Baseline Aquatic Community Survey at Restoration Stream Segments (P138-00-00, T101-0-00, L100-00-00) Final Report

Prepared in cooperation with the Harris County Flood Control District
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Environmental Institute of Houston
University of Houston - Clear Lake

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Final Report

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EXECUTIVE SUMMARY

During 2010 and 2011, surveys were conducted at two future stream restorations project sites located within the Greens Bayou and Little Cypress Creek watersheds, and an existing site located in the Mason Creek watershed. These restoration projects and associated streams were located adjacent to or within Harris County Flood Control (HCFCD) stream segments T101-01-00 (Mason Creek), L100-00-00 (Little Cypress Creek) and P138-00-00 (a tributary to Greens Bayou). The Mason Creek site includes a corridor channel created by HCFCD in 2003, while the other two projects have not yet started in terms of construction or modification of the stream. The primary objective of this study was to establish baseline conditions present at current and future restoration sites managed by HCFCD. In order to accomplish this task 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 both hydrological, physical, water quality and biological data. Variables that were monitored included streamflow, velocity, predominant substrate type, basic stream dimensions (width, depth), instream habitat, water quality including nutrients, fish and benthic communities and primary productivity as measured by both periphyton and traditional water column chlorophyll-*a* levels. These data will be compared to future conditions after stream rehabilitation measures are taken. The primary management action that will be exercised at the future sites (Greens Bayou and Little Cypress Creek) is reconnecting portions of the stream that were disconnected in previous years due to various engineering flood management projects.

Based on the results of this study, the site with the lowest aquatic life use designation based on both benthic invertebrates and fish was the Mason Creek Mainstem site. The Little Cypress Creek Mainstem site generally had intermediate and high aquatic life use designations. The Greens Bayou mainstem site exhibited low aquatic life use based on fish community data, and intermediate to high aquatic life use based on benthic invertebrates. In addition, the Greens Bayou mainstem sites seldom exceeded the aquatic life use designations at the associated tributary sites. Based on these limited data the greatest expected increase in aquatic life use after future management efforts would likely occur at the Little Cypress Creek sites. Improvement at the tributaries on the Greens Bayou site may be limited by the “seed” stock of organisms found in the mainstem channel.

The Mason Creek sites were unique in that they were existing sites that were constructed upstream of and drain into a created wetland pond. Therefore, the aquatic life use at these sites may be limited by flow regime due to their location higher in the watershed and limited drainage area. Furthermore the downstream mainstem site possessed limited habitat value and streamflow. At the time of the 2010 survey, the MCUP site had also been impacted by construction of an illegal dam that backed up water and created lentic type pond habitat. This stagnant pond provided ideal habitat for many “stress tolerant” invertebrates which thrive best in depositional areas. Also, the lack of sufficient flows and partial barriers to movement may have resulted in reduced recruitment of fish. The barrier was removed in February 2011. However, during 2011 monitoring drought conditions were present, confounding any possible comparison between years associated with removal of the dam. Seining was not possible during 2011 due to lack of sufficient water and thick vegetation. Based on electrofishing data alone, there did not appear to be a major difference at MCUP in species composition or community metrics between years and the adjacent non-impounded downstream site (MCDN). Aquatic life use, based on benthic aquatic surveys, was consistently designated as “limited” for MCUP, even after removal of the dam. The downstream (MCDN) and mainstem (MCMN) sites had either limited (most frequently) or intermediate aquatic life use designations.

The majority of restoration sites exhibited relatively low stream velocity and flows, low periphyton production, and lacked significant riffle habitat. In some oxygen levels were also depressed (< 4 mg/l). The combination of these factors and their correlation with various aquatic community metrics can result in limited carrying capacity for benthic and fish communities due to insufficient flows for aeration and resulting settling of fine silts and clays. The control sites did in general have higher flows and dissolved oxygen levels. This was most noticeable at the Little Cypress Creek upstream in comparison to the mainstem site in 2010. However, these local control sites have in most cases been channelized, which has resulted in reduced amounts of stream meanders, riparian buffer zones (shading and plant detritus input), instream vegetation used by organisms as food and cover, and deposition of fine silts due to altered flow regime and the loss of riffle habitat.

Each of the restoration sites have limited to intermediate quality aquatic communities. The benthic and fish communities are both dominated by stress tolerant species. The level of stress causing this effect is due to various physical and water quality traits observed in many highly modified urban streams including:

- Past channelization which cut off meanders
- reduced or eliminated connectivity with the watershed
- altered flow regime
- reduced reaeration
- Concurrent losses or reduction in the diversity of various types of macrohabitat needed by aquatic organisms.

As the Harris County Flood Control District improves these streams through active restoration it will be interesting to see how the stream aquatic communities respond to increase connectivity with adjacent waterbodies and possible increased flows. We highly recommend that future validation monitoring be conducted at each of the future restoration sites for a period of several years post restoration implementation to evaluate the response of the stream in terms of geomorphology, hydrology, water chemistry and aquatic communities. This will provide enough data, over a range of possible precipitation and hydrological regimes, to evaluate with sufficient confidence whether the reconnected stream segment has recovered many of the structural and functional components that support aquatic life.

The extent of recovery at the reconnected and restored stream segments will be limited to the attainable levels of aquatic resources within the watershed, hence the need to monitor control sites within the stream system. Based on our data, the mainstem site of Little Cypress Creek has the highest aquatic life use and therefore reconnection of the LCUP and LCDN sites should lead to better improvement than the Greens Bayou sites.

Another issue that may influence ultimate attainment of restoration goals is the presence of invasive species. During this study we encountered several invasive fish species, one of which had been seldom encountered in Texas. Highly urban areas in general are at higher risks of exposure to invasive species due the greater likelihood of release of aquarium and aquaculture specimens. Both the Greens Bayou and to a lesser extent the Mason Creek sites are at risk of invasion of introduced exotic species. The Mason Creek site which is fairly isolated had one species of native exotic fish. The only other documented introduction of this species, *Lucania goodei*, was associated with wetland restoration project in the Guadalupe River. We propose to conduct follow up studies in Mason Creek to determine whether this population will establish itself and or expand its range.

Introduction

The population of Harris County is expected to continue to grow by 55% between 2005 and 2035 resulting in an increase of 2,006,000 individuals (HGAC 2006). As the human population grows there will be increased demands for housing, roads and commercial development. The resulting increased urbanization will alter stream hydrology and contaminant loads (Paul and Meyer 2001; Walsh et al. 2005). The term "urban stream syndrome" has been used to describe the consistently observed ecological degradation of streams draining urban land (Walsh et al. 2005). Symptoms of the urban stream syndrome include a flashier hydrograph, increased sediment loading, elevated concentrations of nutrients and contaminants, altered channel morphology and reduced biotic richness with increased dominance of tolerant species. This is due to the replacement of natural soils and vegetation with impervious surfaces which leads to elevated stormwater runoff containing higher concentrations of contaminants (Paul and Meyer 2001).

Urban fish and aquatic communities face an ever growing number of stressors. These include degraded water quality, lack of suitable instream habitat, invasive species, and altered hydrology (Brown et al. 2005; Bryan and Rutherford 1993). This often leads to altered fish and aquatic communities that are dominated by tolerant species which in turn can be used to evaluate the level of stress in the system (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. This often resulted in the physical detachment and isolation of portions of the river and stream bed from the main channel. Effectively, this resulted in the artificial creation of "oxbow" type remnant ponds and meanders. The resulting mainstem river often exhibited less sinuosity and instream habitat for fish, while the "orphaned" portion of the stream became less hydrologically connected to the watershed and in some cases was filled to reclaim land. However, there are still opportunities to reconnect these historical meanders to enhance habitat for fish and wildlife. Many of these low flow channels would naturally serve as critical nursery habitat for spawning river fish. Certain fish such as gars and other large river fish utilize these habitats during spawning. Their young, upon reaching maturity, return to the river during the next flood event. Since many factors can potentially affect the success of any restoration project it is critical that the physical, chemical and hydrological conditions present during and after management actions be documented and also how the fish community responds to these changes.

Methods

Study Area

Sites were selected based on streams that were of interest to the HCFCD. The streams are all located within an urban environment within Harris County. Paired control sites were chosen within the same or similar watershed to reduce or eliminate inter-watershed variability. The sites were located in "wadeable" streams that can be sampled under normal base flow conditions without a boat. A total of 3 streams including 2-3 sites per stream were identified for documentation of pre-project conditions and/or to document environmental conditions present at current restoration sites (Table 1 and Figure 1 - 4). Site visits with the HCFCD technical staff occurred in early 2010 to document site conditions present. Digital photography and GPS were used to document our location and sites 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.

Table 1. Samples collected during 2010 and 2011 restoration stream surveys. Sampling was attempted on the dates highlighted in yellow, but were not completed due to dry conditions. No sampling was conducted at the Greens Main site during 2010.

Sites	HCFCD Segment ID	Monitoring Dates				Periphyton Chlorophyll-*a* 14 day Deployment Date
		Round 1	Round 2	Round 3	Round 4	
Mason Creek Up	T101-01-00	5/17/2010	8/27/2010	6/13/2011	7/28/2011	10/1/2010
Mason Creek Down	T101-01-00	5/17/2010	8/27/2010	6/13/2011	7/28/2011	10/1/2010
Mason Creek Main	T101-01-00	5/20/2010	8/27/2010	6/20/2011	7/28/2011	10/1/2010
Little Cypress Up	L100-00-00 (Tributary)	7/6/2010	9/7/2010	6/14/2011	8/3/2011	10/4/2010
Little Cypress Down	L100-00-00 (Tributary)	7/6/2010	9/14/2010	6/14/2011	8/3/2011	10/4/2010
Little Cypress Main	L100-00-00 (Tributary)	7/12/2010	9/14/2010	6/14/2011	8/3/2011	10/4/2010
Greens Mid	P138-00-00	7/21/2010	9/2/2010	6/10/2011	7/29/2011	9/30/2010
Greens Down	P138-00-00	7/21/2010	9/2/2010	6/10/2011	7/29/2011	9/30/2010
Greens Main	P100-00-00			6/15/2011	8/1/2011	

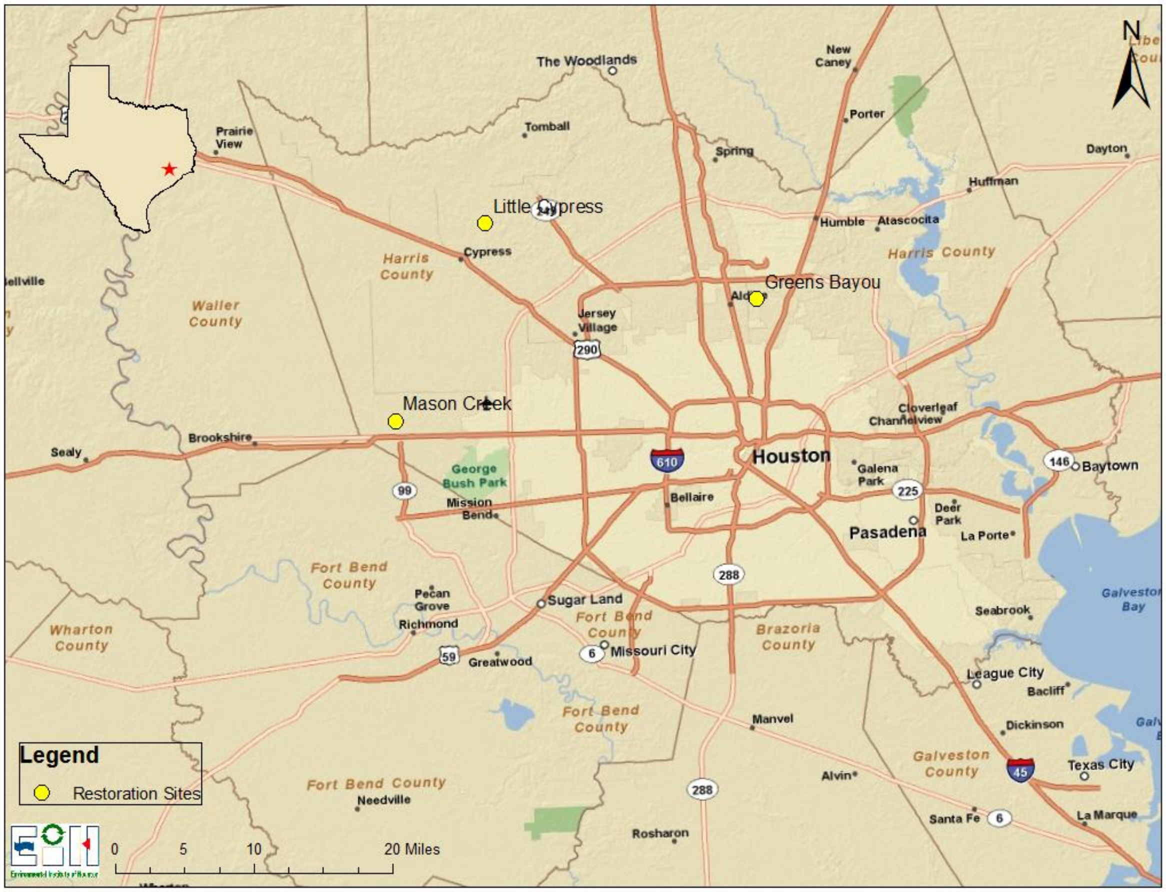


Figure 1. Location of restoration stream site groups surveyed during spring and summer 2010 and 2011.

Figure 2. Location of Greens Bayou tributary stream segments.

Figure 3. Greens Bayou tributary restoration sample sites (red=mid P138-00-00); (green=down P138-01-00); (yellow = mainstream Greens Bayou (P100-00-00) site.

Figure 4. Little Cypress Creek restoration sites (up and down) and associated mainstem downstream control site (LCC3 main) located in L100-00-00.

Figure 5. Mason Creek sites T101-01-00 (up and down) and associated control site (main) T101-01-09.

While visiting each site; the stream substrate, relative streamflow and potential access issues were noted and photographs that were taken. The Greens Bayou restoration site is located in northern Harris County (Figure 1- 3). We established two sampling sites in a tributary (Harris County Stream Number P138-00-00) of Greens Bayou during both years and an additional control site within Greens Bayou (P100-00-00) at a point above the confluence of Greens Bayou and the tributary stream during 2011 (Figure 3). Based on the initial site visit the majority of the surrounding neighborhood was partially abandoned. On the day of the visit there appeared to be some minimum maintenance of the stream bank since the grass appeared to have been recently cut (Figure 6 and 7). The stream was partially shaded by riparian vegetation including trees. The tributary creek at the sites labeled as Greens Bayou Down and Greens Bayou Mid is mostly sandy bottom with short, steep banks (>45°). The color of the water was slightly brown. Since the proposed restoration project would also affect the upstream segment P138-03-00, we also conducted a survey of this segment (Figure 8). However, the site was overgrown with vegetation or completely lacked water throughout the drainage. Therefore no sampling was conducted within this segment throughout the study. Assuming water will flow through the segment when reconnected to Greens Bayou, we will need to assess the effects on the aquatic community that will develop in this area when re-flooded. The main stream site consisted of a typical channelized trapezoidal earthen channel (Figure 9).

Figure 6. Harris County stream segment P138-00-00 facing upstream and downstream, at the Greens Downstream (GBDN) sampling site, a tributary of Greens Bayou.

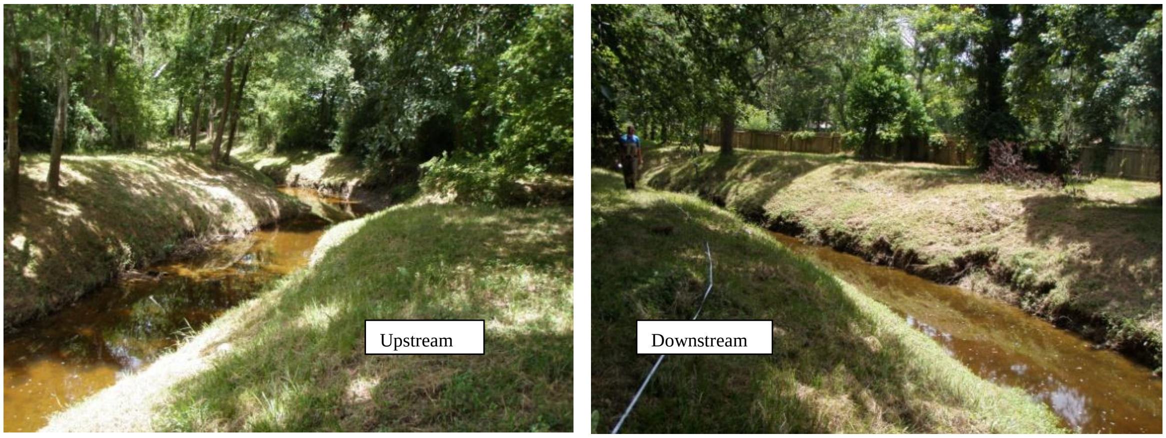


Figure 7. Harris County stream segment P138-00-00 facing upstream and downstream, at the Greens Middle (GBMI) sampling site.

Figure 8. Harris County stream segment P138-03-00 near the upstream and downstream extent showing the largely dry stream bed. This area was not monitored due to lack of water and thick vegetation.

Figure 9. Harris County stream segment (P100-00-00) facing upstream and downstream, at the Greens Bayou mainstem (GBMN) sampling site.

The Little Cypress Creek restoration site is located in northwest Harris County adjacent to stream segment L100-00-00 (Figure 1 and 4). This stream segment has been "rectified" or channelized and straightened in the past which resulted in a reach of the stream meander becoming detached. The relic meander channel will be reconnected to the mainstem segment L100-00-00. The meander channel was surveyed near the upper part of the channel near the end of Steinhagen Road (Little Cypress Creek up), and at the lower end near the Fritsche Cemetery (Little Cypress Creek down) (Figure 10 and 11). The relic meander stream at both sites had extensive riparian vegetation and a mixture of sand and silt sediment. Flows appear to be minimal at both locations with a larger series of disconnected pools being present. Stream flow appears to be driven mostly by surface runoff from adjacent neighborhoods. Stream bank slopes ranged between 30° and 60°. We also surveyed portions of the L100-00-00 mainstream channel for potential sample collection sites. The site selected for sampling is immediately upstream of where the meander will likely be reconnected (Figure 12). Photographs of the control site located in the mainstem of L100-00-00 were not available.

Figure 10. Detached meander associated with stream segment L100-00-00 facing upstream and downstream near the downstream extent (site Little Cypress Creek downstream = LCDN).

Figure 11. Detached meander associated with stream segment L100-00-00 facing upstream and downstream at the upstream extent (Little Cypress Creek upstream = LCUP).

Figure 12. Stream segment L100-00-00 facing upstream and downstream at the Little Cypress mainstream control site (LCMN).

The Mason Creek site was located in western Harris County adjacent to stream segment T101-00-00 (Figure 1 and 5). The target site is a created corridor channel extension of Mason Creek located within a 250-foot wide right-of-way (Figure 13). This site was constructed within historic agricultural land to extend the Mason Creek drainage system into the "frontier" region of the county that is currently being developed as new homes and subdivision are added. The channel and downstream detention basin which includes a constructed wetland were constructed in 2003. A matching control site was located further down, below the wetland area in a tributary stream (Figure 14). It was a mowed channelized drainage ditch which appears to be located in the historic stream channel.

Figure 13. Mason Creek T101-00-00 at the upstream site (MCUP = Mason Creek up, facing upstream) and downstream site (MSDN = Mason Creek down, facing upstream). Sites were located adjacent to each other; the upstream site was located above a man-made dam, which was subsequently removed.

Figure 14. Harris County stream segment (T101-01-09) facing upstream and downstream, at the Mason Creek mainstem (MCMN) sampling site.

Watershed Land Use

Land use upstream of each survey site was determined by delineating the watershed and estimating the percentage of the watershed falling into various land use categories. The land use data used for this study was accessed on October 29, 2012 from the Houston Galveston Area Council (HGAC) (Houston Galveston Area Council 2010). According to the HGAC website, the last update for the 2008 HGAC land cover data set was in 10/14/2010 (http://www.h-gac.com/community/socioeconomic/land_use/default.aspx).

Field Methods

The types of sampling conducted at each site are described below. Each site consisted of a 300-foot long section or reach of the stream. The experimental design that was used during sampling is a repeated measures approach in which replicate measurements of fish and benthic communities, habitat, hydrology, and water quality were made at each site during each sampling period. Data collection was conducted during two periods including late spring and summer 2010 and 2011. In addition, artificial substrates were deployed during the second sampling period in 2010 and monitored for growth of periphyton.

Physical habitat

During each sampling event, instream and riparian habitat was assessed following protocol outlined in the TCEQ surface water quality monitoring procedures and recommended American Fisheries Society habitat assessment methods with few modifications as outlined below (Bain 1999; TCEQ 2007; TCEQ 2008). Detailed physical habitat data was collected at the upstream, middle, and downstream portions of each 300-foot stream segment. In addition, the predominant macrohabitat type was evaluated at 30 foot increments along the 300-foot stream segment and was categorized into one of three categories: riffle, run, or pool. A riffle is described 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, the percent of the stream covered by each macrohabitat (run, percent riffle, and pool) was estimated to the nearest 10% interval.

Predominant sediment type and size distribution was estimated from transects laid at the upper, middle and lower end of each reach. Sediment was collected on the right and left banks and along the thalweg. A modified Wentworth scale was used to classify the sediment (Table 2). The scale uses sediment size to characterize substrate materials. The scale was modified to include sediment/substrates not normally included in the traditional Wentworth scale including concrete lined and irregular hardpan clay and articulating concrete blocks (ACB).

The percentage of stream bottom covered by submerged and emergent vegetation was also estimated at the same three cross sections by establishing a transect across the stream and evaluating the amount of tape that covers the various stream vegetation types. Any additional instream cover types such as undercut banks, logs or snags, overhanging vegetation, leaf packs, and artificial covers (i.e. tires, etc.) were noted.

Table 2. Modified Wentworth sediment scale used to classify stream sediment size (modified from Bain 1999)

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

Stream bank slope (both sides) was estimated using a clinometer and straight edge. The amount of riparian canopy and shading was estimated by standing mid-stream and looking upstream and downstream and averaging the number of points covered by the shadow of overhanging vegetation. Percent shading was determined at the upstream, middle, and downstream sections of the 300-foot stream segment during each sampling event. Shading was determined using a convex spherical densitometer following the methods outlined in TCEQ and AFS (Bain 1999; TCEQ 2007). Sampling was conducted during mid-morning to mid-afternoon to reduce bias. However, this methodology only provides an estimate of the amount of overhead canopy that may obstruct overhead sunlight. It does not provide an actual measurement of ambient light transmission or intensity. Therefore it is not affected by actual light conditions except of course it cannot be used at night or in twilight.

Meteorology and Hydrology

Precipitation data was obtained from the rain gages operating under the Harris County Flood Warning System (http://www.harriscountyfws.org/). Data were obtained from the nearest rainfall gages located at Gage 1640 P100 Greens Bayou at US 59, Gage 1220 L100 Little Cypress Creek at Cypress Hill Road, and Gage 2020 T101 Mason Creek at Prince Creek Drive. For each date of sampling we tallied data on days since recorded rainfall (≥ 0.01 in), and the previous cumulative rainfall for the day of sampling (1 day) and 2 days prior to sampling (3 days total).

During each sampling event, hydrological conditions were assessed following protocol outlined in the TCEQ surface water quality monitoring procedures (TCEQ 2008). Water velocity and depth at the thalweg, and stream width were measured at the upstream end, middle section (150 ft), and downstream border of each 300-foot sampling segment that was established at each site. This was done during each sampling event. At the upstream end at each site, streamflow was also calculated using a minimum of ten equally spaced paired velocity and depth measurements

(TCEQ 2008). Depth and velocity was determined using a top-setting wading rod with an attached Flow Tracker® acoustic doppler velocity meter (ADV) manufactured by SonTek®.

Water Quality and Primary Production

Water quality measurements were collected during each sampling event at the upstream extent of each 300-foot stream site. Measurements included water temperature, specific conductance at 25C, pH, dissolved oxygen, secchi disk/tube turbidity, turbidity (NTU), orthophosphates (O-P), ammonia-nitrogen (NH_4-N), nitrate and nitrite nitrogen (NO_{2+3}-N), total suspended solids (TSS), total alkalinity (as $CaCO_3$), total hardness (as $CaCO_3$) and chlorophyll-*a* (Table 3). Water temperature, pH, specific conductance, and dissolved oxygen were measured in-situ with a calibrated YSI multiparameter meter according to procedures outlined in the current edition of the TCEQ/Clean Rivers Program methods manual (TCEQ 2008).

Turbidity was estimated using two methods including in-situ measurements with a secchi tube and by analysis of grab samples with a nephelometer. The secchi disk/tube procedure was used according to the TCEQ stream monitoring manual. Nephelometric methods used to measure turbidity in NTU's was conducted according to APHA Method 2130B (American Public Health Association et al. 1998).

Turbidity (NTU), alkalinity, hardness, orthophosphates, nitrate and nitrite nitrogen, TSS, chlorophyll-*a* in water, and periphyton samples were collected onsite and measured at the laboratory. Turbidity was measured using a nephelometer. TSS was measured by gravimetric means, and chlorophyll-a by spectrophotometric techniques. Analysis methods used are listed in Table 3 (American Public Health Association et al. 1998; EPA 1983; HACH 2008; HACH 2009).

Prior to daily use, and at the end of each day, all instruments were calibrated and validated against known standards following protocol outlined in the TCEQ/Clean Rivers Program methods manual (TCEQ 2008). Chlorophyll-*a*, turbidity, total suspended solids (TSS), and nutrient analyses were conducted at the EIH laboratory. The laboratory methods and measurements, including nutrient analyses, were used to screen water quality conditions, but should not be used to determine compliance with any regulatory water quality numerical criteria or standards. The presence of excessive nutrients, which would be detectable by our methods, could cause excessive periphyton growth. At the same time, sufficient primary production is needed to provide necessary resources for secondary consumers including fish and invertebrates.

Table 3. Water quality variables monitored and sampling methods used during study.

Parameter	Monitoring and/or Test Method
Temperature (°C)	YSI Meter (TCEQ 2008)[1]
Standard conductance (mS)	YSI Meter (TCEQ 2008)[1]
pH	YSI Meter (TCEQ 2008) [1]
Dissolved oxygen (mg/L)	YSI Meter (TCEQ 2008) [1]
Turbidity (cm & NTU)	Secchi Tube and Scientific Inc. Turbidimeter (TCEQ 2008; APHA 1998 Method 2130 B) [1,2]
Orthophosphate (mg/L PO_4)	Phosphorus, reactive Method 8048 using a Hach DR/890 Colorimeter (filtered with 47mm filter paper) (detection limit 2.50 mg/L). (Equivalent to EPA Method 365.2 and APHA Standard method 4500-PE) [2,3]
Nitrate-nitrogen (mg/L NO_3-N)	Nitrate, low-range Method 8192 using a Hach DR/890 Colorimeter (detection limit 0.50 mg/L)
Total suspended solids (mg/L)	APHA 1998 Method 2540 [2]
Alkalinity (mg/L as $CaCO_3$)	LaMotte Kit Model WAT-DR code 49-DR (LaMotte Chemical 2005)(APHA 1998 2320 B) [1]. Titration with standard acid to total (T) alkalinity endpoint.
Hardness EDTA (mg/L as $CaCO_3$)	Method 8030 HACH DR/890 colorimeter; (APHA Method 1998 2340) C [2]
Chlorophyll-a (mg/m^3)	(APHA Method 1998 10200) [2]
Periphyton Chlorophyll-a (mg/m^2) and periphyton biomass	(APHA Method 1998 10300 C and 10300 D) [2]

[1]TCEQ 2008 (TCEQ 2008); [2]APHA (American Public Health Association et al. 1998); [3](EPA 1983)

Although chlorophyll-*a* in water was monitored, the use of suspended chlorophyll-*a* grossly underestimates the amount of primary production occurring in flowing streams. Consequently, in addition to monitoring suspended algal pigments, that is phytoplankton chlorophyll-*a*, we also monitored attached algal (periphyton) biomass and production during 2010 monitoring. Periphyton monitoring followed protocol outlined for artificial substrates in (American Public Health Association et al. 1998). Due to the lack of sufficient hard substrate and a desire to standardize monitoring between sites, we deployed replicate artificial substrates at each site to monitor periphyton production while minimizing grazing effects. Data generated from this limited monitoring will be used to evaluate potential benthic community production. We decided to use artificial substrates because alternative sampling from natural substrates, although more representative of actual site conditions, is sometimes logistically limited by both the availability of hard substrate and the irregular surfaces on which natural assemblages grow. The advantages of using artificial substrates is it allows more standardized and comparable testing between sites (Aloi 1990). However, the results must be evaluated against the amount of natural suitable substrate and other limiting factors.

At each stream reach (300 ft. segment) we deployed three modified cinder block periphyton samplers. Periphyton samplers were placed at the upper end, midway and at the downstream end of the segment. Prior to deployment we glued 6 non-glazed, 4.5 X 4.5 cm, ceramic tiles on each brick following the pattern outline depicted in Figure 15. Three tiles were used for biomass determination (dry ash-free weight) and three were used for chlorophyll-a determination. This resulted in a total of 3 bricks per site, allowing for 9 replicate measures of biomass and chlorophyll. These were deployed for two weeks to allow for sufficient growth while reducing grazing effects. After two weeks elapsed, the blocks were removed and razor blades were used to scrape the top of the tiles into clean vials.

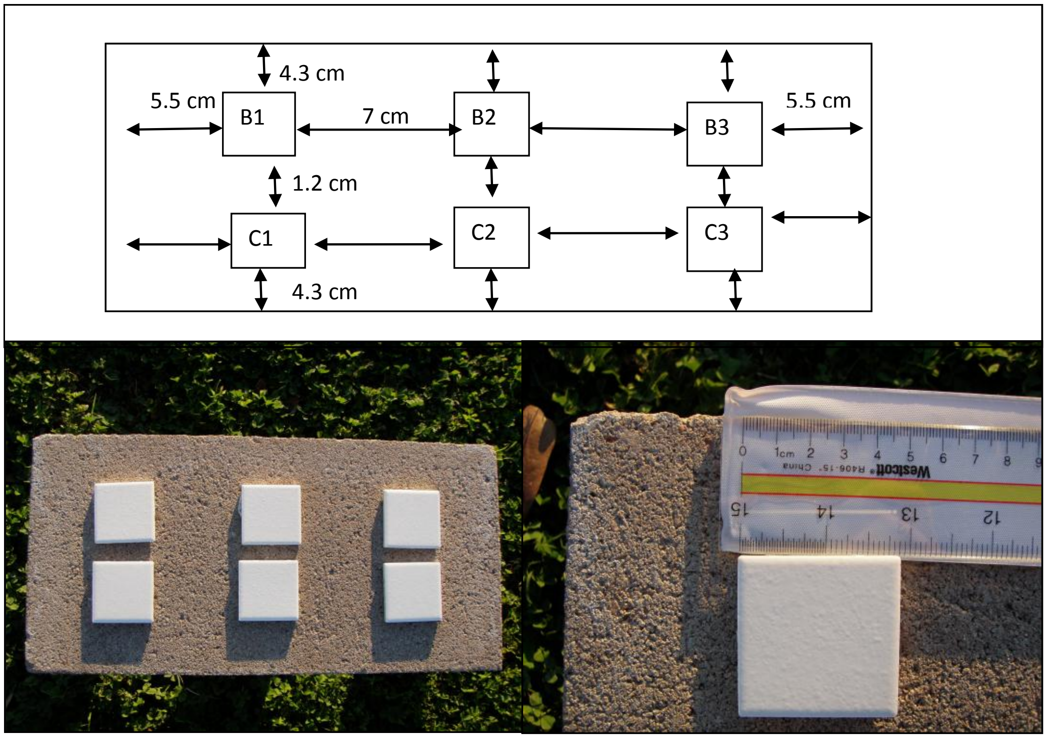


Figure 15. Periphyton sampler (left) showing six 4.5 X 4.5 cm unglazed ceramic tiles mounted on a cinder block and one individual tile close up on right. Dimensions depicted in upper panel (B = biomass samples; C = chlorophyll samples).

Periphyton is scraped off the tiles and placed in aluminum foil or dark bottles. Chlorophyll-*a* samples (water or periphyton) once collected in the field must be kept in the dark (filters in folded foil or original water in amber bottles) in an ice chest. Water samples not filtered in the field were filtered in the lab within 6 hours of collection. Periphyton scrapes were washed onto a filter, placed in a sealed plastic bag and kept in the dark while in transit. The filters were then stored in the -80 freezer for up to 28 days. Once processed in the lab the chlorophyll-*a* and biomass estimates obtained from the periphyton samples were used to calculate ash free dry weight (biomass), chlorophyll-*a* content, Autrophic Index (AI) and primary productivity according to Standard Methods 10300 C and D (American Public Health Association et al. 1998). The formulas for calculating the various metrics are listed below.

Biomass periphyton (B), A= area of tile:

$$B = \frac{\text{mg ash free weight}}{\text{Area of substrate (m}^2\text{)}}$$

Productivity (P), t = exposure time, A= area of tile:

$$P = \frac{\text{mg ash free weight/tile}}{tA}$$

Chlorophyll (mg Chlorophyll-a/m^2) = C_p, Where C_a = mg chlorophyll-a/L calculated from extract.

$$= \frac{C_a * \text{volume of extract (L)}}{\text{Area of substrate (m}^2\text{)}}$$

Autotrophic Index = AI= = B/C_a

Benthic Invertebrate Assessment Methods.

Our benthic invertebrate community characterization consisted of 3 replicate adjacent 100 ft. collections at each 300 ft. site reach. We utilized a rapid bioassessment protocol using a semi-quantitative D-frame kick net with minor modifications (Barbour et al. 1999; TCEQ 2007). Although these techniques recommend pooling of samples to calculate overall community metric scores, we also calculated individual replicate sample community metrics to facilitate statistical comparisons between sites and seasons. The TCEQ benthic protocol for kick net sampling recommends collection of a minimum of 100 organisms over a 5 minute sweep period at riffles and/or woody snags for a maximum of the two habitat types. These data are then used to calculate various community metrics (TCEQ 2007). Since very few woody debris and/or riffles were present at our sites we sampled for 5 minutes by aggressively and actively sweeping across each of the three 100 ft. (total 300 ft.) segments that included undercut banks, vegetation, small riffles and woody debris. As previously noted we also collected data on predominant substrate type, depth and velocity. At each site benthic collections were conducted prior to any fish sampling.

Sampling was initiated at the first 100 ft. transect located at the downstream point facing upstream against the current. The straight edge of the D-frame net was placed on or near the bottom, depending on the substrate. The collector's foot is then used to disturb the bottom of the stream to dislodge the macroinvertebrates and allow the current to push them into the net. However, if the bottom is muddy, the net was not placed on the bottom in order to reduce the amount of mud that would potentially clog the net. The collector then moved upstream in a zigzag fashion for 100 ft. for 5 minutes. If big rocks or vegetation were encountered the net was dragged along the rocks and through the vegetation to capture any macroinvertebrates clinging to rocks or vegetation.

At the end of 5 minutes the net was emptied into a one liter bottle labeled on the outside with the site name, date, and replicate number. A vellum paper tag was also placed inside the bottle with the site name, date, and replicate number. This was done to insure information on each collection was retained with each sample. The net was also rinsed into the bottle using a rinse bottle to ensure that all macroinvertebrates were retained. A funnel, smaller mesh phytoplankton net, tweezers, and lab scoop was used to concentrate the sample prior to transfer to the sample container. Each sample was preserved by adding 95% ethanol to the bottle. In the lab, samples were rinsed through a 500 micrometer sieve with DI water to remove excess dirt. After samples were sorted and identified the archival specimens were stored in 70% ethanol.

Fish Community Assessment Methods

Fish were collected during each sampling event using techniques outlined in the TCEQ procedures manual with some modifications (TCEQ 2007). Sampling consisted of seining and electro-fishing using a backpack shocker. During each sampling event within each 300 ft. stream segment ten seine hauls (30-foot segments) were conducted using a 15' x 4' seine with a 1/8 inch nylon mesh. In addition, a Smith-Root® model LR-24 backpack electrofisher using the standard operational parameters of 30 Hz pulsed D.C. current, duty cycle of 12%, operating at 100-200 volts, with an output amperage of 0.56 amps, was used to collect fish from each site. All settings including the voltage, watts, type of wave, and amps, from the electrofisher were recorded in a field notebook prior to sampling. Electro-fishing was conducted along three (3) adjacent 100-foot segments per site per sampling event.

Once collected the majority of collected fish were euthanized onsite with MS-222, and subsequently preserved in 10% formalin. Larger easily identifiable fish were measured and released back into the stream. The preserved 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.

Biological Laboratory Processing

All fish and invertebrates were identified to the lowest taxonomic level possible using regional guides and taxonomic keys (Hubbs et al. 2008; Merritt et al. 2008; Pennak 1989; Smith 2001; Thomas et al. 2007; Thorp and Covich 2010; Thorp and Rogers 2011; Voshell 2002). In most cases specimens were identified to species level to facilitate comparisons between individual species abundances. This identification was also used for further calculation of number of taxa or species, community indices and fish and benthic IBI metrics. Most species were either small adults or juveniles which are easily captured in seines, usually less than 6 inches long. Mr. Jack Davis, an independent consulting benthic taxonomist, conducted many of the final benthic taxonomic identifications.

Data Analysis

Several methods were used to analyze the data collected during this study. Raw data collected during the study was tabulated and/or plotted using bar graphs. Values below the detection limit were assigned a value of ½ the detection limit to facilitate data analysis. In addition, we also utilized box plots to facilitate comparison of the median value and distribution of the data between sites and sampling methods (

Figure **16**). Data was analyzed using the Minitab® 16.1 statistical software package.

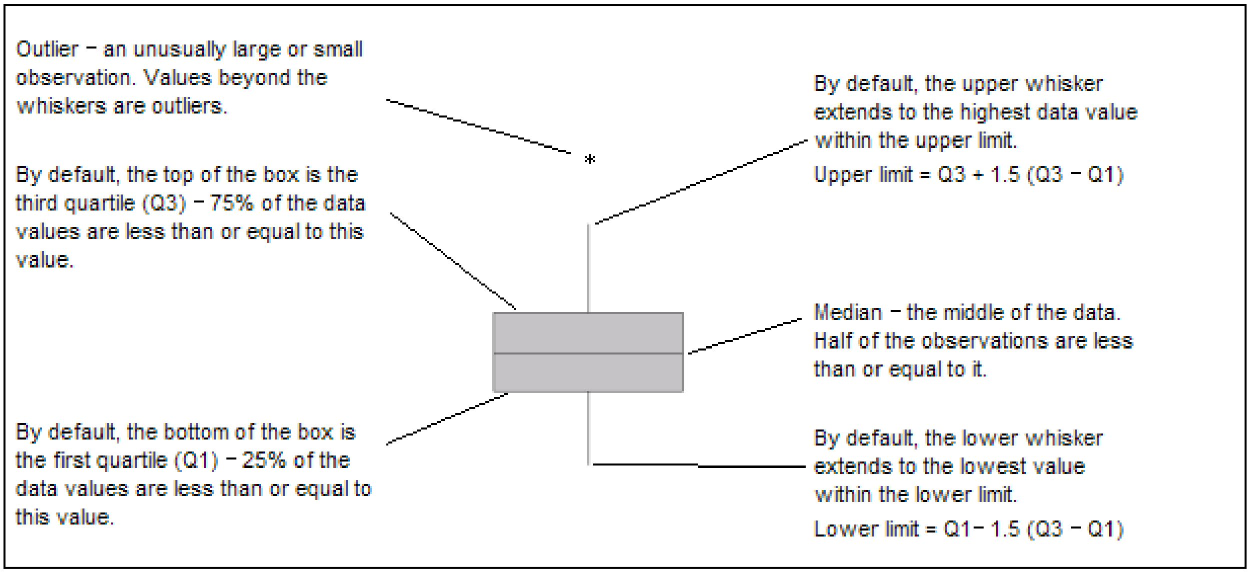


Figure 16. Illustration of boxplot used to analyze distribution of data.

We computed statistics for each variable by collection of data obtained from the three stream reaches (Greens, Little Cypress Creek, Mason Creek) at 9 sites (3 stream systems x 2 restoration and 1 control sites per system) during 4 sampling periods over two years. However during the first year no control site (Greens Main) was monitored for the Greens Bayou sites. Also, as will be discussed later, due to a drought, two sites were not sampled during 2011. A collection was defined as an individual monitoring event at a site during a particular date. For many of the variables measured replicate measurements were made facilitating the use of statistical methods. However, for some variables, only graphical comparisons were possible since these measurements were based on pooled data (IBI metric) or single measurements (e.g. streamflow).

For both benthic and fish collections the total abundance, abundance of numerically abundant species, Shannon-Wiener's Diversity (H), Pielou's evenness (E), Taxa Richness, and Berger Parker Index (BPI or BP) were calculated for each replicate during each collection event (site X date combination) (Krebs 1999; Magurran 2004). The Shannon-Wiener Diversity index (H') is defined as $-\sum P_i (\ln P_i)$ where P_i is the proportion of each species in the sample. Pielou's evenness (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. Richness or number of taxa is a count of the number of species/taxa present in a sample. The Berger Parker Index (d) is defined as N_{max}/N which is the ratio of the most dominant taxa to the total number of organisms collected.

Benthic community (B-IBI) indices, including intermediate metrics, and aquatic life use classifications were calculated using the metrics described and recommended by TCEQ and EPA in Texas (TCEQ 2007). Fish IBI metrics were also calculated including the intermediate metrics and compared to regional expected values provided in (Linam et al. 2002). The experimental design that we used is best described as a repeated measures approach in which replicate measurements of various traits (e.g. fish diversity, benthics, periphyton) were made at each site (treatment) and sampling period (time) combination, or collection. However, due to the high variability and lack of normality we pooled data across dates to compare sites using a non-parametric analysis of variance. A one-way Kruskal Wallis non-parametric ANOVA analyses and associated box plots were conducted to test differences between sites for periphyton biomass, periphyton chlorophyll-*a*, fish and benthic total numbers, Shannon-Wiener diversity, Pielou's Evenness, taxa richness, Berger Parker index scores, and selected water quality and habitat variables. The Kruskal-Wallis test is a nonparametric alternative to a one-way ANOVA. The test does not require the data to be normally distributed, but instead uses the ranks of the data for the analysis. This test performs a hypothesis test of the equality of population medians for a one-way design (two or more populations). A Kruskal-Wallis test looks for differences among the populations' medians. This was followed by Dunn's multiple comparison test when significant differences were detected to determine where these differences occur (Orlich 2010). All univariate analyses were performed with the Minitab® 16.1 statistical software package.

Correlation analysis was also conducted between the average biological metrics described above for fish and benthic communities and physical and chemical variables. This analysis was used to determine the possible relationship between individual abiotic and biotic characteristics (variables) at each site. This was supplemented with principal components analysis (PCA) to characterize the environmental characteristics of each site and how these individual chemical and physical variables may be interrelated and combine into common "factors" or principal components that may influence the distribution of fish and benthic invertebrate community metrics (Peck 2010). PCA is an ordination technique that reduces the number of original variables into a smaller set of linear combination of these variables that can be used to predict interrelationships between variables and observations (Tabachnick and Fidell 2001). All PCA analyses were performed with the PRIMER® 6.1 statistical software package (Clarke and Gorley 2006).

We also utilized two multivariate classification methods called cluster analysis and non-metric dimensional scaling (NMDS) to determine if the community assemblages differ between sites and dates (Tabachnick and Fidell 2001)(Clarke and Warwick 2001). Prior to analysis the average number of organisms collected per replicate was computed for each site and date of collection. All fish taxa were used during the analysis. However, due to the high number of taxa, only benthic taxa occurring in >20% of the collections were used. Prior to analysis all abundance data was log transformed, $\log_e (N_i+1)$, where N is the abundance of species *i*.

Cluster analysis of the fish and benthic community data was conducted to determine the similarity of collections based on gear type, in terms of community composition. The Bray Curtis similarity coefficient and group average linkage method were used for cluster determination using the PRIMER® 6.1 statistical software package (Clarke and Gorley 2006). A dendrogram was produced depicting the similarity of collections and groups of collections. The PRIMER software SIMPROF procedure was employed to estimate and identify a reasonable number of cluster groupings by testing for internal structure in newly created groups. Cluster analysis was also used to classify sites according to similarity of physicochemical data using standardized variables and Euclidean distance.

Non-metric dimensional scaling (NMDS) was used to complement the results of cluster analysis by evaluating the similarity of sites in a non-hierarchical approach (Clarke and Gorley 2006). The Bray Curtis similarity coefficient was used to determine the similarity and distance between collections based on fish and benthic community structure by sampling method using the

PRIMER® 6.1 statistical software package. This was not done with physicochemical data since PCA was used for ordination of this data set.

Results

Meteorology and Hydrology

Rainfall during the study period when collections were made was generally low. During 2011 a statewide drought resulted in very dry conditions leading to a drying out of many streams and lowering of lake levels in southeast Texas (Nielsen-Gammon 2011). During this study rainfall amounts generally declined from 2010 through 2011 with rainfall concentrated most often during the early spring and late fall (Figure 17 - 21). Overall rainfall amounts and frequency were lower during 2011 in comparison to 2010. Total cumulative monthly precipitation seldom exceeded 4 inches during the study period which extended from May 1 to October 1 of each year. The highest monthly and daily precipitation occurred during July 2010. The lowest monthly and daily precipitation generally occurred during February through June 2011. During 2011, the cumulative 24 hour and 3 day precipitation was generally lower than 0.1 and 1.0 respectively (Figure 19 and 20). In addition, the number of days since the last significant (0.1 inches) rainfall event occurred was longer during 2011 (< 35 days) versus in 2010 (< 12 days) (Figure 21).

