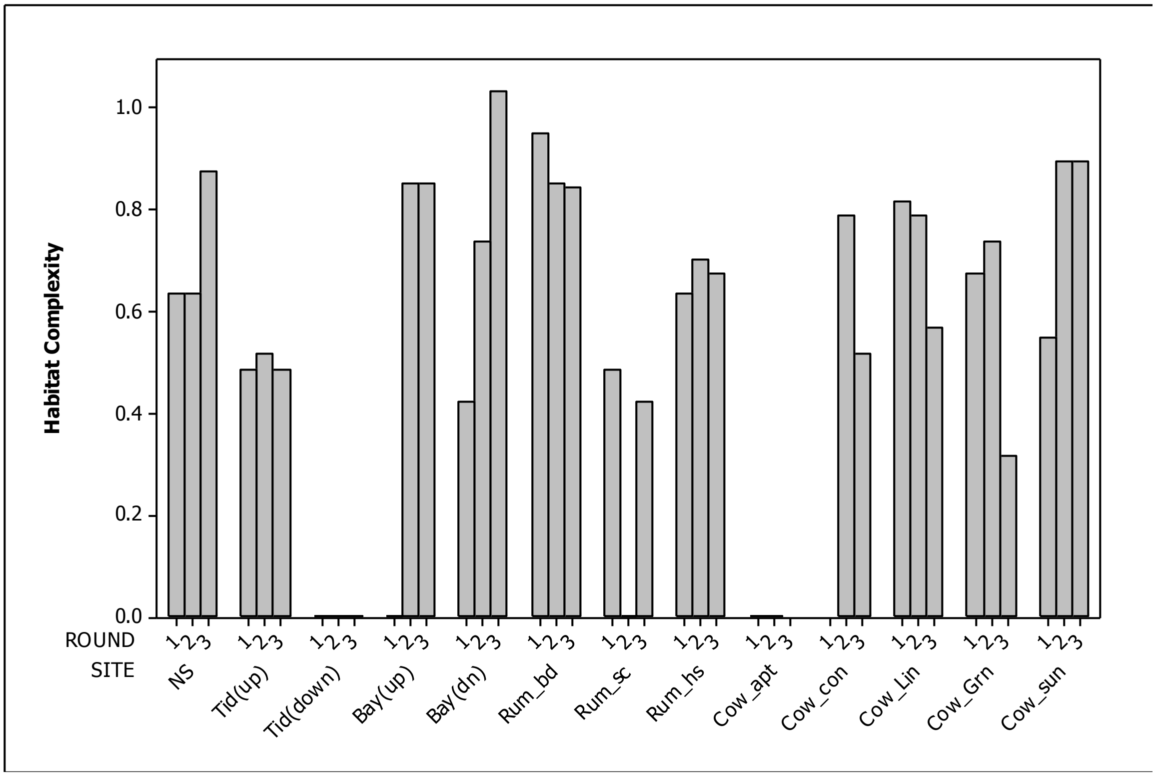

Figure 7: Habitat complexity score calculated for each collection. 1 = early spring 2007, 2 = late spring 2007, 3 = summer 2007.

Summary data for bank slope is provided in Figure 8. The greater the angle of the bank slope the steeper the bank. Bank slope was significantly different between collections (p= 0.000 R^2= 48.04). Tid(down) had the lowest mean bank slope (~10°). Cow_sun (early spring) and Rum_bd (late spring) had the steepest mean bank slopes at 55 to 59°. Some differences in bank slopes between collections at the sites is due to starting a transect slightly upstream or downstream of the original location. Other differences in bank slopes are due to bank erosion and/or sediment deposition.

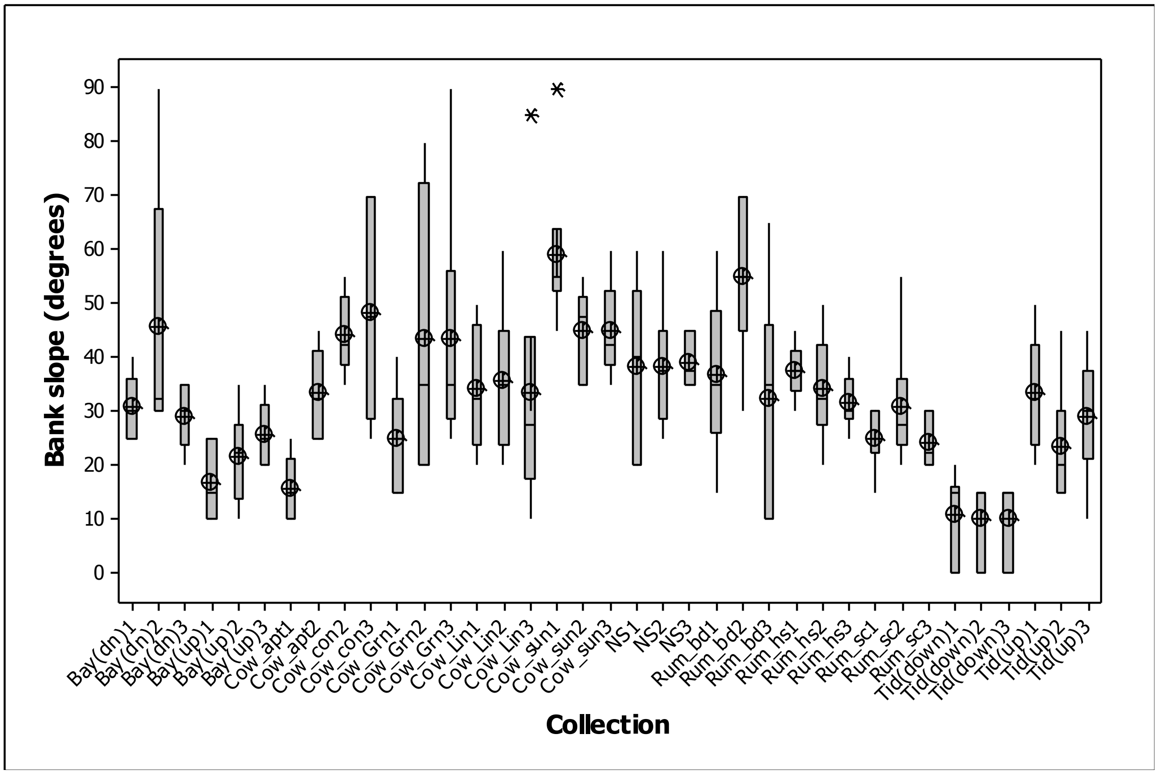

Figure 8: Bank slope degrees per collection. Boxplots of interquartile range with median line and whiskers representing highest and lowest data values, * represents outliers. ANOVA (p=0.000, R^2=48.04). 1 = early spring 2007, 2 = late spring 2007, 3 = summer 2007.

There was significant difference found between collections for emergent vegetation, p=0.002, R^2 = 51.59 but not for submergent vegetation, p=0.487, R^2 = 32.73, respectively (Figures 9 and 10). The sites Bay(dn), Rum_sc, Rum_hs had the highest average percentages of emergent vegetation. NS, Tid(up), Tid(down), Rum_bd, Cow_con, Cow_Lin had the lowest percentages of emergent vegetation. Some of the low percentages of emergent vegetation are due to high flows or a stream substrate that is unlikely to support emergent vegetation. Only one collection (Cow_Lin – early spring) had any detectable submergent vegetation. The remainder of the sites had no detectable submergent vegetation.

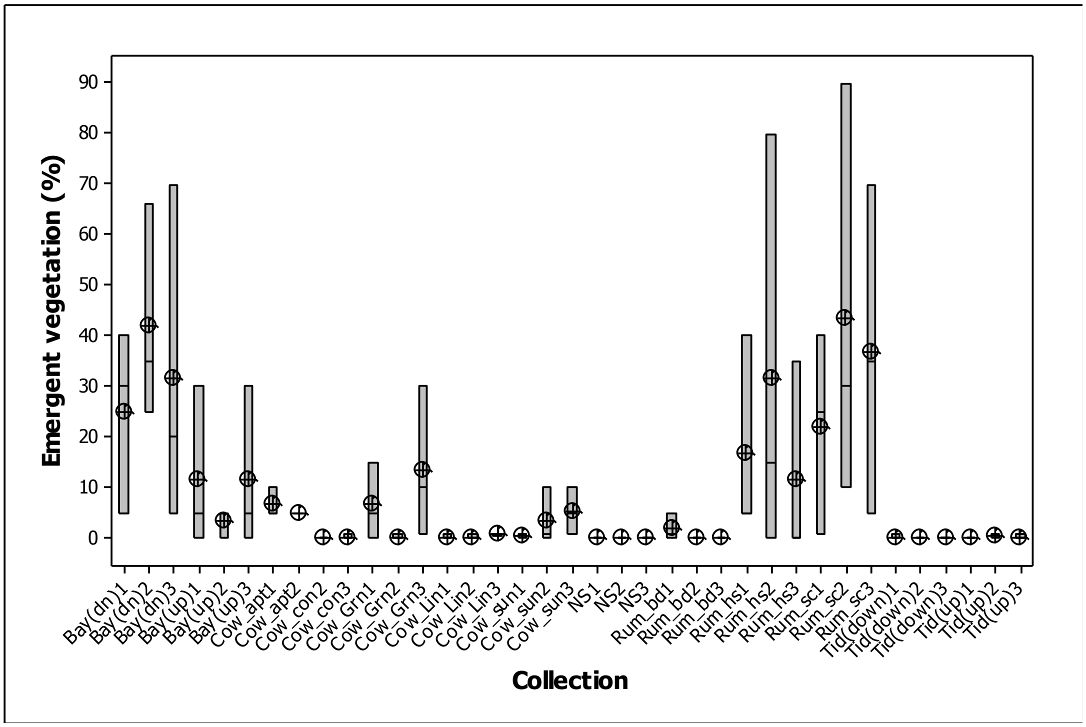

Figure 9: Percent emergent vegetation per collection. Boxplots of interquartile range with median line. ANOVA (p=0.002, R^2=51.59). 1 = early spring 2007, 2 = late spring 2007, 3 = summer 2007.

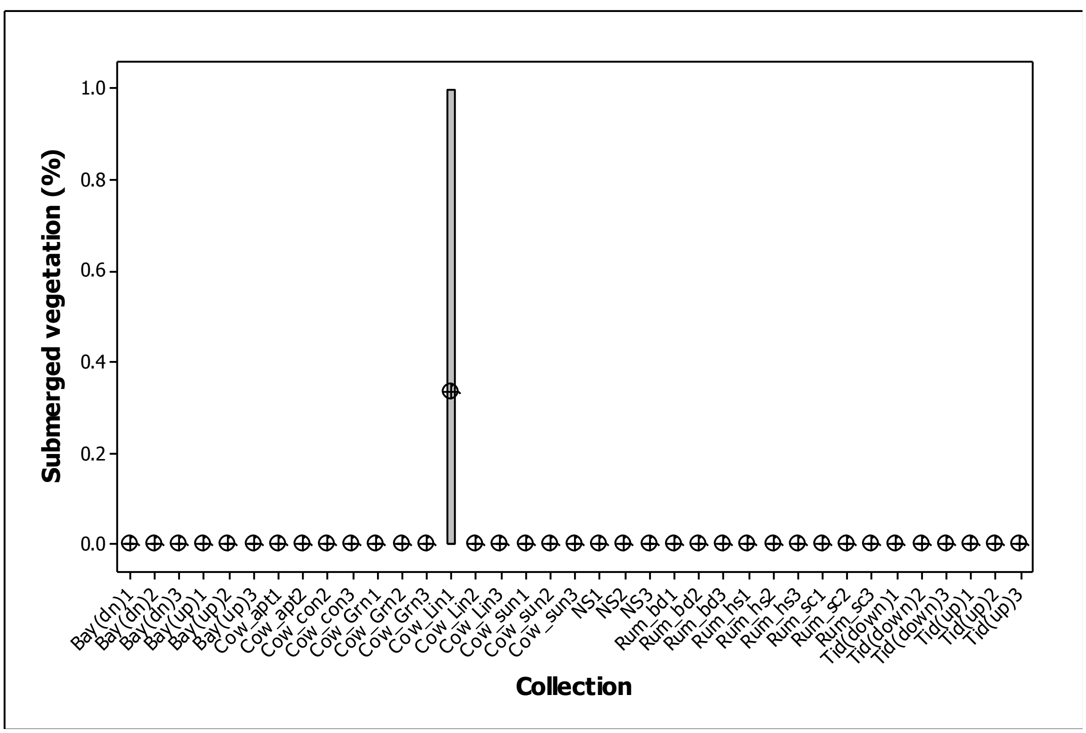

Figure 10: Percent submergent vegetation per collection. Boxplots of interquartile range with median line. ANOVA (p=0.487, R^2=32.73). 1 = early spring 2007, 2 = late spring 2007, 3 = summer 2007.

Percent of shoreline vegetated was estimated for the stream banks (Figure 11). Bank vegetation was significantly different between collections (p= 0.000, R^2= 71.53). The stream bank was defined as water's edge to the bank full point. Bank full is the flow stage of a river/stream in which the stream completely fills its channel and the elevation of the water surface coincides with the bank margins. NS and Tid(down) sites had the lowest average bank vegetation percentage (0 to 20%). NS and Rum_bd sites had highly eroded banks which explain the lower average bank vegetation percentage.

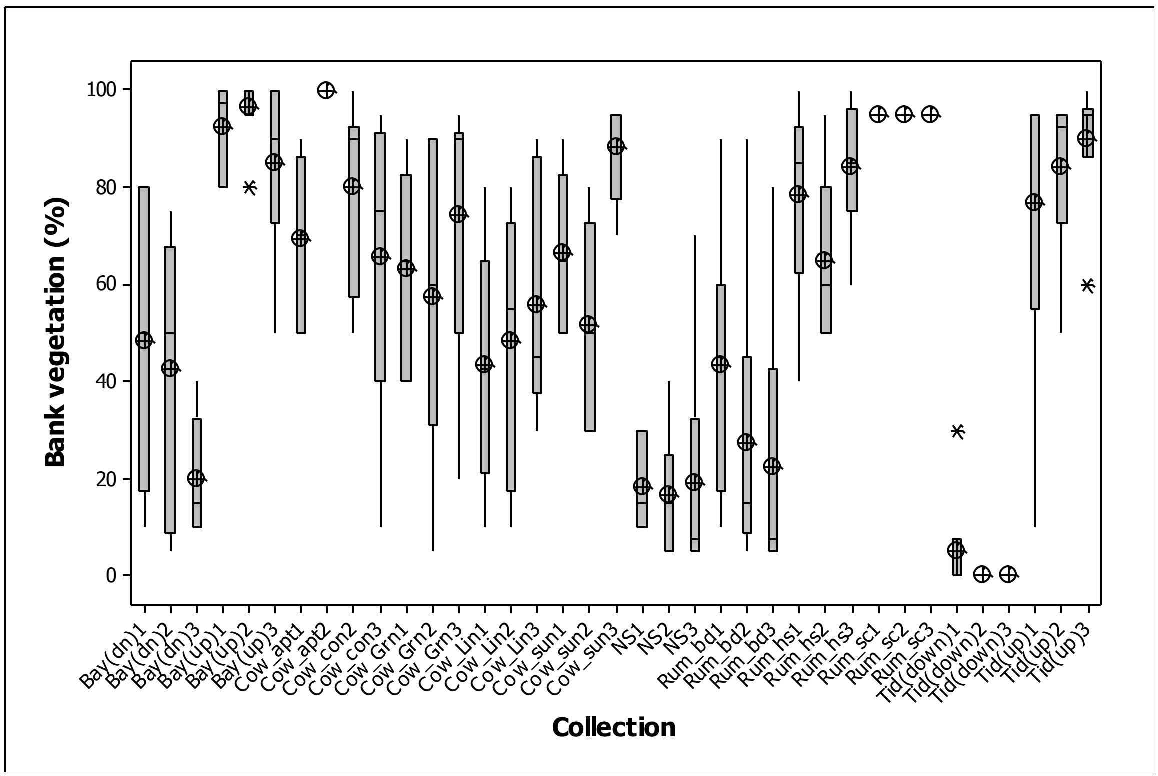

Figure 11: Bank vegetation per collection. Boxplots of interquartile range with median line and whiskers representing highest and lowest data values, * represents outliers. ANOVA (p=0.000, R^2=71.53). 1 = early spring 2007, 2 = late spring 2007, 3 = summer 2007.

Modified Wentworth scores were significantly different between collections (p= 0.000, R^2= 56.58) (Figure 12). Tid(up), Bay(dn), Rum_sc, Rum_hs, Cow_con, and Cow_Lin had the highest average modified Wentworth scores which indicates larger sediment sizes. Tid(down) had average modified Wentworth scores of zero which indicates smaller sediment. Cow_apt had the second lowest values. Sediment at that site consisted of clay and silt. As mentioned earlier, Table 2 contains stream substrate types for the sampling sites and Table 5 contains classifications for sediment sizes (modified Wentworth scale).

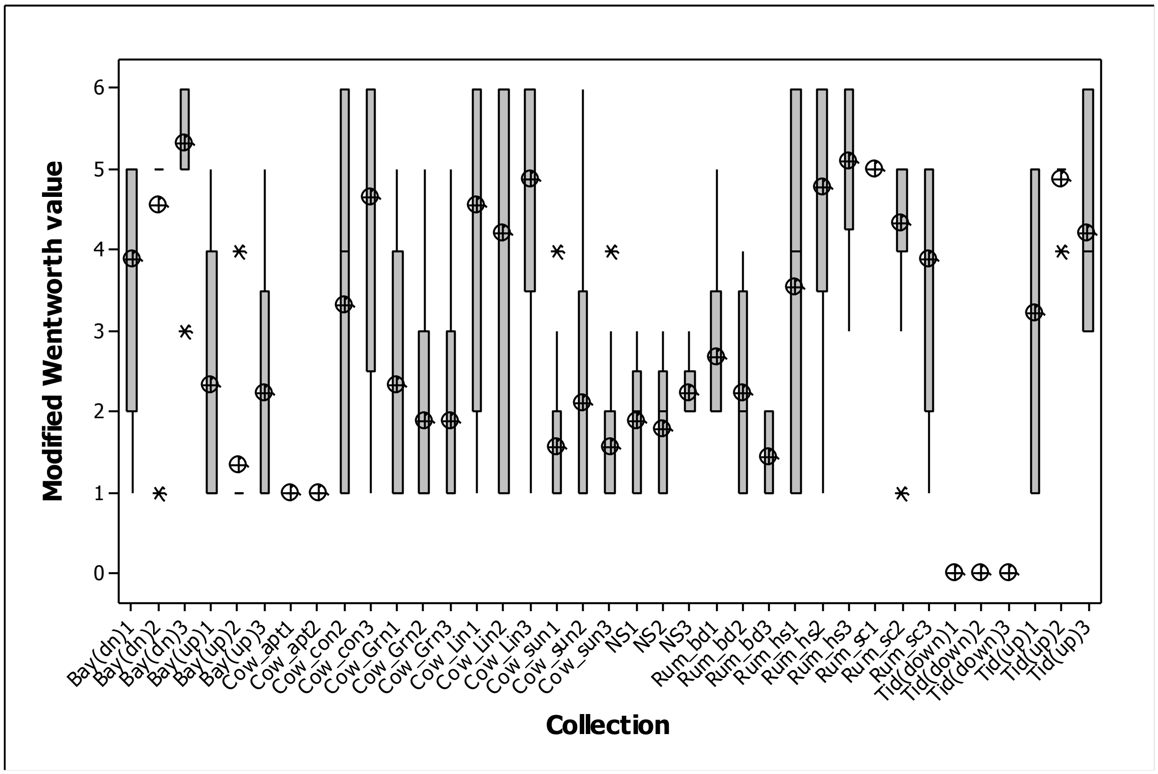

Figure 12: Sediment/substrate size based on modified Wentworth score per collection. Boxplots of interquartile range with median line and whiskers representing highest and lowest data values, * represents outliers. ANOVA (p=0.000, R^2=56.58). 1 = early spring 2007, 2 = late spring 2007, 3 = summer 2007.

Overhead shade measurements (i.e. canopy cover) were collected at each of the sites using a convex spherical densitometer (Figure 13). Shade values were significantly different between collections (p= 0.000, R^2= 92.87). High numbers denote more canopy cover at the site. NS and Rum_bd sites had the highest shade values. Cow_con, Cow_Lin, and Cow_Grn sites had lower shade values. The remainder of the sites had no shade/canopy cover and therefore exhibited the lowest values.

