Response of Aquatic Communities in Urban Areas of Harris County to Stream Substrate: 2007 to 2010 - FINAL REPORT

A comparison of natural and man-made stream substrate

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George Guillen - EIH

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Executive Summary

Surveys were conducted between 2007 to 2010 at multiple urban streams within Harris County and adjacent county reference streams. These wadeable streams were located across a spectrum of urban disturbance including: minimally disturbed "natural" stream channels; earthen channelized; and channelized with various types of man-made material (e.g. rip rap, and solid concrete). In order to accomplish the survey we utilized a BACI (before-after-control-impact) design that utilized both nearby control sites, and in the case of new projects, collection of pre-project environmental data. This included collection of hydrological, physical, water quality and biological data. Variables that were monitored included: streamflow; thalweg velocity; predominant substrate type; basic stream dimensions (width, depth); instream habitat (sediment type, vegetation cover); water quality (including nutrients); fish communities; benthic community; and primary productivity (as measured by both periphyton and traditional water column chlorophyll-*a* levels). Data from modified urban streams were compared to pre-modification conditions or regional control sites exhibiting little alteration in stream habitat.

Based on the results of this study we can conclude that the combination of channel substrate along with increased wastewater loading, altered streamflow and land use appear to be major factors affecting the fish and benthic invertebrate communities. Our results agree with previously documented stream conditions resulting from "urban stream syndrome". These conditions include increased impermeable land within the watershed which leads to increased storm flows, increased erosion of stream banks and usual response of construction of simple channel design to convey increased flood waters (i.e., straightening and/or reinforcing stream channel bed and banks).

Our data supports our conclusion that the most negatively impacted sites assessed during the survey were located within White Oak Bayou. The fish community assemblage at the White Oak Bayou survey sites were species depauperate in comparison to other urban and non-urban streams surveyed. In contrast, the sites exhibiting the highest fish diversity overall were the Cowart Creek sites including the Cowart Creek Airport (COA), Cowart Creek control (COC) and Cowart Creek Linson (COL - artificial riffle site). The primary characteristics differentiating White Oak Bayou from the other streams surveyed was: lack of submerged aquatic vegetation (SAV); extremely low instream habitat complexity; large watershed size and percent impervious surfaces; high percent concrete channel substrate or erodible bed material; and the highest number of upstream permitted wastewater facilities. These conditions provide very little instream cover for fish and the interaction of several factors including: 1) high amounts of impermeable land and resulting increased storm flows; 2) elevated effluent-dominated base flows; and 3) lack of instream habitat are likely the primary factors contributing to the low fish diversity observed at the White Oak Bayou sites.

In contrast the Cowart Creek sites including the artificial riffle area were generally less modified and contained a mixture of habitat and sediment types. In addition, the upstream Cowart Creek watershed contained less development, less percent impervious surface, and a low number of wastewater facilities. These features would lead to: 1) reduced wet weather flows; 2) less wastewater loading; and 3) increased suitable instream habitat, which supports higher densities and diversity of freshwater fish.

Overall the highest number of benthic organisms collected occurred in Armand Bayou. In contrast the lowest abundance in benthic organisms was documented at the Big Creek regional reference site, Big Gulch site, one site in a tributary of Goose Creek and one of the White Oak Bayou sites. The lowest number of benthic invertebrate taxa was generally observed at the Big Creek site, whereas the highest number of taxa was generally observed at the Armand Bayou sites. The response of benthic communities to site conditions was difficult to evaluate due to the low correlation between total benthic organism abundance and benthic taxa, and any physicochemical variable measured during this study. Examination of site characteristics suggest that low numbers of benthic taxa are associated with higher numbers of wastewater facilities and/or high streamflow as documented at selected White Oak Bayou and Big Creek sites. The low benthic invertebrate community diversity observed at the White Oak Bayou upstream site (WOU) site is likely due to the highly eroded clay stream substrate that does not provide a stable attachment site for periphyton or benthic organisms. This suggests that suitable substrate may be the primary limiting factor controlling benthic organism production at some of the White Oak Bayou sites.

We conclude that the worst type of channel design for support of native fish communities in Harris County streams is the historically-used, simple, straight-line, concrete-lined channel. This design provides little habitat complexity, minimum cover and protection from predators, promotes higher temperatures, and is usually associated with rapid change in hydrology. These traits are consistent with the results of other studies on urban streams which have undergone channelization.

We recommend that an ongoing baseline aquatic monitoring program be established to monitor urban streams and evaluate long-term changes in fish and benthic communities. The use of these aquatic community surveys has demonstrated to be cost effective and applicable to a wide range of stressors. It is expected that Harris County and adjacent areas will continue to experience increased urban population growth. This growth will create pressure to develop additional land for housing and business which will ultimately lead to addition wastewater loading. The increased amount of impervious surfaces associated with housing and businesses will likely result in increased stormwater runoff within these watersheds. It will be critical for management agencies to develop best management practices for stream restoration and protection under these future scenarios. In order to differentiate the influence of these various stressors and the effectiveness of these mitigation measures there will be a continued need to monitor and evaluate the impacts on aquatic communities using a combination of hydrological, water quality and biological community metrics.

We recommend that annual two season (spring and summer) monitoring be continued at several of the sites surveyed during our study, regional reference sites, and planned project sites. We also recommend that the scope of sampling be expanded to other representative streams in Harris County and adjacent areas using a probabilistic sampling approach that incorporates some benchmark sites. We also recommend the inclusion of automated monitoring of water quality and routine toxicity testing (lab and in-situ) to evaluate potentially toxic, but transient, conditions that may be influencing fish and benthic community structure. Better coordination and inclusion of data on reported spills, overflows and bypasses, streamflow, water quality, habitat, and biological communities will facilitate the development of predictive models to understand the major mechanisms affecting aquatic communities and inform resource and floodplain managers.

The information in this report should provide the Harris County Flood Control District with essential data needed for future project planning and to evaluate environmental impacts on urban aquatic communities. It is recommended that future routine baseline monitoring be conducted at a periodicity ranging between 2 to 5 years to assess changes in aquatic community structure, and several years pre- and post-project implementation to evaluate the response of the stream in terms of biological communities.

Introduction

Urban fish and aquatic communities face an ever growing number of stressors, including:

- degraded water quality;
- lack of suitable instream habitat;
- invasive species; and
- altered hydrology.

These effects often lead to altered fish and aquatic communities that are dominated by tolerant generalist species which in turn serve as indicators of stress (Barbour et al. 1999; Karr et al. 1986; Simon 2002).

During the 1940-50's many federal flood control projects were implemented that resulted in the dredging and deepening of streams and rivers in an attempt to reduce flooding in new communities developing in the area. In addition, instream woody debris was often removed. This often resulted in a range of physical changes to the original stream bed including straightening of the stream channel, physical detachment of meanders from the main channel, loss of instream woody debris, and reinforcement of the bottom and sides with rocky substrate or concrete to reduce erosion. The remaining mainstem river usually exhibited less sinuosity and instream habitat for aquatic organisms, while the "orphaned" portion of the stream resembled an oxbow lake and in many cases was filled to reclaim land. Naturally produced oxbow lakes provide critical habitat for certain fish species such as gars and other large river fish. Past studies have documented that oxbow lakes support greater juvenile abundances of most species relative to the main channel and were particularly important for nest building species with parental care (Zeug et al. 2005).

In addition to changes in physical habitat, urban streams are also subjected to detrimental changes in hydrology and water quality which leads to altered aquatic communities. Many of these changes have been described and collectively called "urban stream syndrome" (Paul and Meyer 2001; Walsh et al. 2009). Common symptoms include increased imperviousness, flashier streams, increased runoff of pollutants and increased base flows from additional wastewater flows. This often leads to reduced species diversity and an increase in the number of tolerant species (Walsh et al. 2009). Since many factors can therefore potentially affect aquatic communities in streams it is critical that the physical, chemical and hydrological conditions present during and after human management actions be documented, as well as how aquatic communities respond to these changes.

The Harris County Flood Control District (HCFCD) was created in 1937 to serve as a local sponsor of U.S. Corps of Engineers projects. The HCFCD provides flood damage reduction projects throughout Harris County (HCFCD 2003; HCFCD 2013). Platt reported in 2006 that the HCFCD had channelized over 6,000 miles of local streams and bayous in the Houston region at the time of their study (Platt 2006). The HCFCD and other flood control districts have utilized 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 rock or concrete. 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. Articulating 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 (Figure 1). 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.

Figure 1. Example of articulating concrete block used at various sites.

The HCFCD has also implemented other substrate types that represent newer approaches that 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.

Study Objectives

The primary objective of this study was to compare the composition of aquatic communities inhabiting different types of streams that varied primarily based on stream substrate. Our hypothesis was that streams that mimicked natural streams in terms of substrate and cover would support a more diverse fish and invertebrate community than simplified urban streams containing channelized concrete, rip-rap or simple earthen bottoms. In order to test this hypothesis we used upstream and downstream controls, minimally impacted reference streams, and measured potential confounding variables, such as: stream discharge, water quality, and riparian habitat, addressing the potential influence of these factors on aquatic communities. This was done using a variety of univariate and multivariate descriptive and statistical tests.

Study Area

Sites were selected on streams identified by HCFCD staff based on the degree of instream habitat modification and other criteria. Whenever possible, paired control sites were chosen within the same or a similar watershed to reduce sources of inter-watershed variability. Sites were located in "wadeable" streams that could be sampled under normal base flow conditions. Ten streams including 1 to 4 reaches per stream were ultimately selected (Figure 2 and Table 1 and 2). All site reaches with the exception of Peach Creek were located within Ecoregion 34, the Western Gulf Coastal Plain (Griffith et al. 2007). The Peach Creek site was located within Ecoregion 35, the South Central Plains.

The reaches and sites within a stream were also selected to represent varying degrees of urban development within Harris and adjacent counties. Since the majority of Harris County is subjected to various stages of development we selected additional reference stream sites located in or at the border of adjacent counties including Austin, Brazoria, Fort Bend, and Montgomery counties. At the request of HCFCD, we also investigated a series of sites within Cowart Creek, located primarily in Galveston County, including a recently created artificial "riffle site" constructed with concrete "rip-rap" by Galveston County.

Visits to most sites were conducted with the HCFCD technical staff in early 2007 to document site conditions. Digital photography and GPS were used to document location and site conditions. The latitude and longitude for each sampling site was verified in the field and input into ArcGIS and/or Google Earth Pro for future site analysis and documentation. At each site, the total reach study area consisted of a 300-foot long section of stream with the exception of one site (Cowart Creek at Sunset Lane) which consisted of a 150-foot long section. Individual site descriptions are provided below. We utilized a combination of published and electronic data to provide approximate estimates of upstream land use and number of permitted outfalls. Data sources primarily included the EPA WATERS data set, and TCEQ GIS data on permitted outfalls, hydrology, and basin delineation tools that are compatible with ArcGIS and Google Earth Pro (EPA 2013; TCEQ 2013). Data on the amount of different types of land use and land cover within each contributing watershed was obtained from the Houston-Galveston Area Council (H-GAC)(Meyer 2008). The 2008 land cover data uses a 10-category classification, which follows the hierarchical classification scheme utilized by the National Land Cover Data (NLCD).

Goose Creek Sites. The first stream and pair of sites surveyed were located in an unnamed tributary to the East Fork of Goose Creek (Table 1and 2, Figure 3- 5). These sites are located at the upper end of the East Fork of Goose Creek on the eastern edge of Harris County, in Baytown. The upper site (**GCU**) is primarily channelized drainage consisting of earthen substrate. The downstream site (**GCD**), located immediately downstream of GCU, was similar in size (width approximately 1-3 feet wide, 0.5-2 ft maximum depth) but the shoreline and part of the stream bottom consisted of concrete rip rap. Both locations were located between St. John Catholic Church and Ross S. Sterling High School. The downstream limit of GCD was W. Baker Rd., in Baytown.

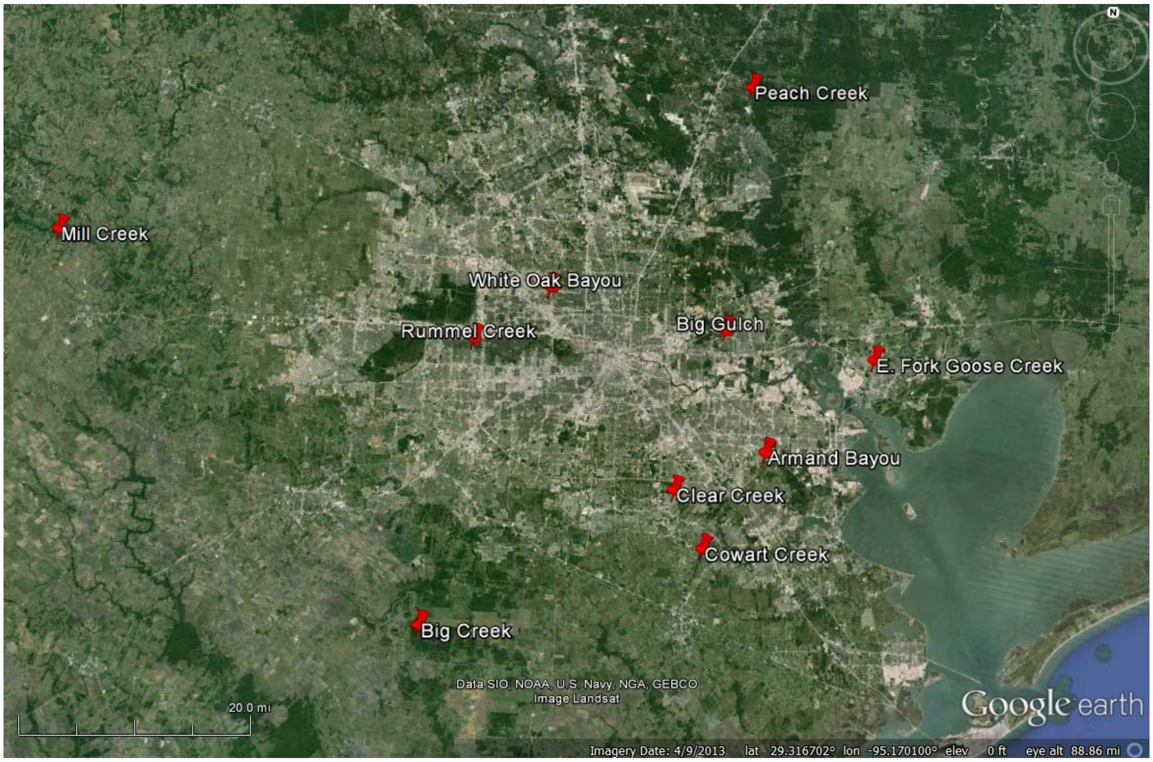

Figure 2. Location of stream study sites surveyed during 2007-2010.

Table 1. Streams surveyed during 2007-2010.

Stream Name	County	HCFCD Unit	TCEQ Segment & Major Basin	Channel Types	Substrate Types	Latitude	Longitude	Number of Sites
E. Fork - Goose Creek	Harris	O105-00-00	2426 Tabbs Bay	Channelized	Earthen	29.773362	-94.971889	2
Cowart Creek	Brazoria/ Galveston	N/A	1102A Clear Creek	Channelized & Restored	Earthen, Artificial Riffle	29.515430	-95.215495	5
Rummel Creek	Harris	W156-00-00	1014 Buffalo Bayou - San Jacinto	Channelized & Natural	Earthen & Concrete	29.773202	-95.570764	3
White Oak Bayou	Harris	E100-00-00	1017 White Oak - San Jacinto R.	Channelized	Earthen & Concrete	29.847034	-95.460945	2
Big Gulch	Harris	P107-00-00	1006 HSC Tidal - San Jacinto R.	Natural	Earthen	29.802049	-95.195386	1
Armand Bayou	Harris	B100-00-00 & B113-00-00	1113 Armand Bayou	Channelized	Earthen	29.644151	-95.128663	2
Big Creek	Fort Bend	N/A	1202J- Brazos R.	Natural	Substrate	29.397835	-95.620003	1
Mill Creek	Austin	N/A	1202K - Brazos R.	Natural	Substrate	29.880995	-96.205116	1
Clear Creek	Harris	A100-00-00	1102	Channelized	Substrate	29.588987	-95.260851	2
Peach Creek	Montgomery	N/A	1011 - San Jacinto R.	Natural	Substrate	30.136823	-95.169774	1

Table 2. Description of sites at each stream surveyed during the study.

Stream	Site	Code	HCFCD Unit	Type	Substrate	Lat	Long	No. Samp.	Years
Armand Bayou	Armand at Fairmont Parkway	ABF	B100-00-00	Channelized	Earthen	29.649653	-95.129274	2	2010
Armand Bayou	Armand at Holly Bay	ABH	B113-00-00	Channelized	Earthen	29.637933	-95.131110	2	2010
Big Crk.	Big Creek upstream Sawmill Rd.	BIC	N/A	Natural	Substrate	29.397704	-95.620238	2	2010
Big Gulch	Big Gulch at Northshore, in Jim and Joan Fonteno Family Park	BGN	P107-00-00	Natural	Earthen	29.802049	-95.195386	11	2007-10
Clear Crk.	Clear Creek Down	CCD	A100-00-00	Chanelized	Earthen	29.572970	-95.258495	2	2010
Clear Crk.	Clear Creek Up	CCU	A100-00-00	Channelized	Earthen	29.597857	-95.285318	2	2010
Cowart Crk.	Cowart at Cloverfield Airport	COA	N/A	Channelized	Earthen	29.514157	-95.239246	2	2007
Cowart Crk.	Cowart at Control site upstream of Linson	COC	N/A	Channelized	Earthen	29.515382	-95.216212	10	2007-10
Cowart Crk.	Cowards @ Linson	COL	N/A	Restored	Articulated concrete and rip rap	29.515220	-95.214962	9	2007-10
Cowart Crk.	Cowards @ Greenbriar	COG	N/A	Restored	Rip rap	29.516084	-95.212397	11	2007-10
Cowart Crk.	Cowards @ Sunset	COS	N/A	Restored	Channelized	29.519342	-95.207876	9	2007-10
E. Fork Goose Creek	Goose Crk. Immediately downstream in rip rap, and upstream W. Baker Rd.	GCD	O105-00-00	Chanelized	Rip rap	29.770626	-94.971877	11	2007-10
E. Fork Goose Creek	Goose Crk. Immediately upstream of rip rap area	GCU	O105-00-00	Channelized	Earthen	29.773035	-94.971931	11	2007-10
Mill Crk.	Mill Creek, downstream SH 36	MIC	N/A	Natural	Earthen	29.886531	-96.210010	2	2010
Peach Crk.	Peach Creek @ Lake Houston Park	PEC	N/A	Natural	Substrate	30.136823	-95.169774	2	2010
Rummel Crk.	Rummel at Bird Sanctuary downstream Memorial Dr.	RCB	W156-00-00	Natural	Earthen/Rip rap[1]	29.771990	-95.569626	11	2007-10
Rummel Crk.	Rummel at upstream in Rip Rap area, upstream of school	RCR	W156-00-00	Channelized	Rip rap	29.775740	-95.573729	11	2007-10
Rummel Creek	Rummel at Elementary School upstream of Memorial Dr.	RCS	W156-00-00	Channelized	Corrugated Plastic	29.773332	-95.570834	9	2007-10
White Oak Bayou	White Oak Downstream of Tidwell	WOD	E100-00-00	Channelized	Solid Concrete	29.845379	-95.460189	11	2007-10
White Oak Bayou	White Oak Upstream of Tidwell	WOU	E100-00-00	Channelized	Earthen	29.847222	-95.461112	11	2007-10

[1]Additional concrete rip rap was added during the study period.

Figure 3. Location of the two East Fork of Goose Creek study sites.


Figure 4. East Fork Goose Creek Upstream site (GCU). View is looking upstream with Ross S. Sterling High School on the right.

Figure 5. East Fork Goose Creek downstream site (GCD). View looking downstream at W. Baker Rd., with St. John Catholic church on right.

The drainage area upstream of these sites is approximately 8.0 km^2. There are no wastewater facilities located upstream. Both streams lacked any observable riparian shading. Observed stream flow on the day of our initial visit was negligible. Other than occasional crossings by high school students it is highly unlikely the site was visited by many people. These sites were surveyed during 2007 through 2010.

Big Gulch. The second stream surveyed, Big Gulch, contained one study site (**BIG**). It is mainly a backwater tributary of the tidal portion of Greens Bayou, which discharges into the Houston Ship Channel (Table 1 and 2, Figure 2 and Figure 6 - 8). The BIG site consists of numerous cypress trees and a thick riparian canopy. It is located within the Jim and JoAnn Fonteno Family Park. The average depth and width were 0.6 meters and 3 meters, respectively. The site contained dense woody debris and the stream exhibited high sinuosity. The site did exhibit copious amounts of trash and debris that had apparently washed in from upstream areas. Although the immediate area was wooded and appeared to be minimally impacted, the upper part of the drainage has been extensively modified and provides drainage for at least 38 km^2 of mixed residential and highway frontage. Evidence of extremely high (>3 m) stream levels, such as debris lines, during extreme discharge events were evident. There are 10 permitted discharge facilities upstream of the study site. The BIG site was surveyed during 2007 through 2010. Due to the high amount of woody debris this site ended up being very challenging to sample using traditional fish seines.

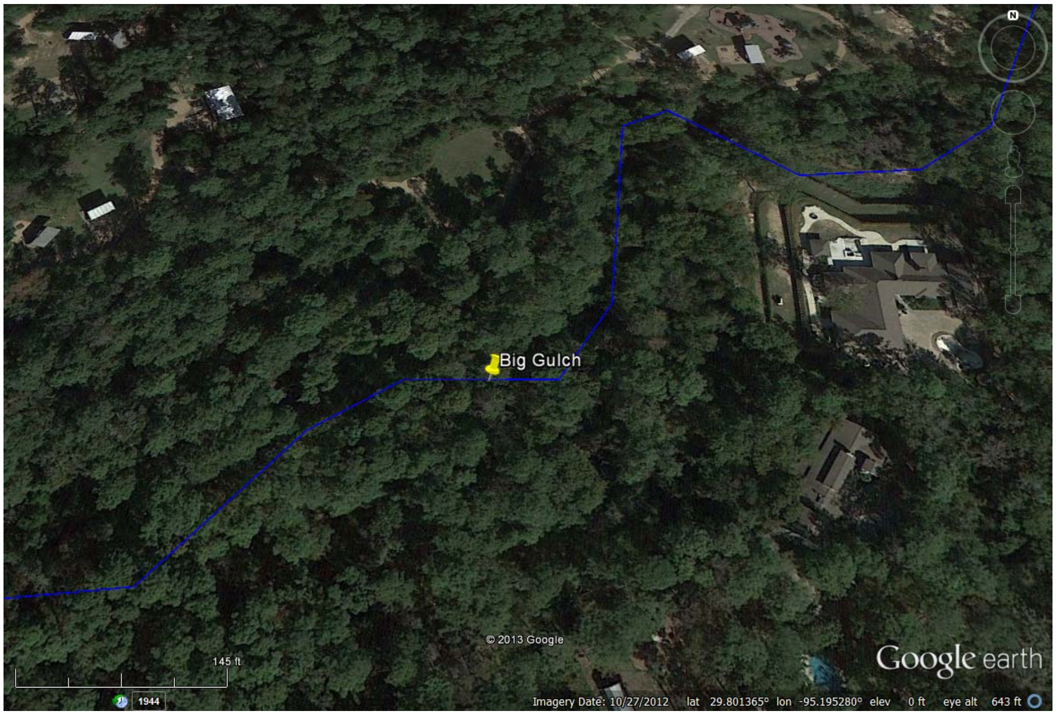

Figure 6. Big Gulch stream site (BIG) within Jim and JoAnn Fontenot Family Park.

Figure 7. Big Gulch stream site (BIG) looking upstream.


Figure 8. Big Gulch site (BIG) looking downstream.

Peach Creek. One survey site (**PEC**) was located on Peach Creek in southeastern Montgomery County (Table 1 and 2, Figure 2 and Figure 9 - 11). The majority of the 112 km^2 watershed is undeveloped. Peach Creek was the only survey site located within Ecoregion 35. There are 5 small wastewater facilities upstream. The shoreline is heavily wooded and substrate was primarily sand. An extensive riparian canopy was present. The water was generally clear. The average width and depth were 3.0 and 0.6 meters respectively. We considered this site to be a minimally impacted site. This site was monitored in 2010 only.

White Oak Bayou. The next pair of stream sites where located on White Oak Bayou near Tidwell Drive (Table 1 and 2, Figure 2 and Figure 12 - 14). The drainage area is approximately 121 km^2. There are 24 permitted discharge facilities above the survey sites. A wastewater treatment facility (WWTP) located at Golden Forest Dr., Permit No. TX0063011001 discharged at the lower end of the White Oak downstream (**WOD**) site. The White Oak Bayou upstream site (**WOU**) consisted of eroded hard clay substrate and was approximately 16.5 meters wide and 1.0 meter deep. Site WOD was primarily concrete lined and was approximately 16.5 meters wide and 0.15 meters deep. Below the Golden Forest WWTP the stream was narrower (2.8 meters) and deeper (1.3 meters). Both of the White Oak sites were heavily channelized and lacked extensive riparian vegetation and shading. Based on historical data the stream discharge was highly variable and could rise up to 10 meters during storm events.

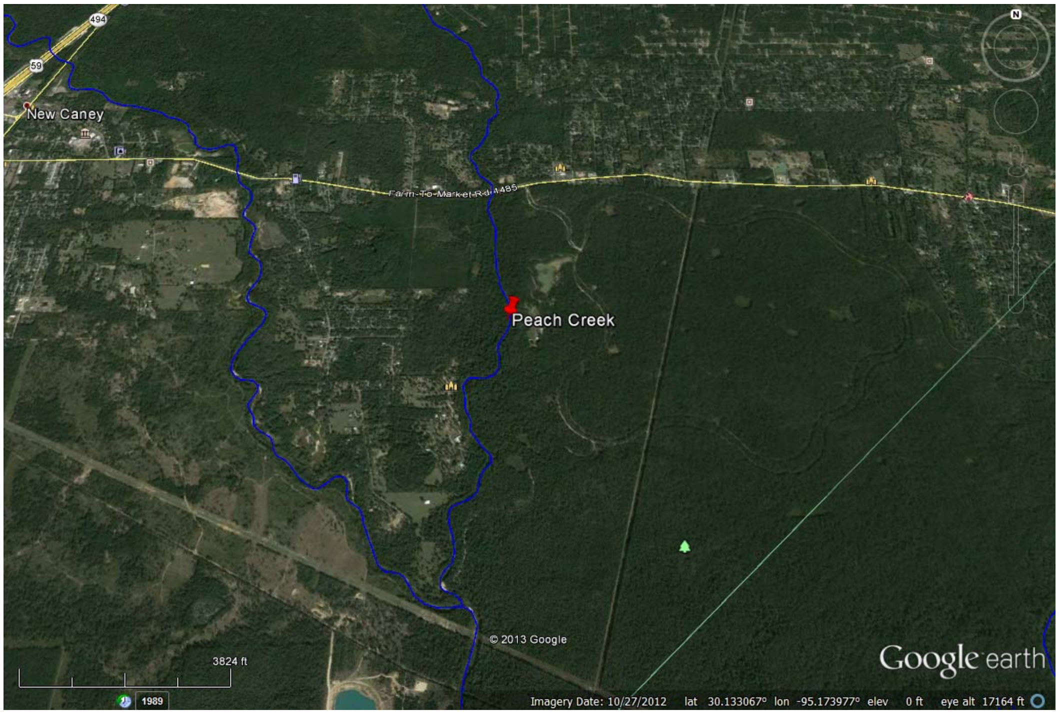

Figure 9. Location of the Peach Creek site (PEC) in Montgomery County in Lake Houston Park.

Figure 10. Peach Creek site (PEC) in Lake Houston Park looking upstream.

Figure 11. Peach Creek site (PEC) at Lake Houston Park, looking downstream.

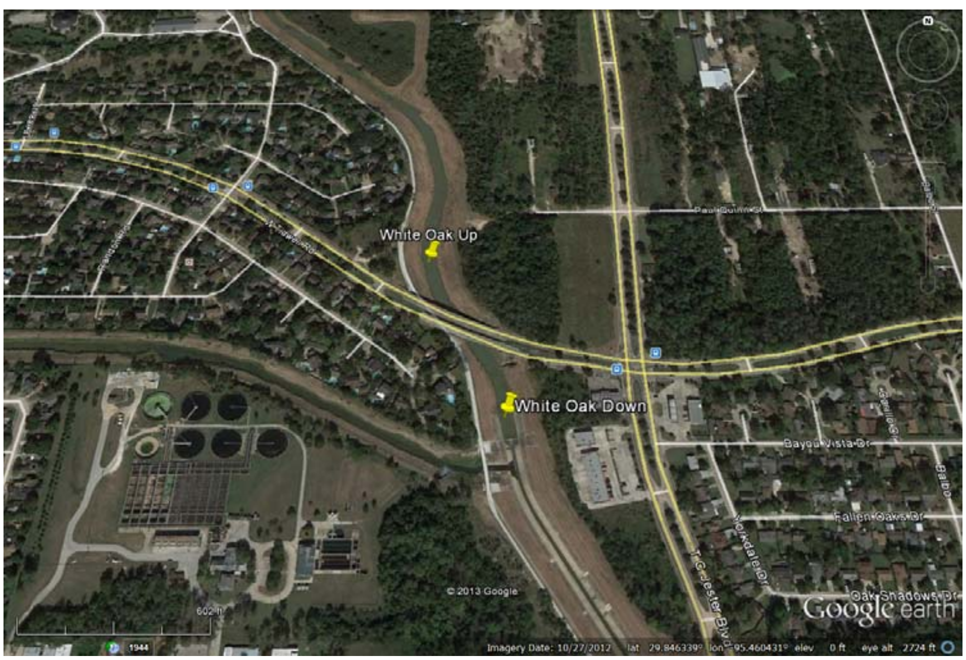

Figure 12. Location of survey sites on White Oak Bayou at W. Tidwell Rd.


Figure 13. White Oak Bayou upstream site (WOU), looking upstream.


Figure 14. White Oak Bayou downstream site (WOD), looking downstream.

Mill Creek. The Mill Creek site (**MIC**) was located in Austin County (Table 1 and 2, Figure 1 and Figure 15 - 16). It is a tributary of the Brazos River where it discharges northeast of Sealy. The creek's channel is narrow (0.5 to 1 meter wide) and shallow (< 1.0 meter deep) with a sandy substrate and numerous sandbars. The creek follows a meandering path through interspersed pasture land and hardwood forest floodplain. The drainage area upstream of SH 36 is approximately 100 km^2. There are 3 permitted discharges upstream of the study site. Based on past studies the stream provides habitat for a diverse fish community including spotted gar, various species of minnow, channel catfish, and several sunfish species (Moring et al. 1998). The surrounding land area is known as the Katy Prairie and provides habitat for wintering waterfowl. The majority of historical grasslands have been converted to rice fields. Mill Creek has been identified as having "High Water Quality/Exceptional Aquatic Life/High Aesthetic Value" and has been identified as an Ecoregion Reference Stream by the TPWD River Studies Program due to high dissolved oxygen and biodiversity of benthic macroinvertebrates (TPWD 2013).

Rummel Creek. The Rummel Creek survey consisted of three sites representing multiple substrate types (Table 1 and 2, Figure 2, Figure 17-23). The drainage area for this small drainage ditch and stream had recently been vastly expanded by diversion of stormwater from the I-10 frontage drainage. The overall drainage basin of Rummel Creek as it enters Buffalo Bayou is 15.2 km^2. The contributing watershed at the point of our survey sites is approximately 13.5 km^2. There appears to be at least one permitted discharge upstream of the survey sites. The upstream site surveyed was labeled Rummel Creek Rip Rap (**RCR**) (Figure 18). This site was located adjacent to a residential neighborhood and characterized by having a large amount of rubble and rip rap along the banks and in the channel. The approximate width and average depth was 2 and 1 meter, respectively. The middle survey site was labeled Rummel Creek School (**RCS**), since it was located adjacent to the Rummel Creek Elementary School (Figure 19 - 20). This site had a unique stream bank composed of a corrugated plastic matrix (Geoweb® cellular confinement) that was used to stabilize the shoreline (Figure 21). The width of the stream averaged 1.3 meter and was only 0.3 meters deep on average. There was no significant riparian vegetation other than lawn grass. Riparian shading was lacking.

The downstream Rummel Creek site was located within the Edith L. Moore Nature Sanctuary and was labeled Rummel Creek Bird (**RCB**) (Figure 22- 24). The site is heavily wooded with significant amounts of riparian shading. At this site the stream exhibited significant sinuosity. The bottom substrate was sandy with some shoreline rip rap dispersed at different parts of the stream to apparently reduce erosion. According to the HCFCD, bank erosion had increased in recent years due to increased flow, in part to expansion of the upstream drainage area. As a consequence, HCFCD placed additional rip rap at this site, and further downstream, sometime during 2008 to reduce erosion (Figure 24). The bottom depth at this site averaged 0.6 meters and the average stream width was approximately 1.3 meters. These sites were surveyed during 2007-2010.

Figure 15. Close up of Mill Creek site (MIC) at Hwy 36 in Austin County. Photo provided by TCEQ.

Figure 16. Close up of Mill Creek site (MIC) showing survey area downstream of SH 36 and railroad bridge.

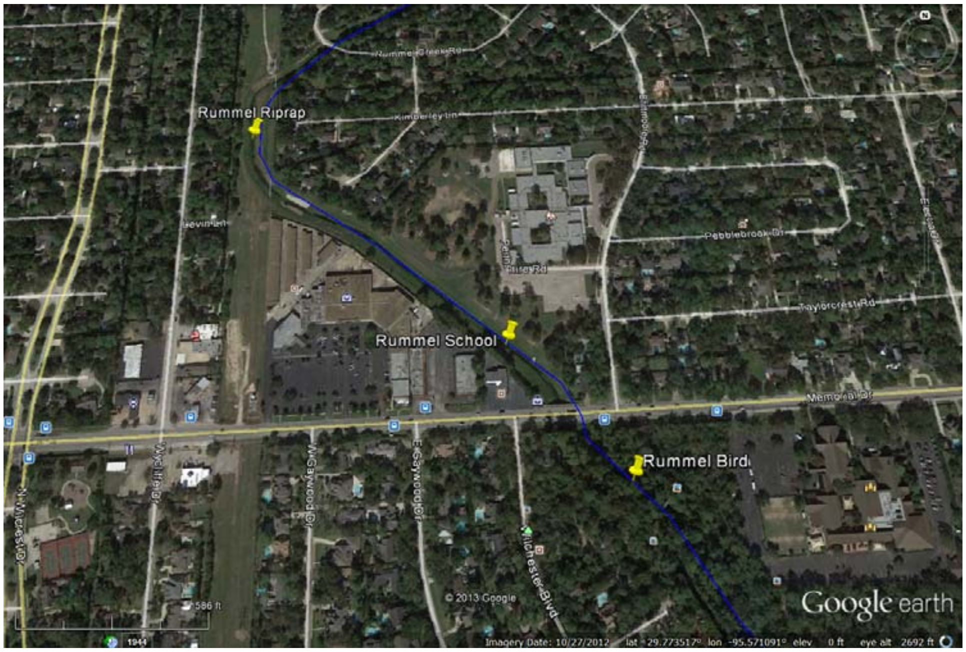

Figure 17. Location of Rummel Creek sites.


Figure 18. Rummel Creek at upstream end near rip rap field (RCR) on 4/6/07, mid-site, looking downstream.

Figure 19. Rummel Creek at upstream end of elementary school site containing corrugated plastic reinforced shoreline (RCS) on 4/4/07, looking downstream.

Figure 20. Rummel Creek at downstream end of elementary school site containing corrugated plastic reinforced shoreline (RCS) on 1/10/07, looking downstream.

Figure 21. Close-up photo of corrugated plastic reinforced bank material at the Rummel Creek elementary school site (RCS). Photo taken 1/10/07.

Figure 22. Rummel at the downstream Audubon Bird Sanctuary (RCB) on 1/10/07 prior to placement of rip-rap. View looking upstream.

Figure 23. Rummel at the downstream Audubon Bird Sanctuary (RCB) on 1/10/07 prior to placement of new rip-rap. Note placement of existing rip rap on left bank. View looking downstream

.

Figure 24. Rummel at the downstream Audubon Bird Sanctuary (RCB) on 4/1/09 after placement of rip-rap. View looking upstream.

Big Creek. The Big Creek site (**BIC**) was located in Fort Bend County (Table 1 and 2, Figure 2 and Figure 25 - 26). The Big Creek watershed is dominated by farmlands, scattered forests, and a limited riparian zone. The stream was approximately 5 meters wide and approximately 1 meter deep. The substrate was primarily sand and silt. The total estimated watershed above the study area is approximately 568.45 km^2. Sixteen permitted discharges are located upstream of the study site. Portions of the City of Rosenberg are included in the upper northern portion of the watershed. This site was surveyed only during 2010.

Clear Creek. The Clear Creek sites are located at the border of Harris and Brazoria counties (Table 1 and 2, Figure 2 and Figure 27 - 31). The average width and depth of the Clear Creek upstream site (**CCU**) was 2 and 0.6 meters, respectively. The contributing watershed was approximately 100 km^2 and was composed of 18% impervious land area (Knothe 2012). This agrees closely with the independent estimate using the EPA WATERS database of 88 km^2. There are a total of 15 permitted dischargers upstream of the CCU site. The area immediately upstream of this site is bordered by light industry, roads and some undeveloped green space. The majority of the stream at this location was bordered by riparian forest trees providing ample shading. The bottom of the stream was composed of silt, clay and debris. The average width and depth of the Clear Creek downstream site (**CCD**) was 4.5 and 1.0 meters, respectively. The size of the watershed above this site was approximately 132 km^2 which includes the previous upstream area of 88 km^2. A total of 15 permitted discharges including the previous 14 facilities. This includes the City of Pearland WWTP located less than 1 km upstream. The bottom sediment was primarily silt and clay. Little riparian vegetation was present, with the exception of mowed grass.

Cowart Creek. Five survey study reaches were established within Cowart Creek (Table 1 and 2, Figure 2 and Figure 33 - 40). The upstream site (**COA**) was located next to the Cloverfield Airport at the intersection of CR 130 and 430 in Brazoria County (Figure 34 and 36). The other 4 sites were located 2.5 km downstream from the COA site (Figure 35). The COA site was originally selected as a control site, but subsequently it was discovered that this site was subject to upstream contamination from saline groundwater exposed during sand pit mining operations and associated discharges. Therefore COA was only surveyed during part of 2007. The stream was approximately 3 meters wide and up to 1.5 meters deep. The bottom was composed of silt and clay and limited shoreline vegetation. The stream had been subjected to channelization. There was limited riparian vegetation. Riparian trees and shade were completely lacking. The site appeared to be mowed. The lower end of the site was bounded by a road crossing and bridge. Immediately downstream of the bridge was a large "rip-rap" concrete field that would likely back-up water during low flows.

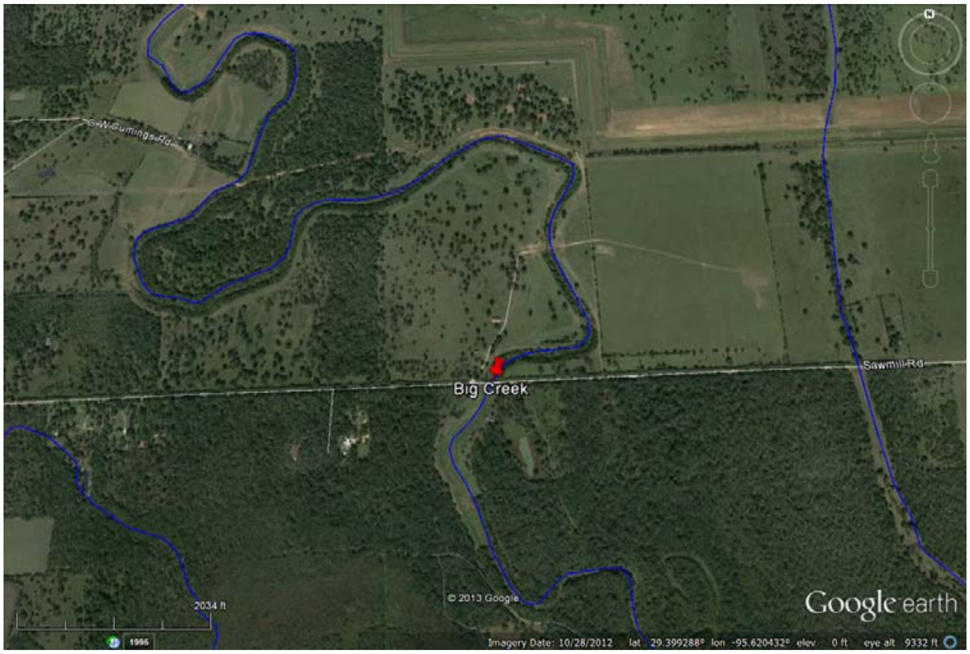

Figure 25. Big Creek site (BIC) in Fort Bend County at Sawmill Rd.

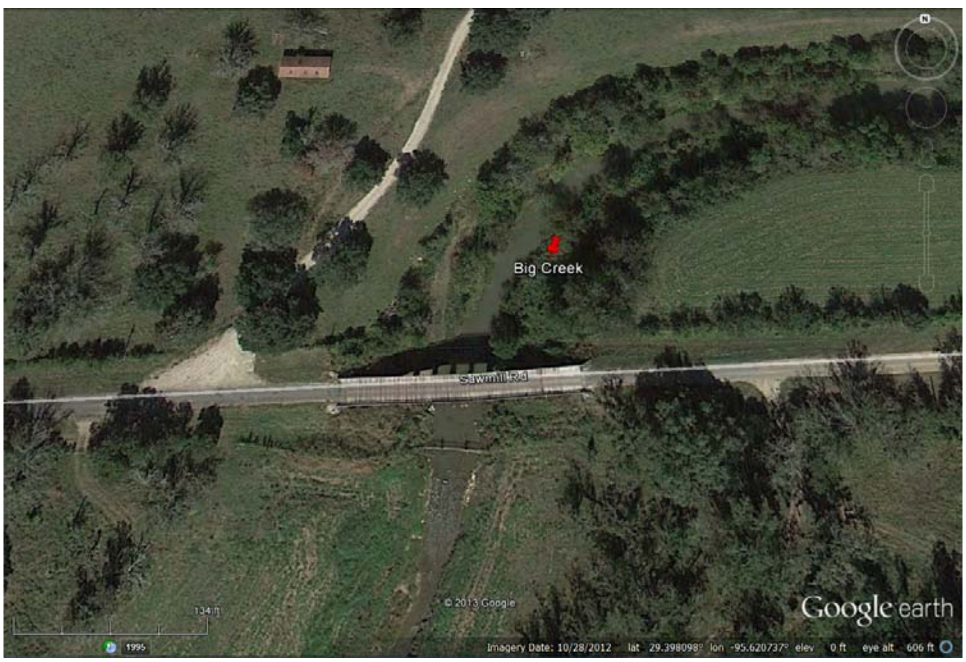

Figure 26. Close up of Big Creek site (BIC) in Fort Bend County at Sawmill Rd.

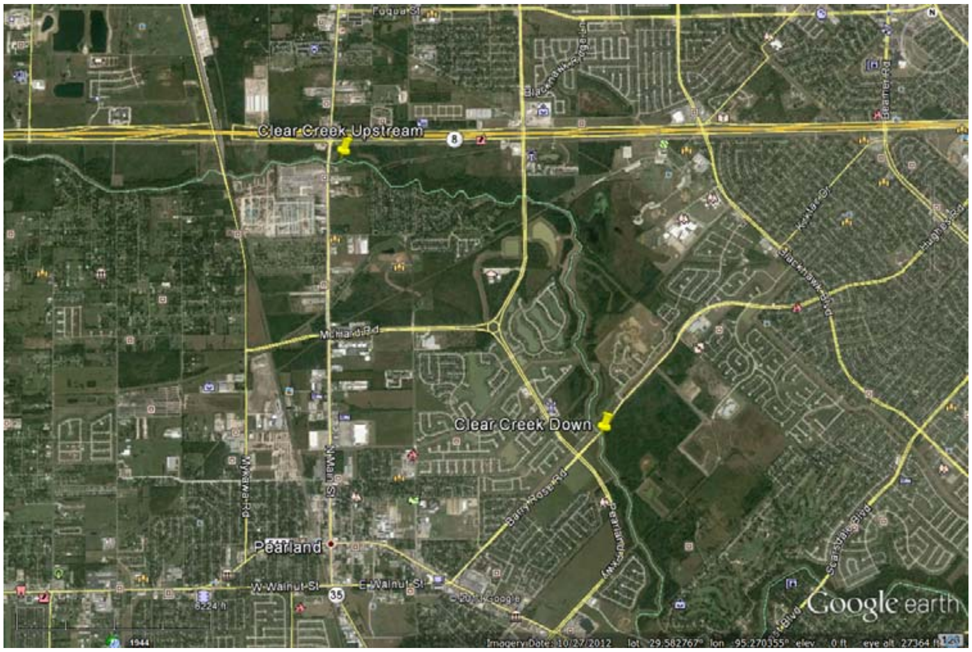

Figure 27. Clear Creek upstream site (CCU) and downstream site (CCD) in HCFCD unit O105-00-00 in Harris County.

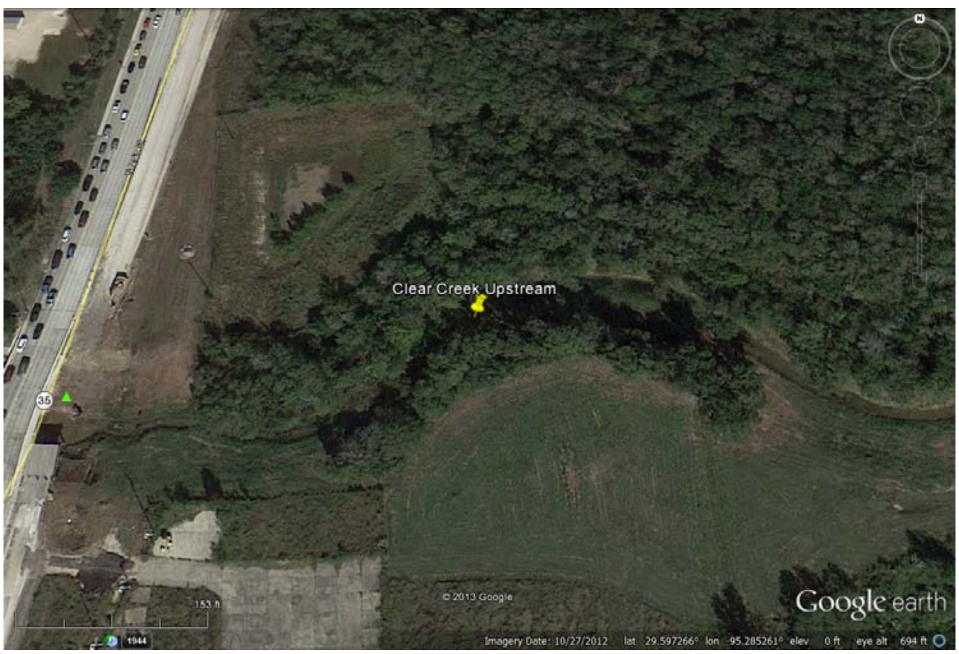

Figure 28. Close up of Clear Creek upstream (CCU) site on Clear Creek at SH 35 in Harris County.

Figure 29. Clear Creek upstream (CCU) site. Facing upstream toward SH 35.

Figure 30. Clear Creek upstream (CCU) site. Facing downstream from SH 35.

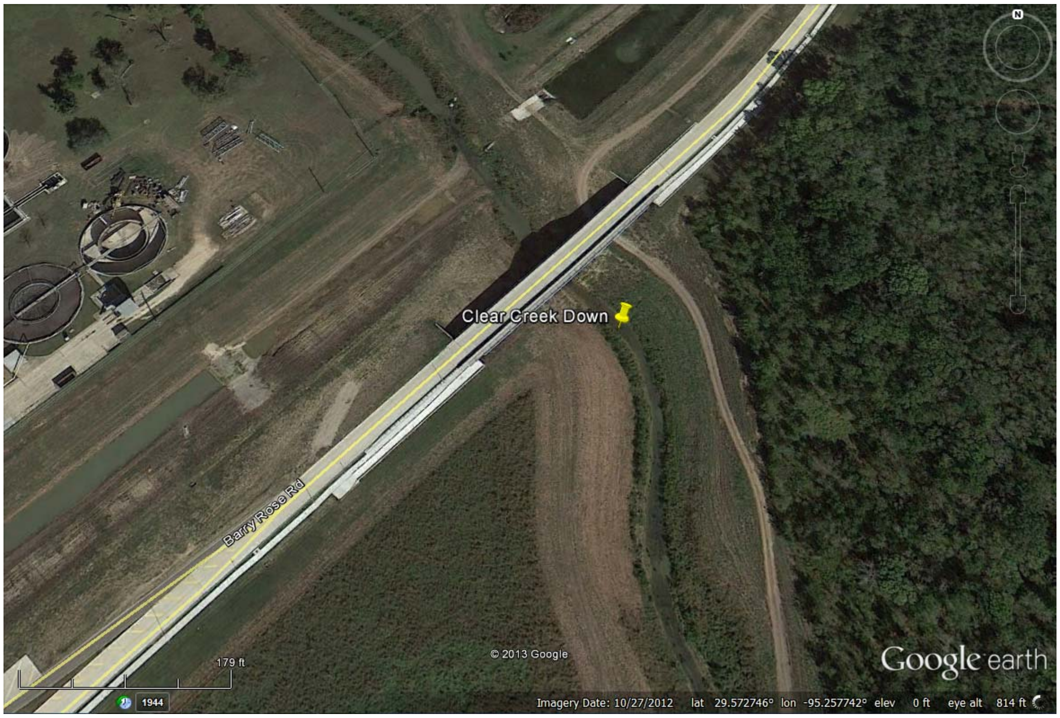

Figure 31. Close up of Clear Creek downstream (CCD) site on Clear Creek at Barry Rose Rd. in Harris County. View looking downstream. Source Google Earth Pro 2013.

Figure 32. Downstream view of Clear Creek downstream (CCD) site at Barry Rose Rd. Source Google Earth Pro 2013.

Figure 33. Location of Cowart Creek sites.

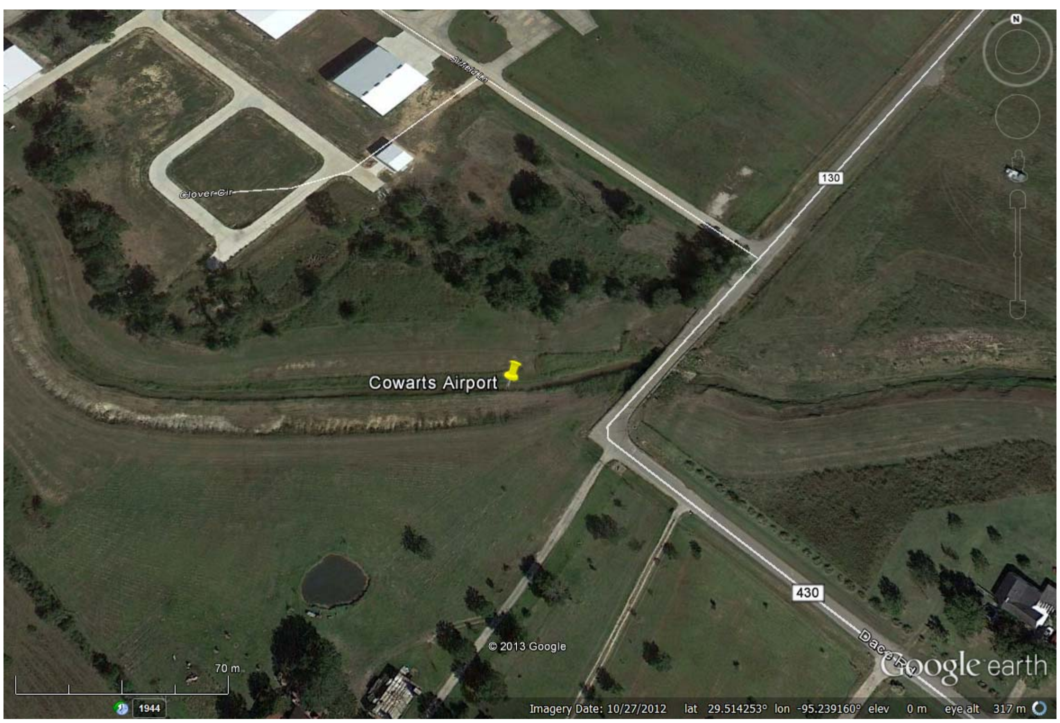

Figure 34. Close up view of the Cowart Creek Airport site (COA) located in Brazoria County which was surveyed during 2007.