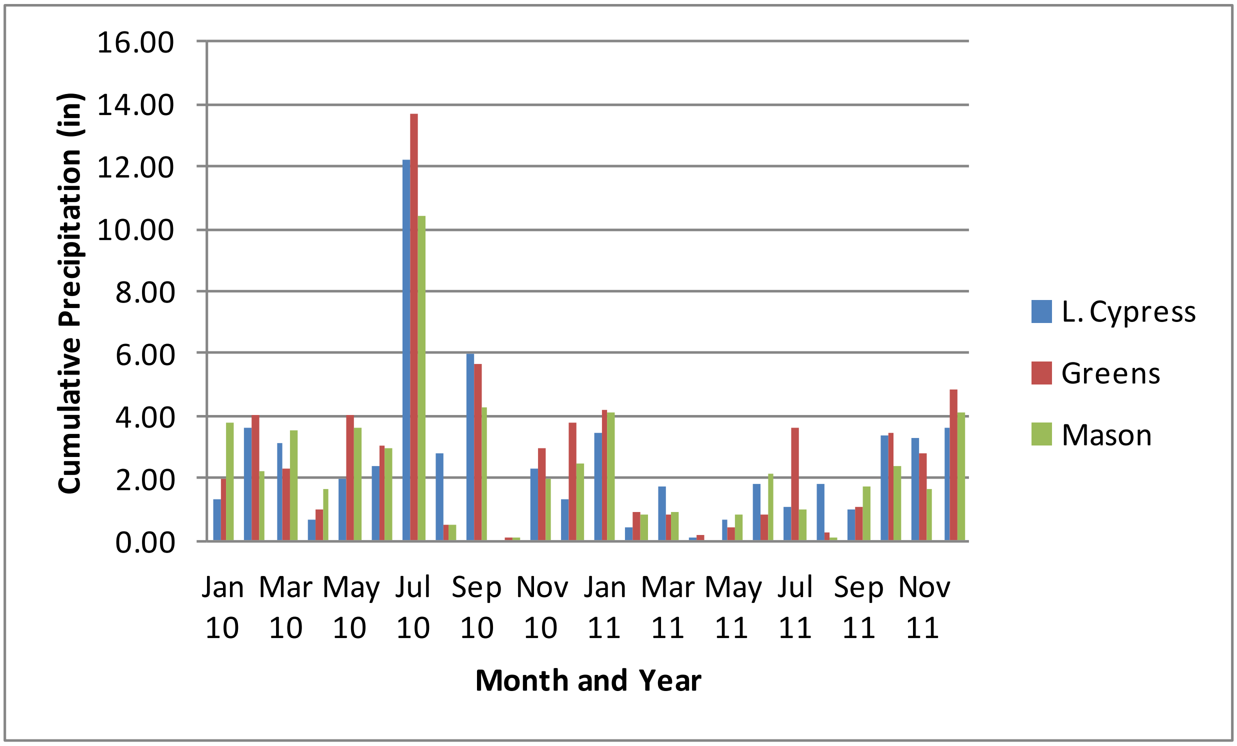


Figure 17. Monthly cumulative precipitation at each restoration site during 2010 and 2011.

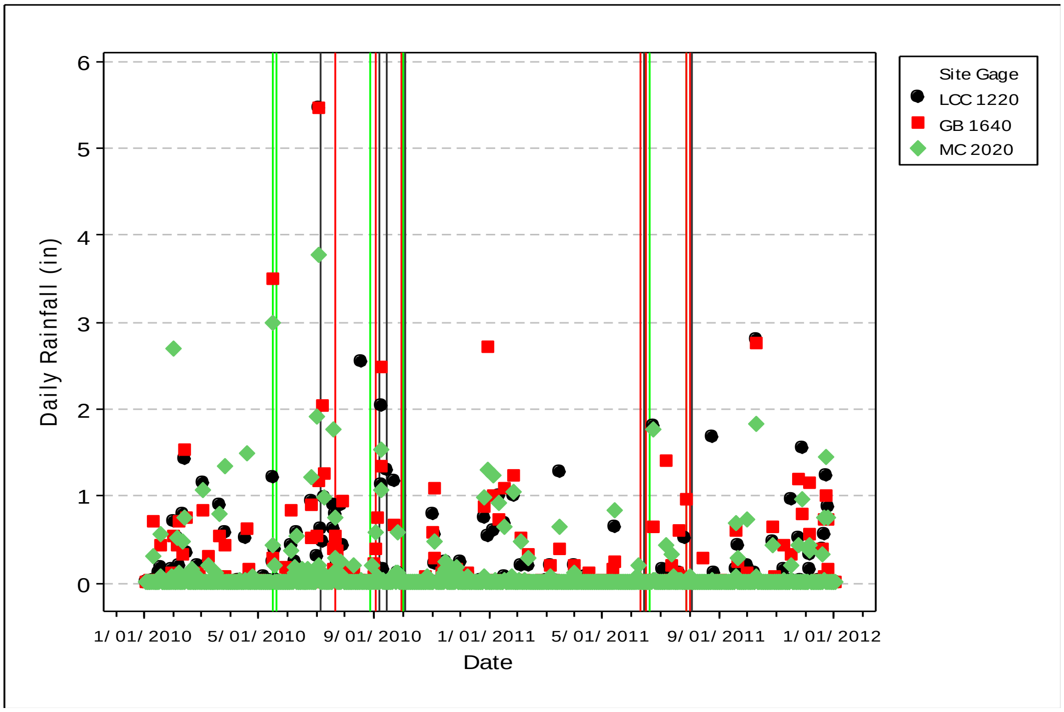


Figure 18. Daily 24 hour precipitation measured at rain gages near survey sites during study period. Vertical lines denote sampling dates at each site.

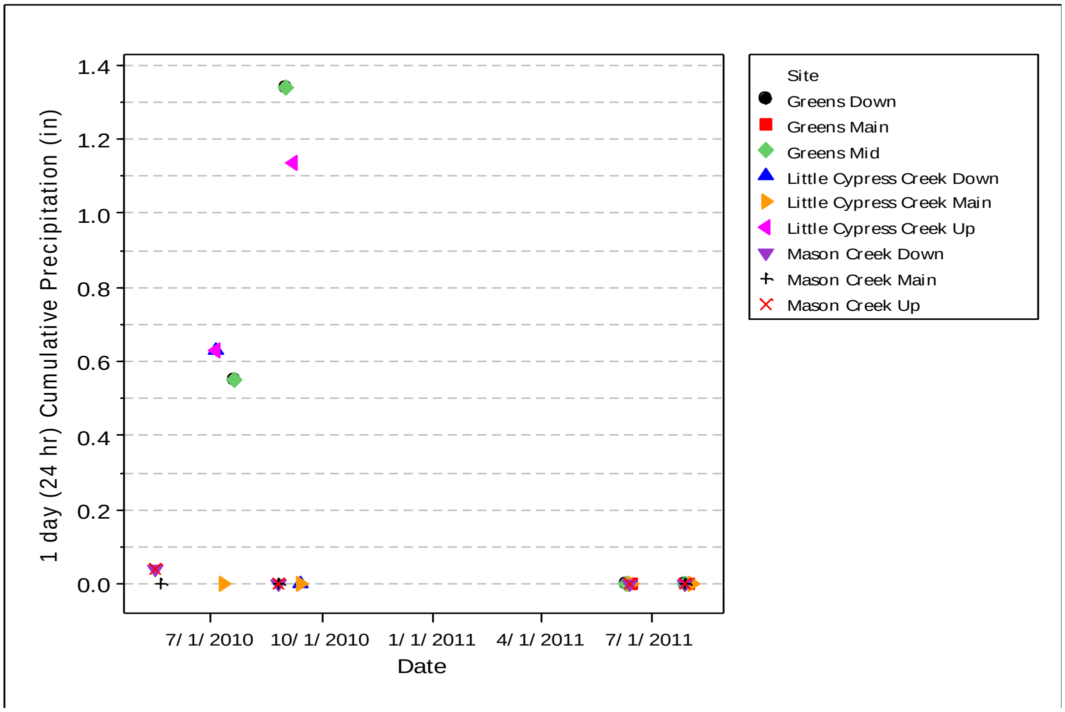


Figure 19. Cumulative 24 hour precipitation at each monitoring site and date. Data obtained from the HCFWS rainfall gages 1640 P100 Greens Bayou at US 59, 1220 L100 Little Cypress Creek at Cypress Hill Road, 2020 T101 Mason Creek at Prince Creek Drive.

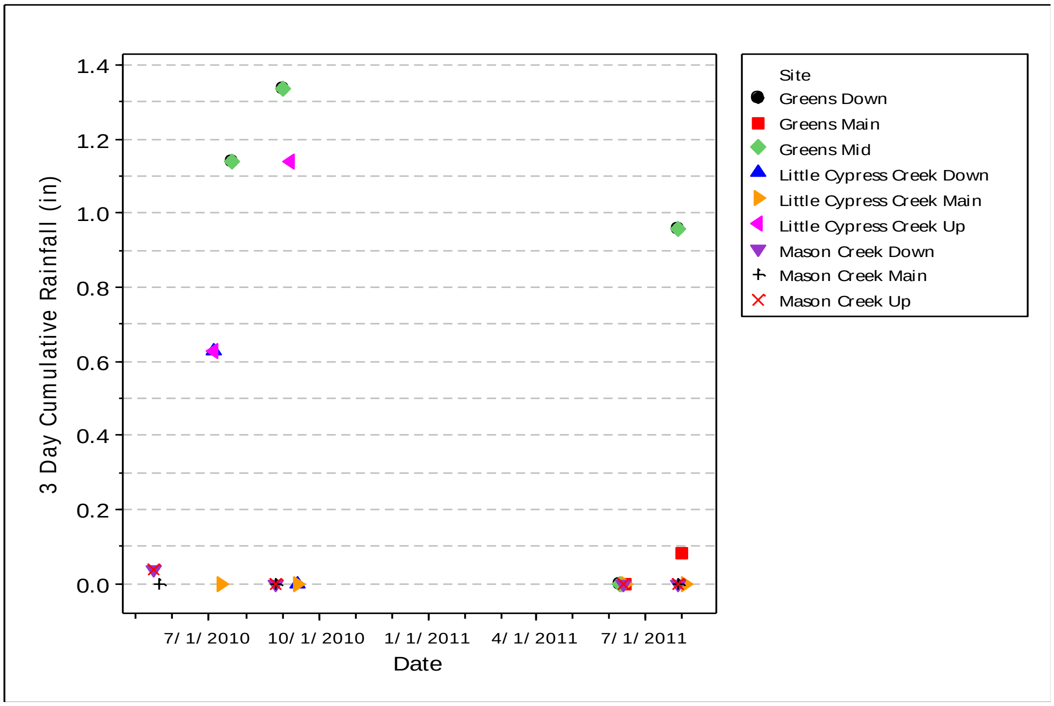


Figure 20. Cumulative 3 day precipitation at each monitoring site and date. Data obtained from the HCFWS rainfall gages 1640 P100 Greens Bayou at US 59, 1220 L100 Little Cypress Creek at Cypress Hill Road, 2020 T101 Mason Creek at Prince Creek Drive.

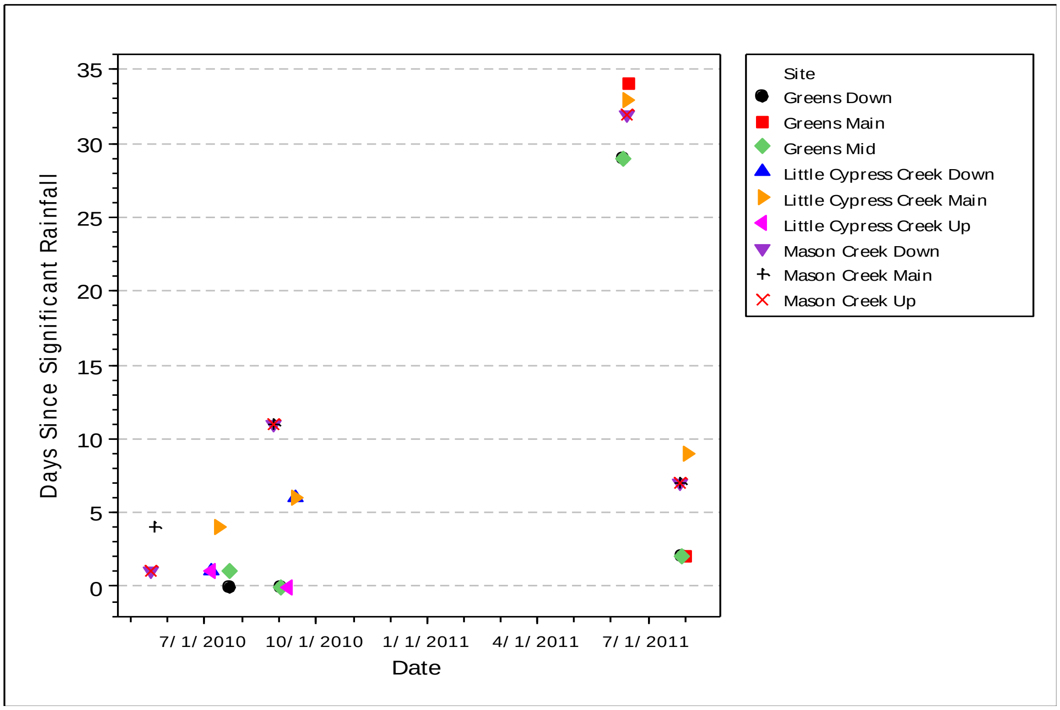


Figure 21. Days since significant rainfall at each monitoring site and date. Data obtained from the HCFWS rainfall gages 1640 P100 Greens Bayou at US 59, 1220 L100 Little Cypress Creek at Cypress Hill Road, 2020 T101 Mason Creek at Prince Creek Drive.

Watershed Land Use

The watershed land use data for each restoration site varied considerably (Table 4 and Figure 22). The site with the largest contributing watershed was the Greens Bayou main (GBMN) site (Table 4). In contrast the site with the smallest watershed was the Mason Creek Main (MCMN) site. The sites with the highest upstream percentage of impervious surface were those associated with the Greens Bayou sites (Table 4 and Figure 22).

Table 4. Contributing watershed size and estimated land use above each site.

Site	MCU	MCD	MCM	GBM	GBD	GBMA	LCU	LCD	LCM
Site Name	Mason Creek Up	Mason Creek Down	Mason Creek Main	Greens Bayou Middle	Greens Bayou Down	Greens Bayou Main	Little Cypress Creek Up	Little Cypress Creek Down	Little Cypress Creek Main
HCFCD ID	T101-01-00	T101-01-00	T101-01-00	L100-00-00	L100-00-00	L100-00-00	P138-00-00	P138-00-00	P100-00-00
Latitude	29.808920	29.808929	29.794116	29.917560	29.919082	29.921350	30.011103	30.004717	30.000263
Longitue	-95.798473	-95.793894	-95.785117	-95.343166	-95.341227	-95.342535	-95.67292	-95.666596	-95.66543
Total Contributing Watershed (Hectare)	314.00	1,123.00	173.00	1,599.00	275.00	14,260.00	476.00	607.00	11,503.00
Total Impervious Area (hectare)	30.00	52.00	30.00	705.00	109.00	5,275.00	21.00	25.00	300.00
% Total Impervious Area	9.55	4.63	17.34	44.09	39.64	36.99	4.41	4.12	2.61
% High Intensified Developed	15.92	8.58	29.48	37.40	30.55	34.18	5.67	5.34	4.16
% Low Intesified Developed	19.11	8.13	18.50	45.78	52.73	34.47	13.45	10.76	4.18
% Open Space Developed	3.82	2.57	1.73	3.75	1.09	5.10	3.99	3.07	0.40
% Cultivated	28.66	52.28	15.61	0.00	0.00	0.00	34.87	39.63	62.68
% Grassland/Shrub	30.89	24.32	22.54	8.07	5.09	11.58	22.90	18.34	12.75
% Forest	0.64	0.63	4.62	2.25	6.18	7.64	8.61	8.67	5.00
% Woody Wetland	0.00	0.45	5.78	2.06	3.27	3.61	5.04	8.91	5.85
% Herbaceous Wetland	0.32	0.32	0.58	0.50	0.73	1.27	3.36	3.19	1.89
% Bare	0.64	2.13	0.00	0.06	0.00	1.92	1.89	1.79	2.07
% Open Water	0.00	0.55	1.16	0.00	0.00	0.23	0.42	0.28	1.01

Figure 22. Estimated upstream land use at each site surveyed during the study.

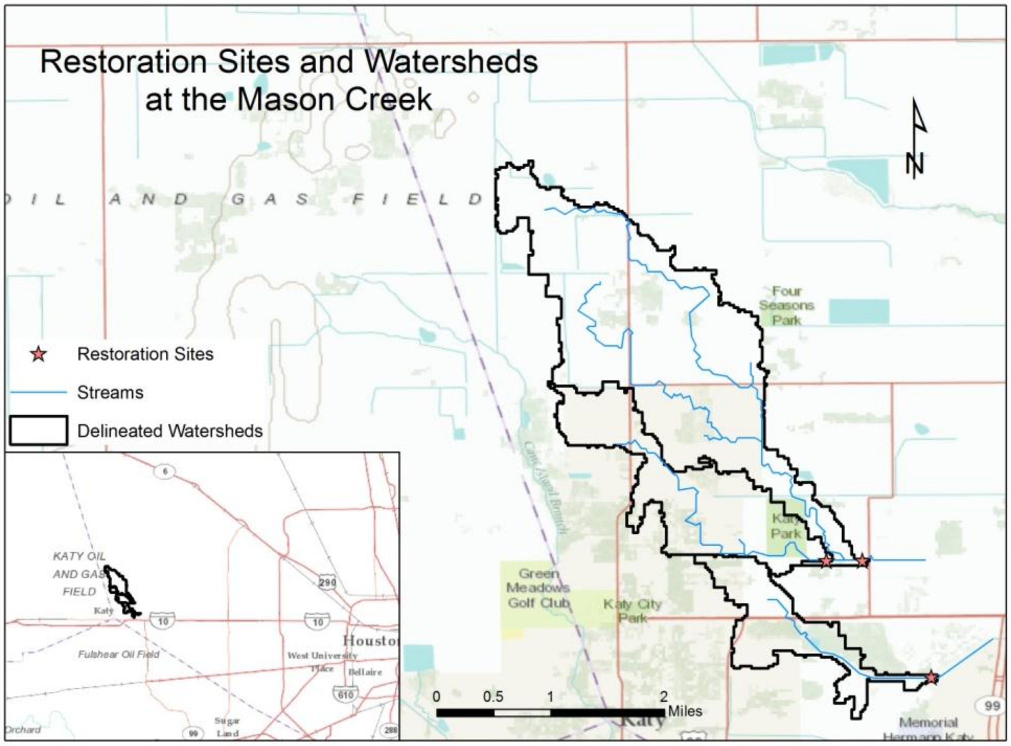


Figure 23. Mason Creek restoration sites and associated drainage basin.

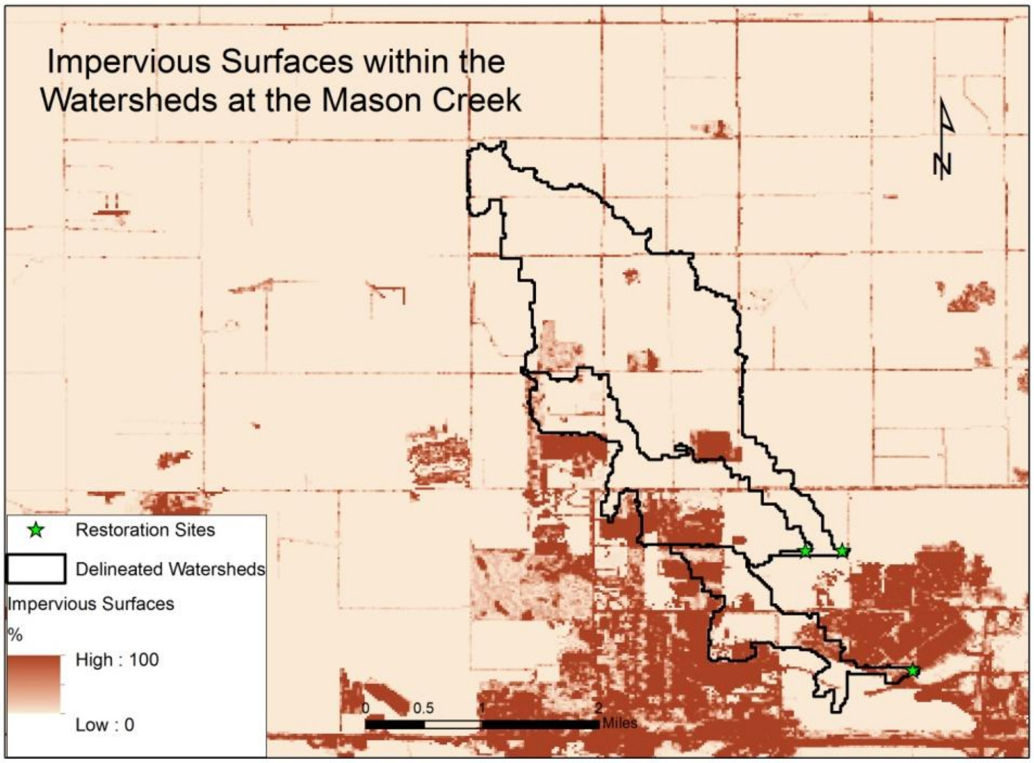


Figure 24. Amount of impervious surface area within the Mason Creek watershed as determined from USGS LULC data.

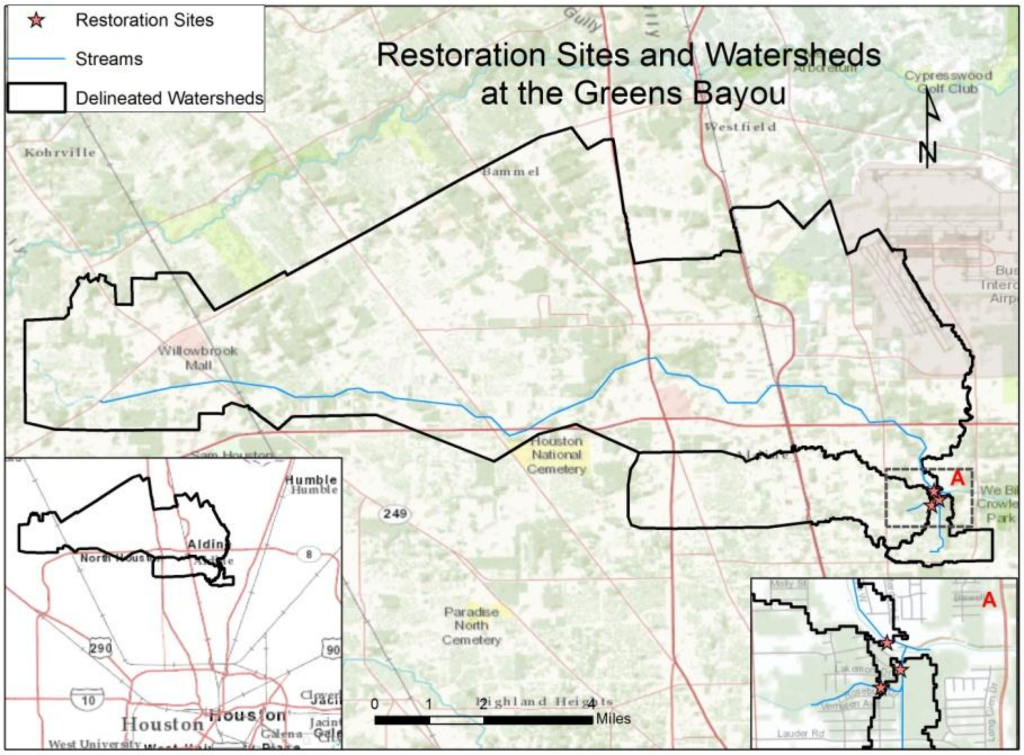


Figure 25. Greens Bayou restoration sites and associated drainage basin.

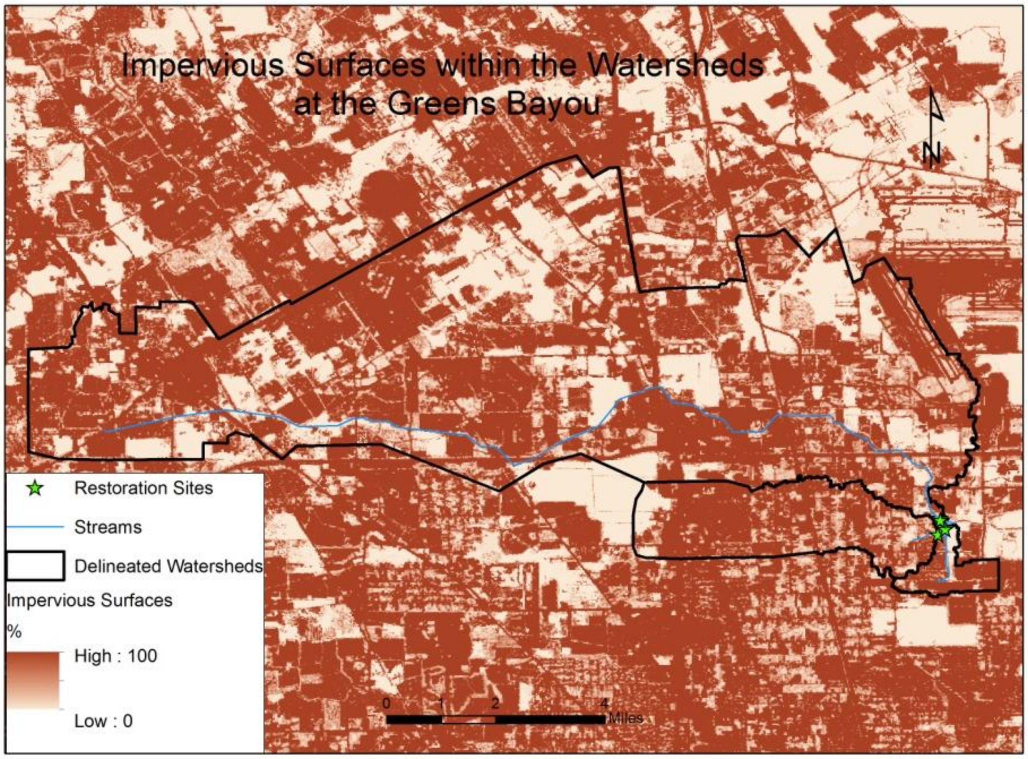


Figure 26. Amount of impervious surface area within the Greens Bayou watershed as determined from USGS LULC data.

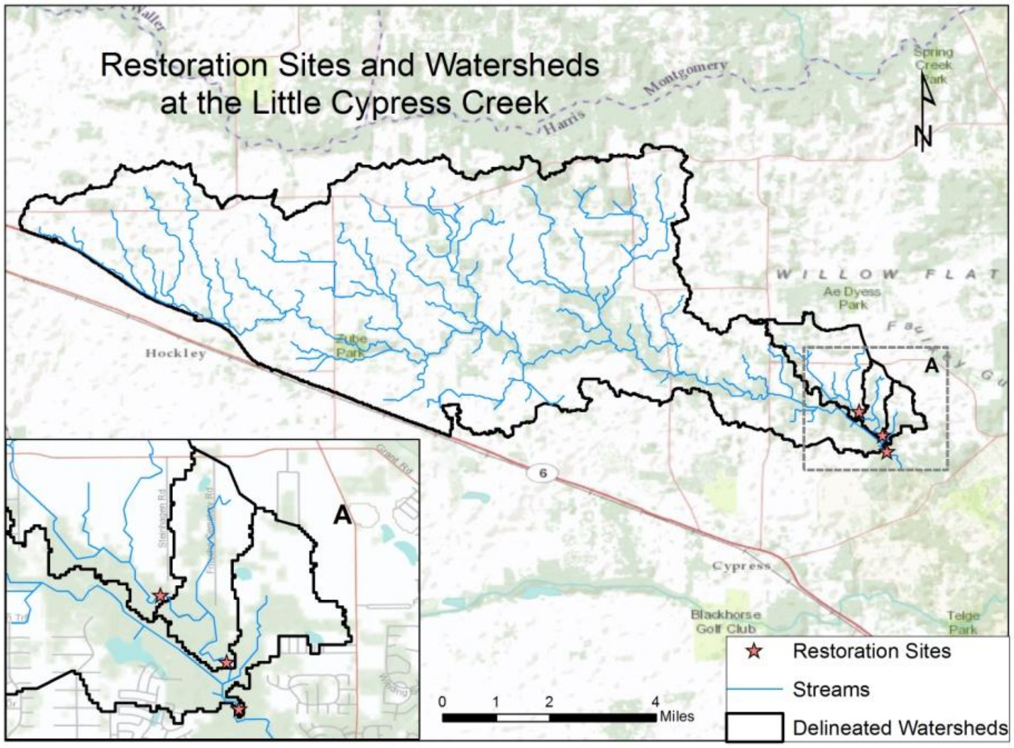


Figure 27. Little Cypress Creek restoration sites and associated drainage basin.

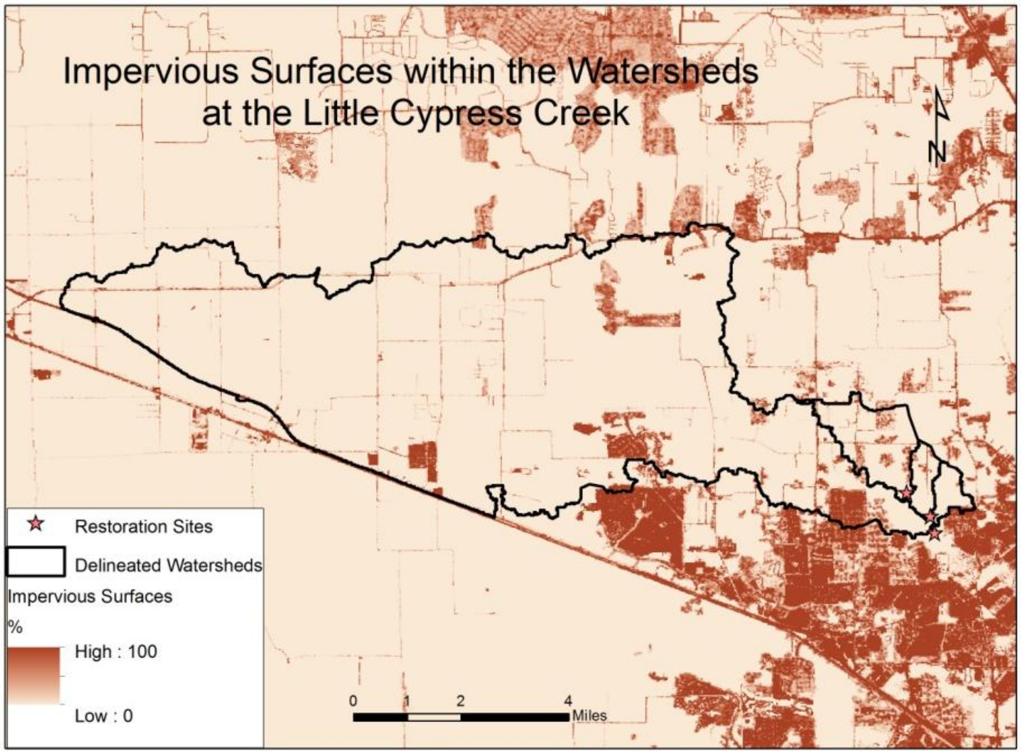


Figure 28. Amount of impervious surface area located within the Little Cypress Creek watershed. Source: USGS LULC data.

Physical Habitat and Hydrology

The description of the major physical habitat attributes present at each site is provided in Table 5 and subsequent figures. Average stream width was determined by averaging three measurements (upstream extent, middle reach and downstream extent) during each collection at each site. The average stream width ranged between 1.8 and 12.9 m. (Figure 29). The widest stream site was the Greens Bayou mainstream site (GBMN). The Mason Creek Upstream (MCUP) site also exhibited high median average stream widths, but also high variation, due in part to the temporary dam that was placed there during 2010 and subsequently removed in 2011. Average stream widths were less than 7 meters at the remaining sites. The Little Cypress Creek Downstream (LCDN) site exhibited the smallest average stream width. Stream thalweg depths ranged between 0.15 and 0.69 m. (Figure 30). With the exception of Greens Bayou sites, sediment type was similar between sites consisting primarily of fine silt (Figure 31). The sediment at Greens Bayou consisted of clay, silt, sand and small amounts of gravel.

Stream velocity was highest at the Greens Bayou sites and in general at the mainstem control sites (Figure 32). The majority of sampling events occurred during very low (<0.5 cfs) stream velocities (Table 5). Streamflow was also very low (<1 cfs) during most collections with the exception of the Greens Bayou sites and the Little Cypress Creek Mainstem (LCMN) site (Figure 33). The highest streamflow was encountered at the Greens Bayou Mainstem (GBMN) site. This is in part due to the much larger contributing watershed that had a high percentage of impervious surface, located upstream of this site (Figure 22 and Table 4).

With the exception of the mainstem control and upper Mason Creek Upstream (MCUP) sites, most sites exhibited average percent shading ranging from approximately 20 to 94% (Figure 34 and Table 5). The Little Cypress Creek Mainstem (LCMN) was the most shaded mainstem control site due to the extensive riparian tree coverage (Figure 12). The Greens Bayou Mainstem (GBMN) site exhibited the largest stream width, which probably contributed to the observed lowest percent shading (Figure 29 and 9). In addition, during the study period the stream bank at the Greens Bayou mainstem (GBMN) site was actively mowed, resulting in very sparse tall shade producing riparian vegetation. Submerged and emergent vegetation varied considerably between sites (Figures 35 - 36). In general, the tributary sites contained more submerged vegetation covering the stream bottom, percentage wise, than the mainstem sites (Figure 35). The Mason Creek sites contained the highest percentage of emergent vegetation ranging between 17 to 100% in contrast to the other sites which exhibited lower levels (< 25%) (Figure 35).

Table 5. Physical and hydrological attributes present at each site and collection period during 2010 and 2011[1].

Collection	Max. Depth (m)	Avg. Width (m)	Flow (cfs)	Thalweg Velocity (f/s)	Avg. Sediment Score	Avg. % Shading	Avg. % Sub. Veg.	Avg. % Emerg. Veg.
GRDN0710	0.35	4.6	2.4880	0.71	1.0	45.10	0.00	5.0
GRDN0910	*NM*	*NM*	*NM*	*NM*	*NM*	*NM*	*NM*	*NM*
GRDN0611	0.23	3.1	0.3806	0.21	0.0	73.53	20.00	5.0
GRDN0711	0.23	2.8	0.8249	-0.10	0.2	94.12	0.00	1.7
GRMI0710	0.69	5.3	1.9600	0.07	0.9	51.96	0.00	3.3
GRMI0910	*NM*	*NM*	*NM*	*NM*	*NM*	*NM*	*NM*	*NM*
GRMI0611	0.56	5.2	0.0000	0.00	0.0	20.59	70.00	5.0
GRMI0711	0.58	4.6	0.9071	0.22	0.0	79.41	0.00	0.3
GRMN0611	0.44	12.9	26.9530	0.89	0.3	2.94	1.67	31.7
GRMN0811	0.46	12.4	31.8270	1.13	0.4	0.00	0.00	6.7
LCDN0710	0.15	2.0	0.0860	0.05	0.0	74.51	0.00	10.0
LCDN0910	0.15	2.7	0.0080	0.13	0.0	94.12	3.33	30.0
LCMN0710	0.60	4.6	2.0170	0.11	1.0	68.63	0.00	0.3
LCMN0910	0.66	5.0	18.0920	0.85	0.1	71.57	0.00	6.7
LCMN0611	0.31	3.5	0.0000	0.00	0.6	75.49	38.33	11.7
LCMN0811	0.30	3.7	0.0027	0.00	0.1	71.57	30.00	3.3
LCUP0710	0.33	5.4	-0.0600	0.00	0.1	91.18	0.00	0.7
LCUP0910	0.35	5.9	0.1160	0.27	0.0	88.24	0.00	10.0
MCDN0510	0.30	7.3	0.5290	0.42	0.0	50.00	0.00	88.3
MCDN0810	0.09	1.8	0.0040	0.01	0.0	85.29	0.00	100.0
MCDN0611	0.24	4.1	0.0000	*NM*	0.0	8.82	20.00	15.0
MCDN0711	0.22	2.6	0.0000	0.00	0.0	39.22	8.33	31.7
MCMN0510	0.54	6.8	-0.0190	0.01	0.0	0.00	0.00	60.0
MCMN0810	0.57	4.5	-0.0322	0.01	0.0	0.00	0.00	71.7
MCMN0711	0.38	5.5	0.0000	0.00	0.0	0.00	3.33	61.7
MCUP0510	0.40	12.5	1.1710	0.06	0.0	3.92	38.33	26.7
MCUP0810	0.27	7.2	0.0001	0.02	0.0	0.00	16.67	85.0
MCUP0611	0.28	6.6	0.0000	*NM*	0.0	25.49	5.00	90.0
MCUP0711	0.27	5.4	0.0000	0.00	0.0	35.29	13.33	70.0

[1] G = Greens Bayou, LC = Little Cypress Crk, MC - Mason Crk, DN = down, MI = middle, UP = up, MN = mainstem control, *XX*11 or *XX*12 = sample month and year, *NM* = not measured. Due to drought conditions LCDN and LCUP were not monitored during 2011.

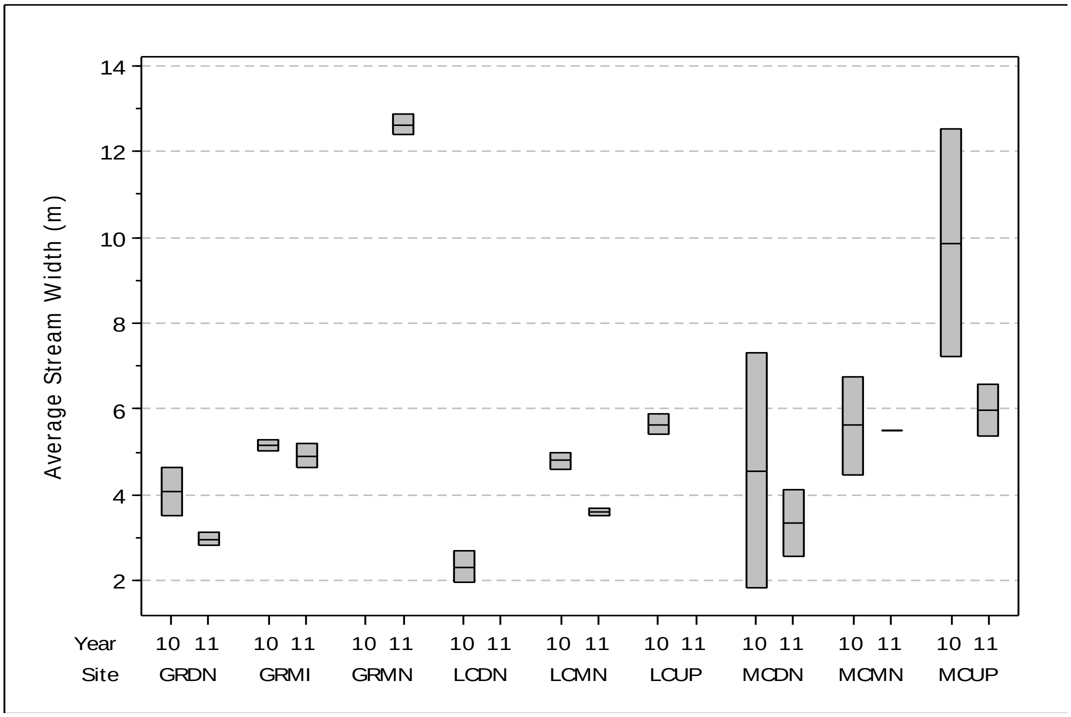


Figure 29. Boxplot of average stream width at each site during 2010 and 2011. GR = Greens Bayou; LC= Little Cypress Creek; MC = Mason Creek; DN = down, MN = main, MI = middle, UP = up. LCDN and LCUP were not monitored during 2011 and GRMN was not monitored in 2010.

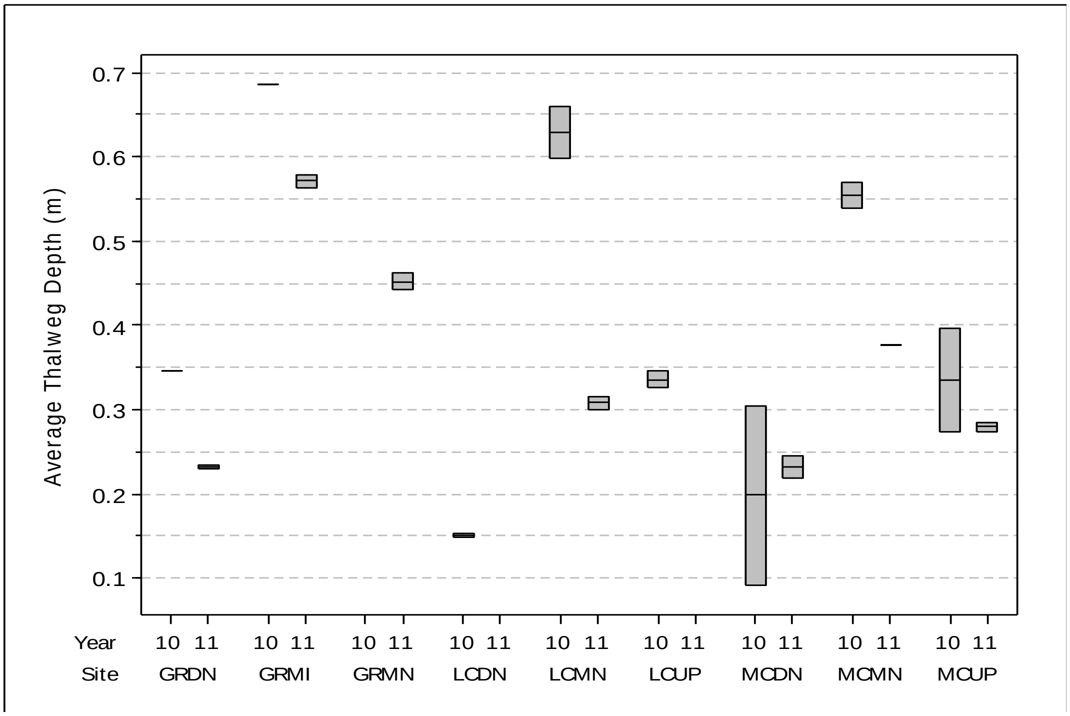


Figure 30. Boxplot of average thalweg depth at each site during 2010 and 2011. GR = Greens Bayou; LC= Little Cypress Creek; Mason Creek; DN = down, MA = main, MI = middle, UP = up. LCDN and LCUP were not monitored during 2011 and GRMN was not monitored in 2010.

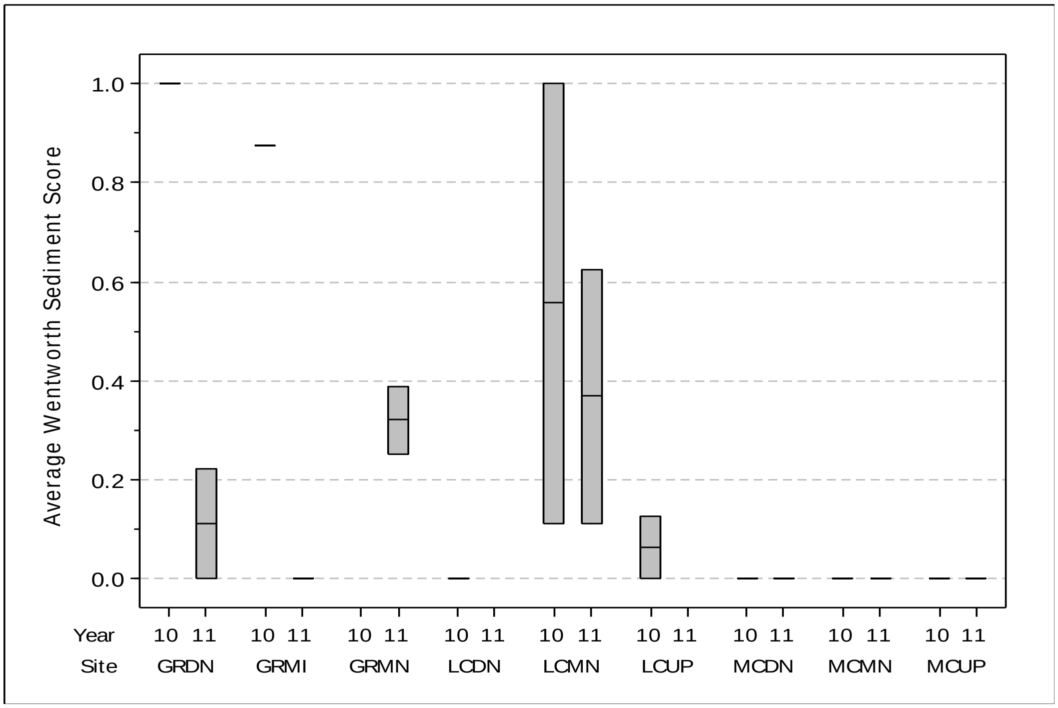


Figure 31. Boxplot of average Wentworth sediment score at each site during 2010 and 2011. GR = Greens Bayou; LC= Little Cypress Creek; Mason Creek; DN = down, MI = middle, MN = main, UP = up. LCDN and LCUP were not monitored during 2011 and GRMN was not monitored in 2010.

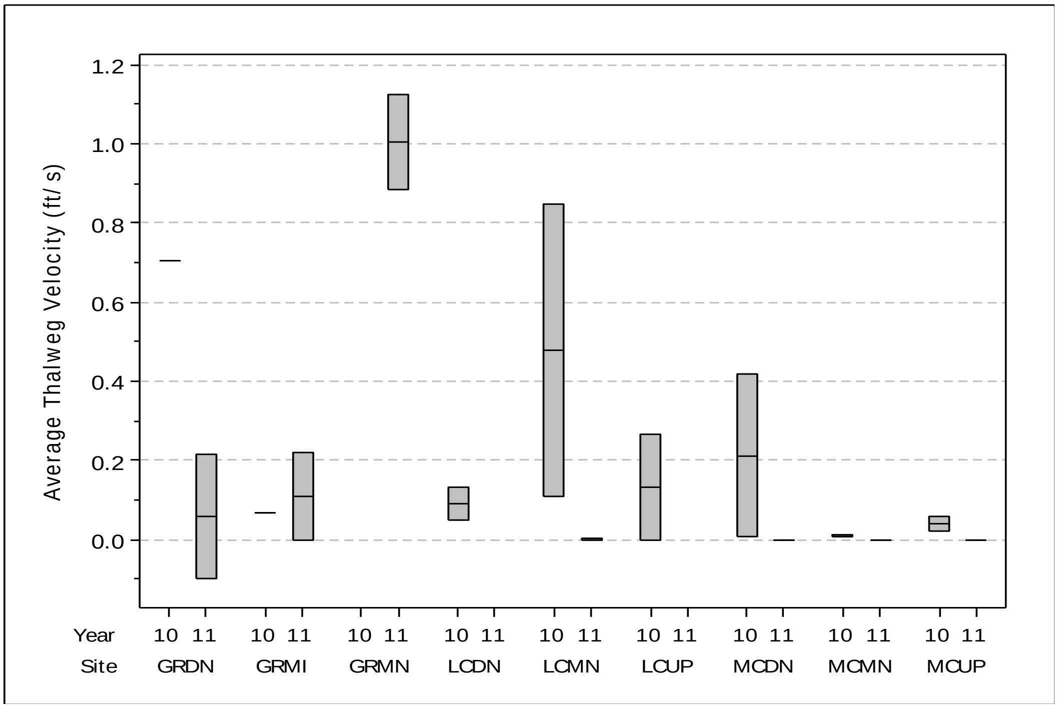


Figure 32. Boxplot of average thalweg velocity at each site during 2010 and 2011. GR = Greens Bayou; LC= Little Cypress Creek; MC = Mason Creek; DN = down, MI= middle, MN = main, UP = up. LCDN and LCUP not monitored during 2011; GRMN not monitored in 2010.