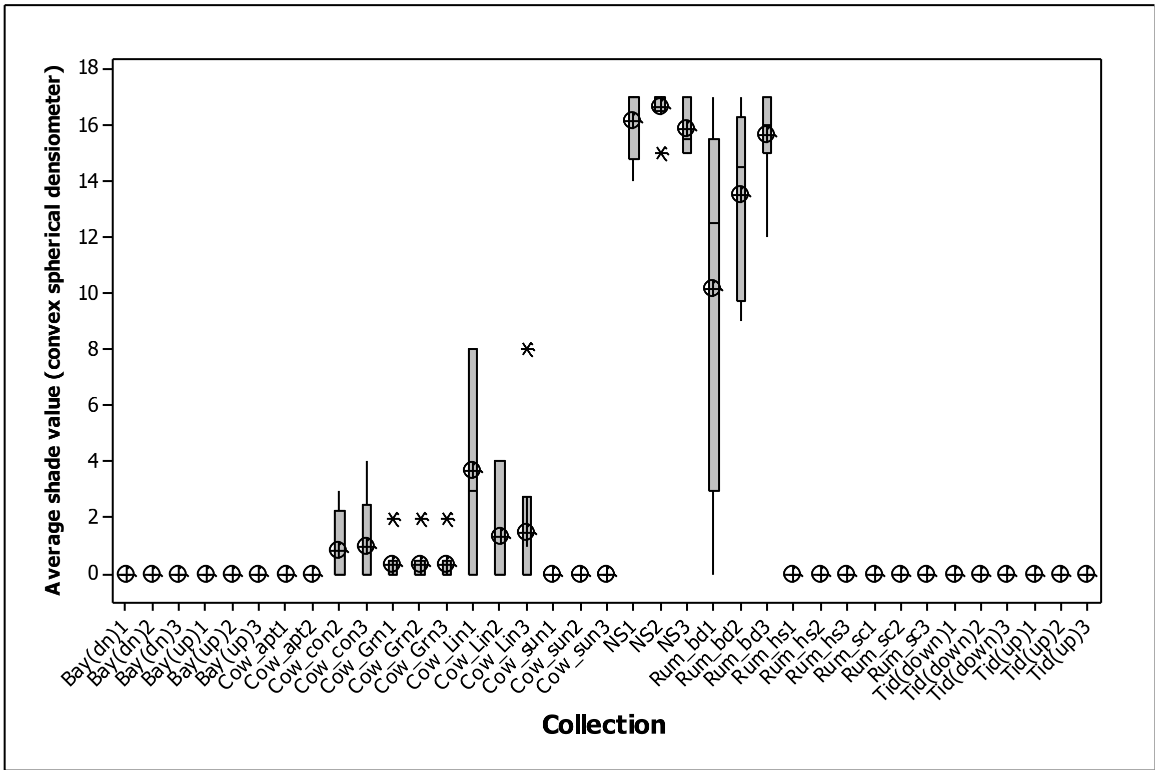

Figure 13: Shade value (0-17) per collection. Boxplots of interquartile range with median line and whiskers representing highest and lowest data values, * represents outliers. ANOVA (p=0.000, R^2=92.87). 1 = early spring 2007, 2 = late spring 2007, 3 = summer 2007.

Hydrology

The hydrology at each site varied throughout the study. Due to missing values caused by instrument failure, we were unable to conduct an ANOVA on the thalweg velocities. Some of the velocity measurements (mainly Coward's Creek sites) were based on the "float method" because of instrument failure (i.e. flow meter not working properly). Figure 14 illustrates the thalweg velocities at each collection. Average velocities ranged from 0.04 to 2.55 ft/sec (fps). In general, most of the sites exhibited higher velocities during the summer because of more frequent rainfall events. In some of the cases, this is due to rainfall events prior to sampling which increased the velocity of the stream. Bay(up), Bay(dn), Rum_bd, and Rum_hs sites generally exhibited lower velocities than the other sites. The majority of the Coward's Creek sites had higher velocities when compared to the other sites during the summer.

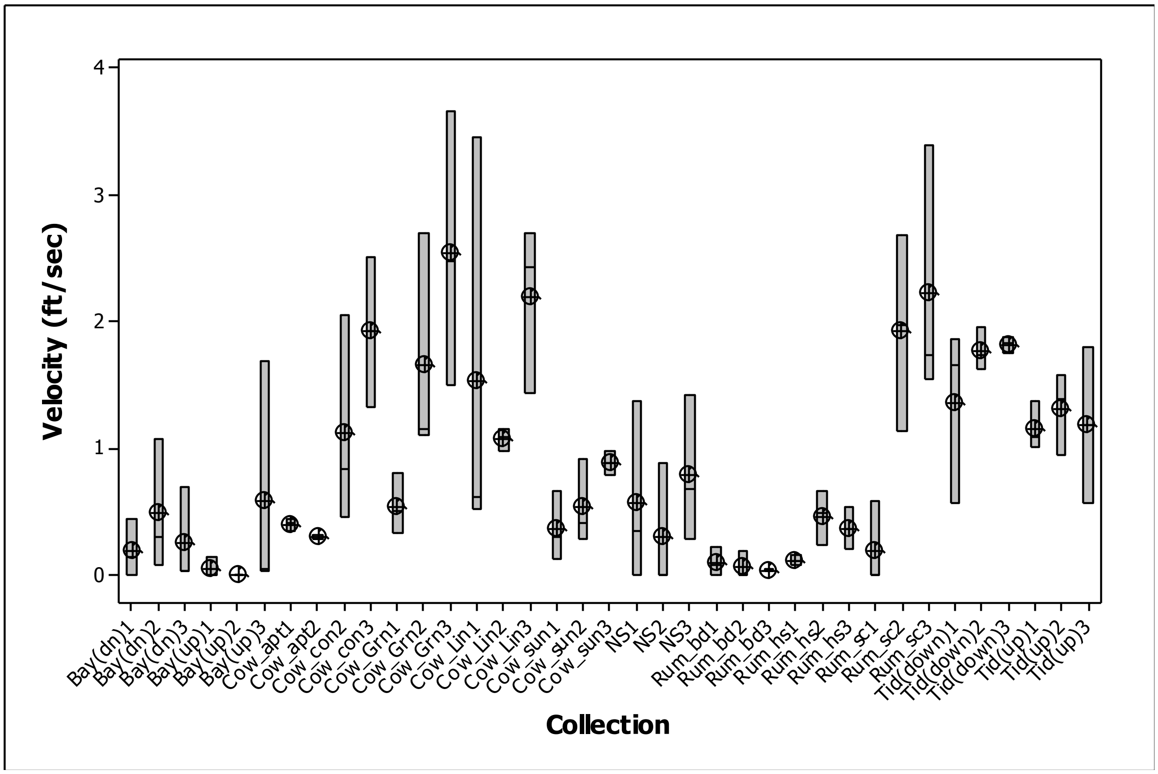

Figure 14: Thalweg velocities (ft/s) per collection. Boxplots of interquartile range with median line. 1 = early spring 2007, 2 = late spring 2007, 3 = summer 2007.

Flow was calculated at the majority of sites (Figure 15). The flow measurement for Tid(up) was also used for Tid(down) given the close proximity of the sites. Due to instrument failure, flow measurements for some of the sites (mainly Coward's Creek sites) and sampling events were not taken. White Oak Bayou sites [Tid(up) and Tid(down)] consistently exhibited high flow measurements (29 to 48 cfs) when compared to the other sites. This is expected given the size of the water body. NS, Bay(up), Bay(dn), Rum_bd, and Rum_hs consistently showed lower flow values compared to the other sites.

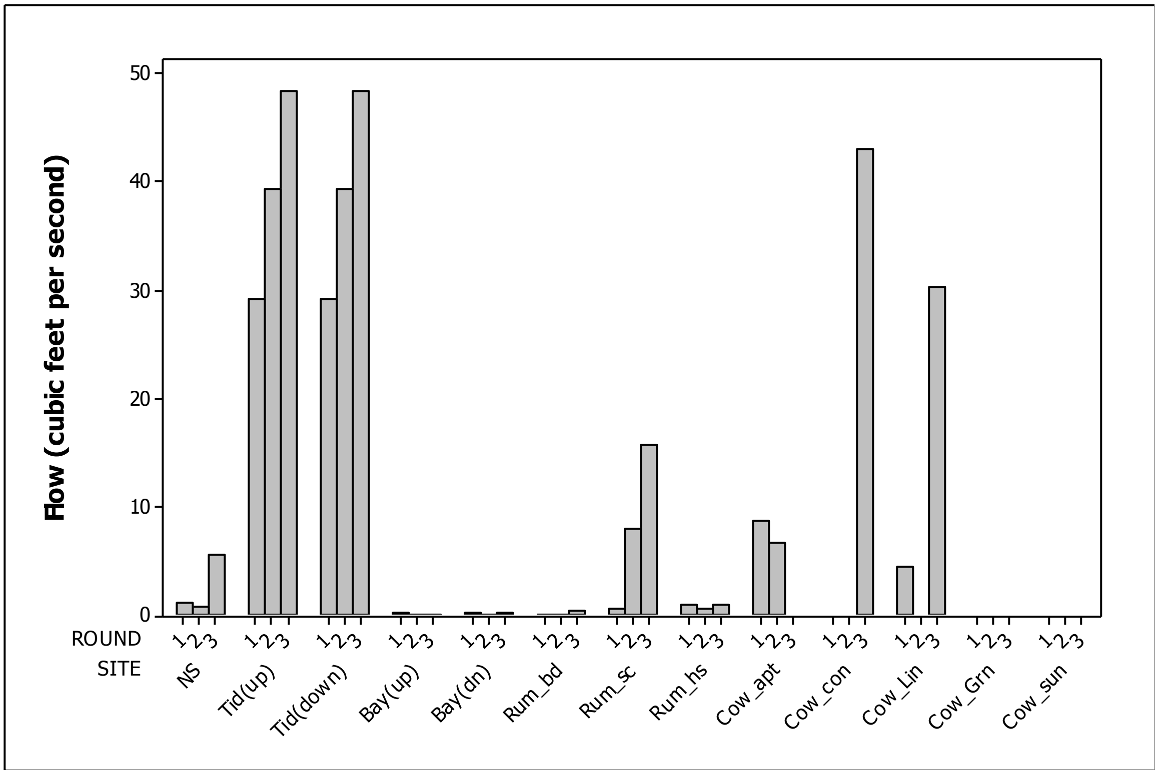

Figure 15: Flow (cfs) per collection. 1 = early spring 2007, 2 = late spring 2007, 3 = summer 2007.

Water Quality

Discussed below are the measured water quality variables at each site. An ANOVA was unable to be conducted on water quality measurements collected due to small sample size.

Water temperatures for the sites ranged from 15 to 35 degrees Celsius and followed expected seasonal trends (Figure 16). Summer sampling periods at sites Tid(down) and Bay(dn) exhibited the highest temperatures. Early spring sampling at sites Rum_bd and Rum_hs exhibited the lowest temperatures. Rum_bd contained a lot of riparian tree canopy cover which likely explains the lower water temperature.

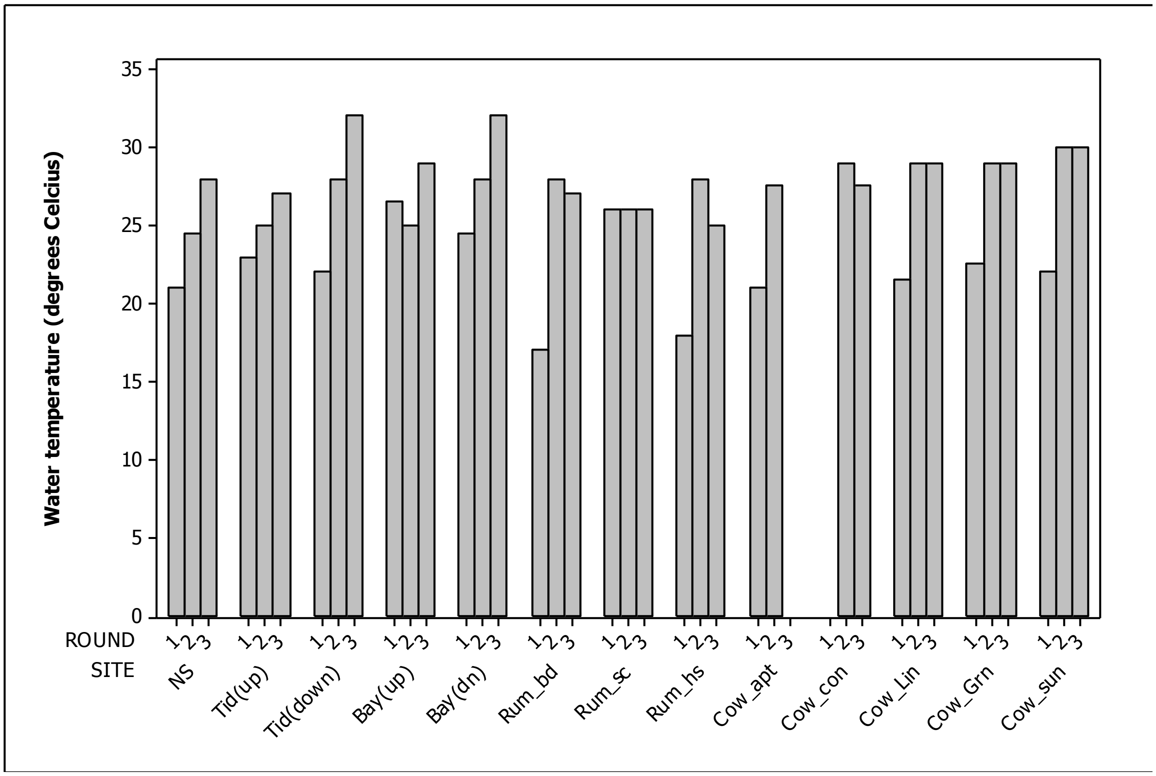

Figure 16: Water temperature measured during each collection. 1 = early spring 2007, 2 = late spring 2007, 3 = summer 2007.

Specific conductance measurements were taken during each collection (Figure 17). The Coward's Creek site exhibited high specific conductance measurements when compared to the other sites. The elevated levels at Coward's Creek are probably due to brine leakage from inactive, improperly sealed oil wells in the watershed. In general, specific conductance levels declined between early spring through summer. Higher rainfall amounts in the summer time likely explain the drop in specific conductivity levels.

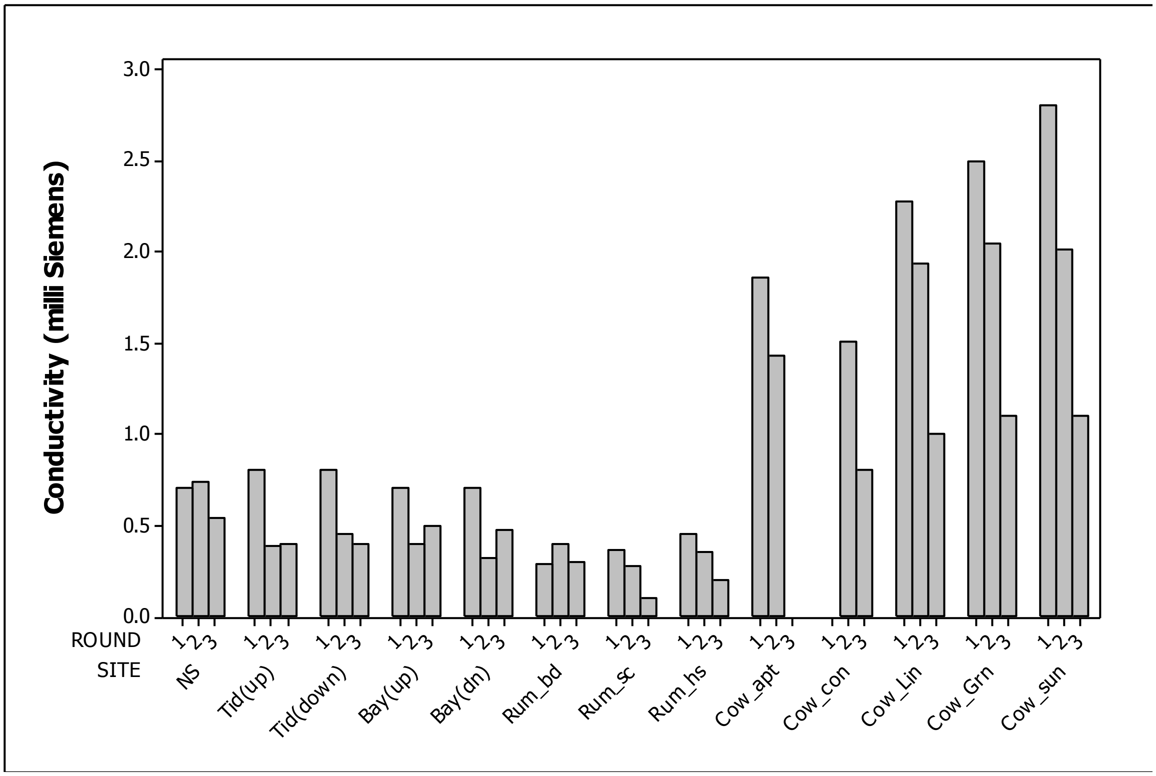

Figure 17: Specific conductivity measurements per collection. 1 = early spring 2007, 2 = late spring 2007, 3 = summer 2007.

Values for pH for the sites ranged from 6.8 to 9.5 (Figure 18). Cow_sun (summer collection) had the lowest pH value and Rum_sc (early spring) had the highest pH value. All values appeared to be within the range that supports freshwater fishes.

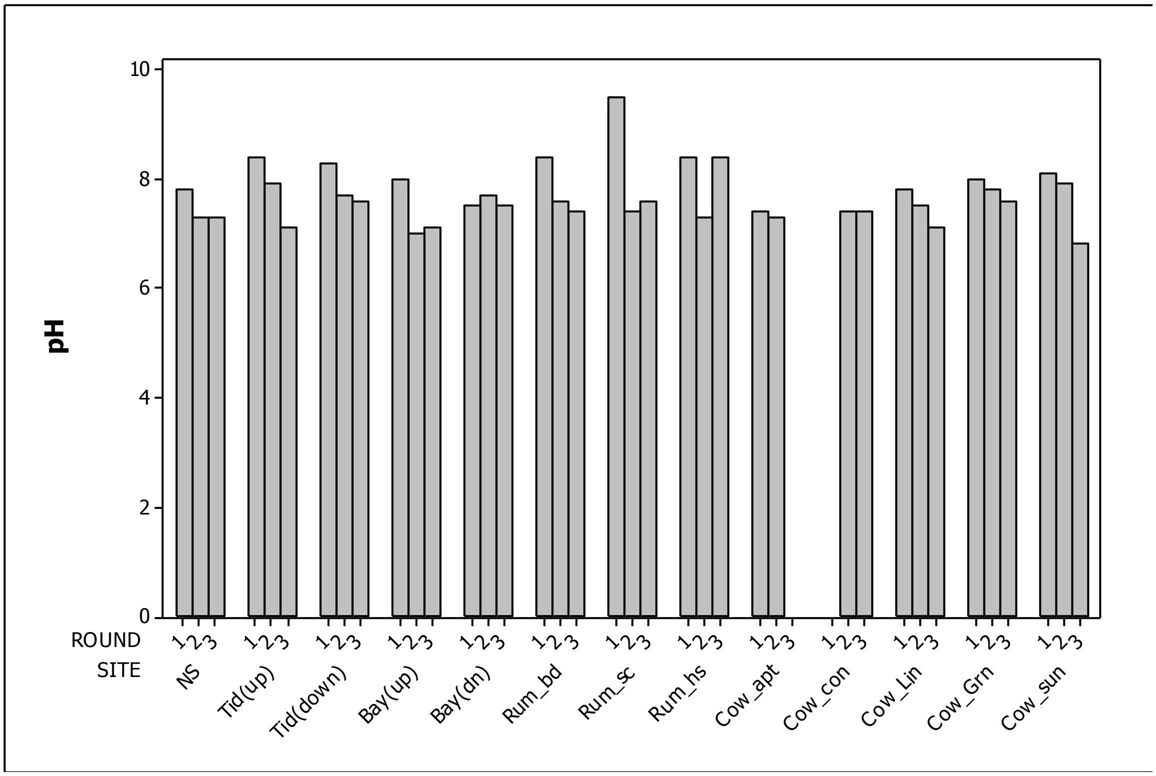

Figure 18: pH measurements per collection. 1 = early spring 2007, 2 = late spring 2007, 3 = summer 2007.

Dissolved oxygen levels varied throughout the sites (Figure 19). Dissolved oxygen levels ranged from 2.2 to 8.5 mg/L. Dissolved oxygen is generally lower in the morning and increases throughout the day. During some sampling events we sampled multiple sites on the same day. Therefore, dissolved oxygen measurements were collected at different times of the day. This explains some of the variability in the values measured. With the exception of the low value measured at Bay (up) most values were within the range of dissolved oxygen supportive of freshwater fishes.

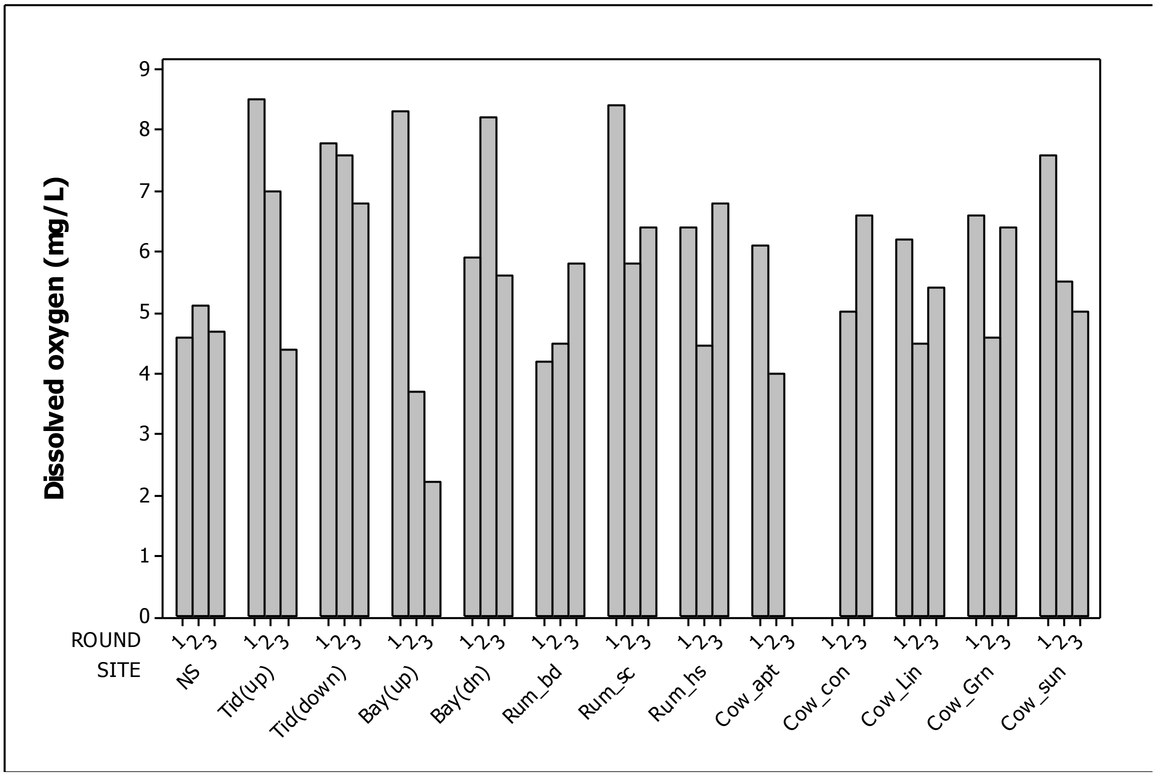

Figure 19: Dissolved oxygen values measured during collections at each site. 1 = early spring 2007, 2 = late spring 2007, 3 = summer 2007.