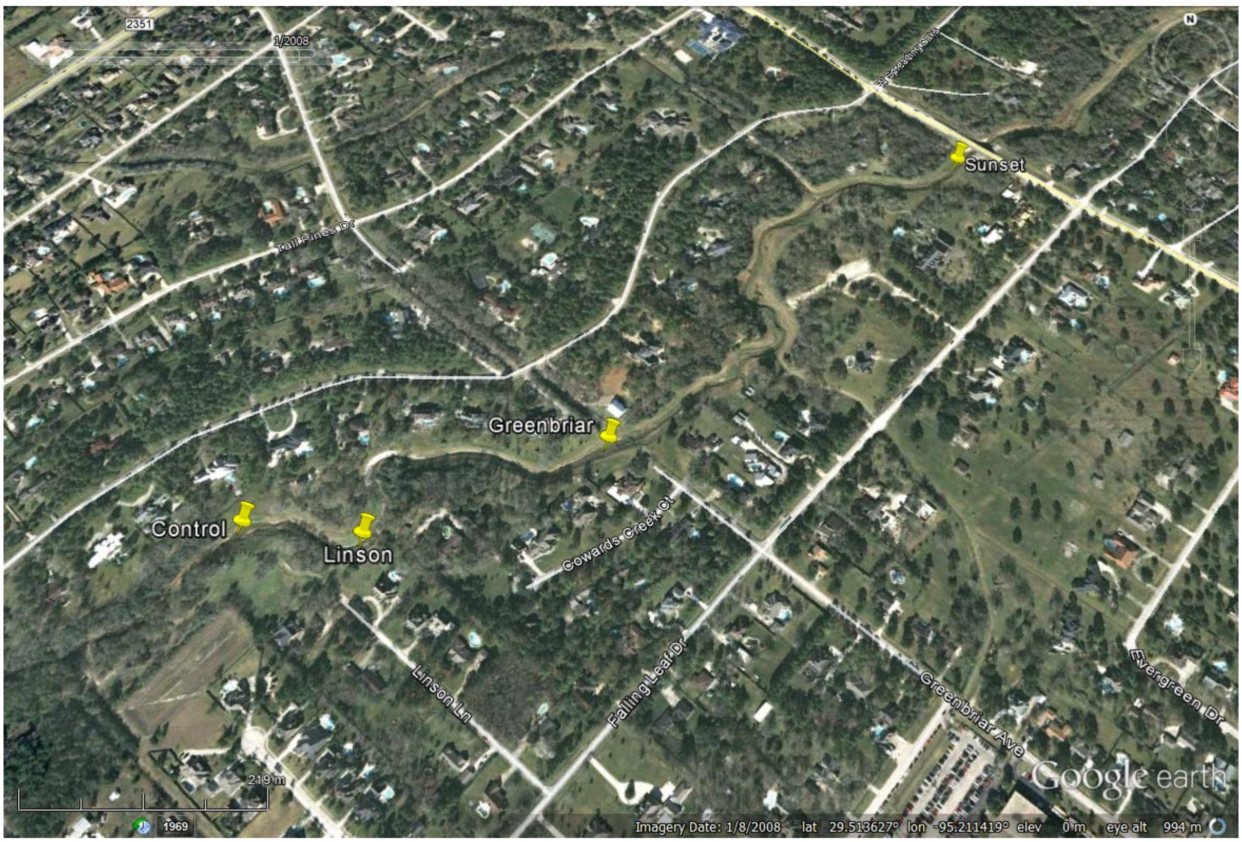

Figure 35. Location of Cowart Creek Sunset (COS), Greenbriar (COG), Linson (COL), and Control (COC) sites in Galveston County.

Figure 36. Cowart Creek at Airport (CCA) looking upstream from the CR 130.

A new control site Cowart Creek control site (**COC**) was established upstream of Linson Drive (Figure 37). This site was surveyed during 2007-2010 and replaced the original airport site (COA). The average width and depth at this site was 6 and 1.3 meters respectively. The bottom sediment at the COC was composed primarily of clay and the shoreline was composed of grasses and shrubs. Riparian shading was lacking. The estimated drainage basin upstream of this site was 30.0 km^2. There are 3 permitted discharges located upstream of the lower 4 sites, while only 2 of the permitted discharges are located above the COA site. The land-use was primarily residential neighborhood.

The Cowart Creek Linson site (**COL**) was located at Linson Drive (Figure 38). This site was unique in possessing a combination of articulating concrete block along a portion of its shoreline, a constructed rip rap artificial pool-riffle complex and a downstream concrete reinforced shoreline. Galveston County had constructed this site for mitigation, although the background details of the project are unknown. The average width and depth at this site was about 1.3 and 0.6 meters respectively. Riparian vegetation was limited to sparse grasses and some brush with almost no riparian shading. The land-use was primarily residential neighborhood.

The Cowart Creek Greenbriar site (**COG**) was located at Greenbriar Dr. (Figure 39). This site had also been modified by Galveston County. A series of small riffles and pools had previously been created with concrete rip rap. The shoreline and stream, at the time of the study, had been reinforced with concrete rip rap sitting on top of plastic sheeting. The average width and depth of this site was 1.0 and 0.3 meters. Riparian vegetation was limited to shoreline grasses. Riparian shading was lacking. The land-use was primarily residential neighborhood.

The furthest downstream site, Cowart Creek at Sunset Lane (**COS**) was located upstream of the Sunset Drive road bridge (Figure 40). This site was only minimally modified by placement of rip rap. The remaining shoreline and bottom material was composed of silt and clay. The shoreline was covered by a mixture of wild and cultivated grasses. The land-use was primarily residential neighborhood. The average width and depth at this site was 1.3 and 1.6 meters respectively. Riparian shading was largely lacking.

Armand Bayou. Two sites were surveyed within Armand Bayou in Harris County (Figure 41). Both of these sites are located downstream of mostly residential development. These two sites were surveyed in 2010 only. The upstream site, (**ABF**) was located immediately downstream of Fairmont Parkway, where recent upstream neighborhoods had been built. The watershed above ABF is approximately 12.83 km^2. There are 4 permitted wastewater discharges located upstream of this site. The riparian zone consisted of extensive trees that provided a shaded canopy for most of Armand Bayou within the study reach (Figure 42). The average width and depth was 1.3 and 0.3 meters, respectively. The bottom was composed of a mixture of sand, silts and gravel. The stream bank was very steep and evidence of down cutting of the stream channel was visible. The downstream Armand Bayou Holly Bay (**ABH**) site is located immediately upstream of Holly Bay Court (

Figure 43). The upstream watershed was estimated to be 7.06 km^2. There were two permitted discharges found upstream of ABH.

Figure 37. Cowart Creek Control site (COC) looking upstream on 3-30-09.

Figure 38. Cowart Creek Linson Site (COL) looking downstream showing articulated concrete bank and downstream artificial riffle habitat. Photo taken in 2007.

Figure 39. Cowart Creek Greenbriar site (COG) looking downstream showing partial rip rap shoreline with plastic liner. Rip rap was also deposited in stream to create minimal artificial riffle habitat. Photo taken in 2007.

Figure 40. Cowart Creek at Sunset Lane (COS) in Galveston County. View looking downstream at Sunset Dr. Photo taken in 2007.

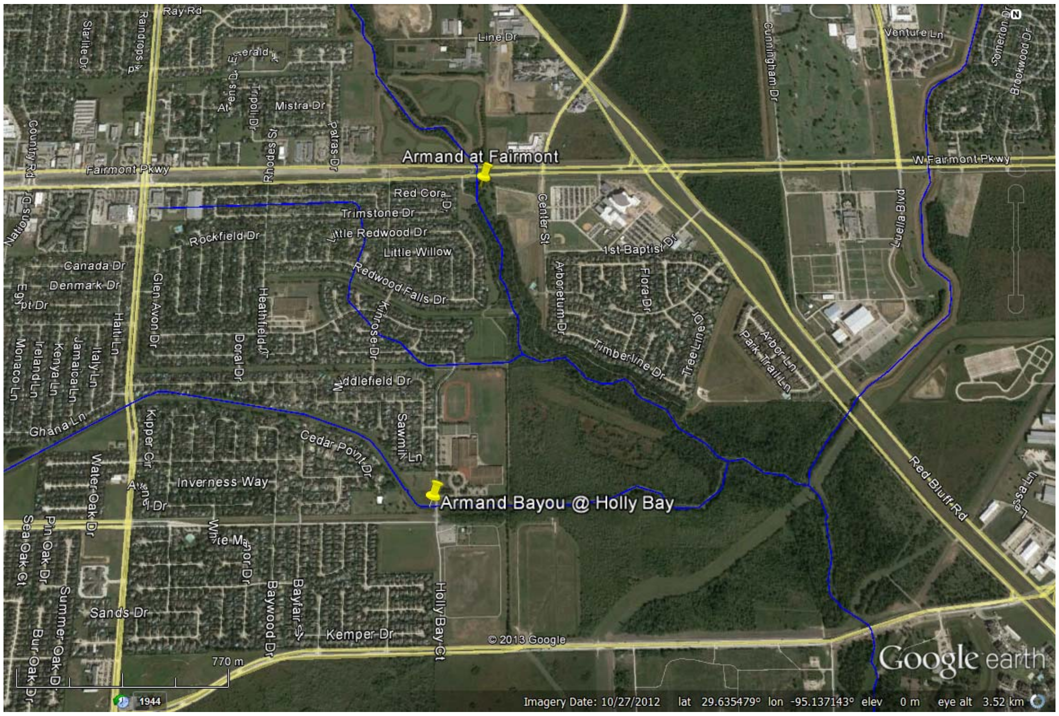

Figure 41. Location of the Armand Bayou sites including Armand Bayou at Fairmont (ABF) and at Holly Bay (ABH) in Harris County.

Figure 42. Armand Bayou at Fairmont Parkway (ABF). View looking downstream from Fairmont Parkway. Photo taken in 2008.

Figure 43. Armand Bayou at Holly Bay (ABH) site. View looking upstream from Holly Bay Court. Photo source: Google Earth Pro street view, 2013.

Methods

At each study site, the total area surveyed consisted of a 300-ft. (91.4 m) long section or reach of the stream with the exception of one site (Cowart Creek at Sunset Lane - COS) which consisted of a 150-foot (45.7 m) long section. All data collection was generally made during three sampling periods each year including early spring (Mar-Apr), late spring (May-Jun), and summer (Jul-Sep). As previously mentioned the Cowart Creek at Airport site (COA) was monitored only twice in 2007, whereas the Peach Creek, Mills Creek, Big Creek, Clear Creek and Armand Bayou sites were only monitored during 2010. The Cowart Creek control site (COC) was monitored twice in 2007 and 3 times each year in 2008, 2009, and 2010. The remaining sites located at tributary to the East Fork of Goose Creek, Big Gulch, White Oak Bayou, and Cowart Creek were monitored three times each year during 2007 through 2010. Sampling was initiated at each site usually early in the morning before 9:00 a.m.

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 (TCEQ 2007; TCEQ 2008; TNRCC 1999). 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. To facilitate statistical analysis (correlation and multivariate analysis), variables were averaged for each site during each collection. For example, the average stream velocity was obtained from three thalweg measurements. Sediment size classes, stream width, thalweg depth, shoreline slope, and sediment size classification were averaged prior to selected statistical analyses.

Habitat Type

Predominant stream habitat type was evaluated at each 30 ft. (9.15 m) increment along the 300-ft. (91.5 m) stream site and was categorized into one of three categories: riffle, run, or pool. A riffle is described by (TCEQ 2007) 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, riffle, and pool were calculated and graphed. In addition, pools, runs and riffles were given scores of 0, 1, and 2 and the sample standard deviation of the 10 scores calculated as a "habitat complexity" score for the site.

Sediment Type and Size

At the upstream, middle, and downstream areas of the 91.5 m (300 ft) segment, the stream sediment size composition was visually assessed by obtaining a sediment grab sample at 0.3 meters from each bank and midstream. An average score was then calculated based on these 9 replicates. An approximate percent composition of major sediment types at each study site was calculated based on these samples. Predominant stream sediment type was given a numeric rank based on its size observed using the Modified Wentworth Scale (Bain 1999) (Table 3). The Wentworth scale is used to quickly classify predominant sediment size within stream reaches. The scale was modified to include sediment/substrates not normally included in the traditional Wentworth scale including concrete lined channels and irregular hardpan clay and articulated concrete bricks.

Table 3. Sediment size distributions modified from (Fitzpatrick et al. 1998).

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

Submerged and Emergent Aquatic Vegetation

Percent of the stream bottom covered by submerged aquatic (SAV) and emergent aquatic vegetation (EAV) at the upstream (1 m), middle (45.75 m), and downstream extent (91.5 m) of the 91.5 m stream reach was measured 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) were also noted. The median or mean percent submerged and emergent vegetation was calculated for selected analyses. SAV and EAV are used as cover and stream velocity breaks by many stream fish to maximize energy conservation, facilitate thermoregulation, decrease predation and for spawning (Ross 2013).

Stream Bank Slope

The slope of both stream banks was determined using a Suunto brand clinometer at the upstream (1 m), middle (45.75 m), and downstream (91.5 m) sections of the 91.5 m stream reach during each sampling event. Excessively steep banks may indicate higher rates of erosion at a site or down-cutting due to higher flow rates.

Riparian Shading

Percent shading was determined at the upstream (1 m), middle (45.75 m), and downstream (91.5 m) sections of the 91.5 m stream segment during each sampling event. Shading was determined using a convex spherical densitometer following the methods outlined in (TCEQ 2012). Water temperatures in un-shaded streams are often much higher during summer months. This can induce additional thermal stress in native fauna and reduce dissolved oxygen carrying capacity (Brown et al. 2005).

Stream 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 (TCEQ 2007; TCEQ 2008; TNRCC 1999). Stream velocity, thalweg depth, and stream width were determined at the upstream (1 m), middle (45.75 m), and downstream (91.5 m) sections of the 91.5 m segment during each sampling event. Stream velocity was measured at 60 percent of the total depth, or at 20 and 80 percent total depth, and then averaged. Stream discharge was measured at the upstream transect using a minimum of ten equally spaced velocity measurements. Depth and velocity was determined using a top-setting wading rod with an attached Sontek River Surveyor acoustic velocity meter or pygmy price velocity meter.

Water Quality

Water quality measurements were obtained during each sampling event at the upstream section of each stream segment. Variables included water temperature, specific conductance at 25 ºC, pH, dissolved oxygen (DO), Secchi disk (SD) transparency, turbidity (NTU), orthophosphates (OP), ammonia-nitrogen (NH_3-N), nitrate + nitrite-nitrogen (NO_{2+3}-N), total suspended solids (TSS), total alkalinity (T-Alk), total hardness, and chlorophyll-*a* (Chl-*a*) (Table 4).

Table 4. List of water quality variables measured during the study.

Parameter and Location of Analysis	Type of kit, meter, and/or method
Temperature (°C) – field	Thermometer or YSI electronic multiprobe meter[1]
Specific conductance (uS) @ 25 ºC – field	Oakton Instruments: EC Testr or YSI meter[1]
pH – field	Oakton Instruments: pH Testr 2 or YSI meter[1]
Dissolved oxygen (mg/L) – field	LaMotte Test Model EDO Code 7414 or YSI meter[1]
Secchi disk transparency (cm) – field	Secchi Tube[1]
Turbidity (NTU) – lab	Scientific Inc. Turbidimeter[2]
Total suspended solids (mg/L) – lab	APHA 2540[2]
Total Hardness (mg/L Mg and Ca) – lab	Hach method 8030[3] with DR/890
Total Alkalinity (mg/L $CaCO_3$) – lab	LaMotte WAT-DR code 49-DR 4491-DR-01[2]
Orthophosphate (mg/L PO_4) – lab	Phosphorus, reactive Method 8048[3] using a Hach DR/890 Colorimeter (filtered with 47mm filter paper) (detection limit 2.50 mg/L) EPA 365.1
Ammonia-nitrogen (mg/L NH_3-N) – lab	Hach Kit Midrange Model NI-8 (quantitation limit 0.3 mg/L) SM 4500-NH3 C [3]
Nitrate-nitrogen (mg/L NO_3-N) – lab	Nitrate, low-range Method 8192 using a Hach DR/890 Colorimeter (detection limit 0.50 mg/L)[3]
Nitrite-nitrogen (mg/L NO_2-N) – lab	Hach method 8507[3, 4]
Chlorophyll-*a* (mg/m^3= ug/L) - lab	Spectrophotometric APHA 10200[2]

[1] (TCEQ 2008), [2] (American Public Health Association et al. 1998), [3] (HACH 2013)
[4] Combined with nitrate nitrogen to estimate NO_{2+3}-N

Water temperature, specific conductance, pH, dissolved oxygen and Secchi disk were measured in the field. All other variables were analyzed in the laboratory after being collected in clean sample containers (Table 4). Whenever measurement errors occurred, predicted values for TSS, NTU and SD generated from measured values of the non-missing member of this group, were substituted using models developed by (Guillen et al. 2012). Values below detection limits were substituted with the value of ½ the detection limit for statistical analysis.

Fish Community

Stream fish were collected during each sampling event using techniques outlined in the TCEQ procedures manual (TCEQ 2007; TNRCC 1999). Sampling consisted of seining and electro-fishing using a Smith-Root backpack shocker. At each site, a 91.44 m stream segment was measured out (except at the Cowart Creek Sunset Lane - COS site). Within the stream segment and during each sampling event, ten seine hauls (9.14 m segments) were conducted (five seine hauls for COS site) 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 also used to obtain fish samples at 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 published literature and manufacturers recommendations, at specific conductivities exceeding 1,000 µS electrofishing is ineffective with the back pack shocker. Therefore when specific conductivities exceeded 1,000 μS only seining was used to collect fish (Hill and Willis 1994). Electro-fishing was conducted along three 30.48 m segments for a total of three adjacent electro-fishing replicates per site (91.44 total length) per event. Electro-fishing was generally not conducted at the Cowart Creek sites because of the elevated specific conductance levels, which were generally greater than 1000 μS/cm.

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 70% ethanol for long-term storage prior to identification. Total abundance, abundance of numerically abundant species, Shannon-Wiener's Diversity (H), Pielou's evenness (J), Berger Parker Index (BP), and taxa richness were calculated for each replicate and compared between sites (Krebs 1999). Shannon-Wiener Diversity (H') is defined as $-\sum P_i(\ln P_i)$ where P_i is the proportion of each species *i* in the sample. Pielou's Evenness (J) 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. The Berger Parker Index (BP) is simply the numerical ratio of the most dominant taxa to the total number of individuals in the collection. Richness is a count of the number of species or taxa present in a replicate sample and at the site overall.

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). The statewide regionalized index of numerical criteria for assessing fish assemblages when determining aquatic life uses in small (usually wadeable) Texas streams was developed by (Linam et al. 2002). The Fish IBI is comprised of twelve metrics that fall into three broad categories: species composition; trophic composition; and fish abundance and condition. The majority of survey sites were located within 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.

For each metric we provided a score of either 1, 3, or 5 based on the value of the fish community metric. The scores are added together to obtain an overall IBI/Aquatic Life score and use. For Ecoregion 34 an IBI score of >49 is considered exceptional use, while 39-48 is considered high use, 31-38 is considered intermediate use, and <31 is considered limited. As stated earlier, Peach

Creek was located in Ecoregion 35. Calculation of the metrics for this site differs slightly from Ecoregion 34.

Benthic Invertebrate Community

Benthic organisms were also generally collected at each site by sampling benthic habitat with a d-frame benthic sampler using methodology described in (TCEQ 2007). The benthic organisms were collected in 3 non-overlapping 30.48 meter replicate sample reaches. Benthic samples were collected using a 5 minute sweep per 30.48 meters of stream. All benthic organisms were identified to the lowest taxonomic levels (generally family or genus). Total abundance and taxa richness were calculated from the community data for each replicate and compared between sites and collections (Krebs 1999). We did not conduct any further analysis due to the lower accuracy inherent in the identification of benthic invertebrates and the qualitative nature of the data. However, benthic stream invertebrate community data provides complimentary biological information that aids in the interpretation of stream quality since benthic invertebrates are much less mobile than fish and reflect changes in local conditions (Barbour et al. 1999; Rosenberg and Resh 1993). Benthic invertebrates are generally more sensitive to local scale changes in the environment than fish, which provide information at a larger scale in terms of integrating water quality and watershed scale processes (Karr and Chu 1999; Karr et al. 1986).

Data Analysis

All organisms were identified to the lowest taxonomic level possible. In most cases specimens were identified to species level to facilitate comparisons between individual species abundances. Benthic organisms were usually identified to family or generic levels according to TCEQ guidance manuals (TCEQ 2007). This identification was also used for further calculation of number of fish species, fish diversity indices, Fish IBI metrics and benthic number of taxa. 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. 2008; Thomas et al. 2007). Boxplot and median confidence interval plots of mean values of physical and biological variables were used to graphically compare sites and/or sample collections. A non-parametric Kruskal-Wallis (K-W) one way ANOVA and Dunn's multiple range test, was used to compare physicochemical and biological variables between sites and/or collections (Ryan et al. 2013). The K-W ANOVA test does not require the data to be normally distribute, but instead uses the rank of the data values rather than the actual data values for the analysis. As such it usually has less power (ability to detect a difference of certain magnitude when present) than the parametric ANOVA. Due to the high number of replicates we decided to focus on differences between sites and not individual collections. This approach was taken for several reasons. We believe the primary question of interest is determining broad patterns in physicochemical and biological community data between sites and the relationship between them with particular focus on stream substrate and habitat.

Correlation analyses and scatterplots when necessary were constructed and conducted on physicochemical and biological data to visually inspect the data and explore possible relationships between these variables. Multivariate cluster analysis was conducted on the physicochemical, fish and benthic community data to compare patterns in between collections.

The analysis was conducted with both the Minitab and PRIMER © software package (Clarke and Gorley 2006).

Cluster analysis was used to create groups composed of a similar attributes based on species composition and abundance or variable composition and abundance. In our case, the entities were collections at each site by date and the attributes and were either fish species or quantitative physico-chemical variables. Prior to analyzing the White Oak Bayou upstream site (WOU) fish community data we transformed the species abundance data by reducing the number of species in the data matrix to only commonly collected species (frequency > 20% of the collections). In addition, fish abundance data (X) were log transformed (log X+1). Both of these steps are routinely conducted prior to conducting multivariate analyses to reduce variability and influence of rare or uncommon species with many zero occurrences (Clarke and Warwick 2001). For cluster analyses conducted on biological data we used the Bray-Curtis similarity metric and Group Average clustering algorithm which has been shown to be superior in dealing with data containing zero cells (no occurrence of the species). This method is recommended for abundance and biomass data.

For physicochemical data we used the Euclidean distance measure and Group Average clustering algorithm during cluster analysis which is recommended for environmental data (Clarke and Warwick 2001). Prior to conducting cluster analysis we standardized each physicochemical variable to provide equal weighting. This was accomplished by subtracting the mean of the values from each variable value and then dividing by the standard deviation. It is usually necessary to do this for environmental data where variables are often measured on completely different scales, with different origins. It then makes it possible to derive meaningful distances between samples, using Euclidean distance. The means and standard deviations are dependent on the actual data selection so all data for each variable was selected for this operation.

After the cluster analysis we constructed a dendrogram depicting the distances (Bray Curtis or Euclidean) between collections. A SIMPROF test for structure in the data was conducted to define groups or clusters of similar collections based on fish community similarities (Clarke and Gorley 2006). This procedure first creates a resemblance profile by ranking the resemblance matrix for the data. A mean profile is then calculated by randomizing the order of each variables values and re-calculating the profile. A *pi* statistic is calculated as the deviation of the actual data profile with the mean one. This is compared with the deviations of further randomly generated profiles to test for significance. The null hypothesis is the data contains no structure and the whole data set belongs to one large cluster.

Principal components analysis (PCA) was used to evaluate the interrelationship of environmental variables examined during the study and how combinations of these variables may be responsible for observed patterns in the distribution of environmental data and/or aquatic organisms. PCA is an ordination technique that reduces numerous variables into fewer explanatory “principal components” composed of the linear combinations of the original variables. These new PCA’s can be used to later predict interrelationships between variables and observations (Tabachnick and Fidell 2001). Prior to analysis all physical variables were standardized to assure equal weighting of each variable. PCA was conducted using the Minitab software package (Ryan et al. 2013).

A non-metric dimensional (NMDS) scaling method was similarly used to evaluate the relationship of various sites based on the similarity of fish taxa (Clarke and Gorley 2006). Unlike PCA, this method is non-metric, based on ranks. Although this method also produces a classification of sites based on taxa, it does not attempt to place these in mutually exclusive groups like cluster analysis. So it provides a complementary method to examine community patterns. The PRIMER software package was used to conduct this analysis.

Results

Watershed Characteristics

The contributing watershed area for each site varied considerably (Figure 44). The smallest (4 ha) upstream watershed was found at the Cowards Creek Airport (COA) site. In contrast the largest (>10,000 ha) upstream watersheds were found at Big Creek (BIC) and Peach Creek (PEC) sites. The degree of urban development of the upstream watershed was determined by two different measurements, amount of impervious surface and number of wastewater facilities. The Rummel Creek sites (RCR, RCS, and RCB) had the highest percentage (56%) of impervious surface within the upstream watershed (Figure 45). The majority of this watershed is urbanized and includes a large amount of roads and freeway. The sites with the least (< 2%) percentage of impervious surfaces within the upstream watershed included BIC, Mill Creek (MIC), and PEC sites. The total amount of impervious area in each watershed varied between >5,000 hectares at the White Oak sites (WOU and WOD) to < 2 hectares at the Cowart Creek sites (Figure 46). The BIC, MIC, and PEC watersheds contained high amount of woodlands, prairies and/or farmlands (Figure 47). The Armand Bayou (ABF and ABH), Rummel Creek, and White Oak Bayou watersheds exhibited the highest amount of urban development, with high percentages of low and high intensity development. The White Oak and Peach Creek watersheds also contained the highest number of permitted wastewater facilities (Figure 48). Many (12/20) of the survey sites did not have any permitted wastewater facilities upstream of their respective sampling sites.

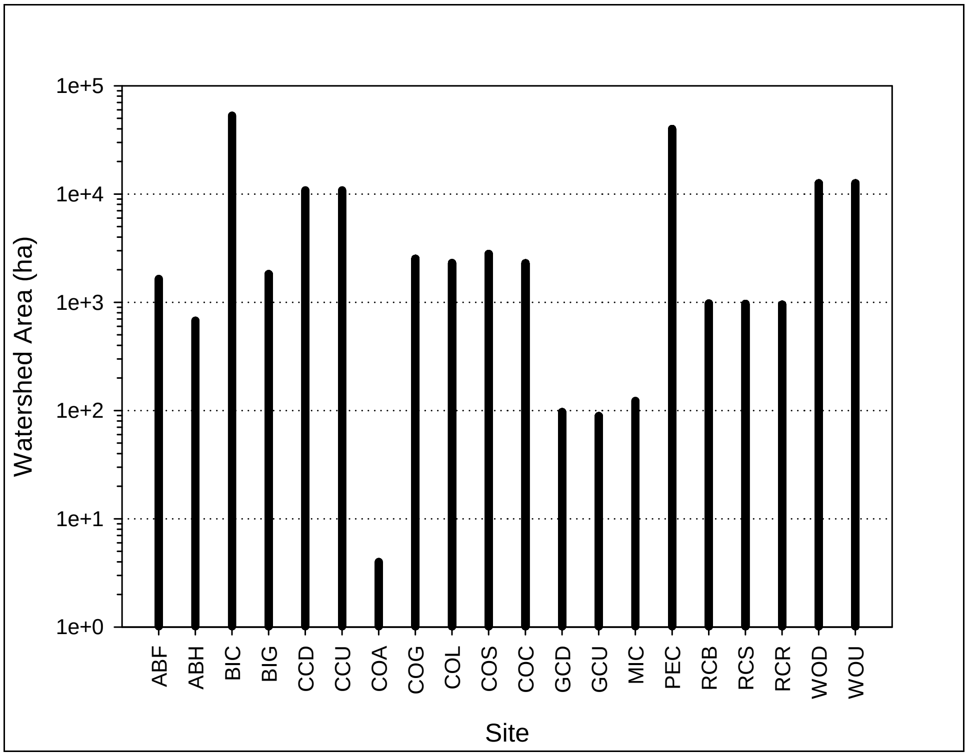

Figure 44. Size of the upstream watershed at each survey site.

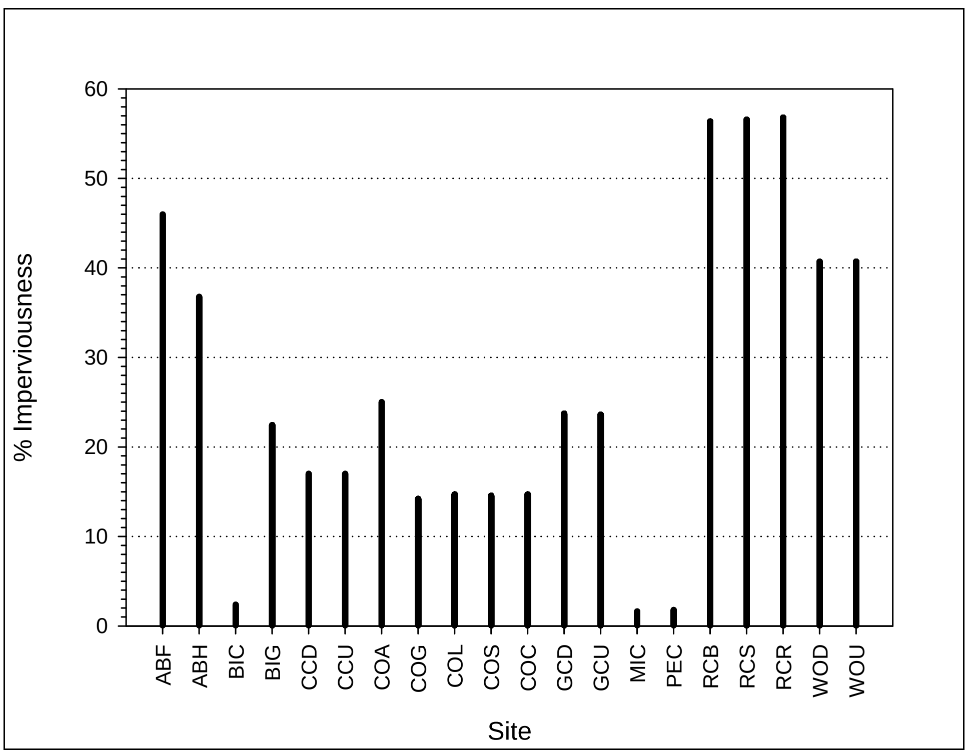

Figure 45. Percent impervious area within the upstream watershed of each survey site.

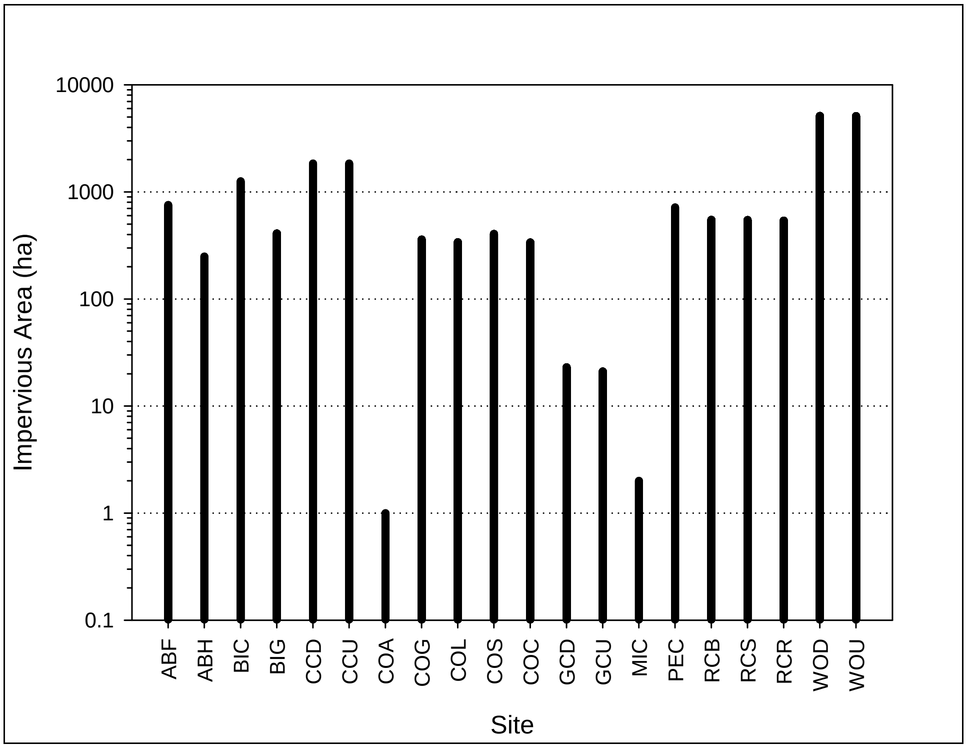

Figure 46. Impervious area within the upstream watershed at each survey site.

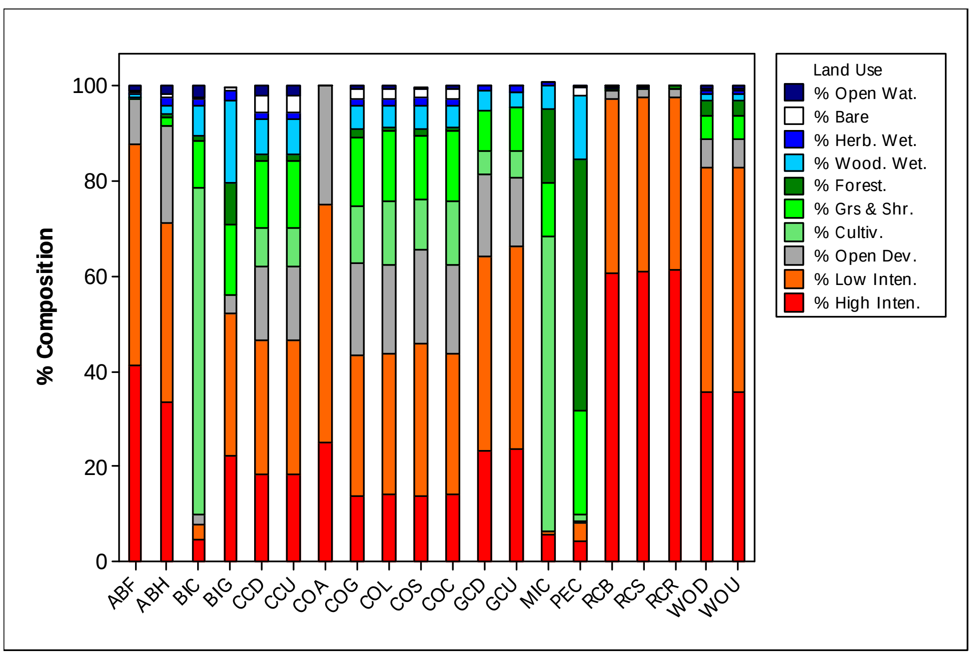

Figure 47. Land use in the upstream watershed at each site.

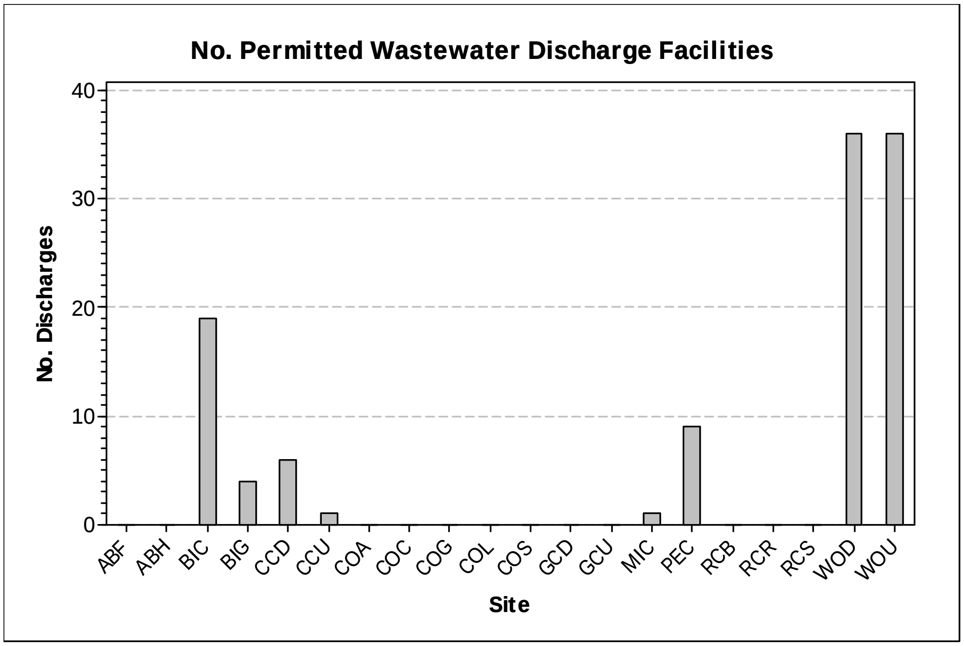

Figure 48. Number of permitted wastewater facilities upstream of the each survey site.

Hydrology and Vegetation

Rainfall. Collections were generally made during low or base flow periods at each site. Examination of rainfall records indicated that the 50th percentile (median) value for days since last significant rainfall for all sites combined was approximately 3 days (Figure 49). The Mills Creek (MIC) and Peach Creek (PEC) sites generally had the highest median number of elapsed days since significant rainfall (Figure 50). However, several periods of very low rainfall were observed during the study. This included one event when rain had not fallen for over 158 days prior to the April 2009 collections at Rummel Creek. During May 2009 rain had not fallen for 41 days prior to collections made at the White Oak sites.

Ninety percent of all surveys were conducted when the area had experienced significant rainfall during the preceding 19 days. The majority of collections occurred when 1- and 3-day cumulative rainfall amounts were < 0.5 inches (1-day – 95 percentile; 3-day – 80 percentile) (Figure 51). The median 1- and 3-day amounts of rainfall were both zero, which means that at least 50% of the observations exhibited 0.00 inches of rainfall for both categories of rainfall. Furthermore, the 79th percentile for cumulative 1-day rainfall and the 52th percentile for cumulative 3-day rainfall amount were both 0.00 inches. The majority of sites exhibited similar amounts of 1- and 3-day precipitation (Figure 52). The majority of the 1- and 3-day median rainfall amounts for each site were below 0.2 and 0.5 inches, respectively. However, both 1- and 3-day median precipitation amounts were significantly higher at the Armand Bayou Holly Bay site. The highest individual 1- and 3-day cumulative precipitation (0.92 and 1.80 inches, respectively) amount was reported at the Rummel Creek sites during August 2009.

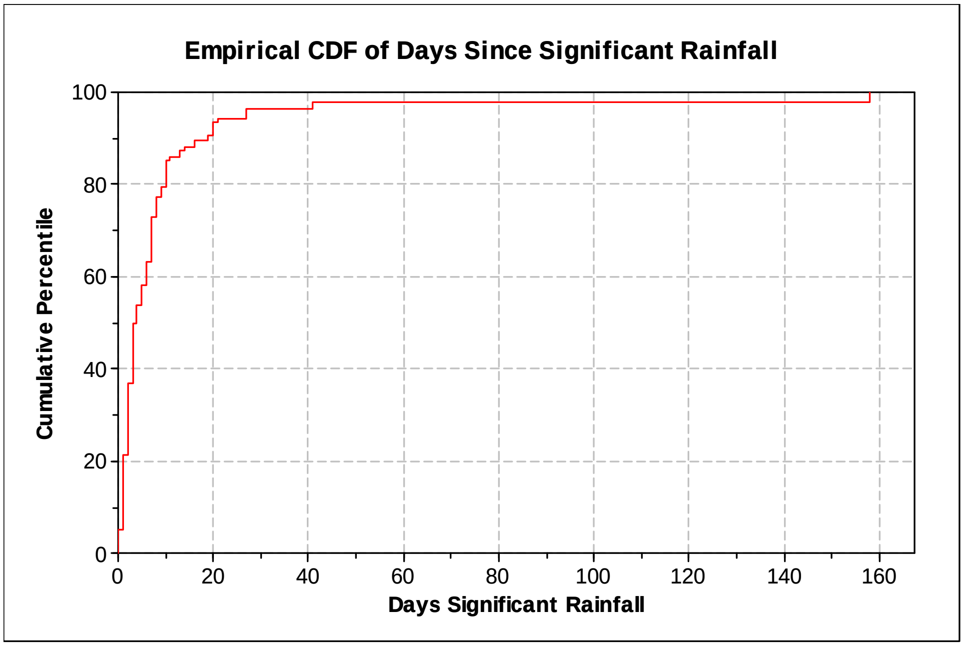

Figure 49. Cumulative distribution of rainfall during the study period during each sampling event at all sites during 2007-2010.

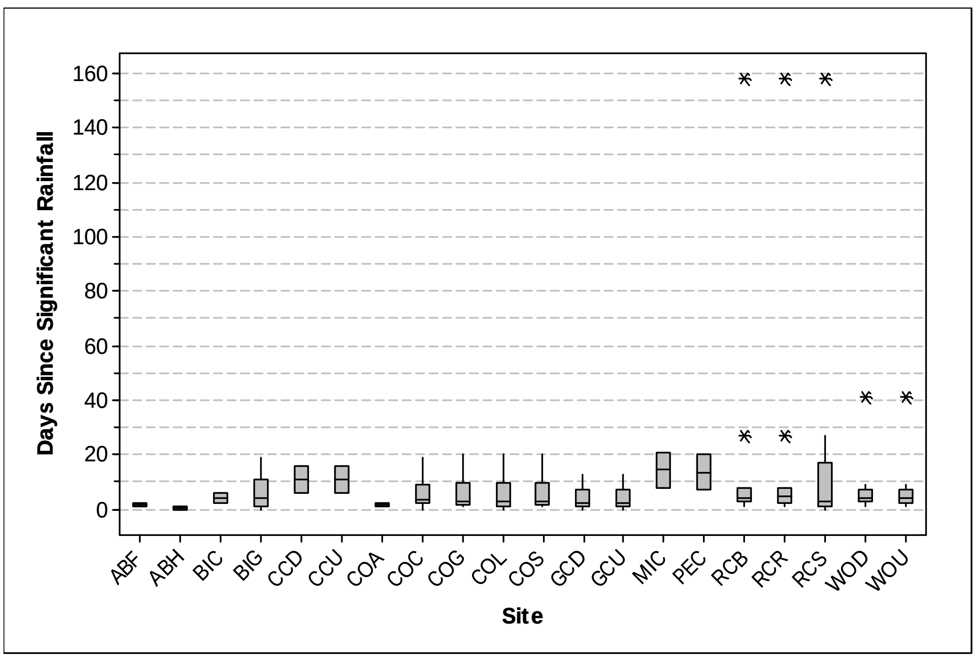

Figure 50. Boxplot depicting the distribution of periods of prior rainfall during sampling events at each site during the study period 2007-2010.

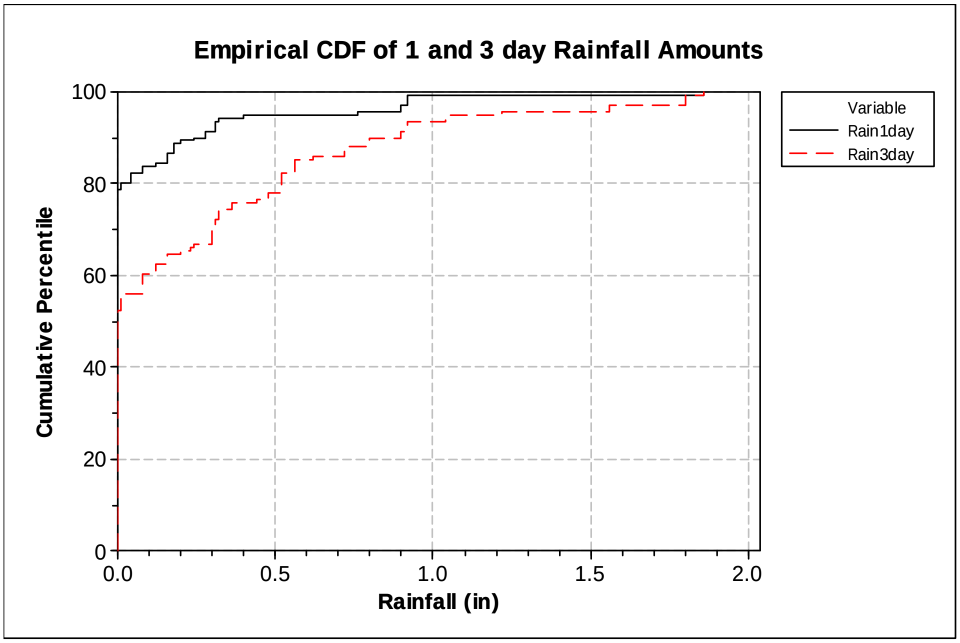

Figure 51. Cumulative distribution of 1 and 3-day rainfall amounts during sampling events at each site during the study period 2007-2010.

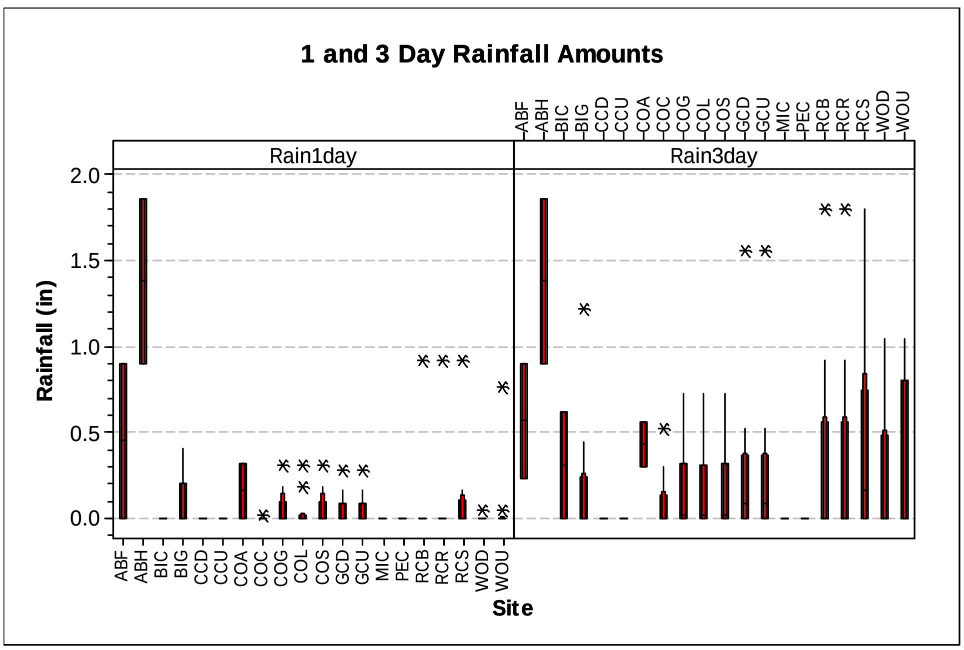

Figure 52. Boxplot depicting the distribution of 1- and 3-day cumulative rainfall events at each site during the study period 2007-2010. Red bar depicts the 95% confidence interval for the median.

<u>Stream Hydrology</u>. The median streamflow recorded for all sites combined was 0.64 cfs (Figure 53). The highest streamflow recorded was 67.27 cfs. Streamflow less than 6 cfs was commonly (70^{th} percentile) observed. The distribution and median streamflow varied considerably between sites (Figure 54). The highest recorded median flows generally occurred at the Big Creek and White Oak Bayou sites. This is most likely due to their individually large watersheds and/or increased urbanization which can often lead to increased base flows and/or flashier storm flows (Figure 55). These two sites exhibited statistically higher median flows in comparison to all other sites except Peach Creek. Higher flows were observed at the more urbanized White Oak sites even though the contributing watershed was smaller in comparison to the Big Creek and Peach Creek sites. As previously noted, White Oak Bayou had the highest total amount and percentages of impervious land upstream of the survey site (Figure 45- 47). In addition, White Oak Bayou contained the most numerous wastewater facilities (Figure 48). The high number of wastewater facilities has most likely increased the base flow observed at White Oak Bayou. Although there appeared to be differences in streamflow between sites, based on the low sampling frequency used in our study at these sites we could not detect any statistically significant differences in mean streamflow between sites (Figure 56).

The highest stream thalweg velocity measured during the study occurred at the Cowart Creek Greenbriar (COG) site (Figure 57). Overall median average velocity ranged between 0.02 to 1.76 f/s. The highest recorded median velocities were at the Armand Bayou and White Oak Bayou sites. However, due to the high variability in velocity between sampling events at each site, there was considerable overlap of confidence intervals for the median streamflow. Several sites including Armand Bayou, Big Creek, Peach Creek, Mill Creek and White Oak Bayou exhibited significantly higher median flows than Big Gulch, Goose Creek and Rummel Creek. Similarly the confidence interval plots for the mean thalweg velocity were extremely large and overlapped each other and included zero velocity. These extremely large confidence intervals were likely due to the small sample size used to calculate the mean values at these sites. Based on graphical comparisons of confidence intervals we can conclude that the average thalweg stream velocity between sites were not statistically different from each other (Figure 58).

Average stream width was estimated from three transects measured at the upper, middle and lower portion of each sampling site (Figure 59). Based on these average values, White Oak Bayou, Peach Creek, and Mill Creek were statistically wider than all the other streams surveyed except Big Creek and Clear Creek downstream (CCD). During most sampling events, stream width was generally wider at the Peach Creek and White Oak Bayou sites in contrast to other sites. The Armand Bayou, Clear Creek upstream (CCU), and Peach Creek sites exhibited extremely wide confidence intervals for mean stream width (Figure 60). This was likely due to the small sample size (n=2) at these sites. Although statistically insignificant, the widest reported mean stream width reported was from the White Oak Bayou and Peach Creek sites.

Stream depth varied between sites ranging between 0.12 and 1.12 meters (Figure 61). Armand Bayou Holly Bay (ABH) and Big Creek sites exhibited statistically deeper thalweg depths than nine of the other sites. Due to the small sample size (n=2), the ABH, Big Creek (BIC), and Peach Creek (PEC) sites exhibited extremely wide confidence intervals for mean stream thalweg depth (Figure 62). Although statistically insignificant, the deepest calculated mean stream thalweg depths were observed at the ABH, BIC and PEC sites.

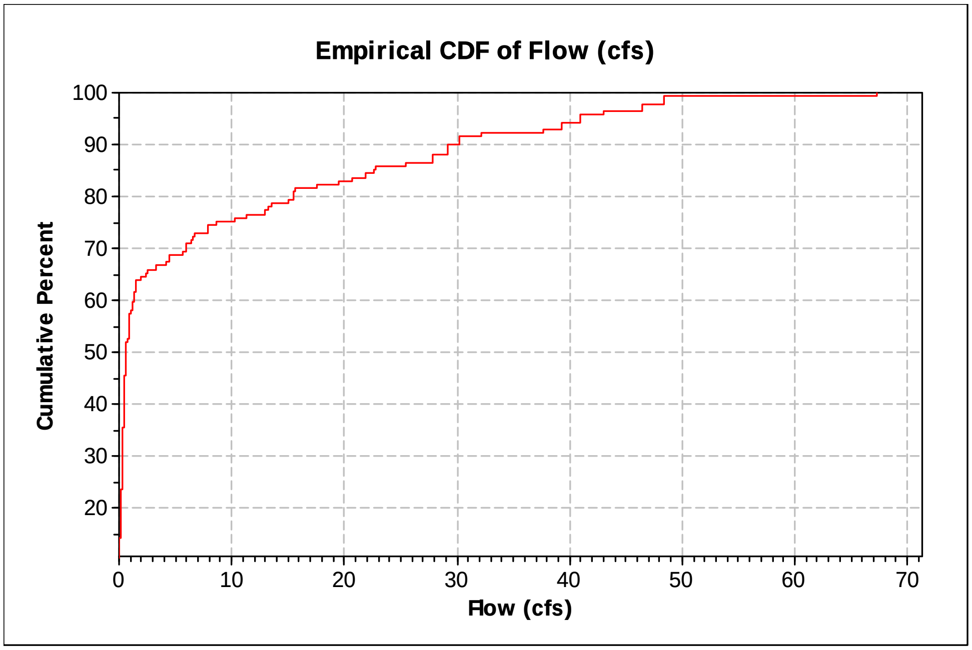

Figure 53. Cumulative distribution of streamflow measured during sampling events at each site during the study period 2007-2010.