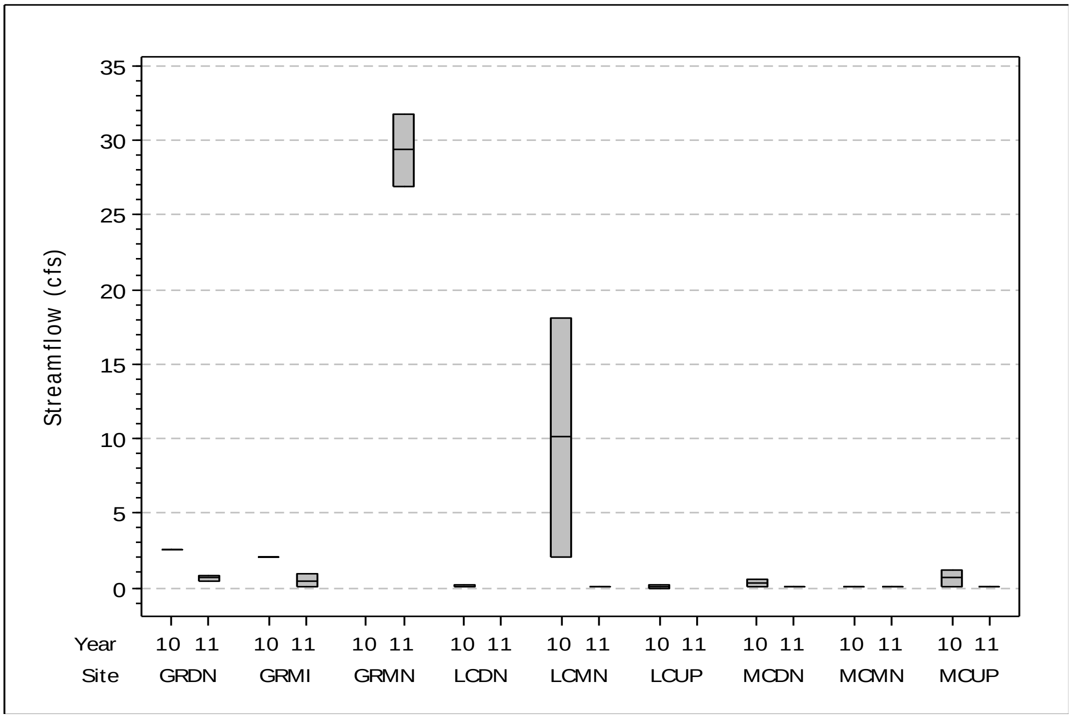


Figure 33. Boxplot of estimated streamflow at each site during 2010 and 2011. GR = Greens Bayou; LC = Little Cypress Creek; MC = Mason Creek; DN = down, MN = main, MI = middle, UP = up. LCDN and LCUP not monitored during 2011; GRMN not monitored in 2010.

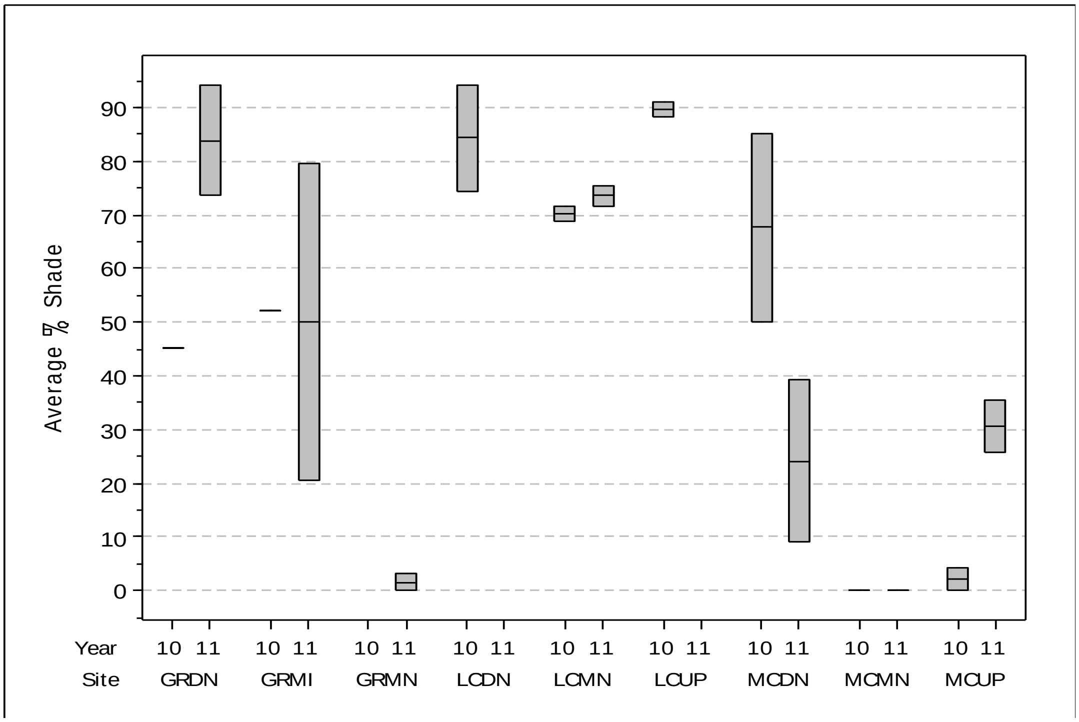


Figure 34. Boxplot of average percent riparian shading measured at each site during 2010 and 2011. GR = Greens Bayou; LC= Little Cypress Creek; MC = Mason Creek; DN = down, MN = main, MI = middle, UP = up. LCDN and LCUP not monitored during 2011; GRMN not monitored in 2010.

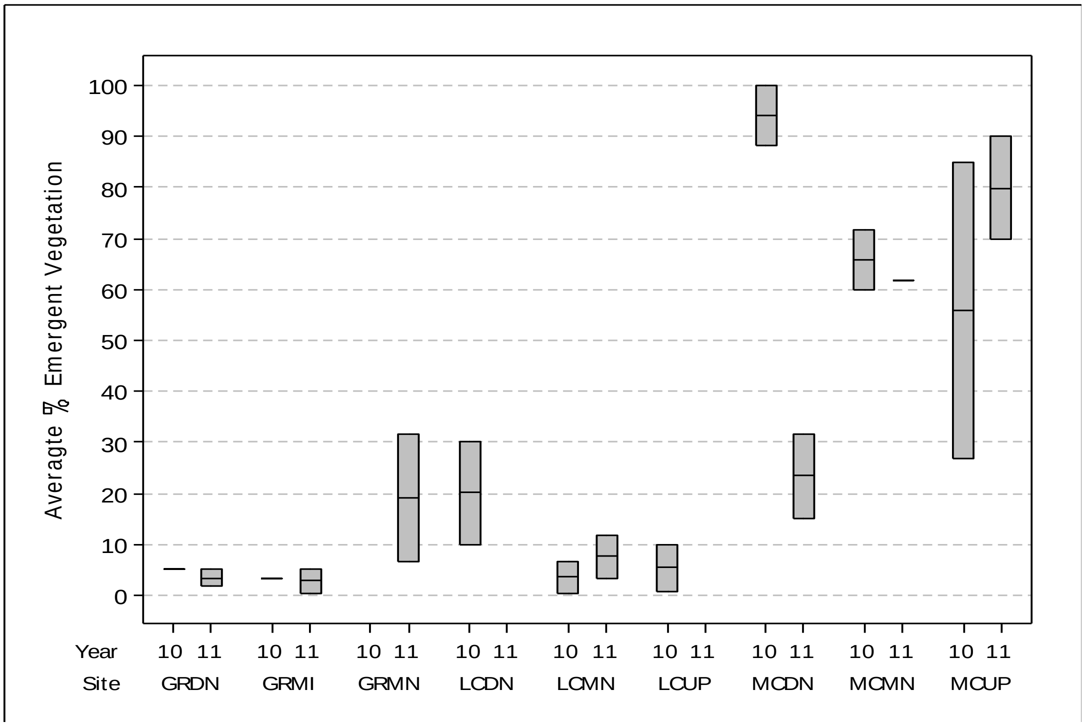


Figure 35. Boxplot of observed instream emergent vegetation coverage measured at each site during 2010 and 2011. LCDN and LCUP were not monitored during 2011; GRMN was not monitored in 2010. LCDN and LCUP not monitored during 2011; GRMN not monitored in 2010.

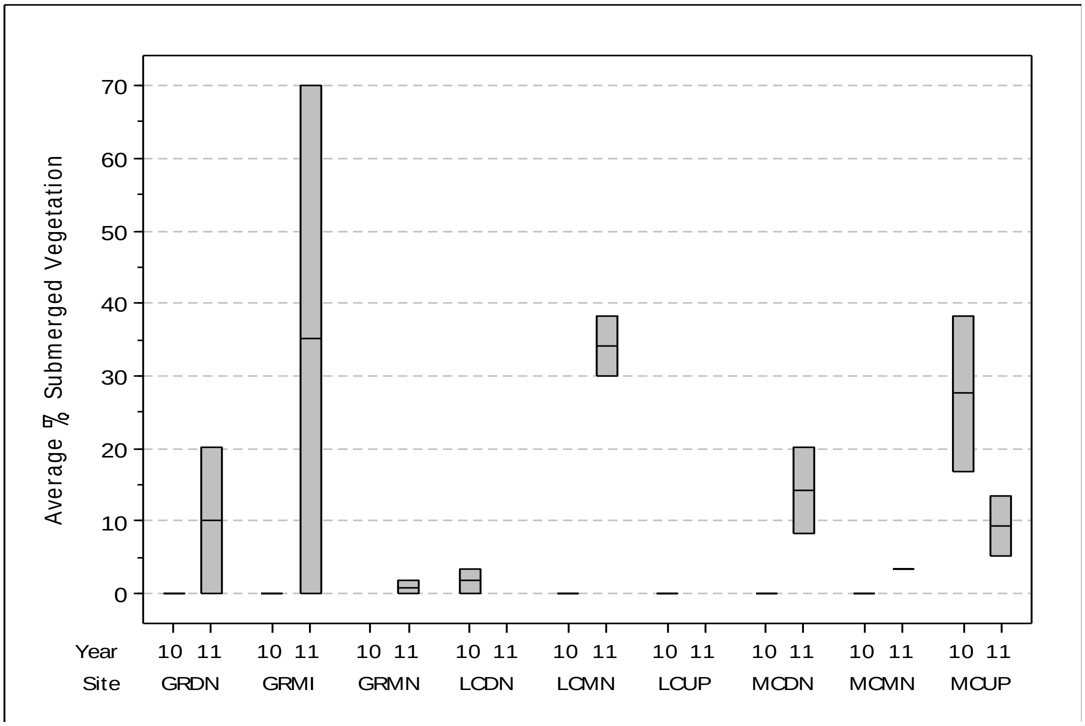


Figure 36. Boxplot of observed instream submerged vegetation coverage measured at each site during 2010 and 2011. LCDN and LCUP not monitored during 2011; GRMN not monitored in 2010.

Stream macrohabitat was not monitored at Greens Bayou sites during the second sampling period in 2010 due in part, to a loss or theft of equipment from vehicle prior to sampling that day. However, conditions were qualitatively similar to the first period (e.g. low base flows, no precipitation, and clear skies). With the exception of possibly stream flow, it is highly unlikely the physical habitat deviated much between collection periods at these sites. We therefore utilized the same values recorded during the first sampling period for use in computation of habitat metrics and statistical analyses when required.

The macrohabitat at each site consisted primarily of either pools or runs (Table 6). The only riffle habitat was observed at the Greens Bayou Downstream (GBDN) site. Stream banks at each site were similar and relatively steep (>45°) with the exception of the Mason Creek sites. These results suggest that riffle habitat is limited at most sites. This is partially related to low or non-existent stream flows and velocities observed at most sites during the study period (Figures 32 and 33).

Water Quality

The Greens Bayou and Little Cypress sites generally exhibited the highest water temperatures (Figure 37). This was most likely due to sampling being conducted during the warmer months of July and September at these sites during 2010 (Table 1). Water temperatures were also generally higher during 2011 in contrast to 2010 due to a later sampling period and the lack of rainfall in 2011 (Figure 17).

The pH measured during the study was neutral to slightly acidic reflecting the high organic content of many of the sites (Little Cypress and Mason Creeks) which contained large amounts of leaf litter (Figure 38). Specific conductance at 25 °C was slightly lower at the future Little Cypress Creek restoration sites (LCUP and LCDN), which suggests most of the water at this site is derived from rainfall and local runoff (Figure 39).

Dissolved oxygen levels varied considerably between sites (Figure 40). Levels exceeding supersaturation were observed at the Little Cypress Creek Downstream (LCDN) during the study period (Figure 41). Other sites generally exhibited lower dissolved oxygen levels ranging between 2.0 and 6.0 mg/l.

Table 6. Macrohabitat observed at each site during 2010 and 2011[1].

Collection	% Pool	% Run	% Riffle	Avg. Bank Slope Degrees
GRDN0710	0	70	30	46.7
GRDN0910	0	70	30	46.7
GRDN0611	0	70	30	40.8
GRDN0711	0	100	0	45.8
GRMI0710	0	100	0	50.0
GRMD0910	0	100	0	50.0
GRMI0611	100	0	0	53.3
GRMI0711	0	100	0	72.5
GRMN0611	0	100	0	44.0
GRMN0811	0	100	0	49.5
LCDN0710	0	100	0	37.0
LCDN0910	0	100	0	38.3
LCMN0710	0	100	0	23.7
LCMN0910	0	90	10	53.3
LCMN0611	100	0	0	37.5
LCMN0811	0	100	0	50.5
LCUP0710	0	100	0	50.0
LCUP0910	100	0	0	35.0
MCDN0510	0	100	0	6.7
MCDN0810	0	100	0	11.7
MCDN0611	100	0	0	6.2
MCDN0711	90	10	0	28.5
MCMN0510	0	100	0	19.2
MCMN0810	0	100	0	45.0
MCMN0711	100	0	0	19.7
MCUP0510	100	0	0	10.4
MCUP0810	100	0	0	15.0
MCUP0611	100	0	0	3.7
MCUP0711	100	0	0	9.0

[1] G = Greens Bayou, LC = Little Cypress Crk, MC - Mason Crk, DN = down, UP = up, MN = mainstem, MI= middle, 0*X* = Month, 1*X* = Year.

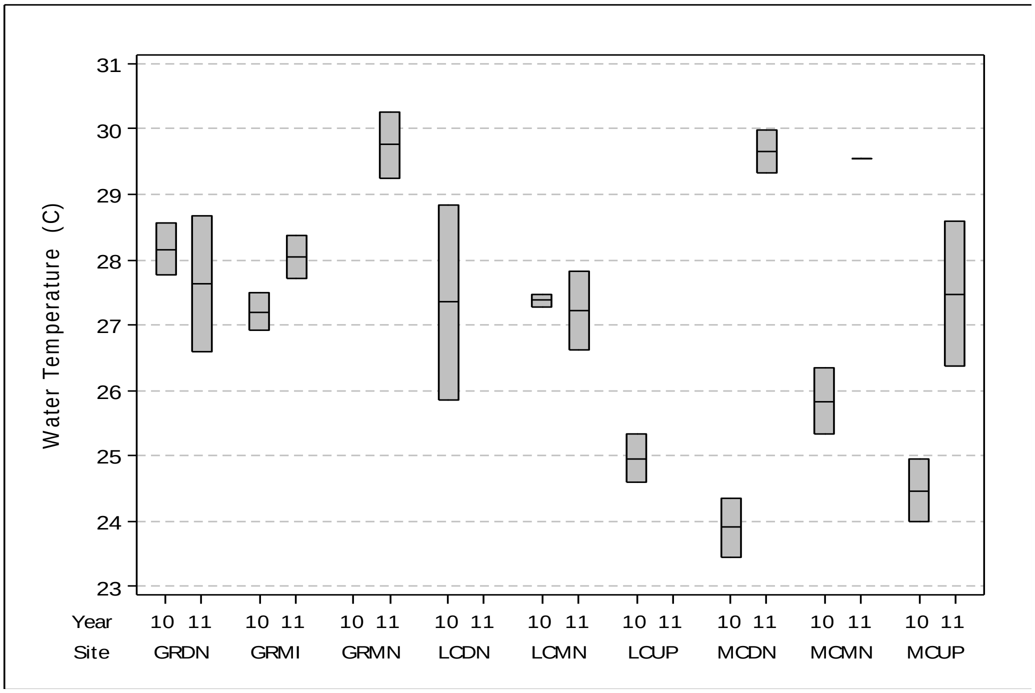


Figure 37. Boxplot of water temperature measured at each site during 2010 and 2011. GR = Greens Bayou, LC = Little Cypress Crk, MC - Mason Crk, DN = down, UP = up, MN = mainstem control for MI for Mid. LCDN and LCUP were not monitored during 2011; GRMN was not monitored in 2010.

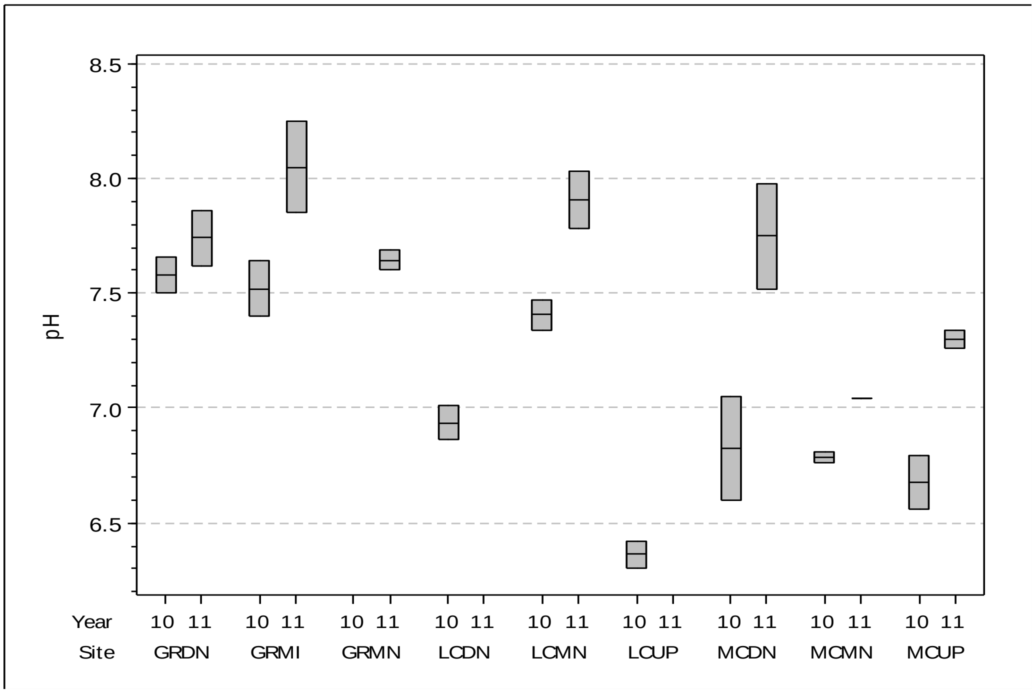


Figure 38. Boxplot of pH levels measured at each site during 2010 and 2011. GR = Greens Bayou, LC = Little Cypress Crk, MC - Mason Crk, DN = down, UP = up, MN = mainstem control for MI for Mid. LCDN and LCUP were not monitored during 2011; GRMN was not monitored in 2010.

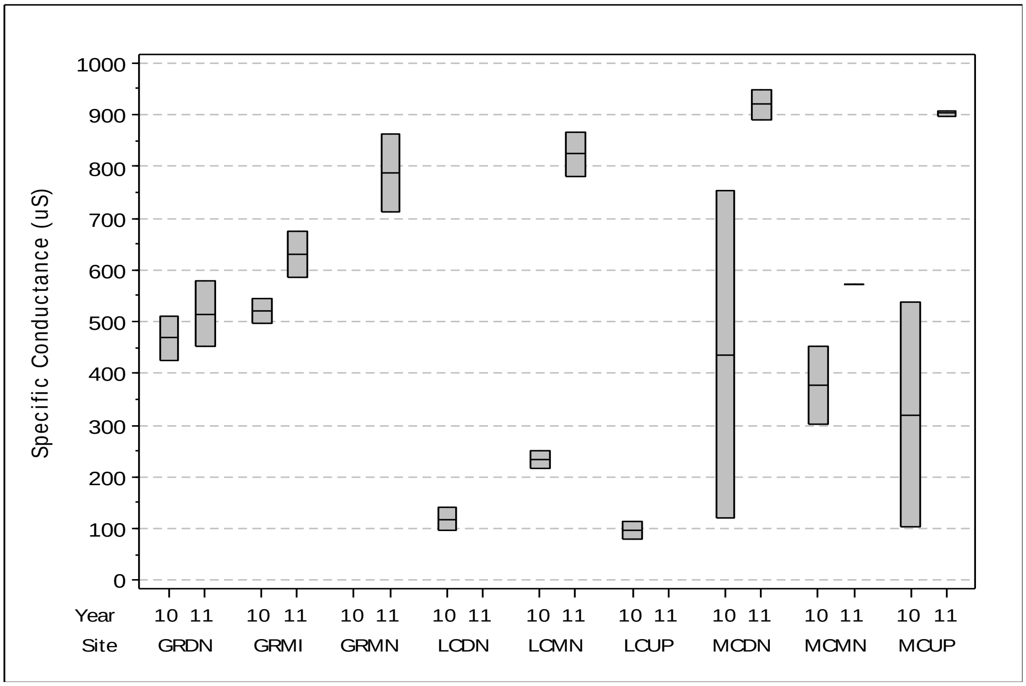


Figure 39. Boxplot of specific conductance @ 25 C measured at each site during 2010 and 2011. GR = Greens Bayou, LC = Little Cypress Crk, MC - Mason Crk, DN = down, UP = up, MN = mainstem control for MI for Mid. LCDN and LCUP were not monitored during 2011; GRMN was not monitored in 2010.

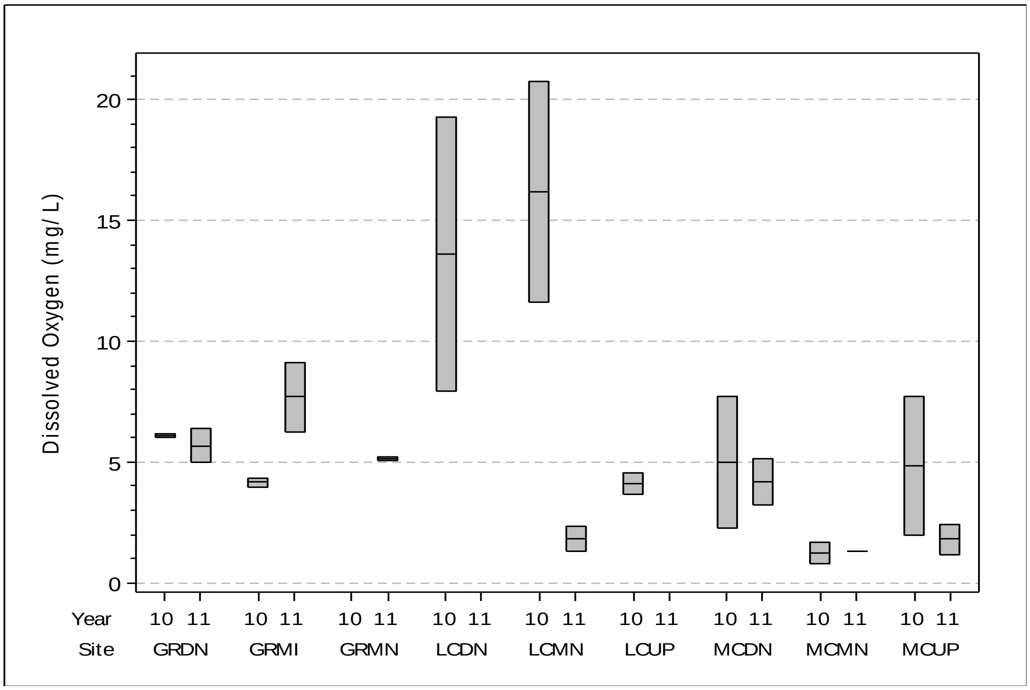


Figure 40. Boxplot of dissolved oxygen levels measured at each site during 2010 and 2011. GR = Greens Bayou, LC = Little Cypress Crk, MC - Mason Crk, DN = down, UP = up, MN = mainstem control for MI for Mid. LCDN and LCUP were not monitored during 2011; GRMN was not monitored in 2010.

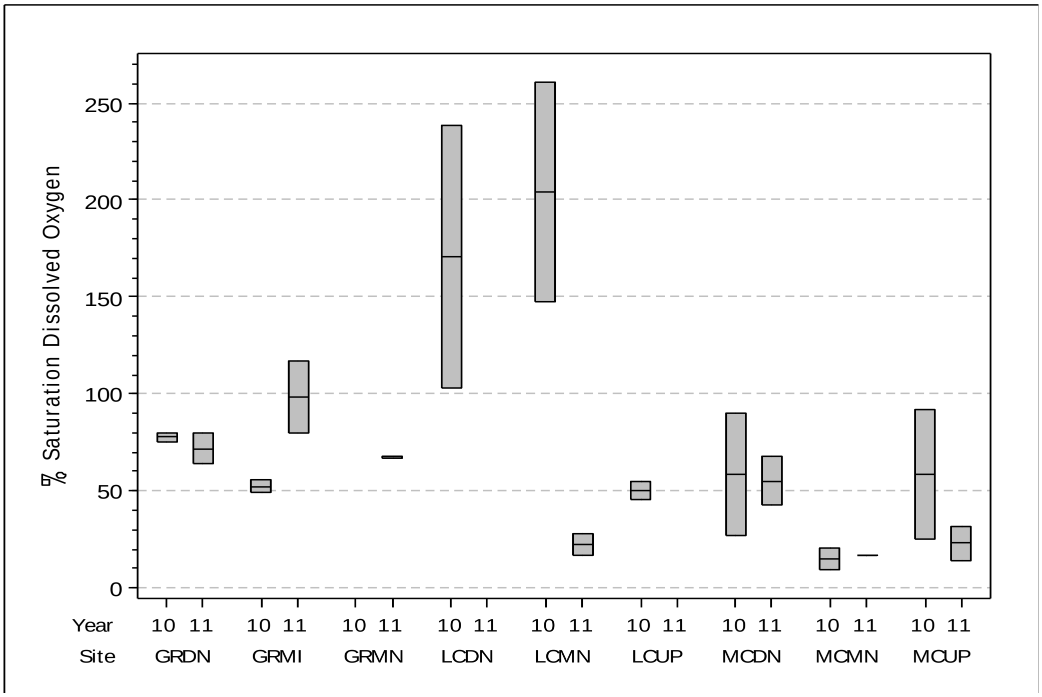


Figure 41. Boxplot of percent saturation of dissolved oxygen levels measured at each site during 2010 and 2011. GR = Greens Bayou, LC = Little Cypress Crk, MC - Mason Crk, DN = down, UP = up, MN = mainstem control for MI for Mid. LCDN and LCUP were not monitored during 2011; GRMN was not monitored in 2010.

Turbidity was measured using two methods including secchi disk transparency and nephelometric turbidity units (NTU). Lowest turbidities (highest transparency) were generally observed at the Greens Bayou sites (Figure 42 and 43). Highest turbidities were observed at the Little Cypress Creek Upstream (LCUP) site. This suggests that samples collected for turbidity may have contained excessive amounts of particulates perhaps suspended during other sampling activities (e.g. seining). Although biological sampling was conducted after water quality sampling, field biologists may have disturbed the bottom sediment while collecting other water quality and habitat data. Suspended solids were elevated at the Little Cypress Creek Up site which supports this hypothesis (Figure 44). However, the Mason Creek Down site did not exhibit excessively high suspended solids. The other sites exhibited relatively low median TSS levels ranging between approximately 5 to 100 mg/l.

Total alkalinity levels were similar between the Greens Bayou and Mason Creek sites (Figure 45). Total alkalinity was much lower at the Little Cypress Creek sites which indicating a lower buffering capacity. Some of these same sites also exhibited the lowest pH values (Figure 38). Measured total alkalinity and pH were, however, within levels that support aquatic life (Nielsen-Gammon 2011). The majority of carbonates and bicarbonates anions were associated sodium and other monovalent cations since total hardness (Ca^{2+} and Mg^{2+}) was very low (< 13 mg/L as $CaCO_3$) (Figure 46).

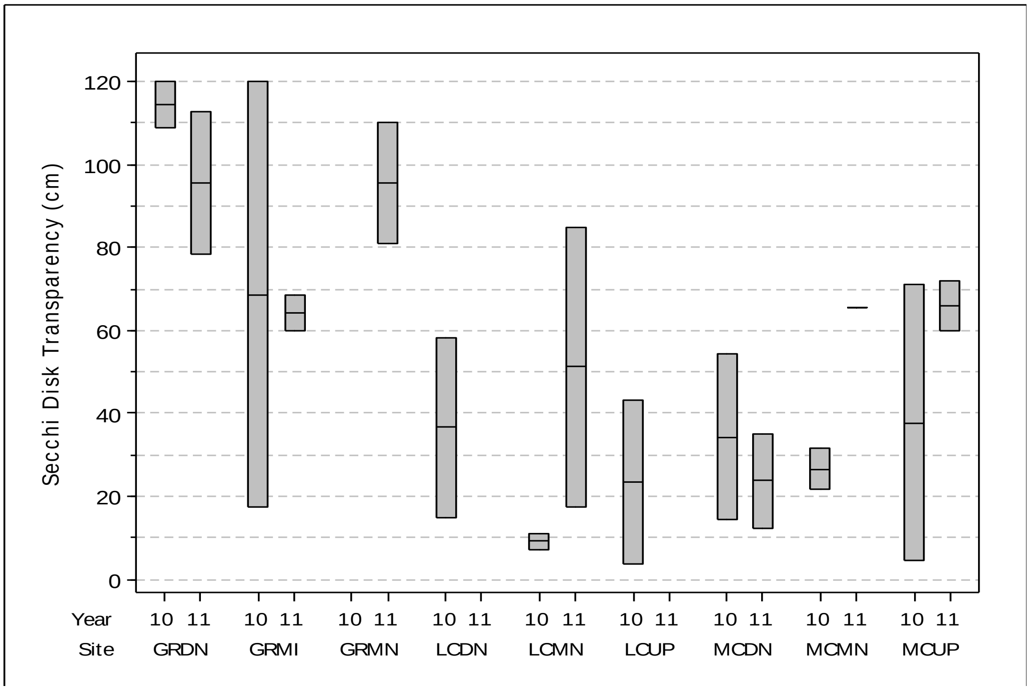


Figure 42. Boxplot of secchi disk transparency measured at each site during 2010 and 2011. GR = Greens Bayou, LC = Little Cypress Crk, MC - Mason Crk, DN = down, UP = up, MN = mainstem control for MI for Mid. LCDN and LCUP not monitored during 2011; GRMN not monitored in 2010.

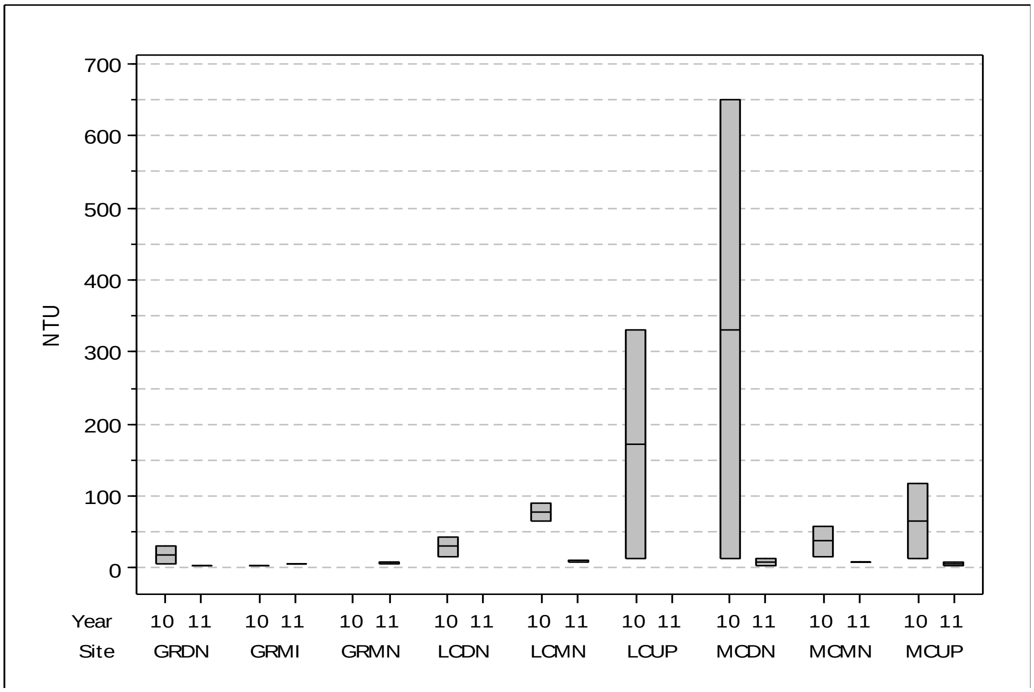


Figure 43. Boxplot of nephelometric turbidity units (NTU) measured at each site during 2010 and 2011. GR = Greens Bayou, LC = Little Cypress Crk, MC - Mason Crk, DN = down, UP = up, MN = mainstem control for MI for Mid. LCDN and LCUP not monitored during 2011; GRMN not monitored in 2010.

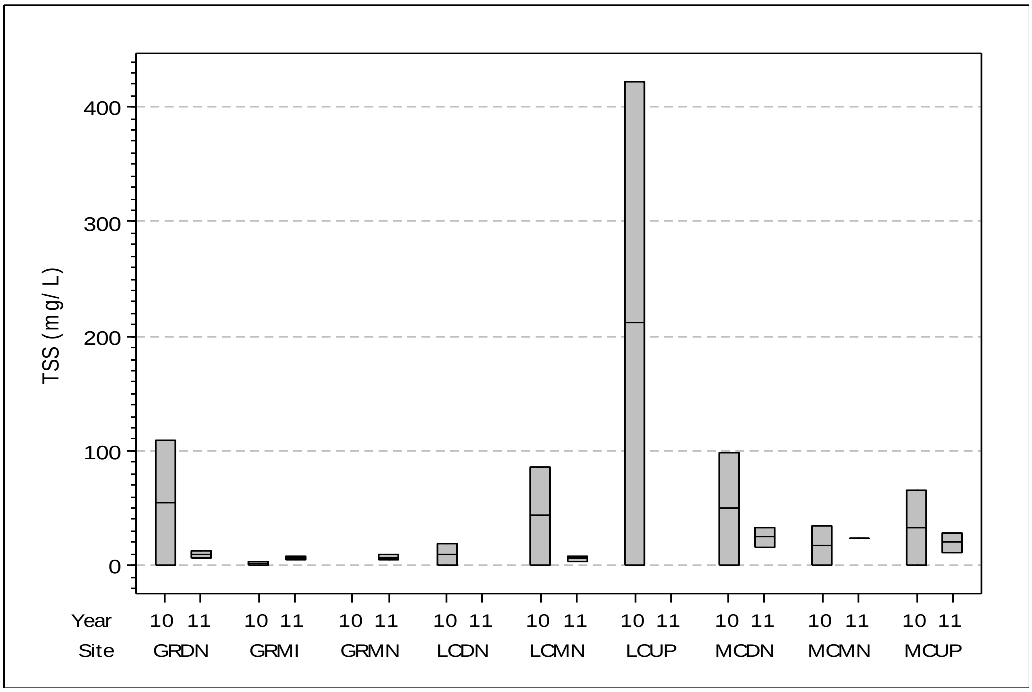


Figure 44. Boxplot of total suspended solids measured at each site during 2010 and 2011. GR = Greens Bayou, LC = Little Cypress Crk, MC - Mason Crk, DN = down, UP = up, MN = mainstem control for MI for Mid. LCDN and LCUP not monitored during 2011; GRMN not monitored in 2010.

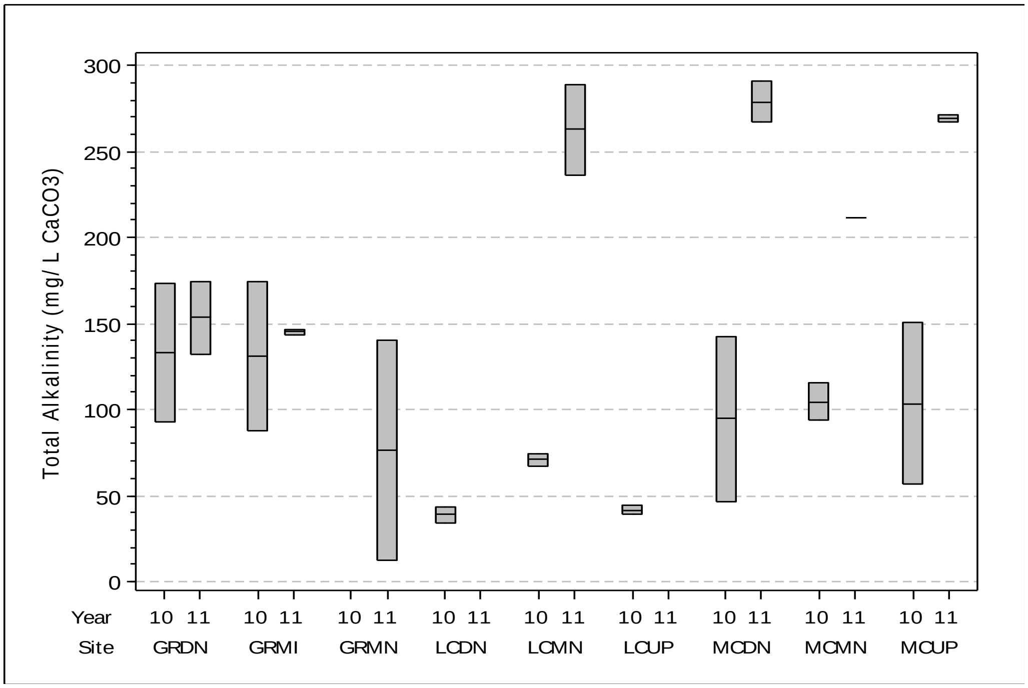


Figure 45. Boxplot of total alkalinity measured at each site during 2010 and 2011. GR = Greens Bayou, LC = Little Cypress Crk, MC - Mason Crk, DN = down, UP = up, MN = mainstem control for MI for Mid. LCDN and LCUP were not monitored during 2011; GRMN was not monitored in 2010.

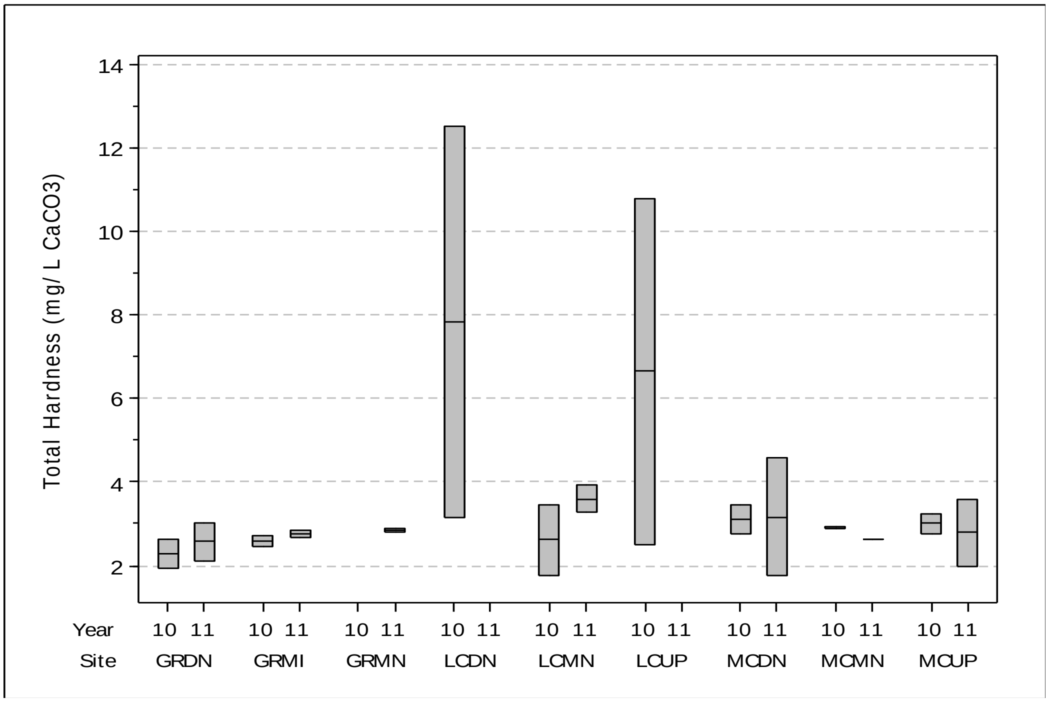


Figure 46. Boxplot of total hardness measured at each site during 2010 and 2011. GR = Greens Bayou, LC = Little Cypress Crk, MC - Mason Crk, DN = down, UP = up, MN = mainstem control for MI for Mid. LCDN and LCUP were not monitored during 2011; GRMN was not monitored in 2010.

Patterns in nutrient levels between sites were not consistent between all monitored nutrients. Orthophosphate levels were generally highest at the Greens Bayou sites and the Mason Creek Upstream (MCUP) site (Figure 47). In contrast, ammonia nitrogen levels were lowest at the Greens Bayou sites (Figure 48). Nitrate and nitrite nitrogen levels were also generally higher at the Greens Bayou sites along with the Little Cypress Creek Main control sites (Figure 49). These data suggest that there are likely more upstream sources of phosphorus and nitrogen at the Greens Bayou, Little Cypress Main control, and the Mason Creek Up sites. These elevated levels however did not correspond with any observed chlorophyll-*a* in water levels suggesting other variables, such as available light, may be limiting primary productivity at sites with elevated nutrients (Figure 50). For example, the Mason Creek Up and Main sites have little or no riparian and consequently the stream at these sites is exposed to full strength sunlight which partially explains the higher chlorophyll-*a* levels observed at these sites (Figure 34). However, periphyton chlorophyll-*a* levels did not exhibit the same pattern as chlorophyll-*a* in water (Figure 51). Periphyton chlorophyll-*a* levels exhibited fluctuations similar to observed nutrient levels suggesting they provide a better index of long term exposure to nutrients assuming other critical factors such as light area not limited. Statistical comparisons of pooled data from both sample periods for each site indicated that the Greens Bayou and Little Cypress Main sites had significantly higher amounts of periphyton chlorophyll-*a* than the other sites (Figure 51 and Table 7).

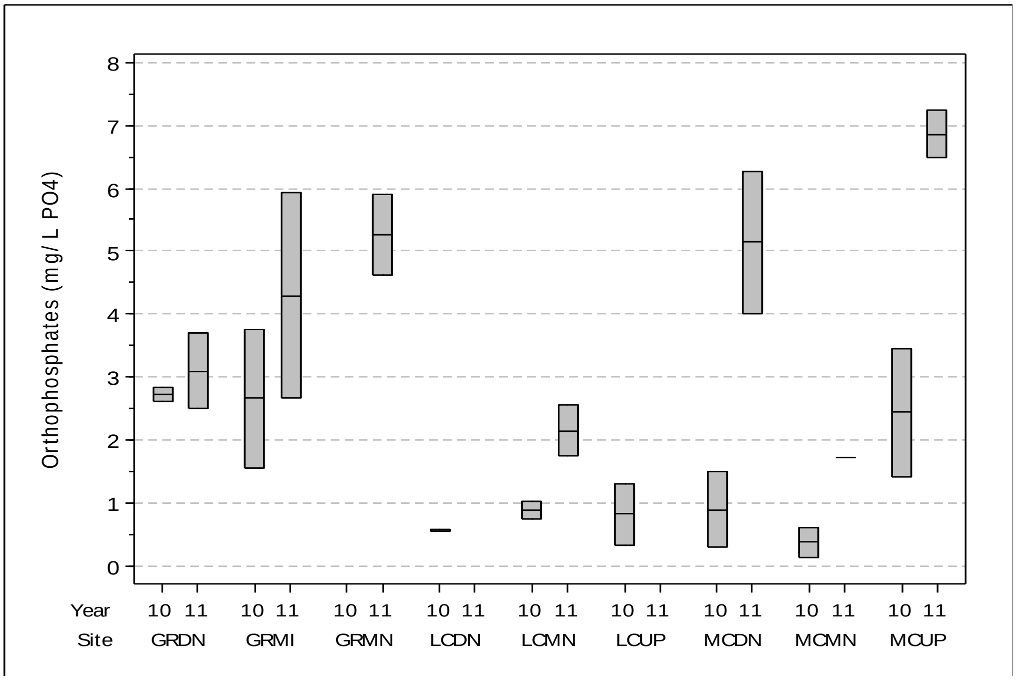


Figure 47. Boxplot of orthophosphate levels measured at each site during 2010 and 2011. GR = Greens Bayou, LC = Little Cypress Crk, MC - Mason Crk, DN = down, UP = up, MN = mainstem control for MI for Mid. LCDN and LCUP not monitored during 2011; GRMN not monitored in 2010.