Ammonia levels varied throughout the sites (Figure 20). Levels ranged from 0.1 to 1.0 mg/L NH_4-N). Ammonia levels were not collected at the Cow_Grn and Cow_sun sites. Tid(up) (early and late spring collections) had the lowest ammonia levels. Cow_Lin had the highest ammonia level.

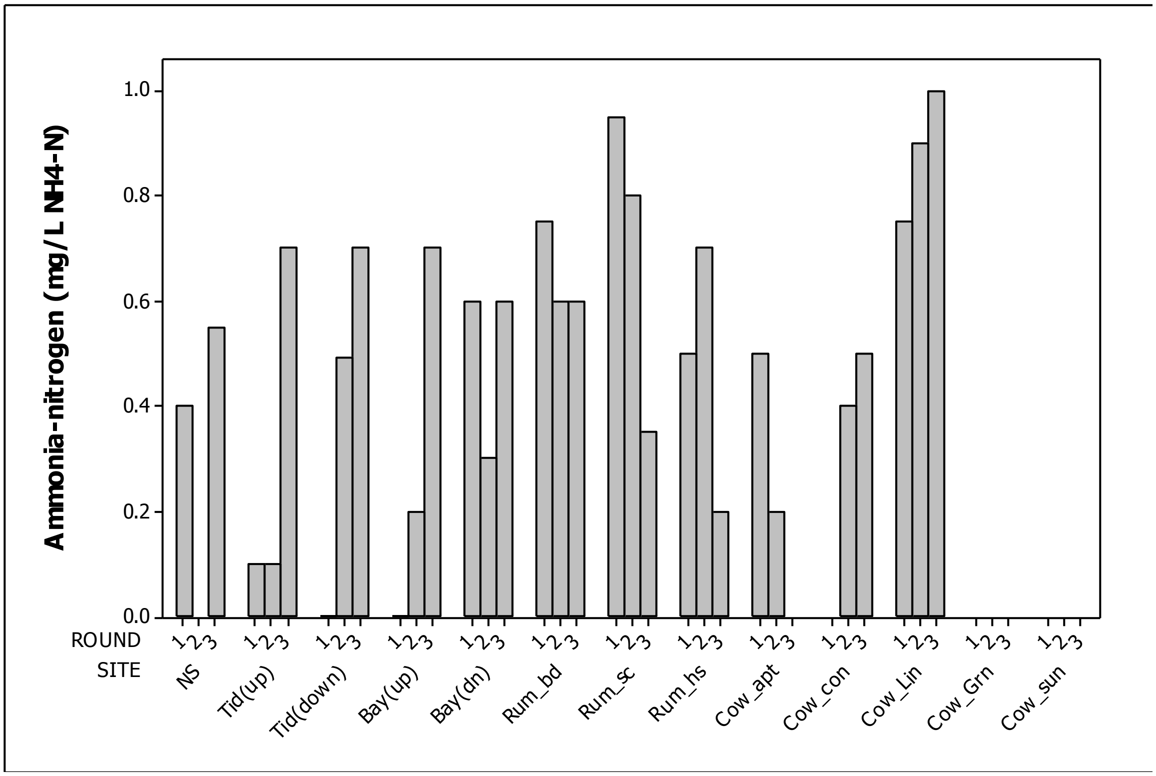

Figure 20: Total ammonia levels per collection. 1 = early spring 2007, 2 = late spring 2007, 3 = summer 2007.

Nitrate levels were highest at Tid(up) and Tid(down) sites during the summer sampling period (1.0 mg/L) (Figure 21). Baytown sites generally had the lowest nitrate levels. Nitrate levels were not measured not at the Cow_Grn and Cow_sun sites given the close proximity to the Cow_Lin site.

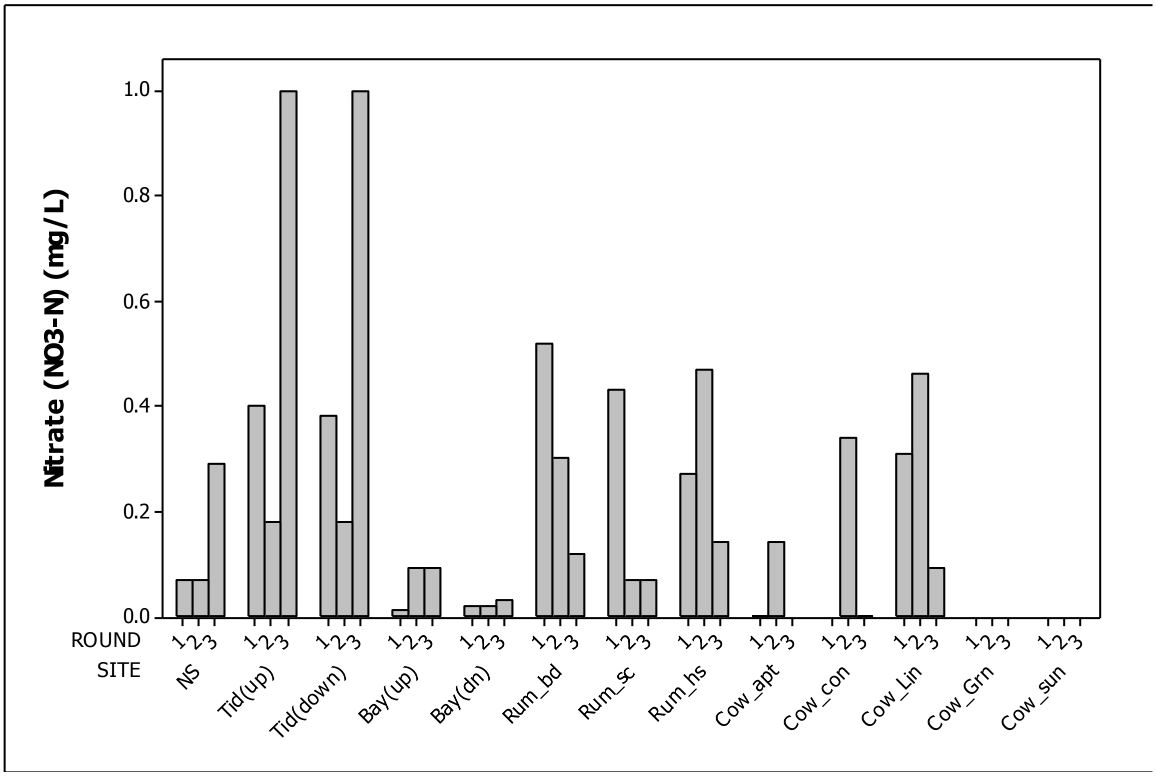

Figure 21: Nitrate levels per collection. 1 = early spring 2007, 2 = late spring 2007, 3 = summer 2007.

Nitrite levels were highest at Rum_bd (early spring), Rum_sc (early spring), Rum_hs (late spring), and Cow_Lin (late spring) (Figure 22). Bay(up), Bay(dn), NS had the lowest nitrite levels. Nitrite levels were not collected at the Cow_Grn and Cow_sun sites given the close proximity to the Cow_Lin site.

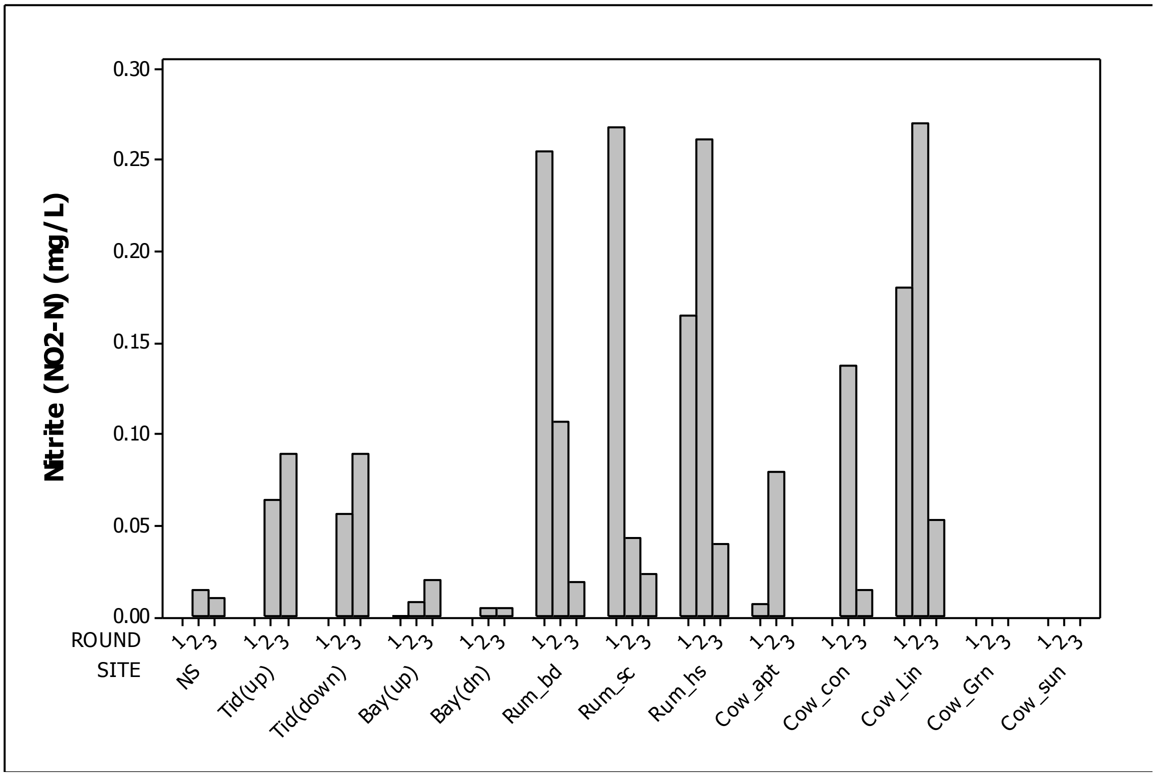

Figure 22: Nitrite levels per collection. 1 = early spring 2007, 2 = late spring 2007, 3 = summer 2007.

Phosphorous (orthophosphate) levels were highest at Tid(up) and Tid(down) sites (Figure 23). Phosphorous levels were not collected at the Cow_Grn and Cow_sun sites given the close proximity to the Cow_Lin site.

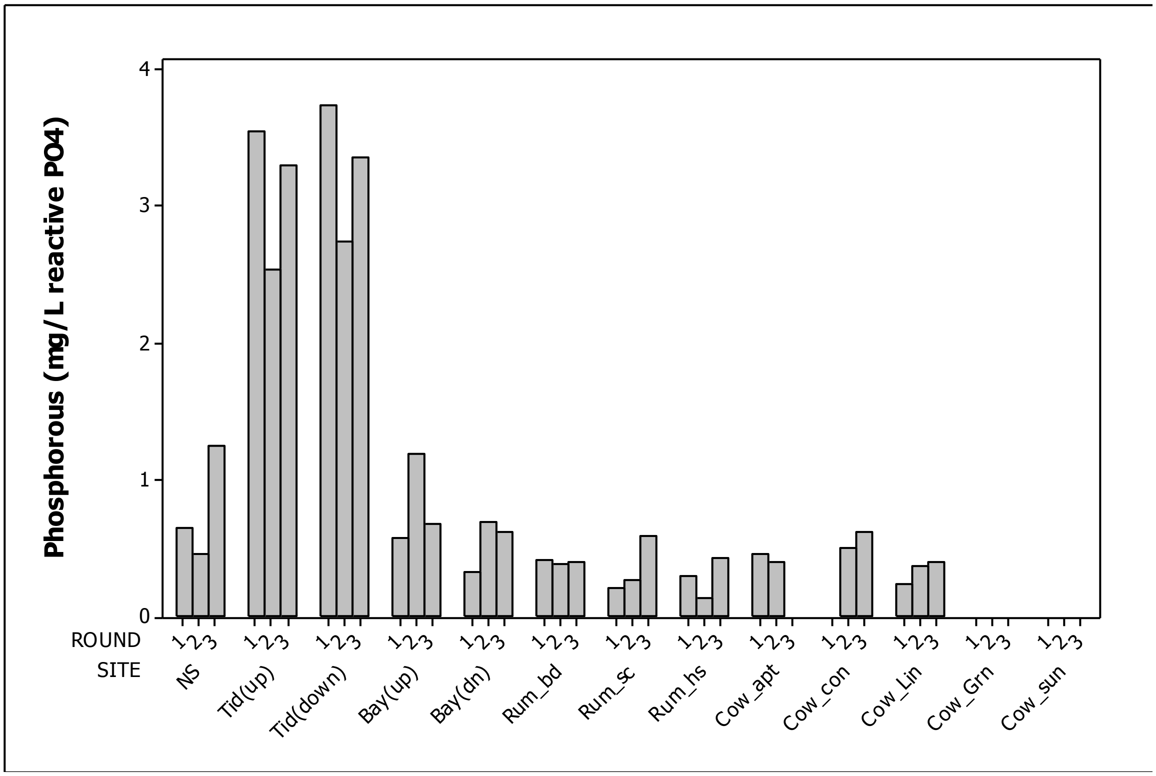

Figure 23: Phosphorous (orthophosphate) levels per collection. 1 = early spring 2007, 2 = late spring 2007, 3 = summer 2007.

Cow_Lin (late spring) and Cow_con (late spring) had the highest hardness (Ca) levels (Figure 24). Hardness (Ca) levels were not collected at the Cow_Grn and Cow_sun sites given the close proximity to the Cow_Lin site.

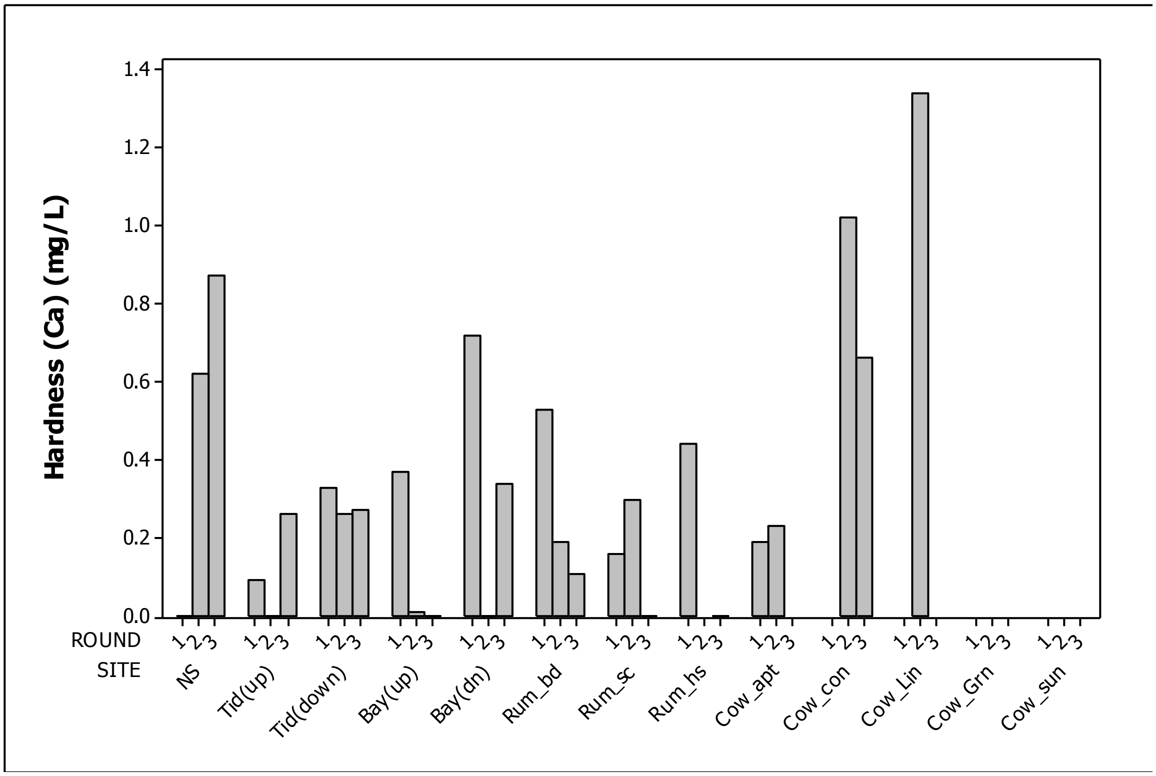

Figure 24: Hardness (Ca) levels measured at each collection. 1 = early spring 2007, 2 = late spring 2007, 3 = summer 2007.

Tid(up) (summer) had the highest hardness (Mg) levels (Figure 25). Cow_apt, Cow_con, and Cow_Lin had the lowest hardness (Mg) levels. Hardness (Mg) levels were not collected at the Cow_Grn and Cow_sun sites given the close proximity to Cow_Lin.

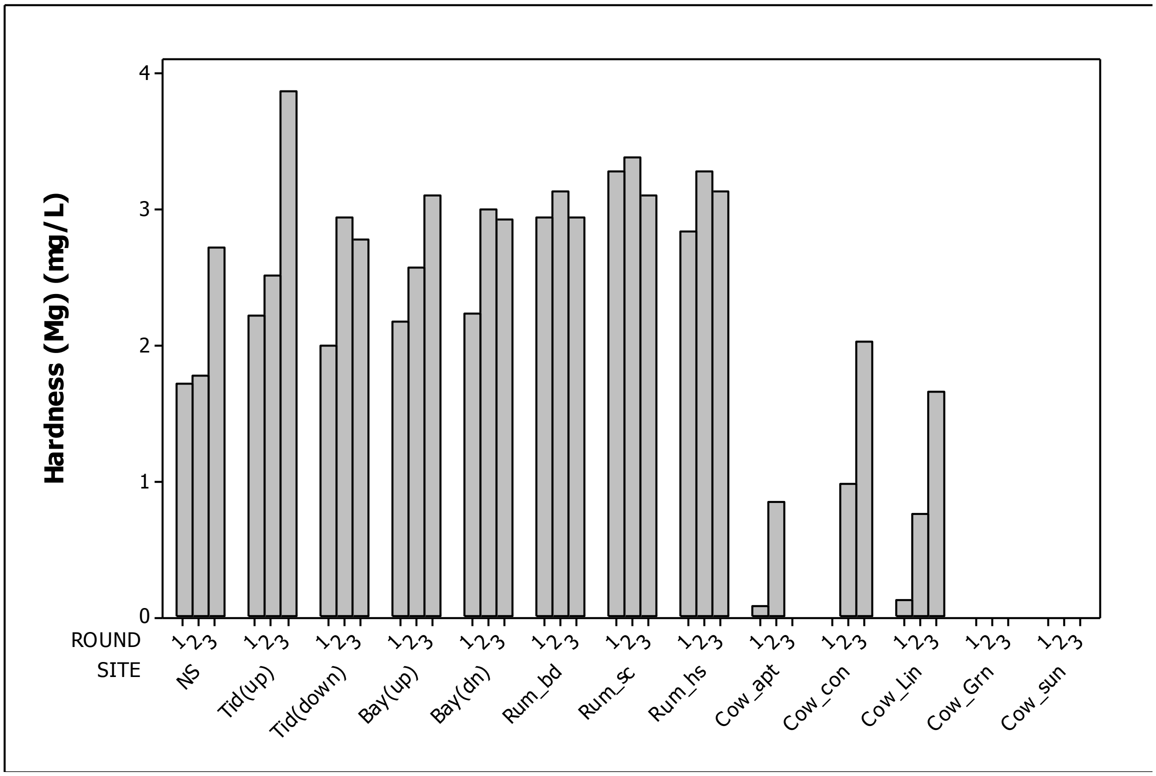

Figure 25: Hardness (Mg) levels measured at each collection. 1 = early spring 2007, 2 = late spring 2007, 3 = summer 2007.

Bay(up) (early spring) and Bay(dn) (early spring) had the highest alkalinity levels (Figure 26). Rummels Creek sites had the lowest alkalinity levels. Alkalinity levels were not collected at the Cow_Grn and Cow_sun sites given the close proximity to the Cow_Lin site.