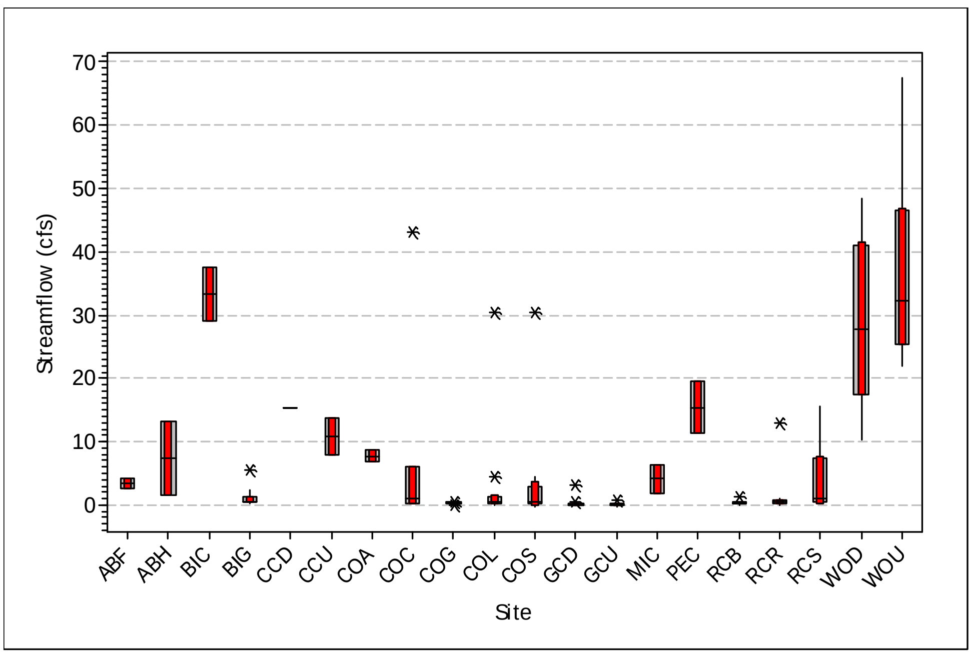

Figure 54. Boxplot depicting the distribution of streamflow measured during sampling events at each site within the study period 2007-2010. Red bar depicts the 95% confidence interval for the median.

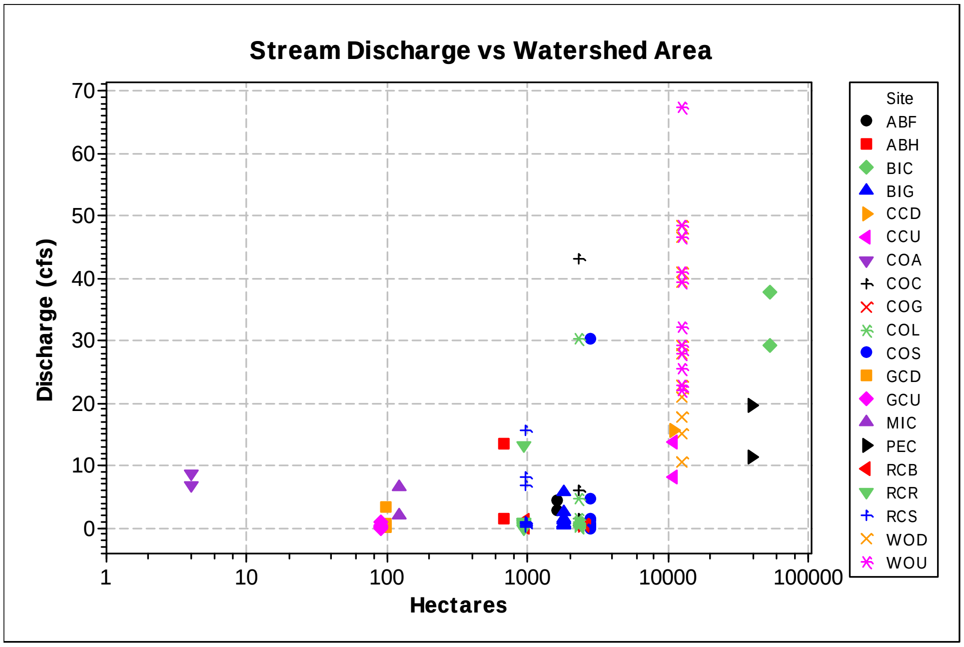

Figure 55. Distribution of streamflow versus watershed size. X-axis is on a semi-logarithmic scale.

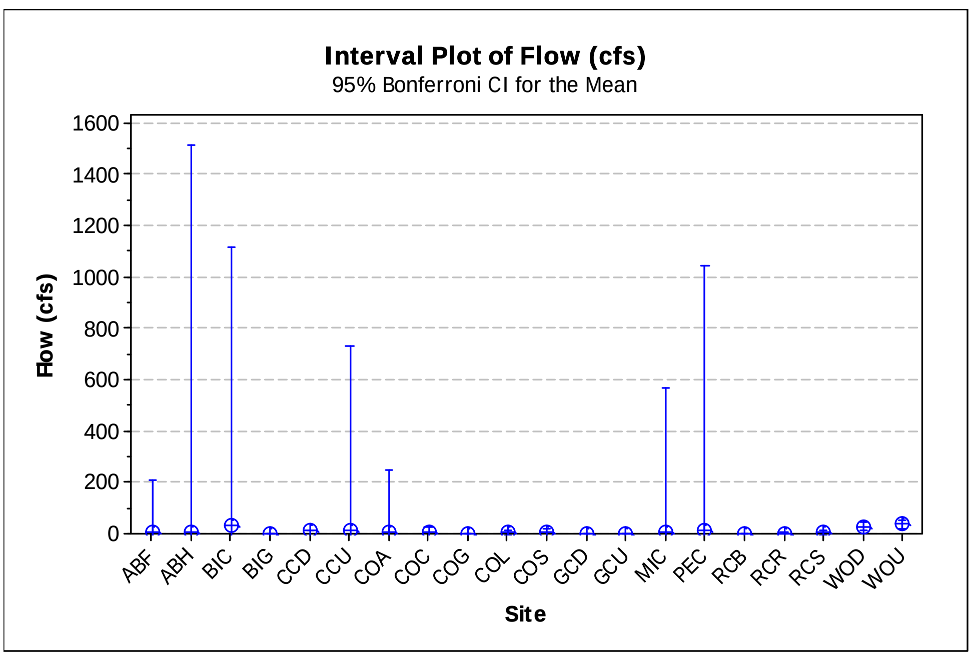

Figure 56. Bonferroni 95% confidence intervals for stream flow by site (99% individual confidence intervals) sampled during 2007-2010.

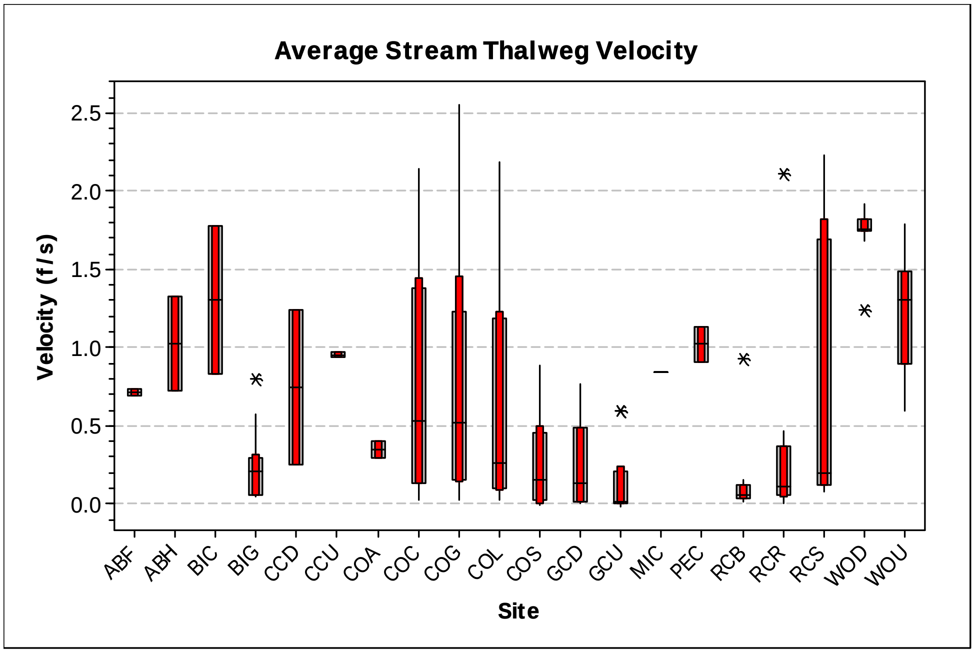

Figure 57. Boxplot depicting the distribution of average thalweg velocity measured during sampling events at each site during the study period 2007-2010. Red bar depicts the 95% confidence interval for the median.

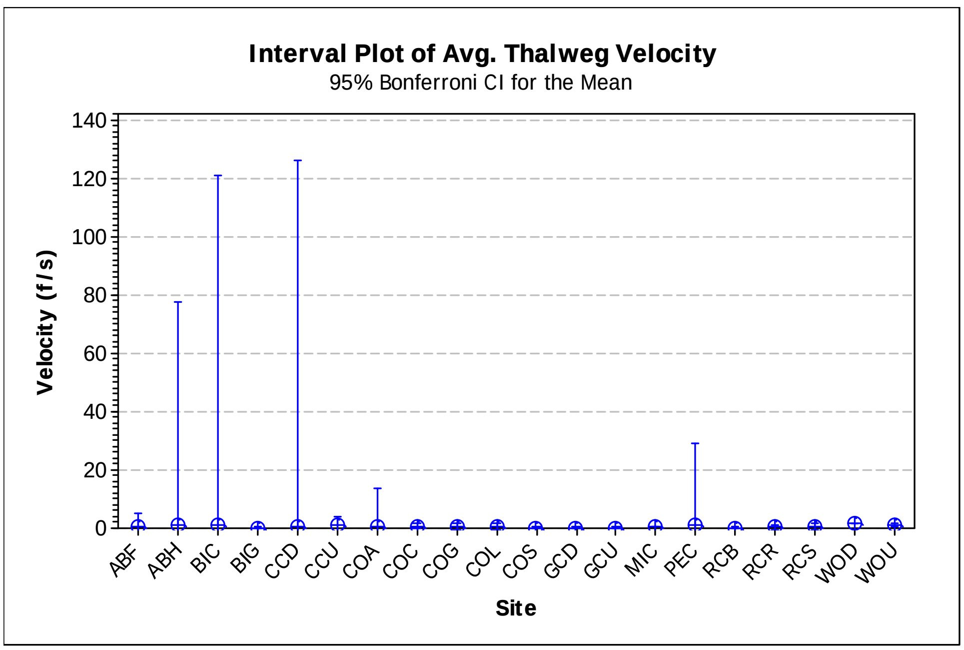

Figure 58. Bonferroni 95% confidence intervals for average thalweg velocity for sites (99% individual confidence intervals) sampled during 2007-2010.

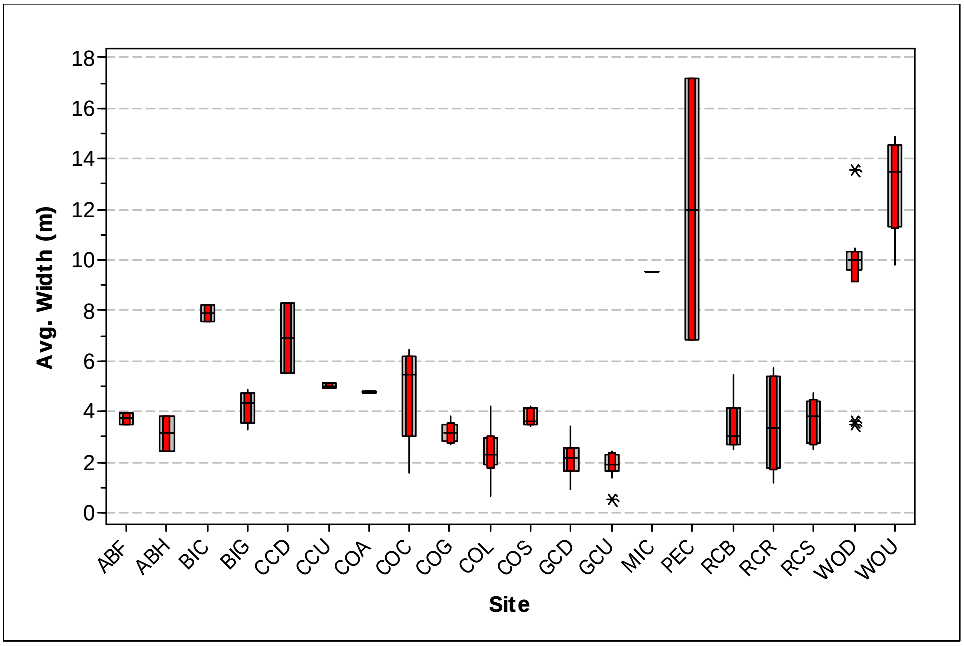

Figure 59. Boxplot depicting the distribution of average stream width measured during sampling events at each site during the study period 2007-2010. Red bar depicts the 95% confidence interval for the median.

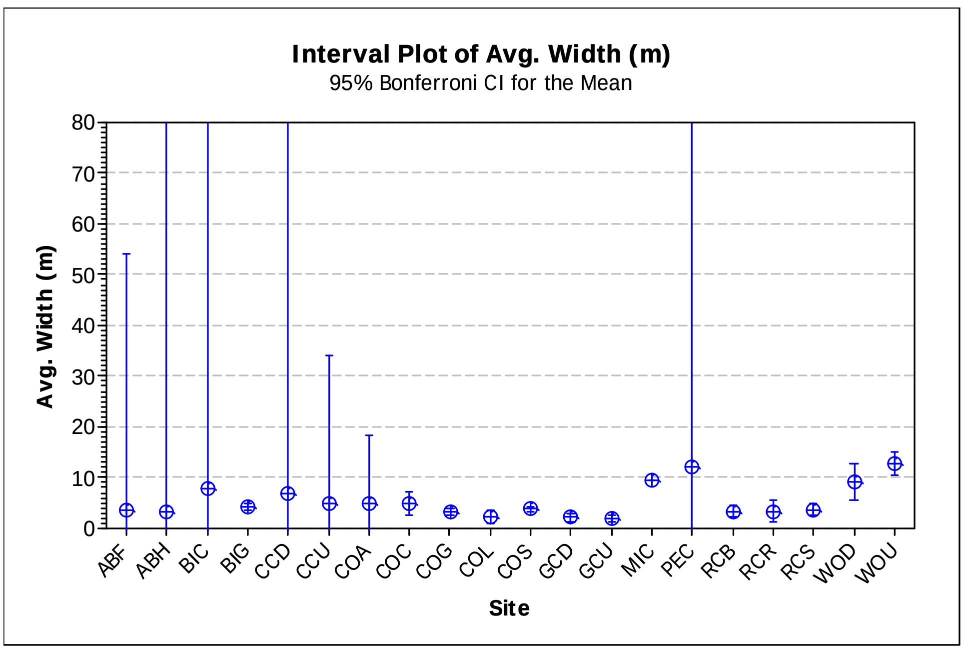

Figure 60. Bonferroni 95% confidence intervals for average stream width by site (99% individual confidence intervals) sampled during 2007-2010.

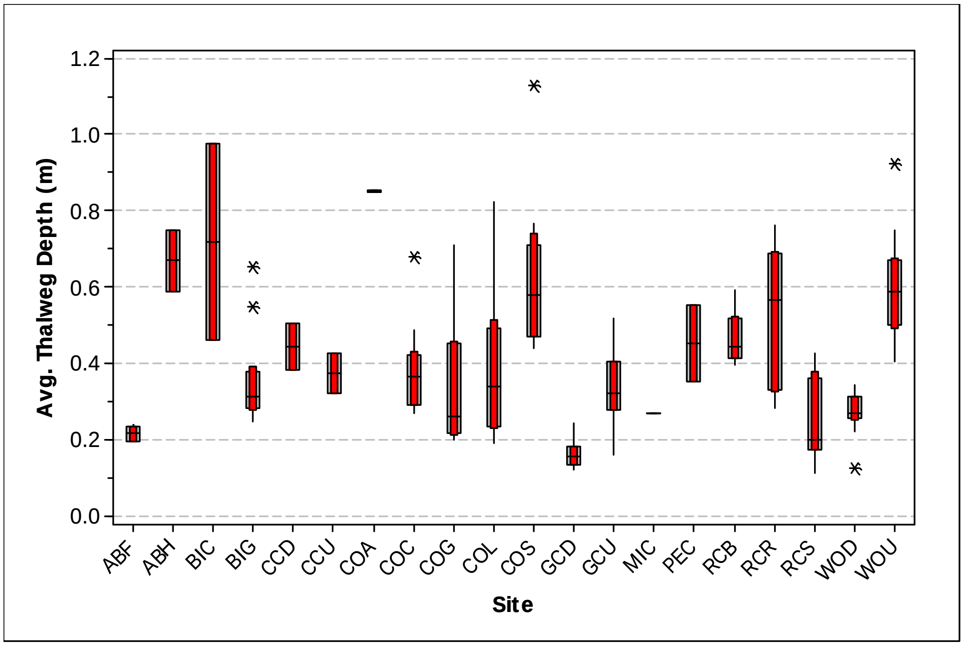

Figure 61. Boxplot depicting the distribution of average thalweg depth measured during sampling events at each site during the study period 2007-2010. Red bar depicts the 95% confidence interval for the median.

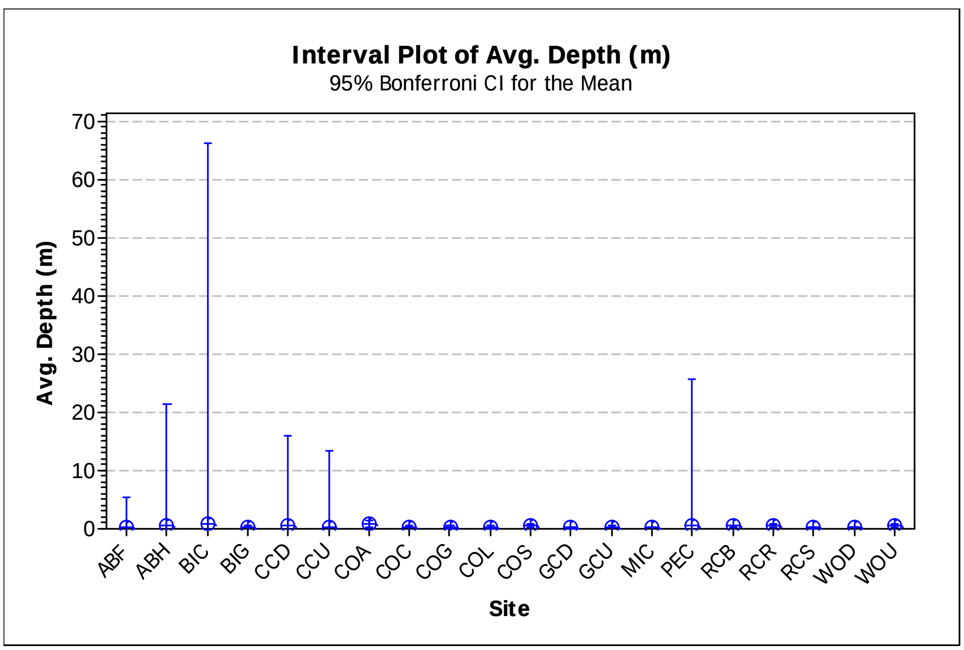

Figure 62. Bonferroni 95% confidence intervals for average stream thalweg depth by site (99% individual confidence intervals) sampled during 2007-2010.

Sediment. Sediment type as measured by the Wentworth sediment score scale varied between silt/clay (score = 0) and solid concrete (score = 6) (Figure 63). The majority of sites contained varying amounts of sand, silt and clay. However, in some cases hardened clay pan would form large dense rock-like structures. This created additional instream three dimensional habitats. This type of substrate was observed at the White Oak upstream (WOU) site. The White Oak downstream (WOD) site consisted of 100% concrete channel, whereas the substrate at Big Creek (BIC), Cowart Creek Airport (COA), Cowart Creek control (COC), Goose Creek upstream (GCU) and Mill Creek (MIC) sites consisted mainly of silt and clay. The confidence interval for mean sediment size was extremely wide at the Armand Bayou, BIC, Big Gulch (BIG), and Clear Creek sites (Figure 64). Due to these large confidence intervals it is difficult to statistically differentiate between sites based on sediment size with the exception of sites characterized by homogenous sediment at either extreme of the size spectrum (silt or concrete).

Aquatic Vegetation. The amount of submerged aquatic vegetation (SAV) at each site was generally low (< 10%) at most sites (Figure 66). The highest amount observed at any site during any collection was at the Cowart Creek Sunset Lane (COS) site. A majority of sites contained no SAV at all. Some sites exhibited significant seasonal fluctuations in SAV (e.g. submerged algal mats) including Cowart Creek, Clear Creek downstream (CCD) and Goose Creek sites. Due to this variability in part the confidence intervals for mean SAV percent coverage was very large at several of these sites (Figure 67). Stream sites possessing SAV were in most cases also the shallowest and narrowest survey sites (Figure 59 and 61).

The amount of emergent aquatic vegetation (EAV) varied considerably between and within sites depending on collection period (Figure 68). The highest percentage (66%) observed at any site during any collection was at the Goose Creek downstream (GCD) site. EAV was totally lacking at some sites and collection periods including Big Creek (BIC), Big Gulch (BIG), Cowart Creek, Peach Creek (PEC), Rummel Creek Bird Sanctuary (RCB), and White Oak Bayou. Some sites exhibited significant seasonal fluctuations in EAV (e.g. alligator weed) including Armand Bayou Holly Bay (ABH), Clear Creek, Goose Creek downstream (GCD), Rummel Creek rip rap (RCR), and Rummel Creek school (RCS) sites. Due to this inherent variability the confidence intervals for mean EAV percent coverage was very large at many sites (Figure 69). Stream sites possessing significant EAV were in most cases the shallowest and narrowest survey sites (Figure 59 and 61).

The amount of stream bank vegetation (SBV) ranged between 0 and 100% (Figure 70). The Higher percentages of SBV were generally observed at the Armand Bayou, Big Creek (BIC), Clear Creek downstream (CCD), Goose Creek upstream (GCU), Peach Creek (PEC), Rummel Creek rip rap (RCR) and White Oak upstream (WOU) sites. SBV was largely absent from the White Oak downstream (WOD) site. The Rummel Creek Bird Sanctuary (RCB) and WOD site exhibited statistically lower median amounts of SBV. The confidence intervals for the mean average SBV percent coverage were very large at most sites (Figure 71). The average percent SBV at the WOD site was significantly smaller than most of the Cowart Creek sites and the Goose Creek, Mill Creek (MIC), Rummel Creek and WOU sites.

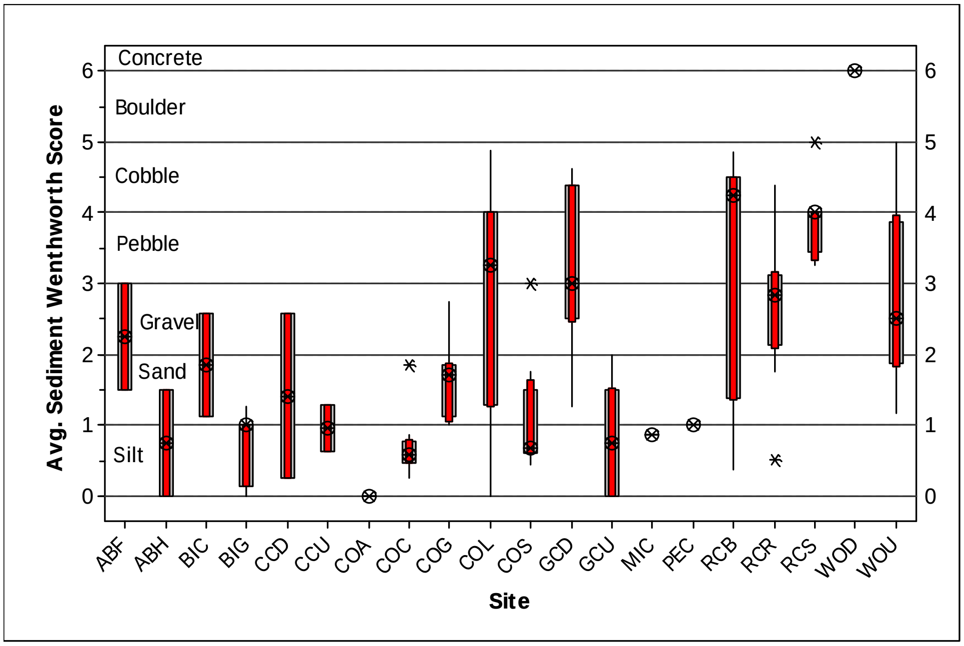

Figure 63. Boxplot depicting the distribution of average sediment Wentworth score recorded during sampling events at each site during the study period 2007-2010. Median symbol =î . Red bar depicts the 95% confidence interval for the median.

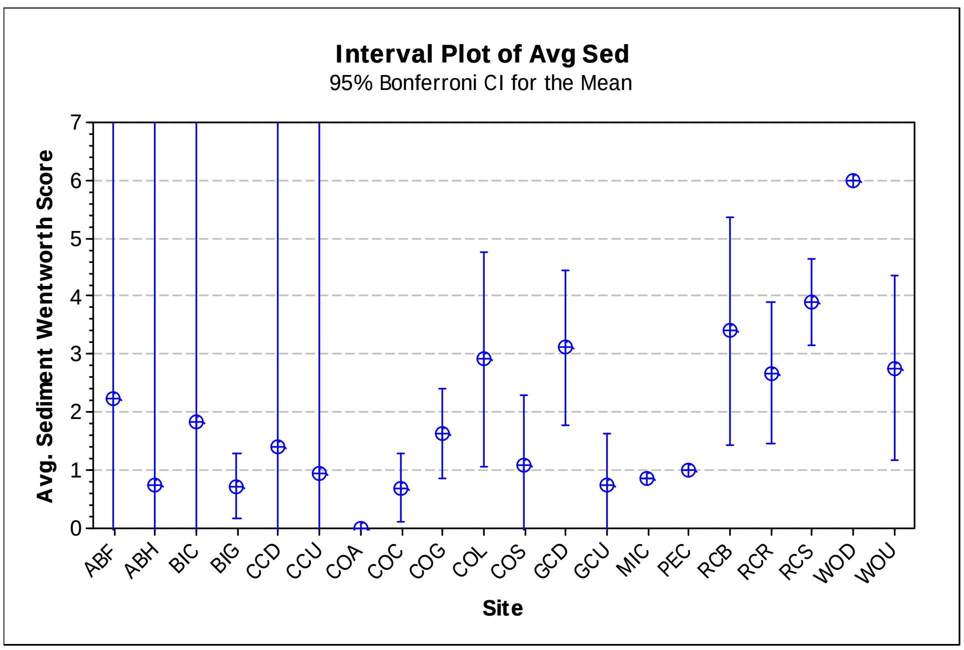

Figure 64. Bonferroni 95% confidence intervals for average sediment Wentworth scores by site (99% individual confidence intervals) sampled during 2007-2010.

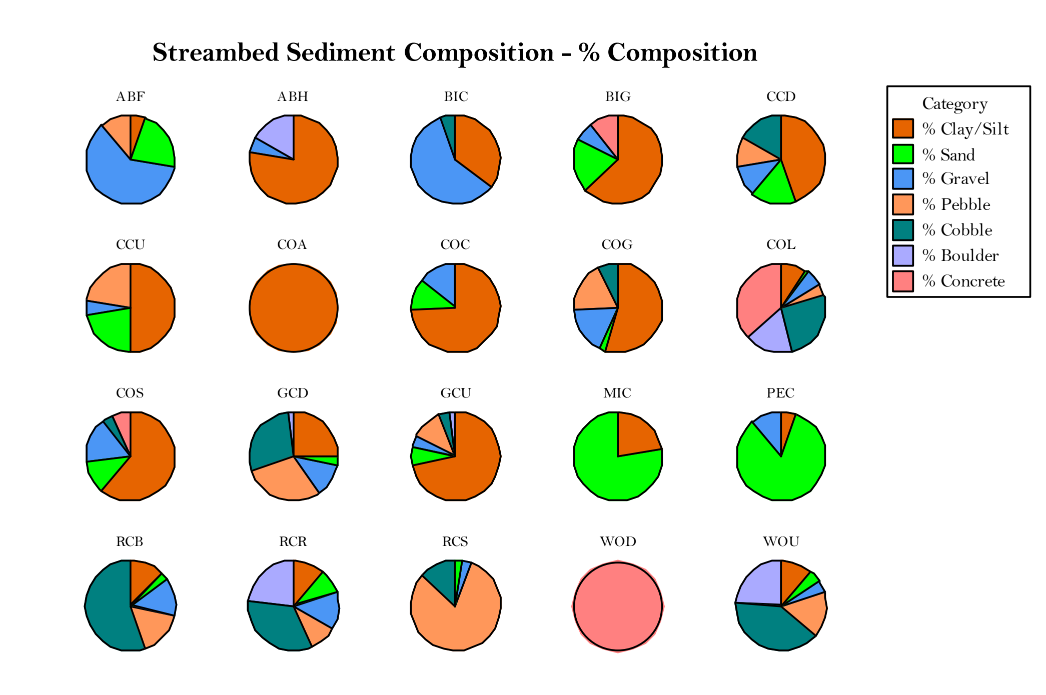

Figure 65. Percent composition of streambed at each site based on modified Wentworth classification data.

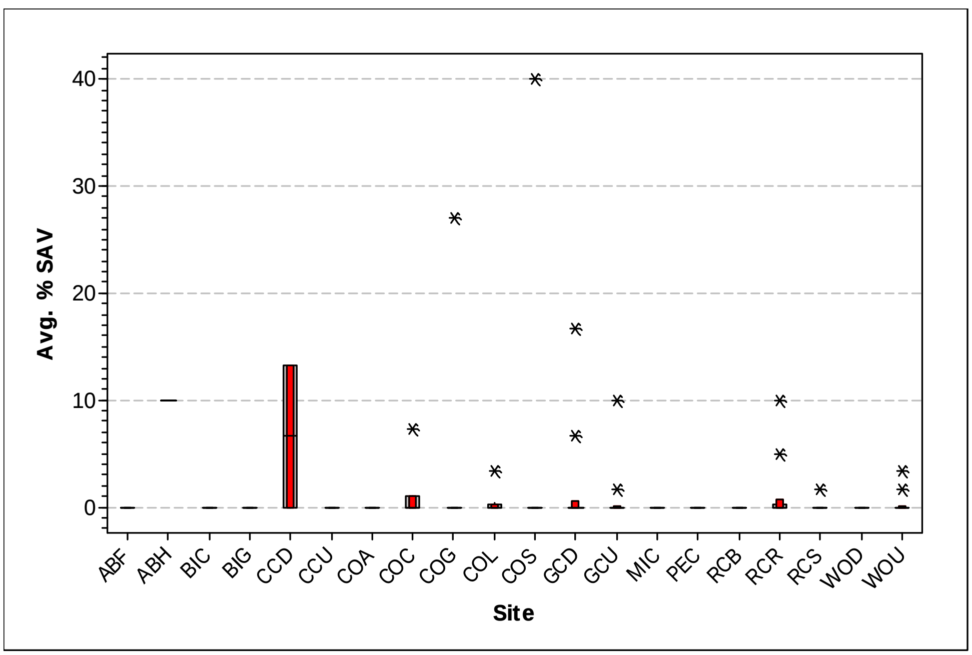

Figure 66. Boxplot depicting the distribution of average percent submerged vegetation measured during sampling events at each site during the study period 2007-2010. Red bar depicts the 95% confidence interval for the median.

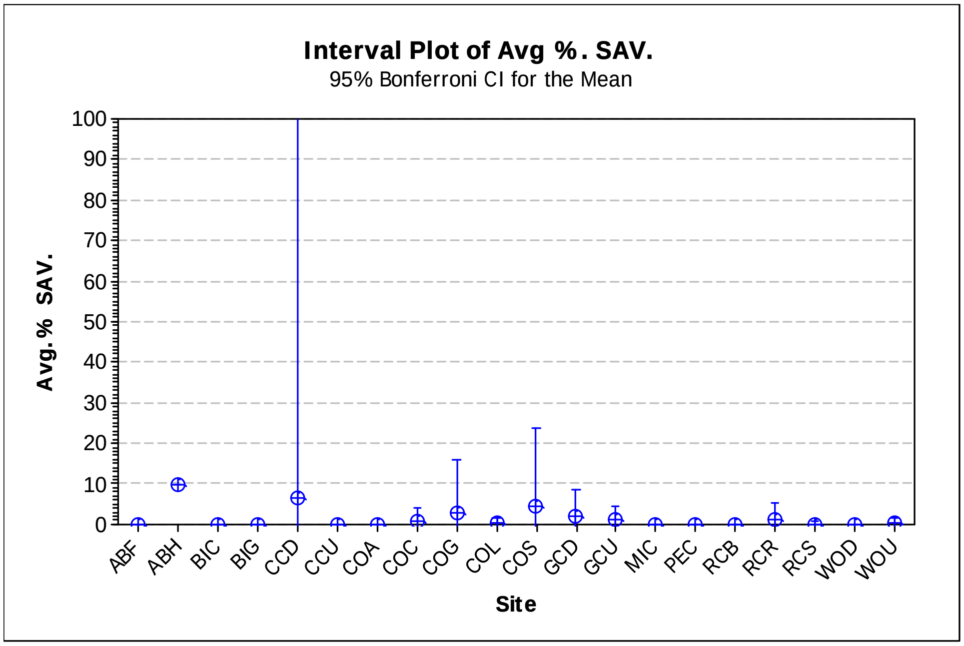

Figure 67. Bonferroni 95% confidence intervals for average percent SAV by site (99% individual confidence intervals) sampled during 2007-2010.

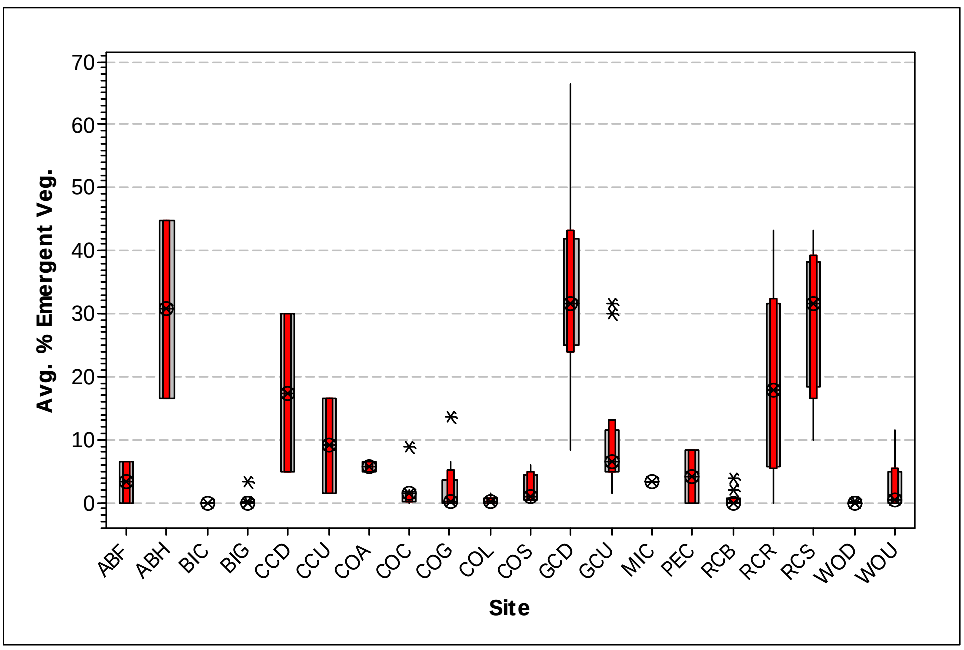

Figure 68. Boxplot depicting the distribution of average percent emergent vegetation measured during sampling events at each site during the study period 2007-2010. Median symbol =î . Red bar depicts the 95% confidence interval for the median.

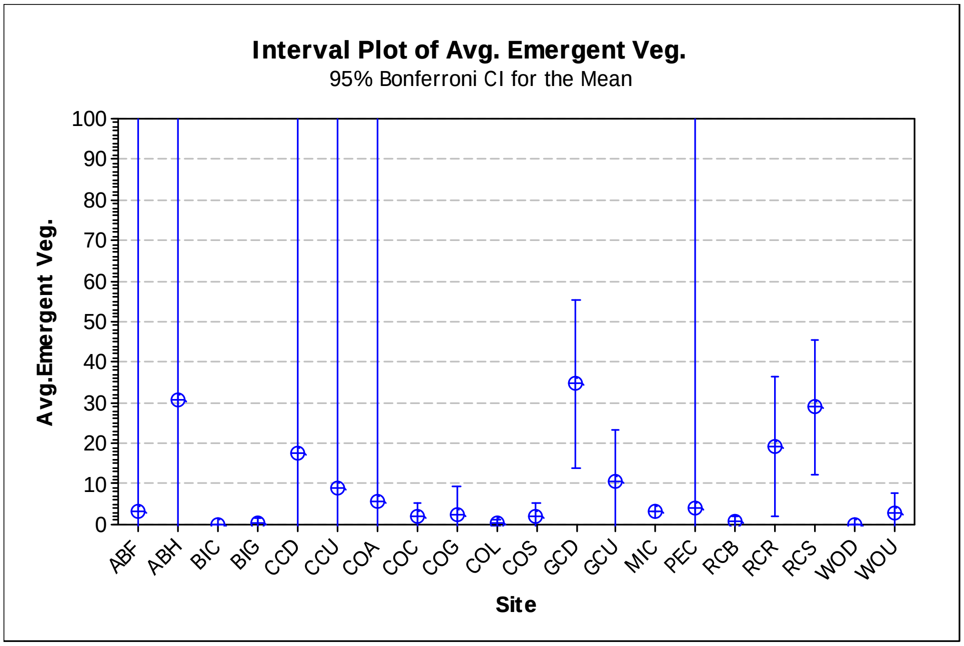

Figure 69. Bonferroni 95% confidence intervals for average percent emergent vegetation by site (99% individual confidence intervals) sampled during 2007-2010.

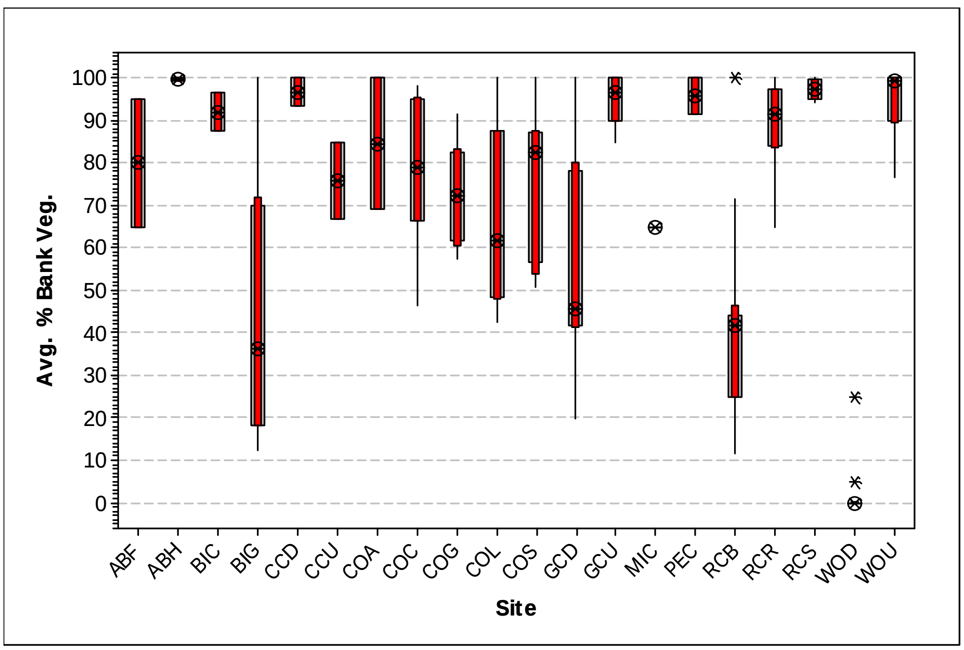

Figure 70. Boxplot depicting the distribution of average percent stream bank vegetation measured during sampling events at each site during the study period 2007-2010. Median symbol =î . Red bar depicts the 95% confidence interval for the median.

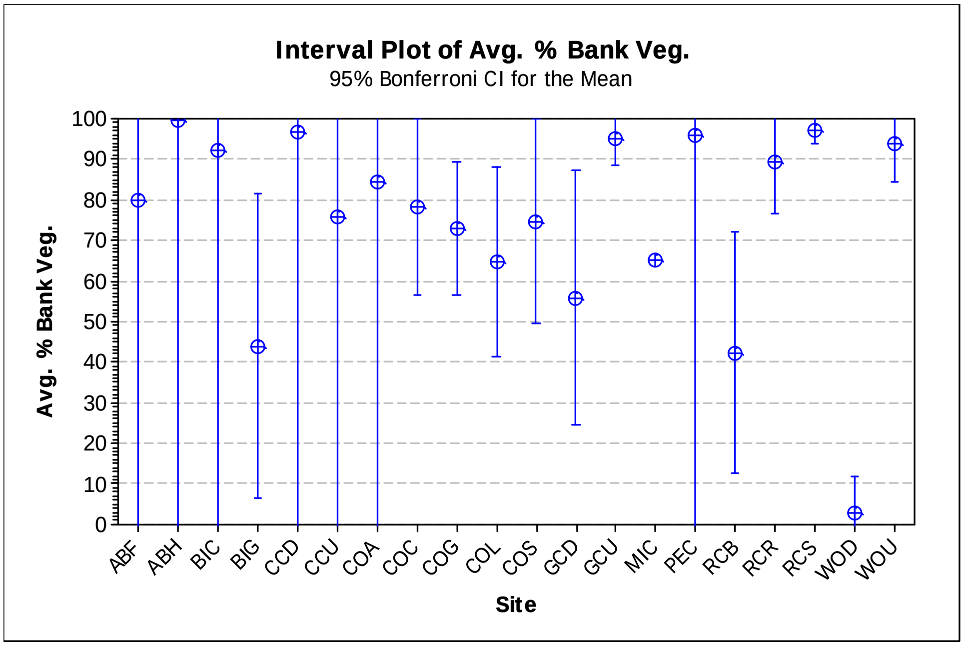

Figure 71. Bonferroni 95% confidence intervals for average percent stream bank vegetation by site (99% individual confidence intervals) sampled during 2007-2010.

Streambank Angle. The range of stream bank angle (SBA) observed during the study ranged between 10 and 73.3° (Figure 72). The majority of sites surveyed fell between 20 and 55°. The Mill Creek (MIC), Clear Creek downstream (CCD) and White Oak downstream (WOD) sites exhibited the smallest median angles when compared to all other sites. As a result of the large confidence interval for the mean average SBA at most sites, we were unable to discern any statistically significant pattern in the data regarding this population parameter (Figure 73).

Stream Profile. Runs were the major habitat unit observed at most surveyed sites (Figure 74). Armand Bayou Holly Bay (ABH), Big Creek (BIC), Big Gulch (BIG), Cowart Creek (excluding the airport site), Goose Creek, and Rummel Creek sites also contained varying amounts of pool and riffle habitat. The highest percentage of riffle habitat was found at the Cowart Creek Greenbriar (COG), which incorporated an instream habitat creation project. Riffle habitat was completely lacking at Arman Bayou Fairmont (ABF), Clear Creek downstream (CCD), Cowart Creek Airport (COA), Mill Creek (MIC), and Peach Creek (PEC). Habitat complexity scores (standard deviation of habitat scores/30 ft segment) for each site reflected the homogeneity of the habitat types present at each site (Figure 75). This score tracked the number of identified habitat types present (all three habitat present or pools and riffles present in equal amounts, highest feasible score = 1.05 versus only one habitat type present = lowest score =0).

Riparian Vegetation. The range of riparian shading observed during the study ranged between 0 and 100% (Figure 76). The majority of sites surveyed experienced less than 40% shading. Nine sites lacked riparian shading during the study period. As a result of the large confidence interval for the mean average riparian shading at five sites, it was difficult to discern any statistically significant pattern in the data regarding this population parameter (Figure 77). However, the Big

Creek (BIC), Mill Creek (MIC), and Rummel Creek Bird Sanctuary (RCB) sites exhibited statistically higher levels of average shading in comparison to the majority of stream sites.

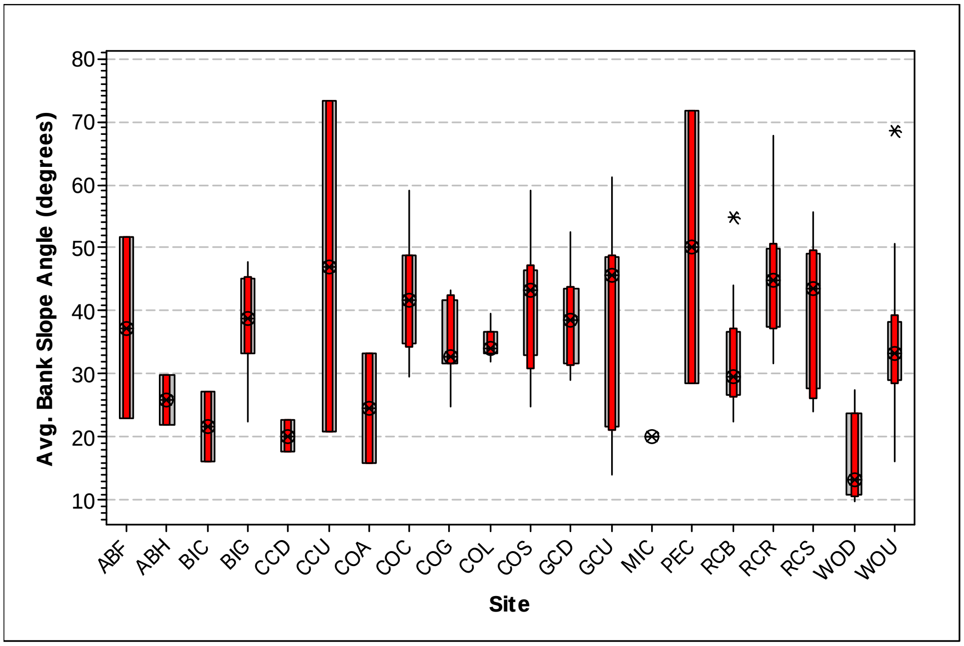

Figure 72. Boxplot depicting the distribution of average stream bank angle measured during sampling events at each site during the study period 2007-2010. Median symbol =î . Red bar depicts the 95% confidence interval for the median.

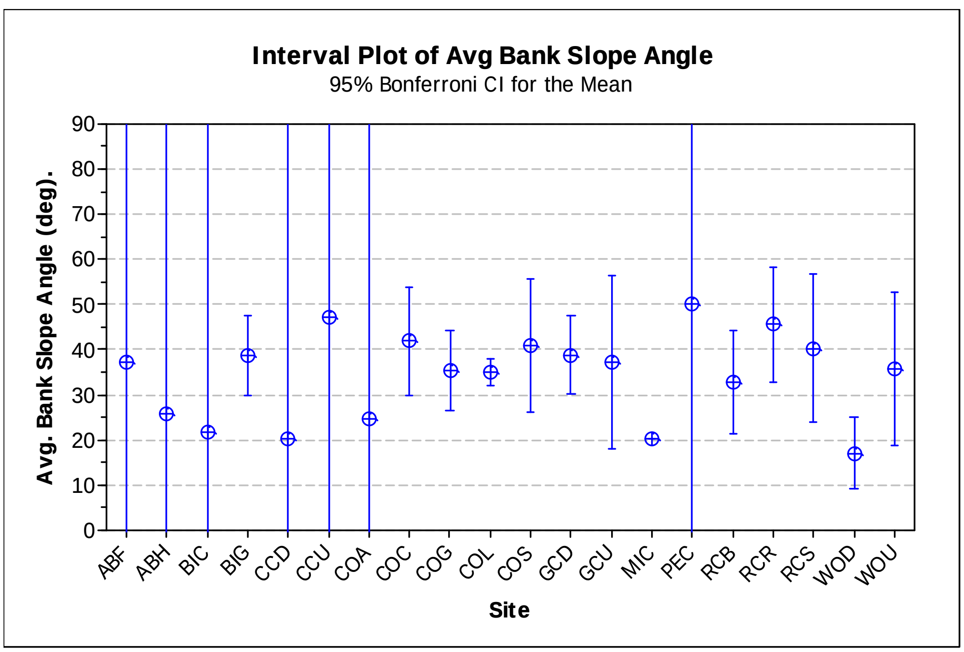

Figure 73. Bonferroni 95% confidence intervals for average stream bank angle (degrees) by site (99% individual confidence intervals) sampled during 2007-2010.

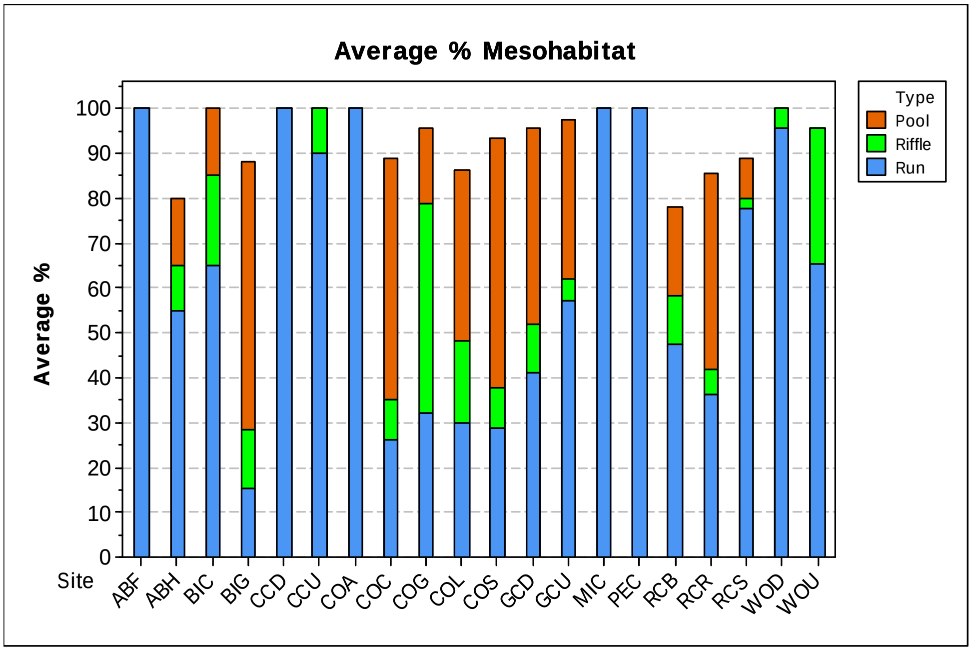

Figure 74. Average percent mesohabitat type at each site.

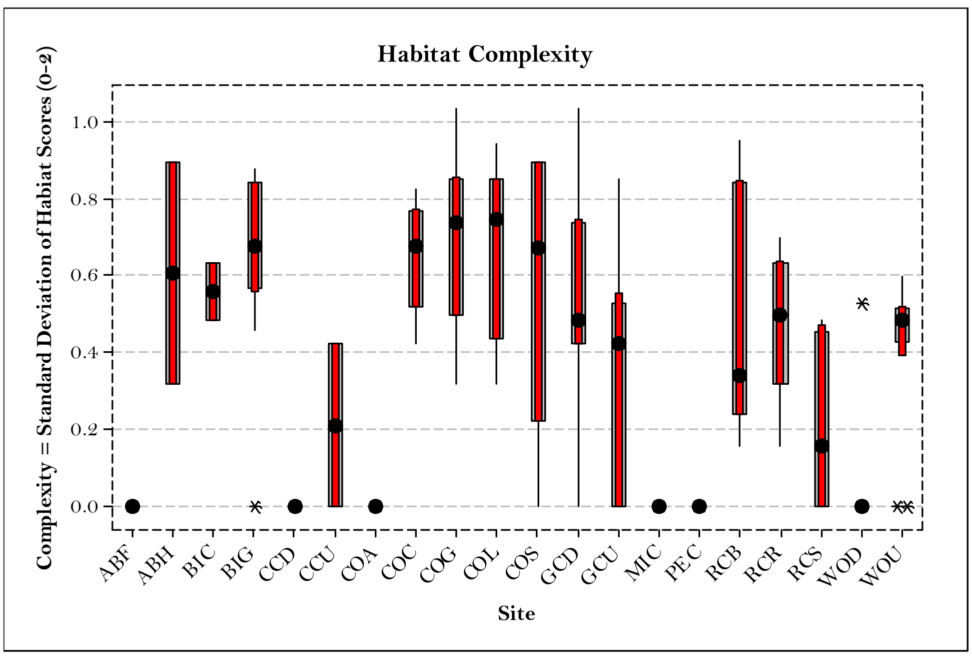

Figure 75. Calculated habitat complexity at each stream study site. Complexity = Sample standard deviation of 10 replicate 30 ft habitat type rankings per site.