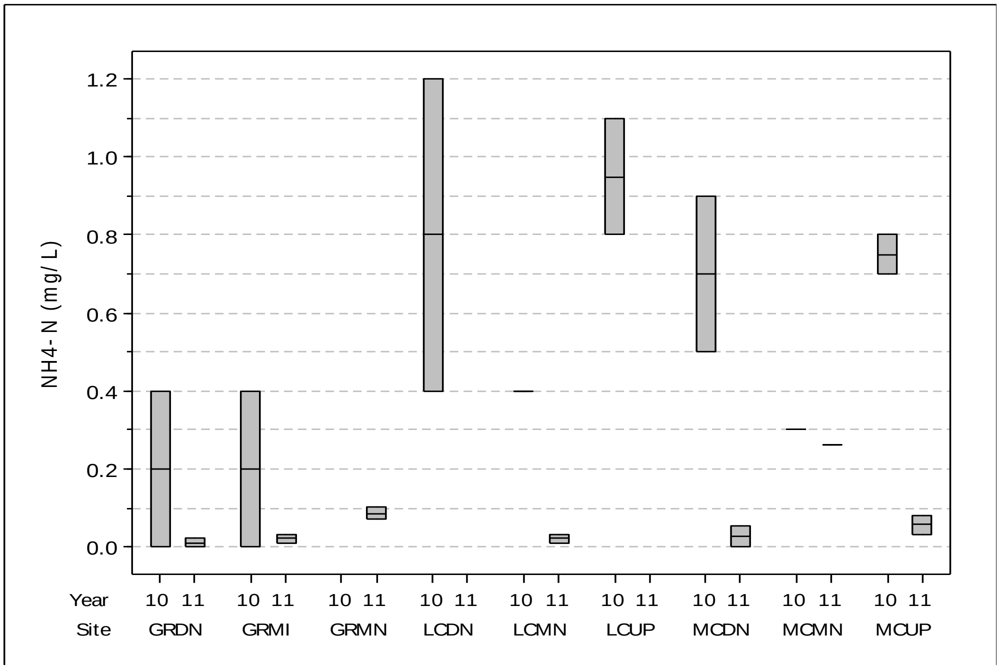


Figure 48. Boxplot of ammonia nitrogen levels measured at each site during 2010 and 2011. GR = Greens Bayou, LC = Little Cypress Crk, MC - Mason Crk, DN = down, UP = up, MN = mainstem control for MI for Mid. LCDN and LCUP not monitored during 2011; GRMN not monitored in 2010.

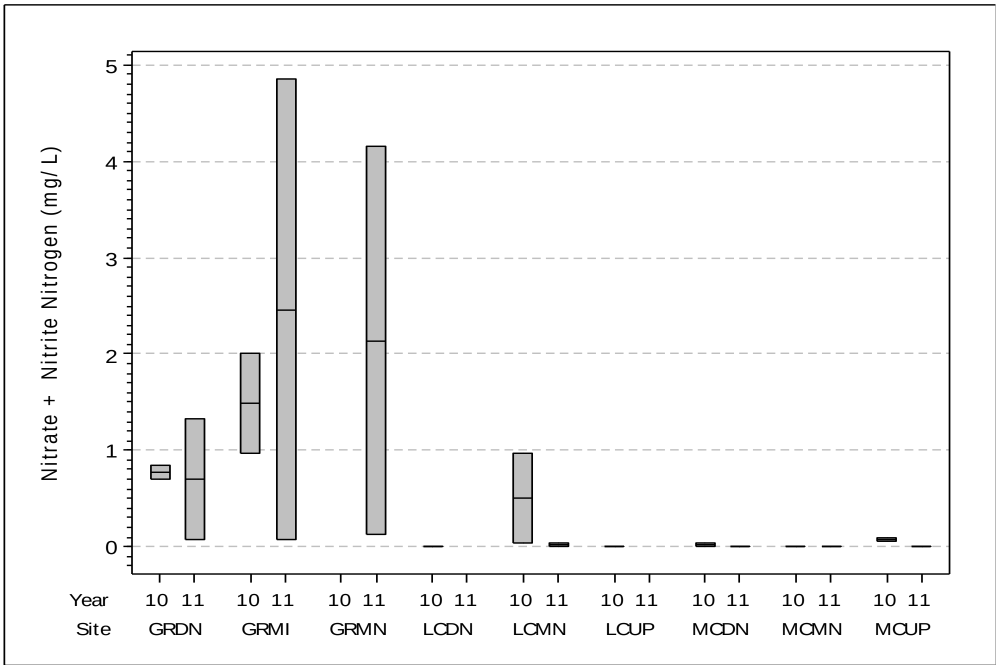


Figure 49. Boxplot of nitrate and nitrite as nitrogen (NO_2+NO_3-N) levels measured at each site during 2010 and 2011. GR = Greens Bayou, LC = Little Cypress Crk, MC - Mason Crk, DN = down, UP = up, MN = mainstem control for MI for Mid. LCDN and LCUP not monitored during 2011; GRMN not monitored in 2010.

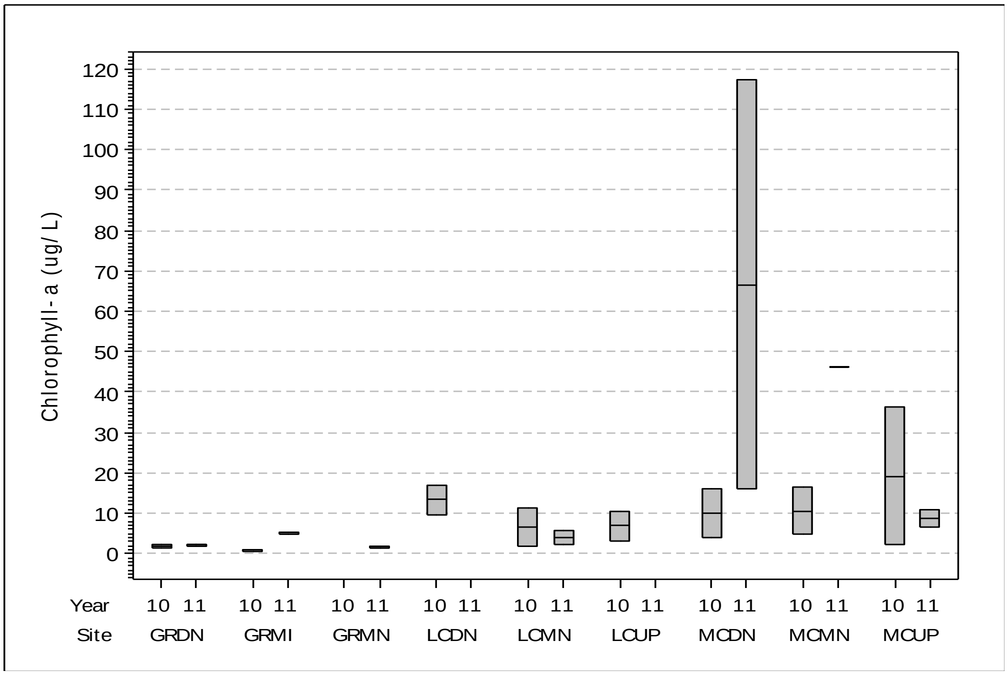


Figure 50. Boxplot of chlorophyll-*a* in water levels measured at each site during 2010 and 2011. GR = Greens Bayou, LC = Little Cypress Crk, MC - Mason Crk, DN = down, UP = up, MN = mainstem control for MI for Mid. LCDN and LCUP not monitored during 2011; GRMN not monitored in 2010.

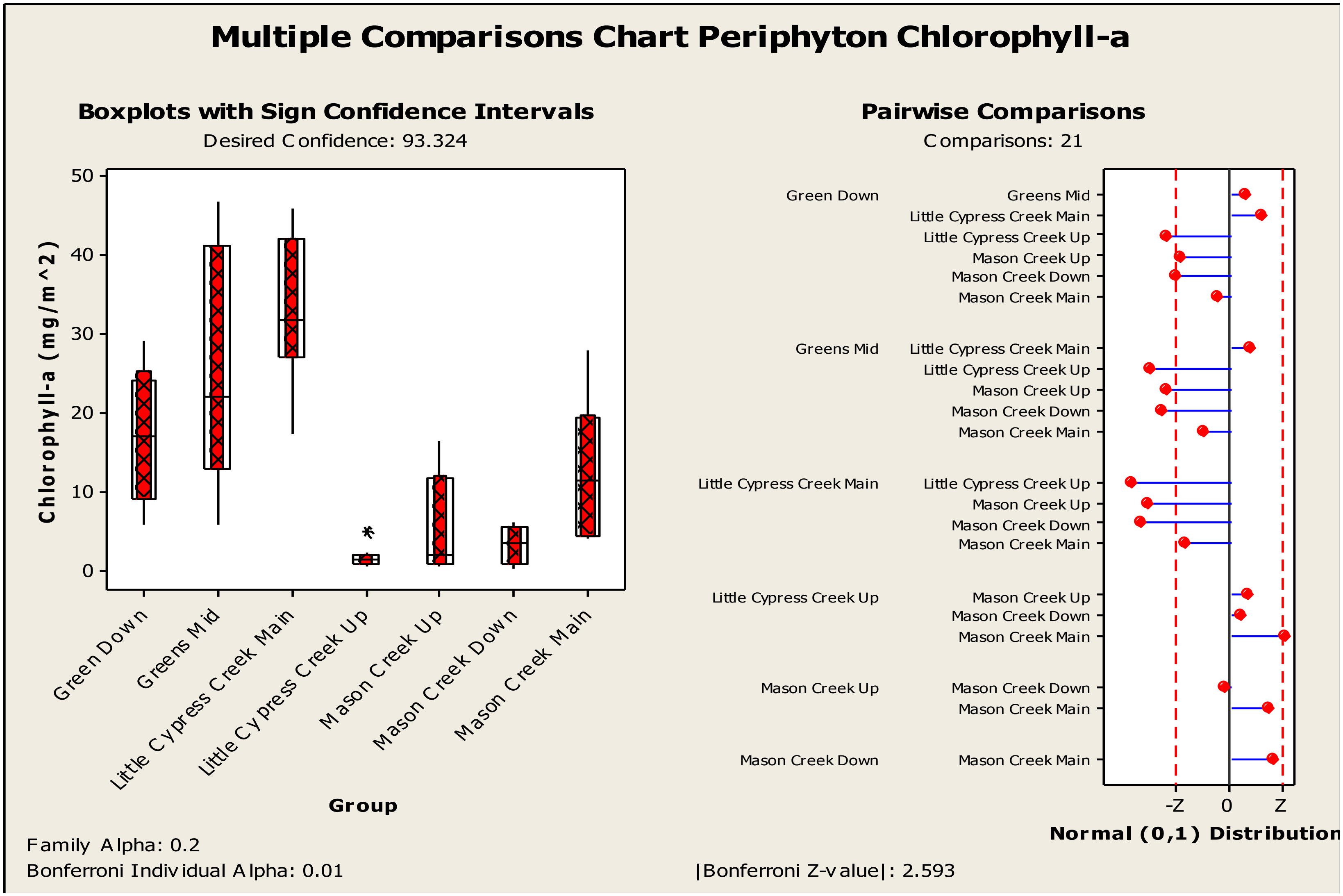


Figure 51. Results of Dunn's multiple range test and boxplots with sign confidence intervals for periphyton chlorophyll-*a* collected during September and October 2010. Periphyton not monitored at the Little Cypress Creek Downstream and Greens Bayou Mainstem sites.

Table 7. Results of Kruskal-Wallis One Way ANOVA with Dunn's multiple range test on periphyton chlorophyll-*a* collected during September and October 2010. Periphyton not monitored at the Little Cypress Creek Downstream and Greens Bayou Mainstem sites.

```
62 cases were used
1 cases contained missing values
Kruskal-Wallis Test on the data
Group                       N  Median  Ave Rank       Z
Green Down                  8  16.926      40.0    1.43
Greens Mid                  9  21.902      45.9    2.59
Little Cypress Creek Main   9  31.817      53.8    4.01
Little Cypress Creek Up     9   1.371      11.9   -3.53
Mason Creek Up              9   1.982      18.7   -2.31
Mason Creek Down            9   3.233      16.6   -2.69
Mason Creek Main            9  11.320      34.7    0.57
Overall                    62              31.5

H = 42.86  DF = 6  P = 0.000
The following groups showed significant differences:
Groups
Little Cypress Creek Main vs. Little Cypress Creek Up
Little Cypress Creek Main vs. Mason Creek Down
Little Cypress Creek Main vs. Mason Creek Up
Greens Mid vs. Little Cypress Creek Up
Greens Mid vs. Mason Creek Down
Green Down vs. Little Cypress Creek Up
Greens Mid vs. Mason Creek Up
Little Cypress Creek Up vs. Mason Creek Main
Green Down vs. Mason Creek Down

Z vs. Critical value       P-value
4.92526 >= 2.593           0.0000
4.37656 >= 2.593           0.0000
4.12834 >= 2.593           0.0000
3.99770 >= 2.593           0.0001
3.44899 >= 2.593           0.0006
3.20660 >= 2.593           0.0013
3.20077 >= 2.593           0.0014
2.67819 >= 2.593           0.0074
2.67428 >= 2.593           0.0075
```

Periphyton biomass in contrast to chlorophyll-*a* levels was more uniform across sites (Figure 52). Statistical comparisons of pooled data from both seasons for each site indicated that there were few significant differences (Table 8 and Figure 52). Average periphyton chlorophyll-*a* and biomass concentrations were calculated and used to compute average autotrophic indices (Figure 53 and 55). The Little Cypress Creek Upstream (LCUP) site exhibited highly elevated Autotrophic Index (AI) values. Normal AI values range from 50 to 200 (American Public Health Association et al. 1998). Larger values usually indicate heterotrophic associations or poor water quality. Nonviable organic detritus can also affect this index by inflating the numerator in the equation. The LCUP site is highly shaded and contains high amounts of partially decayed leaf litter (Figure 34). It is very likely that the artificial samplers served as ideal substrates for settlement of heterotrophic microorganisms. The only variables that were significantly correlated with periphyton biomass and chlorophyll-*a* levels were specific conductance (r = -0.966) and stream bank slope (r = 0.798) respectively.

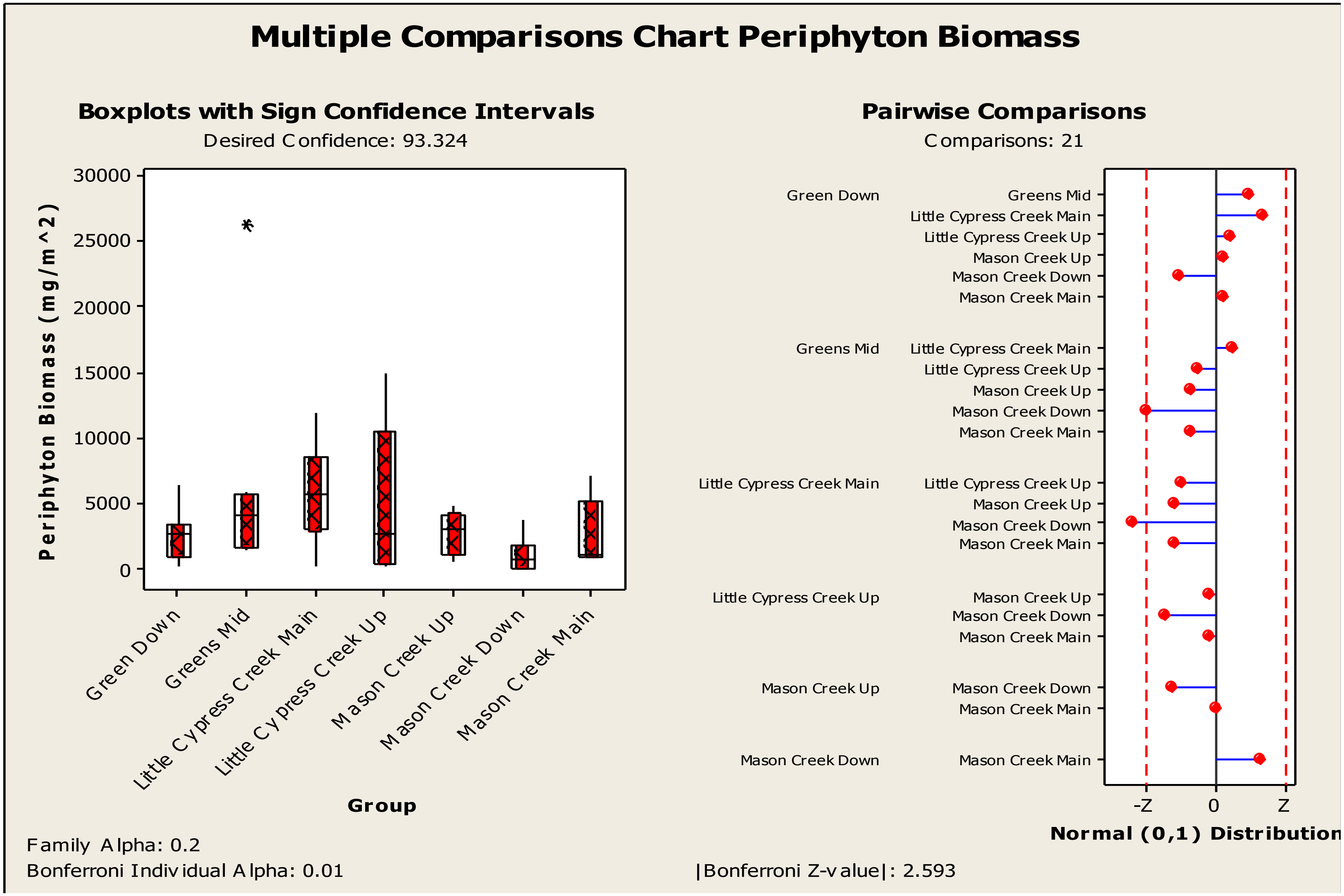


Figure 52. Boxplot and results of Dunn's multiple range test with sign confidence intervals for periphyton biomass measurements obtained during September and October 2010. Periphyton not monitored at the Little Cypress Creek Downstream and Greens Bayou mainstem sites.

Table 8. Results of Kruskal-Wallis One Way ANOVA with Dunn's multiple range test on periphyton biomass during September and October 2010. Periphyton not monitored at the Little Cypress Creek Downstream and Greens Bayou Mainstem sites.

```
62 cases were used
1 cases contained missing values
Kruskal-Wallis Test on the data
Group                        N  Median  Ave Rank       Z
Green Down                   9  2604.2      28.7   -0.50
Greens Mid                   9  4166.7      38.8    1.32
Little Cypress Creek Main    8  5729.2      44.1    2.12
Little Cypress Creek Up      9  2604.2      32.8    0.23
Mason Creek Up               9  2994.8      30.6   -0.17
Mason Creek Down             9   781.2      16.3   -2.73
Mason Creek Main             9  1128.5      30.6   -0.17
Overall                     62                31.5

H = 12.07  DF = 6  P = 0.060
H = 12.07  DF = 6  P = 0.060  (adjusted for ties)

The following groups showed significant differences (adjusted for ties):
Groups
Little Cypress Creek Main vs. Mason Creek Down
Greens Mid vs. Mason Creek Down

Z vs. Critical value       P-value
3.17044 >= 2.593           0.0015
2.64577 >= 2.593           0.0082
```

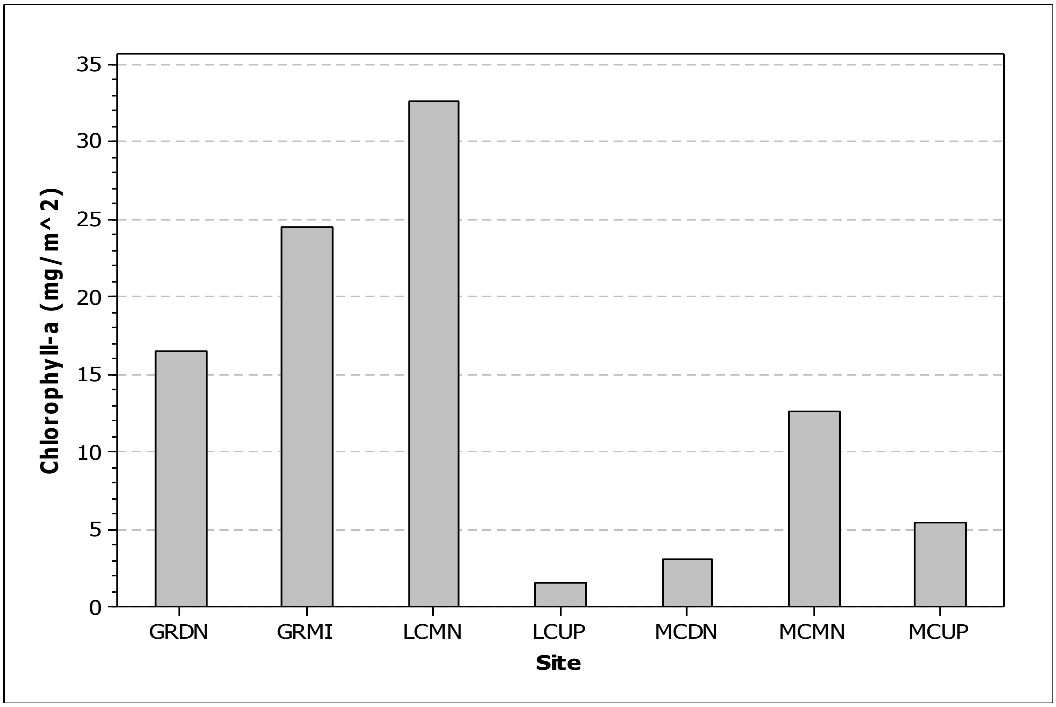


Figure 53. Average periphyton chlorophyll-*a* concentrations at each site during based on data collected during September and October 2010. GR = Greens Bayou, LC = Little Cypress Crk, MC - Mason Crk, DN = down, UP = up, MI = mid, MN = mainstem control. LCDN and GRMN not monitored for periphyton.

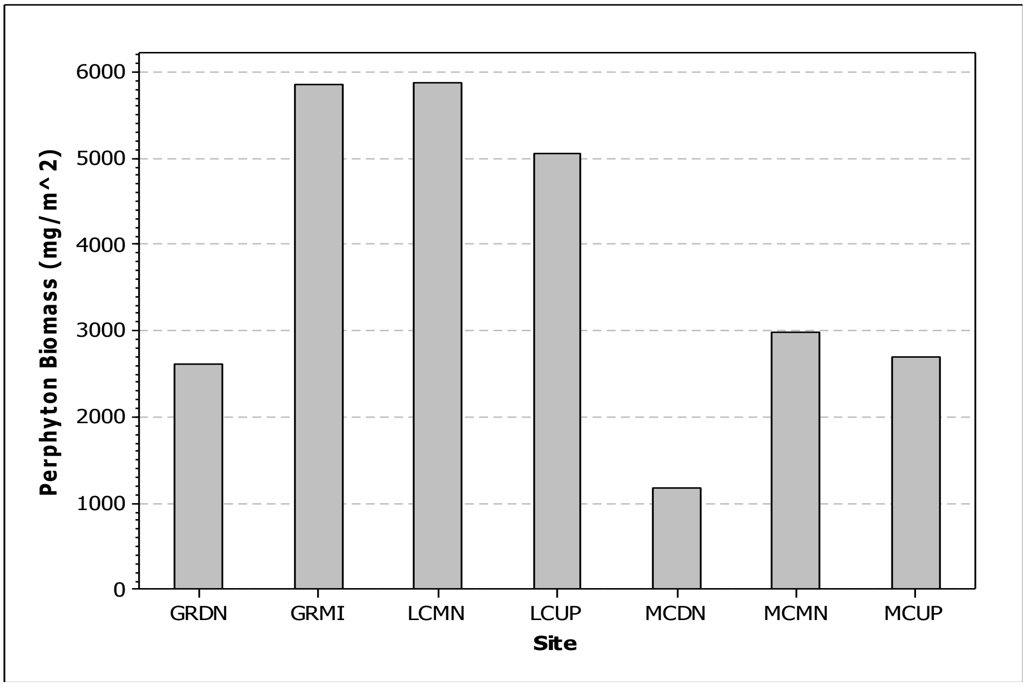


Figure 54. Average periphyton biomass at each site based on data collected during September and October 2010. GR = Greens Bayou, LC = Little Cypress Crk, MC - Mason Crk, DN = down, UP = up, MI = mid, MN = mainstem control. LCDN and GRMN not monitored for periphyton.

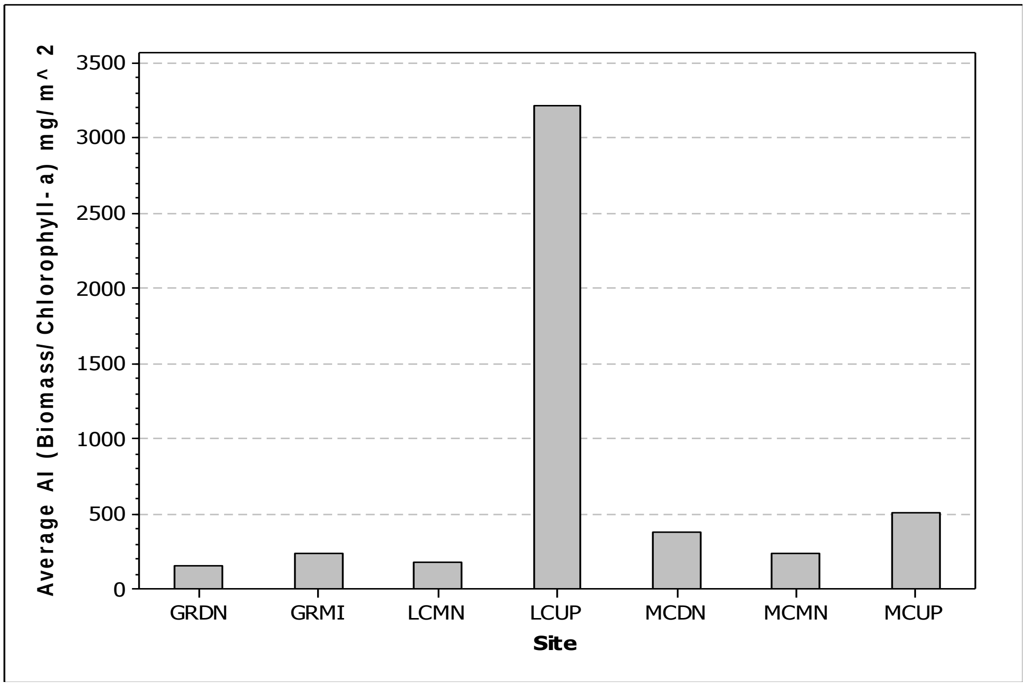


Figure 55. Average periphyton autotrophic index (AI) values calculated for each site based on data collected during September and October 2010. GR = Greens Bayou, LC = Little Cypress Crk, MC - Mason Crk, DN = down, UP = up, MI = mid, MN = mainstem control for MI for Mid. LCDN and GRMN not monitored for periphyton.

Since periphyton metrics were only measured during 2010, we did not include this variable in our multivariate analyses. Based on the results of our cluster analysis we found that the only collections and sites that were dissimilar to other sites based on overall physicochemical characteristics was the Greens Bayou Mainstem (GBMN) site (Figure 56). Examination of Principal Component scores and variable loadings indicate that this separation is mainly due to the difference in hydrology and landscape characteristics including higher levels of streamflow, velocity, upstream point source loading and watershed size and degree of imperviousness. Although not identified by cluster analysis as distinct groups, the PCA also indicated that the sites were separated from each other both spatially (between watersheds), and within watersheds by sampling periods, with the greatest variation occurring between years (Table 9 and Figure 57). In general, during year 2 collections within each watershed exhibited higher PC 2 axis scores. This suggests that during 2011, these sites exhibited higher amounts of pool habitat, lower amounts of runs, lower dissolved oxygen, higher amounts of instream vegetation, and higher specific conductance, chlorophyll-*a* in water and orthophosphates. Examination of the individual variable patterns between years supports this hypothesis (Figure 34-36; 39- 40, 47 and Table 6).

Multiple significant ($p < 0.05$) correlations were observed among the physicochemical variables measured (Table 10). Strong correlations were observed between landscape level features (watershed size, degree of imperviousness, number of wastewater facilities) and hydrological and habitat variables. As watershed size increased the number of wastewater facilities, stream size, velocity and flow increased.

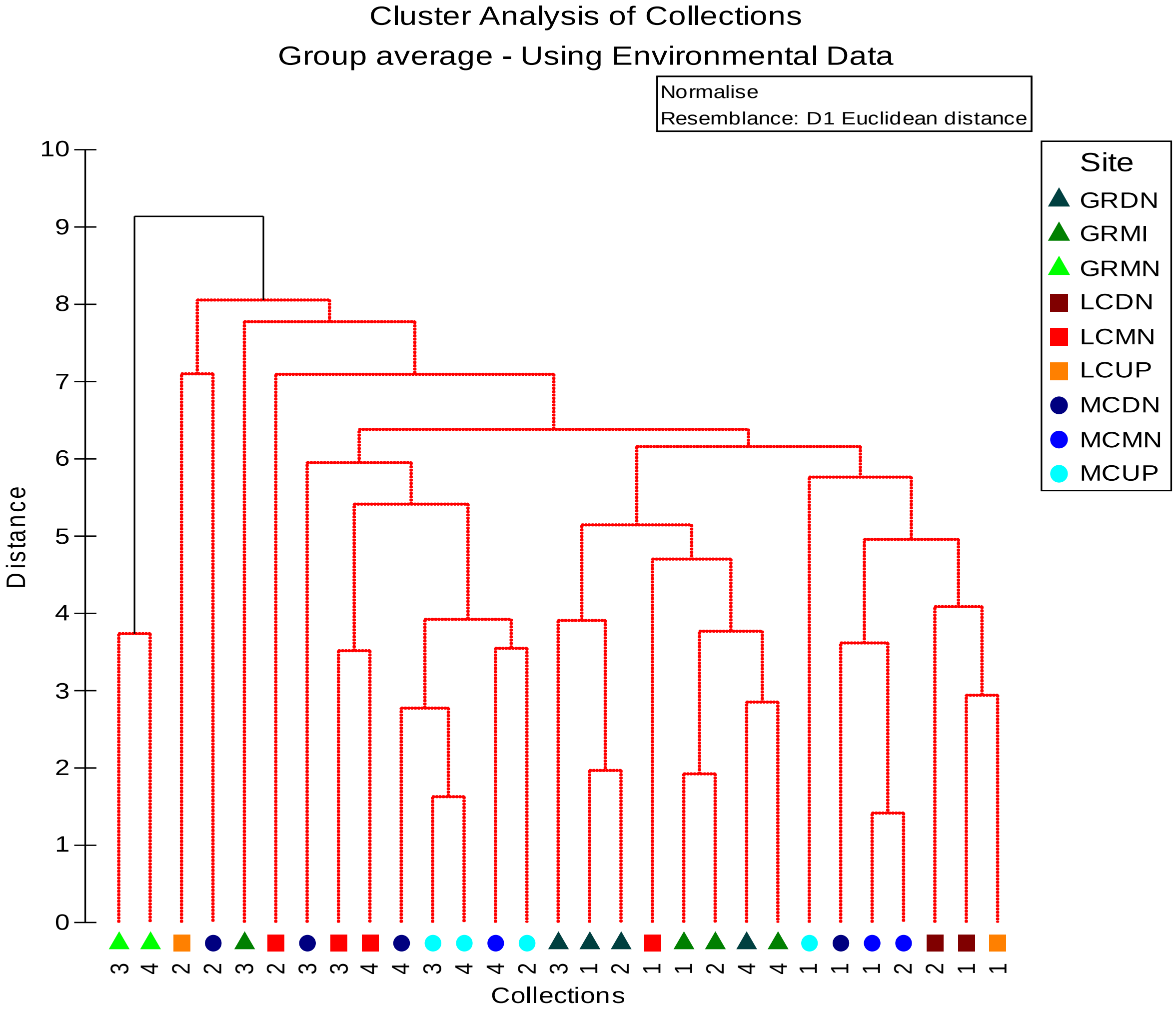


Figure 56. Results of cluster analysis and similarity profile permutation tests (SIMPROF) using Euclidean distance and group averaging method on normalized environmental variables to depict similarity of collections based on environmental factors measured. Numbers refer to sampling periods (1,2 = 2010; 3,4 = 2011). Collections connected by red lines are not dissimilar from each other based on SIMPROF tests. PCA conducted with PRIMER v. 6.

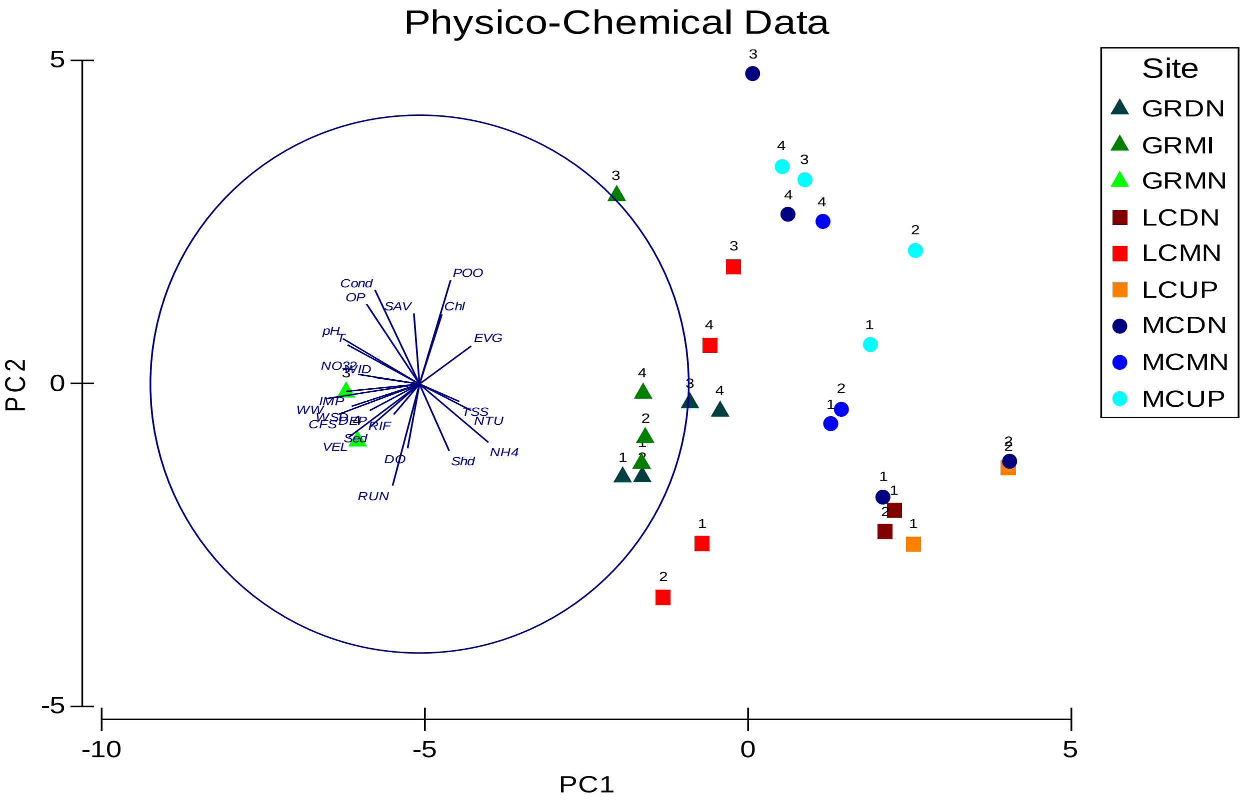


Figure 57. Principal Components Analysis (PCA) biplot showing individual variable loadings and collections PCA scores depicting major environmental gradients present at each site. Numbers refer to sampling periods (1, 2 = 2010; 3, 4 = 2011). PC1 and PC2 explained 42.8% of the variation in the data. PCA conducted with PRIMER v. 6.

Table 9. Results of principal components analysis of environmental data collected during 2010 and 2011 at all three restoration streams during biological collections. Analysis conducted with PRIMER, v. 6.0, on normalized environmental variables.

```
Eigenvalues
PC  Eigenvalues  %Variation  Cum.%Variation
 1         5.96        24.8            24.8
 2         4.31        17.9            42.8
 3         2.76        11.5            54.2
 4         1.83         7.6            61.9
 5         1.67         7.0            68.8

Eigenvectors
(Coefficients in the linear combinations of variables making up PC's)
Variable     PC1     PC2     PC3     PC4     PC5
T         -0.268   0.146  -0.139  -0.259  -0.023
pH        -0.285   0.169  -0.296  -0.061  -0.178
Cond      -0.166   0.350  -0.046  -0.278   0.009
DO        -0.045  -0.239  -0.063   0.132  -0.334
NH4        0.256  -0.217   0.188   0.054  -0.050
Chl        0.083   0.259   0.021  -0.224  -0.105
NTU        0.192  -0.098   0.129  -0.247  -0.250
OP        -0.197   0.297   0.012  -0.218   0.109
NO32      -0.229   0.036  -0.019   0.349  -0.105
TSS        0.148  -0.065   0.127  -0.110  -0.433
CFS       -0.299  -0.112   0.334  -0.142  -0.132
Shd        0.110  -0.248  -0.319  -0.148  -0.246
Sed       -0.185  -0.161  -0.203   0.043   0.025
SAV       -0.021   0.263  -0.087   0.426  -0.290
EVG        0.192   0.141   0.286  -0.141   0.280
DEP       -0.185  -0.098   0.064   0.378   0.114
VEL       -0.263  -0.197   0.214  -0.156  -0.181
WID       -0.167   0.025   0.480   0.210   0.070
POO        0.115   0.386   0.107   0.153  -0.256
RUN       -0.100  -0.377  -0.059  -0.142   0.283
RIF       -0.096  -0.113  -0.254  -0.081  -0.088
WSD       -0.252  -0.083   0.176  -0.074  -0.277
IMP       -0.273  -0.027  -0.166   0.127   0.214
WW        -0.348  -0.054   0.237  -0.108  -0.047
```

Table 10. Significant correlation coefficients between measured environmental variables.

Variable 1	Variable 2	Correlation	p-value
% Imp.	No. WWTP	0.488004614	0.00724
% Imp.	Bank Slope	0.571880102	0.001191
% Imp.	Depth	0.390855242	0.036042
% Imp.	NH-4-N	-0.461668085	0.011701
% Imp.	NO3+2	0.561077416	0.001543
% Imp.	% Riffle	0.386592206	0.038302
% Imp.	pH	0.492875848	0.006598
% Imp.	Secchi	0.641104401	0.000179
% Imp.	% Emerg. Veg.	-0.374824958	0.045132
% Imper.	Sed. Rank	0.407949099	0.028034
W.Shed Area	No. WWTP	0.678997369	5.13E-05
W.Shed Area	Flow	0.721566133	1E-05
W.Shed Area	pH	0.377805341	0.043317
W.Shed Area	Velocity	0.519570905	0.00387
Flow	Velocity	0.832237203	2.18E-08
Flow	No. WWTP	0.901607513	2.49E-11
Flow	Stream Width	0.638563515	0.000193
Flow	Wat. Temp	0.386834533	0.03817
Velocity	% Pool	-0.373466588	0.045979
Velocity	% Riffle	0.433639522	0.018769
Velocity	No. WWTP	0.724819213	8.71E-06
Velocity	Stream Width	0.477650445	0.008782
Velocity	Tot. Alk.	-0.378309839	0.043016
No. WWTP	NO3+2	0.474218663	0.009351
No. WWTP	O-P	0.372255948	0.046745
No. WWTP	pH	0.382562621	0.040541
No. WWTP	Secchi	0.425651679	0.021329
No. WWTP	Wat. Temp	0.456127502	0.012886
Stream Width	No. WWTP	0.619335747	0.000341
Stream Width	% Shading	-0.615403229	0.000381
% Shading	% Bank Veg.	-0.424263436	0.021802
% Shading	% Emerg. Veg	-0.386784993	0.038197
Bank Slope	% Pool	-0.514038595	0.004338
Bank Slope	% Run	0.485424272	0.007601
Bank Slope	% Emerg. Veg.	-0.717264653	1.19E-05
Bank Slope	Chl-a	-0.416906234	0.024455
Bank Slope	Depth	0.431502535	0.019427
Bank Slope	pH	0.381353577	0.041232

Table 10. Continued.

Variable 1	Variable 2	Correlation	p-value
Air Temp.	NH4-N	-0.437387245	0.017658
Air Temp.	pH	0.380779184	0.041564
Air Temp.	Sp. Cond.	0.469547096	0.010174
Air Temp.	Tot. Alk.	0.421014046	0.022943
Wat. Temp	% Emerg. Veg	-0.411539016	0.026551
Wat. Temp	NH4-N	-0.512339853	0.004491
Wat. Temp	NTU	-0.430723432	0.019672
Wat. Temp	O-P	0.534891195	0.002794
Wat. Temp	pH	0.643282212	0.000167
Wat. Temp	Sp. Cond.	0.533320662	0.002891
Wat. Temp	Tot. Alk.	0.374530024	0.045315
Sp. Cond.	% Bank Veg.	0.397938795	0.032526
Sp. Cond.	D.O.	-0.498719572	0.005892
Sp. Cond.	NH4-N	-0.629781099	0.000251
Sp. Cond.	O-P	0.703619538	2.06E-05
Sp. Cond.	Total Alk.	0.830145075	2.55E-08
Sp. Cond.	pH	0.668336406	7.42E-05
Depth	% Bank Veg.	0.374521041	0.045321
% Pool	% Run	-0.980845257	1.02E-20
% Pool	% Sub. Veg	0.545764238	0.002196
% Pool	Chl-a	0.421146207	0.022896
% Pool	Tot. Alk.	0.475343215	0.009161
% Run	% Sub. Veg	-0.550111849	0.00199
% Run	Chl-a	-0.40336894	0.030022
% Run	Tot. Alk.	-0.492651896	0.006626
% Riffle	Secchi	0.4972186	0.006066
% Riffle	Sed. Rank	0.40132937	0.030943
TSS	NTU	0.580429962	0.000964
NTU	NH-4-N	0.460123768	0.012022
NTU	Secchi	-0.398263626	0.032371
Secchi	NO3+2	0.420971049	0.022958
Secchi	Sed. Rank	0.370565325	0.047831
Secchi	pH	0.38718855	0.037979
% Sub. Veg.	NO3+2	0.409505687	0.027383
% Sub. Veg.	pH	0.394839139	0.034029
Sed. Rank	% Emerg. Veg	-0.458546785	0.012357
% Emerg. Veg	pH	-0.441079297	0.016617
Tot. Alk.	D.O.	-0.483216161	0.007922
Tot. Alk.	NH-4-N	-0.517444632	0.004044
Tot. Alk.	pH	0.512233118	0.0045
% Bank Veg.	Tot. Hard	-0.458787763	0.012305
Tot. Hard	NH-4-N	0.609336465	0.000451
Tot. Hard	pH	-0.392523552	0.035188
pH	NO3+2	0.44160048	0.016474
pH	O-P	0.481623124	0.008161
pH	NH4-N	-0.758172178	1.9E-06
NH-4-N	O-P	-0.5909857	0.000736
O-P	Tot. Alk.	0.52529189	0.003433

Biological Data

Benthic Communities

A total of 16,705 benthic organisms representing a minimum of 176 taxa were collected during the study period (Table 11). The most abundant taxa included the amphipod *Hyallela* (2,349, 14.06% of the total organisms collected), Ephemeroptera *Caenis* (1,994, 11.94%), and the unidentified Chironomidae (1,426, 8.54%). If you include the other identified Chironomids the total composition represents a total of 3,858 organisms counted or 23.7% of the total benthic organisms.

The highest median total number of benthic organisms was recorded at the GBMI and LCMN sites during the second and third sampling period respectively (Figure 58). The median number of organisms/100 ft of stream, was generally lower at all sites during 2010 than 2011. This overall pattern was generally repeated with mean levels as well (Figure 59). Overall the GBMN and LCUP sites exhibited statistically higher and lower median abundances when compared to selected sites respectively. (Table 13 and Figure 60).

Benthic Shannon Weiner Diversity (*H'*) values ranged from 0 to 2.9 (Figure 61). The lowest and highest *H'* values were encountered at the LCUP and MCUP sites respectively. The calculated median and average H' values were generally higher during 2011in contrast to 2010 (Figure 61 and 62). However, there was considerable variation and in many cases these trends do not appear to be statistically significant. Overall the only statistically significant difference in *H'* between sites were observed between LCUP and MCUP, LCUP and MCUP and LCUP and GBMN (Figure 63 and Table 13). Overall the LCUP site exhibited the lowest benthic invertebrate *H'* levels.

The highest and lowest median number of benthic invertebrate taxa was recorded at the MCMN and LCUP sites respectively (Figure 64). The MCMN site was generally the site with the highest median number of benthic organism taxa. At most sites, the median number of taxa appear to increase from 2010 to 2011. The average number of benthic taxa also followed this same pattern (Figure 65). There was however, due to considerable variation, large confidence intervals associated with these mean estimates. Overall, median number of benthic invertebrate taxa was statistically lower at the LCUP site when compared to the Greens Bayou sites and MCUP (Table 14 and Figure 65). Based on these patterns it appears the LCUP site generally exhibited the lowest number of taxa between all sites. In contrast, the MCUP site generally exhibited the highest number of benthic invertebrate taxa.

Table 11. Summary of benthic community data species assemblage.