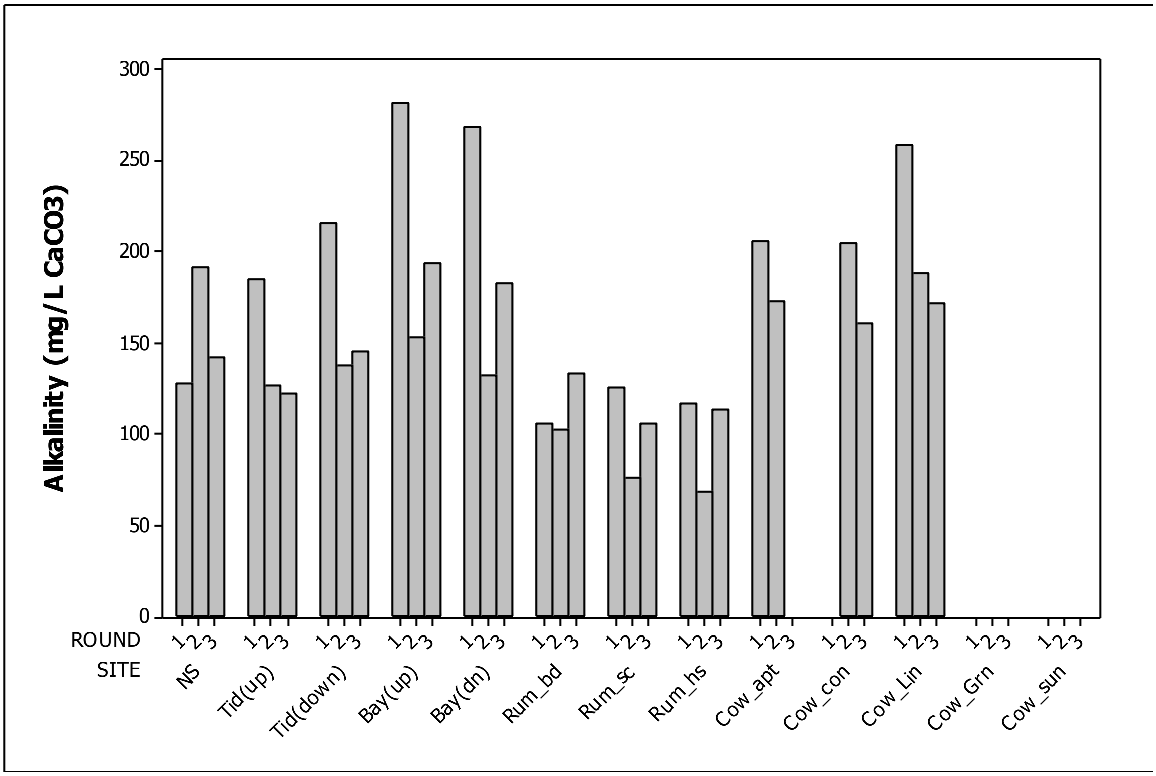

Figure 26: Alkalinity levels per collection. 1 = early spring 2007, 2 = late spring 2007, 3 = summer 2007.

Rum_bd (late spring) had the highest secchi tube measurement (Figure 27) which indicates higher water clarity (less turbid). Cow_con generally had the lowest secchi tube measurements which indicate lower water clarity (more turbid).

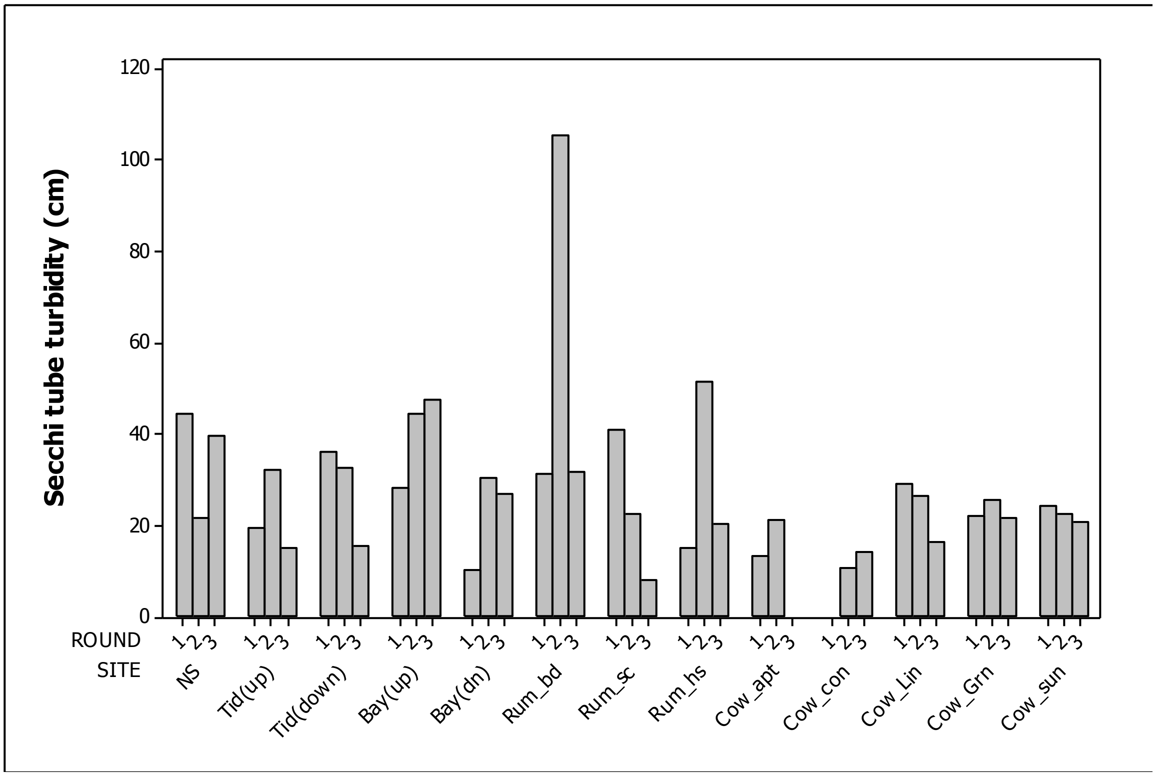

Figure 27: Secchi tube measurements made during collection at each site. 1 = early spring 2007, 2 = late spring 2007, 3 = summer 2007.

TSS levels were highest at Rum_sc (summer), Tid(down) (late spring), and Bay(dn) (early spring) (Figure 28). NS, Bay(up), and Rum_bd sites had the lowest TSS levels. TSS measurements were not collected at the Cow_Grn and Cow_sun sites given the close proximity to the Cow_Lin site. TSS and secchi measurements are inversely related. In general, a higher TSS reading indicates a lower secchi reading and vice versa.

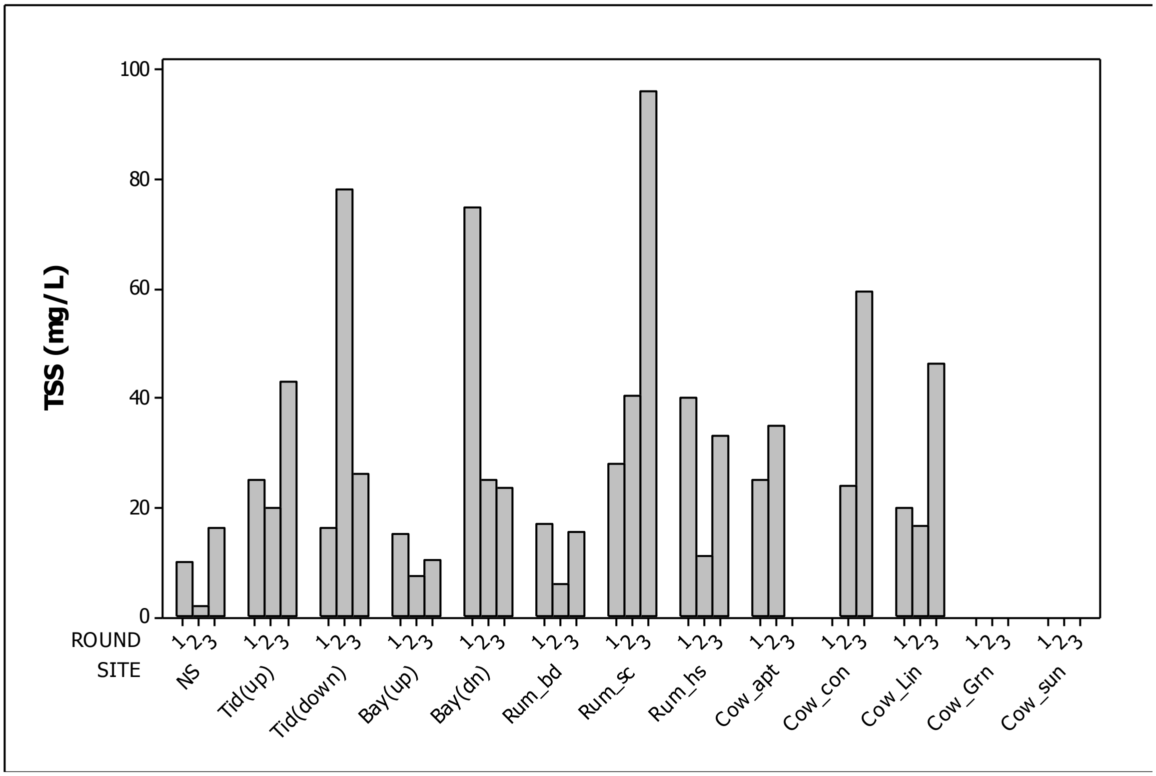

Figure 28: Total Suspended Solids levels per collection. 1 = early spring 2007, 2 = late spring 2007, 3 = summer 2007.

Chlorophyll a levels were generally higher at Rum_bd and Rum_hs sites (Figure 29). Chlorophyll a levels were generally lower at NS, Bay(up), Cow_apt, Cow_con, and Cow_Lin sites. Chlorophyll a levels were not collected at the Cow_Grn and Cow_sun sites given the close proximity to the Cow_Lin site. Higher chlorophyll a levels generally indicate eutrophication (very productive and fertile; low clarity). Lower chlorophyll a levels generally indicate oligotrophic conditions (nutrient poor and low productivity; high clarity)

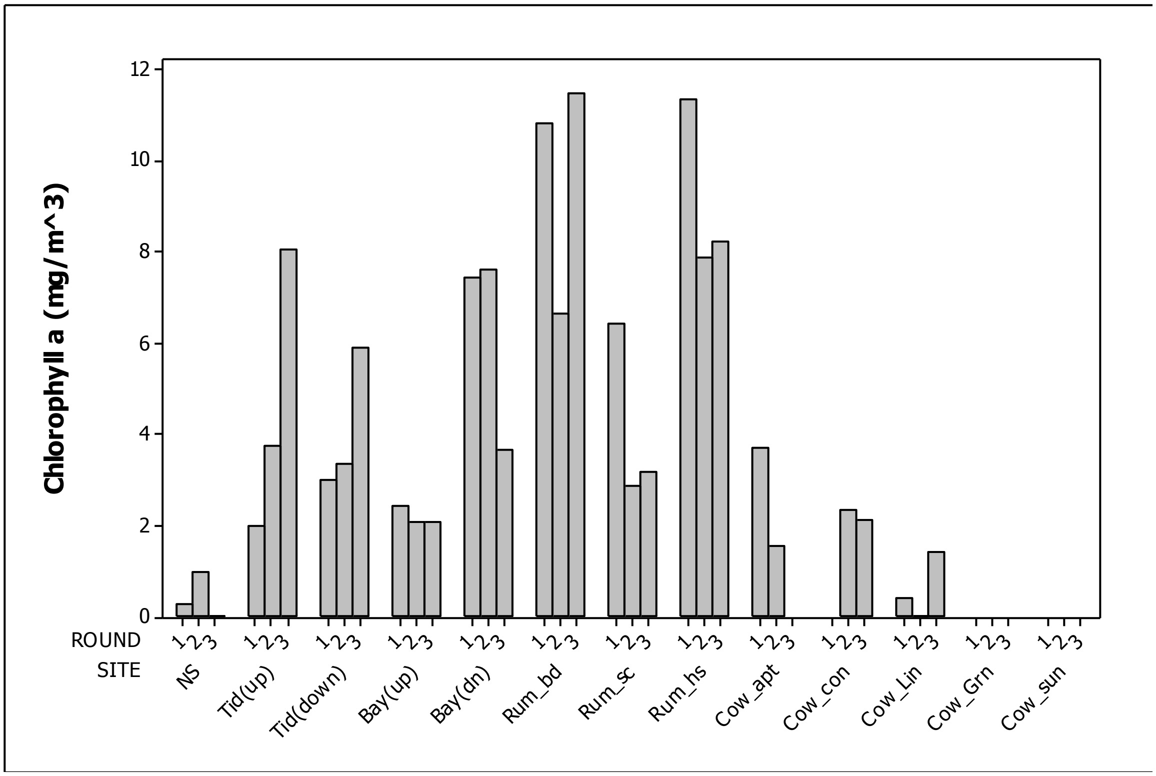

Figure 29: Chlorophyll a levels measured in samples collected at each site. 1 = early spring 2007, 2 = late spring 2007, 3 = summer 2007.

Total and free chlorine was measured at most of the sites. However we experienced instrument trouble and/or interference. In addition, the detection limits were too high and above biologically significant screening levels. Chlorine values obtained from these sites were therefore not analyzed. However, given the presence of fish and attached algae at all sites it is highly unlikely high and/or toxic amounts of free chlorine were present.

Biological Results

During this study we collected 7,422 fish representing 33 taxa in seine collections, and 758 fish representing 23 taxa with electroshocking for a total of 8,180 fish and 35 total taxa. *Gambusia affinis* (western mosquitofish) had the highest number of individuals (5,953) followed by *Pimephales vigilax* (bullhead minnow) (584) and *Cyprinella lutrensis* (red shiner) (550).

Three different taxa of non-native introduced fish species were collected including Rio Grande cichlid *Cichlasoma cyanoguttatum* – 29, Common carp *Cyprinus carpio* – 19, and armored catfish *Pterygoplicthys spp*. – 1).

Seine Catch Results:

The total numbers of fish per site and seine haul are illustrated in Figures 30 and 31. The site Bay(up) (early spring) had the highest number of fish caught (1,063) and highest mean. The other Bay(up) sites, Bay(dn), Rum_bd, Rum_hs, and Cow_apt in general had higher total numbers of fish than the sites NS, Tid(up), Tid(down), Rum_sc, Cow_con, Cow_Lin, Cow_Grn, and Cow_sun. The results of an ANOVA suggest that there is significant difference in total numbers of fish between sites (p=0.000, R^2 = 47.89). Some of the variability in the total numbers of fish caught between sites, particularly the sites NS and Tid(up), can be explained by the debris/snags in the stream and high water velocities resulting in loss of catch or no catch.

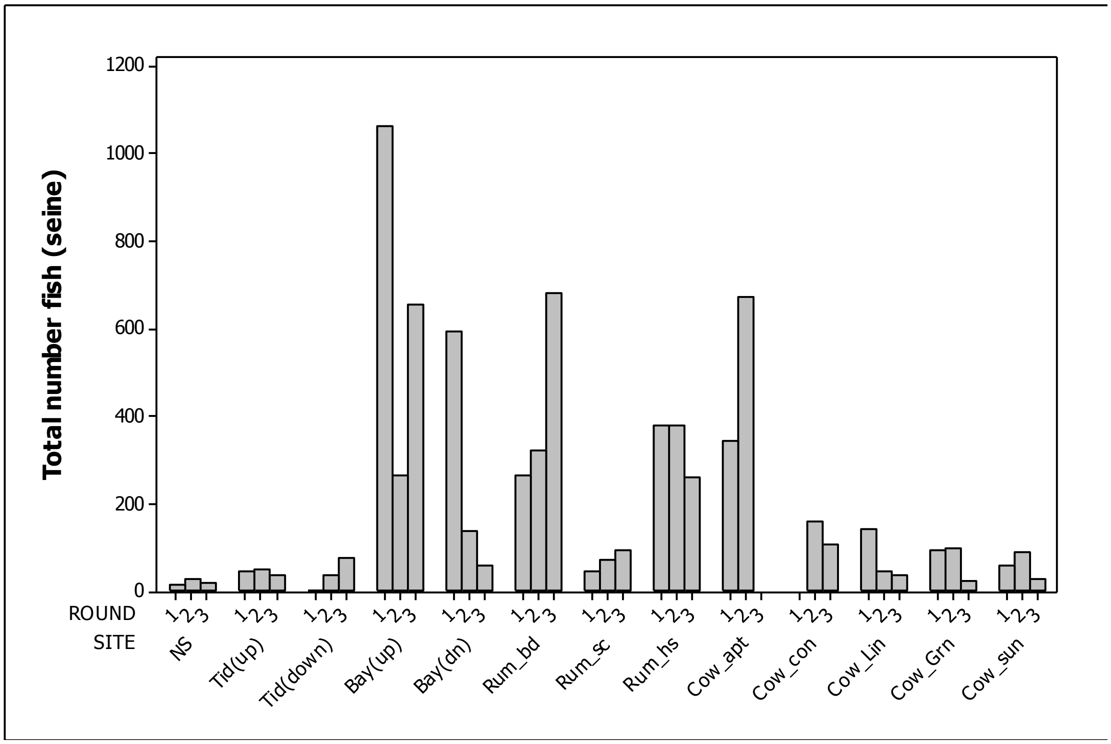

Figure 30: Total number of fish collected (seining) at each site during each season.

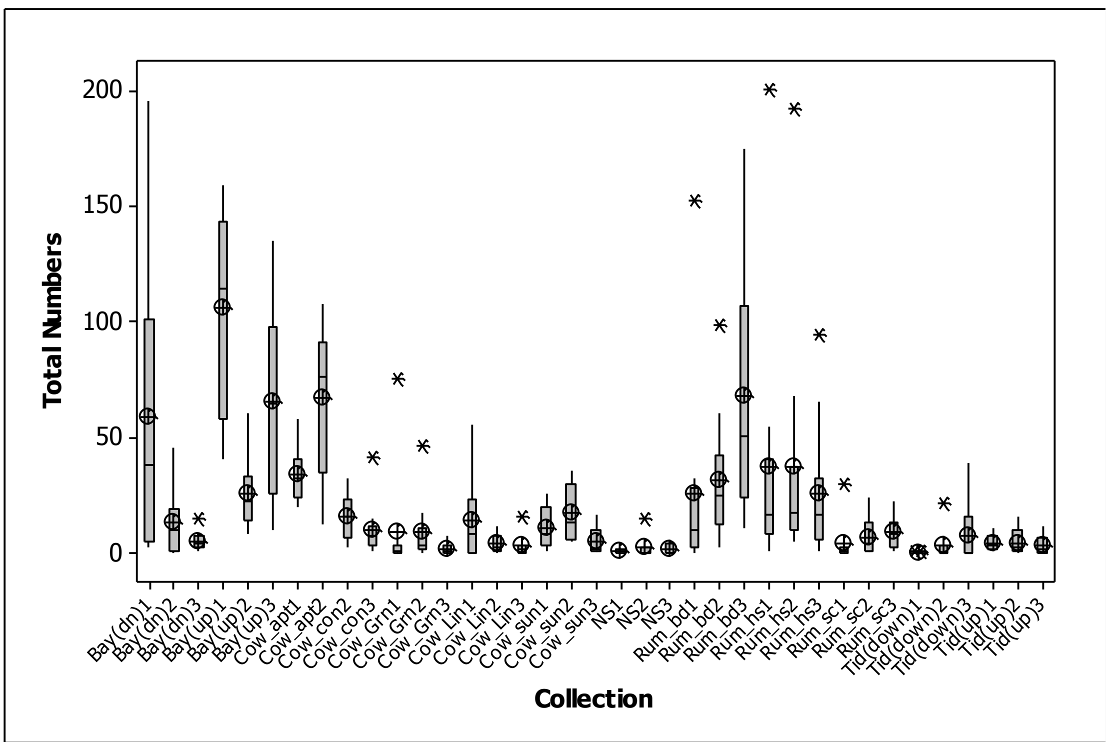

Figure 31: Total number of fish collected per seine haul per collection. Boxplots of interquartile range with median line and whiskers representing highest and lowest data values, * represents outliers. ANOVA (p=0.000, R^2=47.89). Collection = site name + collection period (1 – early spring, 2 – late spring, 3 – summer).

Community richness (number of taxa) in general was highest at most of the Coward's Creek sites (Figure 32). Richness in general was lower at the Northshore and White Oak at Tidwell sites. The results of the ANOVA revealed a significant difference between sites for fish community richness (p=0.000, R^2=54.50).

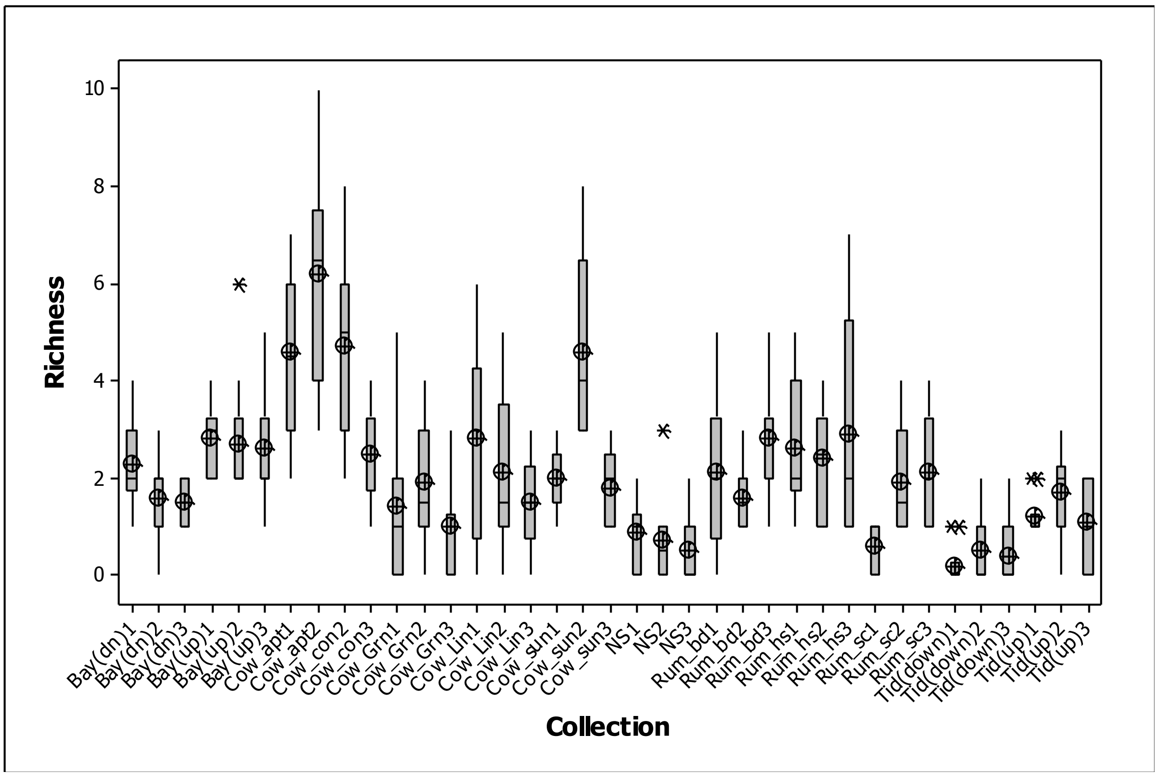

Figure 32: Richness per collection (seining). Boxplots of interquartile range with median line and whiskers representing highest and lowest data values, * represents outliers. ANOVA (p=0.000, R^2 = 54.50). Collection = site name + collection period (1 – early spring, 2 – late spring, 3 – summer).