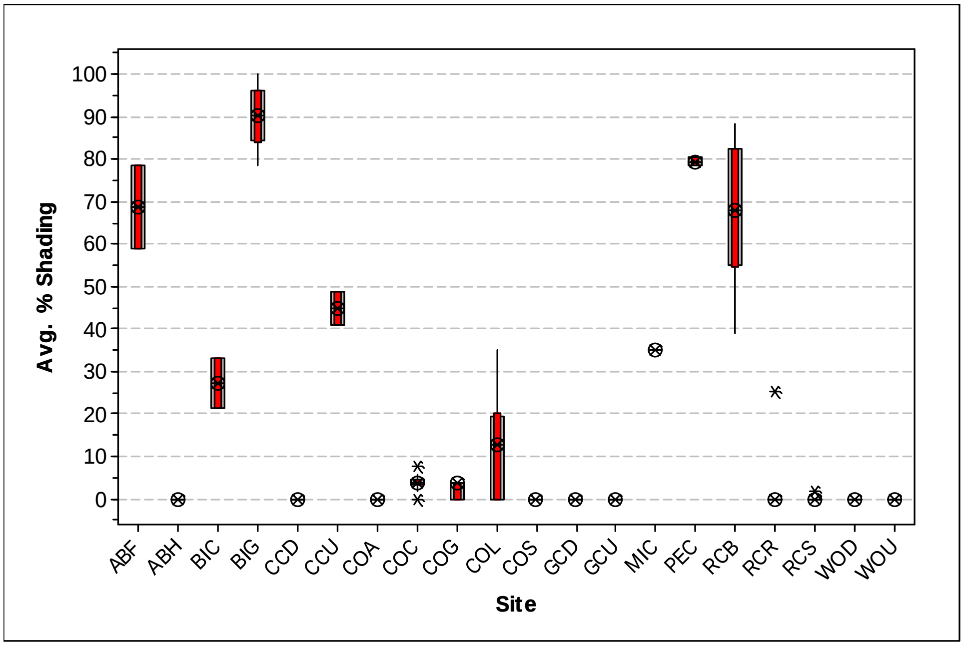

Figure 76. Boxplot depicting the distribution of average percent shading measured during sampling events at each site during the study period 2007-2010. Median symbol =î . Red bar depicts the 95% confidence interval for the median.

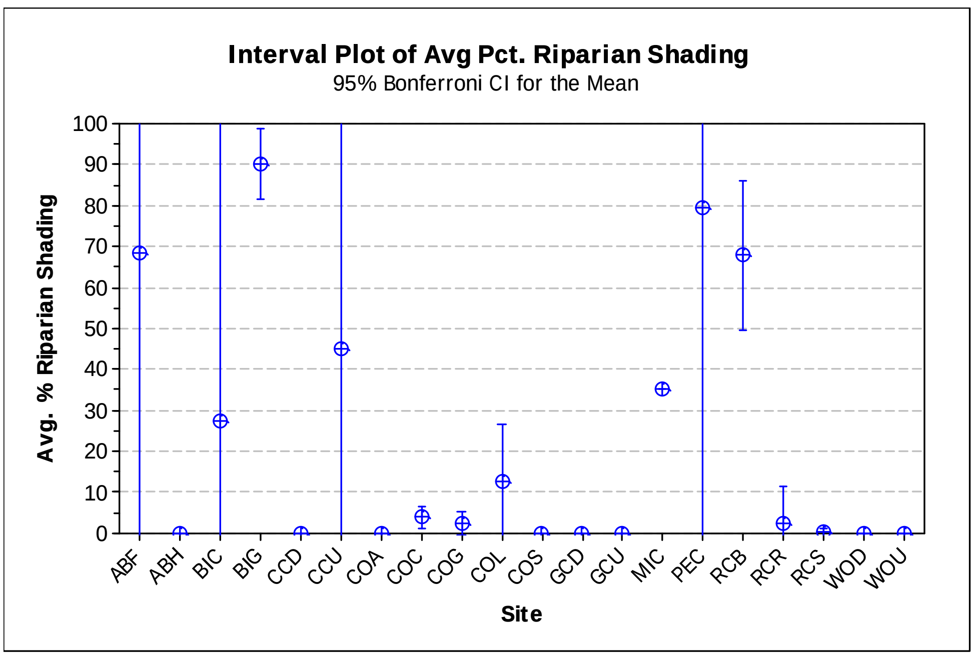

Figure 77. Bonferroni 95% confidence intervals for average percent riparian shading by site (99% individual confidence intervals) sampled during 2007-2010.

Water Quality

Temperature. The range of average water temperature measured during the study ranged between 11 and 32.8 ºC (Figure 78). The majority of average water temperature measurements were between 20 and 30 ºC. The median average water temperatures at the Big Creek (BIC) and Clear Creek (CCU and CCD) sites were significantly warmer than the other sites. These three stream sites lacked riparian shading during the study period. As a result of the large confidence interval for the mean average water temperature we were unable to detect any statistically significant pattern in the average water temperature (Figure 79).

Specific Conductivity. The range of average specific conductance measured during the study ranged between 118 and 4700 uS (Figure 80). Two major groups of sites could be identified based on median specific conductance levels. The first group included Big Creek (BIC) and Cowart Creek which experienced specific conductance levels exceeding 1000 uS during most collections. The second group, consisting of all other sites, was consistently below 1000 uS. As a result of the large confidence interval for mean average specific conductance at multiple sites, it was difficult to detect any statistically significant pattern (Figure 81). However, average mean specific conductance levels at the Cowart Creek sites (with the exception of the Cowart Airport site) were statistically higher than the Goose Creek, Rummel Creek and White Oak sites.

Dissolved Oxygen. The range of average dissolved oxygen measured during the study ranged between 1.8 and 17.0 mg/L (Figure 82). The majority of observations were between 4.0 and 12 mg/L. The dissolved oxygen levels at Big Creek (BIC), Clear Creek and Cowart Creek Airport sites were consistently below 7 mg/L. The lowest dissolved oxygen levels (≤ 2m/L) measured during the study occurred at the Goose Creek sites. As a result of the large confidence interval for mean average dissolved oxygen at multiple sites, it was difficult to detect any statistically significant pattern between sites (Figure 83).

pH. The range of average pH level measured during the study ranged between 5.2 and 9.5 (Figure 84). These extreme values occurred at the Rummel Creek sites. The majority of pH observations were between 7.0 and 8.3. We were unable to determine any statistically significant differences in the pH levels between sites. (Figure 85).

Turbidity. The range of average secchi disk levels during the study ranged between 5 and ≥120 cm (Figure 86). The majority of observations ranged between 20.0 and 60 cm. The highest water clarity was generally measured at the Mill Creek (MIC) site, although similar levels were observed at the Rummel Creek sites during some collections. The lowest water clarity generally occurred at the Big Creek (BIC), Clear Creek downstream (CCD) and Cowart Creek Airport (COA) sites. Due to the large confidence interval for mean average secchi disk levels at multiple sites, we could not detect any statistically significant pattern between sites (Figure 87).

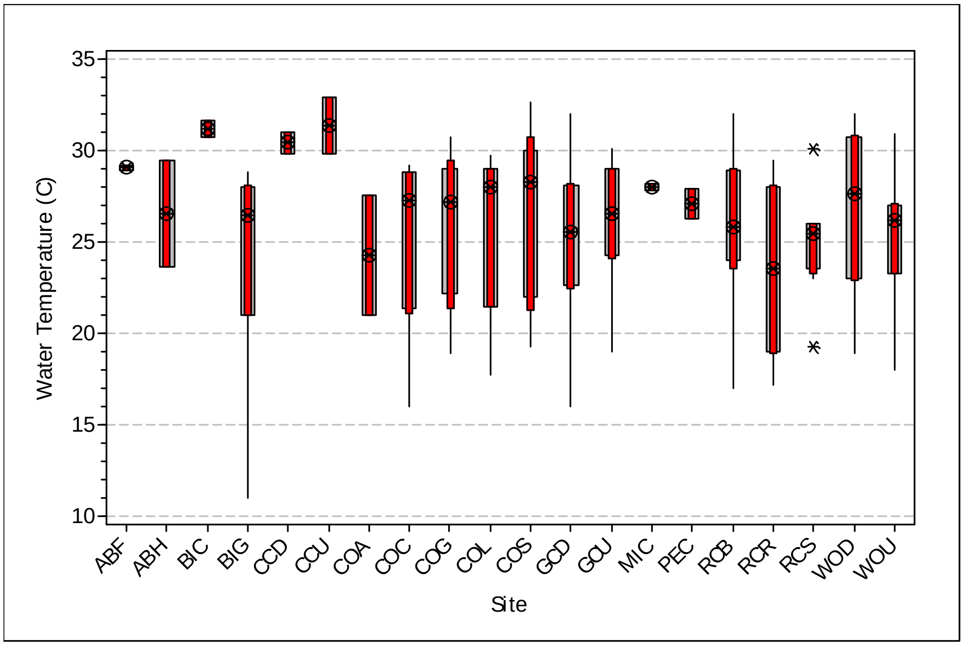

Figure 78. Boxplot depicting the distribution of average water temperature measured during sampling events at each site during the study period 2007-2010. Median symbol =î . Red bar depicts the 95% confidence interval for the median.

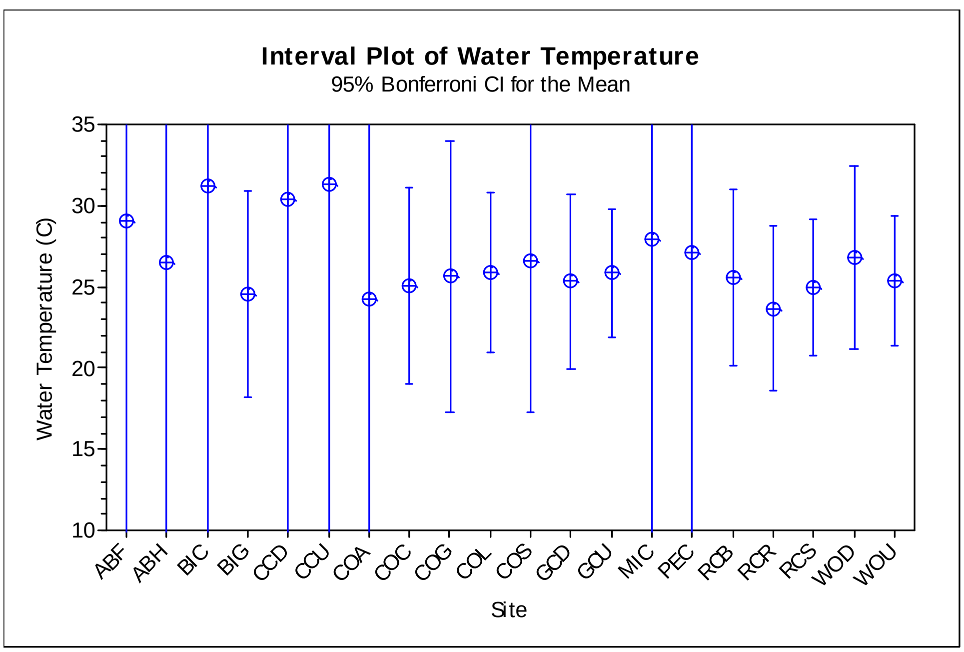

Figure 79. Bonferroni 95% confidence intervals for average water temperature by site (99% individual confidence intervals) sampled during 2007-2010.

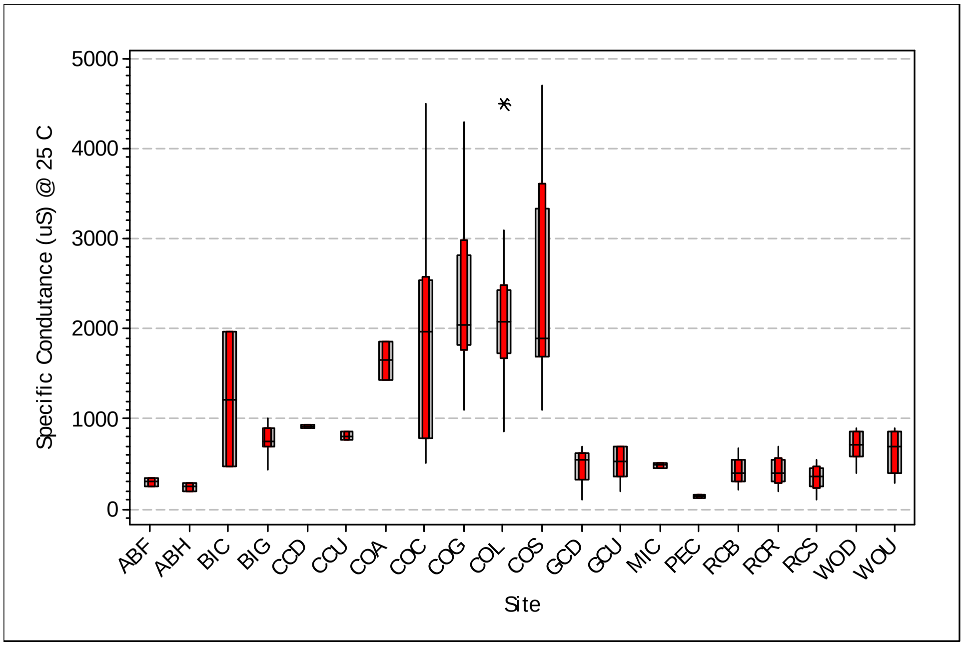

Figure 80. Boxplot depicting the distribution of average specific conductance measured during sampling events at each site during the study period 2007-2010. Median symbol = î . Red bar depicts the 95% confidence interval for the median.

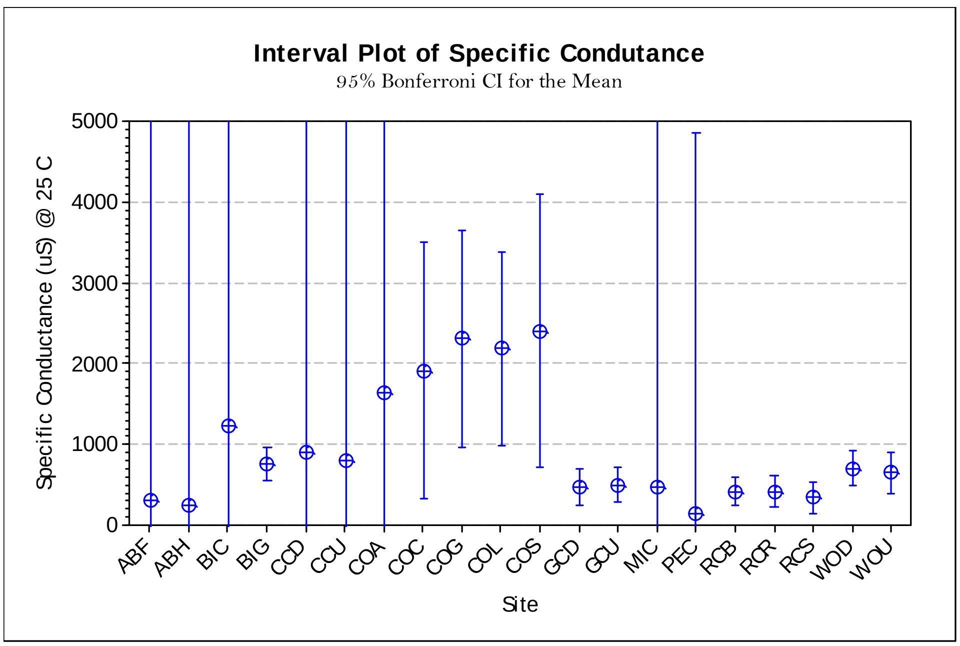

Figure 81. Bonferroni 95% confidence intervals for average specific conductance by site (99% individual confidence intervals) sampled during 2007-2010.

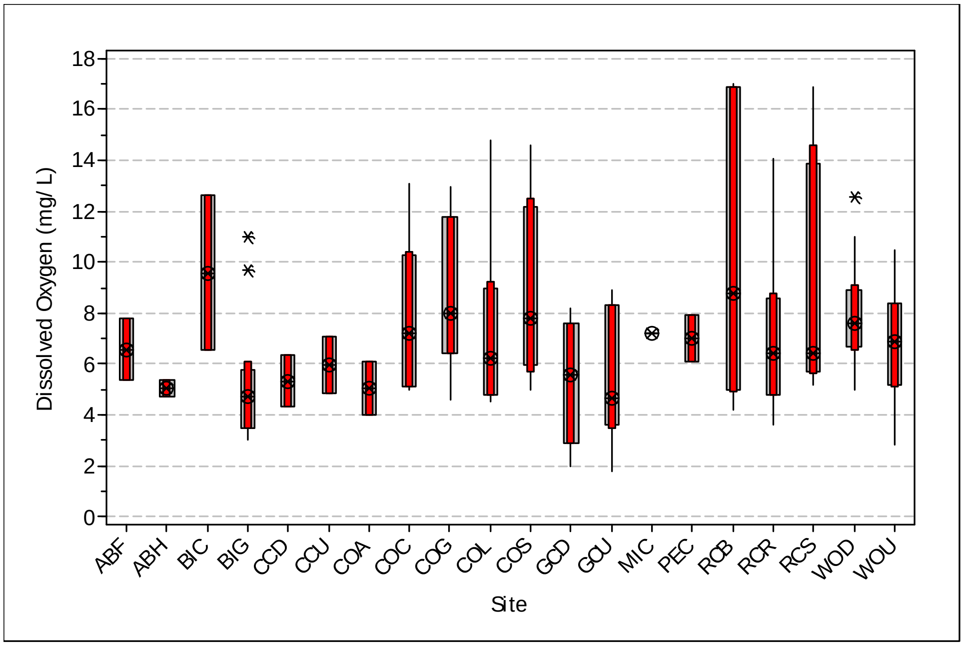

Figure 82. Boxplot depicting the distribution of average dissolved oxygen measured during sampling events at each site during the study period 2007-2010. Median symbol = î . Red bar depicts the 95% confidence interval for the median.

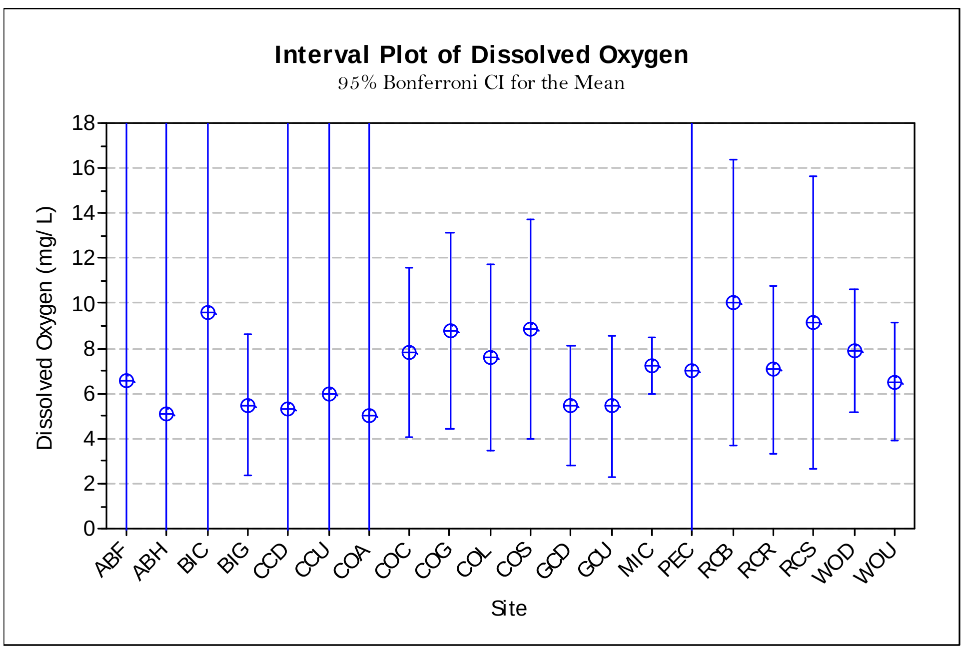

Figure 83. Bonferroni 95% confidence intervals for average dissolved oxygen by site (99% individual confidence intervals) sampled during 2007-2010.

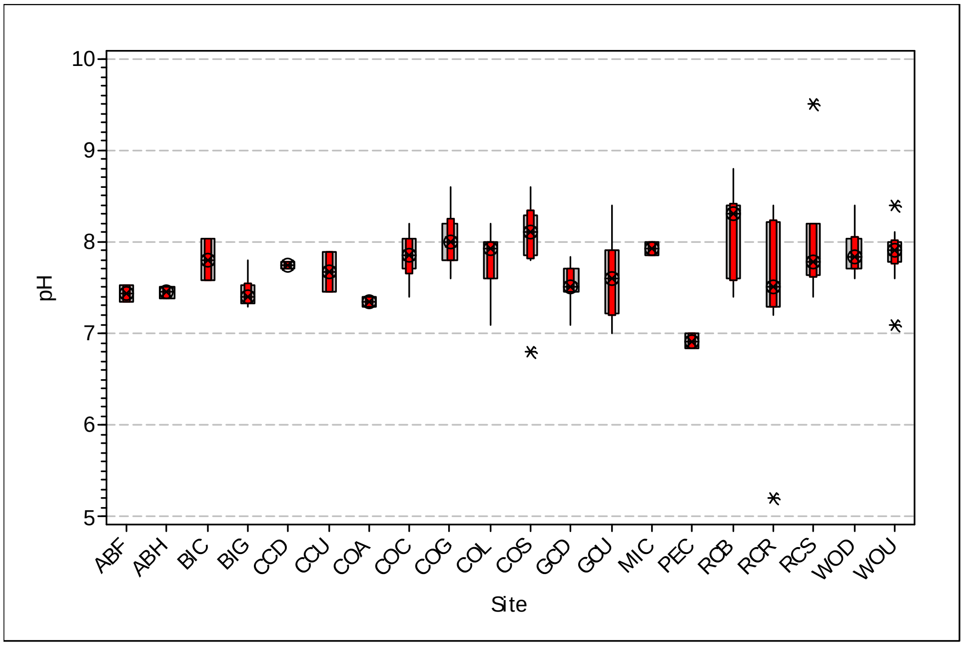

Figure 84. Boxplot depicting the distribution of average pH measured during sampling events at each site during the study period 2007-2010. Median symbol = î . Red bar depicts the 95% confidence interval for the median.

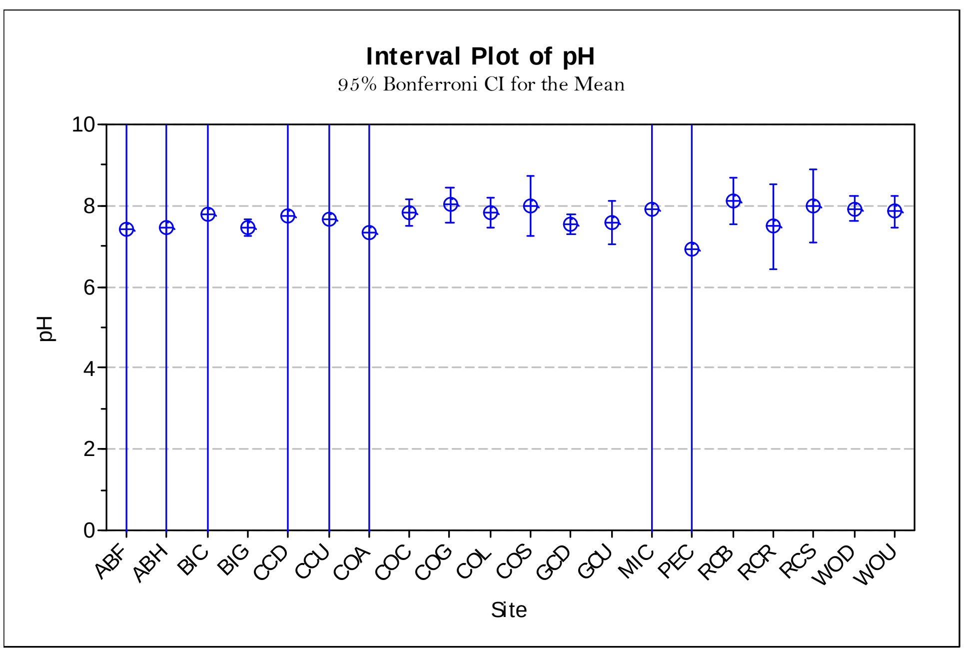

Figure 85. Bonferroni 95% confidence intervals for average pH levels by site (99% individual confidence intervals) sampled during 2007-2010.

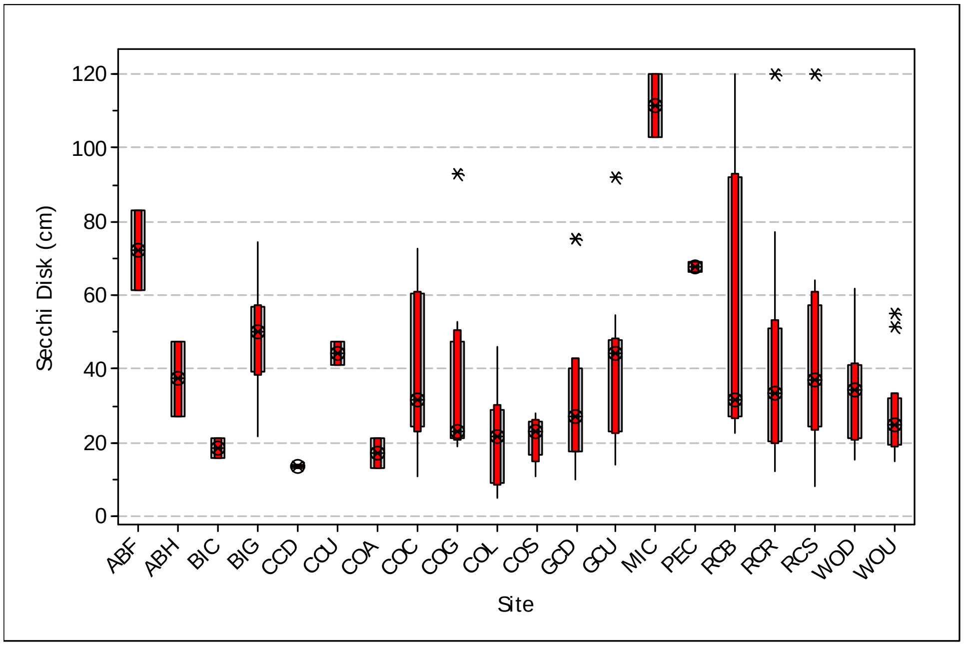

Figure 86. Boxplot depicting the distribution of average secchi disk transparency measured during sampling events at each site during the study period 2007-2010. Median symbol = ĩ . Red bar depicts the 95% confidence interval for the median.

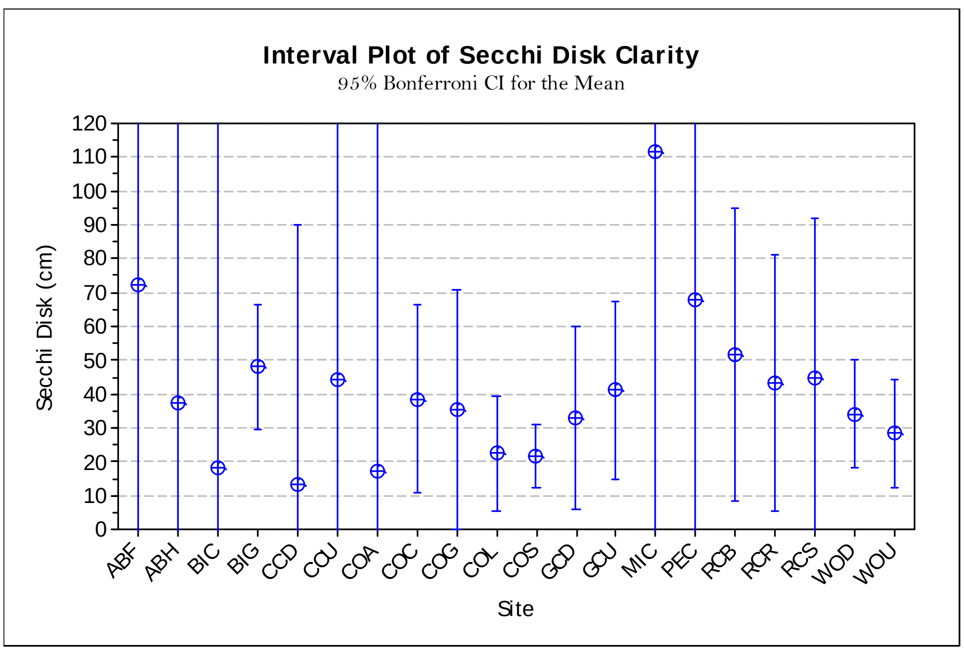

Figure 87. Bonferroni 95% confidence intervals for average secchi disk transparency by site (99% individual confidence intervals) sampled during 2007-2010.

Average turbidity levels observed during the study ranged between 1.68 and 139 NTU's (Figure 88). The majority of observations fell between 10.0 and 50 NTU. The highest individual average turbidity levels were measured at the Cowart Creek Linson (COL) and Rummel Creek rip rap (RCR) site. The lowest turbidity levels were usually measured at the Armand Bayou Fairmont (ABF), Big Creek (BIC) and Mill Creek (MIC) sites. We could not detect any statistically significant pattern between mean average site turbidity due to the large confidence intervals observed at multiple sites, (Figure 89).

Total Suspended Solids. The range of average total suspended solids (TSS) observed during the study was 0.004 and 143 mg/L (Figure 90). The majority of observations ranged between 10.0 and 60 TSS. The highest individual average TSS levels were generally measured at the Cowart Creek Linson (COL) and Goose Creek downstream (GCD) sites. Low ($\leq$ 30 mg/L) TSS levels were common at the Armand Bayou, Big Creek (BIC), Big Gulch (BIG), Clear Creek upstream (CCU), Mill Creek (MIC), and Peach Creek (PEC) sites. These trends were, however, statistically insignificant between most sites in both median and mean average TSS levels. (Figure 91). Only two sites, Cowart Creek Airport (COA) and Cowart Creek Sunset (COS), exhibited significantly higher median TSS levels when compared to the Armand Bayou, BIC, BIG, CCU, MIC and PEC sites.

Hardness. The range of average calculated total (Ca + Mg mg/L as $CaCO_3$) hardness observed during the study was 0.01 and 5.56 mg/L (Figure 92). The majority of observations ranged between 1.0 and 3.5 mg/L as $CaCO_3$ hardness. Median hardness was generally higher at the Armand Bayou, Goose Creek, Mill Creek (MIC), Peach Creek (PEC), Rummel Creek, and White Oak Bayou sites in comparison to the Clear Creek and Cowart Creek sites. These trends in median average levels were not directly reflected in the mean average values (Figure 93). However, the average mean hardness level at Cowart Creek Linson (COL) site was significantly less than the Goose Creek, Rummel Creek, and White Oak Bayou sites.

Alkalinity. The range of average total alkalinity (mg/L as $CaCO_3$) observed during the study was 0.01 and 5.56 mg/L (Figure 94). The majority of observations ranged between 19.7 and 327.0 mg/L as $CaCO_3$ total alkalinity. Median total alkalinity was generally highest at the Cowart Creek sites. Note, total alkalinity was not measured at the Cowart Creek Greenbriar (COG) and Cowart Creek Sunset (COS) sites. Median total alkalinity was significantly lower at the Armand Bayou, Big Creek (BIC), Peach Creek (PEC), Rummel Creek sites in comparison to Cowart Creek sites. Median average total alkalinity (26.4 mg/L) at the PEC site was significantly lower in comparison to all other sites. However, the lowest average value recorded (19.7 mg/L) occurred at the White Oak downstream (WOD) site. These trends in median average levels were only partially reflected in the average mean values (Figure 95). However, due to the large confidence intervals we could not detect significant differences in mean average total alkalinity between sites, with the exception of the COL site which was significantly higher than the Rummel Creek sites.

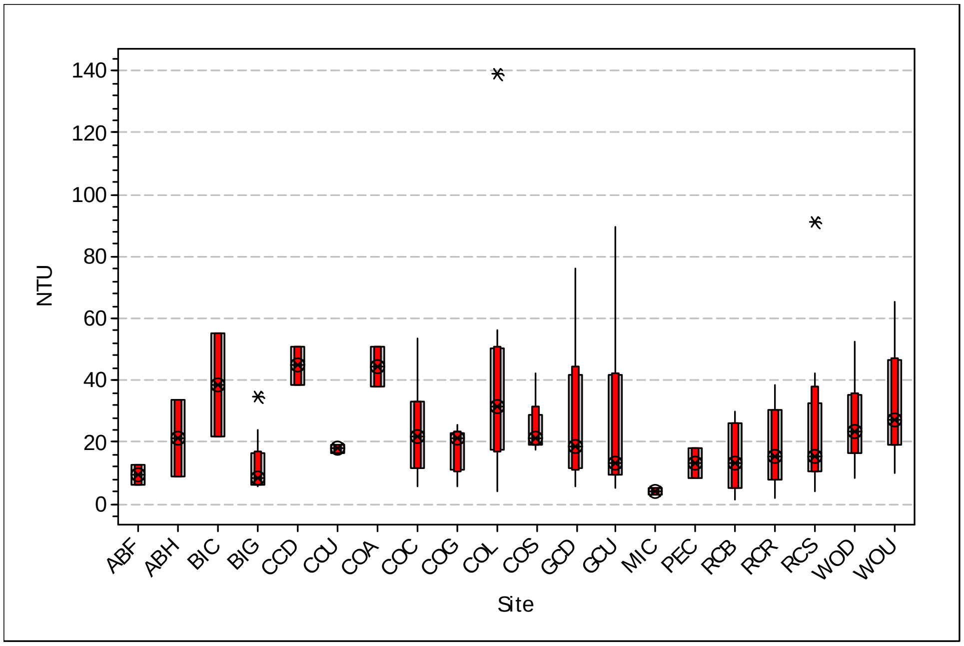

Figure 88. Boxplot depicting the distribution of average turbidity (NTU) levels measured during sampling events at each site during the study period 2007-2010. Median symbol = ȋ . Red bar depicts the 95% confidence interval for the median.

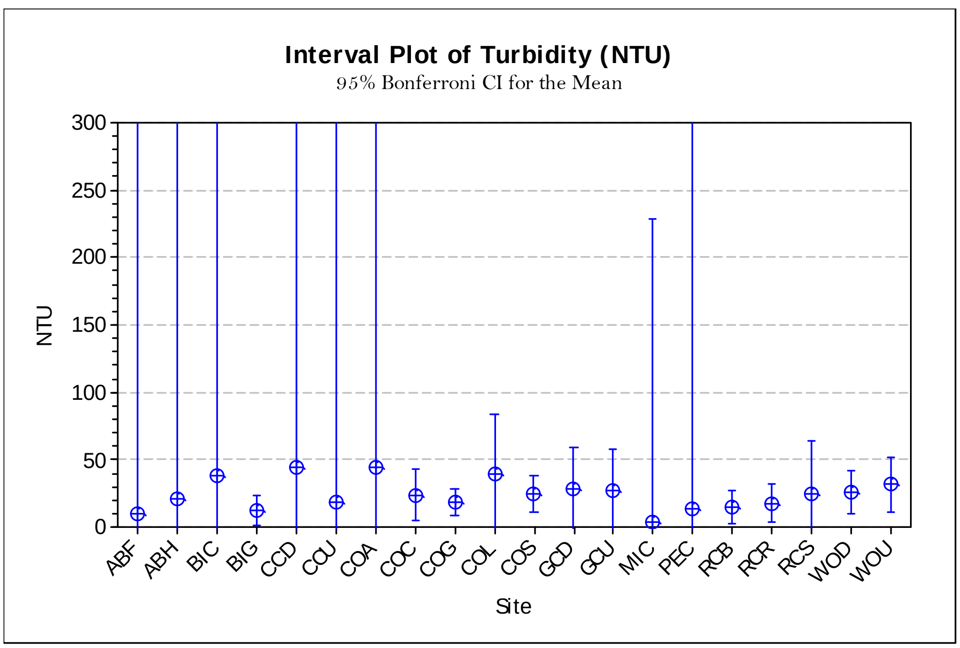

Figure 89. Bonferroni 95% confidence intervals for mean average turbidity levels by site (99% individual confidence intervals) sampled during 2007-2010.

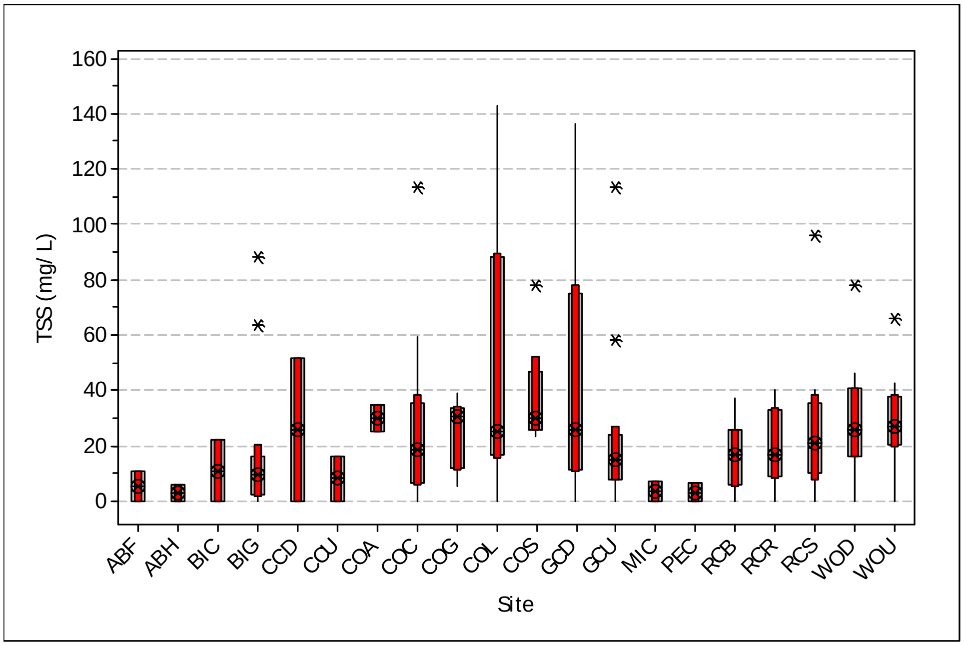

Figure 90. Boxplot depicting the distribution of average total suspended solids (TSS) levels measured during sampling events at each site during the study period 2007-2010. Median symbol = î . Red bar depicts the 95% confidence interval for the median.

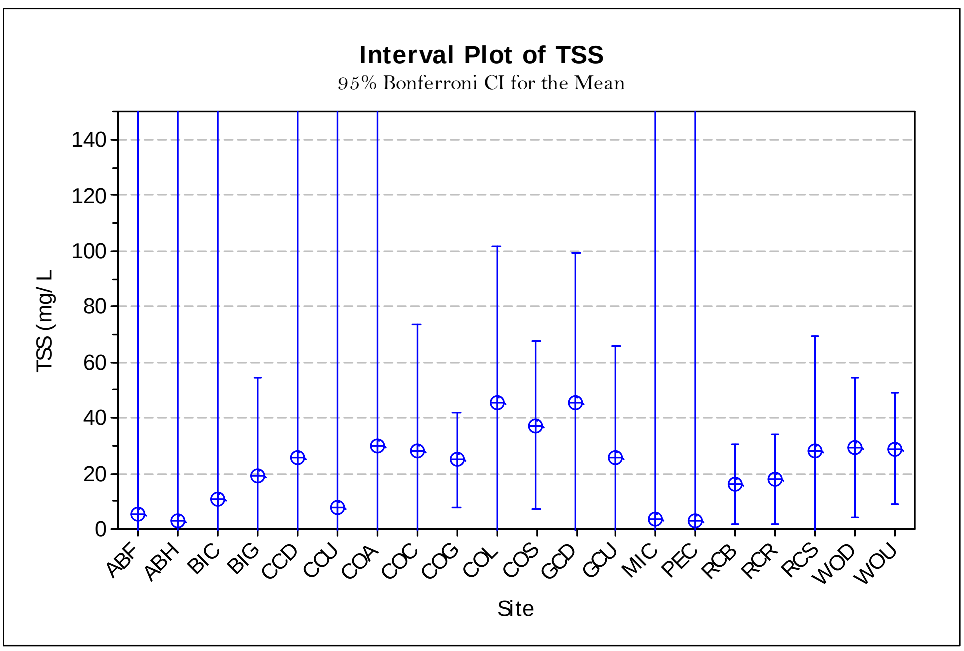

Figure 91. Bonferroni 95% confidence intervals for mean average total suspended levels (TSS) by site (99% individual confidence intervals) sampled during 2007-2010.

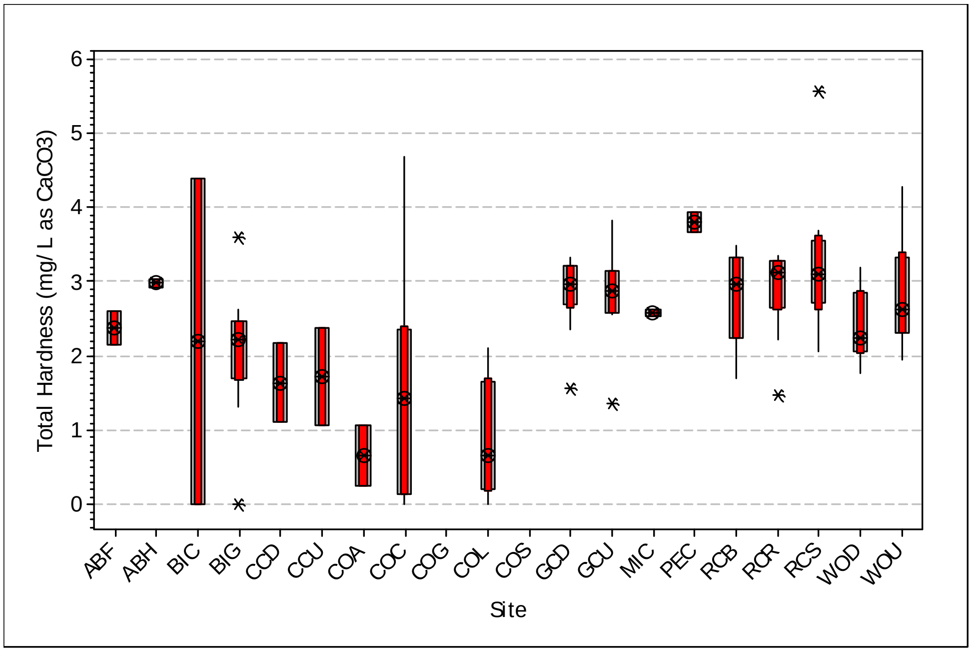

Figure 92. Boxplot depicting the distribution of average total hardness (mg/L Mg + Ca as $CaCO_3$) levels measured during sampling events at each site during the study period 2007-2010. Median symbol = î . Red bar depicts the 95% confidence interval for the median.

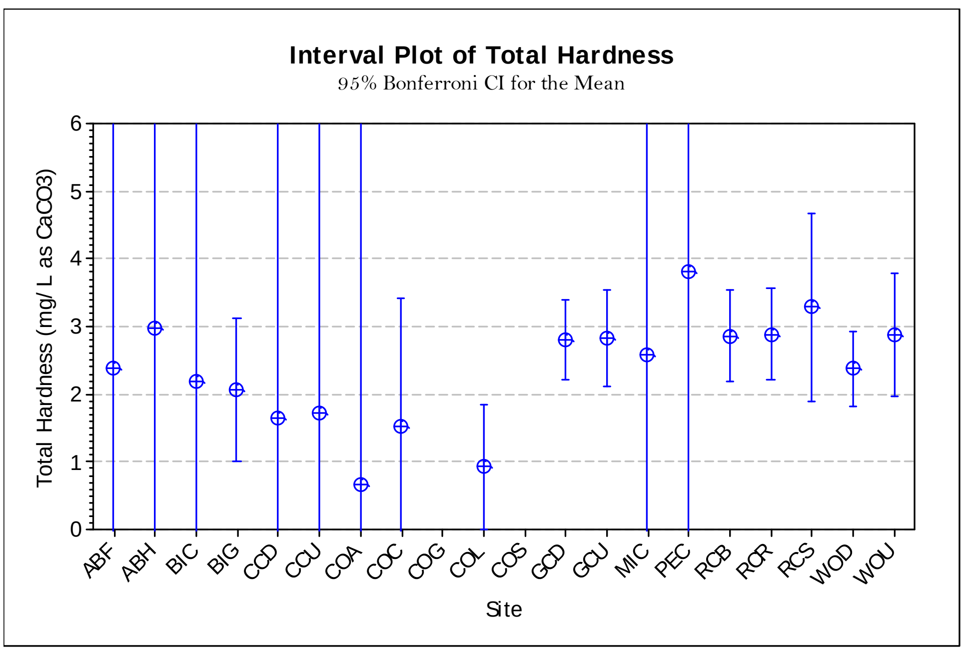

Figure 93. Bonferroni 95% confidence intervals for mean average total calculated hardness (mg/L of Ca + Mg as $CaCO_3$) by site (99% individual confidence intervals) sampled during 2007-2010.

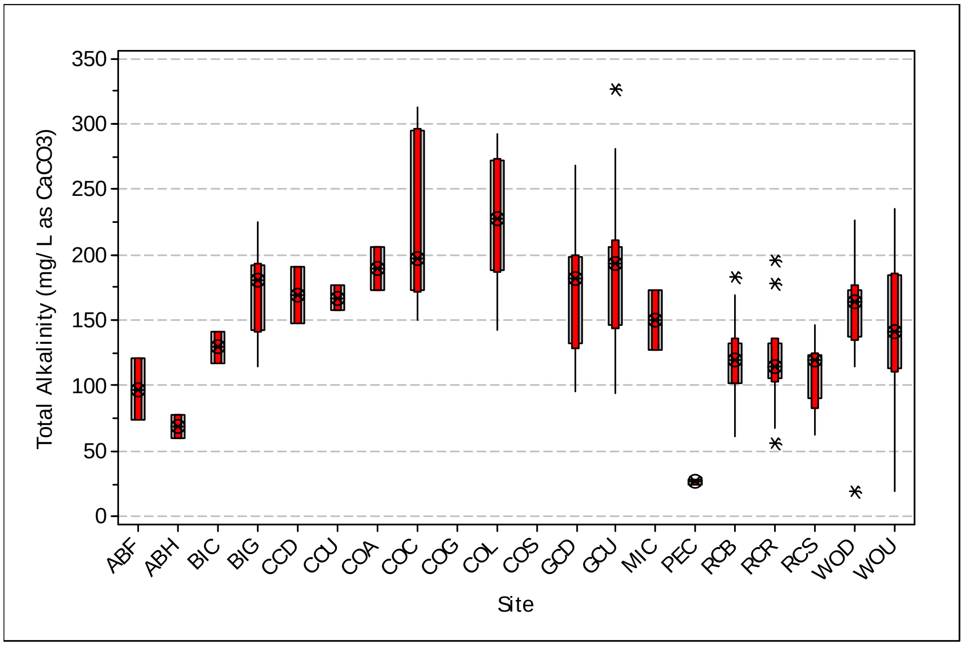

Figure 94. Boxplot depicting the distribution of average total alkalinity (mg/L as $CaCO_3$) levels measured during sampling events at each site during the study period 2007-2010. Median symbol = î . Red bar depicts the 95% confidence interval for the median.

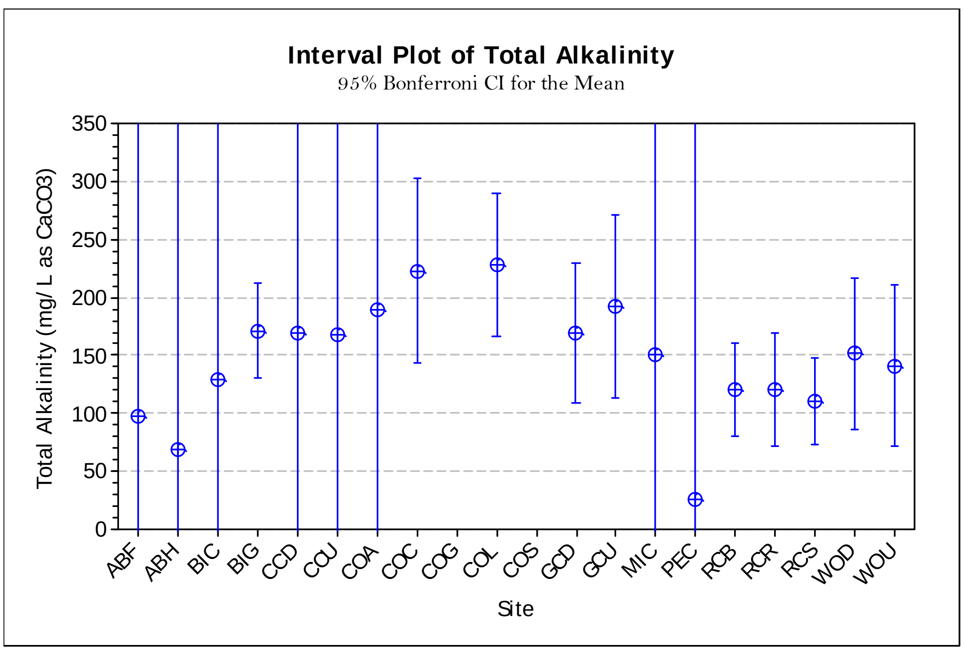

Figure 95. Bonferroni 95% confidence intervals for mean average total alkalinity (mg/L as $CaCO_3$) by site (99% individual confidence intervals) sampled during 2007-2010.

<u>Nutrients</u>. Average orthophosphate concentration during the study ranged between 0.06 and 8.04 mg/L (Figure 96). The majority of observations were below 1.0 mg/L. Statistically higher median and individual levels of orthophosphate were observed at White Oak Bayou sites in contrast to other sites. The Clear Creek sites exhibited moderately high levels (1.88 – 2.75 mg/L) of orthophosphates and intermediate median levels. Due to the large confidence interval for mean average orthophosphate levels at multiple sites, we could differentiate many sites. However, the White Oak Bayou sites exhibited statistically higher levels of orthophosphate when compared to the Big Creek (BIC), Cowart Creek (excluding the Airport site), Goose Creek, and Rummel Creek sites (Figure 97).

Average ammonia nitrogen (NH_3-N) concentration during the study ranged between ≤ 0.1 and 1.2 mg/L (Figure 98). As noted in the methods section, the reliable quantitation limit for this analyte was 0.3 mg/L. However, we report values from 0.1 to 0.3 as well, although these values are less reliable. Values below 0.1 were reported as 0.0 mg/L. The majority of observations ranged between 0.2 to 0.8 mg/L N-NH_3. The lowest reported median average N-NH_3 was observed at Mill Creek (MIC), however this did not statistically differ from the Clear Creek sites. Due to the large confidence interval for mean average N-NH_3 levels at most sites, we could not identify any differences between sites (Figure 99).

Average nitrate plus nitrite nitrogen (NO_3 + NO_2-N or NO_{2+3}-N) concentration during the study ranged between ≤ 0.001 and 17.1 mg/L (Figure 100). The reliable quantitation limit for this analyte was 0.001 mg/L. We therefore report values less than this as ½ the detection limit (0.0005). The majority of observations ranged between 0.050 to 2.000 mg/L N-NH_3. The highest median average values were reported from the White Oak Bayou sites. Low median average NO_{2+3}-N values were recorded at the Armand Bayou and Goose Creek sites. Median average NO_{2+3}-N values at these sites along with the Cowart Creek Airport (COA) and the Rummel Creek rip rap (RCR) sites were statistically smaller than the White Oak Bayou and Clear Creek downstream (CCD) sites. Due to the large confidence interval for mean average NO_{2+3}-N levels at most sites, we could not identify any statistically differences between sites for this parameter (Figure 101).

Average chlorophyll-*concentrations* during the study ranged between 0.005 and 23.229 ug/L (Figure 102). The majority of observations ranged between 0.27 and 13.7 ug/L. The highest median average values were reported from the White Oak Bayou sites. Lowest median average chlorophyll-*a* values were recorded at the Armand Bayou, Big Creek (BIC), Clear Creek, Cowart Creek and Peach Creek (PEC) sites. Due to the large confidence interval for mean average chlorophyll-*levels* at most sites, we did not identify any statistically differences between sites for this parameter (Figure 103).