Phylum or Class	Order	Family	Genus	GBMI1	GBMI2	GBMI3	GBMI4	GBMN3	GBMN4	GBDN1	GBDN2	GBDN3	GBDN4	LCDN1	LCDN2	LCMN1	LCMN2	LCMN3	LCMN4	LCUP1	LCUP2	MCDN1	MCDN2	MCDN3	MCDN4	MCMN1	MCMN2	MCMN4	MCUP1	MCUP2	MCUP3	MCUP4	Total	Freq.
Turbellaria			*Dugesia*	0	0	0	1	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	3
Nematoda				0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	3	6	0	2	1	0	0	0	0	14	5
Oligochaeta	Haplotaxida	Lumbricidae		0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Oligochaeta	Haplotaxida	Naididae	*Dero*	0	0	4	164	2	0	0	0	0	2	0	0	0	0	5	0	0	0	0	0	28	49	0	0	138	0	0	29	45	466	10
Oligochaeta	Haplotaxida	Naididae	*Pristina*	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	1	0	0	5	0	0	0	1	38	5
Oligochaeta	Haplotaxida	Naididae	*Slavina*	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	2
Oligochaeta	Haplotaxida	Naididae	*Stylaria*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	1
Oligochaeta	Haplotaxida	Tubificidae	*Aulodrilus*	0	0	1	25	0	0	0	0	1	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	30	5
Oligochaeta	Haplotaxida	Tubificidae	*Ilyodrilus*	0	0	0	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	1
Oligochaeta	Haplotaxida	Tubificidae	*Limnodrilus*	0	0	2	46	13	45	0	0	3	11	0	0	0	0	3	5	0	0	0	0	7	31	0	0	43	0	0	39	65	313	13
Oligochaeta				14	0	0	270	255	0	2	2	0	0	115	16	2	0	0	0	12	0	0	0	51	0	42	0	0	30	0	24	0	835	13
Hirudinea	Pharyngobdellida	Erpobdellidae	Dina	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	6	3
Hirudinea	Pharyngobdellida	Erpobdellidae	*Mooreobdella*	0	0	1	0	16	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	1	22	6
Hirudinea	Rhynchobdellida	Glossiphoniidae	*Helobdella*	0	0	7	7	4	1	0	0	0	2	0	0	0	0	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	27	7
Hirudinea	Rhynchobdellida	Glossiphoniidae	*Placobdella*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1
Hirudinea				1	1	0	0	0	0	1	5	1	0	3	1	0	5	0	0	0	0	0	6	0	0	4	0	0	4	0	0	0	32	11
Gastropoda	Basommatophora	Planorbidae	*Biomphalaria*	0	0	12	24	3	0	0	0	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	45	6
Gastropoda	Basommatophora	Planorbidae		0	0	0	0	0	0	0	2	0	0	6	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	3
Gastropoda	Caenogastropoda	Ampullariidae	*Pomacea*	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0	22	27	5
Gastropoda	Caenogastropoda	Thiaridae	*Melanoides*	0	1	1	0	6	8	0	40	6	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	73	7
Gastropoda	Limnophila	Ancylidae	*Ferrissia*	0	0	0	1	44	0	0	0	4	2	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	1	3	59	8
Gastropoda	Limnophila	Ancylidae	*Hebetancylus*	0	7	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	2
Gastropoda	Limnophila	Ancylidae		0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	9	3
Gastropoda	Limnophila	Lymnaeidae	*Fossaria*	0	0	0	0	2	5	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	4
Gastropoda	Limnophila	Physidae	*Physella*	0	8	3	1	0	0	0	1	1	1	132	7	0	0	0	0	0	0	19	1	4	7	8	0	0	35	1	2	0	231	16
Gastropoda	Limnophila	Planorbidae	*Gyraulus*	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	3	4	0	0	0	0	2	0	0	11	4
Gastropoda	Limnophila	Planorbidae	*Helisoma*	0	18	15	3	0	0	0	1	2	5	11	7	0	0	0	0	0	0	0	0	0	1	0	0	4	0	0	0	0	67	10
Gastropoda	Limnophila	Planorbidae	*Planorbula*	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	5	2
Gastropoda	Mesogastropoda	Hydrobiidae	*Pyrgophorus*	0	0	48	57	0	11	0	0	152	103	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	371	5
Gastropoda	Neotaenioglossa	Hydrobiidae		12	159	0	0	0	0	30	153	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	358	7
Gastropoda				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1
Pelecypoda	Heterodonta	Corbiculidae	*Corbicula*	0	0	0	16	7	3	2	0	0	31	0	0	4	54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	117	7
Pelecypoda	Heterodonta	Sphaeriidae	*Pisidium*	0	0	6	234	3	0	0	0	30	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	313	5
Pelecypoda	Heterodonta	Sphaeriidae	*Sphaerium*	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	0	0	1	0	19	0	0	0	0	33	3
Pelecypoda	Unionoida	Unionidae		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1
Crustacea	Cladocera			0	0	34	2	0	0	0	0	2	1	0	0	1	0	123	24	0	0	0	0	6	7	0	2	20	0	3	1	0	226	13
Crustacea	Ostracoda			2	0	34	1	1	2	0	0	31	1	0	0	0	0	34	150	0	0	0	1	36	85	0	0	24	0	6	2	16	426	16
Crustacea	Copepoda	Cyclopidae	*Cyclops*	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Crustacea	Copepoda			0	6	13	3	0	0	0	0	0	0	0	0	0	0	103	51	0	1	0	0	15	1	0	1	9	0	3	4	1	211	13
Crustacea	Isopoda	Asellidae	*Caecidotea*	0	0	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	1
Crustacea	Isopoda			0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	1
Crustacea	Amphipoda	Talitridae	*Talitroides*	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1
Crustacea	Amphipoda	Taltridae	*Hyalella*	14	82	541	95	346	45	9	3	238	30	0	0	0	1	307	272	0	0	0	0	31	22	141	3	2	0	2	156	9	2,349	21
Crustacea	Decapoda	Astacidae	*Procambarus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1
Crustacea	Decapoda	Cambaridae		0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0	1	0	0	1	0	1	0	6	6

Table 11. Continued.

Phylum or Class	Order	Family	Genus	GBMI1	GBMI2	GBMI3	GBMI4	GBMN3	GBMN4	GBDN1	GBDN2	GBDN3	GBDN4	LCDN1	LCDN2	LCMN1	LCMN2	LCMN3	LCMN4	LCUP1	LCUP2	MCDN1	MCDN2	MCDN3	MCDN4	MCMN1	MCMN2	MCMN4	MCUP1	MCUP2	MCUP3	MCUP4	Total	Freq.
Crustacea	Decapoda	Palaemonidae	*Macrobrachium*	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2
Crustacea	Decapoda	Palaemonidae	*Palaemontes*	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Arachnida	Acarina	Arrenuridae	*Arrenurus*	0	34	0	2	0	0	0	0	0	0	0	0	0	0	2	3	0	0	0	0	2	0	0	0	0	0	0	3	1	47	7
Arachnida	Acarina	Hygrobatidae	*Atractides*	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	4	2
Arachnida	Acarina	Lebertiidae	*Lebertia*	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Arachnida	Acarina	Limnesiidae	*Limnesia*	0	0	3	10	0	2	0	0	5	6	0	0	0	0	1	9	0	0	0	0	0	0	0	0	2	0	0	0	0	38	8
Arachnida	Acarina	Mideidae	*Midea*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1
Arachnida	Acarina	Torrenticolidae	*Torrenticola*	0	0	8	2	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	4
Arachnida	Acarina	Unionicolidae	*Neumania*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	4	2
Arachnida	Acarina			2	0	9	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	9	0	0	6	0	0	5	0	0	34	7
Arachnida				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1
Hydracarina				0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1
Insecta	Coleoptera	Carabidae		0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	4	2
Insecta	Coleoptera	Chrysomelidae	*Disonycha*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	2
Insecta	Coleoptera	Chrysomelidae		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	3	0	5	3
Insecta	Coleoptera	Curculionidae		0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	2	0	2	1	0	0	0	5	0	0	12	0	0	24	7
Insecta	Coleoptera	Dytiscidae	*Agabus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	4	0	0	0	0	5	2
Insecta	Coleoptera	Dytiscidae	*Copelatus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1
Insecta	Coleoptera	Dytiscidae	*Coptotomus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Insecta	Coleoptera	Dytiscidae	*Hydrovatus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	10	0	0	8	0	0	8	12	39	5
Insecta	Coleoptera	Dytiscidae	*Laccodytes*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	6	1
Insecta	Coleoptera	Dytiscidae	*Laccophilus*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	5	2	0	2	2	76	89	7
Insecta	Coleoptera	Dytiscidae	*Neobidessus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	3	0	0	3	0	7	3
Insecta	Coleoptera	Dytiscidae	*Neoporus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1
Insecta	Coleoptera	Dytiscidae	*Oreodytes*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1	0	3	2
Insecta	Coleoptera	Dytiscidae	*Thermonectus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1
Insecta	Coleoptera	Dytiscidae	*Uvarus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	3	1
Insecta	Coleoptera	Dytiscidae		0	0	0	0	0	0	0	0	0	0	8	2	0	0	0	0	28	0	0	0	0	0	0	0	0	0	2	0	0	40	4
Insecta	Coleoptera	Elmidae	*Dubiraphia*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2
Insecta	Coleoptera	Elmidae	*Stenelmis*	0	9	6	2	246	295	9	105	43	68	0	0	5	53	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	843	12
Insecta	Coleoptera	Haliplidae	*Peltodytes*	0	0	1	6	0	0	0	1	0	1	0	0	0	0	0	0	3	0	0	0	0	0	0	0	2	0	1	0	0	15	7
Insecta	Coleoptera	Helophoridae	*Helophorus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Insecta	Coleoptera	Hydrophilidae	*Berosus*	0	0	1	0	1	3	0	0	1	0	0	0	0	0	0	0	0	0	2	0	9	8	1	0	2	3	1	4	3	39	13
Insecta	Coleoptera	Hydrophilidae	*Enochrus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	9	0	21	7	2	41	5
Insecta	Coleoptera	Hydrophilidae	*Laccobius*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	3	0	0	0	0	0	5	2
Insecta	Coleoptera	Hydrophilidae	*Paracymus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0	11	5	1	20	5
Insecta	Coleoptera	Hydrophilidae	*Tropisternus*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	0	3	1	0	1	0	0	8	1	0	17	7
Insecta	Coleoptera	Noteridae	*Suphisellus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	6	1
Insecta	Coleoptera	Staphylinidae	*Stenus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1
Insecta	Coleoptera	Staphylinidae		0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	0	0	0	6	4
Insecta	Coleoptera			0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	3	0	0	0	0	0	0	10	0	0	16	4
Insecta	Collembola	Isotomidae	*Isotomurus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	3	0	0	2	0	7	3
Insecta	Collembola	Sminthuridae	*Sminthurides*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	6	1
Insecta	Collembola			0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	1	0	0	10	3

Table 11. Continued.

Phylum or Class	Order	Family	Genus	GBMI1	GBMI2	GBMI3	GBMI4	GBMN3	GBMN4	GBDN1	GBDN2	GBDN3	GBDN4	LCDN1	LCDN2	LCMN1	LCMN2	LCMN3	LCMN4	LCUP1	LCUP2	MCDN1	MCDN2	MCDN3	MCDN4	MCMN1	MCMN2	MCMN4	MCUP1	MCUP2	MCUP3	MCUP4	Total	Freq.
Insecta	Diptera	Ceratopogonidae	*Atrichopogon*	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Insecta	Diptera	Ceratopogonidae	*Bezzia*	0	2	0	3	1	2	0	1	10	3	0	5	0	0	0	0	0	0	0	0	0	3	0	0	1	0	1	2	1	35	13
Insecta	Diptera	Ceratopogonidae	*Ceratopogon*	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	9	2
Insecta	Diptera	Ceratopogonidae	*Culicoides*	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	6	2
Insecta	Diptera	Ceratopogonidae	*Dasyhelea*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	62	0	0	47	0	0	30	14	203	5
Insecta	Diptera	Ceratopogonidae	*Forcipomyia*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Insecta	Diptera	Ceratopogonidae	*Probezzia*	0	0	1	0	0	0	0	0	2	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	1	0	0	3	1	14	6
Insecta	Diptera	Ceratopogonidae	*Stilobezzia*	0	0	0	46	0	0	0	0	0	7	0	0	0	0	0	19	0	0	0	0	21	40	0	0	16	0	0	24	3	176	8
Insecta	Diptera	Ceratopogonidae		0	8	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	13	0	4	5	0	0	32	6
Insecta	Diptera	Chaoboridae	*Chaoborus*	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	4	0	0	0	1	23	5
Insecta	Diptera	Chironomidae	*Chironomini*	0	0	0	2	62	18	0	0	8	82	0	0	0	0	18	9	0	0	0	0	149	25	0	0	273	0	0	45	42	733	12
Insecta	Diptera	Chironomidae	*Orthocladiinae*	0	0	1	0	83	11	0	0	6	29	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	133	6
Insecta	Diptera	Chironomidae	*Pseudochironomi*	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3
Insecta	Diptera	Chironomidae	*Tanypodinae*	0	0	36	171	4	13	0	0	49	34	0	0	0	0	111	109	0	0	0	0	250	330	0	0	36	0	0	181	245	1,569	13
Insecta	Diptera	Chironomidae	*Tanytarsini*	0	0	1	4	4	1	0	0	11	13	0	0	0	0	2	14	0	0	0	0	4	35	0	0	4	0	0	0	1	94	12
Insecta	Diptera	Chironomidae		159	404	0	0	0	0	53	244	0	0	177	10	27	14	0	0	23	1	1	4	102	0	3	32	0	77	35	60	0	1,426	18
Insecta	Diptera	Culicidae	*Aedes*	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1
Insecta	Diptera	Culicidae	*Anopheles*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	8	0	0	0	0	9	2
Insecta	Diptera	Culicidae	*Culex*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Insecta	Diptera	Culicidae	*Psorophora*	0	0	0	0	0	0	0	0	0	0	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	1
Insecta	Diptera	Dolichopodidae		0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	2
Insecta	Diptera	Empididae	*Hemerodromia*	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2
Insecta	Diptera	Ephydridae	*Hydrellia*	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	3	6	4
Insecta	Diptera	Ephydridae		0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	2
Insecta	Diptera	Psychodidae	*Psychoda*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0	15	1
Insecta	Diptera	Sciomyzidae		0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Insecta	Diptera	Stratiomyidae	*Nemotelus*	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2
Insecta	Diptera	Stratiomyidae	*Odontomyia*	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	6	5	0	1	16	1	10	11	8	61	10
Insecta	Diptera	Stratiomyidae	*Stratiomys*	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	2
Insecta	Diptera	Tabanidae	*Chrysops*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1
Insecta	Diptera	Tabanidae		0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	2
Insecta	Diptera	Tipulidae	*Geranomyia*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1
Insecta	Diptera	Tipulidae		0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	4	2
Insecta	Diptera			0	0	0	0	0	0	1	1	0	0	7	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	12	5
Insecta	Ephemeroptera	Baetidae	*Baetis*	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1
Insecta	Ephemeroptera	Baetidae	*Callibaetis*	4	78	105	5	0	1	0	0	0	0	0	0	0	0	4	10	0	0	9	0	10	2	0	0	9	0	0	1	0	238	12
Insecta	Ephemeroptera	Baetidae	*Fallceon*	0	0	0	0	63	15	0	0	3	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	93	4
Insecta	Ephemeroptera	Baetidae	*Procloeon*	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Insecta	Ephemeroptera	Baetidae		0	0	0	0	0	0	11	40	0	0	0	0	14	4	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	71	5
Insecta	Ephemeroptera	Caenidae	*Caenis*	158	180	27	0	231	161	62	171	126	105	0	0	143	26	438	151	0	0	0	0	0	0	0	0	0	0	14	0	1	1,994	15
Insecta	Ephemeroptera	Heptageniidae	*Stenacron*	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	1
Insecta	Ephemeroptera	Heptageniidae		0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2
Insecta	Ephemeroptera	Leptohyphidae		0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	1
Insecta	Ephemeroptera	Tricorythidae	*Tricorythodes*	0	0	0	0	93	193	0	0	13	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	323	4
Insecta	Hemiptera	Aphididae		0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	2
Insecta	Hemiptera	Belostomatidae	*Belostoma*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	3	8	2
Insecta	Hemiptera	Belostomatidae	*Lethocerus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	7	7	0	0	1	6	22	5
Insecta	Hemiptera	Belostomatidae		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	8	0	0	11	3
Insecta	Hemiptera	Cicadellidae		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	5	1	8	3
Insecta	Hemiptera	Corixidae	*Hesperocorixa*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Insecta	Hemiptera	Corixidae	*Trichocorixa*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	7	1
Insecta	Hemiptera	Gerridae	*Trepobates*	6	12	0	0	0	0	1	8	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	5
Insecta	Hemiptera	Gerridae		0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Insecta	Hemiptera	Hebridae	*Hebrus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1
Insecta	Hemiptera	Hydrometridae	*Hydrometra*	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	5	3
Insecta	Hemiptera	Macroveliidae		0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Insecta	Hemiptera	Mesoveliidae	*Mesovelia*	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	10	0	0	2	0	1	2	0	69	18	15	118	8
Insecta	Hemiptera	Nepidae	*Ranatra*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	2	2

Table 11. Continued.

Phylum or Class	Order	Family	Genus	GBMI1	GBMI2	GBMI3	GBMI4	GBMN3	GBMN4	GBDN1	GBDN2	GBDN3	GBDN4	LCDN1	LCDN2	LCMN1	LCMN2	LCMN3	LCMN4	LCUP1	LCUP2	MCDN1	MCDN2	MCDN3	MCDN4	MCMN1	MCMN2	MCMN4	MCUP1	MCUP2	MCUP3	MCUP4	Total	Freq.
Insecta	Hemiptera	Veliidae	*Microvelia*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	2	2
Insecta	Hemiptera	Veliidae	*Rhagovelia*	0	0	0	0	0	0	72	39	12	5	0	0	76	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	204	5
Insecta	Hemiptera			0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	2	0	0	1	8	0	0	25	0	0	38	6
Insecta	Lepidoptera	Crambidae	*Synclita*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	5	0	0	7	2
Insecta	Lepidoptera	Crambidae		0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1
Insecta	Lepidoptera	Noctuidae		0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	7	2
Insecta	Lepidoptera	Pyralidae	*Petrophila*	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Insecta	Lepidoptera	Pyralidae		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	12	0	0	5	0	18	3
Insecta	Megaloptera	Corydalidae	*Chauliodes*	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1
Insecta	Odonata	Aeshnidae	*Aeshna*	0	0	0	0	0	0	0	0	0	0	22	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	2
Insecta	Odonata	Aeshnidae	*Boyeria*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1
Insecta	Odonata	Aeshnidae		0	0	0	0	0	0	0	0	0	0	108	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	0	0	0	111	3
Insecta	Odonata	Calopterygidae	*Hetaerina*	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Insecta	Odonata	Coenagrionidae	*Argia*	9	1	0	0	27	8	0	13	18	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	90	8
Insecta	Odonata	Coenagrionidae	*Enallagma*	0	0	4	3	0	2	0	0	0	0	0	0	0	0	2	1	0	0	0	0	1	0	0	0	13	0	0	4	20	50	9
Insecta	Odonata	Coenagrionidae	*Ischnura*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	0	1	0	0	0	3	1	13	5
Insecta	Odonata	Coenagrionidae		0	7	0	0	0	0	1	0	0	0	0	0	3	0	0	0	0	0	5	0	0	0	4	0	0	11	9	0	0	40	7
Insecta	Odonata	Gomphidae	*Aphylla*	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Insecta	Odonata	Gomphidae		1	0	0	0	0	0	1	0	0	0	0	0	9	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	4
Insecta	Odonata	Libellulidae	*Erythemis*	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	2	0	0	0	5	0	0	2	6	20	7
Insecta	Odonata	Libellulidae	*Pachydiplax*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	1	0	0	0	11	0	0	1	1	20	5
Insecta	Odonata	Libellulidae		0	14	0	0	0	0	0	0	0	0	2	2	1	0	0	0	1	0	0	0	0	0	0	1	0	1	5	0	0	27	8
Insecta	Trichoptera	Hydropsychidae	*Cheumatopsyche*	0	0	0	0	0	0	0	32	1	21	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	57	4
Insecta	Trichoptera	Hydroptilidae	*Hydroptila*	0	0	2	0	0	1	0	0	72	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	76	4
Insecta	Trichoptera	Hydroptilidae	*Ochrotrichia*	0	19	0	0	0	0	0	44	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	65	3
Insecta	Trichoptera	Hydroptilidae		0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Insecta	Trichoptera	Leptoceridae	*Oecetis*	0	0	0	1	1	0	0	0	9	3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	15	5
Insecta	Trichoptera	Limnephilidae		0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1
Insecta	Trichoptera			1	0	0	0	0	0	0	1	0	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	4
Total Number				**384**	**1055**	**933**	**1243**	**1523**	**850**	**260**	**935**	**876**	**677**	**659**	**65**	**318**	**165**	**1186**	**856**	**78**	**20**	**73**	**21**	**838**	**752**	**211**	**106**	**797**	**175**	**305**	**704**	**640**	**16,705**	**29**
Number of Taxa				**14**	**23**	**34**	**33**	**29**	**27**	**19**	**33**	**41**	**37**	**35**	**15**	**19**	**13**	**25**	**24**	**12**	**5**	**20**	**9**	**37**	**32**	**13**	**23**	**47**	**14**	**38**	**47**	**38**	**176**	

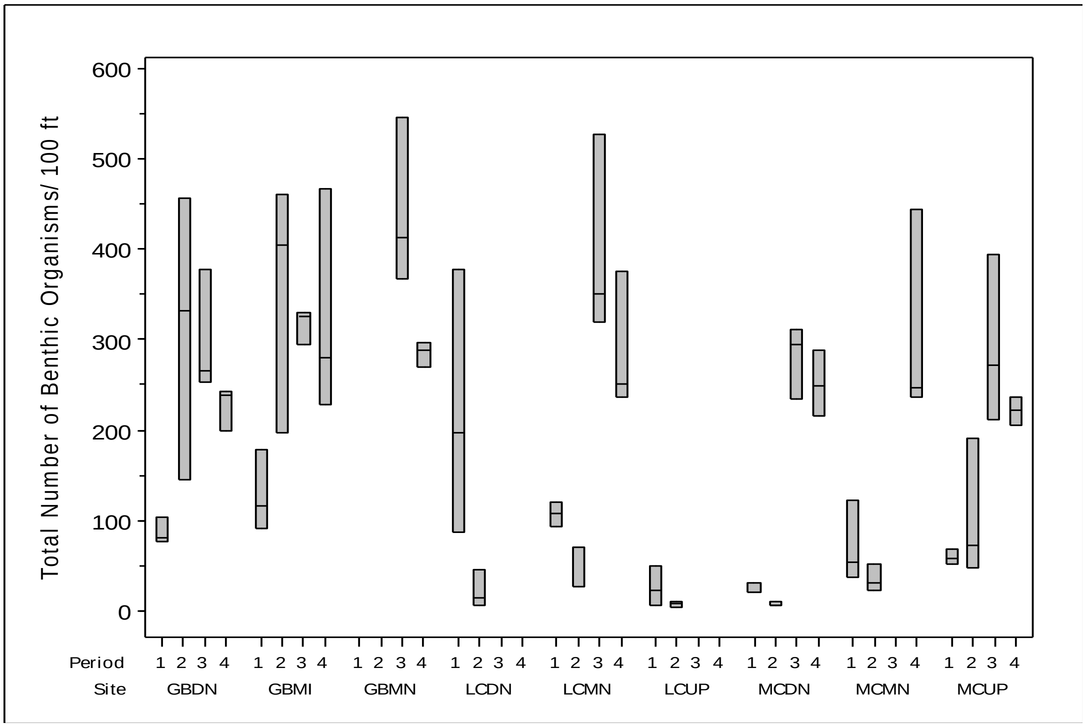


Figure 58. Total number of benthic organisms collected at each site during 2010 (Periods 1 and 2) and 2011 (Periods 3 and 4). GB = Greens Bayou; LC = Little Cypress Creek; MC = Mason Creek; DN = down; UP = up; MN = main; MI = middle.

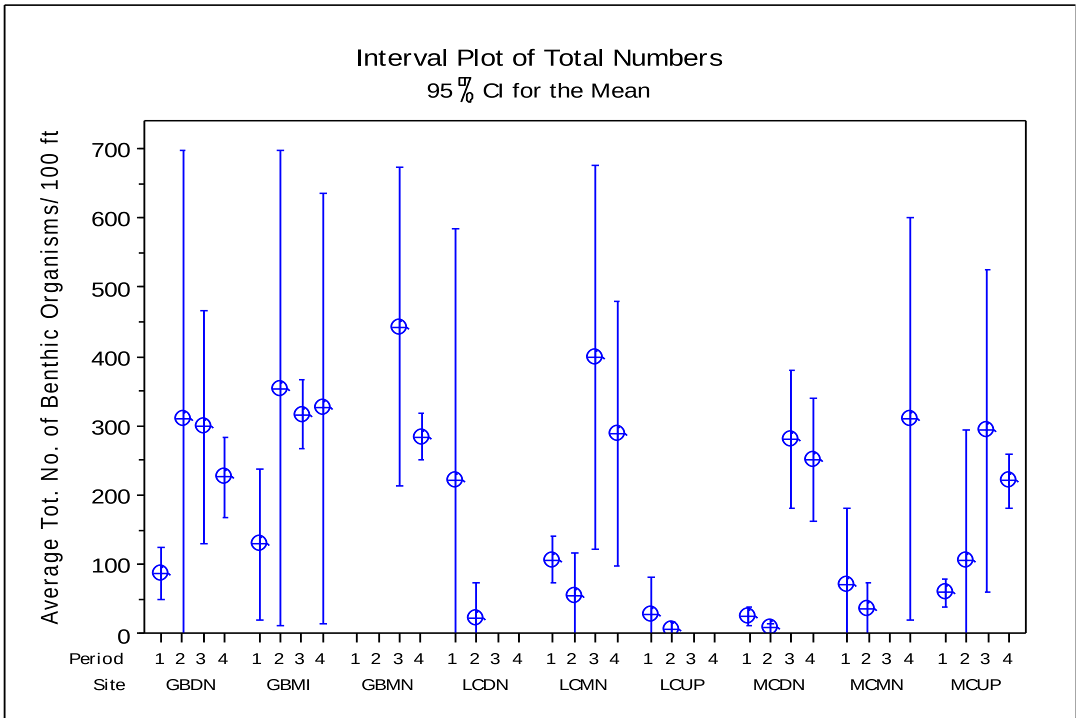


Figure 59. Ninety five percent confidence interval for mean total number of benthic organisms collected over 100 ft of stream bed at each site during 2010 (Periods 1 and 2) and 2011 (Periods 3 and 4). GB = Greens Bayou; LC = Little Cypress Creek; MC = Mason Creek; DN = down; UP = up; MN = main; MI = middle.

Table 12. Results of Kruskal-Wallis One Way ANOVA with Dunn's multiple range test on benthic invertebrate abundance.

```
Kruskal-Wallis Test on the data
Group      N   Median  Ave Rank       Z
GBDN      12  239.000      53.1    1.34
GBMN       6  331.000      72.8    2.89
GBMI      12  286.500      60.1    2.38
LCDN       6   65.500      30.3   -1.37
LCMN      12  177.000      49.0    0.73
LCUP       6    8.500       8.4   -3.58
MCDN      12  123.500      33.7   -1.52
MCMN       9   53.000      35.5   -1.07
MCUP      12  197.500      40.8   -0.47
Overall   87               44.0

H = 31.52  DF = 8  P = 0.000
H = 31.52  DF = 8  P = 0.000  (adjusted for ties)

The following groups showed significant differences (adjusted for ties):
Groups               Z vs. Critical value       P-value
GBMN vs. LCUP        4.41170 >= 2.773           0.0000
GBMI vs. LCUP        4.09119 >= 2.773           0.0000
GBDN vs. LCUP        3.53690 >= 2.773           0.0004
LCMN vs. LCUP        3.21027 >= 2.773           0.0013
GBMN vs. MCDN        3.09149 >= 2.773           0.0020
GBMN vs. LCDN        2.90875 >= 2.773           0.0036
GBMN vs. MCMN        2.79825 >= 2.773           0.0051
```

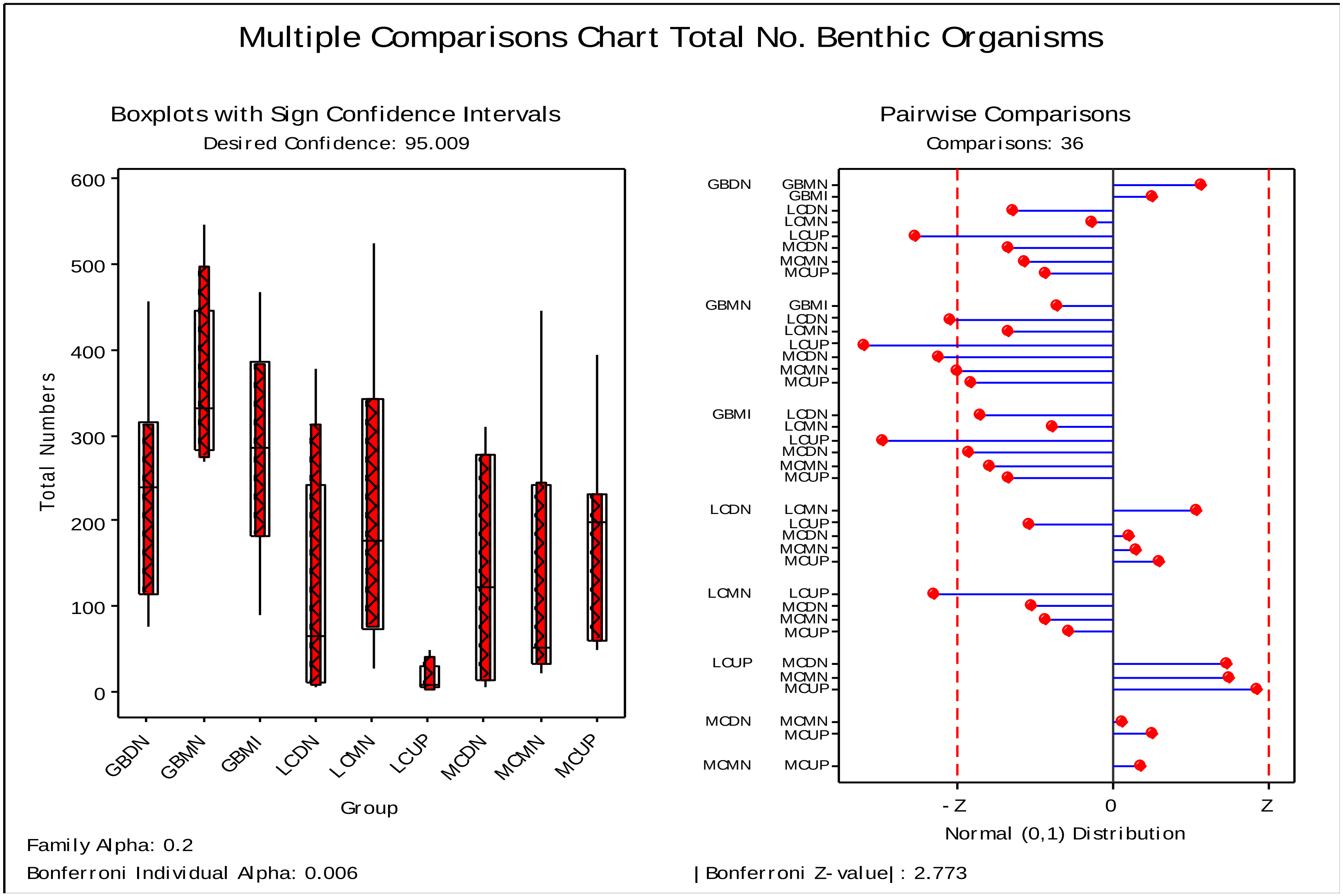


Figure 60. Results of Dunn's multiple range test and boxplots with sign confidence intervals for total number of benthic organisms/100 ft. stream bed at each site during 2010 and 2011.

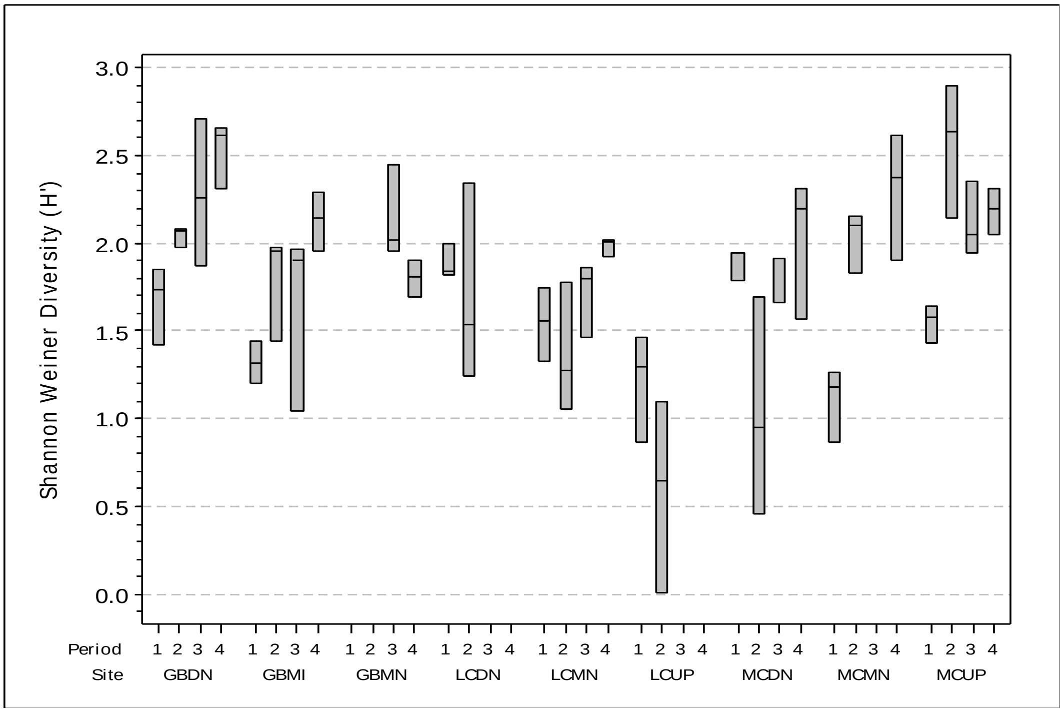


Figure 61. Shannon Weiner Diversity (*H'*) of benthic organisms per 100 ft. segment of stream at each site during 2010 (Periods 1 and 2) and 2011 (Periods 3 and 4). GB = Greens Bayou; LC = Little Cypress Creek; MC = Mason Creek; DN = down; UP = up; MN = main; MI = middle.

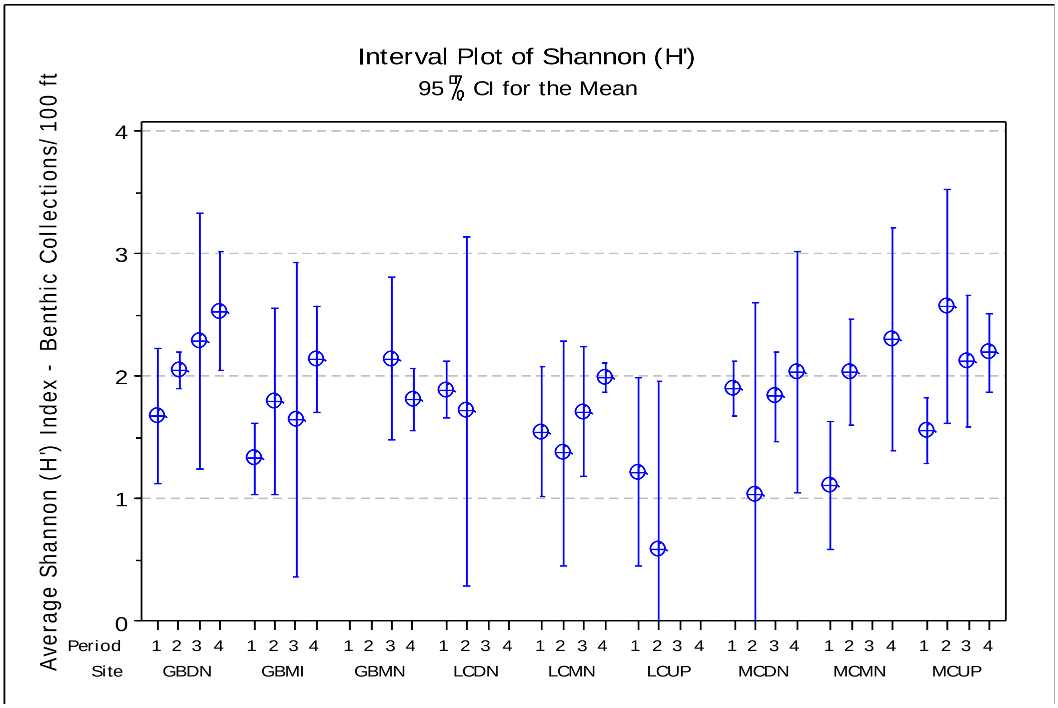


Figure 62. Ninety five percent confidence interval for mean Shannon Diversity Indices (*H'*) for benthic organisms collected over 100 ft of stream bed at each site during 2010 (Periods 1 and 2) and 2011 (Periods 3 and 4). GB = Greens Bayou; LC = Little Cypress Creek; MC = Mason Creek; DN = down; UP = up; MN = main; MI = middle.

Table 13. Results of Kruskal-Wallis One Way ANOVA with Dunn's multiple range test on benthic invertebrate Shannon Weiner Diversity Index levels.

```
Kruskal-Wallis Test on the data
Group      N  Median  Ave Rank      Z
GBDN      12  2.0801      60.3   2.40
GBMN       6  1.9283      51.3   0.74
GBMI      12  1.9279      40.5  -0.52
LCDN       6  1.8295      41.8  -0.22
LCMN      12  1.7621      33.5  -1.55
LCUP       6  0.9831       9.3  -3.48
MCDN      12  1.8517      39.5  -0.66
MCMN       9  1.8978      45.6   0.20
MCUP      12  2.0978      59.8   2.34
Overall   87              44.0

H = 24.25  DF = 8  P = 0.002

The following groups showed significant differences:
Groups                 Z vs. Critical value       P-value
GBDN vs. LCUP          4.03162 >= 2.773           0.0001
LCUP vs. MCUP          3.99863 >= 2.773           0.0001
GBMN vs. LCUP          2.88005 >= 2.773           0.0040
```

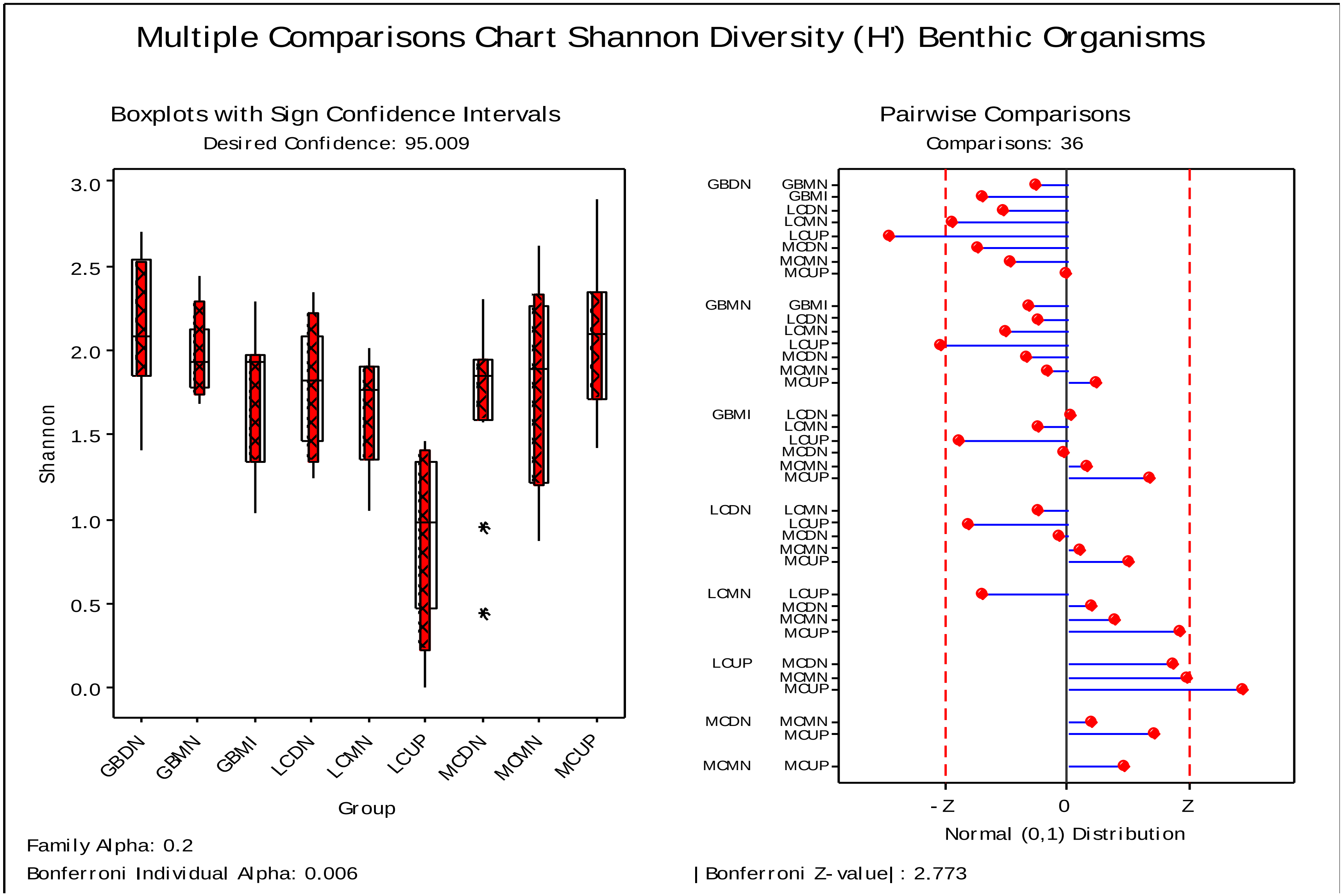


Figure 63. Results of Dunn's multiple range test and boxplots with sign confidence intervals for benthic Shannon-Weiner Diversity (*H'*)/100 ft. stream at each site during 2010 and 2011.

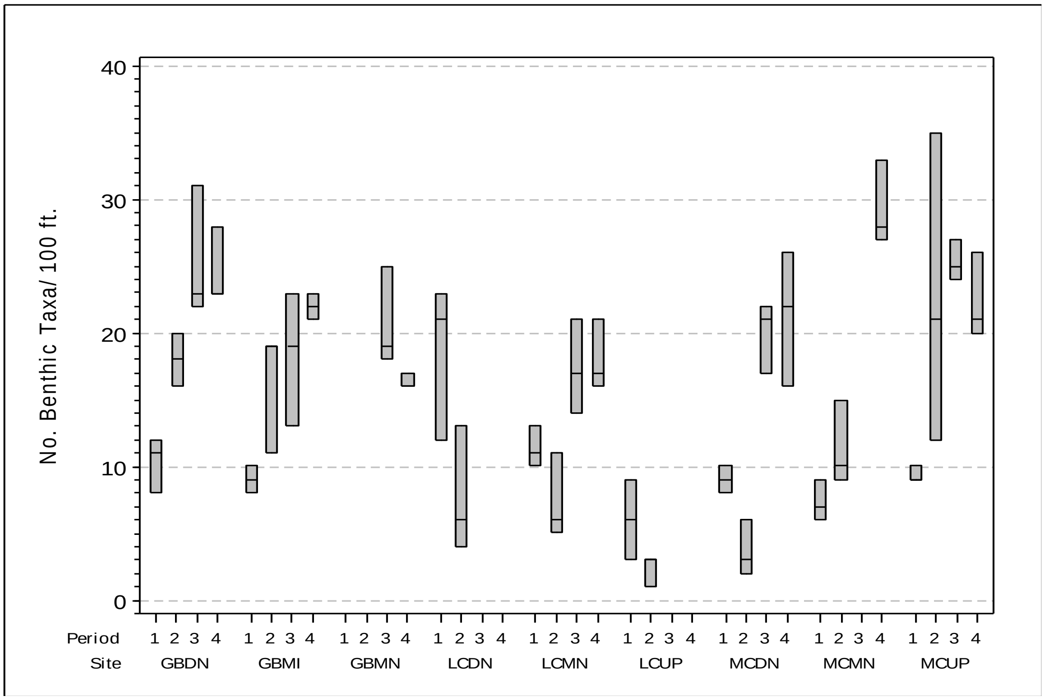


Figure 64. Number of benthic invertebrate taxa per 100 ft. segment of stream collected at each site during 2010 (Periods 1 and 2) and 2011 (Periods 3 and 4). GB = Greens Bayou; LC = Little Cypress Creek; MC = Mason Creek; DN = down; UP = up; MN = main; MI = middle.

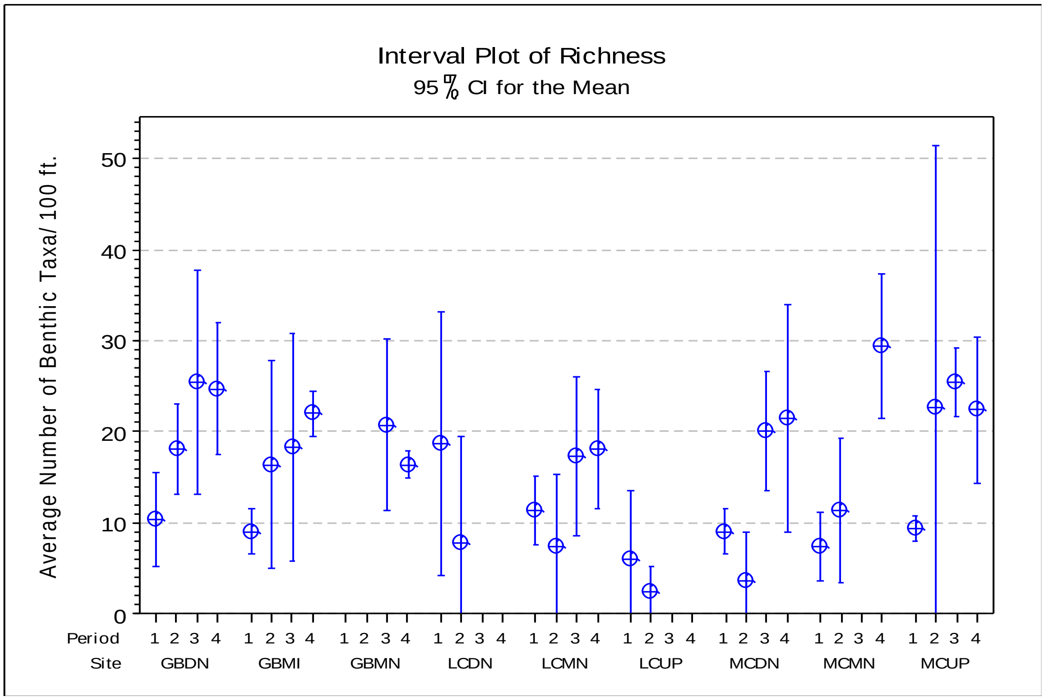


Figure 65. Ninety five percent confidence interval for mean number of benthic taxa collected over 100 ft of stream bed at each site during 2010 (Periods 1 and 2) and 2011 (Periods 3 and 4). GB = Greens Bayou; LC = Little Cypress Creek; MC = Mason Creek; DN = down; UP = up; MN = main; MI = middle.