The site with the lowest community evenness was Bay(up) during the early spring (Figure 33). Rummels Creek sites and Cow_apt also had low evenness values. Rum_sc, Tid(down), and NS during the early spring had the highest mean evenness scores. These three sites also had the lowest total number of fish. There was a significant difference between sites based on ANOVA results (p=0.000, R^2 =39.74).

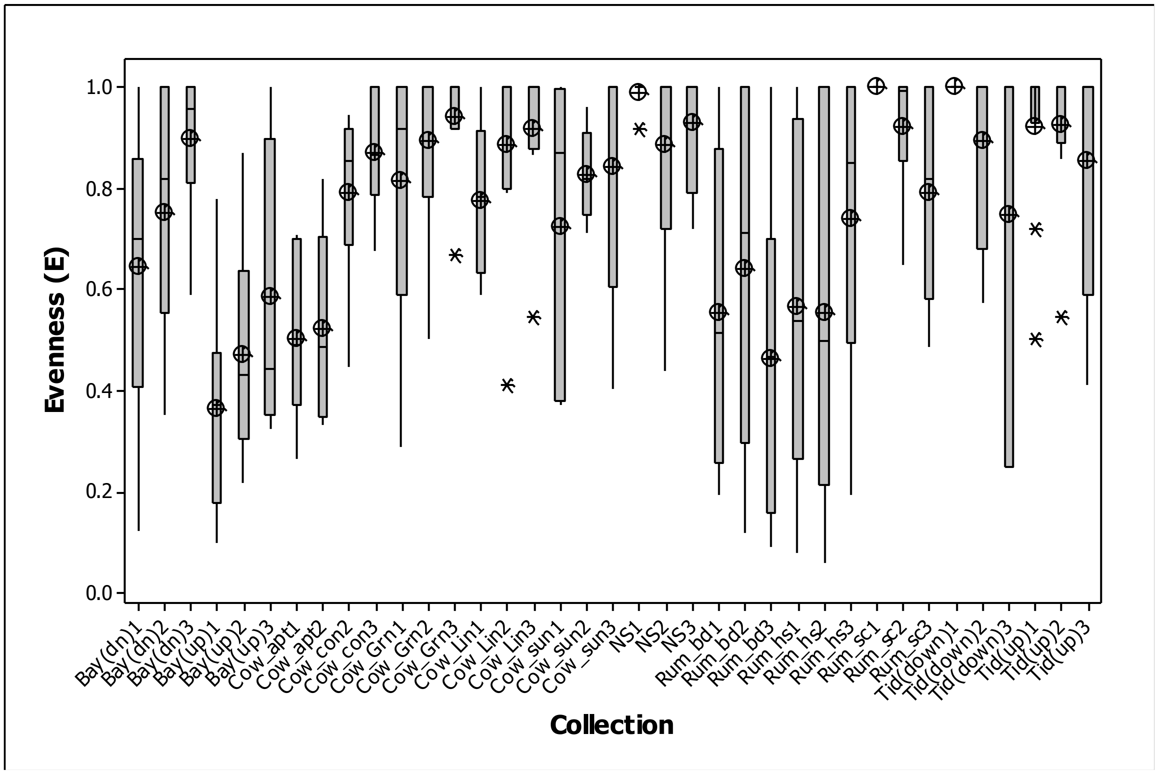

Figure 33: Evenness per collection (seining). Boxplots of interquartile range with median line and whiskers representing highest and lowest data values,   * represents outliers. ANOVA results (p=0.000, R^2=39.74). Collection = site name + collection period (1 – early spring, 2 – late spring, 3 – summer).

The fish community diversity, measured using the Shannon-Wiener Index, is illustrated in Figure 34. Rum_sc (early spring) and Tid(down) (early spring) had diversity values of zero. The majority of the Coward's Creek sites had higher mean diversity values than the other sites. The results of an ANOVA suggest that there is significant difference between sites (p=0.000, R^2=38.84).

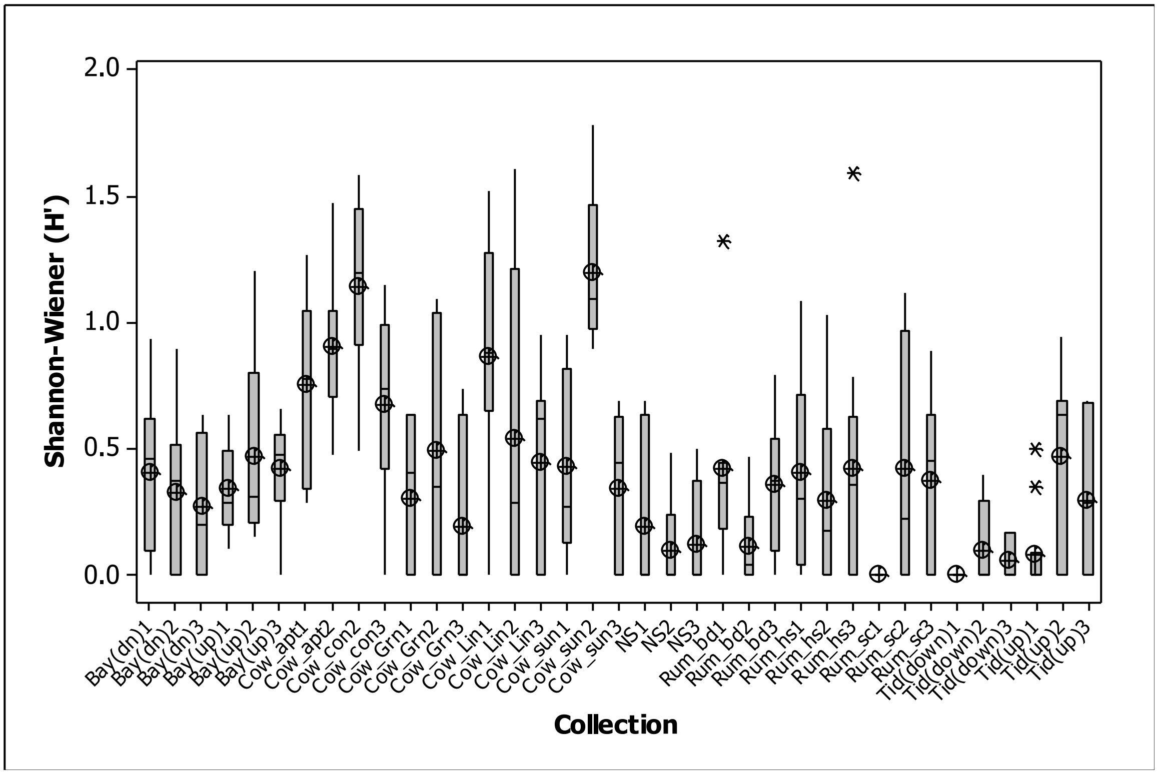

Figure 34: Fish Community Diversity per collection (seining). Boxplots of interquartile range with median line and whiskers representing highest and lowest data values, * represents outliers. ANOVA results (p=0.000, R^2=38.84). Collection = site name + collection period (1 – early spring, 2 – late spring, 3 – summer).

A normality test was performed on the seining data by substrate type for total numbers, richness, evenness, and diversity. Results indicated that all of the data was not normal therefore a Krustal-Wallis test (nonparametric alternative to a one-way ANOVA) was performed per substrate type for the abovementioned four parameters.

Krustal-Wallis results indicate significant differences for total numbers of fish per seine haul per substrate type (p=0.000, H=80.75) (Figure 35). Significant differences were found for concrete vs. earthen, concrete vs. rip rap, earthen vs. earthen/rip rap, earthen/rip rap vs. rip rap, ACB vs. earthen, concrete vs. unmodified earthen, cobble/plastic vs. earthen, earthen vs. unmodified earthen, ACB vs. rip rap, cobble/plastic vs. rip rap, rip rap vs. unmodified earthen, and cobble/plastic vs. concrete. For example, earthen substrate contained a significantly higher number of fish per seine haul than the concrete-lined substrate.

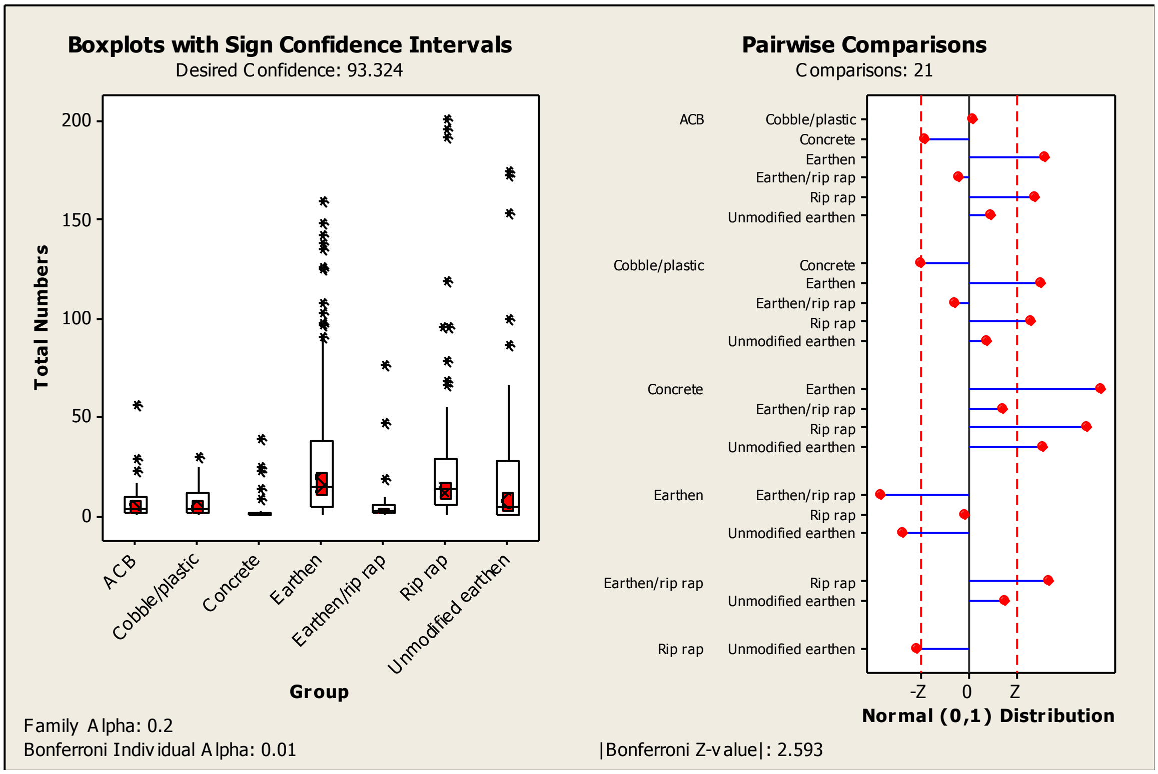

Figure 35: Total number of fish collected per seine haul per substrate type. Boxplots of interquartile range with median line and whiskers representing highest and lowest data values, * represents outliers. Pairwise comparisons – lines past dashed lines are significantly different. Krustal-Wallis (p=0.000, H=80.75).

Krustal-Wallis results indicate significant differences for richness values (seining) per substrate type (p=0.000, H=86.09) (Figure 36). Significant differences were found for concrete vs. earthen, concrete vs. rip rap, ACB vs. concrete, earthen vs. earthen/rip rap, concrete vs. earthen/rip rap, concrete vs. unmodified earthen, cobble/plastic vs. earthen, earthen vs. unmodified earthen, rip rap vs. unmodified earthen, and cobble/plastic vs. concrete.

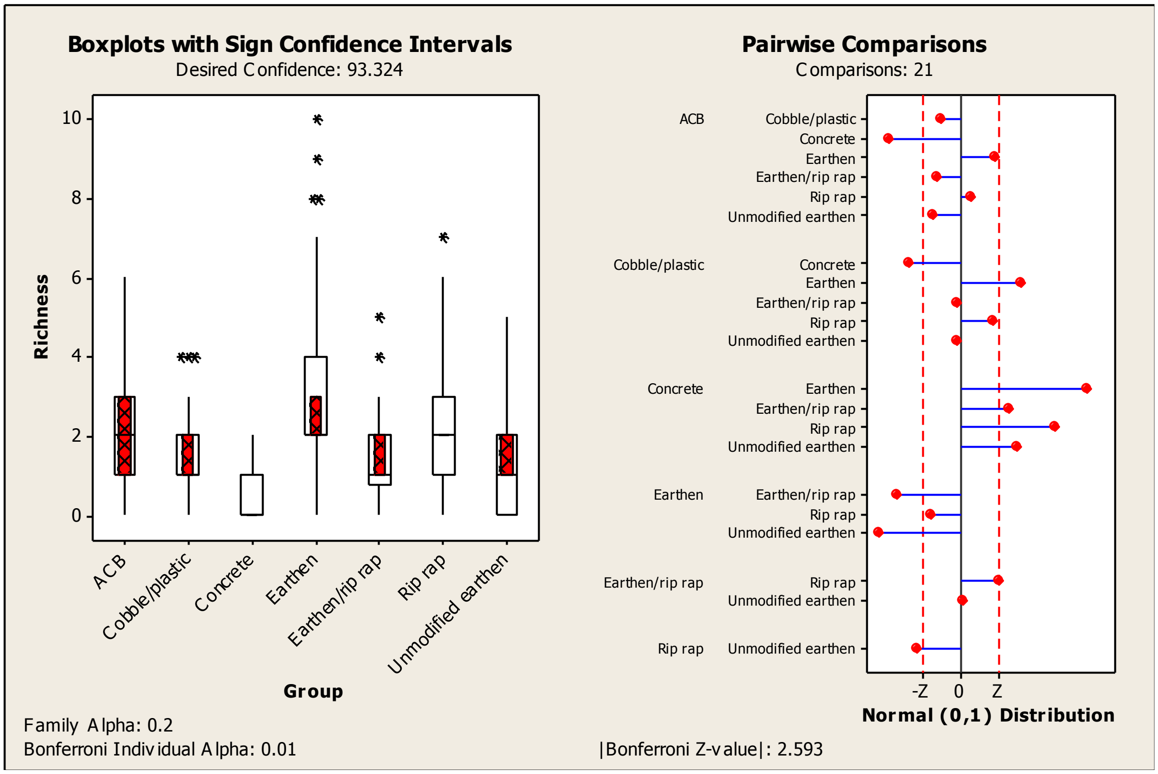

Figure 36: Richness values (seining) per substrate type. Boxplots of interquartile range with median line and whiskers representing highest and lowest data values, * represents outliers. Pairwise comparisons – lines past dashed lines are significantly different. Krustal-Wallis (p=0.000, H=86.09).

Krustal-Wallis results indicate significant differences for evenness values (seining) per substrate type (p=0.000, H=27.09) (Figure 37). Significant differences were found for ACB vs. earthen, earthen vs. earthen/rip rap, earthen/rip rap vs. rip rap, cobble/plastic vs. rip rap, and cobble/plastic vs. earthen.

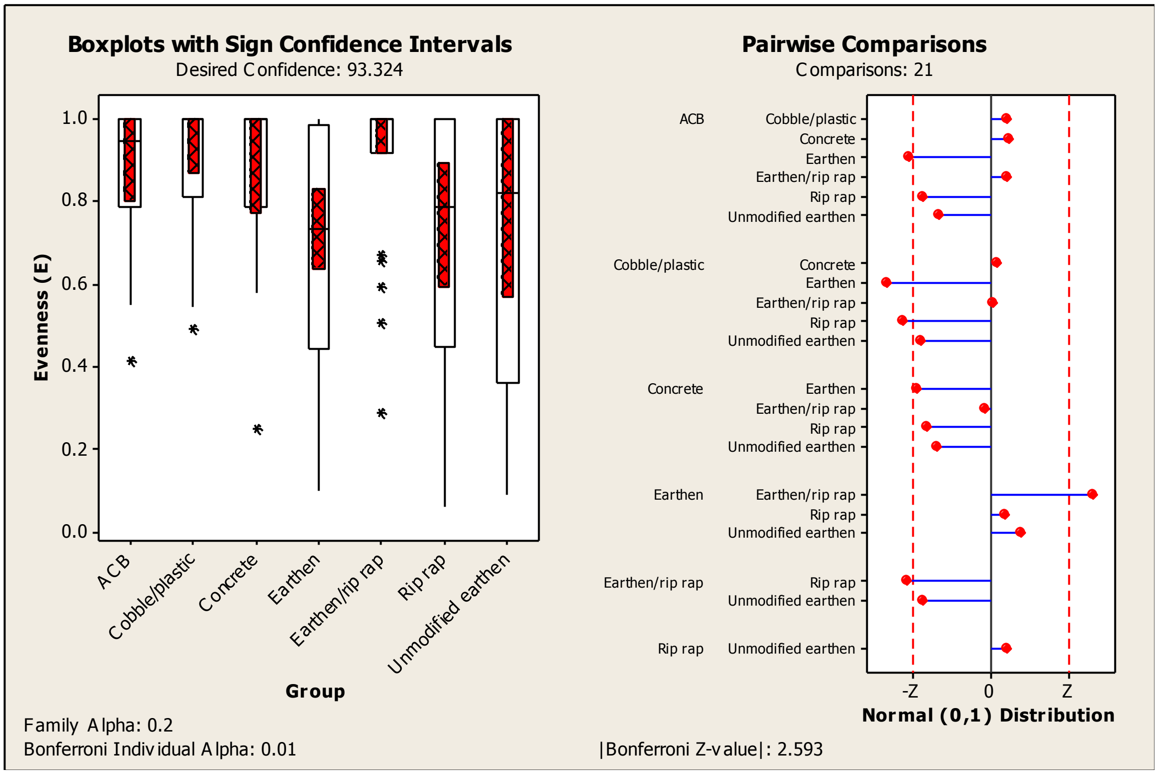

Figure 37: Evenness values (seining) per substrate type. Boxplots of interquartile range with median line and whiskers representing highest and lowest data values, * represents outliers. Pairwise comparisons – lines past dashed lines are significantly different. Krustal-Wallis (p=0.000, H=27.09).

Krustal-Wallis results indicate significant differences for community diversity values (seining) per substrate type (p=0.000, H=37.35) (Figure 38). Significant differences were found for concrete vs. earthen, ACB vs. concrete, earthen vs. rip rap, cobble/plastic vs. earthen, earthen vs. unmodified earthen, and ACB vs. unmodified earthen.

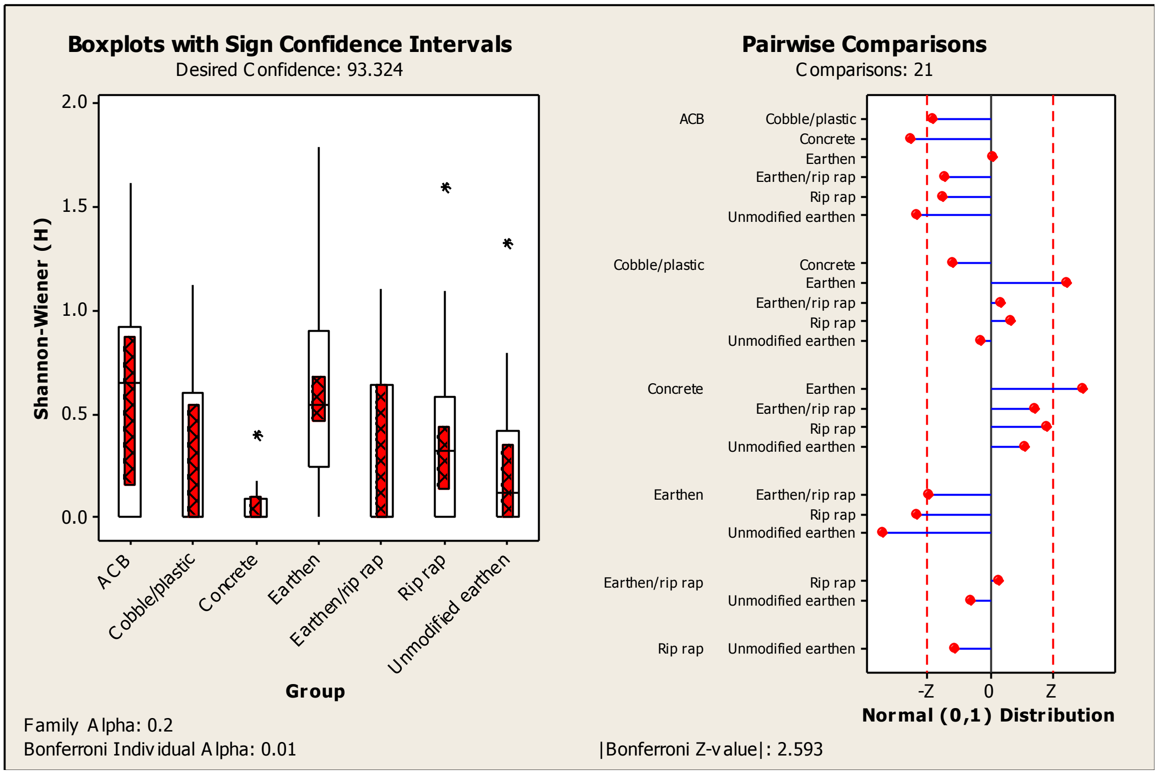

Figure 38: Community diversity values (seining) per substrate type. Boxplots of interquartile range with median line and whiskers representing highest and lowest data values, * represents outliers. Pairwise comparisons – lines past dashed lines are significantly different. Krustal-Wallis (p=0.000, H=37.35).