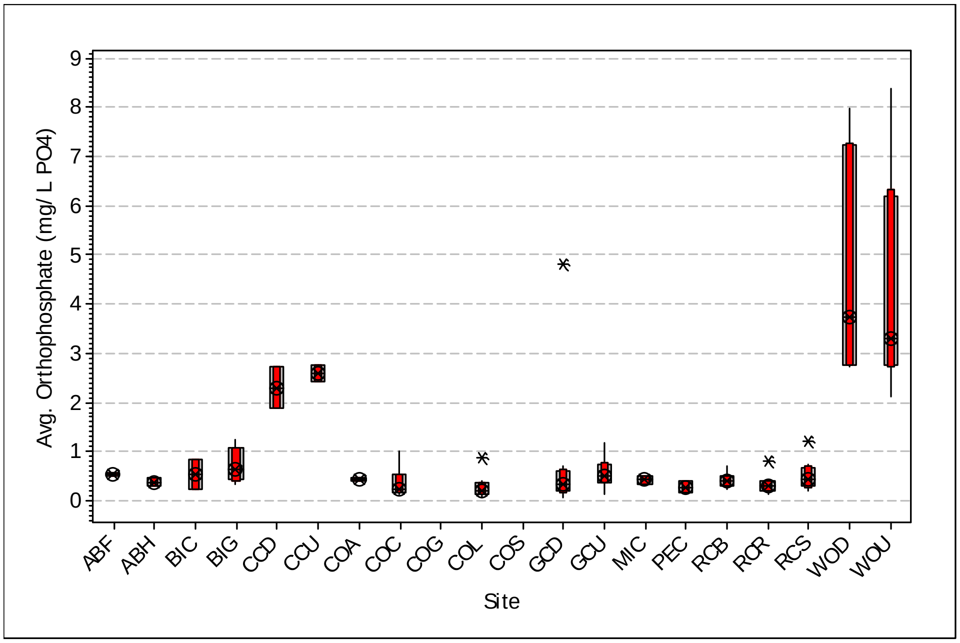

Figure 96. Boxplot depicting the distribution of average orthophosphate levels measured during sampling events at each site during the study period 2007-2010. Median symbol = ⌖ . Red bar depicts the 95% confidence interval for the median.

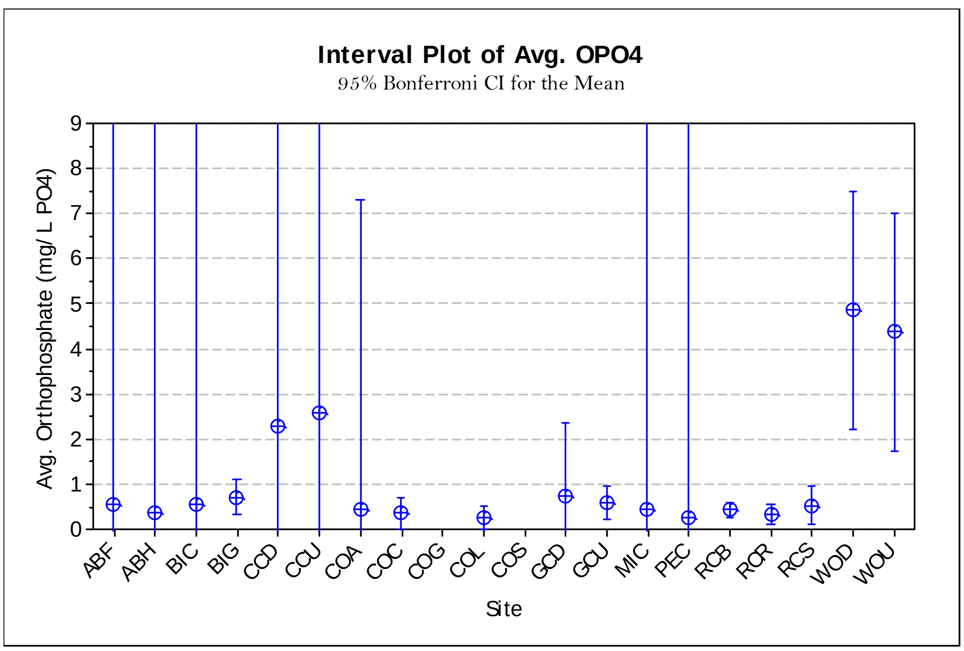

Figure 97. Bonferroni 95% confidence intervals for mean average orthophosphate levels by site (99% individual confidence intervals) sampled during 2007-2010.

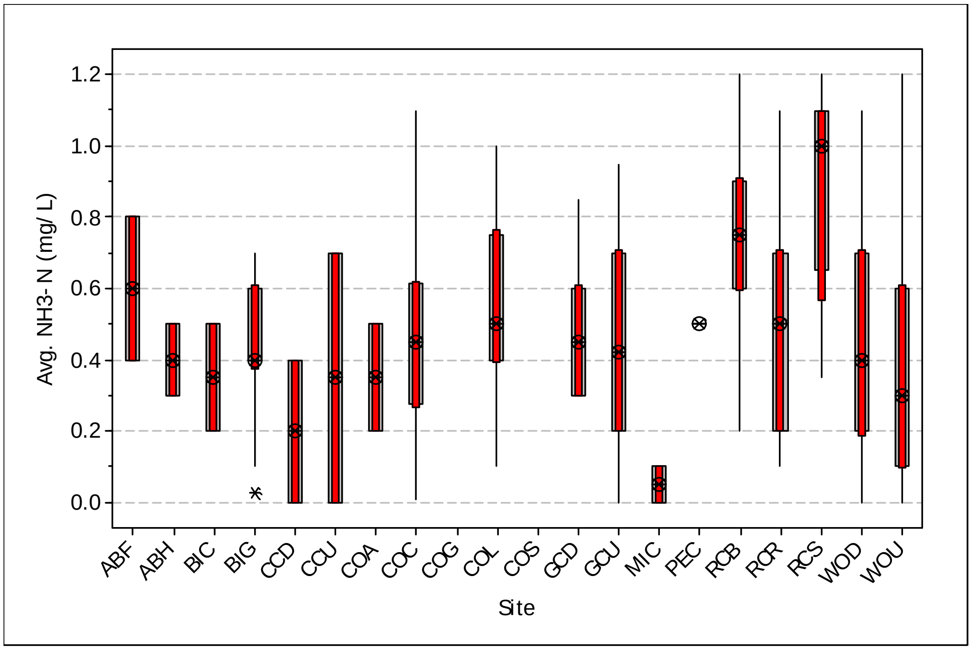

Figure 98. Boxplot depicting the distribution of average ammonia nitrogen levels measured during sampling events at each site during the study period 2007-2010. Median symbol = î . Red bar depicts the 95% confidence interval for the median.

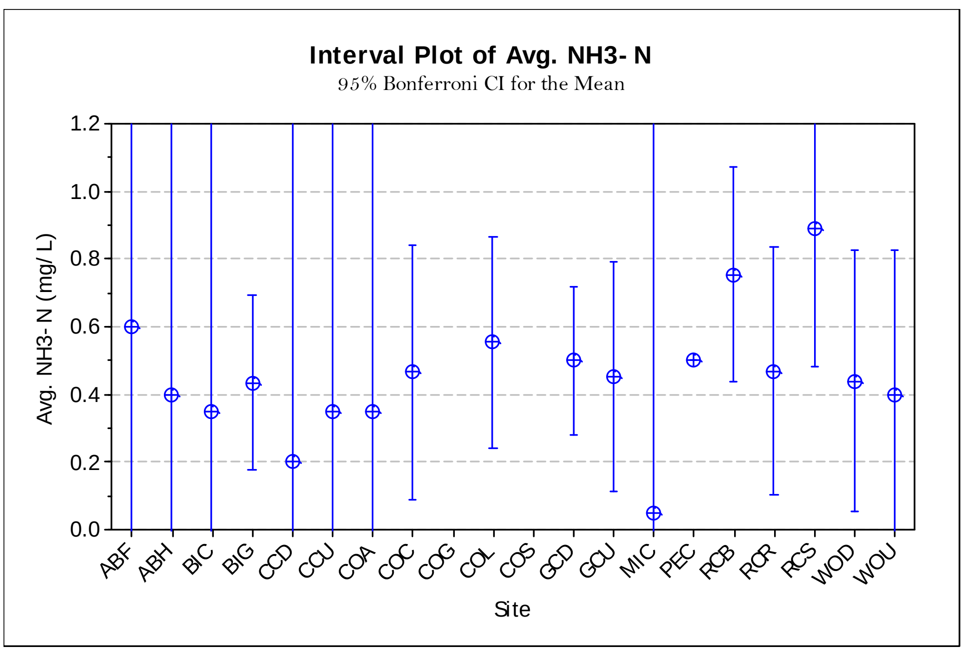

Figure 99. Bonferroni 95% confidence intervals for mean average ammonia nitrogen levels by site (99% individual confidence intervals) sampled during 2007-2010.

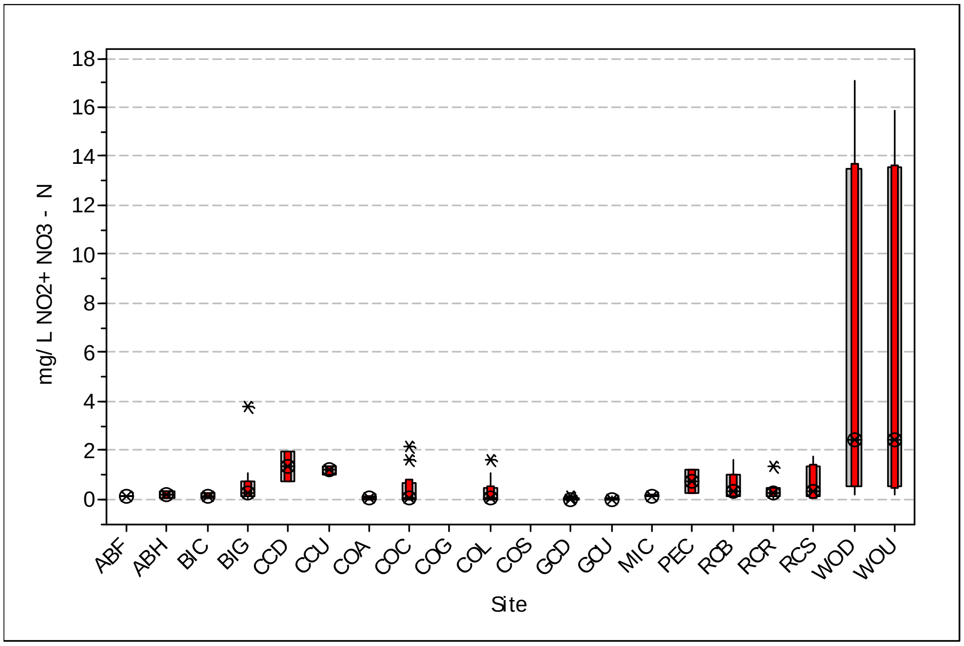

Figure 100. Boxplot depicting the distribution of average nitrate + nitrite nitrogen levels measured during sampling events at each site during the study period 2007-2010. Median symbol = ⨂ . Red bar depicts the 95% confidence interval for the median.

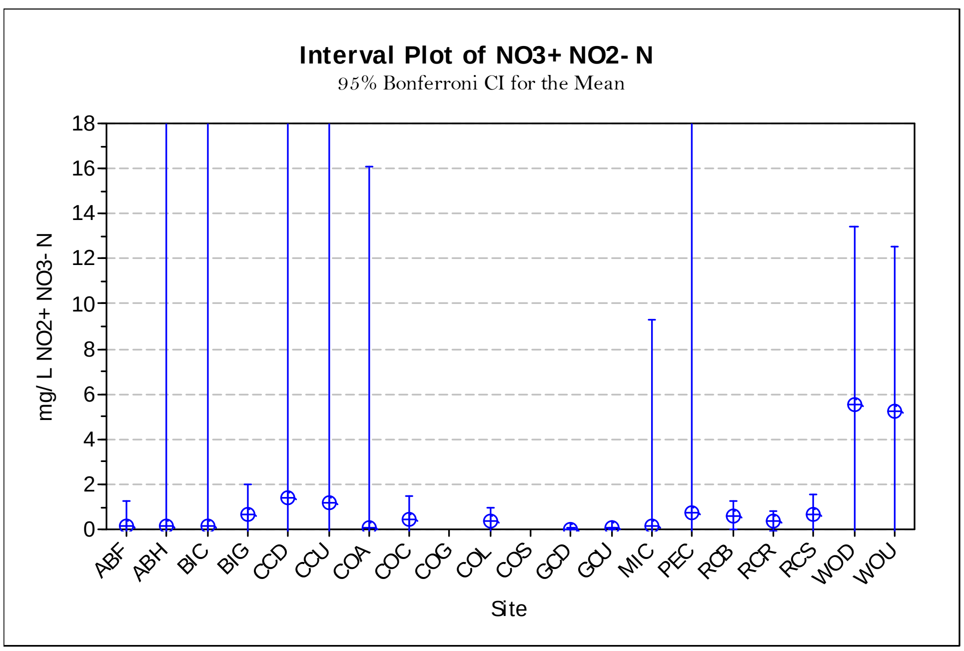

Figure 101. Bonferroni 95% confidence intervals for mean average nitrate + nitrogen as nitrogen levels by site (99% individual confidence intervals) sampled during 2007-2010.

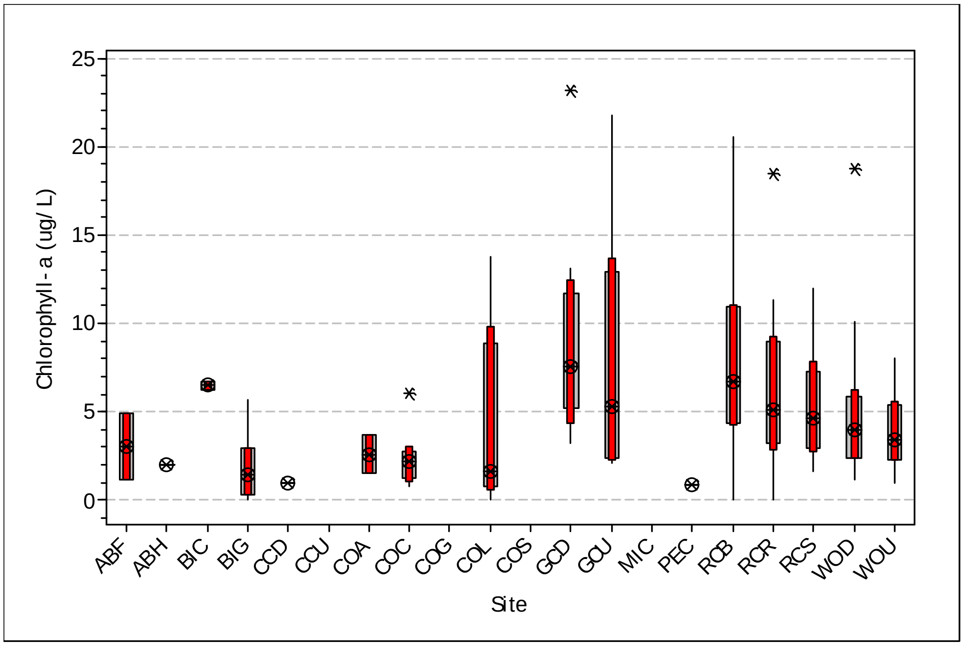

Figure 102. Boxplot depicting the distribution of average chlorophyll-*a* levels measured during sampling events at each site during the study period 2007-2010. Median symbol = î . Red bar depicts the 95% confidence interval for the median.

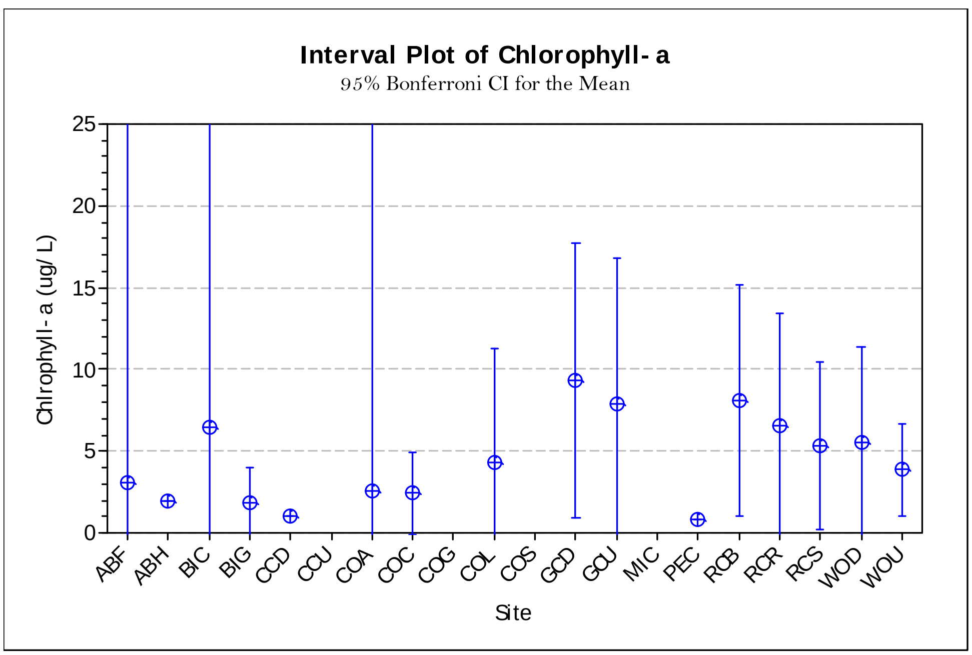

Figure 103. Bonferroni 95% confidence intervals for mean average chlorophyll-*levels* by site (99% individual confidence intervals) sampled during 2007-2010.

Statistical Results. Pearson correlation coefficients were calculated between all physicochemical variables. The resulting most significant ($p < 0.01$, $r < \pm 0.50$) correlations are listed in Table 5. We found that watershed size was positively correlated with average stream width, streamflow, and the number of wastewater dischargers. The amount of impervious surface area in a watershed was positively correlated with average stream velocity, streamflow, number of wastewater dischargers and average Wentworth sediment scores (i.e. sediment size). The number of wastewater dischargers was positively correlated with the size of the watershed, amount of impervious surface in the watershed, average stream width, average orthophosphate levels, average nitrate plus nitrite nitrogen (NO_{2+3}-N) levels, and streamflow.

Streamflow, which is considered the master controlling variable in regards to stream ecology, was positively correlated with six variables including average stream width, average stream thalweg velocity, average orthophosphate levels, and as previously stated, watershed area, the number of wastewater dischargers, and amount of impervious surface in the watershed (Table 5). Average stream thalweg velocity was positively correlated with average stream width and as previously noted the amount of impervious surface in the watershed, number of wastewater dischargers, and streamflow.

Average orthophosphate was positively correlated with average NO_{2+3}-N levels, average stream width, and as previously noted amount of impervious surface area in the watershed, number of wastewater dischargers and streamflow (Table 5). As previously stated, average NO_{2+3}-N levels were positively correlated with the amount of impervious surface in the watershed and number of wastewater dischargers.

Stream habitat complexity was positively correlated with the percentage of riffles and pools and negatively correlated with percentage of runs in the survey reach (Table 5). This correlation suggests that sites containing high complexity contain both riffles and pools. Average sediment scores were positively correlated with percent impervious surface area in the watershed and as previously stated the amount of impervious surface area in the watershed.

There were also several obvious correlations that reflect the documented relationships between variables such as the negative correlation between Secchi disk clarity and average turbidity, and between specific conductance and total hardness; and positive correlations between specific conductance and total alkalinity. The negative correlation between hardness and specific conductance is associated with dilution of tidally influenced coastal streams containing sodium as the dominant cation with freshwater calcium and magnesium cations. Total alkalinity usually increases as the salt content of the water increases, regardless of specific cation composition.

These correlations provide background data that help to explain possible mechanisms controlling stream habitat and water quality. For example increased watershed size and amount of impervious surface along with increased numbers of wastewater dischargers all lead to increased streamflow, which influenced stream velocity. In turn stream hydrology affects stream morphology (e.g. width of the stream, sediment size) and water quality (e.g. nitrogen and phosphorus loading). In addition, loading of nutrients is augmented by increased amounts of stormwater runoff and high intensity of wastewater discharges. Other significant ($p < 0.05$) albeit weak ($r > 0.50$ or < -0.50) correlations were observed but are not presented.

Table 5. Highly significant ($p < 0.01$, $r > 0.50$ or < -0.50) Pearson correlation coefficients between physicochemical variables measured during the study period.

Variable 1	Variable 2	r	p-value
% Pool	% Run	-0.75	0.00
Avg Velocity	Imper (ha)	0.58	0.00
Avg Velocity	No. WWTP	0.57	0.00
Avg Velocity	Avg. Width (m)	0.52	0.00
Avg. NO3+2 (mg/L)	Imper (ha)	0.59	0.00
Avg. NO3+2 (mg/L)	No. WWTP	0.58	0.00
Avg. OPO4 mg/L	Imper (ha)	0.83	0.00
Avg. OPO4 mg/L	No. WWTP	0.81	0.00
Avg. OPO4 mg/L	Avg. NO3+2 (mg/L)	0.77	0.00
Avg. OPO4 mg/L	Avg. Width (m)	0.62	0.00
Avg. OPO4 mg/L	Flow (cfs)	0.62	0.00
Avg. SD (cm)	Avg. Turb. (NTU)	-0.56	0.00
Avg. Sed. Score	% Imp.	0.50	0.00
Avg. Sed. Score	Imper (ha)	0.50	0.00
Avg. Width (m)	No. WWTP	0.80	0.00
Avg. Width (m)	Imper (ha)	0.78	0.00
Avg. Width (m)	WShed Area (ha)	0.59	0.00
Complexity	% Run	-0.71	0.00
Complexity	% Riffle	0.61	0.00
Complexity	% Pool	0.53	0.00
Flow (cfs)	No. WWTP	0.81	0.00
Flow (cfs)	Imper (ha)	0.80	0.00
Flow (cfs)	Avg. Width (m)	0.79	0.00
Flow (cfs)	Avg Velocity	0.66	0.00
Flow (cfs)	WShed Area (ha)	0.58	0.00
Imper (ha)	No. WWTP	0.98	0.00
Sp. Cond (uS)	Tot. Hard. (mg/L)	-0.69	0.00
Sp. Cond (uS)	AvgAlkmgL	0.58	0.00
Sp. Cond (uS)	% Imp.	-0.51	0.00
WShed Area (ha)	No. WWTP	0.56	0.00

Principal Component's analysis (PCA) identified two principal components (PC1 and PC2) which explained 26.5% of the cumulative variation in the data matrix (Figure 104 and 105). White Oak Bayou, Peach Creek (PEC) and Big Creek (BIC) sites possessed one or more of the following characteristics: larger watersheds; larger stream widths; higher streamflow and stream velocity; higher number of wastewater facilities; and higher amounts of concrete lined channel. In contrast most of the other survey reaches can be characterized as having more complex stream morphology, higher amounts of pool habitat, higher amounts of clay substrate and higher conductivity waters.

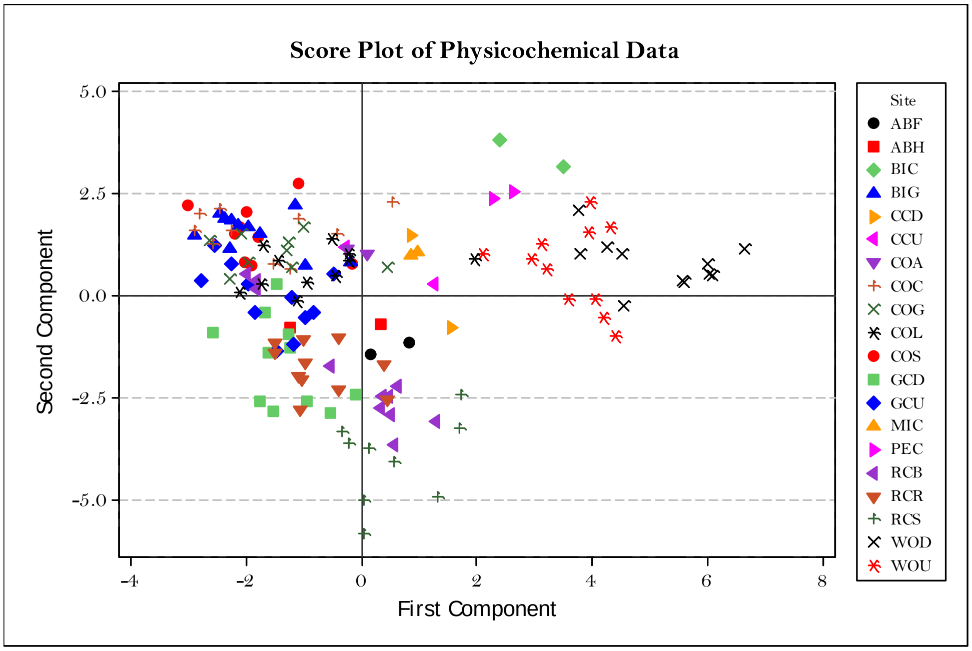

Figure 104. Results of Principal Components Analysis of physicochemical data illustrating resulting ordination score of collections. PC1 and PC2 explain 16.1% and 10.4% of total variation in data.

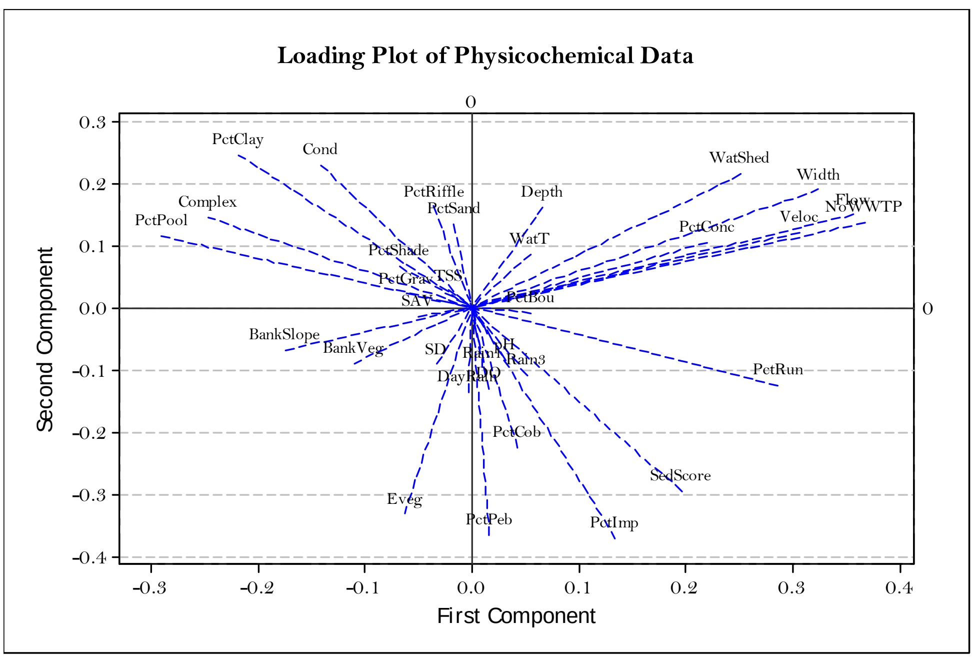

Figure 105. Loading plot illustrating the relative loading of each individual physicochemical variable on the two primary principal component functions (PC1 and PC2) and axes.

Biota

Fish Communities

Fish communities were investigated using two sampling methods: seines and backpack electroshocking. Backpack electroshocking is limited to surface waters containing low (<800 – 1000 uS) specific conductance levels. For simplicity, individual replicate collections were pooled to generate average and median estimates for each site prior to analysis. The number of replicate samples collected during the study at each site varied between 20 to 110 seine hauls and 6 to 33 electrofishing replicates over a 1- to 3-year period.

A total of 56,077 fish representing 62 taxa overall were collected during the study using both seines and electrofishing (Table 6). A total of 48,536 fish representing 57 taxa were collected with seines alone. Twenty-six taxa were unique to seine collections and not collected by electrofishing gear. A total of 7,541 fish representing 42 taxa were collected with electrofishing alone. Five taxa were unique to electrofishing collections and not collected by seine gear. Fish community data and analysis results obtained from seine collections are presented first, followed by electrofishing results.

Seine Collection Results

Total abundance of fish/seine haul varied between 0 and 924 fish (Figure 106). Based on examination of 95% confidence interval plots for the median and mean, and the Kruskal-Wallis ANOVA and Dunn's multiple comparison tests there were multiple significant differences in total abundance between sites (Figure 106-107, and Table 8). The Armand Bayou Fairmont (ABF), Armand Bayou Holly Bay (ABH), Big Creek (BIC), and Big Gulch (BIG) sites exhibited lower total catch rates in comparison to the majority of other sites. In addition, many other sites exhibited significantly higher median catch rates than the White Oak Bayou sites.

The number of fish taxa exhibited similar trends to that of total abundance (Figure 108-109 and Table 8). Based on results of Kruskal-Wallis and Dunn's multiple range tests and examination of confidence interval for the median and mean charts, the ABF, ABH, BIC, BIG, RCB, RCS, White Oak downstream (WOD) and WOU sites exhibited lower number of taxa/seine haul than the majority of other sites. The White Oak downstream (WOD), WOU and ABF sites exhibited the lowest average and median number of taxa. The Cowart Creek sites generally had the highest average and median number of taxa.

Based on examination of Kruskal-Wallis and Dunn's multiple range tests and confidence interval for the median and mean charts, the Big Creek (BIC), Rummel Creek school (RCS), White Oak downstream (WOD) and White Oak upstream (WOU) sites exhibited the lowest Shannon Wiener Diversity (H') (Figure 110-111 and Table 9). Highest H' was generally observed at the Clear Creek downstream (CCD), Clear Creek upstream (CCU), Cowart Creek Airport (COA) and Cowart Creek control (COC) sites. It should be noted that H' and Evenness (J) can only be calculated when catch rates exceeded zero. Otherwise the collection is omitted from the analysis.

Based on examination of Kruskal-Wallis and Dunn's multiple range tests and examination of confidence interval for the median and mean charts, the highest evenness (J) index values were generally observed at the Armand Bayou, Big Creek (BIC), Big Gulch (BIG), White Oak downstream (WOD), and White Oak upstream (WOU) sites (Figure 112-113 and Table 10). Lower J values were documented at the Cowart Creek Airport (COA) and Goose Creek upstream (GCU) sites.

Based on the results of the Kruskal-Wallis and Dunn's multiple range tests and examination of confidence interval for the median and mean charts, the highest Berger Parker Index (BPI) values were generally observed at the Armand Bayou, Big Creek (BIC), Big Gulch (BIG), Rummel Creek and White Oak Bayou sites (Figure 114-115 and Table 11). Lower BPI values were documented at the Clear Creek and Cowart Creek control (COC) sites. It should be noted that BPI can only be calculated when catch rates exceeded zero. Otherwise the collection is omitted from the analysis.

The highest cumulative number of taxa collected in seines throughout the study period was observed at the Cowart Creek control (COC) site where a total of 32 taxa were documented (Figure 116). The remaining Cowart Creek and Goose Creek upstream (GCU) and Rummel Creek rip rap (RCR) sites also yielded relatively high (> 18) number of taxa. However it should be noted that the amount of effort (number of samples collected) will influence the number of taxa observed. So, to evaluate this, we also plotted the number of taxa versus number of samples collected. Although highly variable it did appear that when more than 90 samples were collected, the number of cumulative fish taxa seldom fell below 15 taxa in contrast to sites with less (< 50 replicates) which yielded generally less than 15 taxa (Figure 117). To adjust for this effect we calculated the cumulative number of taxa per replicate sample and found that Armand Bayou, Clear Creek, Cowart Creek Airport (COA), Cowart Creek Sunset (COS), Mill Creek (MIC) and Peach Creek (PEC) sites yielded higher values in comparison to other sites (Figure 118). The Big Gulch (BIG), Goose Creek, and White Oak Bayou sites yielded very low cumulative number of taxa/replicate sample.

Based on review of the fish seine community data it appears the White Oak Bayou sites were species depauperate in comparison to other sites within urban and non-urban areas. This is surprising since seining efficiency was maximized at both sites in comparison to many other locations due to the absence of instream obstacles. The primary characteristics differentiating the White Oak Bayou sites, and in particular the White Oak downstream (WOD) site from the other streams was the lack of SAV, low instream habitat complexity, large watershed area, large stream width, percent concrete channel substrate, higher amount of instream run habitat, higher stream velocity and the highest number of upstream permitted wastewater facilities (Figure 74-75 and 105). However, other streams such as the Peach Creek and Big Creek yielded comparable levels for one or more of the listed variables including stream width, SAV, and/or streamflow conditions. The primary difference between White Oak Bayou and these sites include higher amounts of wastewater dischargers and a very "simplified" substrate consisting of either hardpan clay or concrete channel. Both of these conditions provide very little instream cover for fish. White Oak Bayou like many urban streams is composed primarily of wastewater effluent during dry weather conditions (TCEQ 2009). The interaction of these two factors (effluent dominated flows and lack of instream habitat) may be contributing to the low diversity observed at the White Oak Bayou sites.

Table 6. List of taxa collected with seine and electroshocking gear.

Species	Seine	Electroshocking
Lepisosteus spp		X
Lepisosteus oculatus	X	X
Dorosoma cepedianum	X	X
Dorosoma petenense	X	X
Unidentifiable Cyprinidae	X	
Ctenopharyngodon idella	X	X
Cyprinella lutrensis	X	
Cyprinella venusta	X	
Cyprinus carpio	X	
Hybognathus nuchalis	X	
Lythrurus fumeus	X	
Notemigonus crysoleucas	X	
Notropis atrocaudalis	X	
Notropis sabinae		X
Notropis texanus	X	
Opsopoeodus emiliae	X	
Pimephales promelas	X	X
Pimephales vigilax	X	X
Moxostoma poecilurum	X	
Ameiurus melas	X	X
Ameiurus natalis	X	X
Ictalurus furcatus	X	
Ictalurus punctatus	X	X
Noturus gyrinus	X	X
Pylodictis olivaris	X	
unknown Ictaluridae	X	
Loricariidae spp.(Armored catfish)	X	X
Aphredoderus sayanus		X
Mugil cephalus	X	X
Labidesthes sicculus	X	
Menida beryllina	X	
Cyprinodon variegatus	X	X
Fundulus chrysotus	X	X
Fundulus grandis	X	X
Fundulus notatus	X	
Fundulus olivaceus/ notatus	X	X
Fundulus olivaceus	X	
Fundulus similis	X	
Gambusia affinis	X	X
Poecilia latipinna	X	X
Lepomis auritus	X	X
Lepomis cyanellus	X	X
Lepomis gulosus	X	X

Species	Seine	Electroshocking
Lepomis macrochirus	X	X
L.macrochirus X microlophus hybrid		X
Lepomis megalotis	X	X
Lepomis microlophus	X	X
Lepomis sp. (juvenile)	X	X
Micropterus sp.(juvenile)	X	X
Micropterus punctulatus	X	X
Micropterus salmoides	X	X
Pomoxis annularis	X	X
Pomoxis nigromaculatus	X	
Ammocrypta vivax	X	
Etheostoma chlorosoma	X	X
Etheostoma gracile	X	
Etheostoma spp.	X	
Percina sciera		X
Elassoma zonatum		X
Cichlasomo cyanoguttatum	X	X
Oreochromis sp. (Tilapia)	X	
Dormitator maculatus	X	X
Unidentifiable Fish	X	X
Total No. Taxa Overall	62	
Total No. Collected Overall	56,077	
Total No. Taxa	57	42
Total No. Collected	48,536	7,541
Unique Taxa	26	5
Shared Taxa	31	37

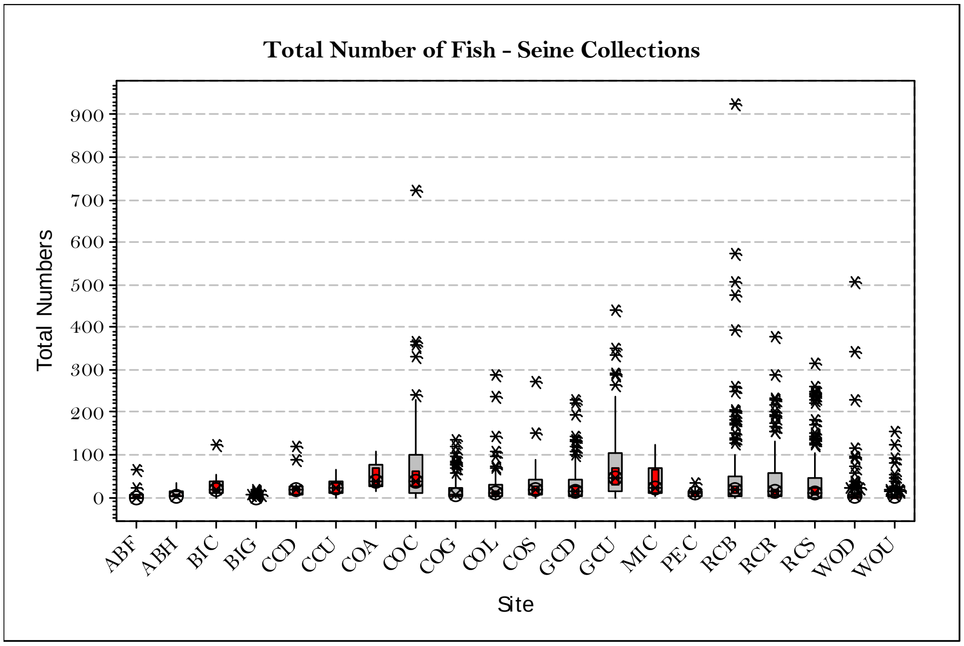

Figure 106. Boxplot depicting the distribution of the total number of fish collected with seines during sampling events at each site during the study period 2007-2010. Median symbol = î . Red bar depicts the 95% confidence interval for the median.

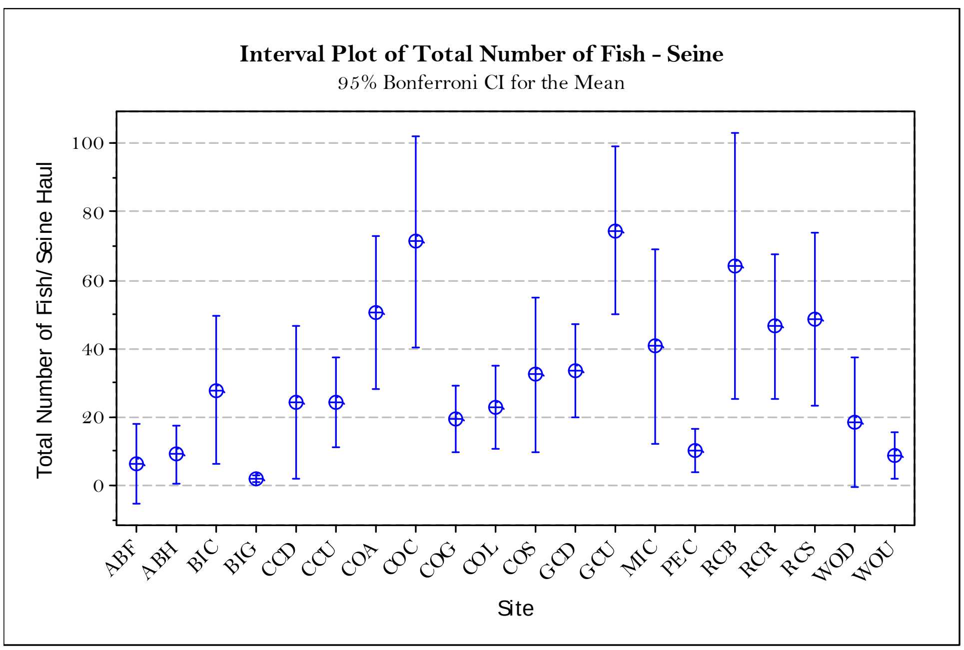

Figure 107. Bonferroni 95% confidence intervals for mean average number of fish collected in seines by site (99% individual confidence intervals) sampled during 2007-2010.

Table 7. Significant results of Kruskal-Wallis ANOVA comparing total number of fish/seine haul collected at each site and the post-hoc Dunn's multiple range tests.

Sites Compared		Z value	v.s.	Critical Value	P-value
ABF	BIC	3.5581	>=	3.276	0.0004
ABF	CCD	3.5837	>=	3.276	0.0003
ABF	CCU	3.8415	>=	3.276	0.0001
ABF	COA	5.5067	>=	3.276	0
ABF	COC	6.1833	>=	3.276	0
ABF	COS	4.2505	>=	3.276	0
ABF	GCD	4.1464	>=	3.276	0
ABF	GCU	6.2256	>=	3.276	0
ABF	MIC	4.2852	>=	3.276	0
ABF	RCB	4.5649	>=	3.276	0
ABF	RCR	4.0409	>=	3.276	0.0001
ABF	RCS	3.8161	>=	3.276	0.0001
ABH	COA	4.1611	>=	3.276	0
ABH	COC	4.4461	>=	3.276	0
ABH	GCU	4.4751	>=	3.276	0
BIC	BIG	5.0099	>=	3.276	0
BIC	WOD	4.0004	>=	3.276	0.0001
BIC	WOU	4.3203	>=	3.276	0
BIG	CCD	5.0431	>=	3.276	0
BIG	CCU	5.3786	>=	3.276	0
BIG	COA	7.5448	>=	3.276	0
BIG	COC	11.6326	>=	3.276	0
BIG	COG	5.0433	>=	3.276	0
BIG	COL	6.3943	>=	3.276	0
BIG	COS	6.9789	>=	3.276	0
BIG	GCD	8.1622	>=	3.276	0
BIG	GCU	11.9106	>=	3.276	0
BIG	MIC	5.9557	>=	3.276	0
BIG	RCB	8.9166	>=	3.276	0
BIG	RCR	7.972	>=	3.276	0
BIG	RCS	7.289	>=	3.276	0
CCD	WOD	4.0336	>=	3.276	0.0001
CCD	WOU	4.3535	>=	3.276	0
CCU	WOD	4.3691	>=	3.276	0
CCU	WOU	4.689	>=	3.276	0
COA	COG	4.5194	>=	3.276	0
COA	COL	3.9979	>=	3.276	0.0001
COA	PEC	3.313	>=	3.276	0.0009
COA	WOD	6.5353	>=	3.276	0

Sites Compared		Z value	v.s.	Critical Value	P-value
COA	WOU	6.8552	>=	3.276	0
COC	COG	6.1285	>=	3.276	0
COC	COL	5.3924	>=	3.276	0
COC	GCD	3.6671	>=	3.276	0.0002
COC	PEC	3.3512	>=	3.276	0.0008
COC	RCR	3.8527	>=	3.276	0.0001
COC	RCS	3.9316	>=	3.276	0.0001
COC	WOD	9.8565	>=	3.276	0
COC	WOU	10.4193	>=	3.276	0
COG	GCU	6.2561	>=	3.276	0
COG	RCB	3.4158	>=	3.276	0.0006
COG	WOD	3.3168	>=	3.276	0.0009
COG	WOU	3.8639	>=	3.276	0.0001
COL	GCU	5.5163	>=	3.276	0
COL	WOD	4.5744	>=	3.276	0
COL	WOU	5.1511	>=	3.276	0
COS	WOD	5.5921	>=	3.276	0
COS	WOU	6.0316	>=	3.276	0
GCD	GCU	3.7485	>=	3.276	0.0002
GCD	WOD	6.3422	>=	3.276	0
GCD	WOU	6.919	>=	3.276	0
GCU	PEC	3.3718	>=	3.276	0.0007
GCU	RCR	3.9387	>=	3.276	0.0001
GCU	RCS	4.0104	>=	3.276	0.0001
GCU	WOD	10.0907	>=	3.276	0
GCU	WOU	10.6674	>=	3.276	0
MIC	WOD	4.9462	>=	3.276	0
MIC	WOU	5.2661	>=	3.276	0
RCB	WOD	7.0967	>=	3.276	0
RCB	WOU	7.6734	>=	3.276	0
RCR	WOD	6.152	>=	3.276	0
RCR	WOU	6.7287	>=	3.276	0
RCS	WOD	5.5625	>=	3.276	0
RCS	WOU	6.1096	>=	3.276	0

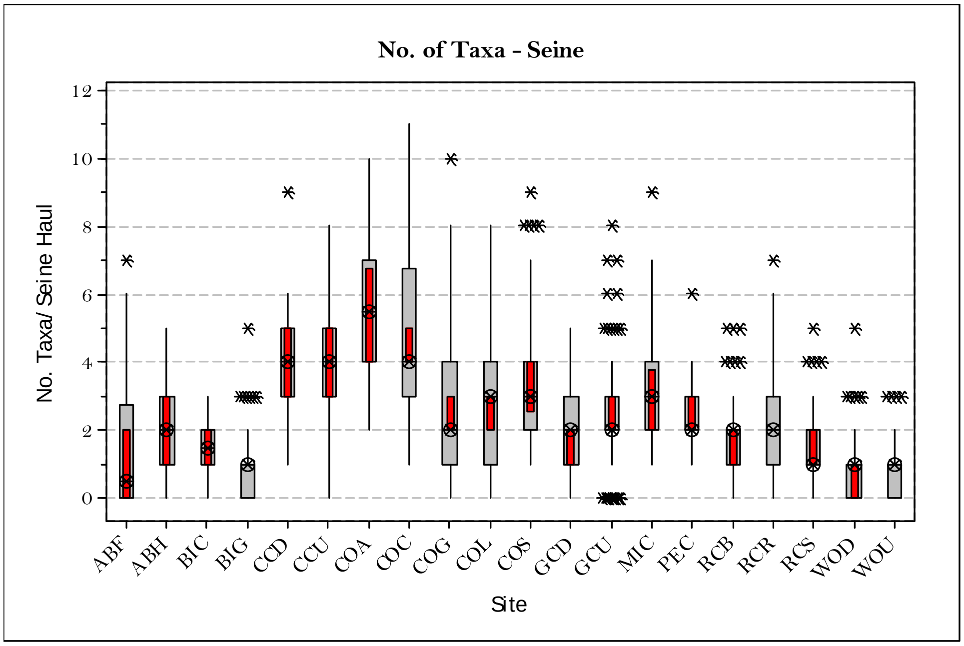

Figure 108. Boxplot depicting the distribution of the total number of fish taxa collected with seines during sampling events at each site during the study period 2007-2010. Median symbol = î . Red bar depicts the 95% confidence interval for the median.

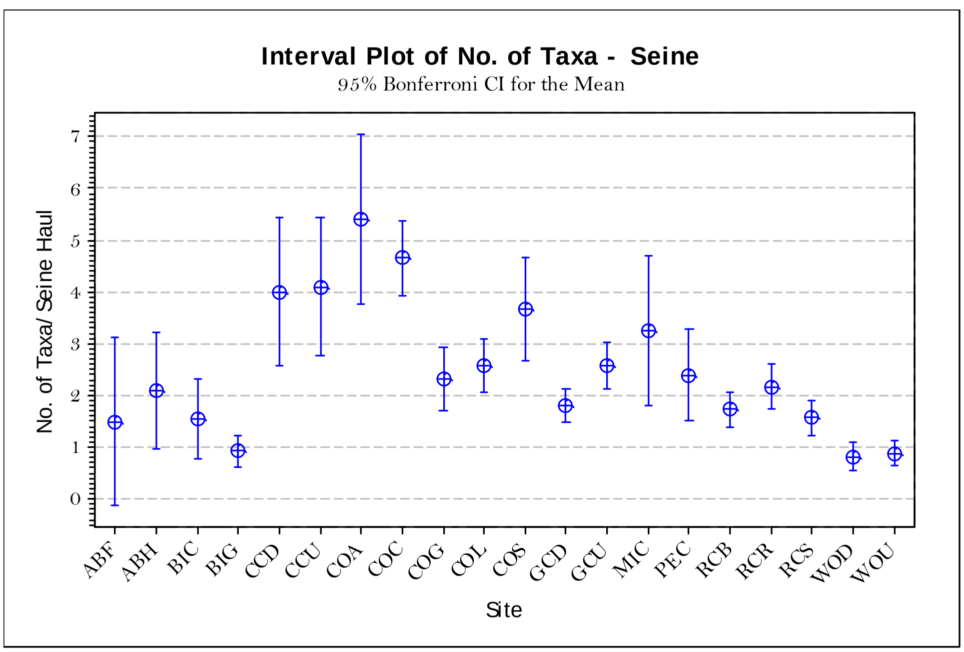

Figure 109. Bonferroni 95% confidence intervals for mean average number of fish taxa collected in seines by site (99% individual confidence intervals) sampled during 2007-2010.

Table 8. Significant results of Kruskal-Wallis ANOVA comparing number of taxa collected by seines at sites and the post-hoc Dunn's multiple range tests.

Sites Compared		Z value	v.s.	Critical Value	P-value
ABF	CCD	4.7367	>=	3.276	0
ABF	CCU	4.9302	>=	3.276	0
ABF	COA	5.872	>=	3.276	0
ABF	COC	6.4249	>=	3.276	0
ABF	COL	3.2764	>=	3.276	0.0011
ABF	COS	4.8455	>=	3.276	0
ABF	GCU	3.4819	>=	3.276	0.0005
ABF	MIC	3.7346	>=	3.276	0.0002
ABH	BIG	3.278	>=	3.276	0.001
ABH	COA	4.0887	>=	3.276	0
ABH	COC	4.1227	>=	3.276	0
ABH	WOD	3.7191	>=	3.276	0.0002
ABH	WOU	3.4998	>=	3.276	0.0005
BIC	CCD	3.9903	>=	3.276	0.0001
BIC	CCU	4.1838	>=	3.276	0
BIC	COA	5.1256	>=	3.276	0
BIC	COC	5.4613	>=	3.276	0
BIC	COS	3.9671	>=	3.276	0.0001
BIG	CCD	7.12	>=	3.276	0
BIG	CCU	7.3718	>=	3.276	0
BIG	COA	8.5969	>=	3.276	0
BIG	COC	13.0758	>=	3.276	0
BIG	COG	5.8898	>=	3.276	0
BIG	COL	7.6338	>=	3.276	0
BIG	COS	8.675	>=	3.276	0
BIG	GCD	4.7419	>=	3.276	0
BIG	GCU	8.0044	>=	3.276	0
BIG	MIC	5.8164	>=	3.276	0
BIG	PEC	4.3028	>=	3.276	0
BIG	RCB	4.3129	>=	3.276	0
BIG	RCR	6.1258	>=	3.276	0
CCD	COG	3.615	>=	3.276	0.0003
CCD	GCD	4.4897	>=	3.276	0
CCD	RCB	4.7277	>=	3.276	0
CCD	RCR	3.7221	>=	3.276	0.0002
CCD	RCS	5.134	>=	3.276	0
CCD	WOD	7.5611	>=	3.276	0
CCD	WOU	7.3418	>=	3.276	0
CCU	COG	3.8625	>=	3.276	0.0001

Sites Compared		Z value	v.s.	Critical Value	P-value
CCU	GCD	4.7415	>=	3.276	0
CCU	RCB	4.9794	>=	3.276	0
CCU	RCR	3.9738	>=	3.276	0.0001
CCU	RCS	5.3815	>=	3.276	0
CCU	WOD	7.8129	>=	3.276	0
CCU	WOU	7.5935	>=	3.276	0
COA	COG	5.0673	>=	3.276	0
COA	COL	4.3624	>=	3.276	0
COA	GCD	5.9666	>=	3.276	0
COA	GCU	4.1569	>=	3.276	0
COA	PEC	3.3009	>=	3.276	0.001
COA	RCB	6.2045	>=	3.276	0
COA	RCR	5.199	>=	3.276	0
COA	RCS	6.5863	>=	3.276	0
COA	WOD	9.038	>=	3.276	0
COA	WOU	8.8187	>=	3.276	0
COC	COG	6.6729	>=	3.276	0
COC	COL	5.626	>=	3.276	0
COC	GCD	8.4482	>=	3.276	0
COC	GCU	5.2644	>=	3.276	0
COC	RCB	8.8669	>=	3.276	0
COC	RCR	7.0977	>=	3.276	0
COC	RCS	9.2574	>=	3.276	0
COC	WOD	13.8519	>=	3.276	0
COC	WOU	13.4659	>=	3.276	0
COG	COS	3.8228	>=	3.276	0.0001
COG	WOD	6.6442	>=	3.276	0
COG	WOU	6.269	>=	3.276	0
COL	RCB	3.3209	>=	3.276	0.0009
COL	RCS	3.9943	>=	3.276	0.0001
COL	WOD	8.4291	>=	3.276	0
COL	WOU	8.0336	>=	3.276	0
COS	GCD	5.0617	>=	3.276	0
COS	RCB	5.3885	>=	3.276	0
COS	RCR	4.0072	>=	3.276	0.0001
COS	RCS	5.8796	>=	3.276	0
COS	WOD	9.2809	>=	3.276	0
COS	WOU	8.9796	>=	3.276	0
GCD	WOD	5.5371	>=	3.276	0
GCD	WOU	5.1416	>=	3.276	0
GCU	RCB	3.6915	>=	3.276	0.0002

Sites Compared		Z value	v.s.	Critical Value	P-value
GCU	RCS	4.3458	>=	3.276	0
GCU	WOD	8.7996	>=	3.276	0
GCU	WOU	8.4041	>=	3.276	0
MIC	RCB	3.424	>=	3.276	0.0006
MIC	RCS	3.8521	>=	3.276	0.0001
MIC	WOD	6.2575	>=	3.276	0
MIC	WOU	6.0381	>=	3.276	0
PEC	WOD	4.7439	>=	3.276	0
PEC	WOU	4.5245	>=	3.276	0
RCB	WOD	5.1081	>=	3.276	0
RCB	WOU	4.7127	>=	3.276	0
RCR	WOD	6.921	>=	3.276	0
RCR	WOU	6.5255	>=	3.276	0
RCS	WOD	4.0022	>=	3.276	0.0001
RCS	WOU	3.627	>=	3.276	0.0003

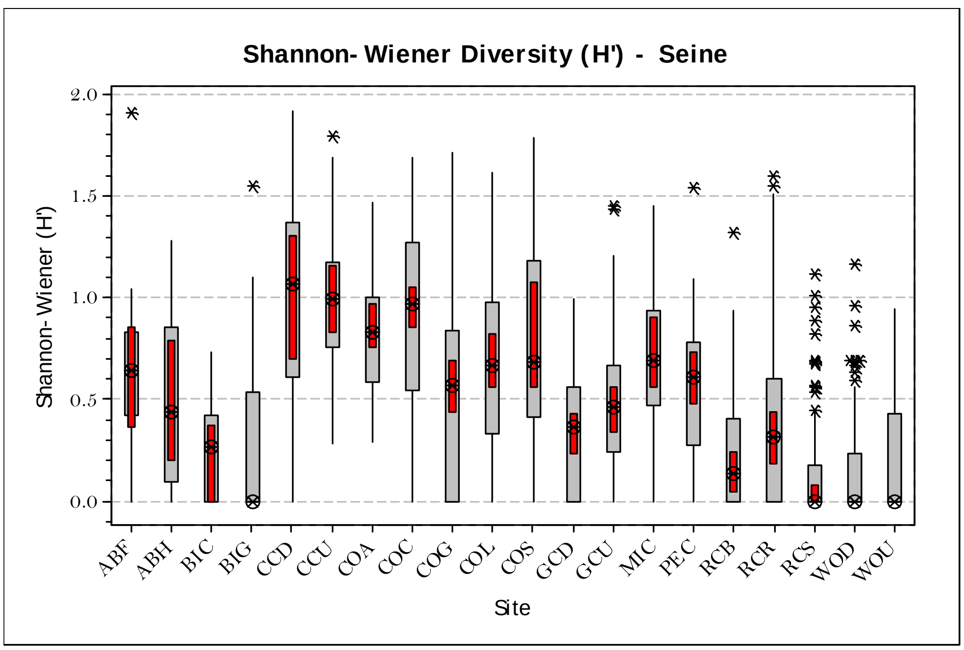

Figure 110. Boxplot depicting the distribution of the Shannon Weiner Diversity (H') calculated from seine fish collections at each site during the study period 2007-2010. Median symbol = ĭ . Red bar depicts the 95% confidence interval for the median.