Table 14. Results of Kruskal-Wallis One Way ANOVA with Dunn's multiple range test on number of benthic invertebrate taxa/100 ft. segment of stream.

```
Kruskal-Wallis Test on the data
Group      N  Median  Ave Rank      Z
GBDN      12  21.000      57.4   1.98
GBMN       6  17.500      53.3   0.94
GBMI      12  19.000      47.6   0.54
LCDN       6  12.500      37.6  -0.64
LCMN      12  13.500      37.7  -0.94
LCUP       6   3.000       7.8  -3.64
MCDN      12  13.000      37.5  -0.95
MCMN       9  10.000      42.9  -0.14
MCUP      12  21.000      57.3   1.96
Overall   87              44.0

H = 22.06  DF = 8  P = 0.005
H = 22.11  DF = 8  P = 0.005  (adjusted for ties)

The following groups showed significant differences (adjusted for ties):
Groups                Z vs. Critical value       P-value
GBDN vs. LCUP         3.93758 >= 2.773           0.0001
LCUP vs. MCUP         3.92437 >= 2.773           0.0001
GBMI vs. LCUP         3.16130 >= 2.773           0.0016
GBMN vs. LCUP         3.12969 >= 2.773           0.0017
```

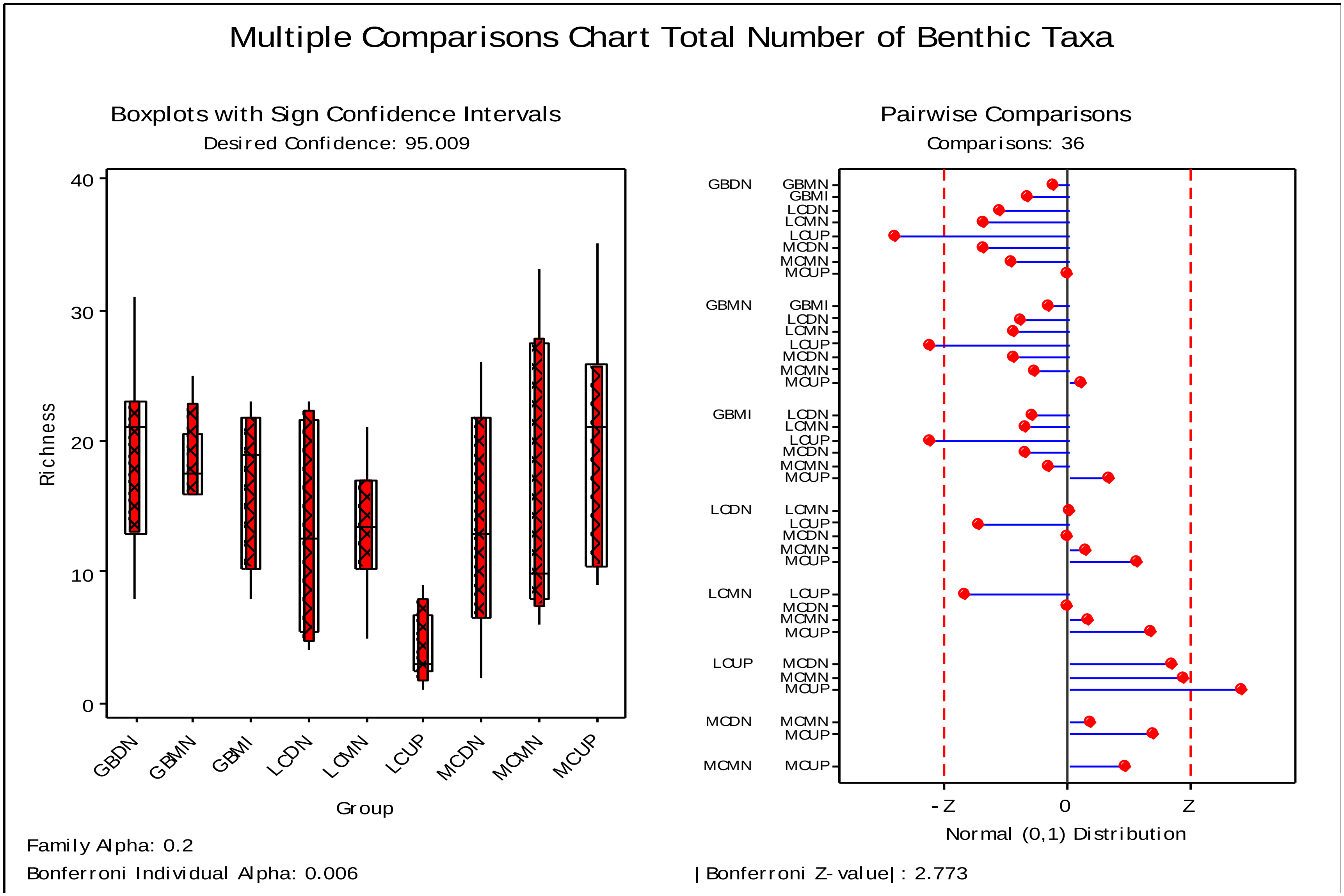
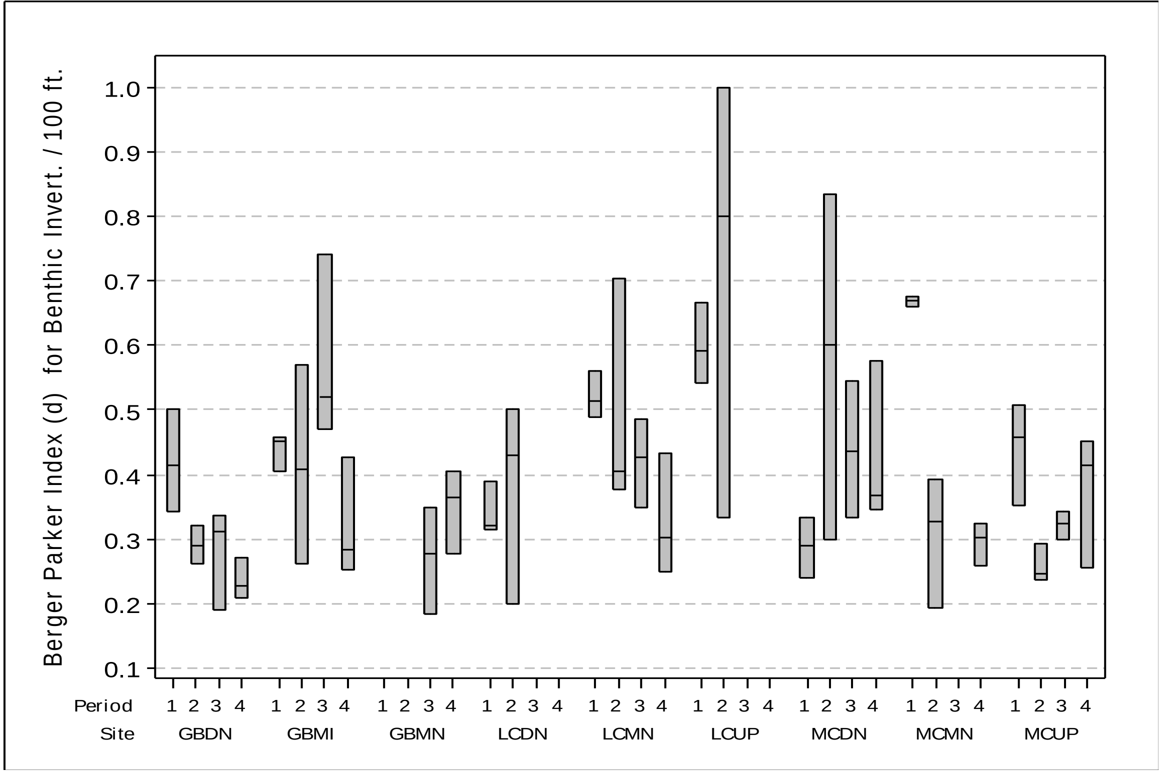


Figure 66. Results of Dunn's multiple range test and boxplots with sign confidence intervals for number of benthic invertebrate taxa/100 ft. stream at each site during 2010 and 2011.

In addition to evaluating the number of benthic invertebrate taxa collected per 100 ft. segment, we also computed the cumulative number of taxa over the entire sample site (300 ft), which effectively is the pooled number of unique taxa for all three replicates at each site. This represents the maximum number of taxa likely present at each site. The cumulative number of benthic invertebrate taxa was generally highest at the MCUP and GBDN sites (Figure 67). The lowest cumulative number of benthic invertebrate taxa was most frequently recorded at the LCUP site. However, the second lowest number of taxa was observed at the MCDN site during the second sampling period in 2010. Similar to the average number of benthic invertebrate taxa, the cumulative number of taxa in also generally increased from 2010 to 2011.

The majority of median benthic invertebrate Pielou's Evenness index (*J'*) fell between 0.6 and 0.8 (Figure 68). The highest and lowest values were observed at the LCDN and MCMN sites respectively. The average *J'* index did not appear to vary much between sampling sites and periods (Figure 69). The confidence interval of the mean overlapped extensively suggesting no significant difference. However, there were no statistical differences observed between sites overall (Figure 70 and Table 15).

The observed median Berger Parker index (*d*) values for benthic invertebrate communities were generally highest and lowest at the LCUP and GBDN sites respectively (Figure 71). This pattern was also observed in average *d* values but there was considerably large overlapping confidence intervals suggesting this was not statistically significant (Figure 72). Statistically significant differences were minimal between sites (Figure 73 and Table 16). The LCUP site with the highest values was significantly different from GBDN and GBMN and MCUP, which possessed the lowest *d* values. This suggests that there were few numerically dominant taxa at GBDN, GBMN and MCUP, in contrast to LCUP. This is consistent with



observed statistically significant lower H’ and number of benthic invertebrate taxa at the LCUP sites (Figure 63, Figure 66). Cumulative number of benthic invertebrate taxa was also generally lowest at this site (Figure 67).

Significant correlations were observed between the various benthic invertebrate community metrics (**Error! Reference source not found.**). The highest positive correlations were observed between average number of taxa and cumulative number of taxa, and *H’* and the average number of taxa. The largest negative correlation occurred between *H’* and *d*, and the average number of taxa and *d*. This indicates that species diversity was positively influenced by higher numbers of species that are evenly distributed. Also, the presence of highly abundant, dominant species (high *d*) reduced the *H’* values. These patterns are consistent with patterns reported in animal communities (Magurran 2004).

Benthic community metrics exhibited numerous significant correlations with physicochemical data (Table 18). The majority of correlation values were however not very high (<0.50). The strongest correlations occurred between the average number of benthic taxa and orthophosphates, ammonia nitrogen, and specific conductance. In addition, the cumulative number of taxa was positively correlated with orthophosphate.

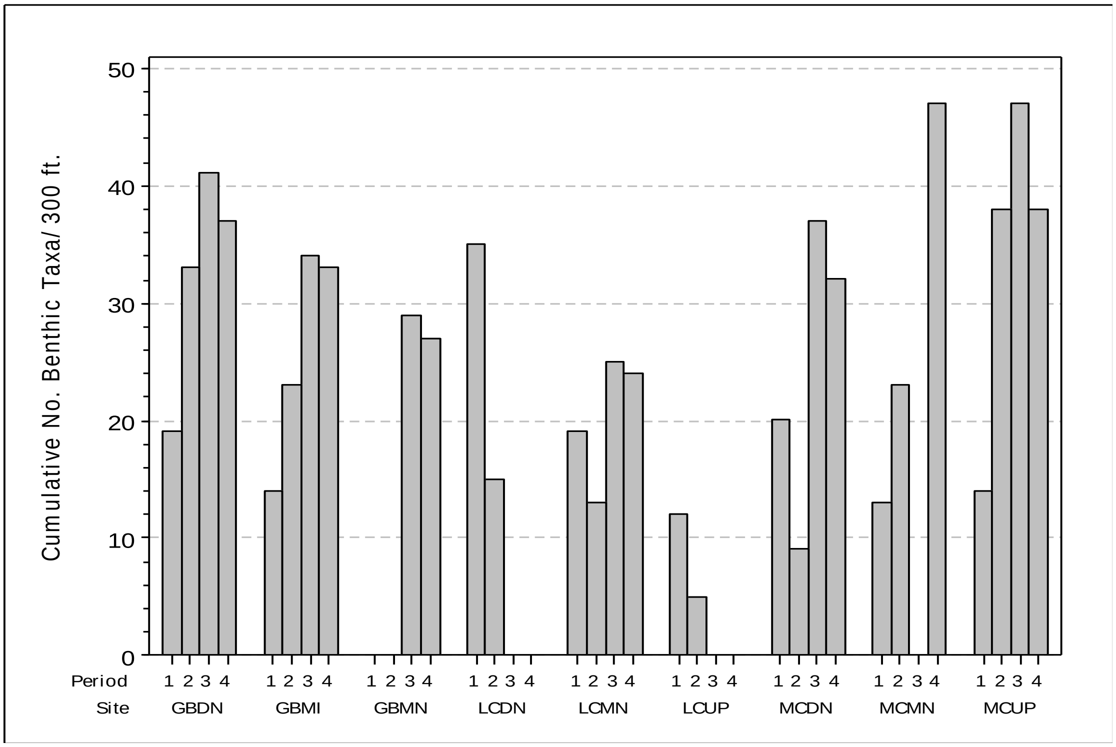


Figure 67. Cumulative number of benthic invertebrate taxa/300 ft. collected at each site and period.

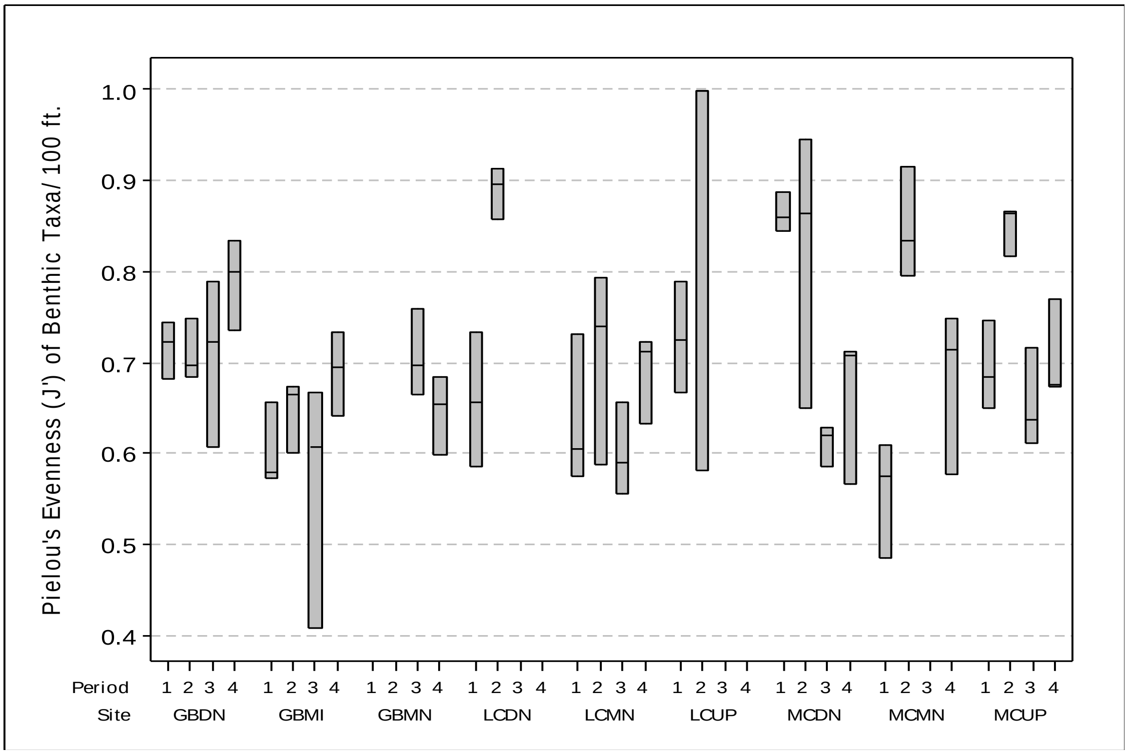


Figure 68. Boxplot of Pielou's Evenness index (*J'*) of benthic organisms/100 ft. segment of stream collected at each site during 2010 (Periods 1 and 2) and 2011 (Periods 3 and 4). GB = Greens Bayou; LC = Little Cypress Creek; MC = Mason Creek; DN = down; UP = up; MN = main; MI = middle.

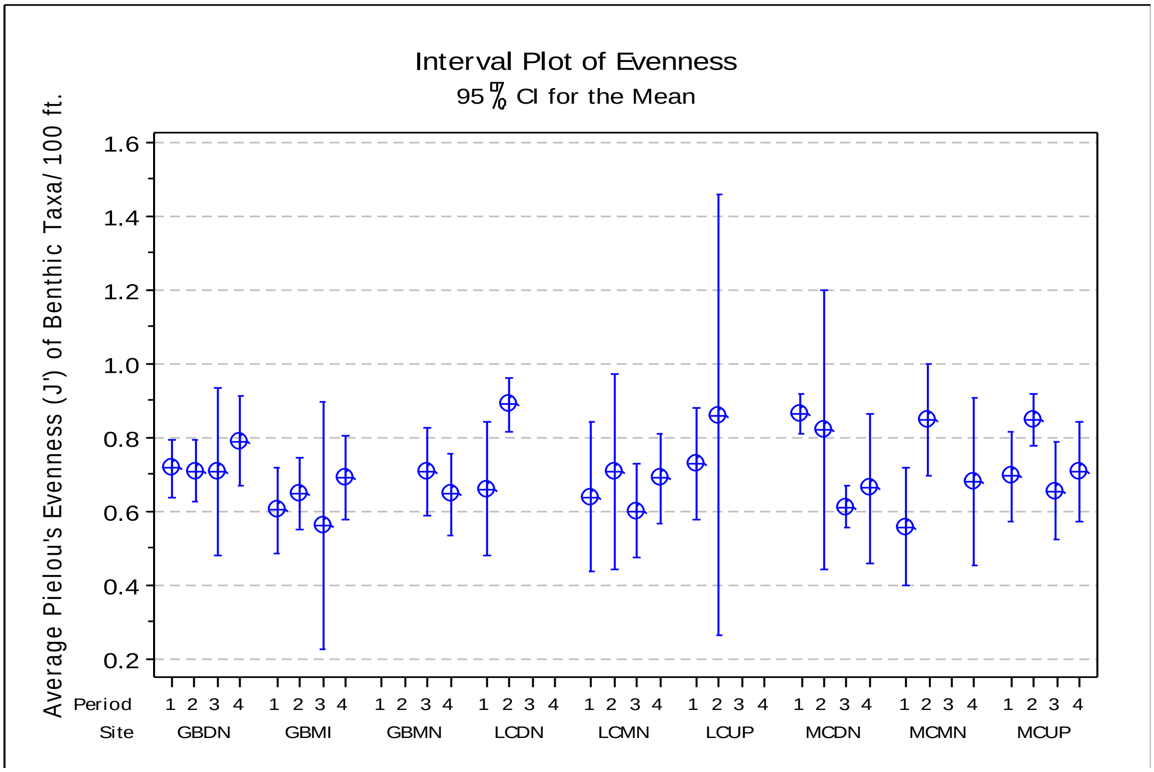


Figure 69. Ninety five percent confidence interval for mean Pielou's Evenness (*J'*) index for benthic taxa collected over 100 ft of stream bed at each site during 2010 (Periods 1 and 2) and 2011 (Periods 3 and 4). GB = Greens Bayou; LC = Little Cypress Creek; MC = Mason Creek; DN = down; UP = up; MN = main; MI = middle.

Table 15. Results of Kruskal-Wallis One Way ANOVA with Dunn's multiple range test on Pielou's Evenness index (*J'*) of benthic invertebrate taxa/100 ft. segment of stream collected at each site during 2010 and 2011.

```
Kruskal-Wallis Test on the data
Group      N  Median  Ave Rank      Z
GBDN      12  0.7293      53.6   1.42
GBMN       6  0.6749      38.5  -0.55
GBMI      12  0.6489      26.2  -2.63
LCDN       6  0.7953      56.8   1.29
LCMN      12  0.6445      33.2  -1.60
LCUP       6  0.7575      57.0   1.31
MCDN      12  0.7094      48.3   0.63
MCMN       9  0.7142      42.0  -0.25
MCUP      12  0.6995      50.2   0.91
Overall   87              44.0

H = 14.45  DF = 8  P = 0.071

There were no significant group differences.
```

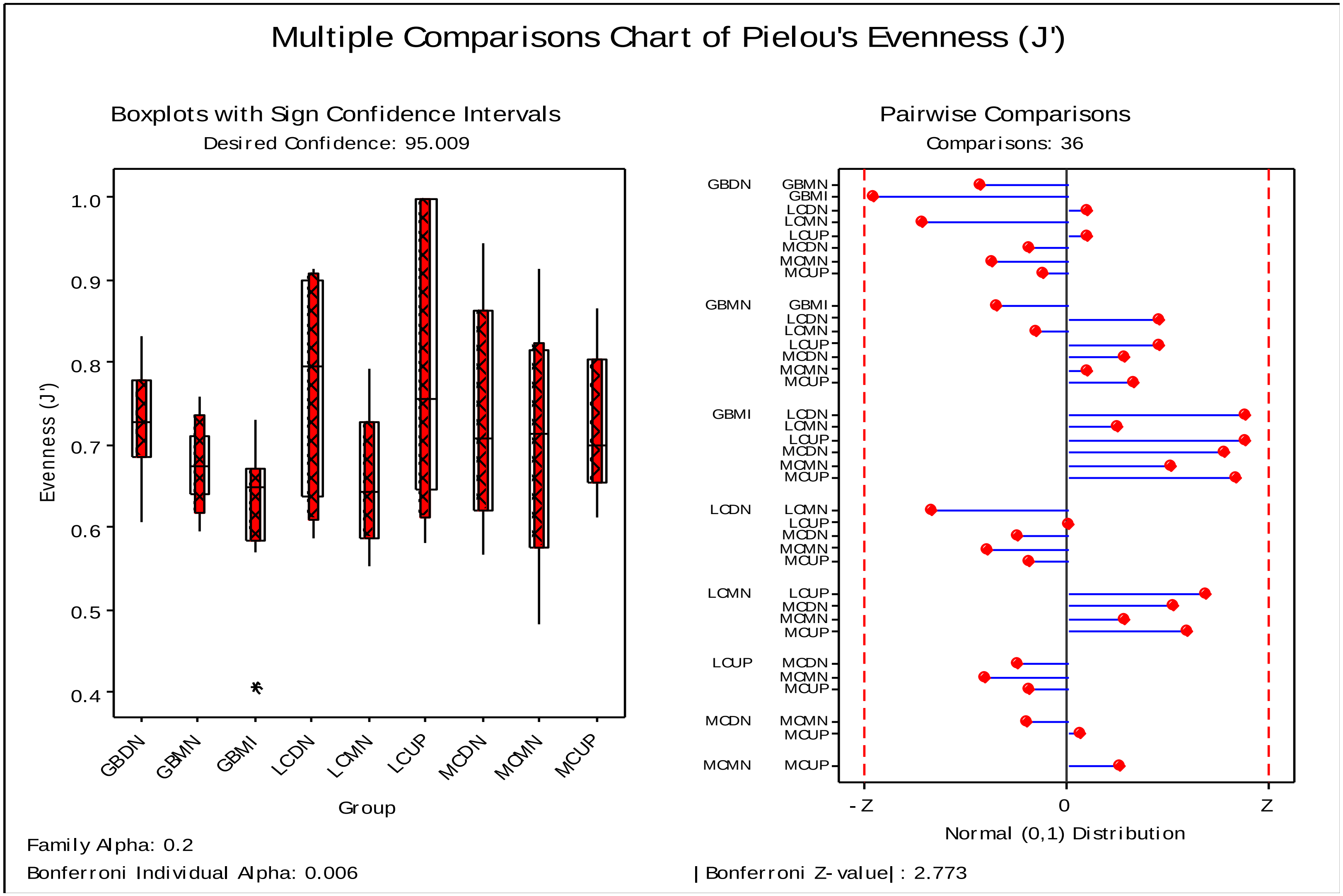


Figure 70. Results of Dunn's multiple range test and boxplots with sign confidence intervals for Pielou's Evenness index (*J'*) of benthic invertebrate taxa/100 ft. stream at each site during 2010 and 2011.

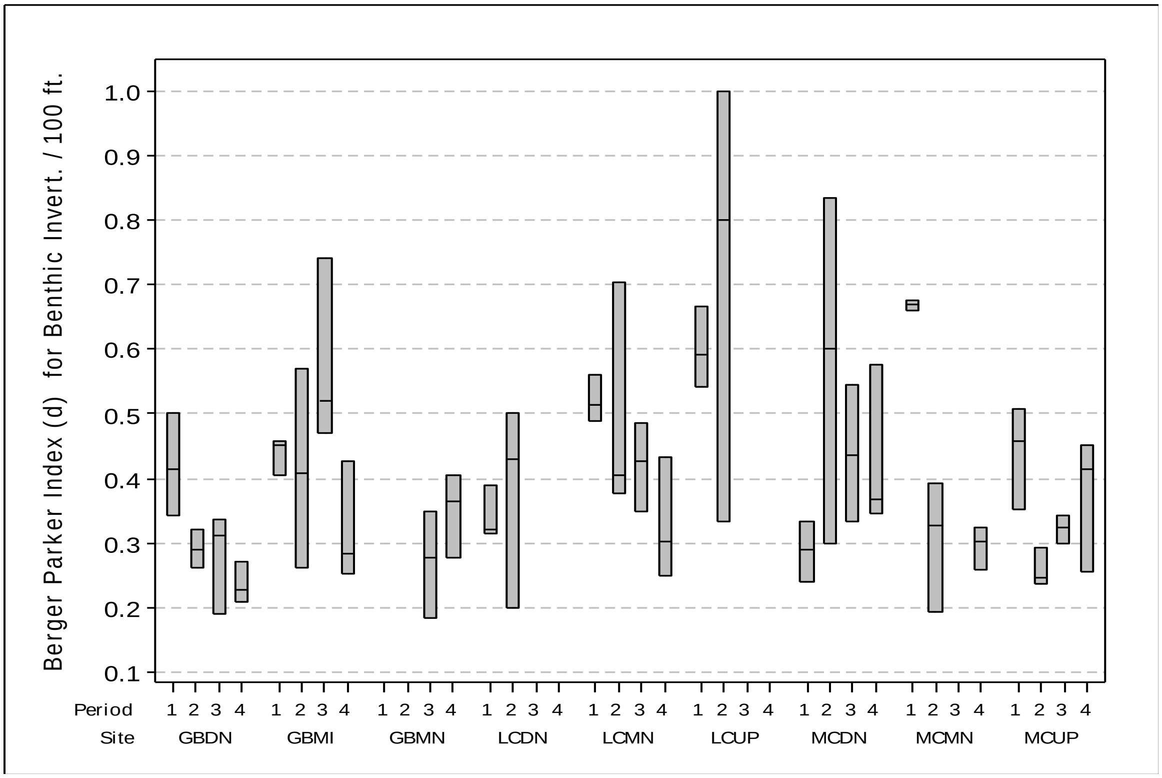


Figure 71. Boxplot of Berger-Parker Index (*d*) of benthic organisms/100 ft. segment of stream collected at each site during 2010 (Periods 1 and 2) and 2011 (Periods 3 and 4). GB = Greens Bayou; LC = Little Cypress Creek; MC = Mason Creek; DN = down; UP = up; MN = main; MI = middle.

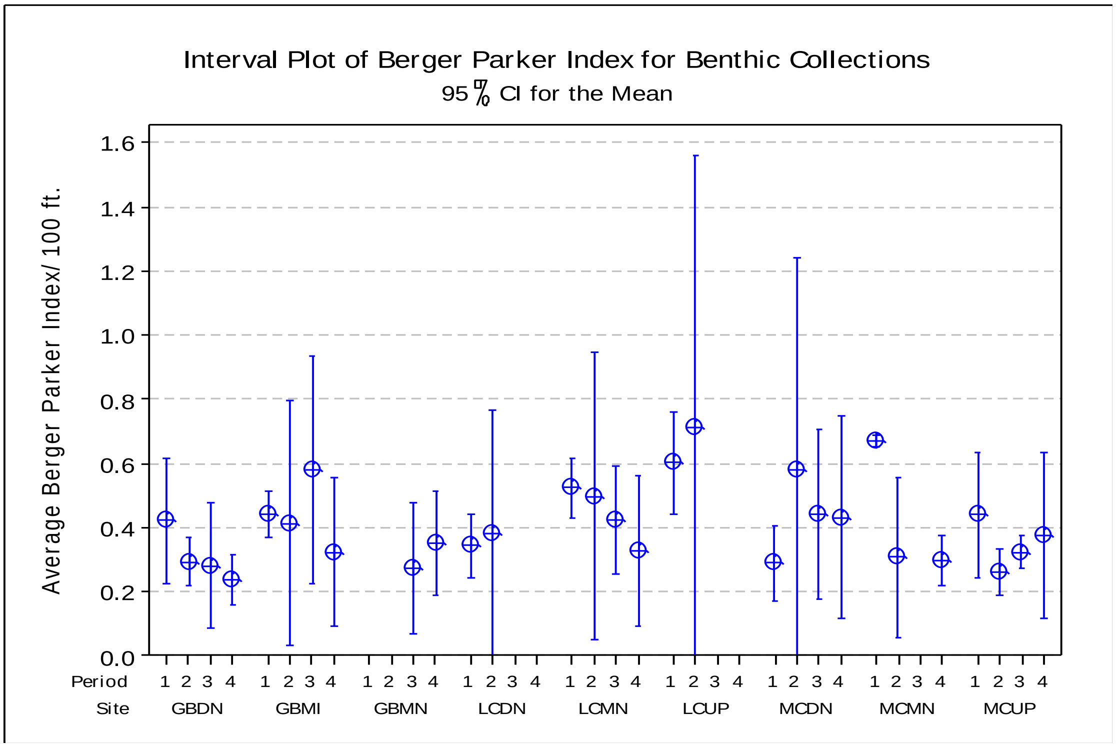


Figure 72. Ninety five percent confidence interval for mean Berger Parker (*d*) index for benthic taxa collected over 100 ft of stream bed at each site during 2010 (Periods 1 and 2) and 2011 (Periods 3 and 4). GB = Greens Bayou; LC = Little Cypress Creek; MC = Mason Creek; DN = down; UP = up; MN = main; MI = middle.

Table 16. Results of Kruskal-Wallis One Way ANOVA with Dunn's multiple range test on Berger-Parker index (*d*) of benthic invertebrate taxa/100 ft. segment of stream collected at each site during 2010 and 2011.

```
Kruskal-Wallis Test on the data
Group      N  Median  Ave Rank      Z
GBDN      12  0.3006      26.4  -2.60
GBMN       6  0.3121      28.3  -1.57
GBMI      12  0.4389      51.6   1.12
LCDN       6  0.3544      38.9  -0.51
LCMN      12  0.4284      53.8   1.45
LCUP       6  0.6288      72.7   2.88
MCDN      12  0.3556      48.3   0.64
MCMN       9  0.3269      43.9  -0.01
MCUP      12  0.3318      36.0  -1.18
Overall  87               44.0
H = 20.58  DF = 8  P = 0.008
H = 20.58  DF = 8  P = 0.008  (adjusted for ties)

The following groups showed significant differences (adjusted for ties):
Groups                 Z vs. Critical value       P-value
GBDN vs. LCUP          3.66549 >= 2.773           0.0002
GBMN vs. LCUP          3.04012 >= 2.773           0.0024
LCUP vs. MCUP          2.90336 >= 2.773           0.0037
```

Table 17. Significant ($p < 0.05$) correlation coefficients observed between benthic community metrics.

Benthic Metric 1	Benthic Metric 2	Correlation	*p*-value
d	Cum. Taxa	-0.67	0.0001
J'	Total No.	-0.55	0.0021
No. Taxa	*d*	-0.69	0.0000
No. Taxa	Cum. Taxa	0.97	0.0000
Total No.	*d*	-0.45	0.0141
Total No.	No. Taxa	0.78	0.0000
Total No.	Cum. Taxa	0.69	0.0000
H '	*d*	-0.91	0.0000
H '	No. Taxa	0.87	0.0000
H '	Total No.	0.55	0.0021
H '	Cum. Taxa	0.85	0.0000

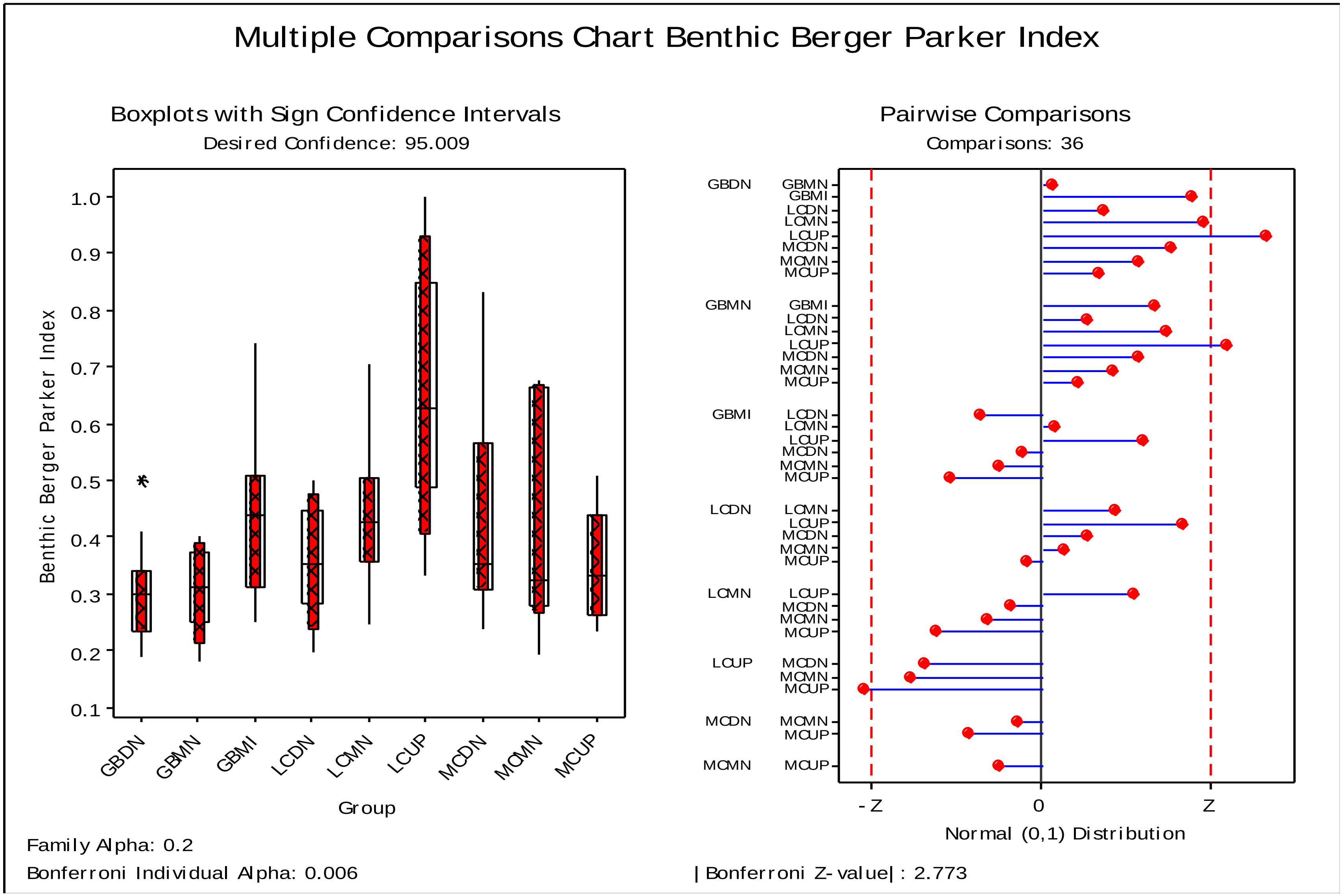
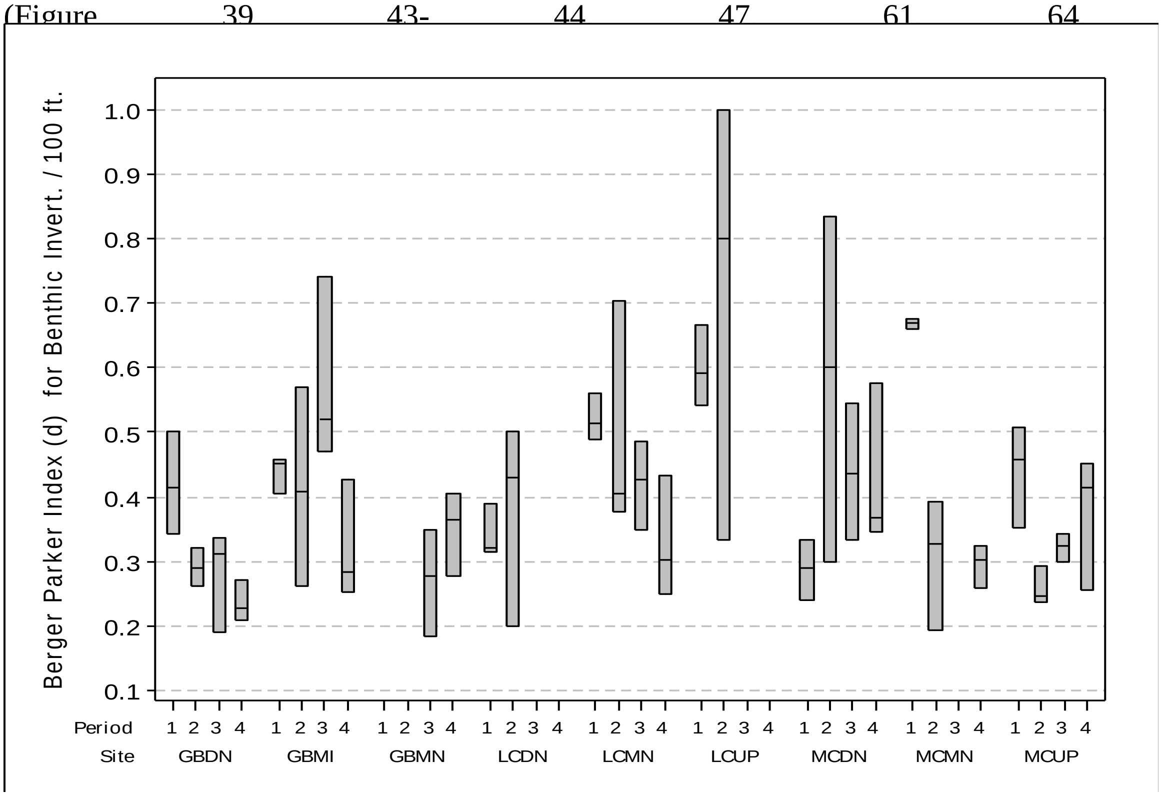


Figure 73. Dunn's multiple range test and boxplots with sign confidence intervals for Berger Parker index (*d*) of benthic invertebrate taxa/100 ft. stream at each site during 2010 and 2011.

Table 18. Significant ($p < 0.05$) correlation analysis between benthic community metrics and environmental variables.

Benthic Metric	Variable	Correlation	p-value
d	NTU	0.43	0.0193
d	TSS	0.42	0.0234
d	O-P	-0.42	0.0240
d	Secchi	-0.39	0.0360
J'	NTU	0.44	0.0175
J'	TSS	0.41	0.0254
J'	Depth	-0.40	0.0326
J'	NH4-N	0.39	0.0374
J'	% Emerg. Veg	0.38	0.0395
J'	Sp. Cond	-0.37	0.0497
Number of Taxa	O-P	0.66	0.0001
Number of Taxa	Sp. Cond	0.59	0.0007
Number of Taxa	Wat. Temp	0.59	0.0007
Number of Taxa	Tot. Alkalinity	0.58	0.0010
Number of Taxa	NH4-N	-0.56	0.0017
Number of Taxa	pH	0.49	0.0076
Number of Taxa	NTU	-0.47	0.0096
Total Number	pH	0.71	0.0000
Total Number	NH4-N	-0.69	0.0000
Total Number	Sp. Cond	0.66	0.0001
Total Number	Wat. Temp	0.65	0.0001
Total Number	O-P	0.64	0.0002
Total Number	Tot. Alkalinity	0.48	0.0084
Total Number	No. WWTP	0.47	0.0110
Total Number	Secchi	0.45	0.0135
Total Number	NTU	-0.45	0.0155
Total Number	% Impervious	0.45	0.0155
Total Number	NO2+NO3	0.39	0.0363
Cumulative Taxa	O-P	0.64	0.0002
Cumulative Taxa	Sp. Cond	0.54	0.0023
Cumulative Taxa	Wat. Temp	0.54	0.0025
Cumulative Taxa	Tot. Alkalinity	0.53	0.0028
Cumulative Taxa	NH4-N	-0.48	0.0084
Cumulative Taxa	NTU	-0.44	0.0169
Cumulative Taxa	pH	0.42	0.0251
Cumulative Taxa	% Run	-0.39	0.0353
H '	O-P	0.55	0.0018
H '	NTU	-0.50	0.0055
H '	TSS	-0.48	0.0080
H '	NH4-N	-0.47	0.0108
H '	Wat Temp	0.43	0.0203
H '	Sp. Cond	0.41	0.0279
H '	Tot. Alkalinity	0.40	0.0313

Several physicochemical variables were more commonly associated with benthic community metrics including specific conductance, NTU, TSS, and orthophosphates (Table 10). These correlations may in part be due to each variable exhibiting a similar spatial pattern between sites (Figure 39 43- 44 47 61 64 67, Figure 71).



We identified 4 major collection groupings and 5 minor groupings based on the similarity of common taxa (occurring in at least 20% of all collections) analyzed by cluster analysis (Figure 74). The 2011 GBMN sites grouped together along with the 2011 GBDN collections. Other groupings seemed to group at higher levels of similarity based on temporal versus spatial differences. The other major 2011 group consisted of collections from Mason Creek sites. Two major groups of sites composed of 2010 collections were formed. The first consisted of a mixture of MCDN, LCUP, LCDN, and MCUP, while the second consisted of LCMN, GBDN and GBMI. This strong interannual pattern is more clearly viewed in the NMDS ordination plot, which shows strong separation along the horizontal axis (Figure 75). The patterns in taxa assemblage are manifested in distinct interannual and spatial trends in selected community metrics (Figure 76). In general, mean total number of benthic invertebrates and number of invertebrate taxa increased during 2011 despite lower velocities, streamflows and dissolved oxygen at most sites (Figure 32-33, and 40).

The numerically dominant taxa based on pooled collections at each site are presented in Figure 77. The most commonly observed and or numerically occurring species collected during the study were Family Chironomidae (midges), *Caenis* (Small Squaregill Mayflies), *Hyallela* (Order Amphipoda) and Class Oligochaeta (aquatic earthworms). Chironomid larvae were found at most sites. Chironomid larvae are considered tolerant of poor water quality and are adapted to living in hypoxic waters (Johnson et al. 1993; TCEQ 2007; Thorp and Covich 2010; Thorp and Rogers 2011). Another common taxa collected at LCMN and Green Bayou sites were *Caenis* spp. (Squaregill mayflies). Members of the genus *Caenis* are considered tolerant species and capable of living in degraded organically enriched environments containing low oxygen (TCEQ 2007; Voshell 2002). Oligochaetes (aquatic earthworms) were common at the GBMN, LCDN, and Mason Creek sites during most collections (Figure 77). Oligochaete worms are tolerant of poor water quality, including hypoxia, and are found in organically enriched sediment (TCEQ 2007; Voshell 2002). Other tolerant dominant taxa collected at some sites included *Hyallela* (amphipods) (Thorp and Rogers 2011; Voshell 2002). Table 11 lists all invertebrates species collected.

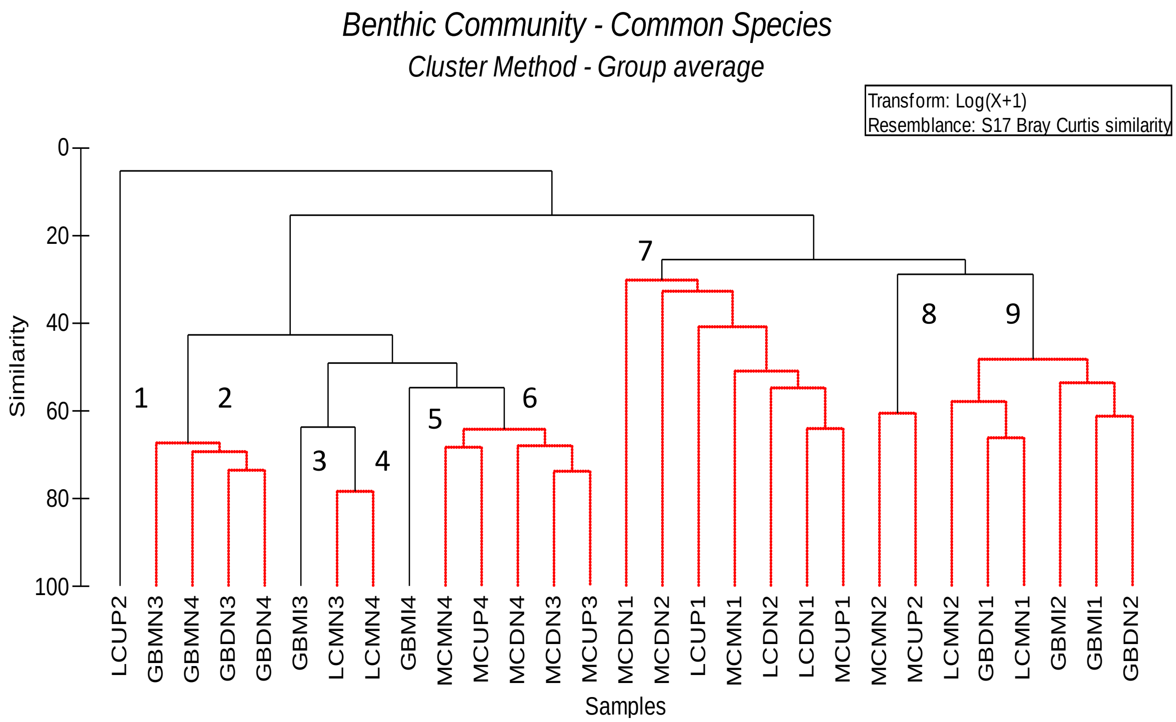


Figure 74. Results of cluster analysis on dominant benthic organisms collected at each site and collection. Collections = Site ID + Collection Period. Collections outlined in red form distinct groupings as identified by the SIMPROF technique. Numerals refer to cluster groupings.