A cluster analysis was conducted on biological data using average density per species per collection for seine data, using Minitab 15. This same data was run in Clustan, which uses an algorithm to validate where to cut the clusters. Four clusters were designated significant by the Clustan software. These are shown in Figure 39. Some of the Baytown sites are clustered together most likely due to predominantly *Gambusia affinis* and *Poecilia latipinna* that inhabit these sites. Some of the Rummels Creek sites are clustered together because many of them primarily contain *Cyprinella lutrensis.* Cow_apt (late spring) is in a cluster by itself. A great majority of sites are grouped into one cluster.

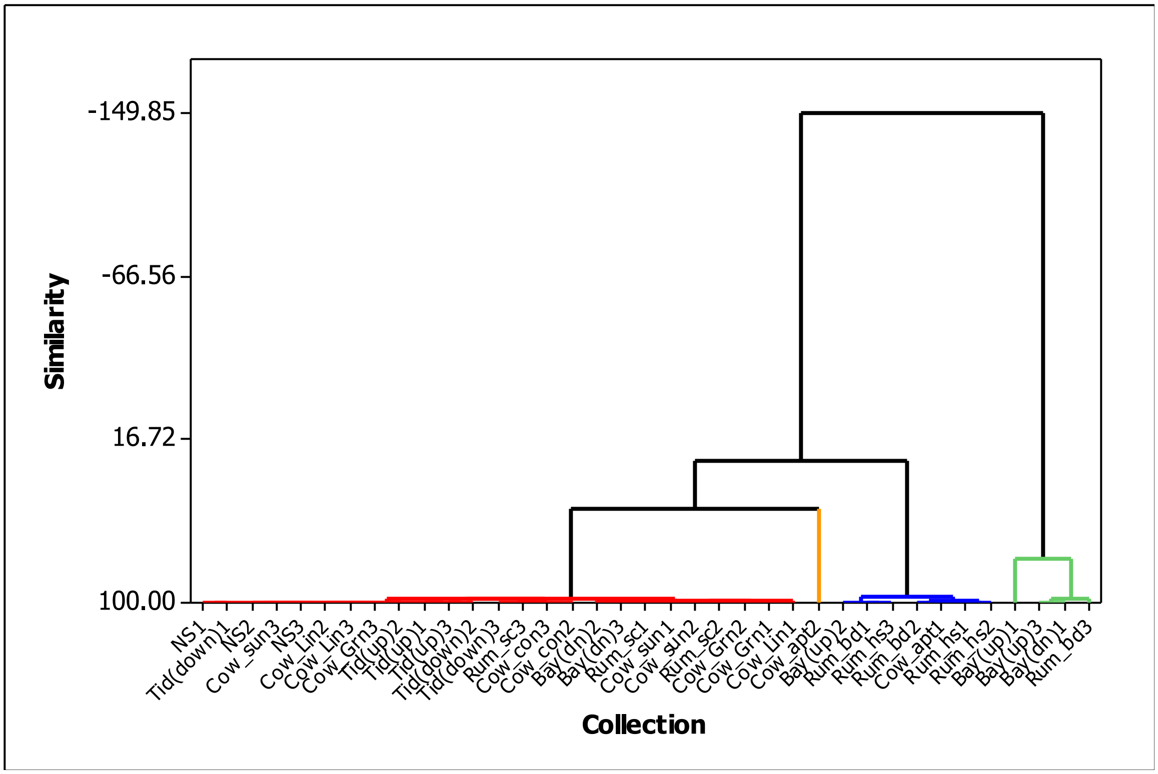

Figure 39: Seine data cluster analysis with numbers representing cluster designations based on fish community composition.

Electroshocking Results:

The site with the highest total numbers and mean total numbers of fish was Rum_hs (late spring) (Figures 40 and 41). Electroshocking was not performed at the Coward's Creek sites given the high conductivity levels. Tid(down) had the lowest mean total numbers of fish captures per site. The results of the ANOVA show a significant difference between collections for catch per unit effort (CPUE) fish abundance (p=0.000, R^2=60.79).

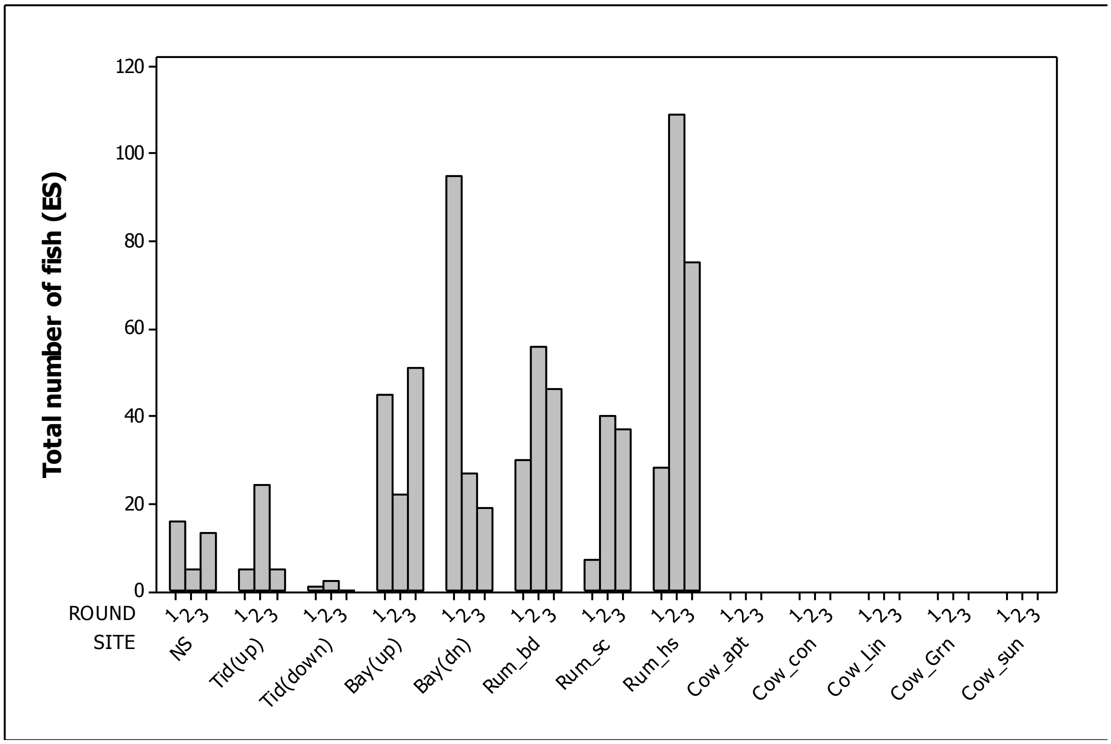

Figure 40: Total number of fish (ES) per site. Coward's Creek sites not sampled due to high conductivity. 1=early spring, 2=late spring, 3=summer.

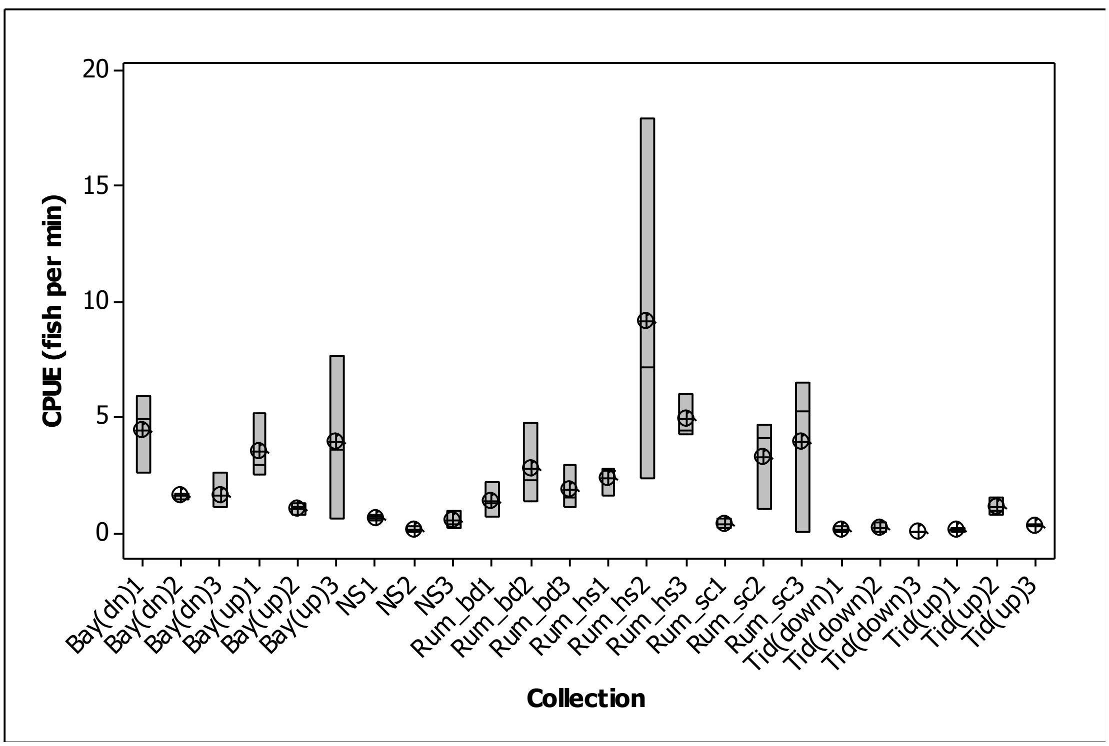

Figure 41: Electroshocking fish abundance (catch per unit effort [i.e. number of fish per minute]). Boxplots of interquartile range with median line. ANOVA (p=0.000, R^2=60.79). 1=early spring, 2=late spring, 3=summer.

Community richness was highest at Bay(dn) (early spring) (Figure 42). Richness in general was lowest at most of the White Oak at Tidwell sites particularly the downstream site (concrete-lined substrate). The results of the ANOVA show a significant difference between collections for fish community richness (p=0.000, R^2=70.51).

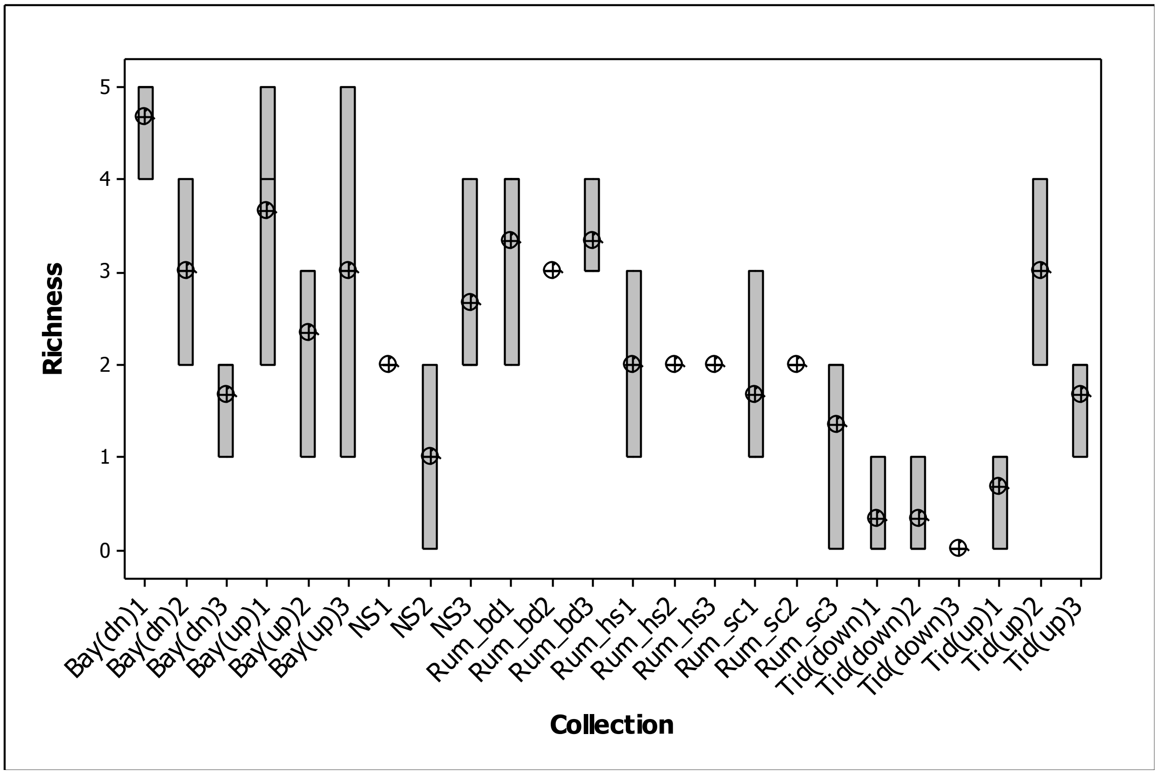

Figure 42: Fish community richness (ES) per collection. Boxplots of interquartile range with median line. ANOVA (p=0.000, R^2=70.51). 1=early spring, 2=late spring, 3=summer.

The site with the lowest community evenness was Rum_hs (late spring) (Figure 43). Most of the Northshore and White Oak Bayou at Tidwell sites had the highest mean evenness scores which are likely explained by the lower total numbers of fish caught. There was a significant difference between collections based on ANOVA results (p=0.000, R^2=58.11).

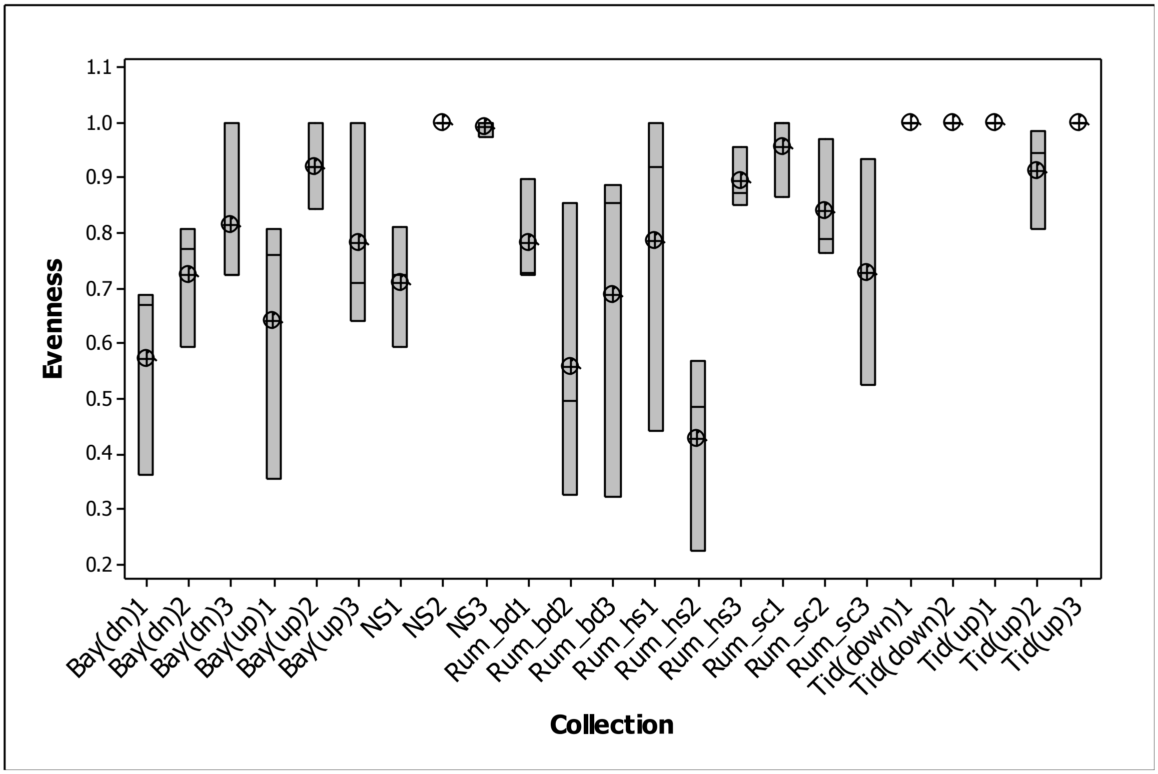

Figure 43: Fish community evenness (ES) per collection. Boxplots of interquartile range with median line. ANOVA (p=0.007, R^2=58.11). 1=early spring, 2=late spring, 3=summer.

The fish community diversity, measured using the Shannon-Wiener Index, is illustrated in Figure 44. The majority of the White Oak Bayou at Tidwell sites had the lowest diversity values. The results of an ANOVA suggest that there is not a significant difference between collections (p=0.135, R^2=45.70).

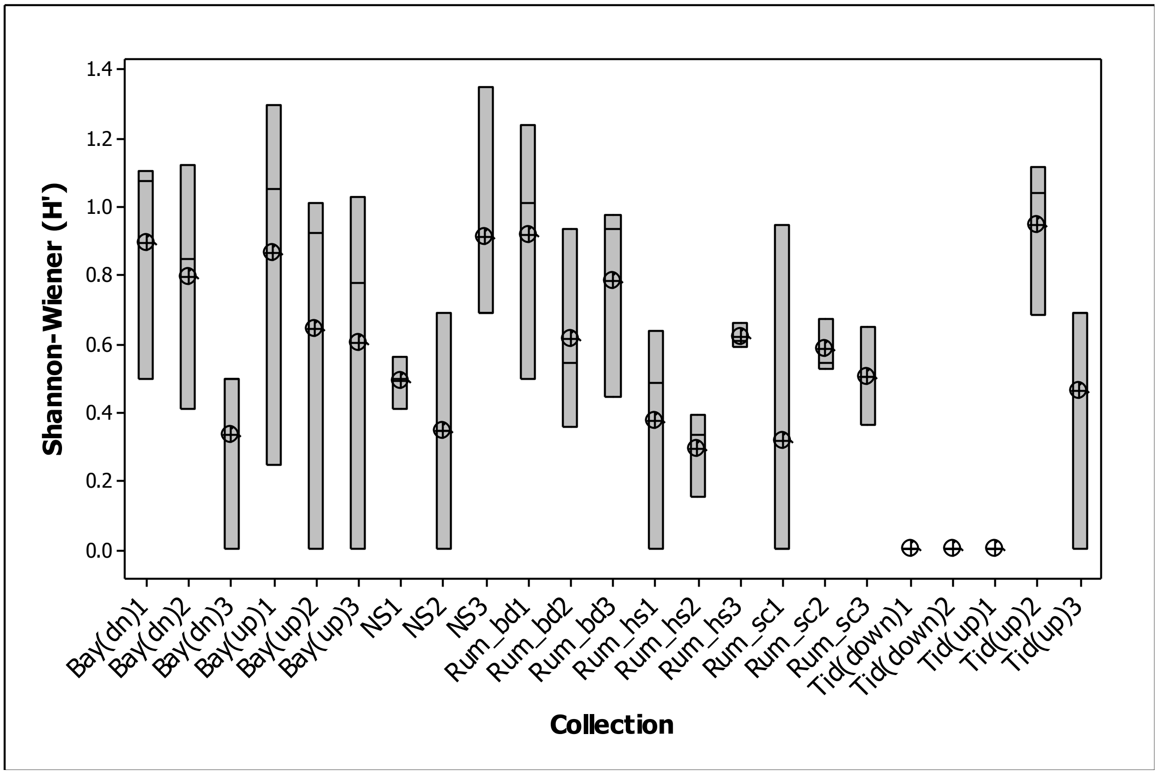

Figure 44: Shannon-Wiener diversity (ES) per collection. Boxplots of interquartile range with median line. ANOVA (p=0.135, R^2=45.70). 1=early spring, 2=late spring, 3=summer.

A normality test was performed on the electroshocking data by substrate type for total numbers, richness, evenness, and diversity. Results indicated that all of the data was not normal therefore a Krustal-Wallis test (nonparametric alternative to a one-way ANOVA) was performed per substrate type for the abovementioned four parameters.

Krustal-Wallis results indicate significant differences for total numbers of fish (electroshocking) per substrate type (p=0.000, H=27.42) (Figure 45). Significant differences were found for concrete vs. earthen, concrete vs. rip rap, earthen vs. rip rap, concrete vs. unmodified earthen, and cobble/plastic vs. concrete.