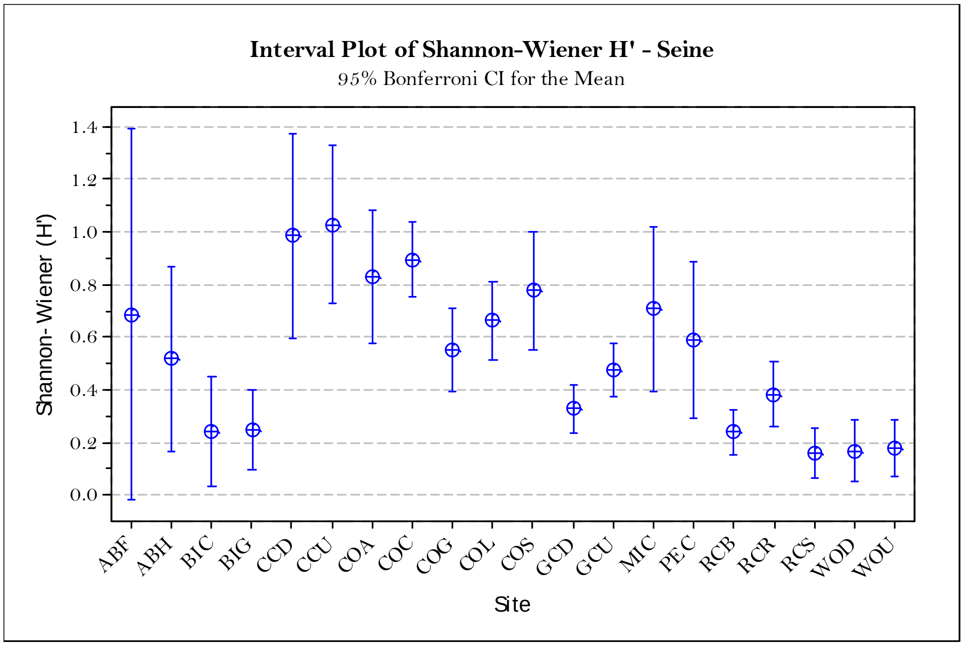

Figure 111. Bonferroni 95% confidence intervals for mean average Shannon-Weiner (H') calculated from seine fish collections at each site (99% individual confidence intervals) during 2007-2010.

Table 9. Significant results of Kruskal-Wallis ANOVA comparing Shannon-Wiener Diversity (H') calculated from seine collections at each site and the post-hoc Dunn's multiple range tests.

Sites Compared		Z value	v.s.	Critical Value	P-value
ABF	RCS	3.309	>=	3.276	0.0009
ABF	WOD	3.43	>=	3.276	0.0006
ABF	WOU	3.3463	>=	3.276	0.0008
BIC	CCD	4.4041	>=	3.276	0
BIC	CCU	4.944	>=	3.276	0
BIC	COA	4.1384	>=	3.276	0
BIC	COC	5.1454	>=	3.276	0
BIC	COL	3.4523	>=	3.276	0.0006
BIC	COS	4.0267	>=	3.276	0.0001
BIC	MIC	3.3603	>=	3.276	0.0008
BIG	CCD	6.2331	>=	3.276	0
BIG	CCU	6.8751	>=	3.276	0
BIG	COA	5.8864	>=	3.276	0
BIG	COC	9.5271	>=	3.276	0
BIG	COG	4.9457	>=	3.276	0
BIG	COL	6.5929	>=	3.276	0
BIG	COS	6.6779	>=	3.276	0
BIG	GCU	4.7819	>=	3.276	0

Sites Compared		Z value	v.s.	Critical Value	P-value
BIG	MIC	4.8708	>=	3.276	0
BIG	PEC	3.8069	>=	3.276	0.0001
CCD	GCD	5.017	>=	3.276	0
CCD	GCU	3.4237	>=	3.276	0.0006
CCD	RCB	5.7966	>=	3.276	0
CCD	RCR	4.5077	>=	3.276	0
CCD	RCS	6.5877	>=	3.276	0
CCD	WOD	6.6318	>=	3.276	0
CCD	WOU	6.5698	>=	3.276	0
CCU	COG	3.7268	>=	3.276	0.0002
CCU	GCD	5.6996	>=	3.276	0
CCU	GCU	4.1415	>=	3.276	0
CCU	RCB	6.4622	>=	3.276	0
CCU	RCR	5.2005	>=	3.276	0
CCU	RCS	7.2291	>=	3.276	0
CCU	WOD	7.2585	>=	3.276	0
CCU	WOU	7.2036	>=	3.276	0
COA	GCD	4.6599	>=	3.276	0
COA	RCB	5.4397	>=	3.276	0
COA	RCR	4.1508	>=	3.276	0
COA	RCS	6.2363	>=	3.276	0
COA	WOD	6.2903	>=	3.276	0
COA	WOU	6.2242	>=	3.276	0
COC	COG	4.2978	>=	3.276	0
COC	GCD	7.936	>=	3.276	0
COC	GCU	5.2098	>=	3.276	0
COC	RCB	9.2663	>=	3.276	0
COC	RCR	7.0452	>=	3.276	0
COC	RCS	10.3364	>=	3.276	0
COC	WOD	9.9416	>=	3.276	0
COC	WOU	10.0282	>=	3.276	0
COG	RCB	4.3186	>=	3.276	0
COG	RCS	5.5291	>=	3.276	0
COG	WOD	5.5156	>=	3.276	0
COG	WOU	5.4533	>=	3.276	0
COL	GCD	4.7659	>=	3.276	0
COL	RCB	6.0841	>=	3.276	0
COL	RCR	3.8971	>=	3.276	0.0001
COL	RCS	7.2792	>=	3.276	0
COL	WOD	7.119	>=	3.276	0
COL	WOU	7.1121	>=	3.276	0

Sites Compared		Z value	v.s.	Critical Value	P-value
COS	GCD	5.1341	>=	3.276	0
COS	RCB	6.1931	>=	3.276	0
COS	RCR	4.4382	>=	3.276	0
COS	RCS	7.2036	>=	3.276	0
COS	WOD	7.1503	>=	3.276	0
COS	WOU	7.1139	>=	3.276	0
GCD	MIC	3.6137	>=	3.276	0.0003
GCU	RCB	4.1191	>=	3.276	0
GCU	RCS	5.4153	>=	3.276	0
GCU	WOD	5.3828	>=	3.276	0
GCU	WOU	5.3229	>=	3.276	0
MIC	RCB	4.3945	>=	3.276	0
MIC	RCS	5.207	>=	3.276	0
MIC	WOD	5.2902	>=	3.276	0
MIC	WOU	5.2118	>=	3.276	0
PEC	RCB	3.2994	>=	3.276	0.001
PEC	RCS	4.1286	>=	3.276	0
PEC	WOD	4.2424	>=	3.276	0
PEC	WOU	4.1511	>=	3.276	0
RCR	RCS	3.5724	>=	3.276	0.0004
RCR	WOD	3.6778	>=	3.276	0.0002
RCR	WOU	3.5629	>=	3.276	0.0004

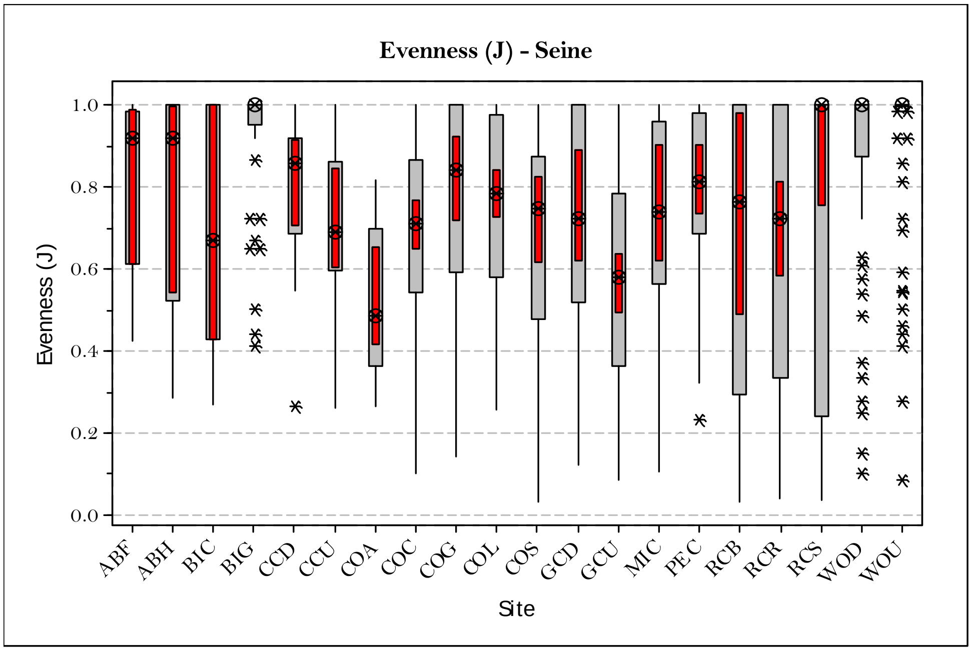

Figure 112. Boxplot depicting the distribution of the Evenness (J) calculated from seine fish collections at each site during the study period 2007-2010. Median symbol = ⊗ . Red bar depicts the 95% confidence interval for the median.

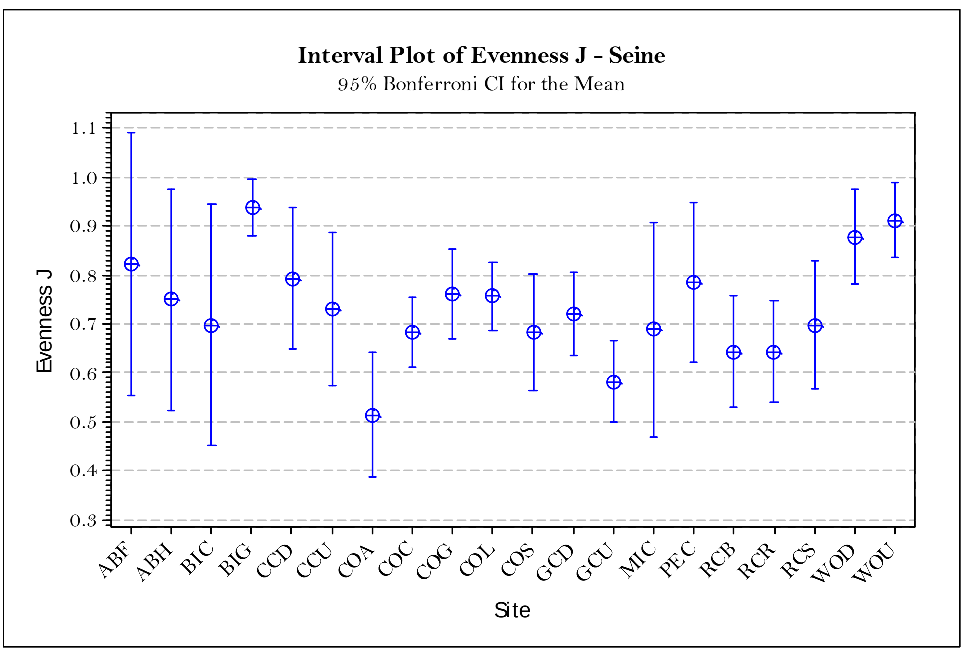

Figure 113. Bonferroni 95% confidence intervals for mean average Evenness (J) calculated from seine fish collections at each site (99% individual confidence intervals) during 2007-2010.

Table 10. Significant results of Kruskal-Wallis ANOVA comparing Evenness (J) calculated from seine collections at each site and the post-hoc Dunn's multiple range tests.

Sites Compared		Z value	v.s.	Critical Value	P-value
BIG	CCU	3.55356	>=	3.276	0.0004
BIG	COA	6.41689	>=	3.276	0
BIG	COC	6.87976	>=	3.276	0
BIG	COG	4.30366	>=	3.276	0
BIG	COL	4.99831	>=	3.276	0
BIG	COS	5.58085	>=	3.276	0
BIG	GCD	5.25135	>=	3.276	0
BIG	GCU	8.62659	>=	3.276	0
BIG	MIC	3.9486	>=	3.276	0.0001
BIG	RCB	6.1949	>=	3.276	0
BIG	RCR	6.65739	>=	3.276	0
BIG	RCS	4.35494	>=	3.276	0
CCU	WOU	3.40052	>=	3.276	0.0007
COA	COG	3.62345	>=	3.276	0.0003
COA	COL	3.40776	>=	3.276	0.0007
COA	GCD	3.28832	>=	3.276	0.001
COA	RCS	3.6834	>=	3.276	0.0002
COA	WOD	5.74316	>=	3.276	0
COA	WOU	6.25168	>=	3.276	0
COC	WOD	5.69106	>=	3.276	0
COC	WOU	6.5868	>=	3.276	0
COG	GCU	4.07073	>=	3.276	0
COG	WOD	3.28933	>=	3.276	0.001
COG	WOU	4.05085	>=	3.276	0.0001
COL	GCU	3.82212	>=	3.276	0.0001
COL	WOD	3.89913	>=	3.276	0.0001
COL	WOU	4.72489	>=	3.276	0
COS	WOD	4.67568	>=	3.276	0
COS	WOU	5.35753	>=	3.276	0
GCD	GCU	3.63526	>=	3.276	0.0003
GCD	WOD	4.13158	>=	3.276	0
GCD	WOU	4.9731	>=	3.276	0
GCU	RCS	4.21947	>=	3.276	0
GCU	WOD	7.36648	>=	3.276	0
GCU	WOU	8.31852	>=	3.276	0
MIC	WOD	3.31232	>=	3.276	0.0009
MIC	WOU	3.79102	>=	3.276	0.0002
RCB	WOD	5.04135	>=	3.276	0
RCB	WOU	5.90969	>=	3.276	0

Sites Compared		Z value	v.s.	Critical Value	P-value
RCR	WOD	5.48597	>=	3.276	0
RCR	WOU	6.36844	>=	3.276	0
RCS	WOD	3.31525	>=	3.276	0.0009
RCS	WOU	4.09569	>=	3.276	0

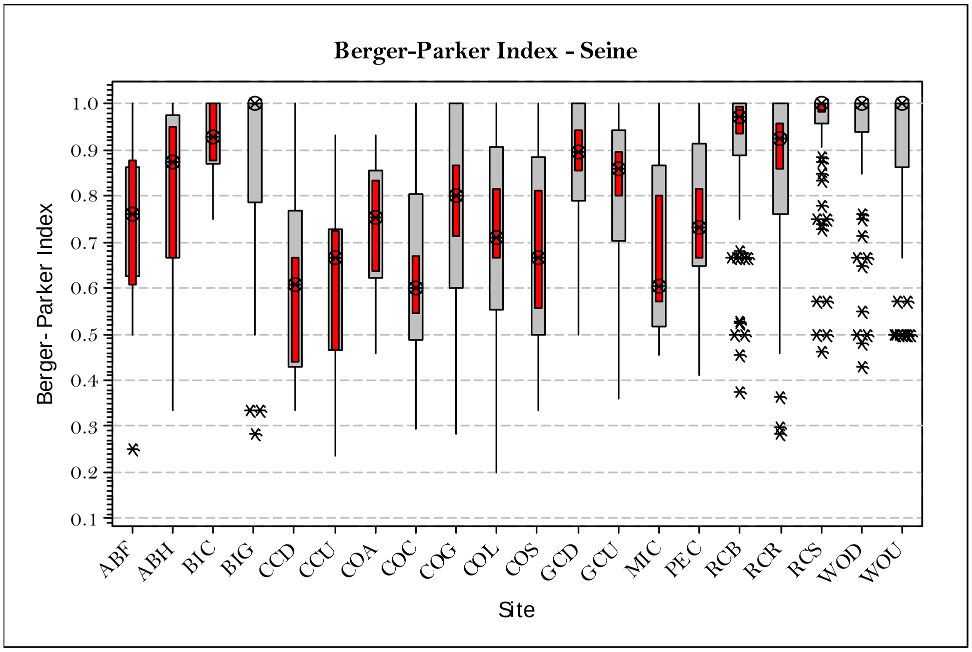

Figure 114. Boxplot depicting the distribution of the Berger Parker Dominance Index calculated from seine fish collections at each site during the study period 2007-2010. Median symbol = ĩ . Red bar depicts the 95% confidence interval for the median.

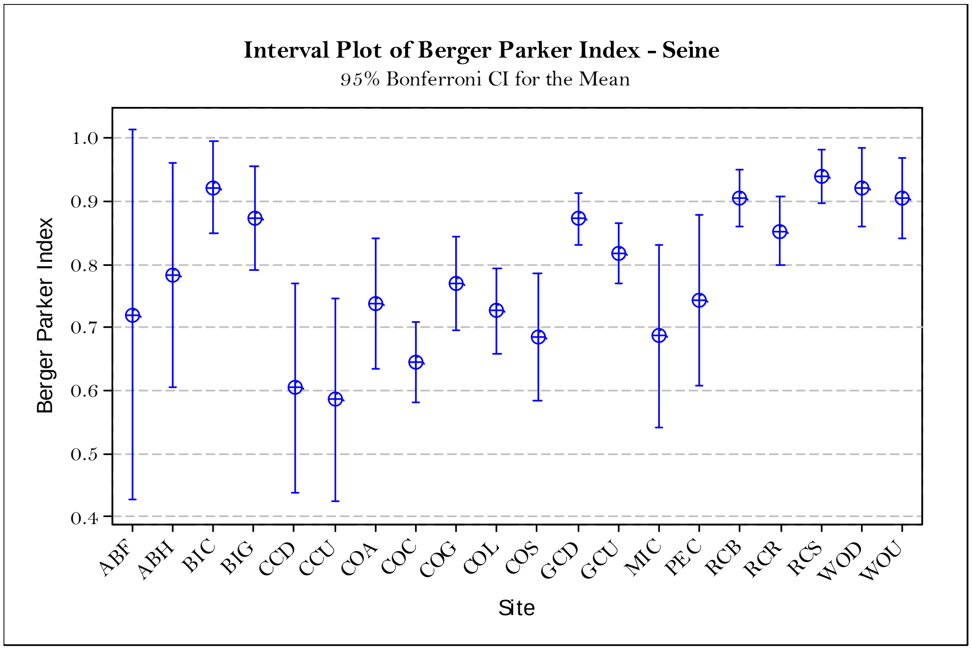

Figure 115. Bonferroni 95% confidence intervals for mean average Berger Parker Dominance Index calculated from seine fish collections at each site (99% individual confidence intervals) during 2007-2010.

Table 11. Significant results of Kruskal-Wallis ANOVA comparing the Berger-Parker dominance index (BPI) calculated from seine collections at each site and the post-hoc Dunn's multiple range tests.

Sites Compared		Z value	v.s.	Critical Value	P-value
BIC	CCD	4.19899	>=	3.276	0
BIC	CCU	4.48093	>=	3.276	0
BIC	COC	4.81324	>=	3.276	0
BIC	COL	3.33093	>=	3.276	0.0009
BIC	COS	3.95712	>=	3.276	0.0001
BIC	MIC	3.49649	>=	3.276	0.0005
BIG	CCD	5.70887	>=	3.276	0
BIG	CCU	6.02431	>=	3.276	0
BIG	COA	4.33329	>=	3.276	0
BIG	COC	8.54376	>=	3.276	0
BIG	COG	4.46788	>=	3.276	0
BIG	COL	5.97463	>=	3.276	0
BIG	COS	6.23243	>=	3.276	0
BIG	GCU	4.37986	>=	3.276	0
BIG	MIC	4.79202	>=	3.276	0
BIG	PEC	3.75766	>=	3.276	0.0002
CCD	GCD	4.62606	>=	3.276	0

Sites Compared		Z value	v.s.	Critical Value	P-value
CCD	RCB	5.37097	>=	3.276	0
CCD	RCR	4.24693	>=	3.276	0
CCD	RCS	6.3109	>=	3.276	0
CCD	WOD	6.20321	>=	3.276	0
CCD	WOU	5.9824	>=	3.276	0
CCU	GCD	4.97007	>=	3.276	0
CCU	GCU	3.51195	>=	3.276	0.0004
CCU	RCB	5.69903	>=	3.276	0
CCU	RCR	4.59875	>=	3.276	0
CCU	RCS	6.61656	>=	3.276	0
CCU	WOD	6.50613	>=	3.276	0
CCU	WOU	6.29181	>=	3.276	0
COA	RCB	3.95516	>=	3.276	0.0001
COA	RCS	4.91672	>=	3.276	0
COA	WOD	4.8485	>=	3.276	0
COA	WOU	4.61107	>=	3.276	0
COC	COG	3.81901	>=	3.276	0.0001
COC	GCD	7.124	>=	3.276	0
COC	GCU	4.57201	>=	3.276	0
COC	RCB	8.39612	>=	3.276	0
COC	RCR	6.45914	>=	3.276	0
COC	RCS	9.7423	>=	3.276	0
COC	WOD	9.13663	>=	3.276	0
COC	WOU	8.9474	>=	3.276	0
COG	RCB	3.98782	>=	3.276	0.0001
COG	RCS	5.43289	>=	3.276	0
COG	WOD	5.18596	>=	3.276	0
COG	WOU	4.8799	>=	3.276	0
COL	GCD	4.34846	>=	3.276	0
COL	RCB	5.60831	>=	3.276	0
COL	RCR	3.70107	>=	3.276	0.0002
COL	RCS	7.05843	>=	3.276	0
COL	WOD	6.66249	>=	3.276	0
COL	WOU	6.3945	>=	3.276	0
COS	GCD	4.86708	>=	3.276	0
COS	RCB	5.87894	>=	3.276	0
COS	RCR	4.34848	>=	3.276	0
COS	RCS	7.08944	>=	3.276	0
COS	WOD	6.83191	>=	3.276	0
COS	WOU	6.58484	>=	3.276	0
GCD	MIC	3.68158	>=	3.276	0.0002

Sites Compared		Z value	v.s.	Critical Value	P-value
GCU	RCB	3.87977	>=	3.276	0.0001
GCU	RCS	5.42513	>=	3.276	0
GCU	WOD	5.13669	>=	3.276	0
GCU	WOU	4.81849	>=	3.276	0
MIC	RCB	4.4273	>=	3.276	0
MIC	RCR	3.30327	>=	3.276	0.001
MIC	RCS	5.38165	>=	3.276	0
MIC	WOD	5.30027	>=	3.276	0
MIC	WOU	5.06839	>=	3.276	0
PEC	RCB	3.36269	>=	3.276	0.0008
PEC	RCS	4.3333	>=	3.276	0
PEC	WOD	4.28161	>=	3.276	0
PEC	WOU	4.03722	>=	3.276	0.0001
RCR	RCS	3.53908	>=	3.276	0.0004
RCR	WOD	3.39374	>=	3.276	0.0007

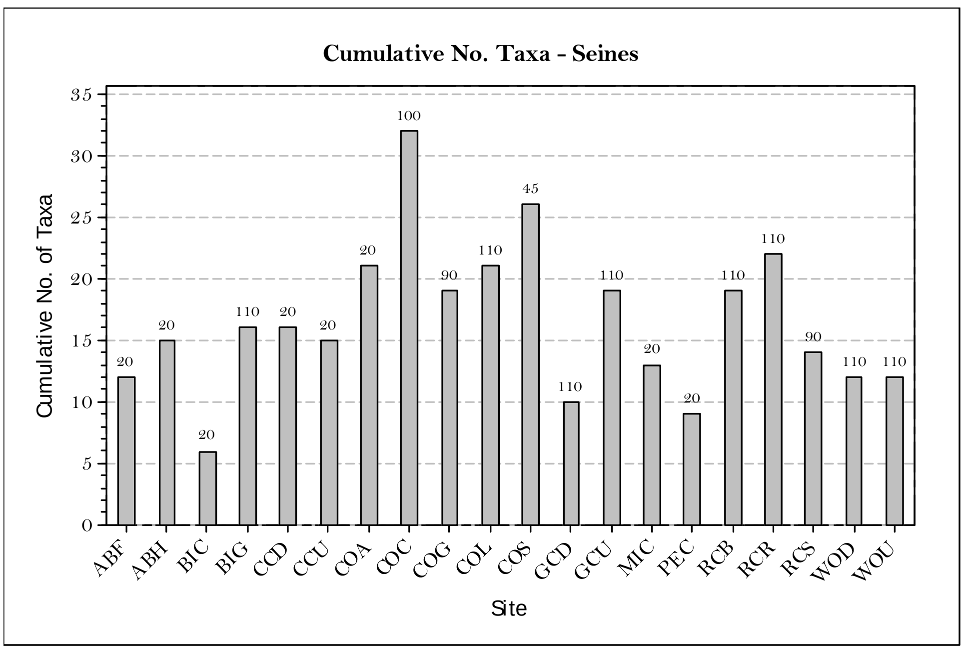

Figure 116. Cumulative number of fish taxa collected at each study site during 2007-2010 using seine nets. The number of replicate samples is posted above each bar.

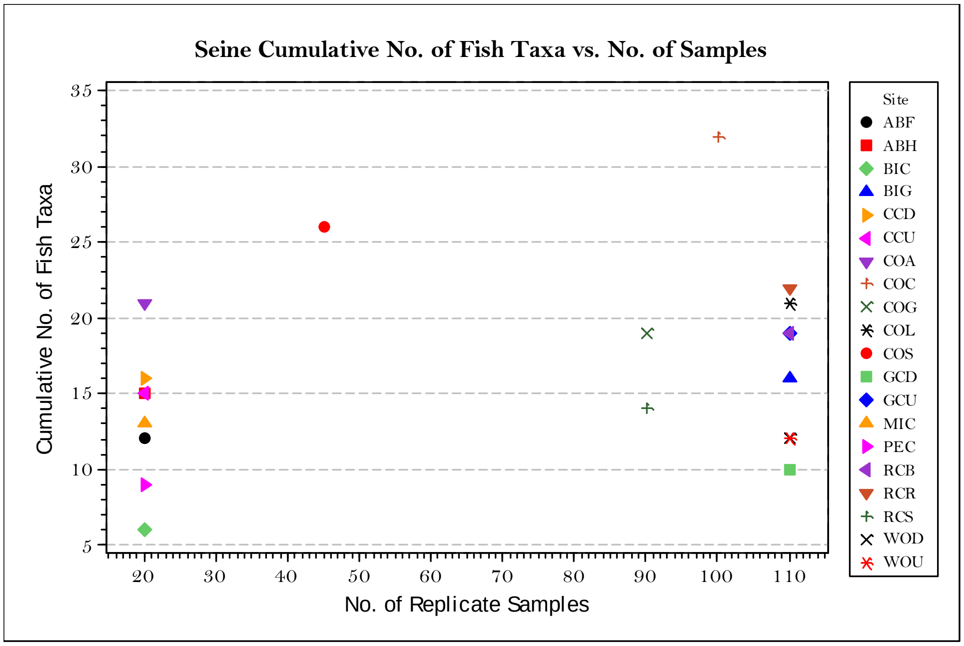

Figure 117. Cumulative number of fish taxa versus the number of replicate samples collected at each study site using seine nets during 2007-2010. The number of replicate samples is posted above each bar.

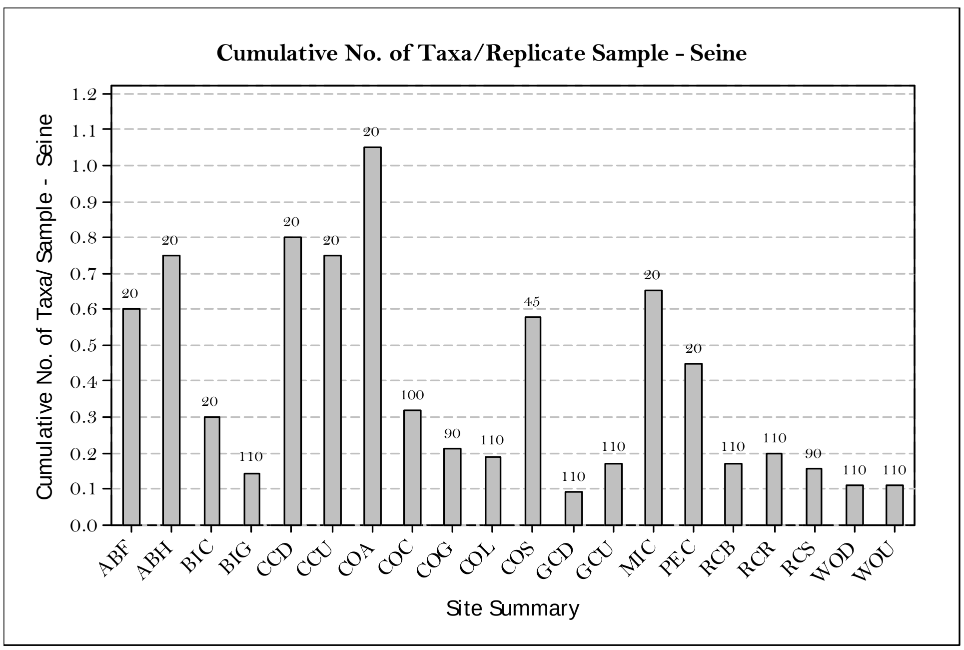

Figure 118. Cumulative number of fish taxa adjusted for the number of replicate seine samples at each study site during 2007-2010. The number of replicate samples is posted above each bar.

Cluster analysis of fish communities sampled with seines yielded twelve significant groupings of sites (Figure 19 and Table 12):

- Groups 2 and 3 consisted primarily of White Oak downstream (WOD) and White Oak downstream (WOU) collections;
- Group 4 consisted primarily of Peach Creek (PEC) and Big Gulch (BIG) collections;
- Groups 5 and 6 consisted of mainly of Cowart Creek sites;
- Group 7 was composed of Cowart Creek control (COC) and Cowart Creek Airport (COA), i.e. Cowart Creek control sites;
- Group 8 was a large heterogeneous group consisting of collections from multiple sites including:
    - Armand Bayou Fairmont Parkway (ABF);
    - Armand Bayou Holly Bay (ABH);
    - Big Gulch (BIG);
    - Cowart Creek control (COC);
    - Cowart Creek Greenbriar (COG);
    - Cowart Creek Linson (COL);
    - Cowart Creek Sunset (COS);
    - Goose Creek downstream (GCD);
    - Goose Creek upstream (GCU);
    - Rummel Creek Bird Sanctuary (RCB);
    - Rummel Creek school (RCS);
    - Rummel Creek rip rap (RCR); and
    - Mill Creek (MIC).
- Groups 9 and 10 consisted of collections from:
    - Cowart Creek control (COC);
    - Cowart Creek Greenbriar (COG);
    - Cowart Creek Linson (COL);
    - Cowart Creek Sunset (COS);
    - Rummel Creek Bird Sanctuary (RCB);
    - Rummel Creek school (RCS);
    - Rummel Creek rip rap (RCR); and
    - White Oak upstream (WOU)
- Group 11 consisted of collections from:
    - Clear Creek downstream (CCD);
    - Cowart Creek control (COC);
    - Cowart Creek Sunset (COS);
    - Big Creek (BIC);
    - White Oak upstream (WOU);
    - Clear Creek upstream (CCU); and
    - Mill Creek (MIC)
- Group 12 was dominated by sites:
    - Armand Bayou Holly Bay (ABH);
    - Big Gulch (BIG);
    - Goose Creek downstream (GCD);
    - Rummel Creek school (RCS); and
    - White Oak downstream (WOD).

The collections are also presented in the MDS plot showing the relative positions of these collections based on similarity of species composition and the similarity levels. The greatest separation was observed between the White Oak collections and other sites (Figure 120). The Peach Creek (PEC), Cowart Creek control (COC), and Big Gulch (BIG) sites also formed distinct groupings. The Armand Bayou Holly Bay (ABH) and Armand Bayou Fairmont (ABF) sites exhibited extreme variability in species composition and similarity between collections.

To facilitate interpretation of the cluster analysis results we analyzed community metrics averaged for each group (Fig 121-126). Based on examination of community metrics we can conclude that that groups 1-3 and 12 generally contained the lowest number of organisms collected, lowest number of taxa, lowest diversity (H'), high evenness (J) and highest BPI values. This suggests that these cluster groupings of collections were composed of low numbers of fish with few species dominated by 1 or 2 taxa. It should be noted that group 2 did not have a low total catch rate, but otherwise met the characteristics described above. Group 7 generally had the highest catch rates, number of taxa, H', J and lowest BPI values. This suggests that members within group 7, which consisted of collections from Cowart Creek control (COC) and Cowart Creek Airport (COA) contained a highly abundant and diverse fish community. Both groups 5 and 6 generally exhibited intermediate catch rates, number of taxa, H', J and low BPI values. These results suggest that members within group 5 and 6, which consisted of collections from Cowart Creek control (COC), Cowart Creek Greenbriar (COG), Cowart Creek Linson (COL), Cowart Creek Sunset (COS), Cowart Creek Airport (COA), and Rummel Creek rip rap (RCR) contained a moderately abundant and highly diverse fish community.

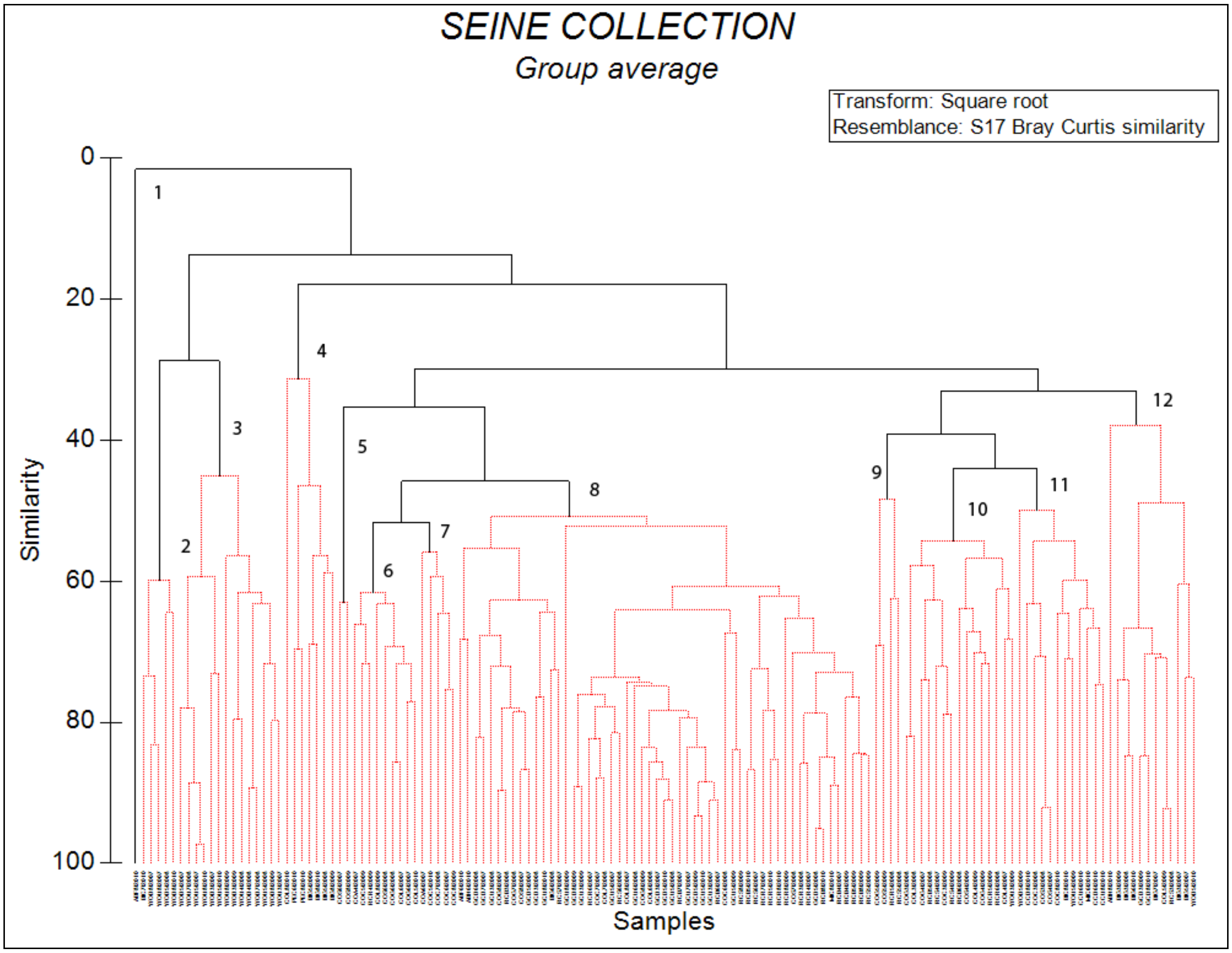

Figure 119. Dendrogram depicting results of cluster analysis of seine collections based on square root transformed common (≥ 5% frequency) taxa occurrences using Bray Curtis distance metrics and group averaging. Cluster groups of collections were determined by the SIMPROF procedure are labeled with numerals and are presented in Table 12.

Table 12. Classification of collections based on the similarity of fish communities sampled with seines using common (≥ 5% of collections) taxa. Classification based on a square root transformed abundance data classified using the Bray Curtis similarity index and the group average method. Groups defined by SIMPROF procedure.

Seine Cluster Groupings											
1	2	3	4	5	6	7	8	9	10	11	12
ABF8/2010	BIC7/2010	WOD5/2007	COL8/2010	COS6/2007	COA4/2007	COA6/2007	ABF6/2010	COG5/2009	RCS5/2008	WOD5/2009	ABH8/2010
	WOD8/2007	WOU7/2008	PEC6/2010	COS8/2009	COC5/2009	COC5/2010	ABH6/2010	COS5/2009	COG3/2008	CCD8/2010	BIG3/2009
	WOU8/2007	WOU5/2007	PEC8/2010		RCR4/2009	COC7/2008	GCD6/2008	RCR5/2008	COL3/2008	COC3/2008	BIG3/2008
	WOD5/2008	WOU8/2010	BIG5/2009		COL8/2009	COC6/2007	GCD7/2007		COG4/2007	COS3/2008	BIG6/2010
	WOD8/2010	WOD3/2007	BIG8/2010		COS6/2008	COC8/2009	GCU3/2008		RCB5/2008	COS4/2007	GCD3/2009
		WOU5/2010	BIG5/2008		COG6/2008		COG8/2007		RCS4/2007	COC8/2010	GCD8/2010
		WOU8/2009	BIG8/2009		COL6/2007		RCB3/2008		COC3/2009	BIC8/2010	BIG7/2007
		WOD3/2009			COG6/2007		COG7/2008		RCS4/2009	WOU5/2009	COL5/2009
		WOU4/2008			COL5/2010		COS8/2007		RCB6/2008	CCU6/2010	RCS3/2008
		WOD4/2008					GCD5/2007		COS4/2009	MIC6/2010	BIG3/2007
		WOD7/2008					GCD3/2008		COL4/2009	CCD6/2010	BIG5/2007
		WOU5/2008					GCU8/2010		COG4/2009	CCU8/2010	WOD5/2010
		WOD8/2009					BIG6/2008		RCR5/2009		
		WOU3/2007					RCS7/2007		RCR6/2008		
							GCU8/2009		COL4/2007		
							GCD8/2009		WOU3/2009		
							GCU3/2009				
							RCR6/2007				
							COC7/2007				
							COL7/2008				
							GCU5/2007				
							RCS6/2008				
							COL8/2007				
							GCU6/2008				
							COG8/2009				
							COL6/2008				
							GCD3/2007				
							GCD5/2010				
							GCU5/2008				
							RCB7/2007				
							GCU7/2007				
							GCD5/2009				
							GCU5/2010				
							GCU3/2007				
							RCB6/2007				
							COC6/2008				
							GCU5/2009				
							RCS8/2009				
							RCB5/2010				
							RCS6/2007				
							RCR7/2007				
							RCR5/2010				
							RCR8/2010				
							RCR8/2009				
							COS7/2008				
							RCR3/2008				
							RCR4/2007				
							GCD5/2008				
							RCB8/2010				
							MIC8/2010				
							RCB4/2007				
							RCB4/2009				
							RCB5/2009				
							RCB8/2009				
							RCS5/2009				

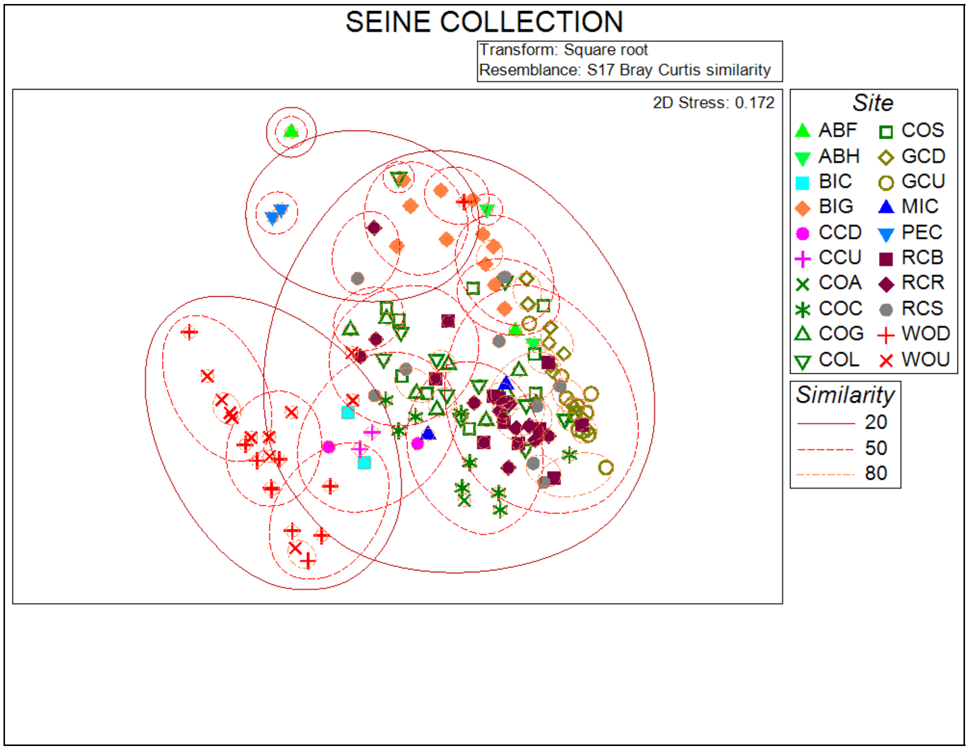

Figure 120. NMDS plot of seine collection cluster groupings based on Bray Curtis similarity levels of square root transformed abundance data.

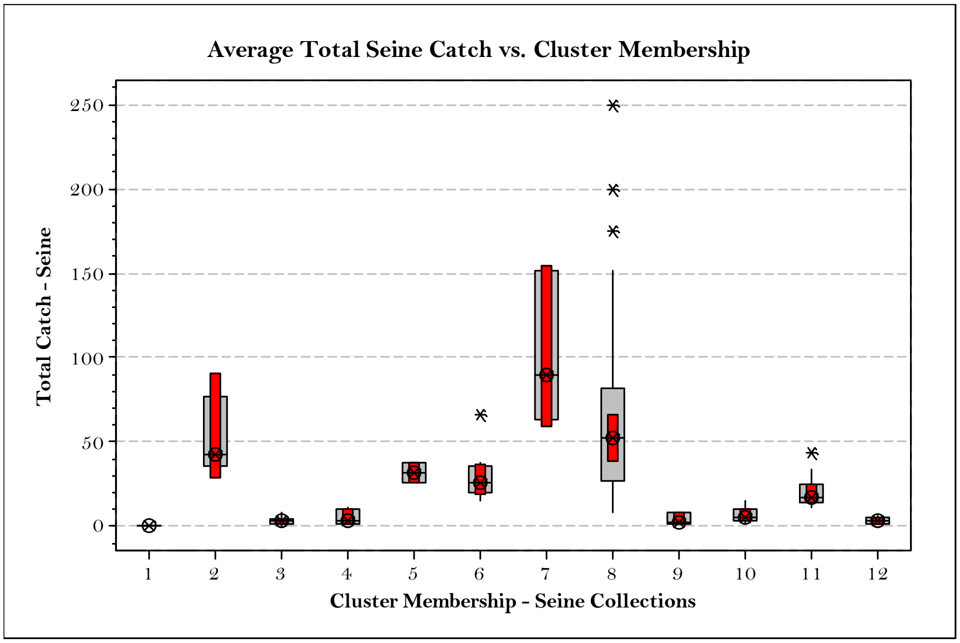

Figure 121. Boxplot depicting the distribution of the average total seine catch calculated from seine fish collections within each cluster defined in Table 12. Median symbol = î . Red bar depicts the 95% confidence interval for the median.

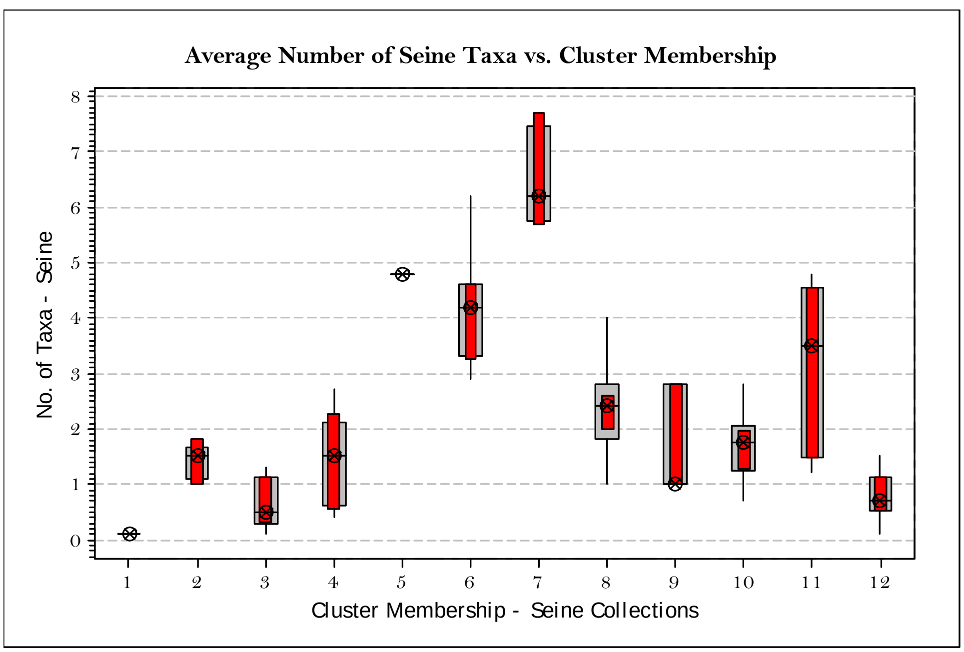

Figure 122. Boxplot depicting the distribution of the average number of taxa collected per seine haul within each cluster defined in **Error! Reference source not found.**. Median symbol = î . Red bar depicts the 95% confidence interval for the median.

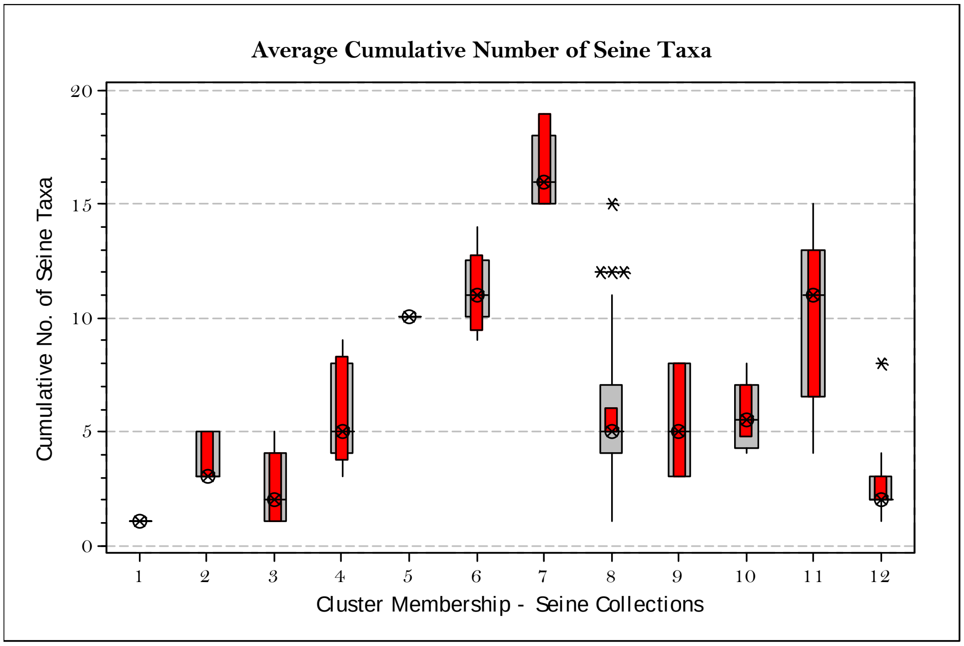

Figure 123. Boxplot depicting the distribution of the average cumulative number of taxa collected per collection within each cluster defined in **Error! Reference source not found.**. Median symbol = ῖ . Red bar depicts the 95% confidence interval for the median.