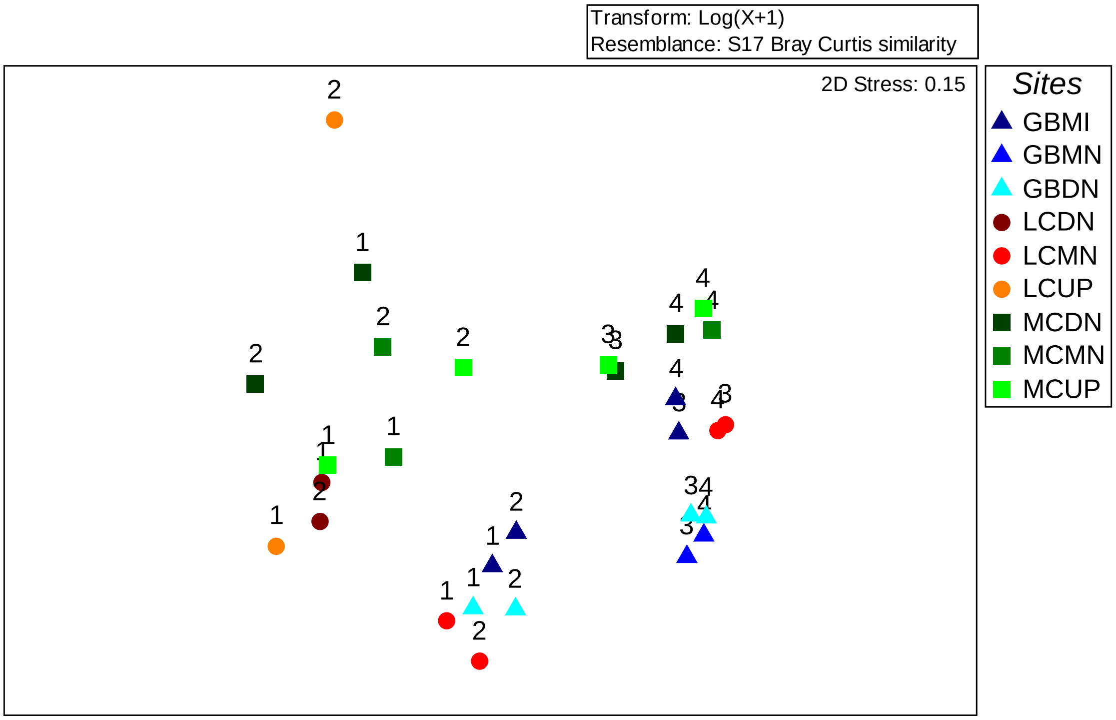


Figure 75. Results of non-metric multidimensional scaling (NMDS) ordination of collections based on similarity of common benthic organisms in the aquatic community.

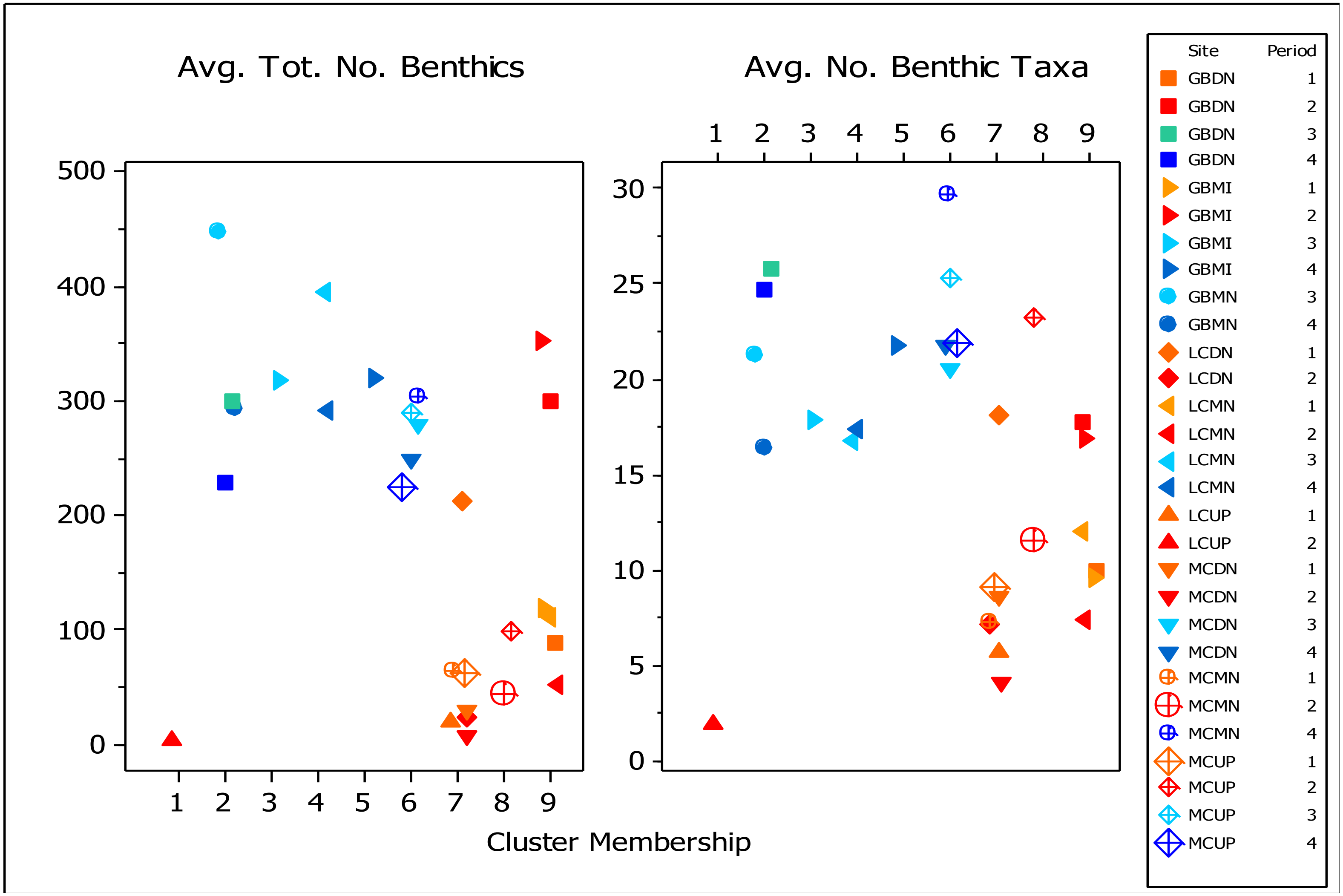


Figure 76. Average total number of benthic invertebrates and number of taxa of individual collections within each cluster membership.

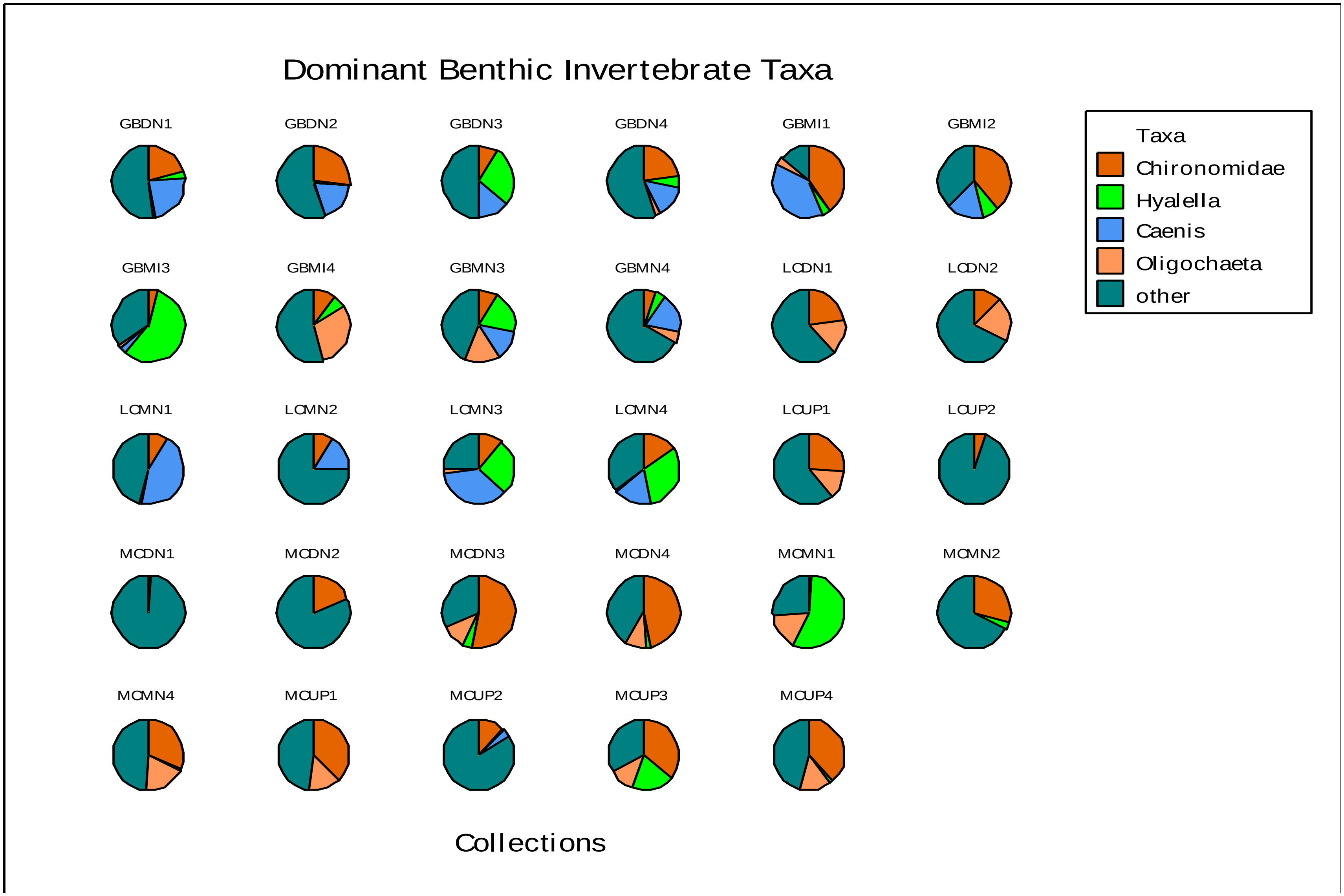


Figure 77. Dominant benthic invertebrate taxa and composition during each collection at each site. Numbers refer to collection periods. 1, 2 = 2010; 3, 4 = 2011. Oligochaeta and Chironomidae included individuals identified to lower taxa.

The benthic index of biotic integrity (B-IBI) and resulting aquatic life use designation for each collection and site is listed in Table 19 - 27 (TCEQ 2007). Based on our assessment four collections at the Greens Bayou site complex were classified as exhibiting high aquatic life use based on benthic invertebrate taxa (Figure 78). The GBMI period 1 collection, LCUP sites and the almost all of the Mason Creek collections were classified as exhibiting limited aquatic life use. The remaining sites were classified as exhibiting intermediate aquatic life use. With the exception of GBDN and GBMI, there did not appear to be any distinct temporal trend in B-IBI scores or aquatic life uses (Figure 76).

Table 19. Results of benthic IBI calculations at the Greens Bayou Down site (GBDN).

Qualitative Benthic IBI								
Period	1		2		3		4	
Date	7/21/2010		9/2/2010		6/10/2011		7/29/2011	
Site	GBDN		GBDN		GBDN		GBDN	
Metric	Value	Score	Value	Score	Value	Score	Value	Score
Taxa Richness	10	2	21	3	31	4	28	4
EPT Index	1	1	3	1	6	2	6	2
HBI	6.69	1	6.34	1	6.49	1	6.35	1
% Chironomidae	25.00	1	35.94	1	8.48	3	23.83	1
% Dominant Taxon	33.96	2	35.94	2	26.92	3	23.83	3
% Dominant FFG	43.24	3	39.67	3	36.03	4	31.22	4
% Predators	43.24	1	22.29	3	9.18	4	14.13	4
Intolerant : Tolerant	0.00	1	0.08	1	0.23	1	0.17	1
% Total Trichoptera as Hydropsychidae	No Trich	1	42.11	3	1.22	4	87.50	1
Number of Non-Insect Taxa	5	3	9	4	15	4	14	4
% CG	28.14	3	39.67	2	32.09	2	30.12	3
% n as Elmidae	4.25	4	15.46	3	4.86	4	10.26	3
AQUATIC LIFE USE SCORE	23		27		36		31	
AQUATIC LIFE USE RATING	Intermediate		Intermediate		High		High	
Kicknet (Qualitative) Scoring Criteria								
Exceptional	>36							
High	29 - 36							
Intermediate	22 - 28							
Limited	<22							

Table 20. Results of benthic IBI calculations at the Greens Bayou mainstem site (GBMN).

Qualitative Benthic IBI				
Period	3		4	
Date	6/15/2011		8/1/2011	
Site	GBMN		GBMN	
Metric	Value	Score	Value	Score
Taxa Richness	20	3	20	3
EPT Index	4	2	5	2
HBI	6.85	1	6.51	1
% Chironomidae	12.23	2	5.23	3
% Dominant Taxon	27.48	3	35.04	2
% Dominant FFG	47.96	2	61.18	1
% Predators	8.21	4	4.06	1
Intolerant : Tolerant	0.15	1	0.34	1
% Total Trichoptera as Hydropsychidae	0.00	4	0.00	4
Number of Non-Insect Taxa	10	4	8	4
% CG	47.96	1	61.18	1
% n as Elmidae	19.54	3	35.04	1
AQUATIC LIFE USE SCORE	30		24	
AQUATIC LIFE USE RATING	High		Intermediate	
Kicknet (Qualitative) Scoring Criteria				
Exceptional	>36			
High	29 - 36			
Intermediate	22 - 28			
Limited	<22			

Table 21. Results of benthic IBI calculations at the Greens Bayou middle site (GBMI).

Qualitative Benthic IBI								
Period	1		2		3		4	
Date	7/21/2010		9/2/2010		6/10/2011		7/29/2011	
Site	GBMI		GBMI		GBMI		GBMI	
Metric	Value	Score	Value	Score	Value	Score	Value	Score
Taxa Richness	10	2	18	3	23	4	23	4
EPT Index	2	1	3	1	3	1	2	1
HBI	6.58	1	6.25	1	7.21	1	6.63	1
% Chironomidae	43.09	1	46.01	1	4.14	3	18.65	1
% Dominant Taxon	43.09	1	46.01	1	58.93	1	28.45	3
% Dominant FFG	43.09	3	42.62	3	50.29	2	40.83	3
% Predators	19.24	3	22.63	3	5.19	4	14.38	4
Intolerant : Tolerant	0.01	1	0.13	1	0.17	1	0.40	1
% Total Trichoptera as Hydropsychidae	No Trich	1	0.00	4	0.00	4	0.00	4
Number of Non-Insect Taxa	5	3	8	4	11	4	14	4
% CG	43.09	1	42.62	1	50.29	1	40.83	2
% n as Elmidae	0.00	1	1.03	4	0.65	1	0.21	1
AQUATIC LIFE USE SCORE	19		27		27		29	
AQUATIC LIFE USE RATING	Limited		Intermediate		Intermediate		High	
Kicknet (Qualitative) Scoring Criteria								
Exceptional	>36							
High	29 - 36							
Intermediate	22 - 28							
Limited	<22							

Table 22. Results of benthic IBI calculations at the Little Cypress Creek Down site (LCDN).

Qualitative Benthic IBI				
Period	1		3	
Date	7/6/2010		9/7/2010	
Site	LCDN		LCDN	
Metric	Value	Score	Value	Score
Taxa Richness	15	3	10	2
EPT Index	0	1	0	1
HBI	7.30	1	7.30	1
% Chironomidae	36.34	1	17.54	1
% Dominant Taxon	36.34	2	28.07	3
% Dominant FFG	38.09	3	40.06	3
% Predators	19.10	3	25.15	3
Intolerant : Tolerant	0.05	1	0.04	1
% Total Trichoptera as Hydropsychidae	No Trich	1	No Trich	1
Number of Non-Insect Taxa	7	4	5	3
% CG	38.09	2	40.06	2
% n as Elmidae	0.00	1	0.00	1
AQUATIC LIFE USE SCORE	23		22	
AQUATIC LIFE USE RATING	Intermediate		Intermediate	
Kicknet (Qualitative) Scoring Criteria				
Exceptional	>36			
High	29 - 36			
Intermediate	22 - 28			
Limited	<22			

Table 23. Results of benthic IBI calculations at the Little Cypress Creek Mainstem site (LCMN).

Qualitative Benthic IBI								
Period	1		2		3		4	
Date	7/12/2010		9/7/2010		6/14/2011		8/3/2011	
Site	LCMN		LCMN		LCMN		LCMN	
Metric	Value	Score	Value	Score	Value	Score	Value	Score
Taxa Richness	14	2	7	1	17	3	17	3
EPT Index	4	2	2	1	3	1	3	1
HBI	6.56	1	6.56	1	7.18	1	7.19	1
% Chironomidae	9.31	3	9.03	3	11.30	2	15.42	2
% Dominant Taxon	49.31	1	34.84	2	36.93	2	31.78	2
% Dominant FFG	31.21	4	37.85	3	48.88	2	55.55	1
% Predators	31.03	2	6.24	4	5.45	4	11.51	4
Intolerant : Tolerant	0.13	1	0.01	1	0.01	1	0.03	1
% Total Trichoptera as Hydropsychidae	100.00	1	0.00	4	0.00	4	0.00	4
Number of Non-Insect Taxa	5	3	3	2	9	4	7	4
% CG	31.21	2	30.11	3	48.88	1	55.55	1
% n as Elmidae	1.72	4	34.19	1	0.08	1	0.47	1
AQUATIC LIFE USE SCORE	26		26		26		25	
AQUATIC LIFE USE RATING	Intermediate		Intermediate		Intermediate		Intermediate	
Kicknet (Qualitative) Scoring Criteria								
Exceptional	>36							
High	29 - 36							
Intermediate	22 - 28							
Limited	<22							

Table 24. Results of benthic IBI calculations at the Little Cypress Creek Upstream site (LCUP).

Qualitative Benthic IBI				
Period	1		2	
Date	7/6/2010		9/7/2010	
Site	LCUP		LCUP	
Metric	Value	Score	Value	Score
Taxa Richness	7	1	3	1
EPT Index	0	1	0	1
HBI	6.90	1	4.12	3
% Chironomidae	53.49	1	5.56	3
% Dominant Taxon	53.49	1	88.89	1
% Dominant FFG	45.74	2	90.74	1
% Predators	32.95	2	90.74	1
Intolerant : Tolerant	0.03	1	16.00	4
% Total Trichoptera as Hydropsychidae	No Trich	1	No Trich	1
Number of Non-Insect Taxa	1	1	1	1
% CG	45.74	1	7.41	1
% n as Elmidae	0.00	1	0.00	1
AQUATIC LIFE USE SCORE	14		19	
AQUATIC LIFE USE RATING	Limited		Limited	
Kicknet (Qualitative) Scoring Criteria				
Exceptional	>36			
High	29 - 36			
Intermediate	22 - 28			
Limited	<22			

Table 25. Results of benthic IBI calculations at the Mason Creek Downstream site (MCDN).

Qualitative Benthic IBI								
Period	1		2		3		4	
Date	5/17/2010		8/27/2010		6/13/2011		7/28/2011	
Site	MCDN		MCDN		MCDN		MCDN	
Metric	Value	Score	Value	Score	Value	Score	Value	Score
Taxa Richness	13	2	5	1	28	4	25	4
EPT Index	1	1	0	1	1	1	1	1
HBI	7.73	1	7.17	1	6.36	1	6.34	1
% Chironomidae	1.67	4	30.77	1	60.41	1	52.07	1
% Dominant Taxon	31.67	2	46.15	1	60.41	1	52.07	1
% Dominant FFG	41.39	3	56.41	1	46.33	2	47.26	2
% Predators	41.39	1	56.41	1	26.77	2	26.44	2
Intolerant : Tolerant	0.33	1	0.09	1	0.10	1	0.15	1
% Total Trichoptera as Hydropsychidae	No Trich	1	No Trich	1	No Trich	1	No Trich	1
Number of Non-Insect Taxa	2	2	4	3	10	4	11	4
% CG	26.39	3	25.64	3	46.33	1	47.26	1
% n as Elmidae	0.00	1	0.00	1	0.00	1	0.00	1
AQUATIC LIFE USE SCORE	22		16		20		20	
AQUATIC LIFE USE RATING	Intermediate		Limited		Limited		Limited	
Kicknet (Qualitative) Scoring Criteria								
Exceptional	>36							
High	29 - 36							
Intermediate	22 - 28							
Limited	<22							

Table 26. Results of benthic IBI calculations at the Mason Creek Mainstem site (MCMN).

Qualitative Benthic IBI						
Period	1		2		4	
Date	5/21/2010		8/27/2010		7/28/2011	
Site	MCMN		MCMN		MCMN	
Metric	Value	Score	Value	Score	Value	Score
Taxa Richness	9	2	15	3	33	4
EPT Index	0	1	0	1	1	1
HBI	7.97	1	6.67	1	6.58	1
% Chironomidae	1.47	4	47.76	1	41.46	1
% Dominant Taxon	69.12	1	47.76	1	41.46	1
% Dominant FFG	56.37	1	47.26	2	52.21	1
% Predators	2.70	1	47.26	1	23.53	3
Intolerant : Tolerant	0.01	1	0.06	1	0.17	1
% Total Trichoptera as Hydropsychidae	No Trich	1	No Trich	1	No Trich	1
Number of Non-Insect Taxa	7	4	5	3	9	4
% CG	56.37	1	31.59	2	52.21	1
% n as Elmidae	0.00	1	0.00	1	0.00	1
AQUATIC LIFE USE SCORE	19		18		20	
AQUATIC LIFE USE RATING	Limited		Limited		Limited	
Kicknet (Qualitative) Scoring Criteria						
Exceptional	>36					
High	29 - 36					
Intermediate	22 - 28					
Limited	<22					

Table 27. Results of benthic IBI calculations at the Mason Creek Upstream site (MCUP).

Qualitative Benthic IBI								
Period	1		2		3		4	
Date	5/17/2010		8/27/2010		6/13/2011		7/28/2011	
Site	MCUP		MCUP		MCUP		MCUP	
Metric	Value	Score	Value	Score	Value	Score	Value	Score
Taxa Richness	9	2	25	4	34	4	29	4
EPT Index	0	1	1	1	1	1	1	1
HBI	7.21	1	7.21	1	6.85	1	6.99	1
% Chironomidae	49.04	1	16.20	1	41.69	1	47.84	1
% Dominant Taxon	49.04	1	31.94	2	41.69	1	47.84	1
% Dominant FFG	37.69	3	58.64	1	45.60	2	41.11	3
% Predators	20.49	3	58.64	1	26.29	2	40.12	1
Intolerant : Tolerant	0.01	1	0.00	1	0.08	1	0.06	1
% Total Trichoptera as Hydropsychidae	No Trich	1	No Trich	1	No Trich	1	No Trich	1
Number of Non-Insect Taxa	5	3	7	4	10	4	7	4
% CG	37.69	2	29.24	3	45.60	1	41.11	2
% n as Elmidae	0.00	1	0.00	1	0.00	1	0.00	1
AQUATIC LIFE USE SCORE	20		21		20		21	
AQUATIC LIFE USE RATING	Limited		Limited		Limited		Limited	
Kicknet (Qualitative) Scoring Criteria								
Exceptional	>36							
High	29 - 36							
Intermediate	22 - 28							
Limited	<22							

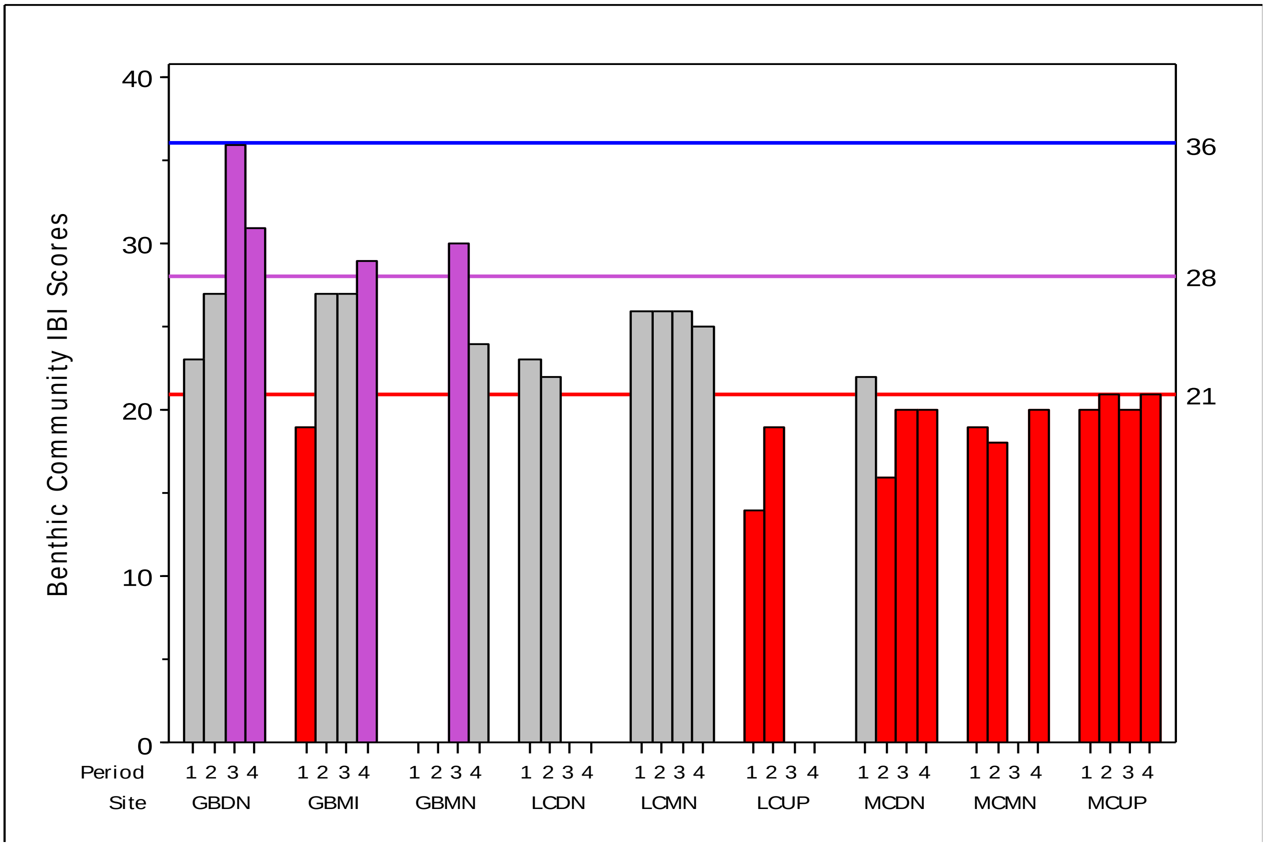


Figure 78. Summary of benthic community B-IBI scores based on d-frame net collections. Aquatic life use >36 exceptional (blue bars); 29-36 High (purple bars); 22-28 Intermediate (gray bars); < 22 Limited (red bars). Sample period's 1 and 2 = 2010 collections; 3 and 4 = 2011 collections. Samples not collected at GRMN during 2010. LCUP, LCDN and MCMN not monitored during one or two sampling periods in 2011 due to drought conditions.

Fish Communities

The highest observed median number of fish collected in seines occurred at the MCMN and MCUP site during the first sampling period (Figure 79). The MCDN and LCDN sites yielded few fish per seine haul throughout the study. Average catch rates also exhibited similar patterns with the highest average rates observed at the MCMN and MCUP sites during the first sampling period (Figure 80). These were statistically significant from most collections since their 95% confidence intervals overlapped with only 3 other collections. There were overall statistically significant differences in median number of fish collected by seines at each site (Figure 81and Table 28). The MCMN and MCUP sites exhibited the highest median catch rates and were statistically significantly higher than most sites.

Electrofishing catch per unit area (CPUE) was defined as the number of fish caught per minute per 100 ft. of stream. Effort was monitored by use of an automatic timer installed on the backpack electroshocker. Highest median CPUE was usually recorded at the most of the collections at the MCDN, MCMN, MCUP, and GRDN sites (Figure 82). Catch rates usually increased at these sites after period 1 through the last collection period in 2011. Low or zero CPUE were observed at most sampling periods at the Little Cypress Creek sites. The average CPUE followed similar patterns exhibited by the median catch rates (Figure 83). However, the 95% confidence interval of most sites was very large suggesting many of the collections are not statistically significant from other collections. Overall median CPUE rates were not statistically significant between most sites with the exception of MCUP and LCUP (Figure 84 and Table 29).

The highest median number of fish taxa collected by seine collections was observed at the LCMN during the first sampling period (Figure 85). Zero catches yielding no taxa occurred at MCDN during all sampling periods and during period 2 at MCUP. Considerable variability was observed in average seine catches (Figure 86). The highest average catch rate occurred at the LCMN site during period 1. The lowest average catch rates occurred at the MCDN site throughout the study. The small confidence intervals indicate that most of these average values are statistically significant. In particular, LCMN (period 2), LCUP (period 2), MCDN (all periods) and MCUP (period 2) had statistically significant smaller catches (Figure 86). Overall statistically significant differences in median number of fish species collected with seines were detected between various sites (Figure 87). Median number of species captured at the MCDN site was statistically lower when compared to the other sites (

Table 30).

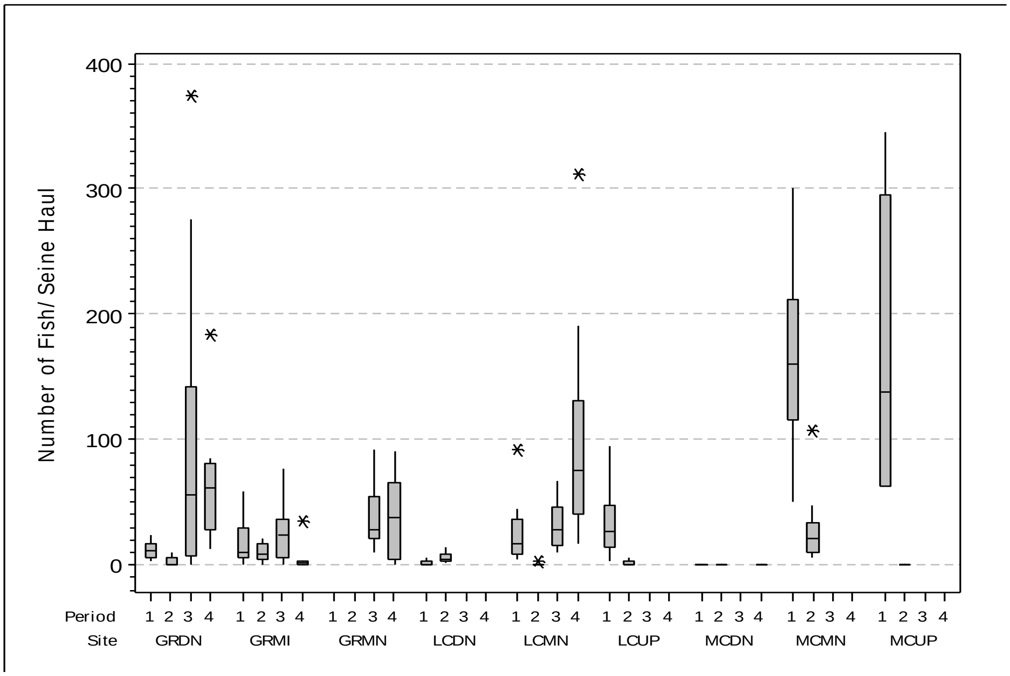


Figure 79. Boxplot of total number of fish collected per 30 ft. seine haul during each collection at each site. Samples not collected at GRMN during 2010. LCUP, LCDN and MCMN not monitored during one or two sampling periods in 2011 due to drought conditions. Only electroshocking was conducted at MCUP periods 3 and 4, and MCDN and MCMN periods 4.

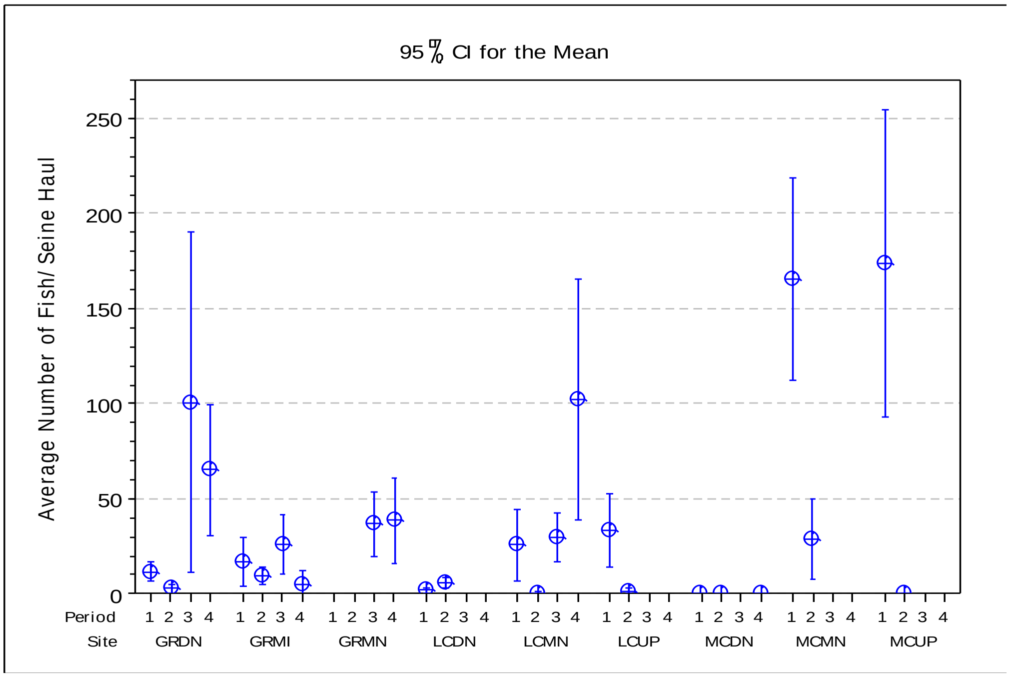


Figure 80. Ninety-five percent confidence interval plot of the average number of fish collected per 30 ft. seine haul during each collection at each site. Samples not collected at GRMN during 2010. LCUP, LCDN and MCMN not monitored during one or two sampling periods in 2011 due to drought conditions. Only electroshocking was conducted at MCUP periods 3 and 4, and MCDN and MCMN periods 4.

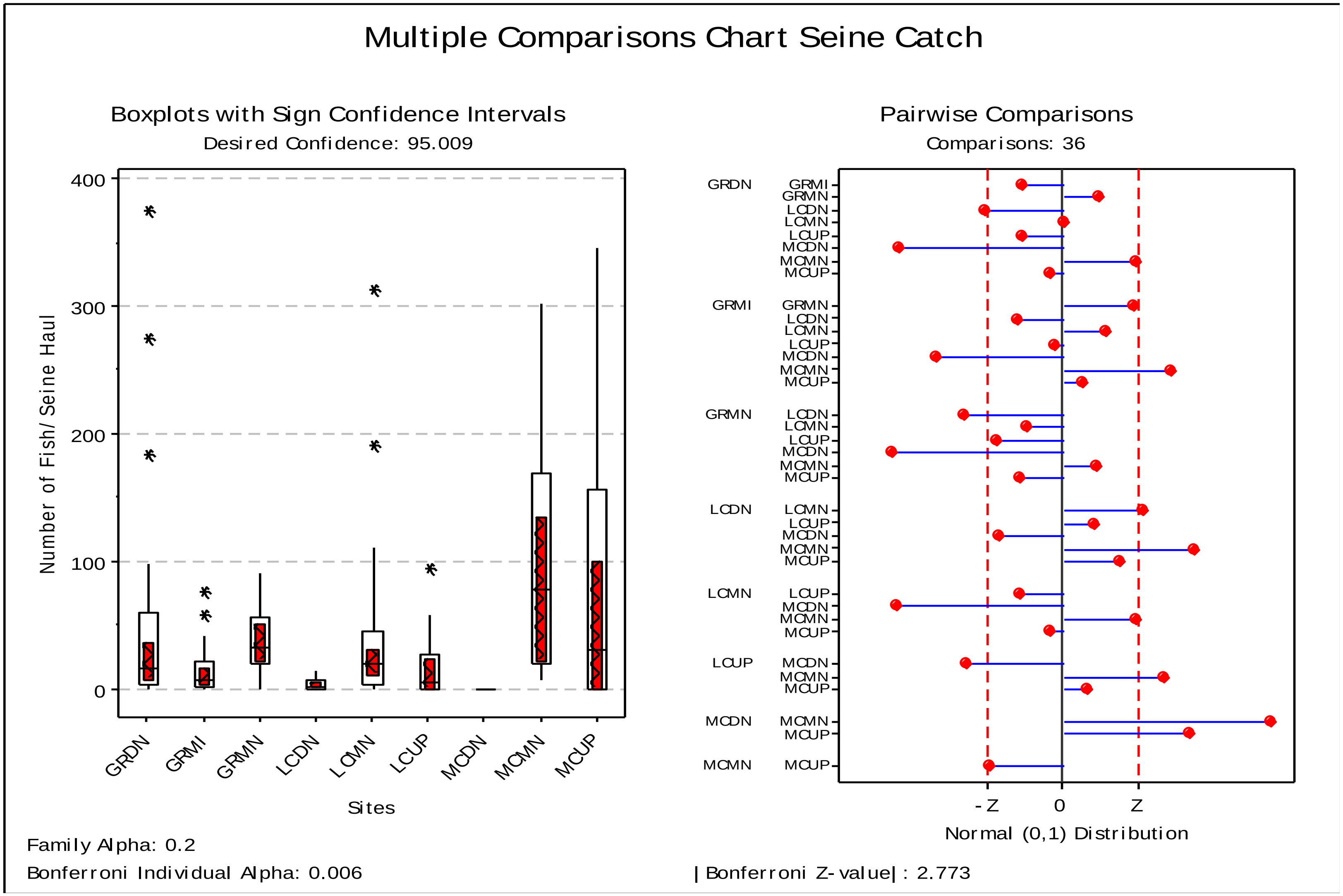


Figure 81. Results of Kruskal-Wallis One Way ANOVA with Dunn's multiple range test on number of fish collected per 30 ft. seine haul at each site during 2010 and 2011.

Table 28. Results of Kruskal-Wallis One Way ANOVA with Dunn's multiple range test on number of fish collected per seine haul at each site.

```
Kruskal-Wallis Test on the data
Group      N       Median  Ave Rank      Z
GRDN      40  1.50000E+01     143.4   1.71
GRMI      40  7.000000000     119.3  -0.59
GRMN      20  3.25000E+01     169.8   2.85
LCDN      20  2.000000000      86.5  -2.51
LCMN      40  1.90000E+01     143.8   1.75
LCUP      20  4.000000000     112.8  -0.82
MCDN      30  0.000000000      37.5  -7.11
MCMN      20  7.85000E+01     196.6   4.59
MCUP      20  3.10000E+01     133.6   0.52
Overall  250                  125.5
H = 83.25  DF = 8  P = 0.000
H = 85.49  DF = 8  P = 0.000  (adjusted for ties)
The following groups showed significant differences (adjusted for ties):
Groups               Z vs. Critical value       P-value
MCDN vs. MCMN        7.72459 >= 2.773           0.0000
GRMN vs. MCDN        6.41997 >= 2.773           0.0000
LCMN vs. MCDN        6.16912 >= 2.773           0.0000
GRDN vs. MCDN        6.14446 >= 2.773           0.0000
LCDN vs. MCMN        4.87903 >= 2.773           0.0000
GRMI vs. MCDN        4.74905 >= 2.773           0.0000
MCDN vs. MCUP        4.66631 >= 2.773           0.0000
GRMI vs. MCMN        3.95416 >= 2.773           0.0001
LCUP vs. MCMN        3.71356 >= 2.773           0.0002
GRMN vs. LCDN        3.68808 >= 2.773           0.0002
LCUP vs. MCDN        3.65659 >= 2.773           0.0003
LCDN vs. LCMN        2.93204 >= 2.773           0.0034
GRDN vs. LCDN        2.91030 >= 2.773           0.0036
MCMN vs. MCUP        2.79182 >= 2.773           0.0052
```

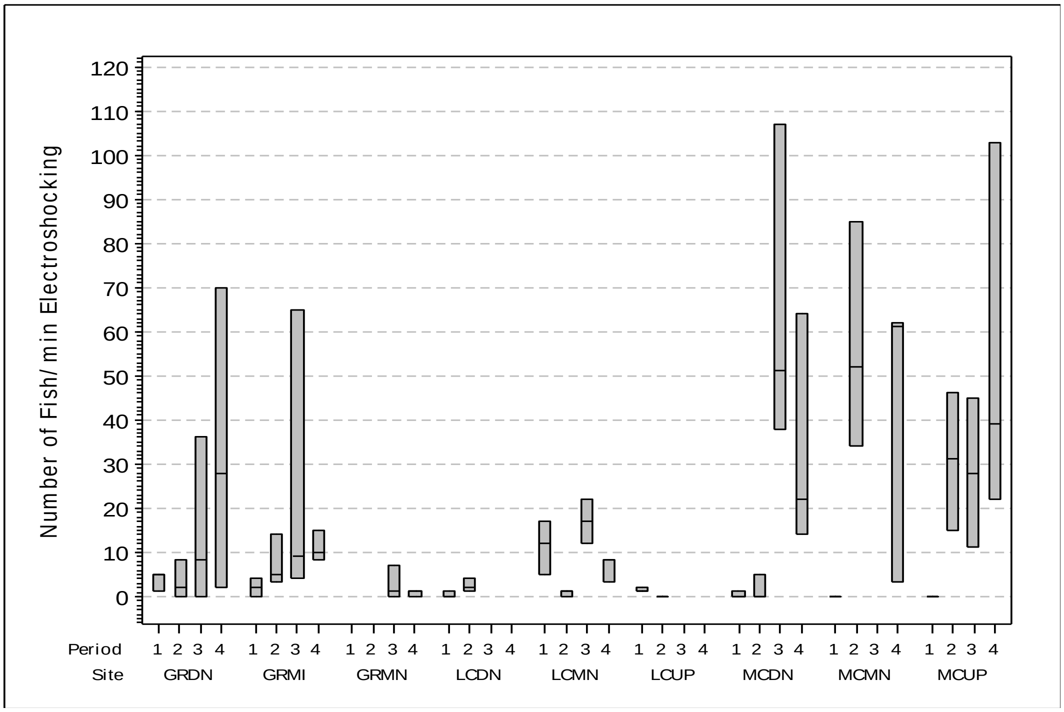


Figure 82. Boxplot of total number of fish collected per minute of electroshocking at each collection. Samples not collected at GRMN during 2010. LCUP, LCDN and MCMN not monitored during one or two sampling periods in 2011 due to drought conditions.

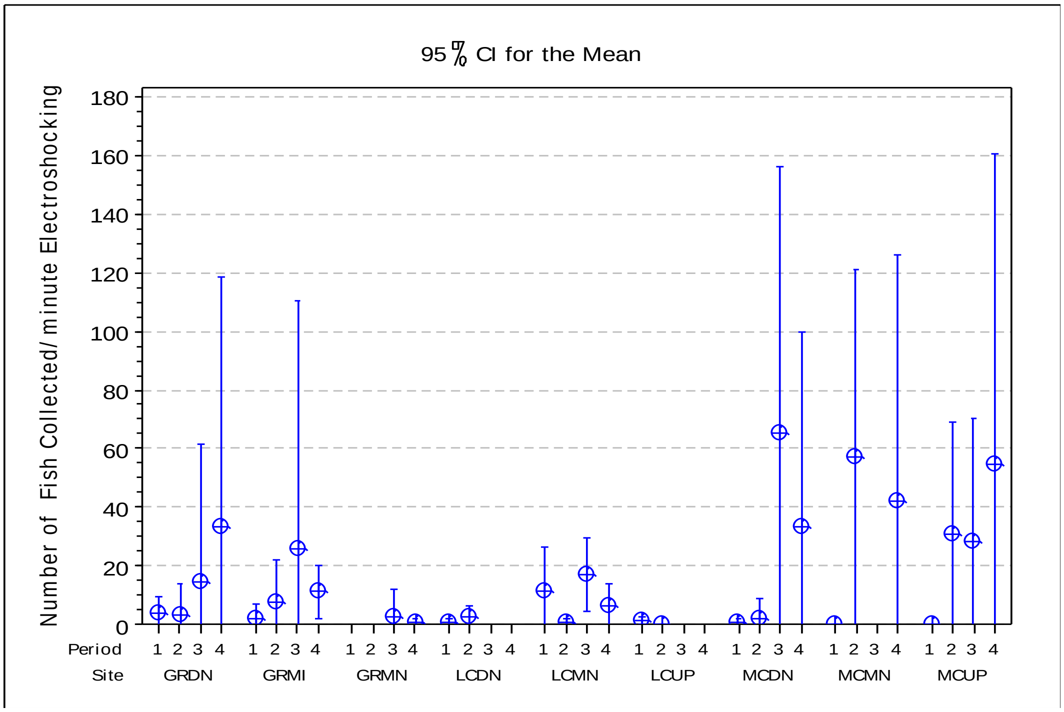


Figure 83. Ninety-five percent confidence interval plot of the average number of fish collected per minute of electroshocking at each collection. Samples not collected at GRMN during 2010. LCUP, LCDN and MCMN not monitored during one or two sampling periods in 2011 due to drought conditions.

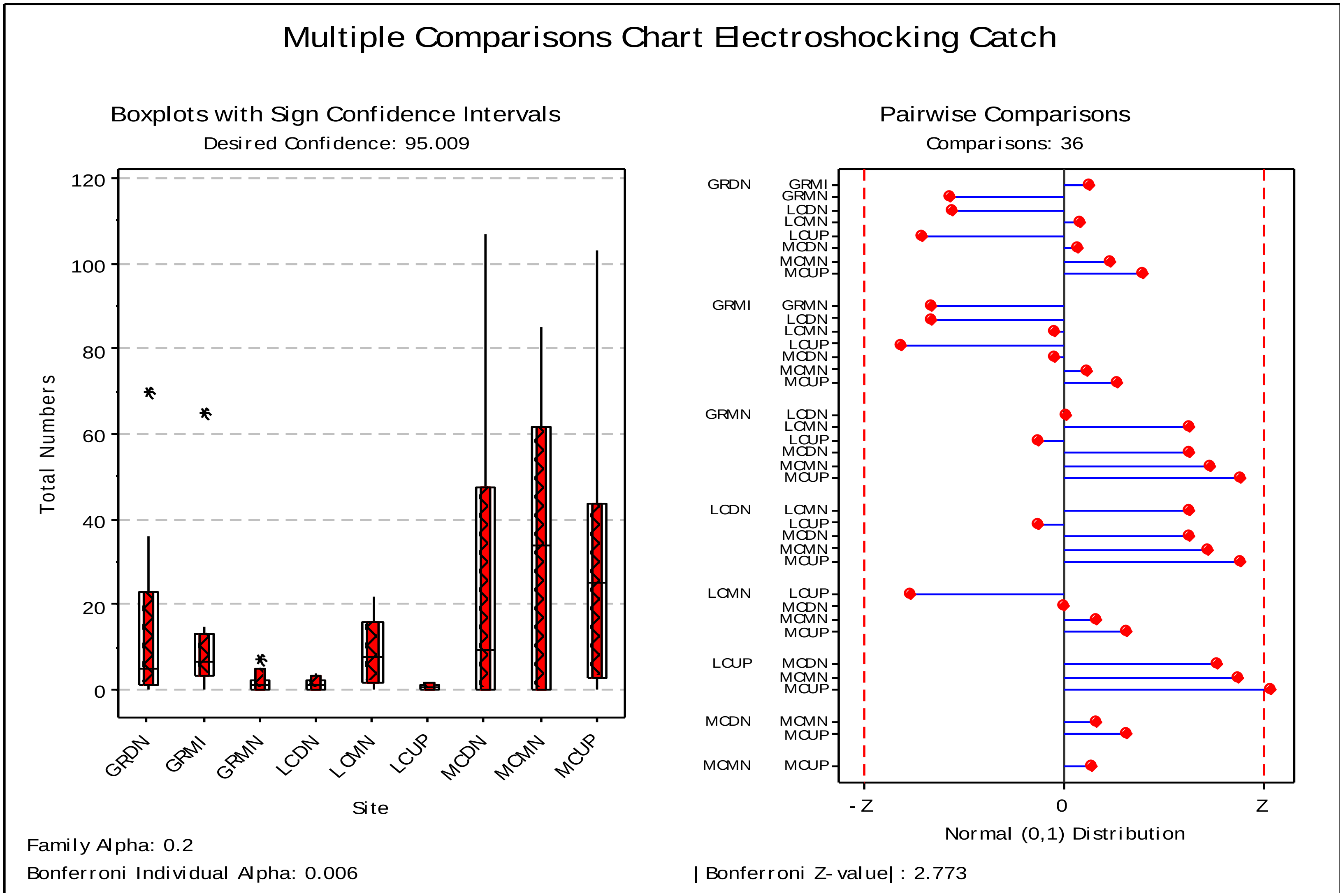


Figure 84. Results of Kruskal-Wallis One Way ANOVA with Dunn’s multiple range test on number of fish per minute of electroshocking at each site during 2010 and 2011.