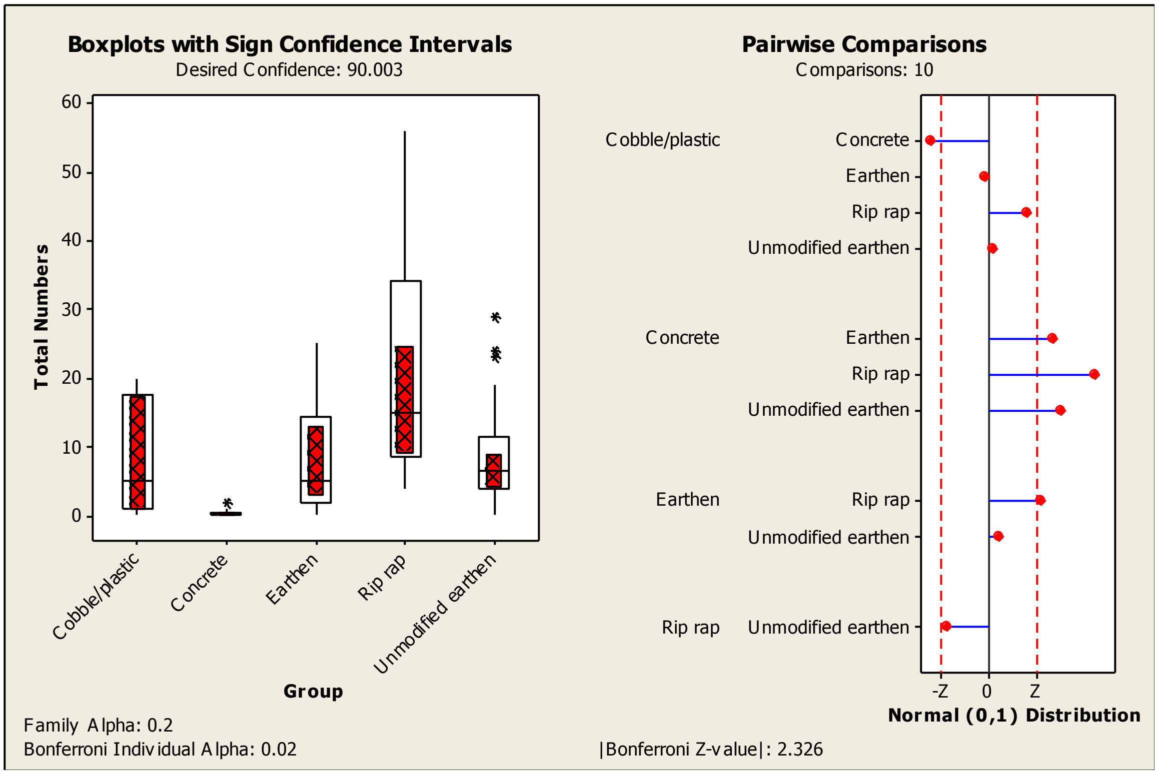

Figure 45: Total number of fish collected (ES) per substrate type. Boxplots of interquartile range with median line and whiskers representing highest and lowest data values, * represents outliers. Pairwise comparisons – lines past dashed lines are significantly different. Krustal-Wallis (p=0.000, H=27.42).

Krustal-Wallis results indicate significant differences for richness values (electroshocking) per substrate type (p=0.000, H=22.25) (Figure 46). Significant differences were found for concrete vs. earthen, concrete vs. rip rap, and concrete vs. unmodified earthen.

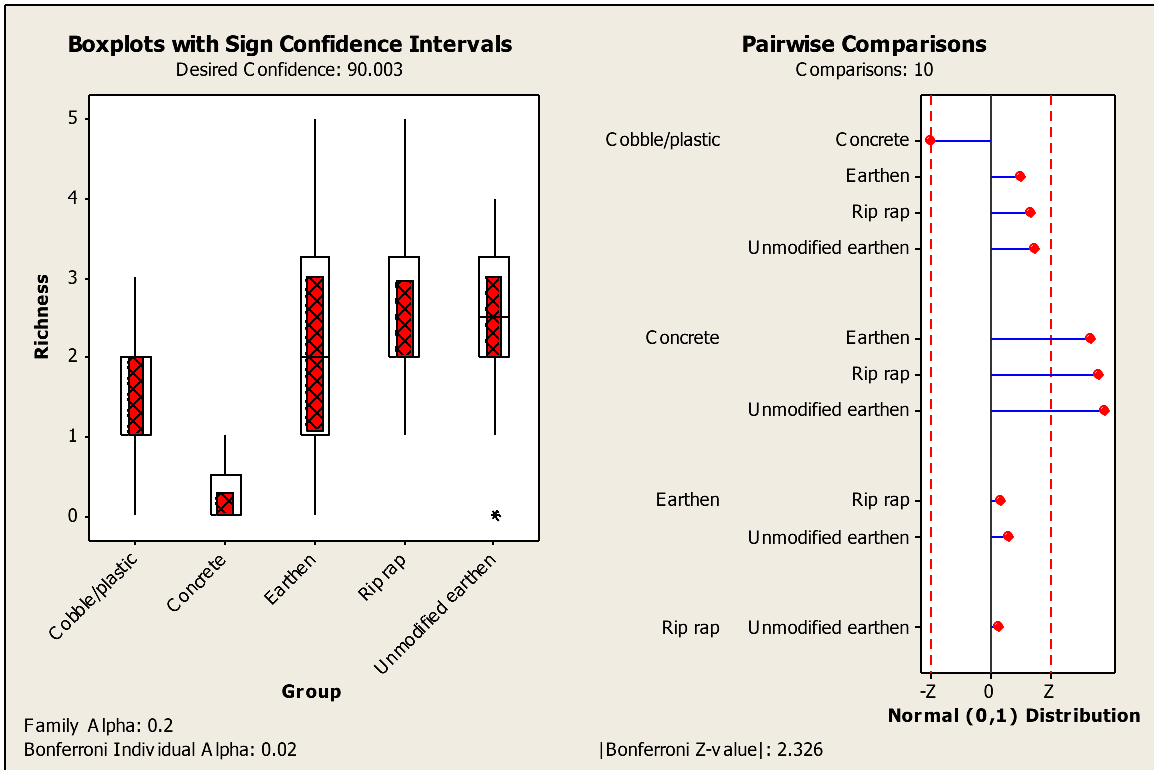

Figure 46: Richness values (electroshocking) per substrate type. Boxplots of interquartile range with median line and whiskers representing highest and lowest data values, * represents outliers. Pairwise comparisons – lines past dashed lines are significantly different. Krustal-Wallis (p=0.000, H=22.25).

Krustal-Wallis results indicate significant differences for evenness values (electroshocking) per substrate type (p=0.046, H=9.66) (Figure 47). Significant differences were found for earthen vs. rip rap and concrete vs. rip rap.

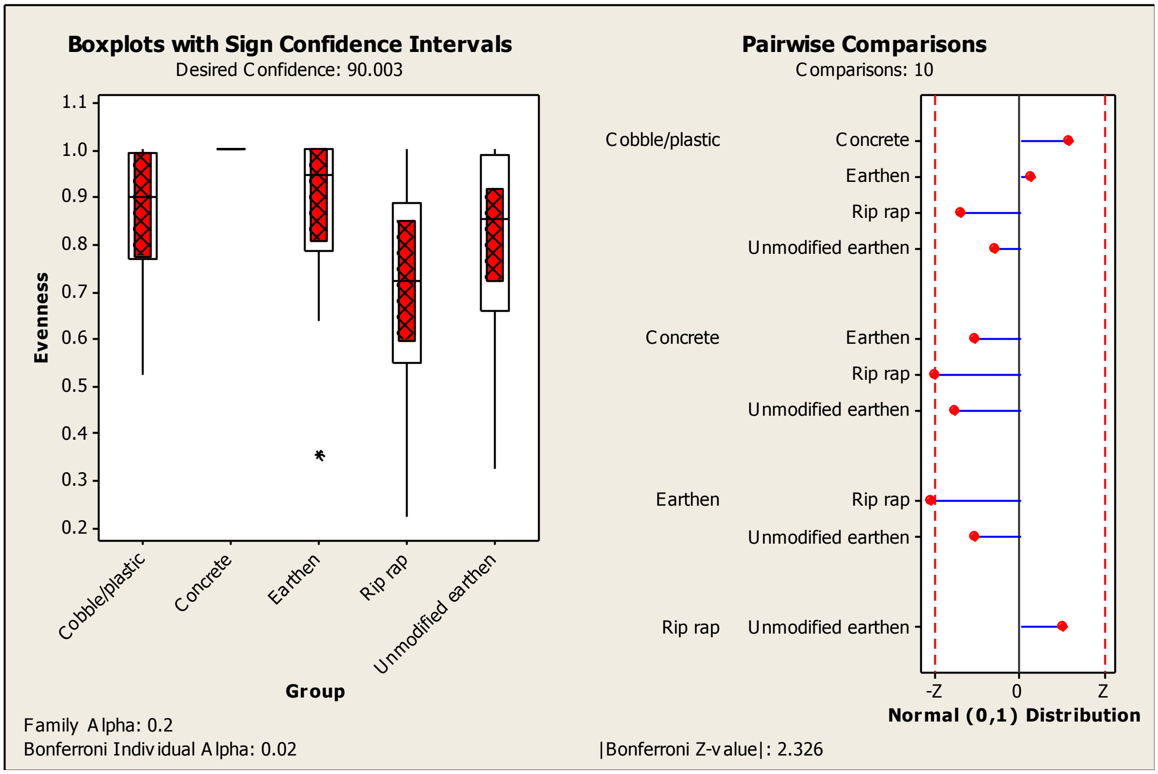

Figure 47: Evenness values (electroshocking) per substrate type. Boxplots of interquartile range with median line and whiskers representing highest and lowest data values, * represents outliers. Pairwise comparisons – lines past dashed lines are significantly different. Krustal-Wallis (p=0.046, H=9.66).

Krustal-Wallis results did not indicate significant differences for community diversity values (electroshocking) per substrate type (p=0.165, H=6.50) (Figure 48).

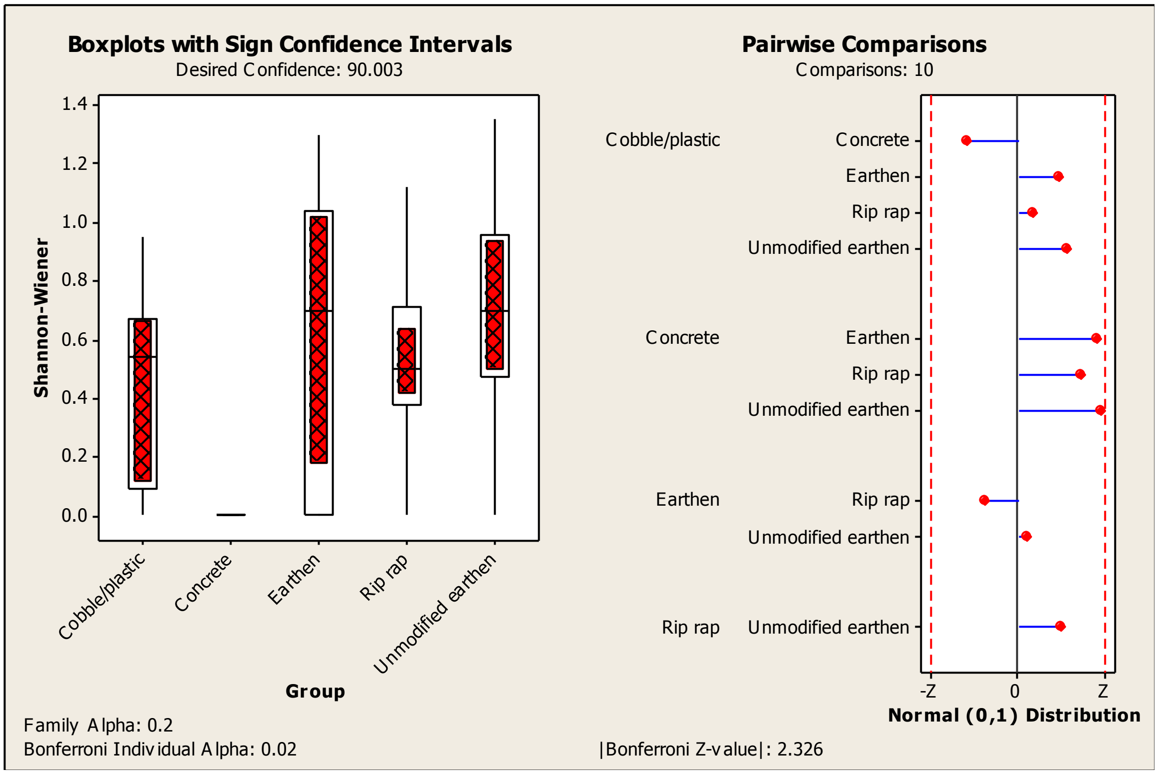

Figure 48: Community diversity values (electroshocking) per substrate type. Boxplots of interquartile range with median line and whiskers representing highest and lowest data values. Pairwise comparisons – lines past dashed lines are significantly different. Krustal-Wallis (p=0.165, H=6.50).

A cluster analysis was conducted on biological data using average density per species per collection for electroshocking data, using Minitab 15. This same data was run in Clustan, which uses an algorithm to validate where to cut the clusters. Four clusters were designated significant by the Clustan software. These are shown in Figure 49. The White Oak at Tidwell sites, Northshore site and some Rummels Creek sites are clustered into one group. The majority of the Baytown sites and some Rummels Creek sites are clustered into another group. One Baytown and two Rummels Creek sites are grouped together and Rum_hs (late spring) is its own group.

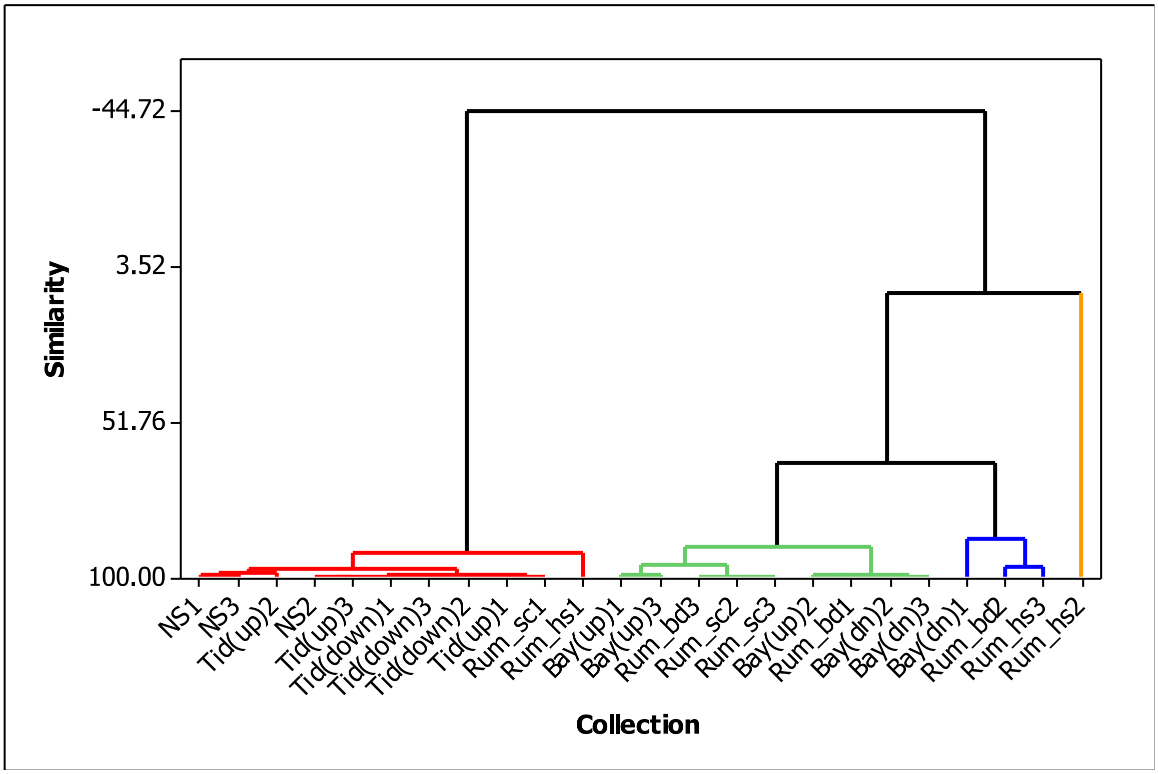

Figure 49: Electroshocking data cluster analysis with numbers representing cluster designations based on fish community composition.

Index of Biotic Integrity

Fish IBI (Index of Biotic Integrity) metrics were calculated and compared to regional expected values provided in Linam et al. (2002). The sampling sites reside within the Western Gulf Coastal Plain (Ecoregion 34). The individual metrics used in the calculation of the IBI for this ecoregion include: 1) total number of fish species, 2) number of native cyprinid species, 3) number of benthic invertivore species, 4) number of sunfish species, 5) number of intolerant species, 6) % of individuals as tolerant species (excluding western mosquitofish), 7) % of individuals as omnivores, 8) % of individuals as invertivores, 9) number of individuals in sample - (a) number of individuals/seine haul and (b) number of individuals/minute electrofishing, 10) % of individuals as non-native species, and 11) % of individuals with disease or other anomaly. Each metric is then given a score of either 1, 3, or 5 based on the value of the metric. The scores are added together to obtain an IBI/Aquatic Life Use score. For Ecoregion 34 an IBI score of >49 is considered Exceptional, while 39-48 is considered High, 31-38 is considered Intermediate, and <31 is considered Limited.

Cow_apt had the highest mean IBI score (High) but also the highest variability (Figure 50). Cow_Lin and Bay(dn) had the lowest mean IBI scores. The majority of the sites (mean values) lie within the IBI intermediate range which is typical of this ecoregion (Linam et al. 2002). IBI scores at the Coward's Creek sites are lower than would be expected because electroshocking was not performed at these sites.

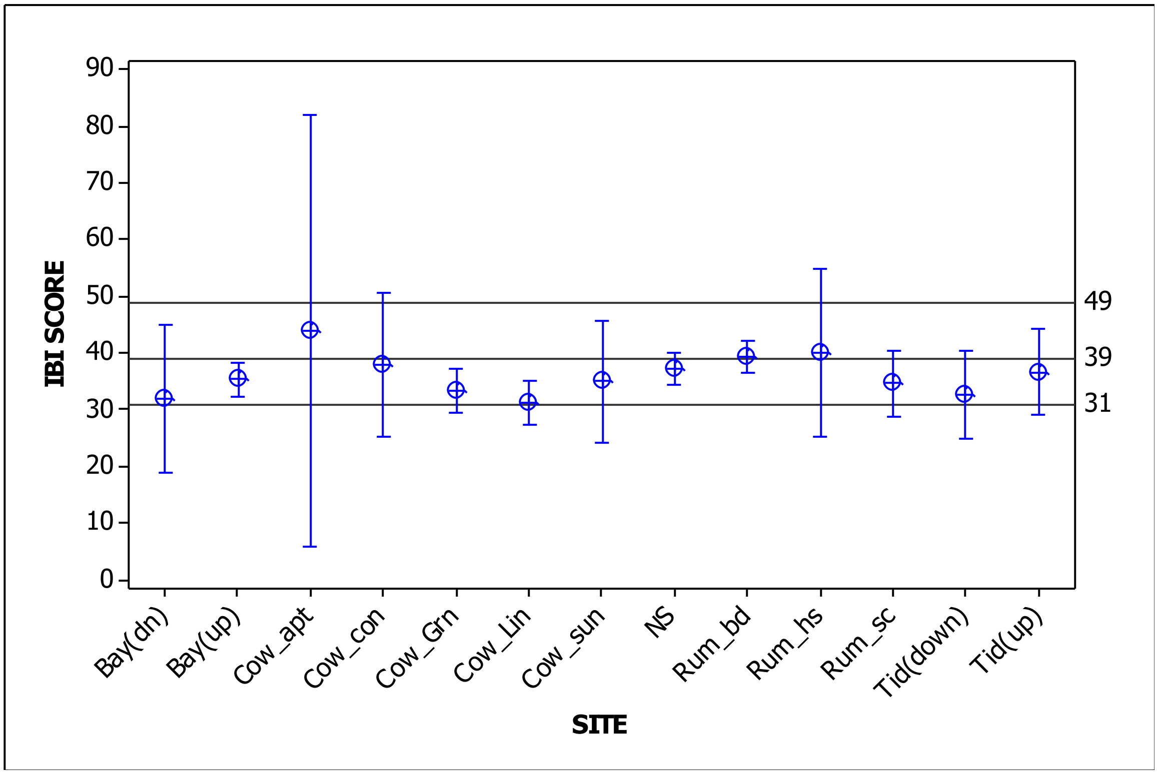

Figure 50: IBI scores per site. >49 Exceptional, 39-48 High, 31-38 Intermediate, and <31 Limited.

Unmodified earthen substrate had the highest mean IBI score and lowest variability (Figure 51). ACB substrate had the lowest mean IBI score followed by concrete. Concrete and rip rap substrates had the highest variability. All of the mean IBI values for substrate lie within the IBI intermediate range.