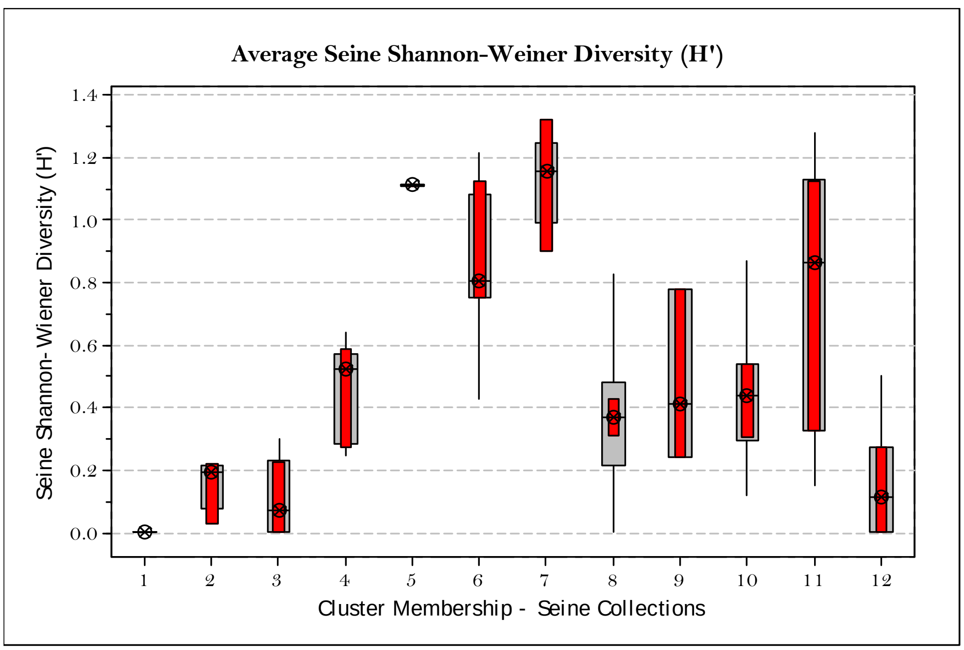

Figure 124. Boxplot depicting the distribution of the average fish community Shannon-Wiener Diversity (H') per seine haul within each cluster defined in **Error! Reference source not found.**. Median symbol = ῖ . Red bar depicts the 95% confidence interval for the median.

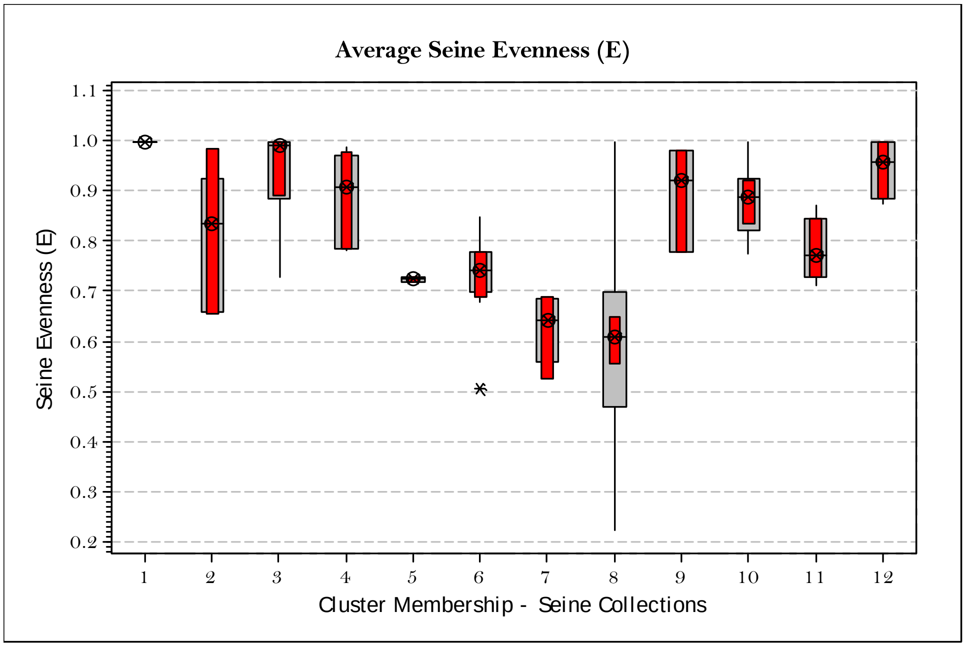

Figure 125. Boxplot depicting the distribution of the average fish community Shannon-Wiener Diversity (H') per seine haul within each cluster defined in Table 12. Median symbol = î . Red bar depicts the 95% confidence interval for the median.

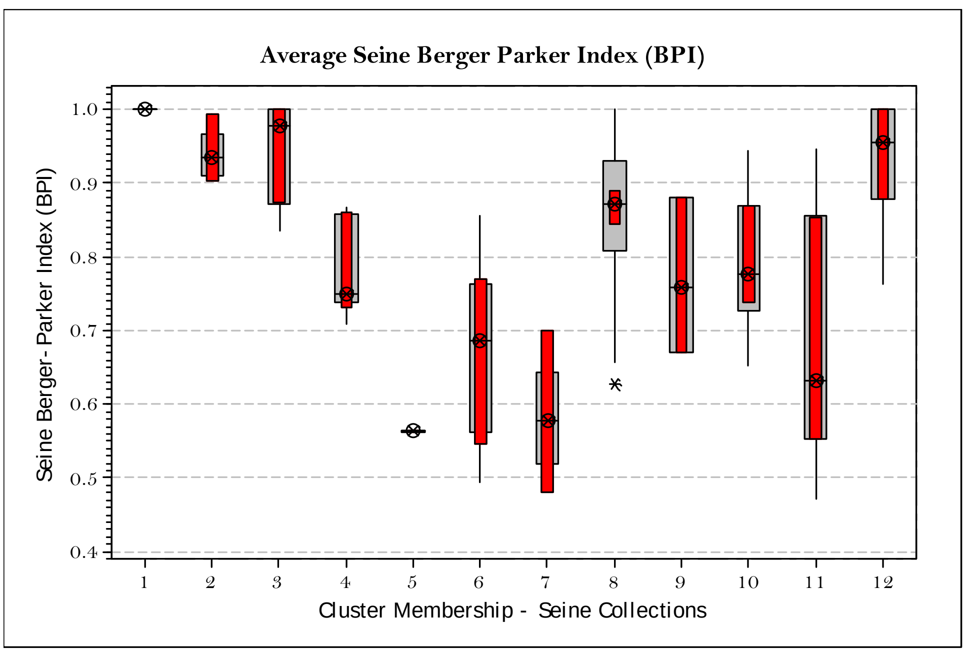

Figure 126. Boxplot depicting the distribution of the average fish community Berger-Parker Dominance (BPI) per seine haul within each cluster defined in Table 12. Median symbol = î . Red bar depicts the 95% confidence interval for the median.

Electrofishing Collection Results

A total of 7,541 fish representing 42 taxa were collected with electrofishing. Total abundance of fish/collection varied between 0 and 256 fish (Figure 127). Based on examination of 95% confidence interval plots for the median and mean, and the Kruskal-Wallis ANOVA and Dunn's multiple comparison test there were multiple significant differences in total unadjusted catch rates between sites (Figure 127-128 and Table 13). The Armand Bayou Fairmont (ABF), Big Creek (BIC), Big Gulch (BIG), Peach Creek (PEC), White Oak downstream (WOD) and White Oak upstream (WOU) sites exhibited lower total catch rates in comparison to the majority of other sites. When catch per unit effort (CPUE - #/min) was examined the magnitude in differences between sites were considerably less or non-existent (Figure 129-130, Table 14). The Armand Bayou Fairmont (ABF), Big Creek (BIC), Big Gulch (BIG), Peach Creek (PEC), White Oak downstream (WOD) and White Oak upstream (WOU) sites exhibited lower CPUE rates when compared to the majority of other sites. The CPUE observed at COL was statistically larger when compared to many of the other sites monitored during the study.

Based on results of Kruskal-Wallis and Dunn's multiple range tests and examination of confidence interval for the median and mean charts, the Armand Bayou Fairmont (ABF), Big Creek (BIC), Big Gulch (BIG), White Oak downstream (WOD) and White Oak upstream (WOU) sites exhibited lower CPUE than the many of other sites (Figure 131-132 and Table 15). The Cowart Creek Linson (COL) and Cowart Creek control (COC) sites exhibited higher median number of taxa when compared to most sites. Based on examination of Kruskal-Wallis and Dunn's multiple range tests and confidence interval for the median and mean charts, the Armand Bayou Fairmont (ABF), Rummel Creek school (RCS), White Oak downstream (WOD) and White Oak upstream (WOU) sites generally exhibited the lowest Shannon Wiener Diversity (H') (Figure 133-134 and Table 16). Highest H' was generally observed at the Cowart Creek Linson (COL) and Cowart Creek control (COC) sites. As noted earlier H', J and BPI can only be calculated when catch rates exceeded zero. Otherwise the collection is omitted from the analysis.

Based on the results of the Kruskal-Wallis and Dunn's multiple range tests and examination of confidence interval for the median and mean charts, the highest evenness (J) index values were generally observed at the Armand Bayou Fairmont (ABF), Big Creek (BIC), Big Gulch (BIG), Mill Creek (MIC), Peach Creek (PEC), White Oak downstream (WOD) and White Oak upstream (WOU) sites (Figure 136-137 and Table 17). Lower J values were documented at the Cowart Creek Linson (COL), Goose Creek downstream (GCD) and Goose Creek upstream (GCU) sites. The highest BPI values observed, based on the results of the Kruskal-Wallis and Dunn's multiple range tests and examination of confidence interval for the median and mean charts, occurred at the ABF site (Figure 138-139 and Table 18). Lower BPI values were documented at the Big Creek (BIC), Peach Creek (PEC), and White Oak downstream (WOD) sites.

The highest cumulative number of taxa collected by electrofishing was observed at the COC and COL sites where a total of 19 taxa were documented (Figure 140). The Armand Bayou Holly Bay (ABH), Goose Creek downstream (GCD), Goose Creek upstream (GCU) Rummel Creek Bird Sanctuary (RCB), and Rummel Creek school (RCS) sites also yielded relatively high (> 12) number of taxa. The amount of effort (number of samples collected and number of minutes shocked) will influence the number of taxa observed. To evaluate this effect we also plotted the cumulative number of taxa versus the number of samples collected. It appears that when more than 30 samples were collected, the number of cumulative fish taxa seldom fell below 10 in contrast to sites with less effort which yielded generally less taxa (Figure 140). To adjust for this effect we calculated the cumulative number of taxa per sample and found that Armand Bayou Holly Bay (ABH), Cowart Creek control (COC), Cowart Creek Linson (COL), Mill Creek (MIC) and Peach Creek (PEC) sites yielded higher values in comparison to other sites (Figure 141). The Big Gulch (BIG), Goose Creek, and White Oak Bayou sites generally yielded low cumulative number of taxa/replicate sample. Similarly the lowest cumulative number of taxa per minute shocked occurred at the Big Gulch (BIG), White Oak downstream (WOD), and White Oak upstream (WOU) sites, whereas the highest values occurred at the Armand Bayou Holly Bay (ABH) and Cowart Creeks (Figure 142).

The electrofishing results appeared to correlate well with data obtained from seines. In particular sites with low and high diversity as identified by seine collections were also similarly identified based on electrofishing data. White Oak Bayou sites generally score poorly in regards to the various diversity measurements. The Cowart Creek sites similarly score high in regards to diversity and abundance measures using both collection methods. It should be noted that sample size for electrofishing at the Cowart Creek sites which was conducted in 2010 (2 events), was much less than samples collected by seining ($n \leq 12$) over a period of 4 years. As documented earlier in the report, the primary reason for the low electrofishing effort at Cowart Creek was the high standard conductance measured at these sites that prevents the use of electrofishing.

As previously discussed the primary characteristics differentiating the White Oak Bayou sites, and in particular the White Oak downstream (WOD) site from the other streams was the lack of SAV, low instream habitat complexity, large watershed area, large stream width, percent concrete channel substrate, higher amount of instream run habitat, higher stream velocity and the highest number of upstream permitted wastewater facilities (Figure 74, 75, Figure 105). As more fully discussed in the seine collection results section, we propose that the primary reason for the low catch rates at the White Oak Bayou sites was the lack of instream habitat and high number of upstream wastewater facilities that contributes a major amount of the stream base flow via effluent discharges.

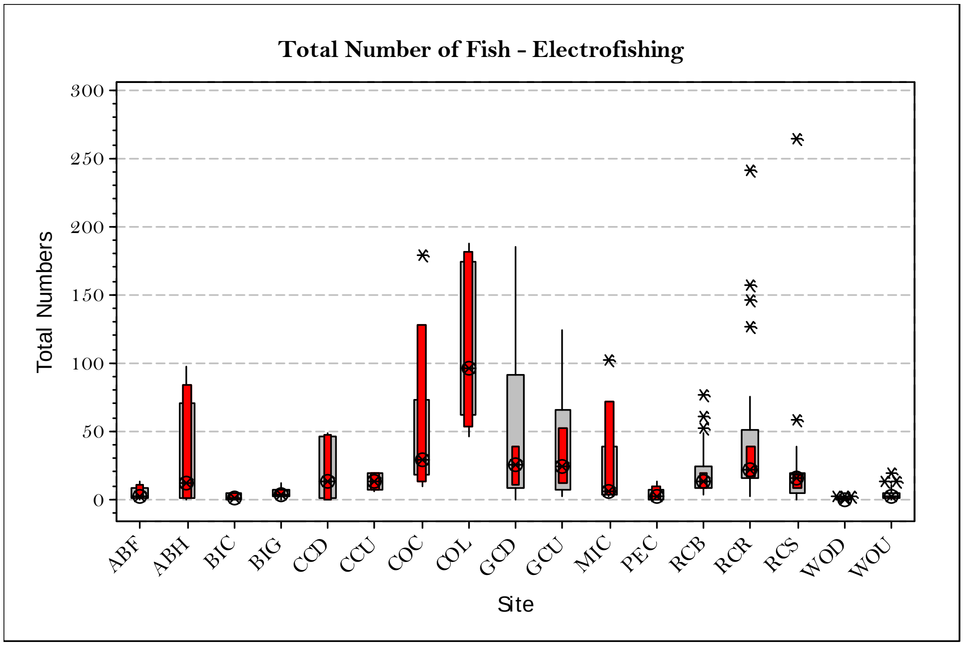

Figure 127. Boxplot depicting the distribution of the total number of fish collected with electrofishing gear during sampling events at each site during the study period 2007-2010. Median symbol = ῑ . Red bar depicts the 95% confidence interval for the median.

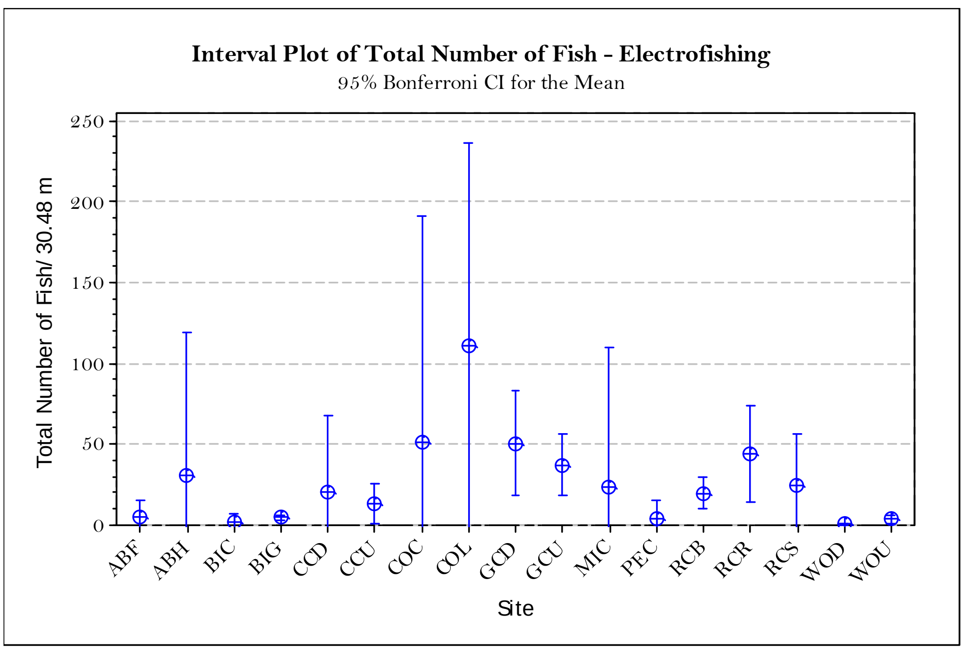

Figure 128. Bonferroni 95% confidence intervals for mean number of fish per 30.48 meter distance collected by electrofishing at each site (99% individual confidence intervals) during 2007-2010.

Table 13. Significant results of Kruskal-Wallis ANOVA comparing total number of fish/electroshocking replicate collected at each site and the post-hoc Dunn's multiple range tests.

Sites Compared		Z value	v.s.	Critical Value	P-value
ABF	COL	3.71445	>=	3.18	0.0002
ABF	RCR	3.21335	>=	3.18	0.0013
BIC	COC	3.41988	>=	3.18	0.0006
BIC	COL	4.40878	>=	3.18	0
BIC	GCD	3.77742	>=	3.18	0.0002
BIC	GCU	3.70392	>=	3.18	0.0002
BIC	RCB	3.23421	>=	3.18	0.0012
BIC	RCR	4.1166	>=	3.18	0
BIG	COC	3.34023	>=	3.18	0.0008
BIG	COL	4.61689	>=	3.18	0
BIG	GCD	4.74027	>=	3.18	0
BIG	GCU	4.61096	>=	3.18	0
BIG	RCB	3.78458	>=	3.18	0.0002
BIG	RCR	5.33699	>=	3.18	0
CCU	WOD	3.62334	>=	3.18	0.0003
COC	WOD	5.03822	>=	3.18	0
COC	WOU	3.94376	>=	3.18	0.0001
COL	PEC	4.05433	>=	3.18	0.0001
COL	WOD	6.32467	>=	3.18	0
COL	WOU	5.23021	>=	3.18	0
GCD	PEC	3.31632	>=	3.18	0.0009
GCD	WOD	7.8723	>=	3.18	0
GCD	WOU	5.89922	>=	3.18	0
GCU	PEC	3.24282	>=	3.18	0.0012
GCU	WOD	7.7398	>=	3.18	0
GCU	WOU	5.76672	>=	3.18	0
PEC	RCR	3.6555	>=	3.18	0.0003
RCB	WOD	6.89301	>=	3.18	0
RCB	WOU	4.91993	>=	3.18	0
RCR	WOD	8.48376	>=	3.18	0
RCR	WOU	6.51068	>=	3.18	0
RCS	WOD	6.01042	>=	3.18	0
RCS	WOU	4.13859	>=	3.18	0

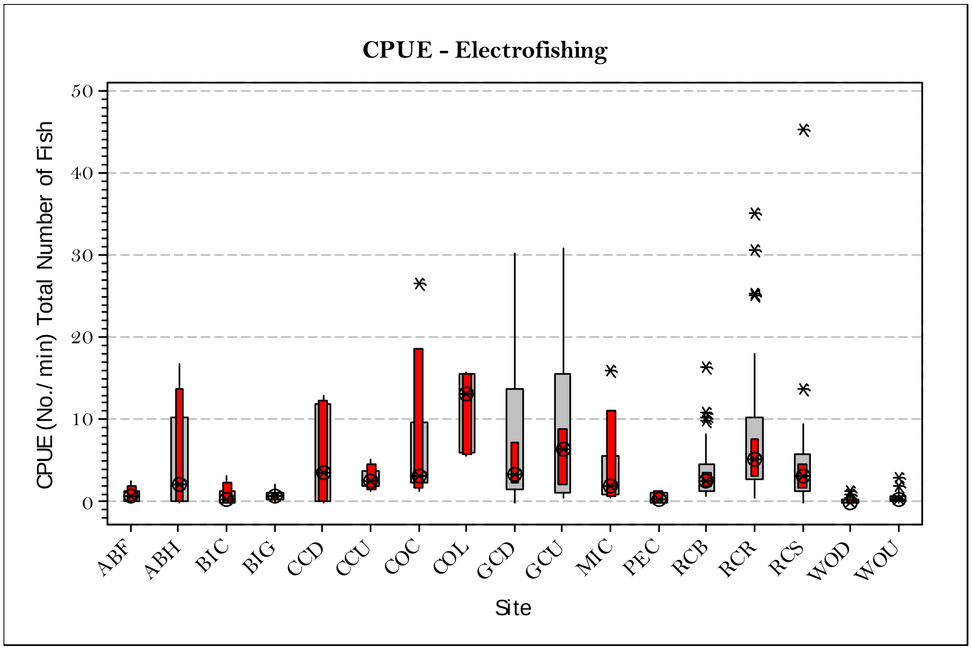

Figure 129. Boxplot depicting the distribution of the CPUE (min) of total number of fish collected with electrofishing gear during sampling events at each site during the study period 2007-2010. Median symbol = ⨂ . Red bar depicts the 95% confidence interval for the median.

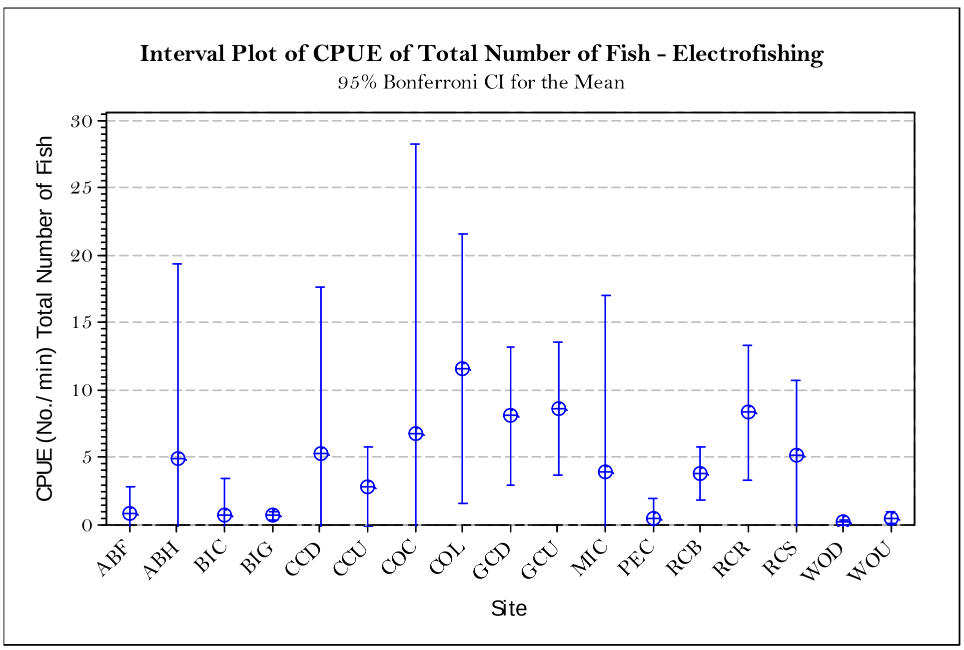

Figure 130. Bonferroni 95% confidence intervals for mean number of fish per minute collected by electrofishing at each site (99% individual confidence intervals) during 2007-2010.

Table 14. Significant results of Kruskal-Wallis ANOVA comparing CPUE (fish/min) of replicate electroshocking samples collected at each site and the post-hoc Dunn's multiple range tests.

Sites Compared		Z value	v.s.	Critical Value	P-value
ABF	COL	3.30495	>=	3.18	0.0009
ABF	RCR	3.2548	>=	3.18	0.0011
BIC	COL	3.74658	>=	3.18	0.0002
BIC	GCD	3.36442	>=	3.18	0.0008
BIC	GCU	3.5079	>=	3.18	0.0005
BIC	RCR	3.82931	>=	3.18	0.0001
BIG	COL	4.37902	>=	3.18	0
BIG	GCD	5.10755	>=	3.18	0
BIG	GCU	5.35999	>=	3.18	0
BIG	RCB	4.25802	>=	3.18	0
BIG	RCR	5.92545	>=	3.18	0
BIG	RCS	3.92811	>=	3.18	0.0001
CCD	WOD	3.237	>=	3.18	0.0012
CCU	WOD	3.6137	>=	3.18	0.0003
COC	WOD	4.16296	>=	3.18	0
COC	WOU	3.44974	>=	3.18	0.0006
COL	PEC	3.77569	>=	3.18	0.0002
COL	WOD	5.58555	>=	3.18	0
COL	WOU	4.87234	>=	3.18	0
GCD	PEC	3.4023	>=	3.18	0.0007
GCD	WOD	7.34829	>=	3.18	0
GCD	WOU	6.06253	>=	3.18	0
GCU	PEC	3.54578	>=	3.18	0.0004
GCU	WOD	7.60696	>=	3.18	0
GCU	WOU	6.3212	>=	3.18	0
PEC	RCR	3.86719	>=	3.18	0.0001
RCB	WOD	6.47778	>=	3.18	0
RCB	WOU	5.19202	>=	3.18	0
RCR	WOD	8.18638	>=	3.18	0
RCR	WOU	6.90062	>=	3.18	0
RCS	WOD	6.02161	>=	3.18	0
RCS	WOU	4.80183	>=	3.18	0

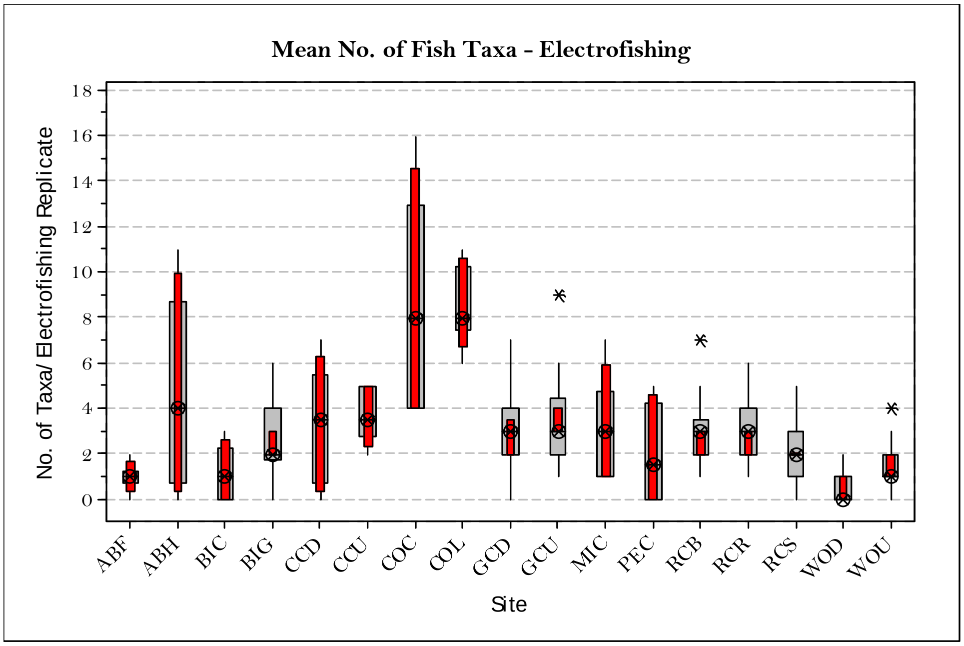

Figure 131. Boxplot depicting the distribution of the mean number of fish taxa/replicate sample collected with electrofishing gear at each site during the study period 2007-2010. Median symbol = ȋ . Red bar depicts the 95% confidence interval for the median.

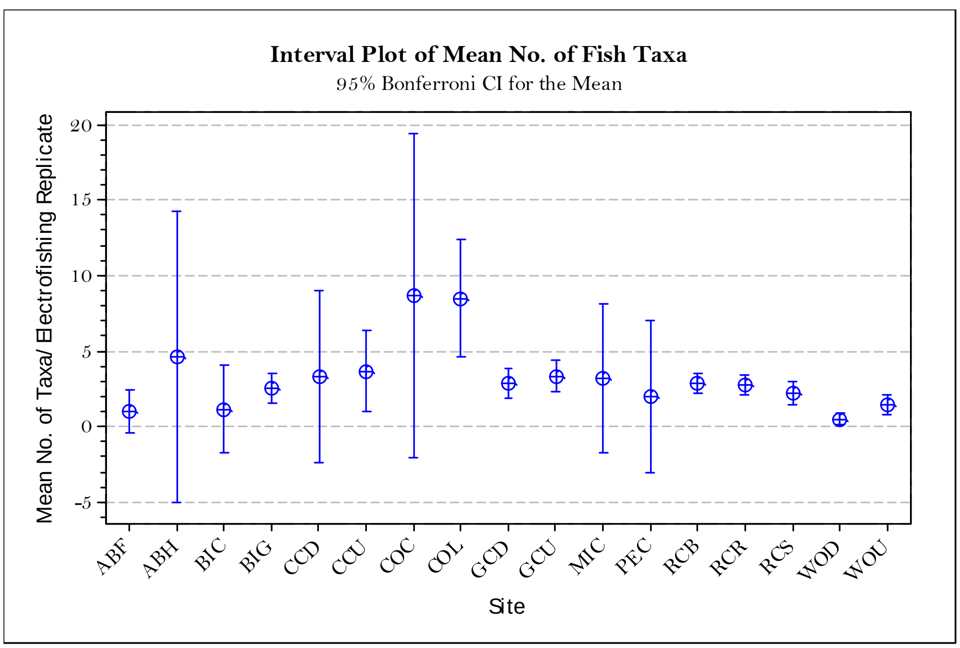

Figure 132. Bonferroni 95% confidence intervals for mean number of fish taxa/replicate electrofishing sample at each site (99% individual confidence intervals) during 2007-2010.

Table 15. Significant results of Kruskal-Wallis ANOVA comparing number of taxa collected by electrofishing at sites and the post-hoc Dunn's multiple range tests.

Sites Compared		Z value	v.s.	Critical Value	P-value
ABF	COC	4.16285	>=	3.18	0
ABF	COL	4.47121	>=	3.18	0
ABH	WOD	3.53481	>=	3.18	0.0004
BIC	COC	3.85613	>=	3.18	0.0001
BIC	COL	4.16449	>=	3.18	0
BIG	COL	3.53877	>=	3.18	0.0004
BIG	WOD	5.03941	>=	3.18	0
CCD	WOD	3.49214	>=	3.18	0.0005
CCU	WOD	4.43525	>=	3.18	0
COC	RCS	3.53004	>=	3.18	0.0004
COC	WOD	6.02914	>=	3.18	0
COC	WOU	4.66317	>=	3.18	0
COL	RCS	3.9245	>=	3.18	0.0001
COL	WOD	6.43028	>=	3.18	0
COL	WOU	5.06431	>=	3.18	0
GCD	WOD	5.86227	>=	3.18	0
GCU	WOD	6.8575	>=	3.18	0
GCU	WOU	4.39495	>=	3.18	0
RCB	WOD	6.13363	>=	3.18	0
RCB	WOU	3.67109	>=	3.18	0.0002
RCR	WOD	5.87906	>=	3.18	0
RCR	WOU	3.41651	>=	3.18	0.0006
RCS	WOD	4.17178	>=	3.18	0

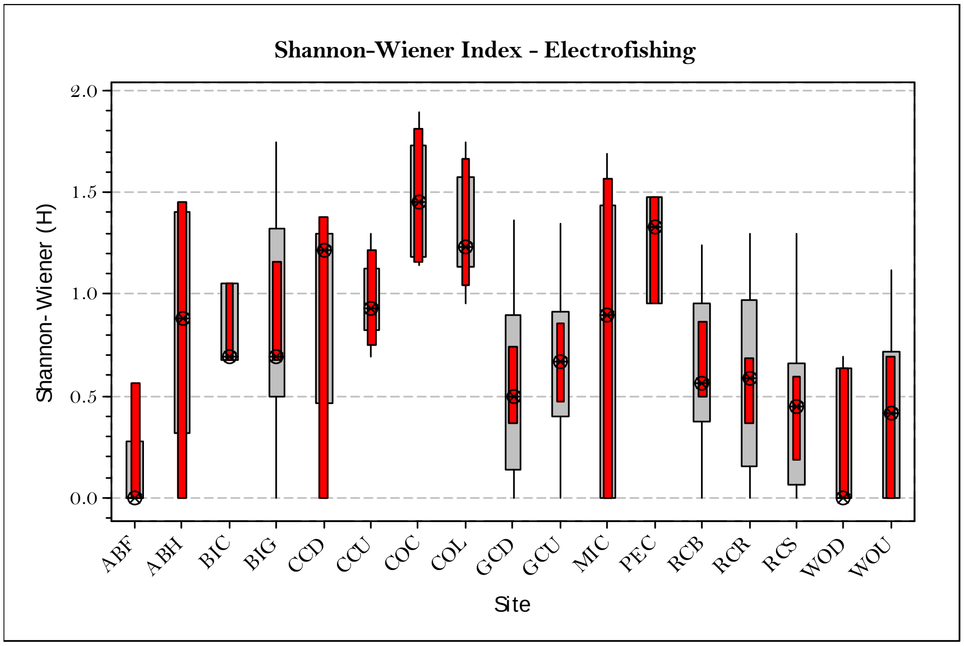

Figure 133. Boxplot depicting the distribution of the Shannon-Wiener Diversity (H') values calculated from the total number of fish collected with electrofishing gear during sampling events at each site during the study period 2007-2010. Median symbol = î . Red bar depicts the 95% confidence interval for the median.

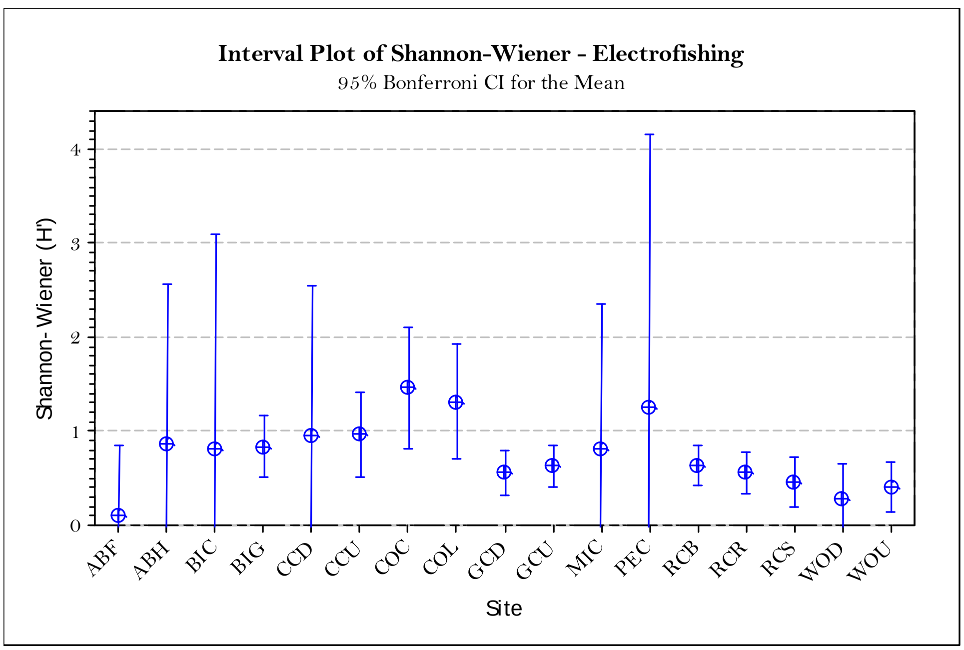

Figure 134. Bonferroni 95% confidence intervals for mean Shannon-Wiener (H') calculated from fish collected by electrofishing at each site (99% individual confidence intervals) during 2007-2010.

Table 16. Significant results of Kruskal-Wallis ANOVA comparing Shannon-Wiener (H') Diversity of fish communities calculated from electrofishing samples at sites and the post-hoc Dunn's multiple range tests.

Sites Compared		Z value	v.s.	Critical Value	P-value
ABF	BIG	3.18548	>=	3.18	0.0014
ABF	COC	4.3602	>=	3.18	0
ABF	COL	4.10144	>=	3.18	0
ABF	PEC	3.32623	>=	3.18	0.0009
BIG	WOD	3.39001	>=	3.18	0.0007
COC	GCD	3.66804	>=	3.18	0.0002
COC	GCU	3.34645	>=	3.18	0.0008
COC	RCB	3.37364	>=	3.18	0.0007
COC	RCR	3.67721	>=	3.18	0.0002
COC	RCS	4.15045	>=	3.18	0
COC	WOD	4.53096	>=	3.18	0
COC	WOU	4.30901	>=	3.18	0
COL	GCD	3.31673	>=	3.18	0.0009
COL	RCR	3.32416	>=	3.18	0.0009
COL	RCS	3.80448	>=	3.18	0.0001
COL	WOD	4.21758	>=	3.18	0
COL	WOU	3.96305	>=	3.18	0.0001
PEC	WOD	3.18264	>=	3.18	0.0015

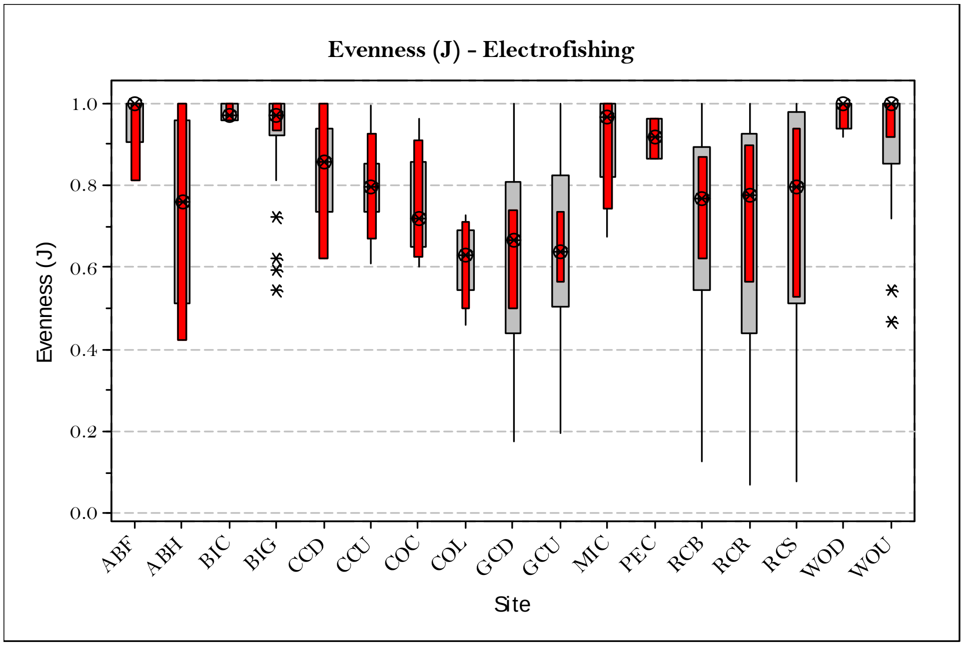

Figure 135. Boxplot depicting the distribution of the Evenness (J) values calculated from the total number of fish collected with electrofishing gear during sampling events at each site during the study period 2007-2010. Median symbol = ⨂ . Red bar depicts the 95% confidence interval for the median.

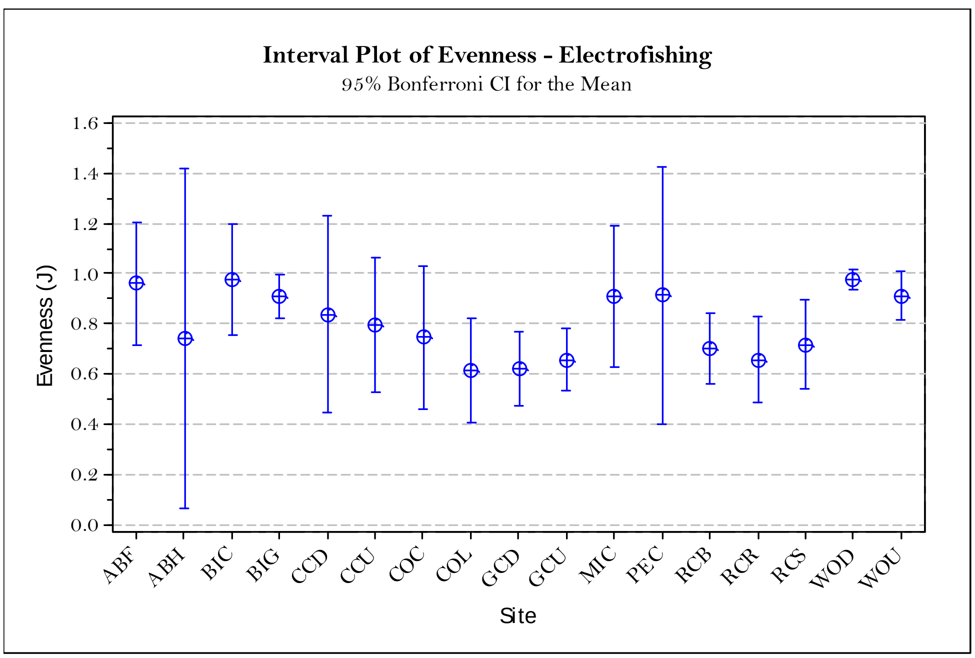

Figure 136. Bonferroni 95% confidence intervals for mean Evenness (J) calculated from fish collected by electrofishing at each site (99% individual confidence intervals) during 2007-2010.

Table 17. Significant results of Kruskal-Wallis ANOVA comparing Evenness (J) of fish communities calculated from electrofishing samples at sites and the post-hoc Dunn's multiple range tests.

Sites Compared		Z value	v.s.	Critical Value	P-value
ABF	GCD	3.23794	>=	3.18	0.0012
BIG	GCD	4.47751	>=	3.18	0
BIG	GCU	4.27729	>=	3.18	0
BIG	RCB	3.4894	>=	3.18	0.0005
BIG	RCR	3.80869	>=	3.18	0.0001
COL	WOD	3.7003	>=	3.18	0.0002
COL	WOU	3.35948	>=	3.18	0.0008
GCD	WOD	4.70357	>=	3.18	0
GCD	WOU	4.77773	>=	3.18	0
GCU	WOD	4.54005	>=	3.18	0
GCU	WOU	4.58317	>=	3.18	0
RCB	WOD	3.93353	>=	3.18	0.0001
RCB	WOU	3.80349	>=	3.18	0.0001
RCR	WOD	4.17932	>=	3.18	0
RCR	WOU	4.11945	>=	3.18	0
RCS	WOD	3.44909	>=	3.18	0.0006

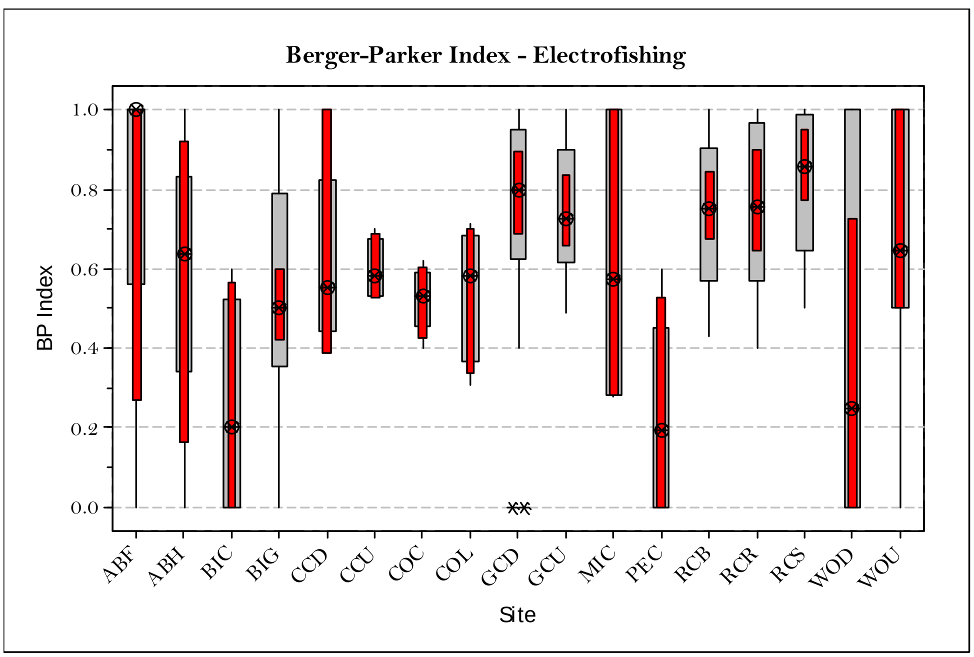

Figure 137. Boxplot depicting the distribution of the Berger-Parker dominance index (BPI) calculated from the total number of fish collected with electrofishing gear during sampling events at each site during the study period 2007-2010. Median symbol = ı̂ . Red bar depicts the 95% confidence interval for the median.

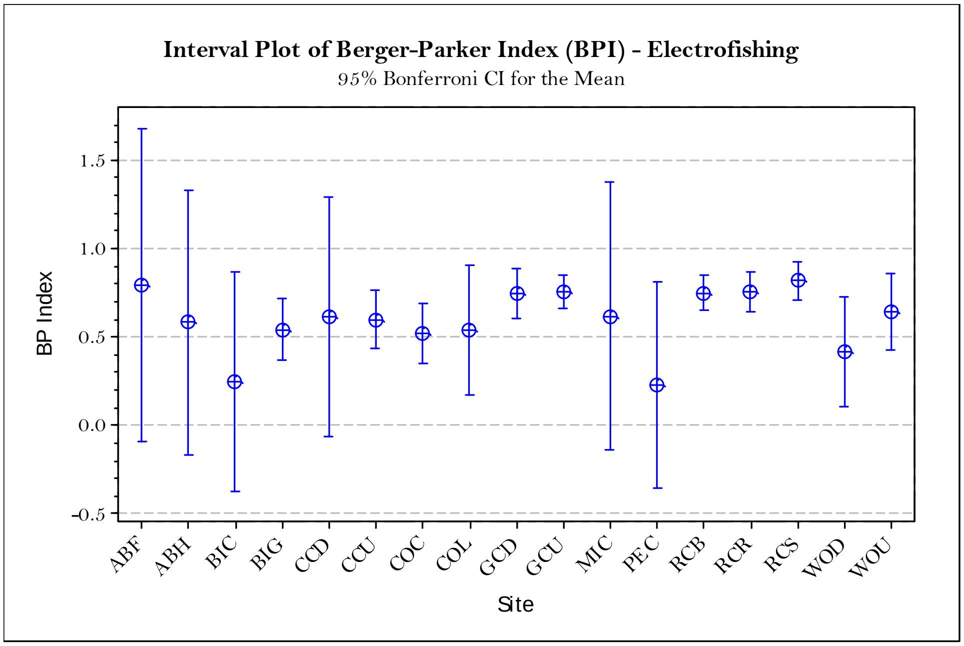

Figure 138. Bonferroni 95% confidence intervals for mean Berger-Parker Index (BPI) calculated from fish collected by electrofishing at each site (99% individual confidence intervals) during 2007-2010.

Table 18. Significant results of Kruskal-Wallis ANOVA comparing Berger-Parker Index (BPI) values of fish communities calculated from electrofishing samples at sites and the post-hoc Dunn's multiple range tests.

Sites Compared		Z value	v.s.	Critical Value	P-value
ABF	BIC	3.30751	>=	3.18	0.0009
ABF	PEC	3.41928	>=	3.18	0.0006
BIC	GCD	3.32671	>=	3.18	0.0009
BIC	GCU	3.29507	>=	3.18	0.001
BIC	RCR	3.22697	>=	3.18	0.0013
BIC	RCS	3.75892	>=	3.18	0.0002
BIG	RCS	3.68938	>=	3.18	0.0002
GCD	PEC	3.47212	>=	3.18	0.0005
GCU	PEC	3.44048	>=	3.18	0.0006
PEC	RCB	3.3159	>=	3.18	0.0009
PEC	RCR	3.37238	>=	3.18	0.0007
PEC	RCS	3.9014	>=	3.18	0.0001
RCS	WOD	3.40118	>=	3.18	0.0007

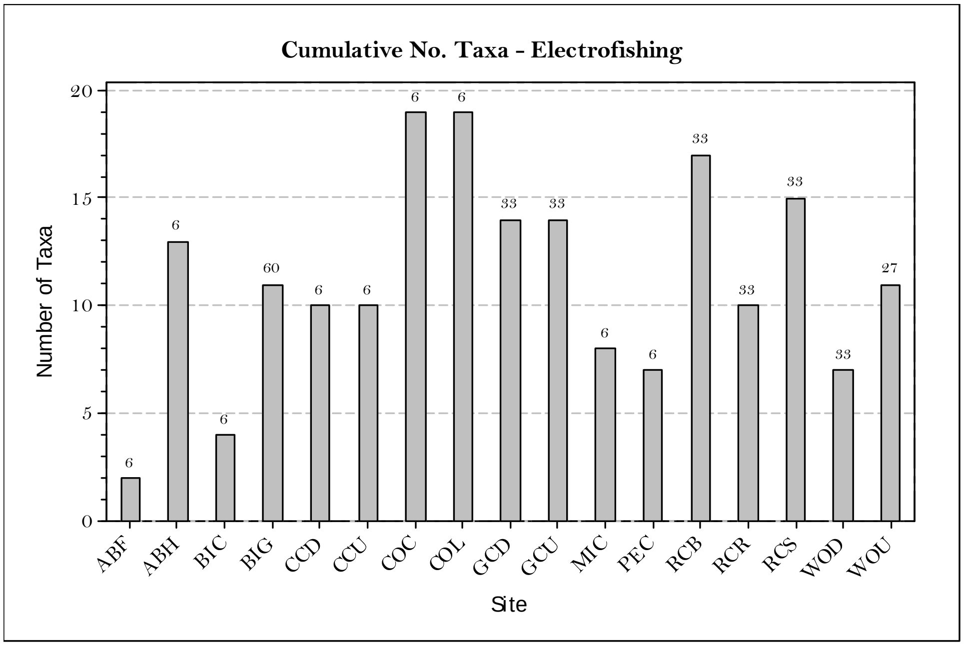

Figure 139. Cumulative number of fish taxa collected at each study site using electroshocking methodology during 2007-2010. The number of replicate samples is posted above each bar.

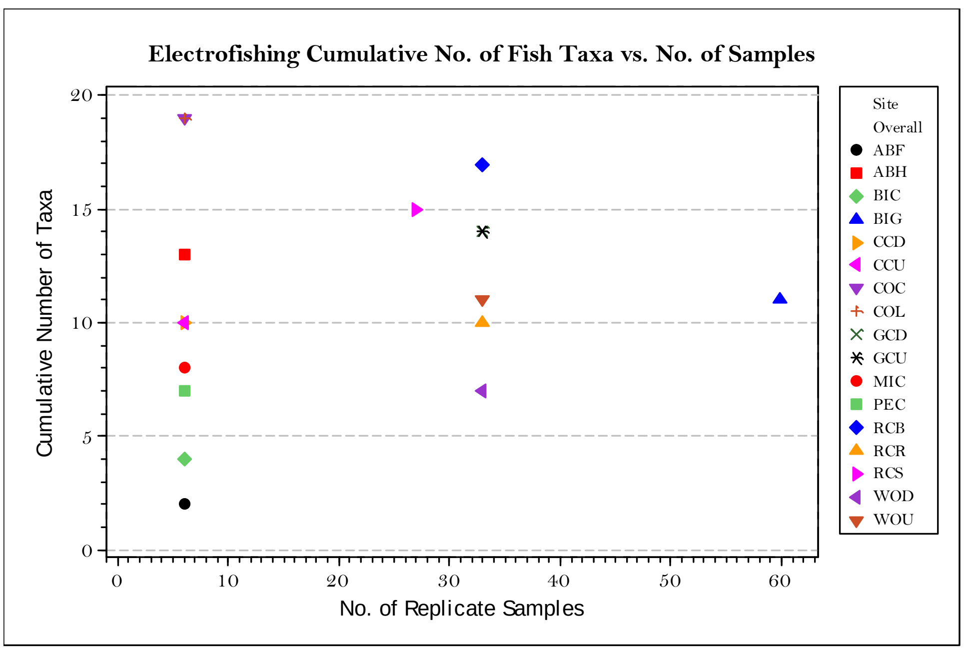

Figure 140. Cumulative number of fish taxa versus the number of replicate samples collected at each study site using electroshocking during 2007-2010. The number of replicate samples is posted above each bar.

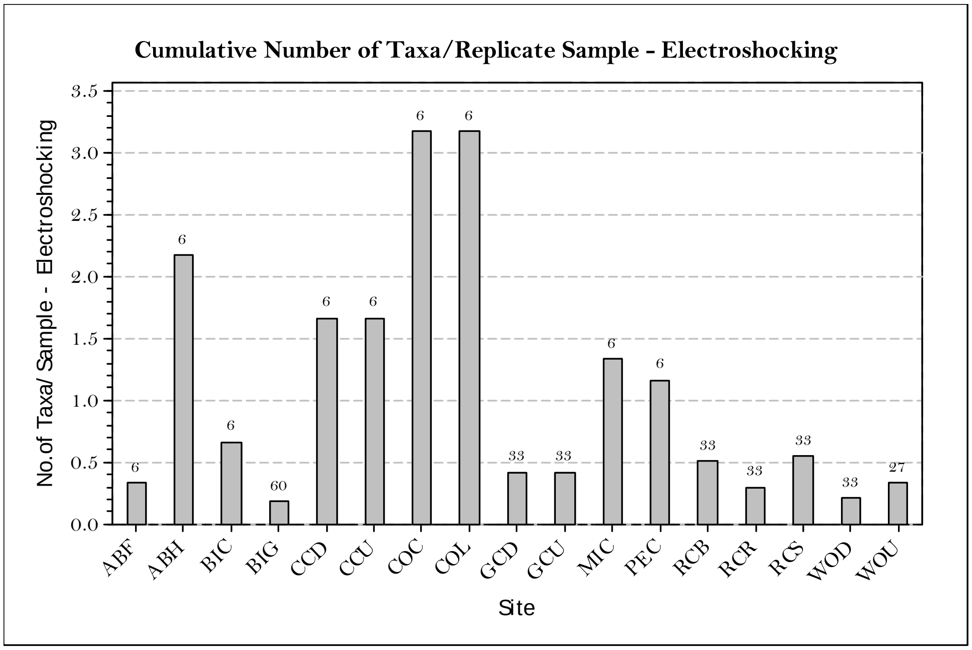

Figure 141. Cumulative number of fish taxa per number of electroshocking replicate samples at each study site during 2007-2010. The number of replicate samples is posted above each bar.

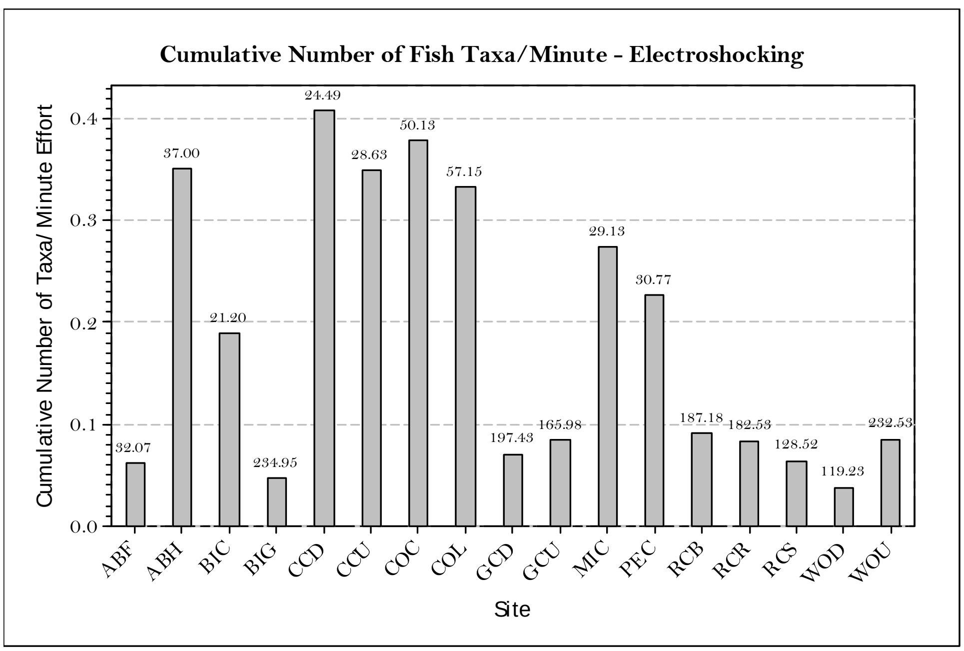

Figure 142. Cumulative number of fish taxa per minute of electroshocking effort at each study site during 2007-2010. The number of cumulative minutes of shocking time is posted above each bar.

Cluster analysis of fish communities sampled with electrofishing yielded 17 significant groupings of sites (Figure 143 and Table 18). Groups 1 through 6 consisted of singleton groups which cannot be interpreted easily but were populated by White Oak downstream (WOD), White Oak upstream (WOU) and Peach Creek (PEC) collections. Group 7 consisted of the two Armand Bayou Fairmont (ABF) collections. Groups 8-10 consisted of a variety of sites including White Oak upstream (WOU) and Cowart Creek Linson (COL) late spring and summer collections. Group 11 consisted primarily of Big Gulch (BIG) collections and only one collection from the Mill Creek (MIC) and Clear Creek downstream (CCD) sites. Group 12 was composed of the two CCU collections obtained in 2010. Group 13 was primarily composed of late spring and summer Rummel Creek rip rap (RCR) and Goose Creek downstream (GCD) collections. Goose Creek upstream (GCU) collections dominated the group 14 collections. Group 15 was a large group dominated by Goose Creek upstream (GCU), Goose Creek downstream (GCD), Rummel Creek Bird Sanctuary (RCB), Rummel Creek rip rap (RCR), Rummel Creek school (RCS), Goose Creek downstream (GCD), Goose Creek upstream (GCU) collections made primarily in the spring and early summer. Group 16 was dominated by White Oak upstream (WOU) and Rummel Creek school (RCS) sites. Group 17 was dominated by White Oak downstream (WOD) collections.

The electrofishing cluster groups are also presented in the MDS plot showing the relative positions of these collections based on similarity of species composition. The greatest separation was observed between the Armand Bayou and White Oak collections and other sites (Figure 144). The Goose Creek downstream (GCD) and Big Gulch (BIG) sites also formed distinct observable groups.

To facilitate interpretation of the cluster analysis results we analyzed community metrics averaged for each group (Figure 145-151). Based on examination of community metrics we can conclude that that group 8 generally contained the highest number of organisms collected, highest number of taxa, highest diversity (H'), moderate evenness (J) and moderate BPI values. This suggests that this cluster grouping of collections was composed of high numbers of fish and high diversity. In contrast, groups 1-7 and 17 generally had the lowest catch rates, number of taxa, H' and the highest J values. However, groups 7 and 17 had relatively high BPI values in contrast to the very low values exhibited by groups 1-6. This suggests that members within these groups, which primarily consisted of collections from White Oak downstream (WOD) and Armand Bayou Fairmont (ABF), contained a depauperate unbalanced fish community. The remaining groups generally exhibited a mixture of intermediate levels of the various metrics measured.

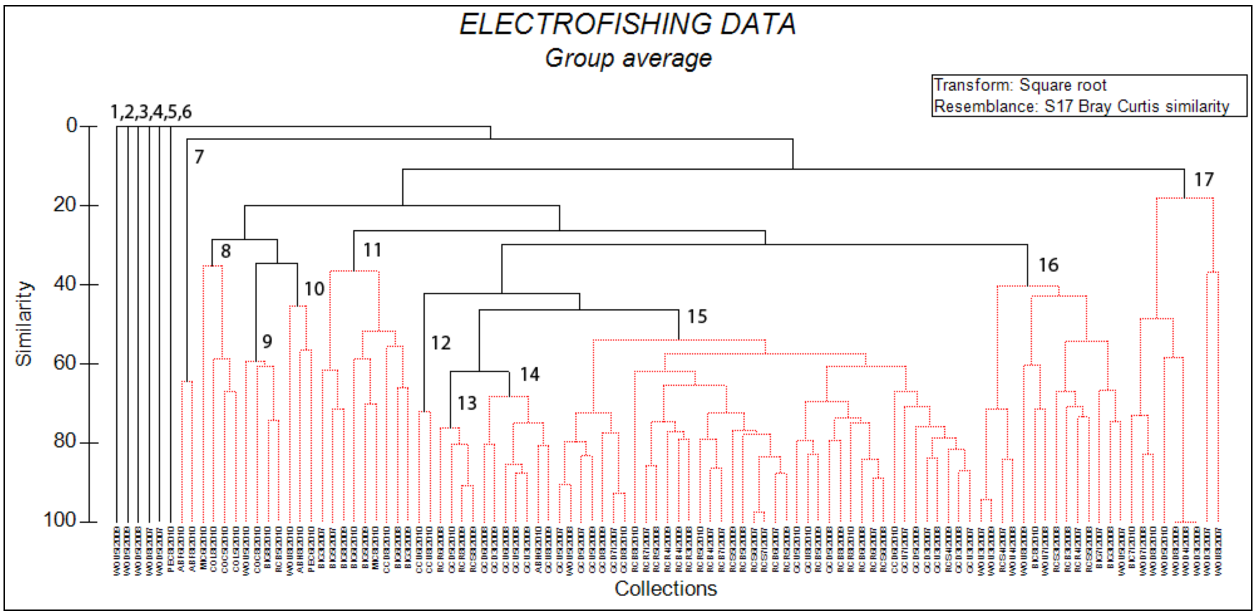

Figure 143. Dendrogram depicting results of cluster analysis of electroshocking collections based on square root transformed common (≥ 5% frequency) taxa occurrences using Bray Curtis distance metrics and group averaging. Cluster groups of collections were determined by the SIMPROF procedure are labeled with numerals and are presented in Table 19.

Table 19. Classification of collections based on the similarity of fish communities sampled by electrofishing using common (≥ 5% of collections) taxa. Classification based on square root transformed abundance data classified using the Bray Curtis similarity index and the group average method. Groups defined by SIMPROF procedure.

Electroshocking Cluster Groupings								
1	2	3	4	5	6	7	8	9
WOU5/2009	WOD5/2009	WOD5/2008	WOD8/2007	WOD5/2007	PEC8/2010	ABF6/2010	MIC6/2010	WOU5/2010
						ABF8/2010	COL8/2010	COC8/2010
							COC5/2010	BIG8/2010
							COL5/2010	RCB5/2010

10	11	12	13	14	15	15	16	17
WOU8/2010	BIG3/2007	CCU6/2010	RCR6/2008	GCD6/2008	GCU5/2007	RCS7/2007	WOU3/2007	BIC7/2010
ABH8/2010	BIG5/2007	CCU8/2010	GCD5/2010	GCD3/2009	WOU5/2008	RCB6/2007	WOU3/2009	WOD7/2008
PEC6/2010	BIG8/2009		RCR8/2009	GCU6/2008	GCD5/2007	RCR5/2009	RCS4/2007	WOD8/2010
	BIG6/2010		RCS8/2009	GCU5/2008	GCU5/2009	GCU5/2010	WOU4/2008	WOD5/2010
	BIG5/2009			GCU3/2009	GCD8/2009	GCU8/2010	WOU8/2009	WOD8/2009
	MIC8/2010			ABH6/2010	GCD7/2007	RCB5/2009	BIC8/2010	WOD4/2008
	CCD8/2010			GCU8/2009	GCD8/2010	GCD5/2008	WOU7/2008	WOD3/2009
	BIG6/2008				RCB8/2010	RCB8/2009	RCS3/2008	WOD3/2007
	BIG3/2009				RCR7/2007	RCR8/2010	RCB3/2008	WOU8/2007
					RCR5/2008	RCB6/2008	RCR4/2007	
					RCR4/2009	RCR6/2007	RCS5/2008	
					RCB4/2009	RCS6/2008	BIG7/2007	
					RCR3/2008	CCD6/2010	BIG3/2008	
					RCR5/2010	GCU7/2007	WOU5/2007	
					RCB4/2007	GCD5/2009		
					RCB7/2007	GCD3/2007		
					RCS5/2009	GCU3/2008		
					RCB5/2008	RCS4/2009		
					RCS6/2007	GCD3/2008		
						GCU3/2007		

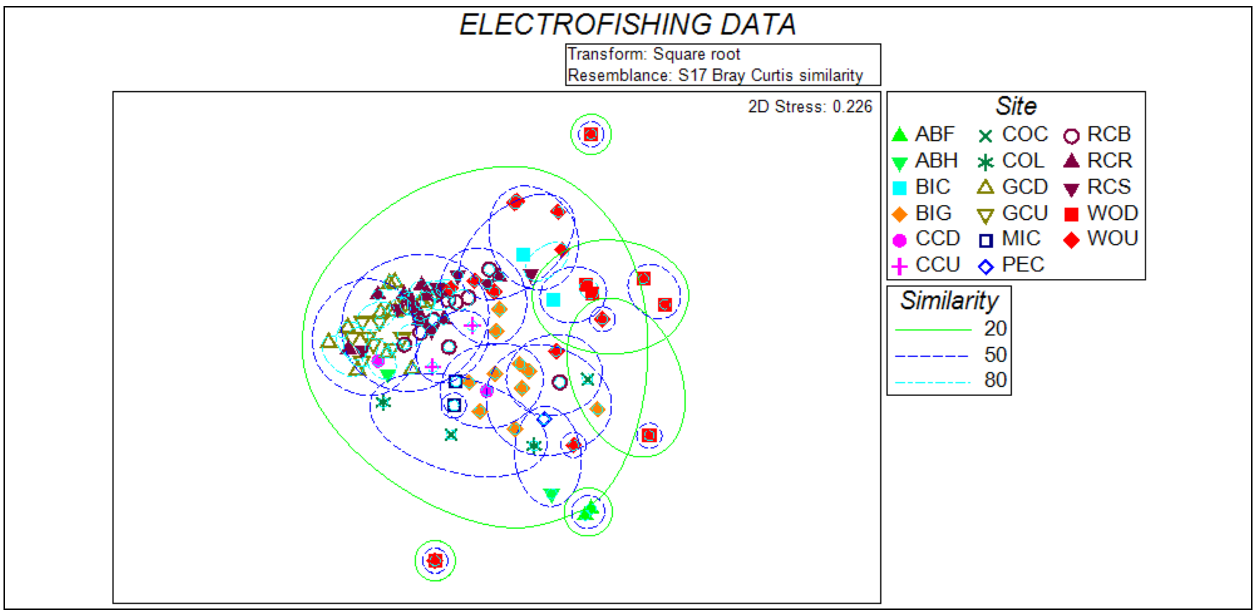

Figure 144. NMDS plot of electrofishing collection cluster groupings based on Bray Curtis similarity levels of square root transformed abundance data.

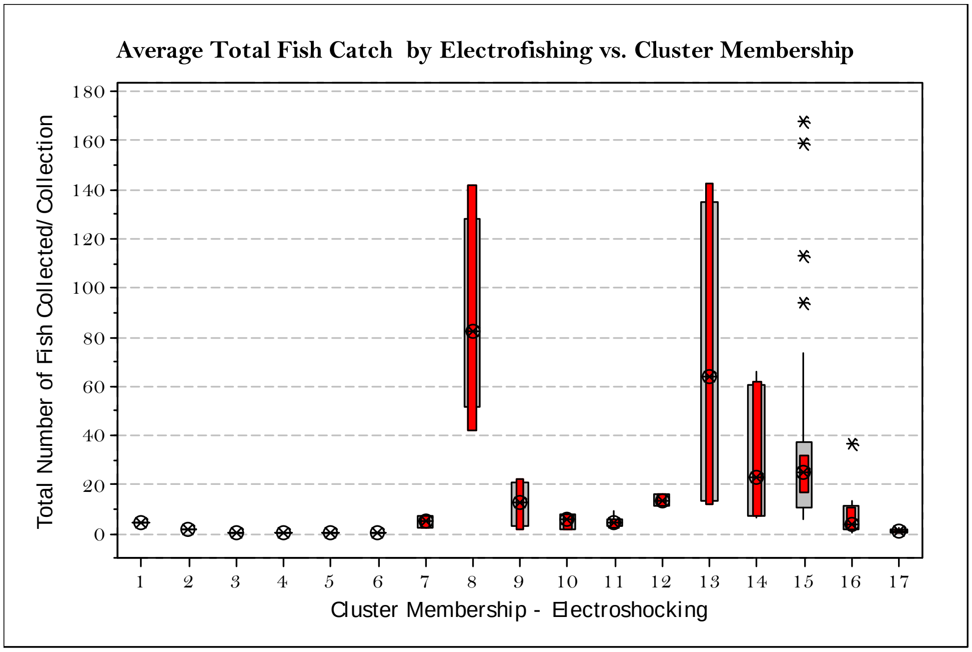

Figure 145. Boxplot depicting the distribution of the average electrofishing catch/30.8 m calculated from collections within each cluster defined in Table 19. Median symbol = ⨂ . Red bar depicts the 95% confidence interval for the median.

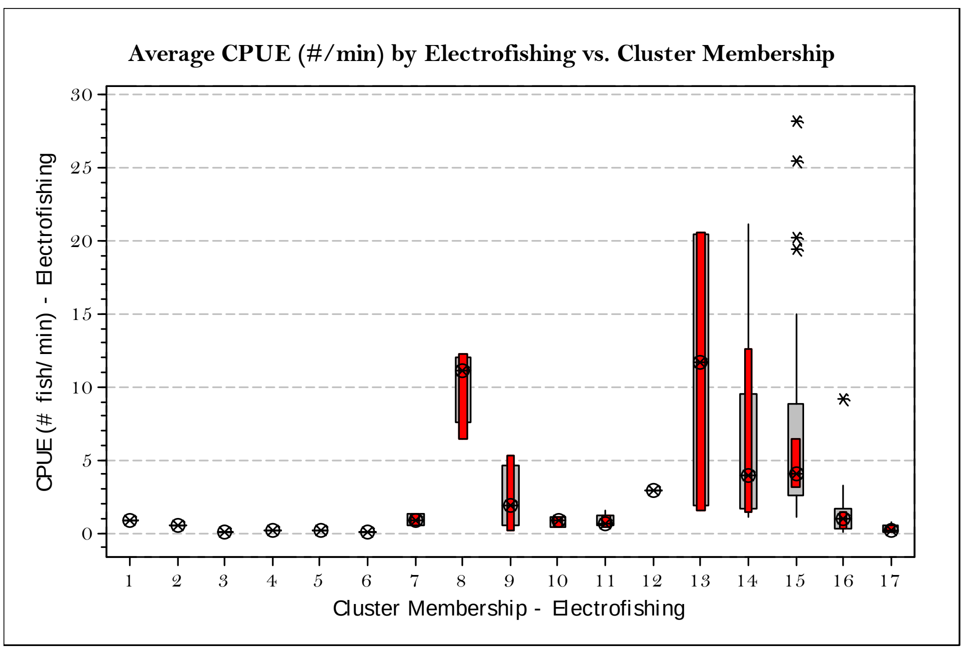

Figure 146. Boxplot depicting the distribution of the average electrofishing catch/min calculated from collections within each cluster defined in Table 19. Median symbol = ⨂ . Red bar depicts the 95% confidence interval for the median.

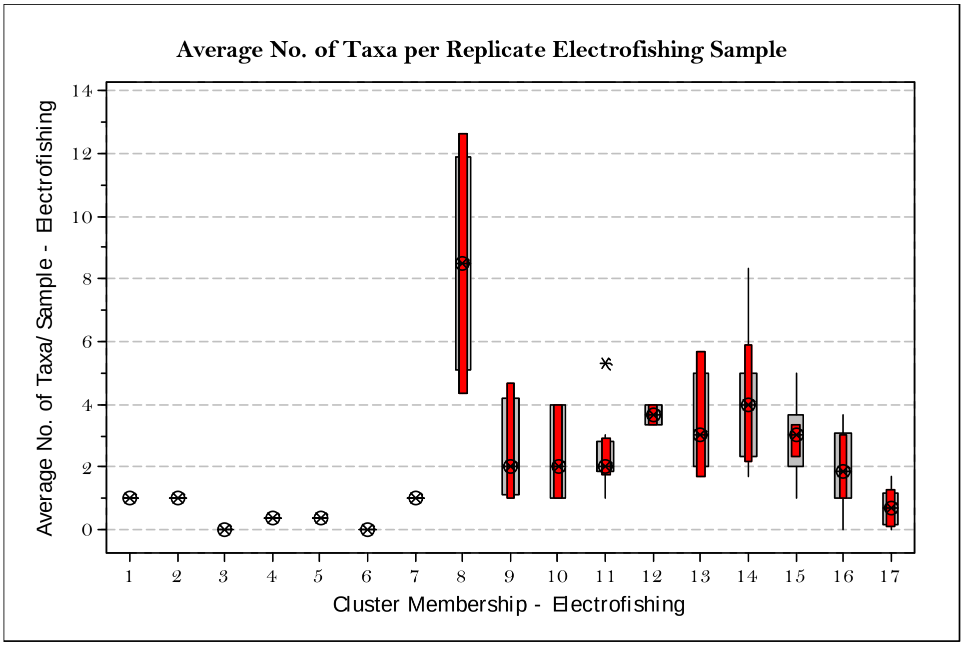

Figure 147. Boxplot depicting the distribution of the average number of fish taxa/30.48 meter collection within each cluster defined in Table 19. Median symbol = ⊗ . Red bar depicts the 95% confidence interval for the median.

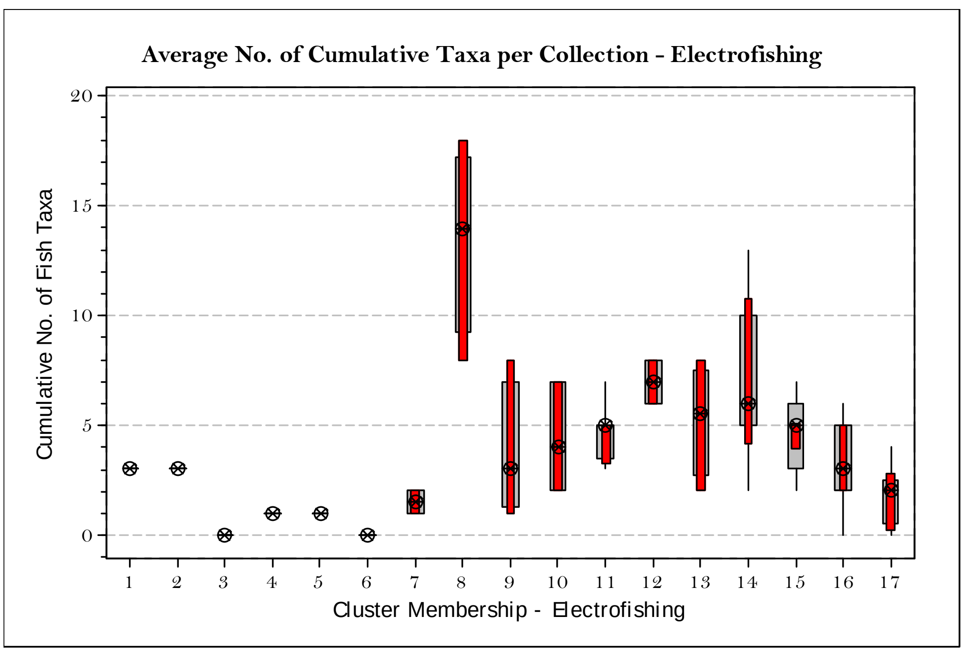

Figure 148. Boxplot depicting the distribution of the average cumulative number of fish taxa/site during each collection within each cluster defined in Table 19. Median symbol = ⊗ . Red bar depicts the 95% confidence interval for the median.

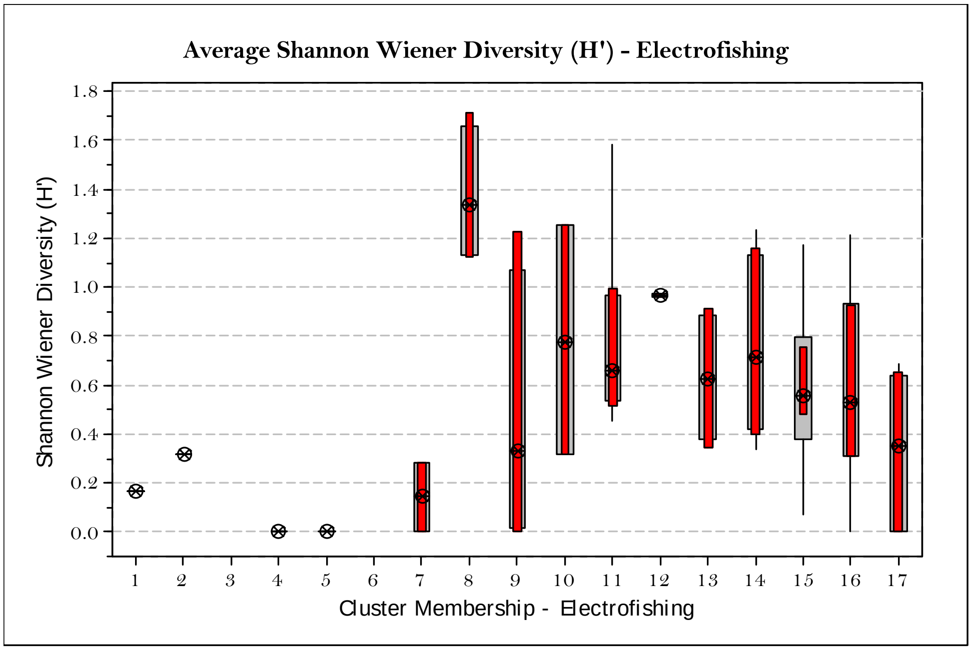

Figure 149. Boxplot depicting the distribution of the average Shannon-Wiener Diversity (H') calculated during each collection within each cluster defined in Table 19. Median symbol = ̂ı . Red bar depicts the 95% confidence interval for the median.

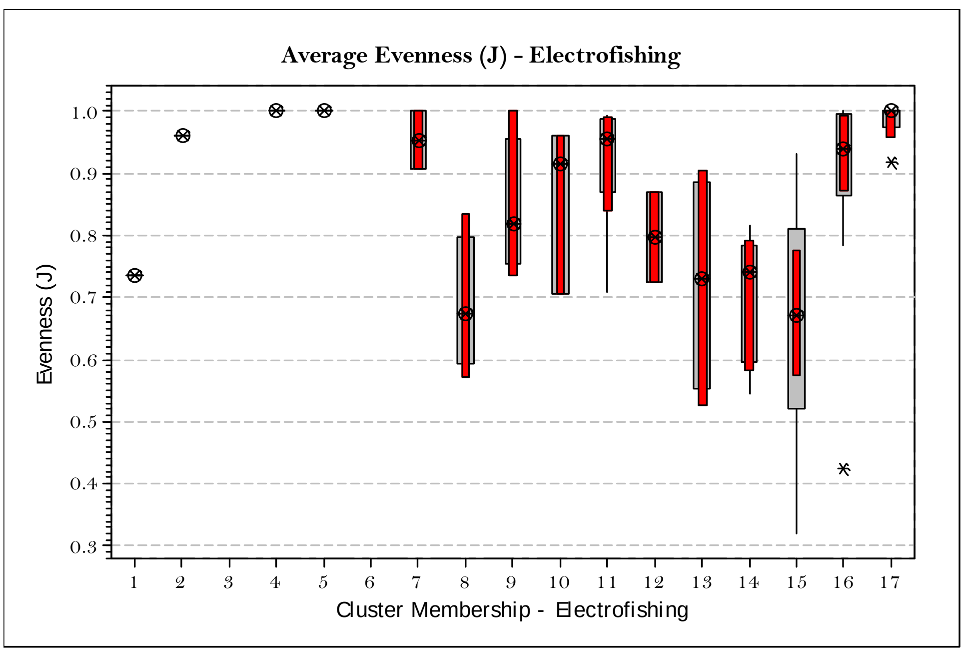

Figure 150. Boxplot depicting the distribution of the average Evenness (J) calculated during each collection within each cluster defined in Table 19. Median symbol = ̂ı . Red bar depicts the 95% confidence interval for the median.

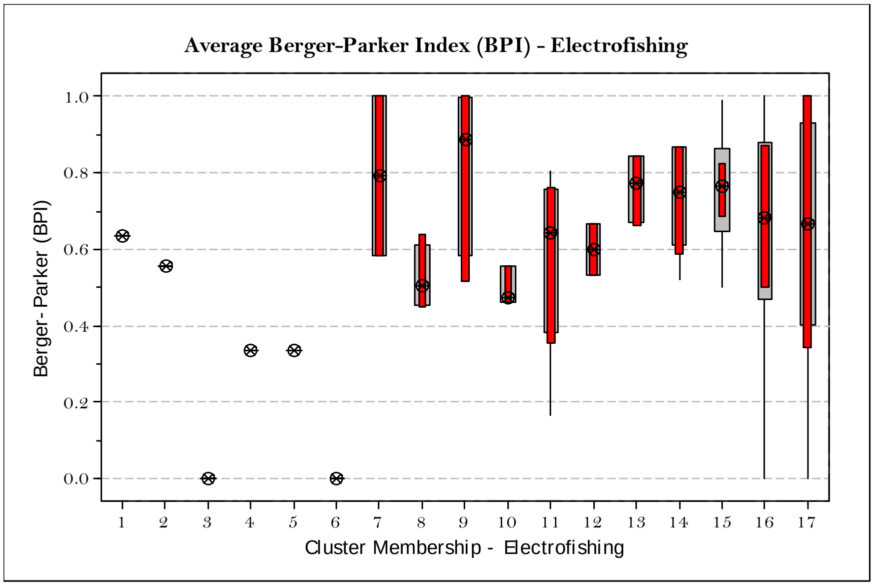

Figure 151. Boxplot depicting the distribution of the average Berger-Parker Index (BPI) calculated during each collection within each cluster defined in Table 19. Median symbol = ⊗ . Red bar depicts the 95% confidence interval for the median.

Results of our Index of Biotic Integrity (IBI) analysis using combined seine and electrofishing results are presented in Figure 152 and 153. During our investigation we did not document any collection that qualified for an "excellent" aquatic life use ranking based on fish community data. The highest median scores and rankings occurred at the Clear Creek downstream (CCD), Clear Creek upstream (CCU), Cowart Creek Airport (COA), Cowart Creek control (COC) and Mill Creek (MIC) sites. The lowest median scores and rankings occurred at the Goose Creek downstream (GCD), White Oak downstream (WOD) and White Oak upstream (WOU) sites. These IBI analyses when taken together with seine and electrofishing community metrics and results of multivariate analysis results suggest that the fish community at White Oak Bayou has been negatively impacted. The primary cause as previously stated, is likely the lack of instream habitat caused by the highly eroded stream bottom or concrete channel which lacks suitable habitat complexity and instream cover. Additional contributing factors would include elevated base flows associated with high wastewater effluent loading and extreme storm flows associated with the high percentage and amount of impervious surface within the watershed. We, however, did not document any detrimental water quality conditions other than high nutrients that would directly and negatively affect fish communities. Infrequent transient events such as elevated chlorine from wastewater discharges or chemical spills that could cause instream toxicity were not however monitored within the watershed.

We found that the majority of seine and electrofishing derived fish community metrics did correlate well, although in many cases this correlation was weak (Table 20). This is to be expected since each method is effective under varying conditions. We also found that various measures of fish community diversity were negatively correlated with the amount of impervious land, average sediment score, stream width, watershed area, and number of wastewater facilities (Table 21). This suggests that as the amount of these variables decreases the fish community diversity would increase, as we have generally observed throughout the study

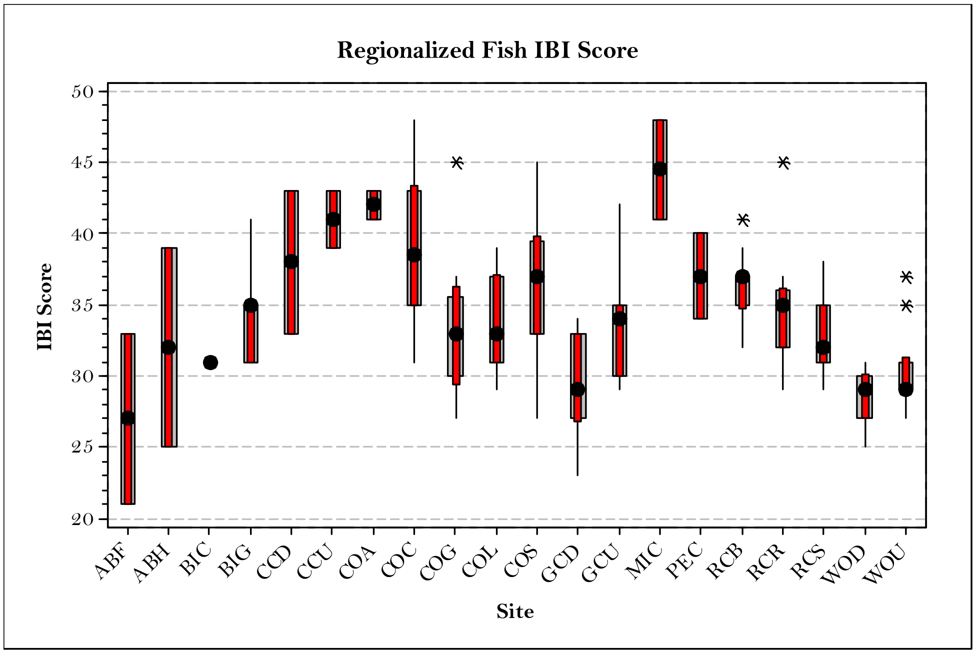

Figure 152. Boxplot depicting the distribution of the Regionalized Fish IBI scores calculated from electrofishing and seine fish collections at each site during the study period 2007-2010. Median symbol = ●. Red bar depicts the 95% confidence interval for the median.

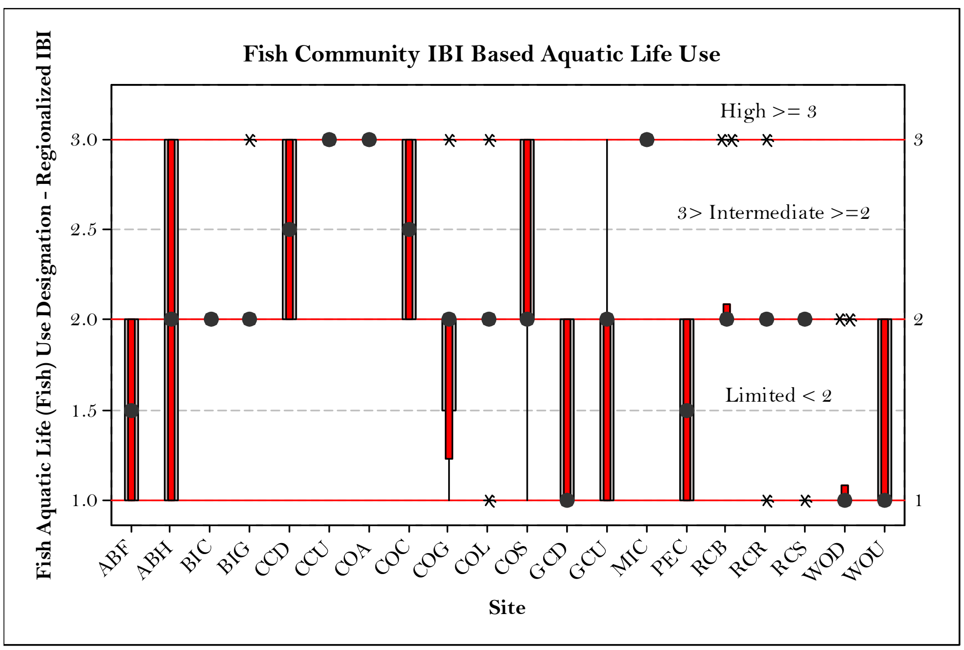

Figure 153. Boxplot depicting the distribution of the aquatic life use designations based on the Regionalized Fish IBI scores calculated from electrofishing and seine fish collections at each site during the study period 2007-2010. Median symbol = ●. Red bar depicts the 95% confidence interval for the median.

Table 20. Significant correlations (r > 0.40 or < -0.40, and p < 0.01) between various fish community metrics.

Variable 1	Variable 2	r	p
Seine BPI	Seine Cum. Taxa	-0.75	0.00
Seine BPI	ES Cum. Taxa	-0.49	0.00
Seine BPI	ES No. Taxa	-0.46	0.00
Seine BPI	ES H	-0.45	0.00
Seine E	Seine Total Catch	-0.68	0.00
Seine E	ES CPUE	-0.56	0.00
Seine E	ES Total Catch	-0.50	0.00
Seine E	Seine Taxa	-0.49	0.00
Seine H	Seine BPI	-0.98	0.00
Seine No. Taxa	Seine BPI	-0.80	0.00
Seine Tot	ES E	-0.48	0.00
ES E	ES CPUE	-0.75	0.00
ES E	ES Total Catch	-0.69	0.00
ES H	ES BPI	-0.63	0.00

Table 21. Significant correlations (r > 0.40 or < -0.40, p < 0.01) between various fish community metrics and physicochemical data.

Variable 1	Variable 2	r	p
% Impervious Land	Seine H	-0.50	0.00
Average Sed. Score	Seine Cum. Taxa	-0.44	0.00
Average Sed. Score	ES Cum. Taxa	-0.43	0.00
Average Sed. Score	Seine H	-0.43	0.00
Average Sed. Score	Shock H	-0.42	0.00
Average Sed. Score	Seine Taxa	-0.41	0.00
Avg. Width (m)	ES CPUE	-0.40	0.00
Impervious Area (ha)	ES No. Taxa	-0.45	0.00
No. WWTP	ES No. Taxa	-0.46	0.00
No. WWTP	Seine No. Taxa	-0.42	0.00
No. WWTP	ES Cum. Taxa	-0.42	0.00
Watershed Area (ha)	ES BPI	-0.45	0.00

Benthic Collections

During the study we collected an overall total of 49,106 benthic organisms were collected within 383 replicate samples (Table 22). The number of taxa varied considerably between years with the highest number being collected during the 2010 collections. The range of values, especially during the 2010 in comparison to previous years is due in part to the variable effort expended. During 2010 additional sites including Mill Creek (MIC), Peach Creek (PEC), Big Creek (BIC), Armand Bayou Fairmont (ABF), and Armand Bayou Holly Bay (ABH) were added. These additional sites contributed to the increased number of taxa documented during that year.

Total benthic invertebrate catch rates varied from 0 to 2073 organisms/replicate sample with an average 383 organisms/sample. Overall the highest number of benthic organisms collected occurred at the Armand Bayou Fairmont (ABF), and Armand Bayou Holly Bay (ABH) sites (Figure 154). The lowest catch rate observed occurred at the Big Creek (BIC), Big Gulch (BIG), and White Oak upstream (WOU) sites. The number of taxa collected per sample ranged between 0 to 35 taxa, with an average 9 taxa/sample. The lowest number of taxa was generally observed at the Big Creek (BIC) site, whereas the highest number of taxa was generally observed at the Armand Bayou sites (Figure 155). The other sites yielded intermediate levels of taxa and overlapped extensively.

Median total number of benthic organisms and number of taxa did exhibit significant correlations, however the strength of these correlations were very weak ($r < 0.30$ or > -0.30) (Table 23). We found some consistency between benthic collection results and fish sampling results. The only inter-community correlation that was observed occurred between the total number of benthic organisms and 1) total number of fish taxa collected with seines; 2) total number of fish and number of fish taxa collected using electroshocking gear; and 3) between the number of benthic taxa and number of seine fish taxa. All of these inter-community correlations were positive.

The strongest correlation observed between benthic community metrics and physicochemical variables occurred between total number of benthic taxa and stream flow, percent pools and number of wastewater facilities. All of these correlations were negative suggesting that as the streamflow, percent pool or number of wastewater facilities increased we would expect to find fewer benthic invertebrate taxa. Since low numbers of benthic taxa and high numbers of wastewater facilities and/or high flows were documented at the White Oak and Big Creek sites this would partially explain the negative relationship between these variables (Figure 48 and 54). Although we cannot explain the low diversity at the Big Creek site, the low diversity observed at the White Oak upstream (WOU) site is likely due to the highly eroded stream substrate that would not provide a stable attachment site for benthic organisms. In contrast, the White Oak downstream (WOD) site is largely concrete lined and is located downstream of a wastewater facility that simultaneously provides stable attachment substrate and high nutrients for benthic algae which sustains many benthic invertebrates. The water clarity and nutrient levels observed at this site would be sufficient to sustain an abundant benthic algae community, which we observed in the field in the form of green slime growing over shallow portions of the concrete at White Oak downstream (WOD) (Figure 86, 88, 96 and 100). As stated above we did not see benthic algae at White Oak upstream (WOU) where erodible clay is dominant. This suggests that suitable substrate is the limiting factor at the White Oak upstream (WOU) site. It should be noted that the White Oak upstream (WOU) site lacked pool habitat which is consistent with the negative correlation observed between number of benthic taxa and percentage of pool habitat. However, this relationship was not observed at the BIG site. As stated earlier these correlations are all relatively weak ($r > -0.25$).

Table 22. Summary of benthic organism collection data including total number of organisms collected and number of taxa collected during the year.

Year	Total	No. Taxa
2007	7,106	117
2008	15,885	124
2009	8,497	87
2010	17,618	180
Total	49,106	Not calculated

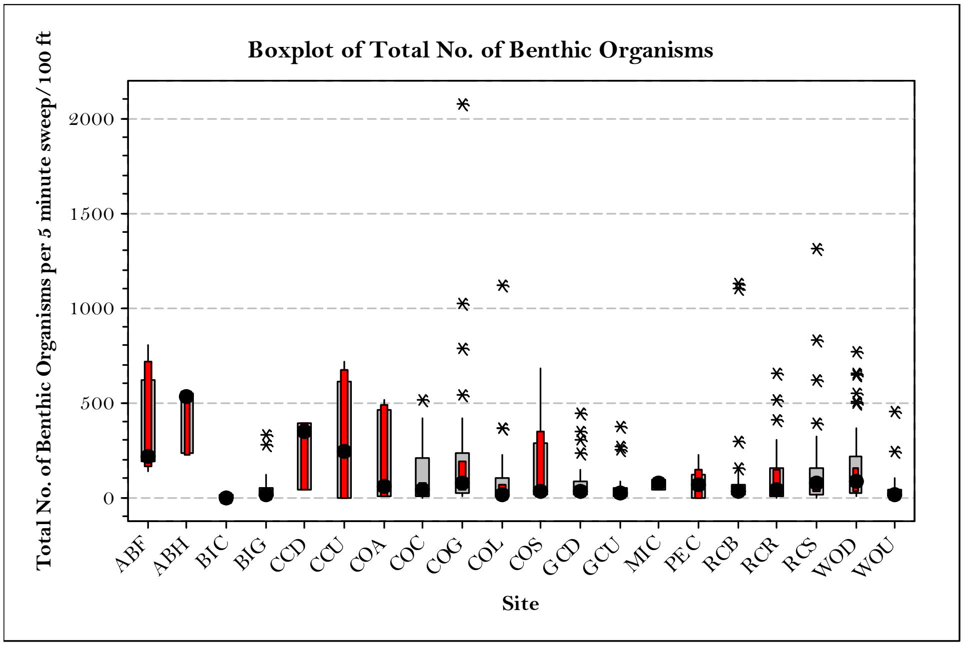

Figure 154. Boxplot depicting the distribution of the total number of benthic organisms collected with d-frame sweep nets during a 5 minute sweep over a 100 ft. segment of stream during the study period 2007-2010. Median symbol = ●. Red bar depicts the 95% confidence interval for the median.

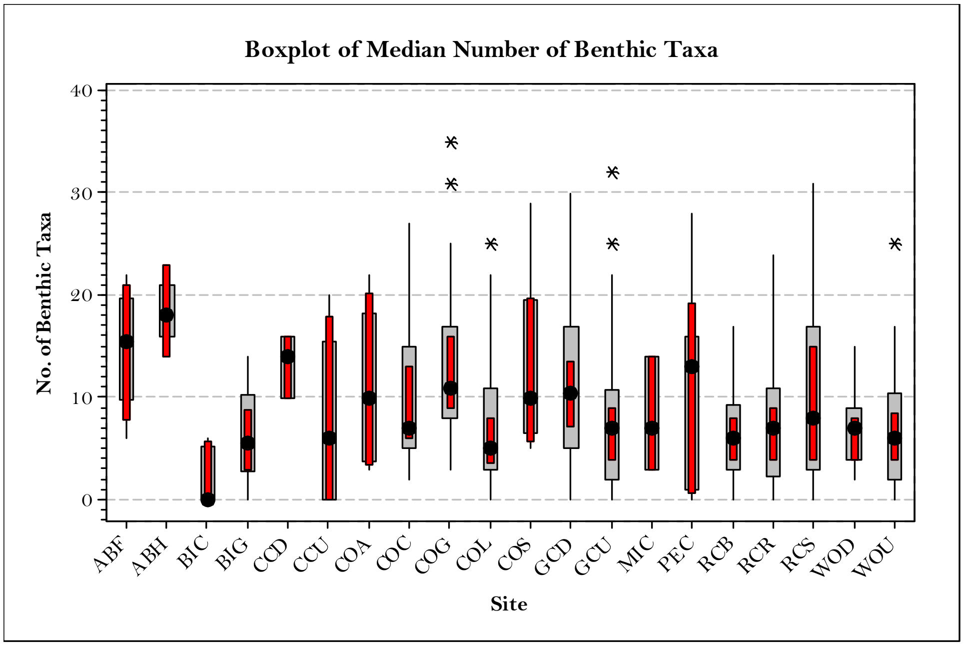

Figure 155. Boxplot depicting the distribution of the number of benthic taxa collected with d-frame sweep nets during a 5 minute sweep over a 100 ft. segment of stream during the study period 2007-2010. A 150 ft. segment was monitored at COS site. Median symbol = ●. Red bar depicts the 95% confidence interval for the median.

Table 23. Significant (p-value < 0.05) correlation coefficients between benthic community metrics (total number and mean number of taxa) and other physicochemical and fish community metrics.

Benthic Metric	Variable	r	p-value
Total No.	% Pool	-0.21	0.02
Total No.	pH	0.19	0.03
Total No.	TSS	-0.18	0.03
Total No.	Seine Taxa	0.20	0.02
Total No.	E. Shock No. Taxa	0.25	0.01
Total No.	E. Shock Total Catch	0.21	0.04
No. Taxa	Flow (cfs)	-0.23	0.01
No. Taxa	No. WWTP	-0.18	0.03
No. Taxa	% Cobble	-0.18	0.04
No. Taxa	1 Day Rain Amt	0.18	0.04
No. Taxa	No. Seine Taxa	0.25	0.00

Conclusion and Recommendations

Based on the results of this study we can conclude that the combination of channel substrate along with increased wastewater loading, altered streamflow and land use appear to be major factors affecting the fish and benthic invertebrate communities. Our results agree with previously documented stream conditions resulting from “urban stream syndrome” (Walsh et al. 2009). This includes increased impermeable land within the watershed which leads to increased storm flows, increased erosion of stream banks and usual response of construction of simple channel design to convey increased flood waters including straightening and/or reinforced stream channels. Attempts to reduce these impacts in areas experiencing ongoing urban development include evaluation of alternative stream channel stabilization methods, retention of flood waters in stormwater detention basins, restoration of the natural flood plain and instream habitat creation (e.g. riffles, sediment supply) (Roni and Beechie 2013). As flood plain managers explore restoration and project options it is important to document the historical assemblage of fishes and invertebrates present within the planned project or representative site before any project activities occur in order to better 1) document baseline conditions, 2) determine the degree of improvement in the aquatic community due to restoration activities and 3) inform decision makers on the expected response of these communities to various restoration options (e.g. stream substrate replacement) in the future.

Based on review of the fish seine community data it appears the most negatively impacted sites assessed during the survey were located within White Oak Bayou. In contrast, the sites exhibiting the highest fish diversity overall were the Cowart Creek sites including the Cowart Creek Airport (COA), Cowart Creek control (COC) and Cowart Creek Linson (COL - artificial riffle site). The fish community assemblage at the White Oak survey sites were species depauperate in comparison to other urban and non-urban streams surveyed. The primary characteristics differentiating White Oak Bayou from the other streams surveyed was the lack of SAV, extremely low instream habitat complexity, large watershed size and percent impervious surfaces, high percent concrete channel substrate or erodible bed material, and the highest number of upstream permitted wastewater facilities. These conditions provide very little instream cover for fish. The interaction of several factors including 1) high amounts of impermeable land and resulting in increased wet weather flows 2) elevated effluent dominated base flows and 3) lack of instream habitat are likely the primary factors contributing to the low fish diversity observed at the White Oak Bayou sites. In contrast the Cowart Creek sites including the artificial riffle area were generally less modified and contained a mixture of habitat and sediment types. In addition the upstream Cowart Creek watershed contained less development, less percent impervious surface, and a low number of wastewater facilities. These features would lead to 1) reduced wet weather flows, 2) less wastewater loading and 3) increased suitable instream habitat which supports higher densities and diversity of freshwater fish.

An additional contributing factor leading to reduced aquatic community diversity may be degraded water quality. We did not document any detrimental water quality conditions at the White Oak Bayou that would negatively affect fish communities other than high nutrients. The major effect of elevated nutrients would be the growth of excessive periphyton, and possibly larger diel variation in dissolved oxygen (Bryan and Rutherford 1993). At moderate levels however, increased loading of nitrogen and phosphorus can ultimately lead to elevated secondary production of fish. Infrequent transient events such as elevated chlorine discharged from wastewater discharges or chemical spills that could cause instream toxicity. However, these chemicals were not monitored within the watershed during this study. It should be noted that we did not find any evidence of impacts associated with the release of toxic substances including dead or dying fish or odors of chlorine or hydrocarbons.

Overall the highest number of benthic organisms collected occurred at the ABF and ABH sites. The lowest abundance in benthic organisms was documented at the Big Creek (BIC), Big Gulch (BIG), Goose Creek upstream (GCU) and White Oak upstream (WOU) sites. The lowest number of taxa was generally observed at Big Creek (BIC) site, whereas the highest number of taxa was generally observed at the Armand Bayou sites. The response of benthic communities to site conditions was difficult to evaluate due to the low correlation between total benthic organism abundance and benthic taxa, and any physicochemical variable. However, we did find some consistency between benthic and fish community metrics but these positive correlations were weak. Examination of site characteristics suggest that low numbers of benthic taxa are associated with higher numbers of wastewater facilities and/or high streamflow as documented at the White Oak upstream (WOU) and Big Creek sites. Furthermore, the low diversity observed at the White Oak upstream (WOU) site is likely due to the highly eroded clay stream substrate that does not provide a stable attachment site for periphyton or benthic organisms. In contrast, the downstream White Oak downstream (WOD) site is concrete lined and is immediately located downstream of a major wastewater facility. These two factors simultaneously provide stable attachment substrate, clear effluent water, and high nutrients for benthic algae production. The enhanced algal production would likely be sufficient to sustain many benthic invertebrates. This suggests that suitable substrate may be the primary the limiting factor controlling benthic organism production at the upstream White Oak upstream (WOU) site.

Based on our study results the worst type of channel design for support of native fish communities in Harris County streams is the historically used simple straight line concrete line channel that provides little habitat complexity, minimum cover and protection from predators, promotes higher temperatures, and usually associated with rapid change in hydrology. These traits are consistent with the results of other studies on urban streams which have undergone channelization (Brown et al. 2005; Bryan and Rutherford 1993; Walsh et al. 2009). We also documented conditions at other sites that have experienced various levels of impact on fish communities including elevated flows (Big Gulch - BIG), limited instream habitat (Armand Bayou Holly Bay - ABH), and contamination with saline water (COA), and limited instream habitat (RCS). These sites would occasionally exhibit low catch rates and/or low species diversity. The lack of any strong negative response in the fish community at these sites may be due to upstream and downstream migration and recolonization of fish from adjacent less impacted sites.

We recommend that an ongoing baseline aquatic monitoring program be established to monitor urban streams and evaluate long-term changes in fish and benthic communities. The use of these aquatic communities have been demonstrated to be cost effective and applicable to a wide range of stressors (Karr and Chu 1999). It is expected that Harris County and adjacent areas will continue to experience increased urban population growth. This growth will create pressure to develop additional land for housing and business which will ultimately lead to addition wastewater loading. The increased amount of impervious surfaces associated with housing and businesses will likely result in increased stormwater runoff within these watersheds. It will be critical for management agencies to develop best management practices for stream restoration and protection under these future scenarios. In order to differentiate the influence of these various stressors and the effectiveness of these mitigation measures there will be a continued need to monitor and evaluate the impacts on aquatic communities using a combination of hydrological, water quality and biological community metrics. We recommend that annual two season (spring and summer) monitoring be continued at several of the sites surveyed during our study, regional reference sites, and planned project sites. This seasonal sampling scheme is consistent with the critical season monitoring period developed by TCEQ to address periods of active reproduction and recruitment (spring) and stress (summer)(TCEQ 2007). We also recommend that the scope of sampling be expanded to other representative streams in Harris County and adjacent areas using a probabilistic sampling approach that incorporates some benchmark sites. This probabilistic sampling scheme will expedite the extrapolation of sampling results to other streams with similar physicochemical characteristics. This approach is currently used by EPA during their National Rivers and Streams Assessment to assess the quality of our nations rivers and streams (EPA 2014). We also recommend the inclusion of automated monitoring of water quality and routine toxicity testing (lab and in-situ) to evaluate potentially toxic but transient conditions that may be influencing fish and benthic community structure. Better coordination and inclusion of data on reported spills, overflows and bypasses, streamflow, water quality, habitat, and biological communities will facilitate the development of predictive models to understand the major mechanisms affecting aquatic communities and inform resource and floodplain managers.

This information should provide the Harris County Flood Control District with essential data needed for future project planning and to evaluate environmental impacts on urban aquatic communities. It is recommended that future routine baseline monitoring be conducted at a periodicity ranging between 2 to 5 years to assess changes in aquatic community structure, and several years pre and post project implementation to evaluate the response of the stream in terms of biological communities.

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