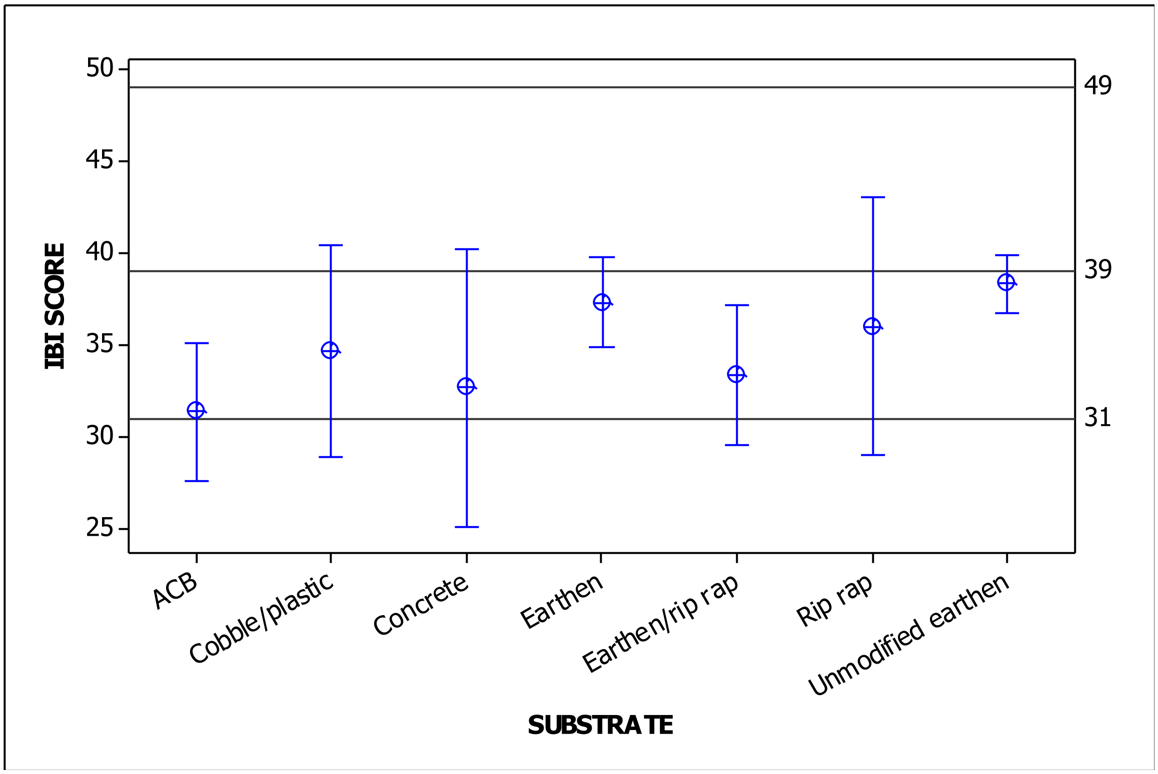

Figure 51: IBI scores per substrate type. >49 Exceptional, 39-48 High, 31-38 Intermediate, and <31 Limited.

Principal Components Analysis (PCA)

Physical and water quality data were analyzed using Principal Components Analysis (PCA) to determine the relationship between physical, water quality, and hydrological variables. A biplot showing the component scores of individual collections and variable loadings on the first two components are depicted in Figure 52. The first principal component explains 20.9% of the variance in the data while the second principal component explains 15.7% of the variance in the data for a combined total of 36.6%. The first principal component in general explains the relationship at the sites between hydrology and nutrient factors. The first principal component indicates that with high flows at the sites are usually accompanied by high velocities, greater width, higher orthophosphate, and higher nitrate-nitrogen and lower slopes, secchi tube readings, and overhead canopy shade. The second principal component indicates that with higher modified Wentworth values comes shallower depths, lower alkalinity, and lower conductivity.

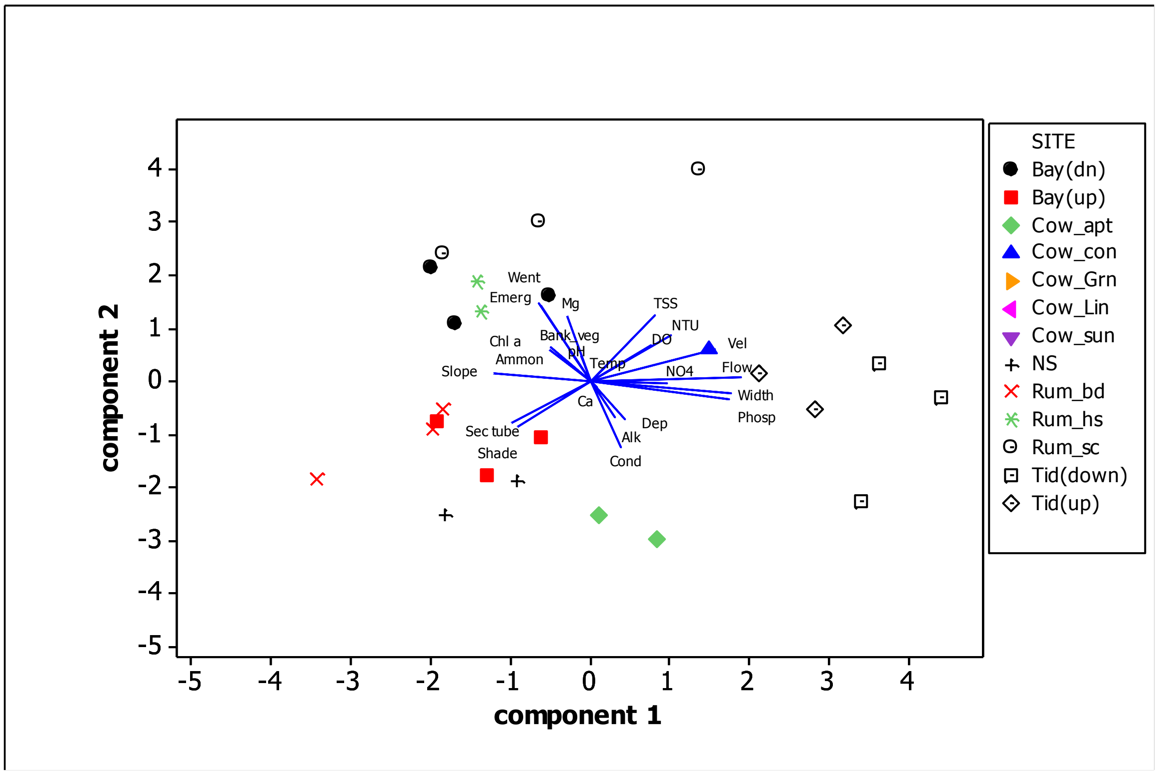

Figure 52: Principal Components Analysis (PCA) biplot depicting the relative loading of each variable for principal component 1 and principal component 2. Percentage of variability explained = 36.6%.

Scatter plots and correlation analyses were conducted for seining and electroshocking collections to compare substrates types with principal components 1 and 2 versus fish abundance, Shannon-Wiener diversity, Pielou's Evenness, and richness. Only correlation analyses that indicated a significant correlation between the diversity indices and the principal components are depicted below. None of the correlation analyses for the seining data revealed significant correlations.

Total numbers of fish (electroshocking) per substrate type versus principal component 1 is depicted in Figure 53. There is a significant correlation between the two factors (p=0.011) and a negative correlation (Pearson correlation = -0.530). This indicates that with higher flows and velocity, etc. there are lower numbers of fish as indicated with the concrete lined site (Tid(down)).

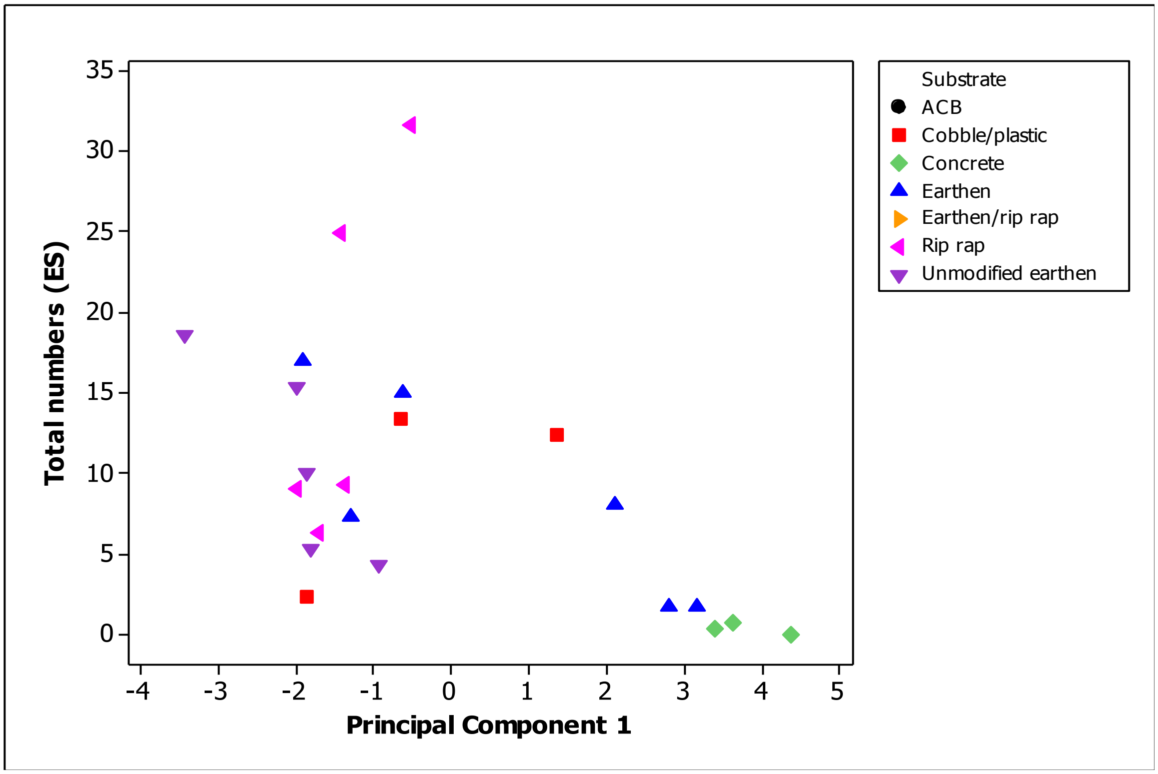

Figure 53: Scatter plot of total numbers of fish (ES) per substrate type versus principal component 1. p=0.011, Pearson correlation = -0.530.

Richness values (electroshocking) per substrate type versus principal component 1 is depicted in Figure 54. There is a significant correlation between the two factors (p=0.001) and a negative correlation (Pearson correlation = -0.668). This indicates that with higher flows and velocity, etc. there are not as many taxa of fish as indicated with the concrete lined site (Tid(down)).

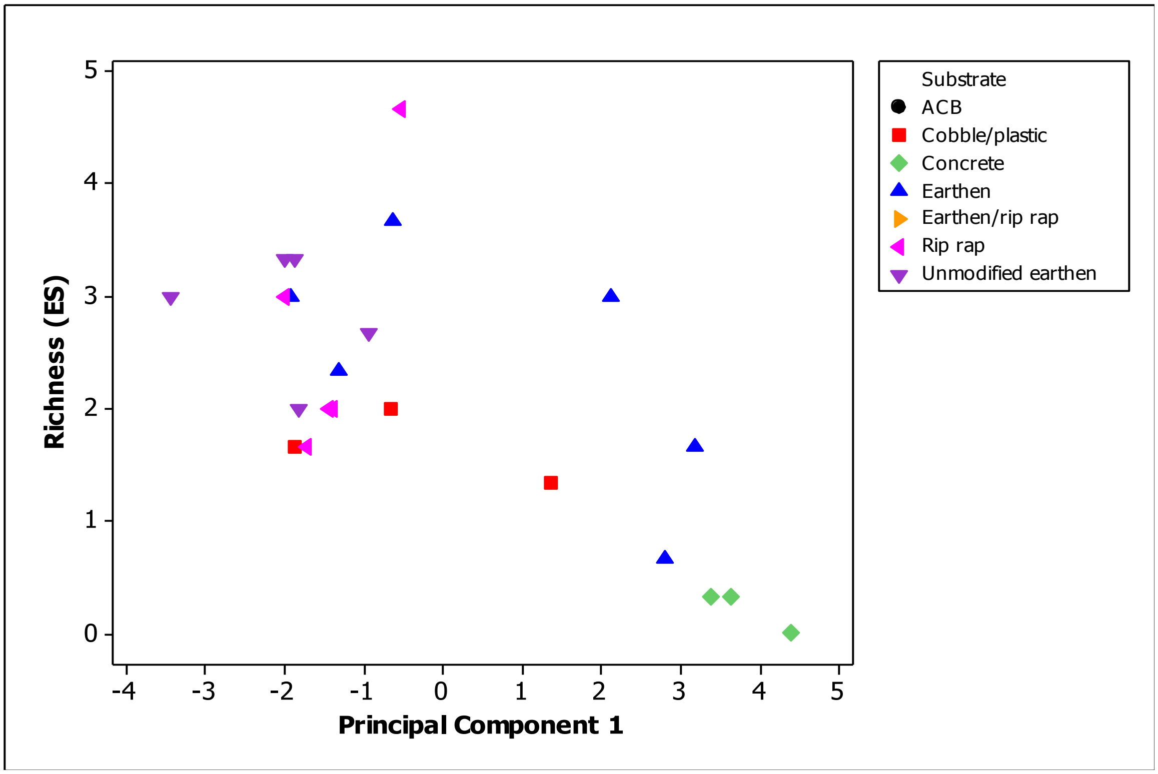

Figure 54: Scatter plot of richness values (ES) per substrate type versus principal component 1. p=0.001, Pearson correlation = -0.668.

Evenness values (electroshocking) per substrate type versus principal component 1 is depicted in Figure 55. There is a significant correlation between the two factors (p=0.003) and a positive correlation (Pearson correlation = 0.614). This indicates that with higher flows and velocity, etc. the evenness values are higher as indicated with the concrete lined site (Tid(down)) and some earthen sites. The higher evenness values for the Tid(down) site are likely explained because of the small number of fish caught at this site.

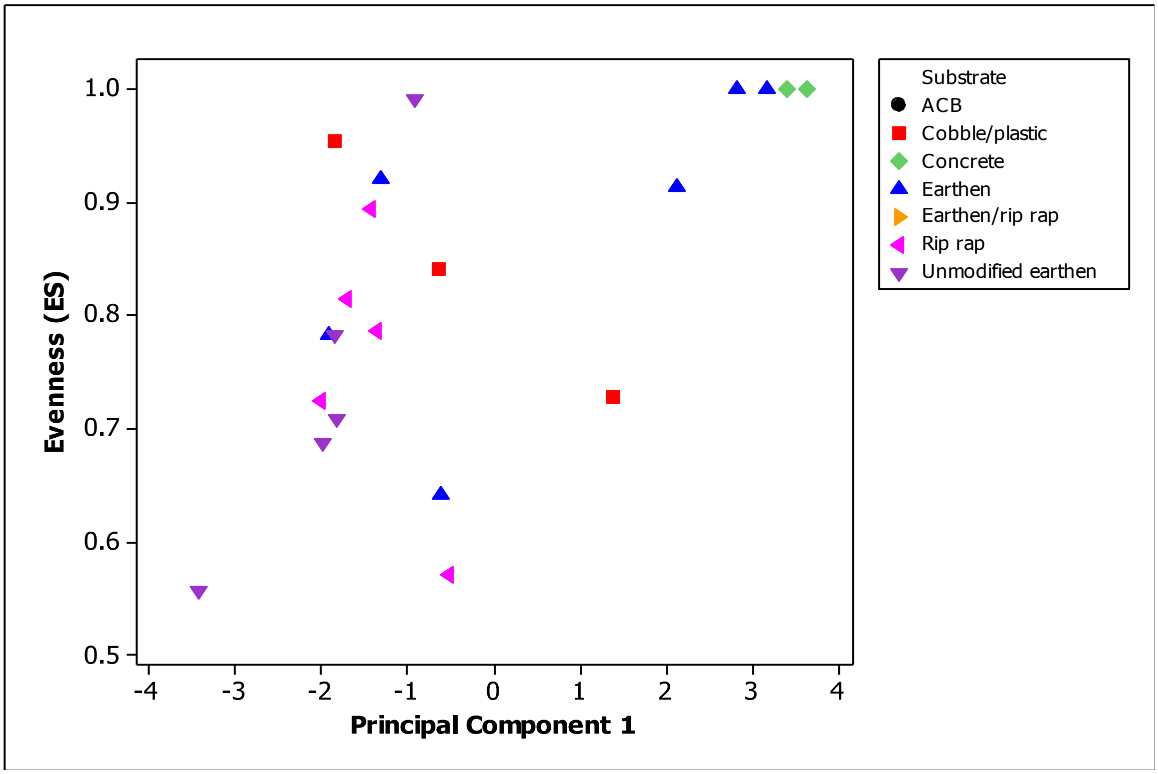

Figure 55: Scatter plot of evenness values (ES) per substrate type versus principal component 1. p=0.003, Pearson correlation = 0.614.

Community diversity values (electroshocking) per substrate type versus principal component 1 is depicted in Figure 56. There is a significant correlation between the two factors (p=0.017) and a negative correlation (Pearson correlation = -0.514). This indicates that with higher flows and velocity, etc. there is less fish community diversity as indicated with the concrete lined site (Tid(down)).

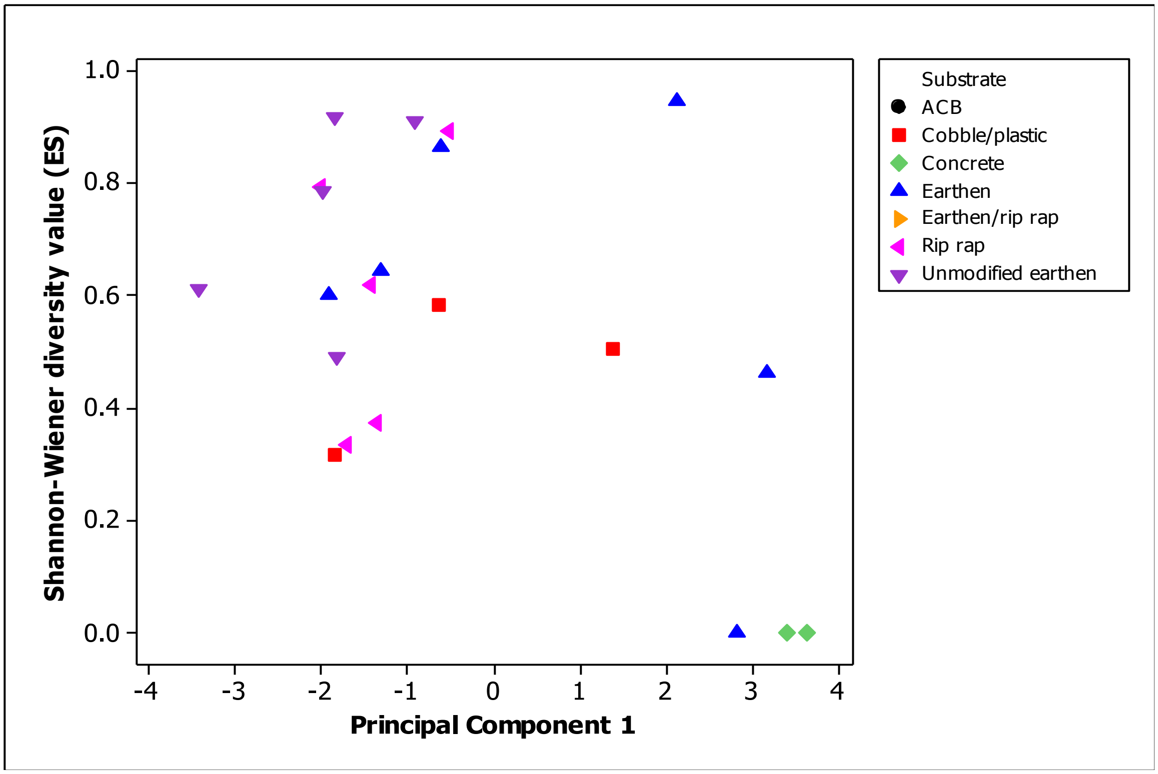

Figure 56: Scatter plot of community diversity values (ES) per substrate type versus principal component 1. p=0.017, Pearson correlation = -0.514.

DISCUSSION

In this study, more fish were collected from seining (7,422) than from electroshocking (758). A total of 35 different taxa were collected during our study. Seining and electroshocking are complimentary sampling methods. Seining generally catches smaller schooling fish while electroshocking general enables the capture of larger fish that are hiding behind rocks or other substrates.

In general, we found that electroshocking collections tended to agree with our hypothesis that substrate type does influence fish communities. Seining collections did not show the relationship between substrate and fish communities as well as the electroshocking collections.

This is most likely due to inefficient seining because of high stream flows and debris/snags causing loss of catch or no catch. Higher diversity values and fish abundances were generally associated with higher sediment/substrate values (i.e. more complex substrate such as boulders/rip rap) and substrates such as unmodified earthen, earthen, and rip rap.

The site Tid(down) is a good example of the relationship between substrate type and fish communities. Tid(down) is a concrete-lined stream with little habitat complexity or diversity. Sampling of this site resulted in very few species and/or number of fish. The site Tid(down) was effectively seined and electroshocked compared to some sites where seining was inefficient. This would indicate a greater difference between the concrete-lined substrate and other substrates if all streams with varying substrates could be effectively seined. Krustal-Wallis tests performed indicated significant differences between the concrete-lined substrate versus the majority of the other substrates for the four diversity indices measured for both seining and electroshocking data. Electroshocking PCA data indicated correlations between principal component 1 and the four diversity indices. Concrete-lined streams enable a greater velocity and greater flow because of lack substrate and as such, lower total numbers, richness, and diversity are indicated.

These results tend to agree with previous studies that state that substrate is an essential habitat attribute in aquatic habitats (Bovee et al. 1998). Substrate provides attachment sites for periphyton (Carr et al. 2005) and invertebrates, secondary production of food for fish, refuge from predators, and rest areas for smaller organisms in flowing streams. This study is year one of a three year fish study being conducted for the HCFCD. Comparison of this data with future data from this study will provide more reliant information on fish communities within these streams and the influence of their associated substrates.

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