Table 29. Results of Kruskal-Wallis One Way ANOVA and Dunn's Multiple Range test on number of fish per minute of electroshocking each site during 2010 and 2011.

```
Kruskal-Wallis Test on the data

Group      N   Median  Ave Rank       Z
GRDN      12   5.0000      45.1    0.17
GRMI      12   6.5000      48.7    0.69
GRMN       6   1.0000      25.3   -1.88
LCDN       6   1.0000      25.5   -1.86
LCMN      12   8.0000      47.3    0.48
LCUP       6   0.5000      20.3   -2.38
MCDN      12   9.5000      47.1    0.46
MCMN       9  34.0000      52.1    1.02
MCUP      12  25.0000      56.2    1.80
Overall   87               44.0

H = 16.29  DF = 8  P = 0.038
H = 16.57  DF = 8  P = 0.035  (adjusted for ties)

The following groups showed significant differences (adjusted for ties):

Groups                Z vs. Critical value       P-value
LCUP vs. MCUP         2.86136 >= 2.773           0.0042
```

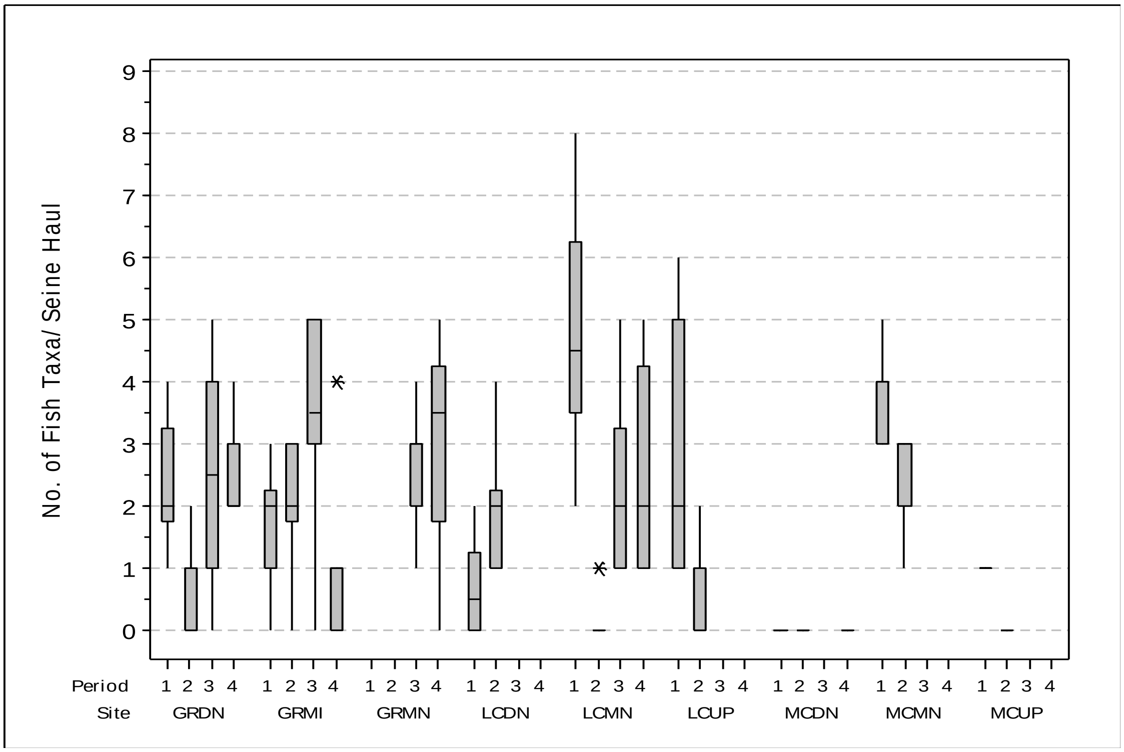


Figure 85. Number of fish taxa collected per 30 ft. seine haul at each site during each collection. Samples not collected at GRMN during 2010. LCUP, LCDN and MCMN not monitored during one or two sampling periods in 2011 due to drought conditions. Only electroshocking was conducted at MCUP periods 3 and 4, and MCDN and MCMN periods 4.

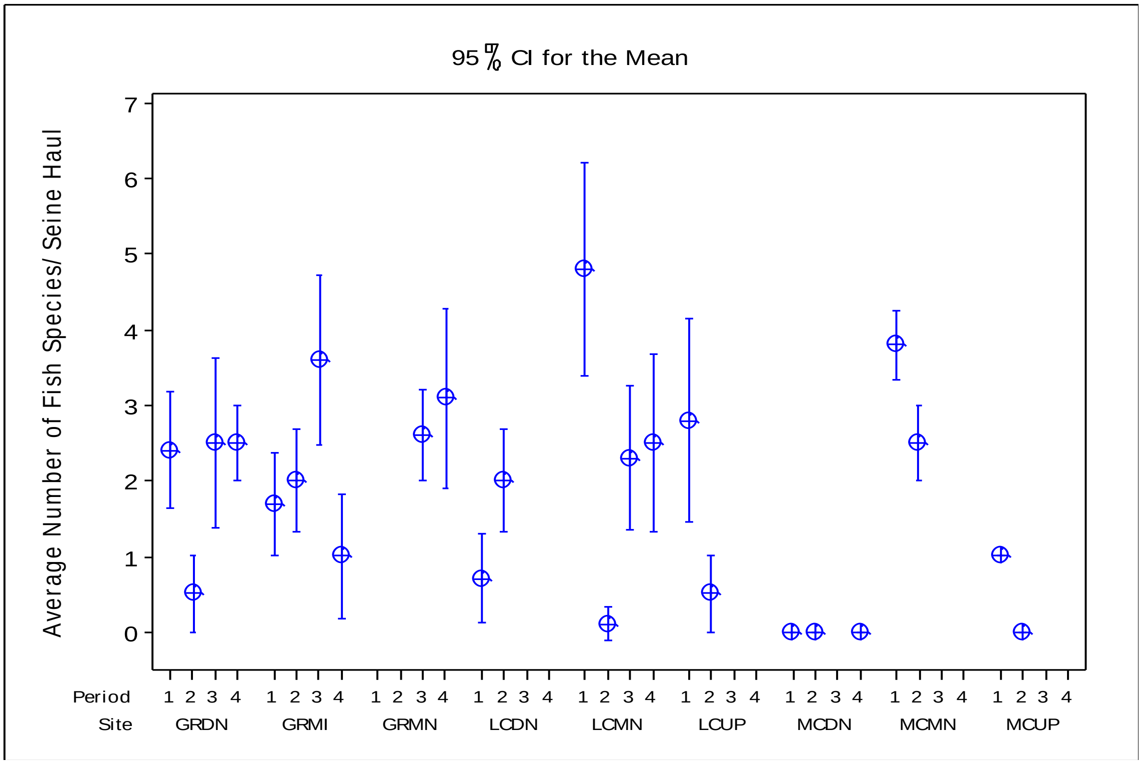


Figure 86. Ninety-five percent confidence interval plot of the average number of taxa collected per 30 ft. seine haul during each collection at each site. Samples not collected at GRMN during 2010. LCUP, LCDN and MCMN not monitored during one or two sampling periods in 2011 due to drought conditions. Only electroshocking was conducted at MCUP periods 3 and 4, and MCDN and MCMN periods 4.

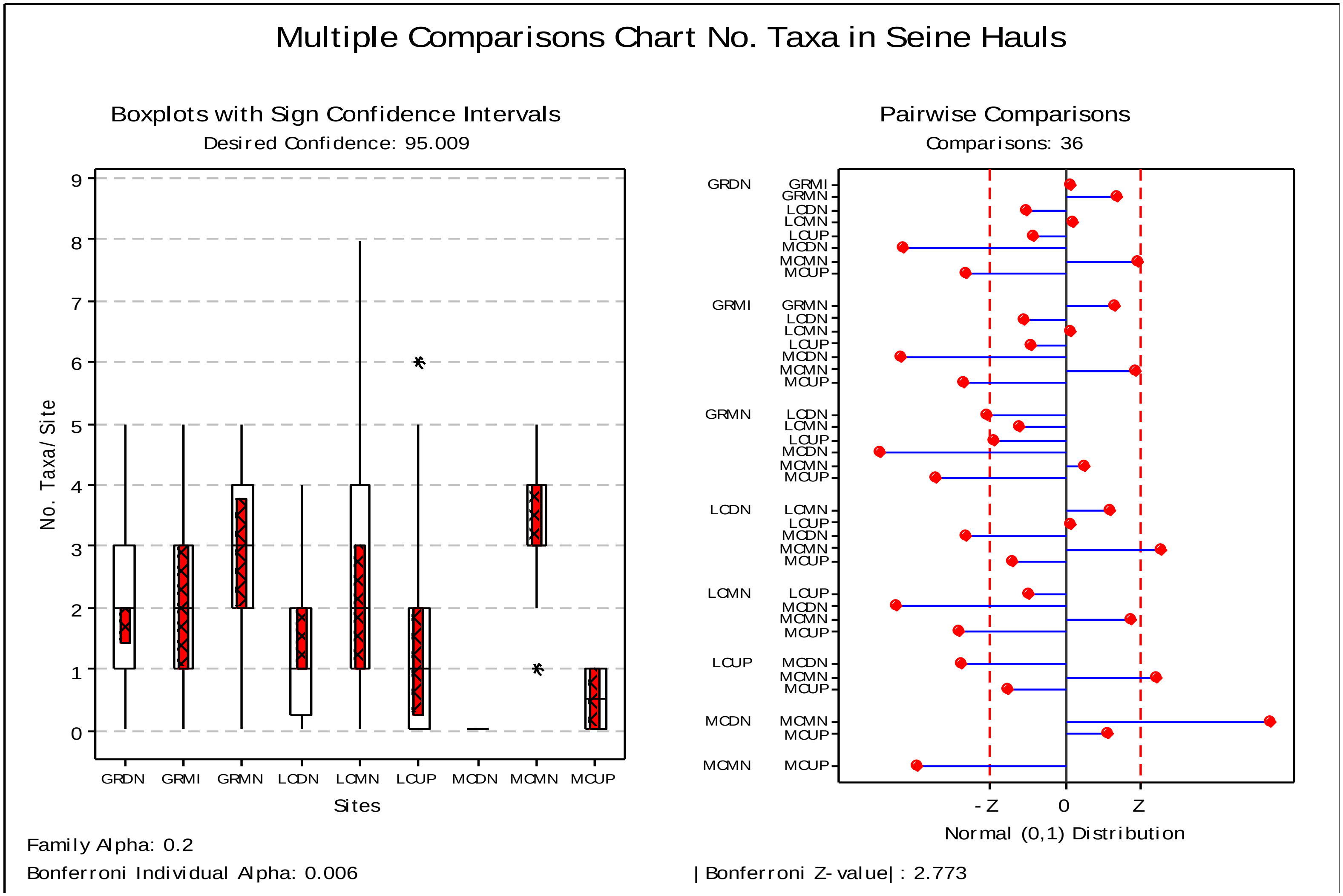


Figure 87. Results of Kruskal-Wallis One Way ANOVA with Dunn's multiple range test on number of fish taxa per seine haul at each site during 2010 and 2011.

Table 30. Results of Kruskal-Wallis One Way ANOVA and Dunn's Multiple Range test on number of fish taxa per seine haul at each site during 2010 and 2011.

```
Kruskal-Wallis Test on the data
Group      N       Median  Ave Rank      Z
GRDN      40  2.000000000     139.0   1.29
GRMI      40  2.000000000     141.6   1.54
GRMN      20  3.000000000     176.1   3.26
LCDN      20  1.000000000     111.7  -0.89
LCMN      40  2.000000000     143.7   1.74
LCUP      20  1.000000000     116.5  -0.58
MCDN      30  0.000000000      37.5  -7.11
MCMN      20  3.000000000     190.9   4.22
MCUP      20  0.500000000      68.5  -3.68
Overall  250                  125.5

H = 89.96  DF = 8  P = 0.000
H = 94.19  DF = 8  P = 0.000  (adjusted for ties)

The following groups showed significant differences (adjusted for ties):

Groups               Z vs. Critical value       P-value
MCDN vs. MCMN        7.51942 >= 2.773           0.0000
GRMN vs. MCDN        6.79149 >= 2.773           0.0000
LCMN vs. MCDN        6.22426 >= 2.773           0.0000
GRMI vs. MCDN        6.10049 >= 2.773           0.0000
GRDN vs. MCDN        5.94889 >= 2.773           0.0000
MCMN vs. MCUP        5.47709 >= 2.773           0.0000
GRMN vs. MCUP        4.81259 >= 2.773           0.0000
LCMN vs. MCUP        3.88751 >= 2.773           0.0001
LCUP vs. MCDN        3.87368 >= 2.773           0.0001
GRMI vs. MCUP        3.77836 >= 2.773           0.0002
GRDN vs. MCUP        3.64467 >= 2.773           0.0003
LCDN vs. MCDN        3.63839 >= 2.773           0.0003
LCDN vs. MCMN        3.54288 >= 2.773           0.0004
LCUP vs. MCMN        3.32809 >= 2.773           0.0009
GRMN vs. LCDN        2.87838 >= 2.773           0.0040
```

The highest cumulative number of fish taxa was collected at the LCMN site during the first sampling period (Figure 88). The MCDN sites yielded zero catches with the seine. It should be noted that the Mason Creek Down site was covered with high amounts of submerged vegetation making it very difficult to seine efficiently (Figure 13). Therefore, low catches and numbers of taxa at Mason Creek Down may be due to inefficient sampling.

The median number of fish taxa collected by electrofishing was generally higher at the GRDEN and LCMN sites during the study period (Figure 89). The Mason Creek sites generally exhibited lower catch rates. Based on the very large confidence intervals there were no statistically significant differences between mean number of taxa per collection (Figure 90). However, overall statistically significant differences in median number of taxa were detected between the LCMN site and several sites including LCUP, MCDN, MCMN, MCUP and GRMN (Figure 91 and Table 31).

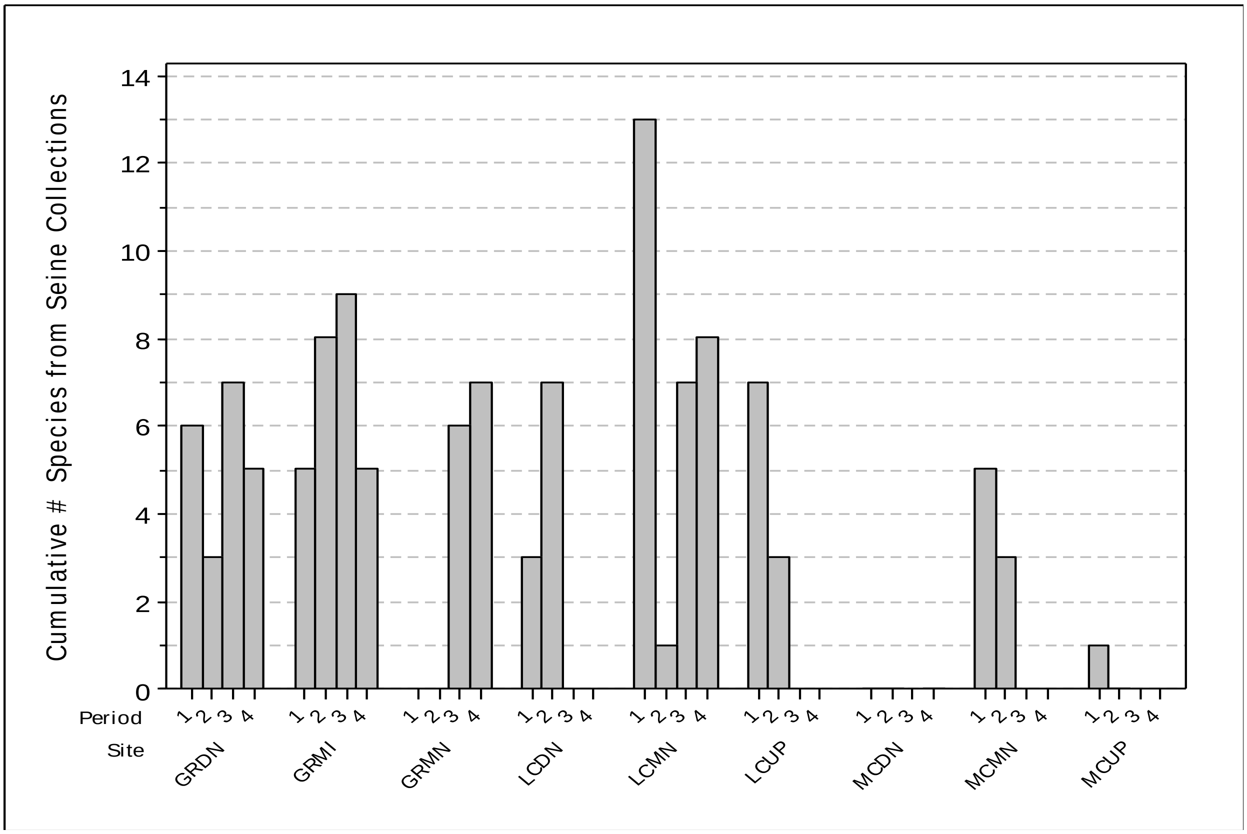


Figure 88. Cumulative number of fish species collected at each site during each seine collection. Periods 1-2 = 2010, 3-4 = 2011. Samples not collected at GRMN during 2010. LCUP, LCDN and MCMN not monitored during one or two sampling periods in 2011 due to drought conditions. Only electroshocking conducted at MCUP periods 3 and 4, and MCDN and MCMN periods 4.

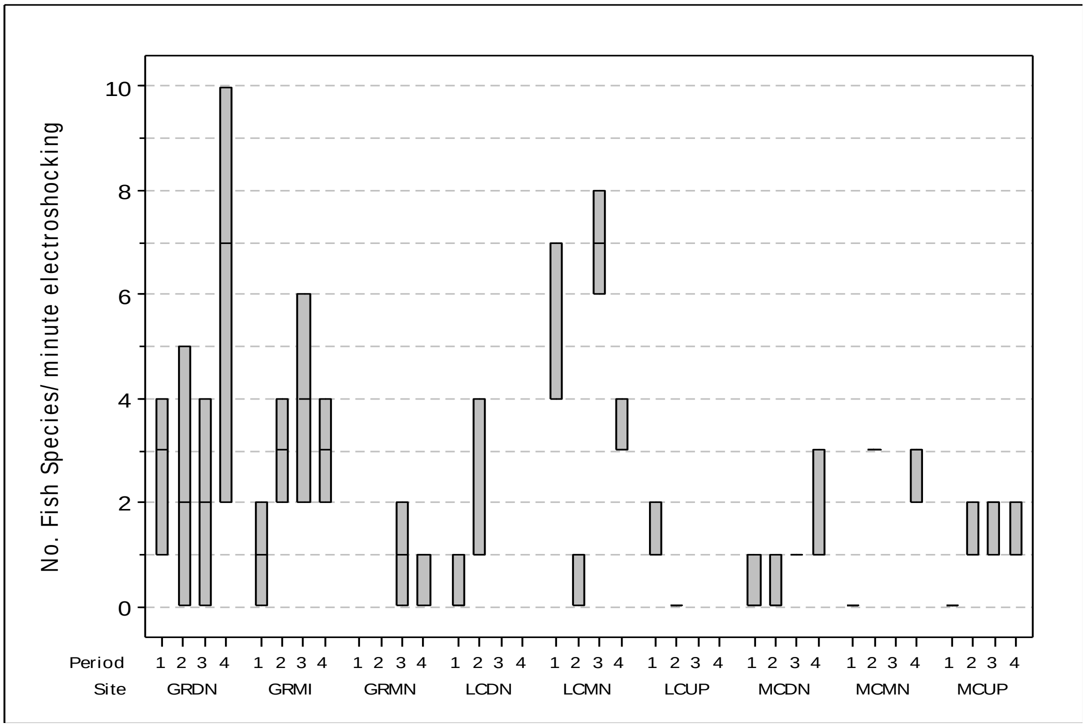


Figure 89. Number of fish taxa collected per minute of electroshocking at each site during each collection. LCUP, LCDN and MCMN not monitored during one or two sampling periods in 2011 due to drought conditions.

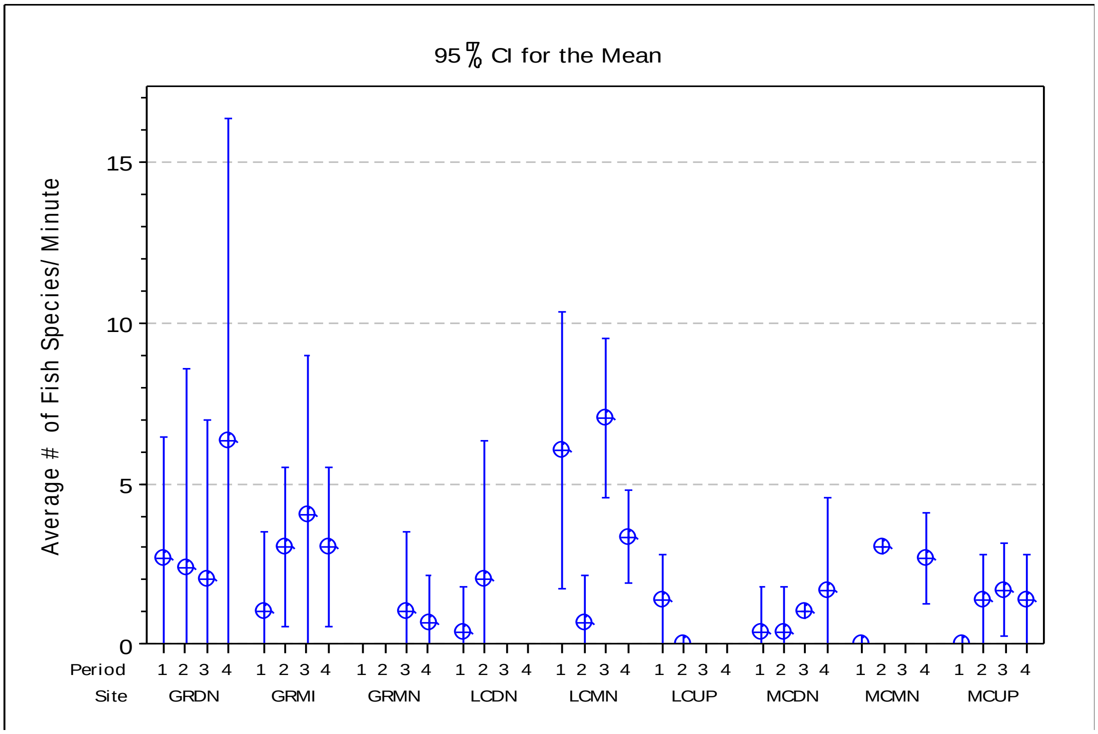


Figure 90. Ninety-five percent confidence interval plot of the average number of taxa collected per minute of electroshocking at each site during each collection. LCUP, LCDN and MCMN not monitored during one or two sampling periods in 2011 due to drought conditions.

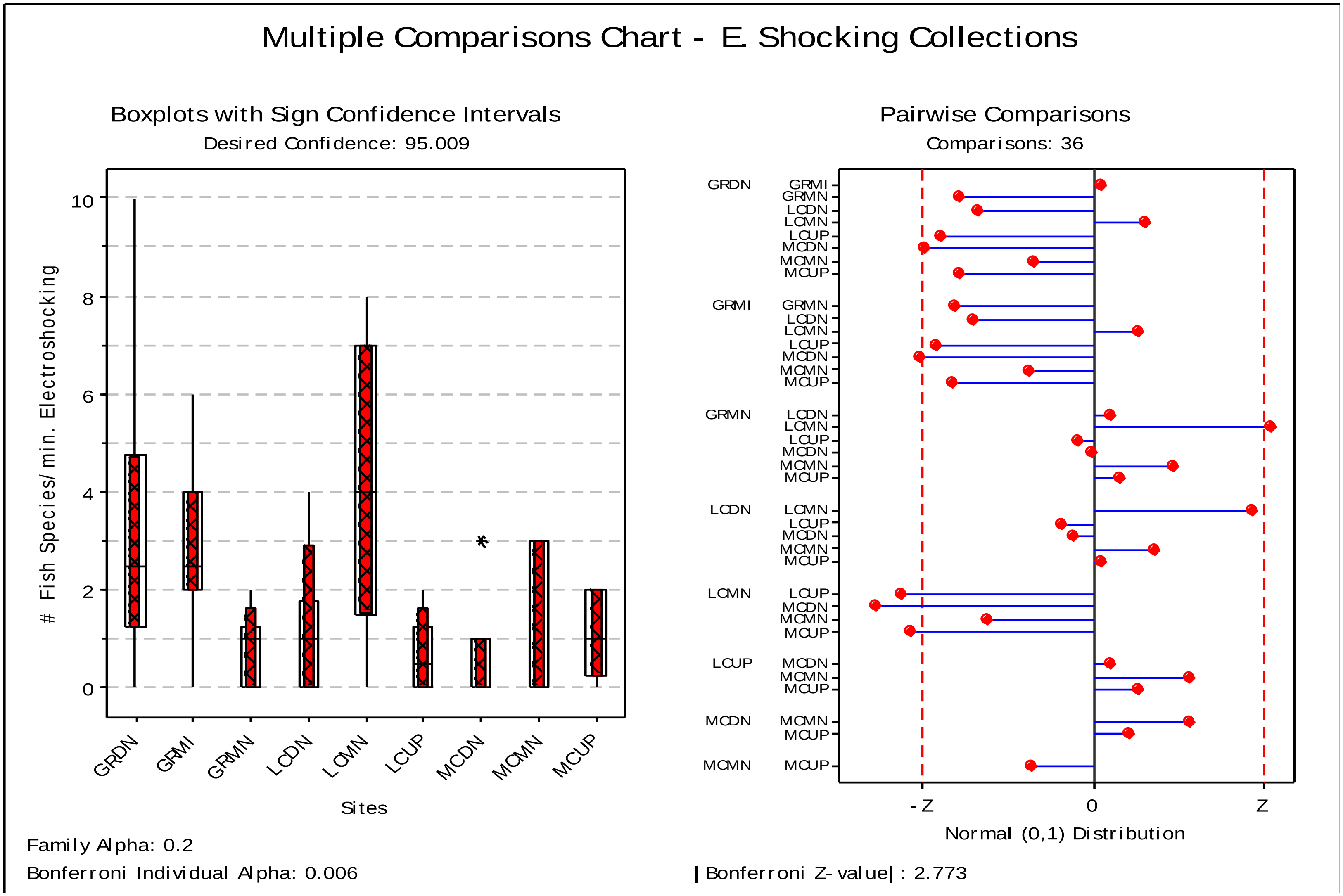


Figure 91. Results of Kruskal-Wallis One Way ANOVA with Dunn's multiple range test on number of fish taxa per minute of electroshocking at each site during 2010 and 2011.

Table 31. Results of Kruskal-Wallis One Way ANOVA and Dunn's Multiple Range test on number of fish taxa per minute of electroshocking at each site during 2010 and 2011.

```
Kruskal-Wallis Test on the data

Group      N  Median  Ave Rank      Z
GRDN      12  2.5000      56.4   1.83
GRMI      12  2.5000      57.4   1.98
GRMN       6  1.0000      29.2  -1.49
LCDN       6  1.0000      32.8  -1.12
LCMN      12  4.0000      64.5   3.03
LCUP       6  0.5000      25.4  -1.87
MCDN      12  1.0000      28.6  -2.27
MCMN       9  3.0000      45.6   0.20
MCUP      12  1.0000      34.2  -1.45
Overall   87              44.0

H = 26.93  DF = 8  P = 0.001
H = 28.11  DF = 8  P = 0.000  (adjusted for ties)

The following groups showed significant differences (adjusted for ties):

Groups                 Z vs. Critical value       P-value
LCMN vs. MCDN          3.55449 >= 2.773           0.0004
LCMN vs. LCUP          3.16177 >= 2.773           0.0016
LCMN vs. MCUP          3.00129 >= 2.773           0.0027
GRMN vs. LCMN          2.85840 >= 2.773           0.0043
GRMI vs. MCDN          2.84854 >= 2.773           0.0044
```

The highest cumulative number of taxa collected by electrofishing was observed at the GRDN, GRMI and LCMN sites (Figure 92). This pattern was mirrored when all catches were combined using both gear types (seine and electrofishing) (Figure 93). Using data from both collection methods we found that the mainstem control sites (LCMN and MCMN) often exhibited a higher cumulative number of taxa per sampling period, when compared to the associated restoration site. In contrast, the GRMN site exhibited similar or lower cumulative number of taxa in comparison to the future restoration sites at GRMI and GRDN (Figure 93). Although not consistent, during the majority of collections, the seine collected more species in comparison to electroshocking (Figure 94). However, the combined use of sampling methods did increase the cumulative number of taxa during most collections. At sites where few species were present the type of sampling method did not seem to influence the cumulative number of fish species collected (Figure 94).

Highest median Shannon Weiner Diversity (*H'*) for seine collections was observed at the LCMN site during the first sampling period (Figure 95). The lowest median levels were recorded at GRMI site during period 4, LCMN site during the period 2, and MCUP site during period 1 (Figure 64). The average H' levels exhibited similar patterns between collections. Due to numerous seine collections in which no fish were obtained, it was impossible to computationally calculate (*H'*) due to division by zero. Therefore, we could not conduct the Kruskal Wallis ANOVA test for (*H*') or the related indices of *J*' or *d* on seine data due to missing cells associated with zero catches.

Median Shannon-Weiner diversity (*H'*) levels based on electrofishing collections was highest at the LCMN during the first and third sampling periods (Figure 97). Very low values of (*H'*) equal to zero, occurred at the GRMN (period 4), LCDN (period 1), LCMN (period 2), and MCDN (Periods 1-3). Higher average and median values occurred most generally at the GRDN and GRMI sites (Figure 98). However, the confidence interval of the mean was very large and none of the collections appeared to be statistically different from the others. We did observe statistically significant differences overall between sites (Figure 99 and Table 32). In many cases the MCDN and MCMN sites exhibited statistically lower median *H'* based on electrofishing collections when compared to many sites.

Lowest median evenness (*J'*) for seine collections was observed at the LCMN (period 3 and 4) (Figure 100). Evenness (*J'*) estimates were lacking for MCDN and MCUP (Periods 2-4) sites due to zero catches and insufficient data to calculate the index. Most median (E) values ranged between 0.6 and 0.9, suggesting that the distribution of specimens between taxa was often skewed with one of more taxa being numerically dominant. Average J' levels were very similar and many had extremely broad confidence intervals indicating these values were not statistically different (Figure 101). There were numerous collections in which no fish were captured, making it impossible to calculate (*J'*). Therefore, we could not calculate the Kruskal Wallis ANOVA test for (*J'*).

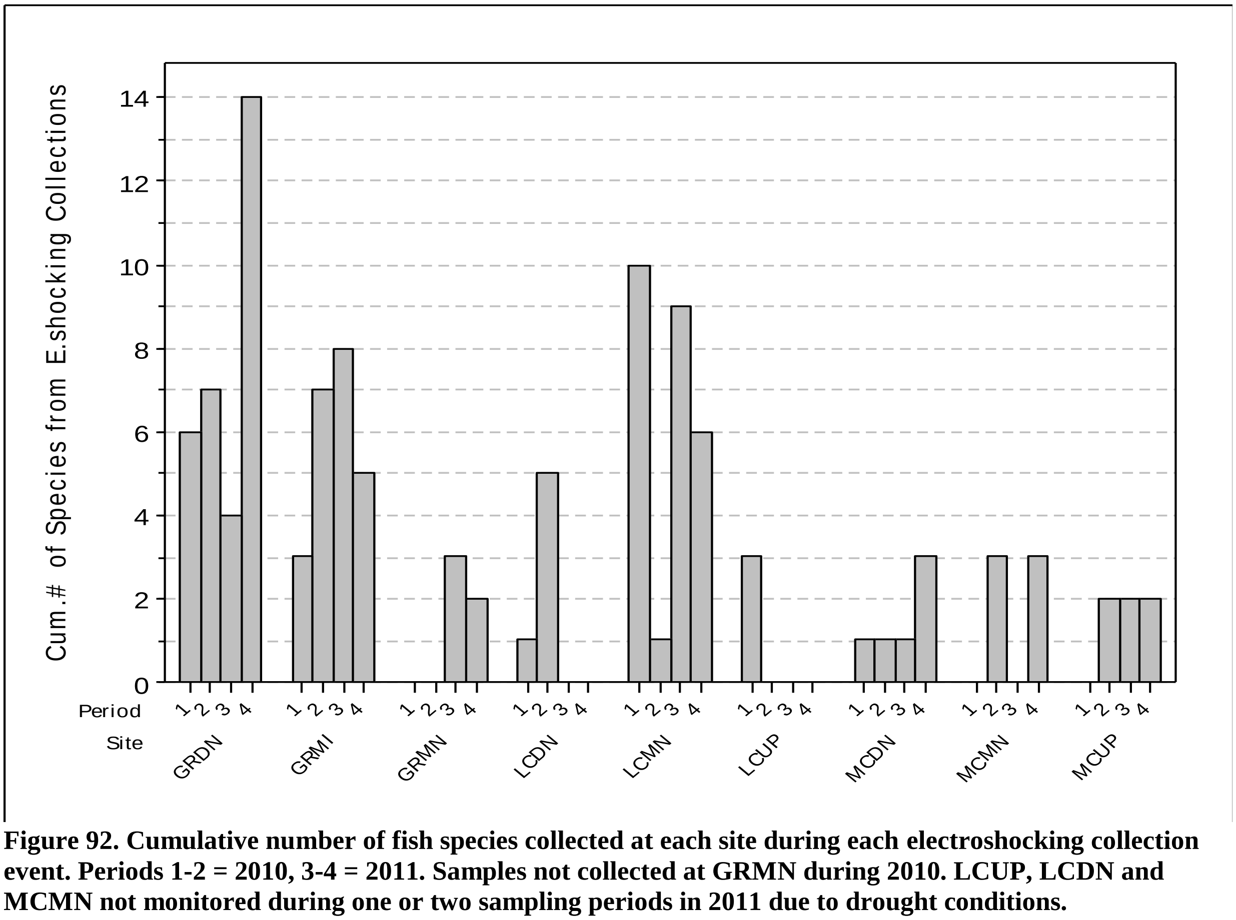


Figure 92. Cumulative number of fish species collected at each site during each electroshocking collection event. Periods 1-2 = 2010, 3-4 = 2011. Samples not collected at GRMN during 2010. LCUP, LCDN and MCMN not monitored during one or two sampling periods in 2011 due to drought conditions.

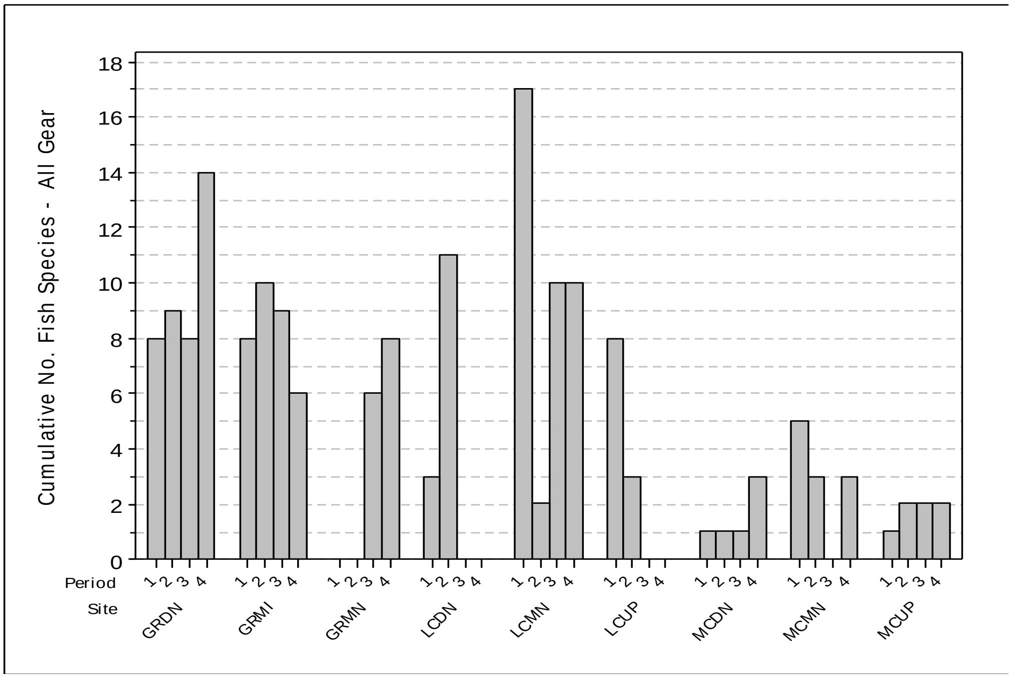


Figure 93. Cumulative number of fish species collected at each site collection using both seines and electrofishing. Periods 1-2 = 2010, 3-4 = 2011. Samples not collected at GRMN in 2010. LCUP, LCDN, MCMN not monitored during 1 or 2 sampling periods in 2011 due to drought. Only electrofishing conducted at MCUP periods 3 and 4, and MCDN and MCMN periods 4.

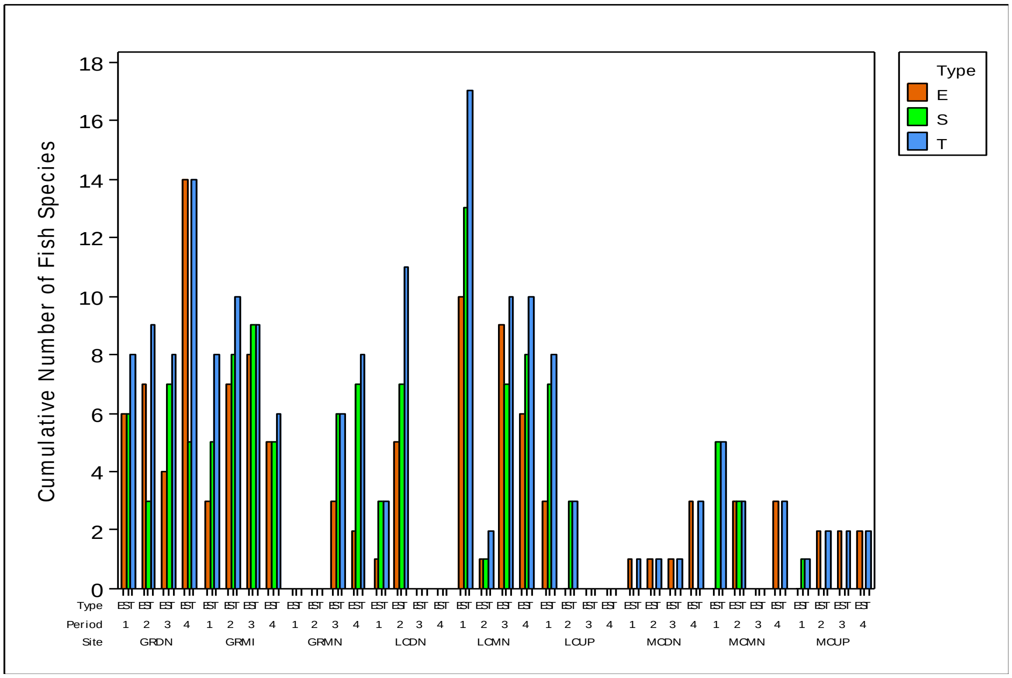


Figure 94. Comparison of cumulative number of fish species collected by different methods (E = electroshocking, S = seine, T = total combined gear) at each site during each sample period. Periods 1-2 = 2010, 3-4 = 2011. Samples not collected at GRMN during 2010. LCUP, LCDN and MCMN not monitored during one or two sampling periods in 2011 due to drought conditions. Only electroshocking conducted at MCUP periods 3 and 4, and MCDN and MCMN periods 4.

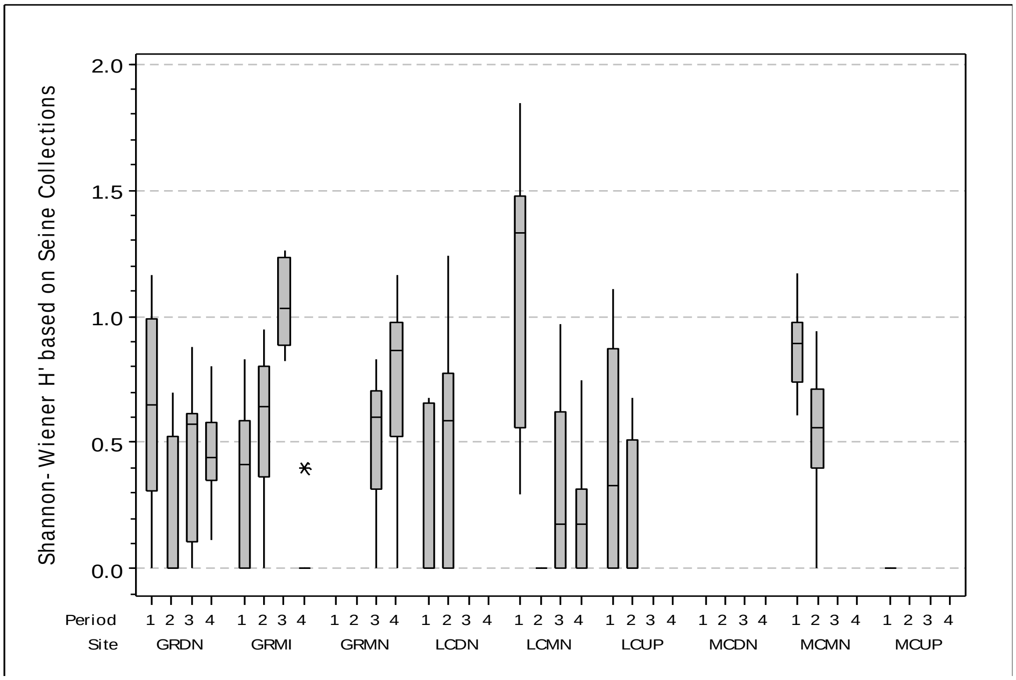


Figure 95. Boxplot of Shanon-Wiener diversity (*H'*) of fish samples collected with a 30 ft. seine haul at each site during each period. Samples not collected at GRMN during 2010. LCUP, LCDN and MCMN not monitored during one or two sampling periods in 2011 due to drought conditions. Only electroshocking was conducted at MCUP periods 3 and 4, and MCDN and MCMN periods 4.

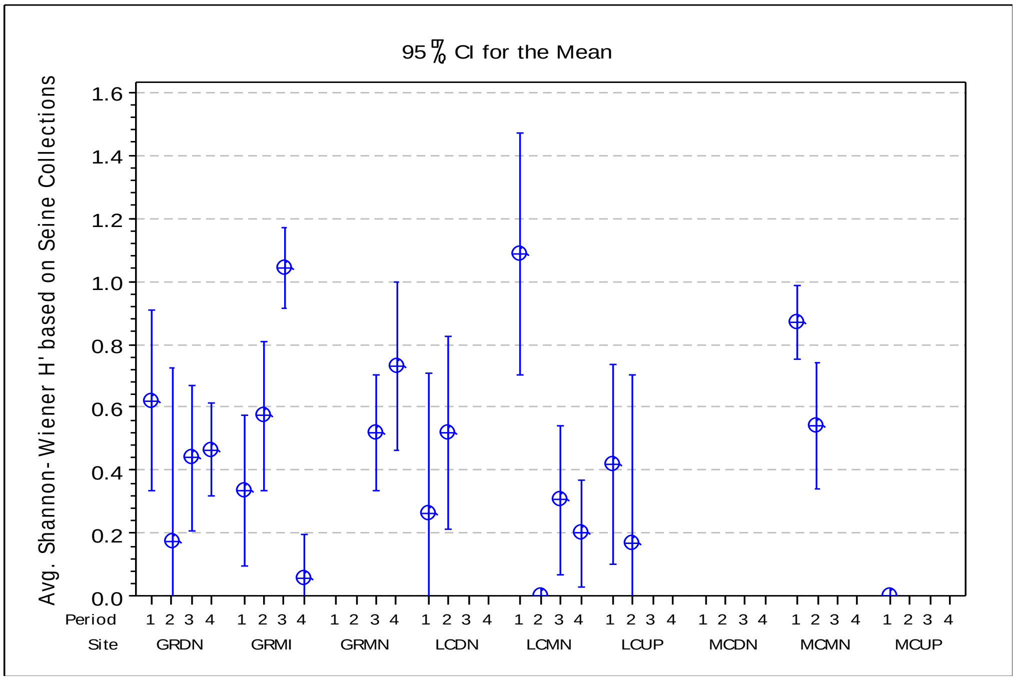


Figure 96. Ninety-five percent confidence interval plot of the average Shannon-Weiner Diversity (*H'*) based on 30 ft. seine haul samples collected at each site. Samples not collected at GRMN during 2010. LCUP, LCDN and MCMN not monitored during one or two sampling periods in 2011 due to drought conditions. Only electroshocking was conducted at MCUP periods 3 and 4, and MCDN and MCMN periods 4. *H'* based on non-zero catches only.

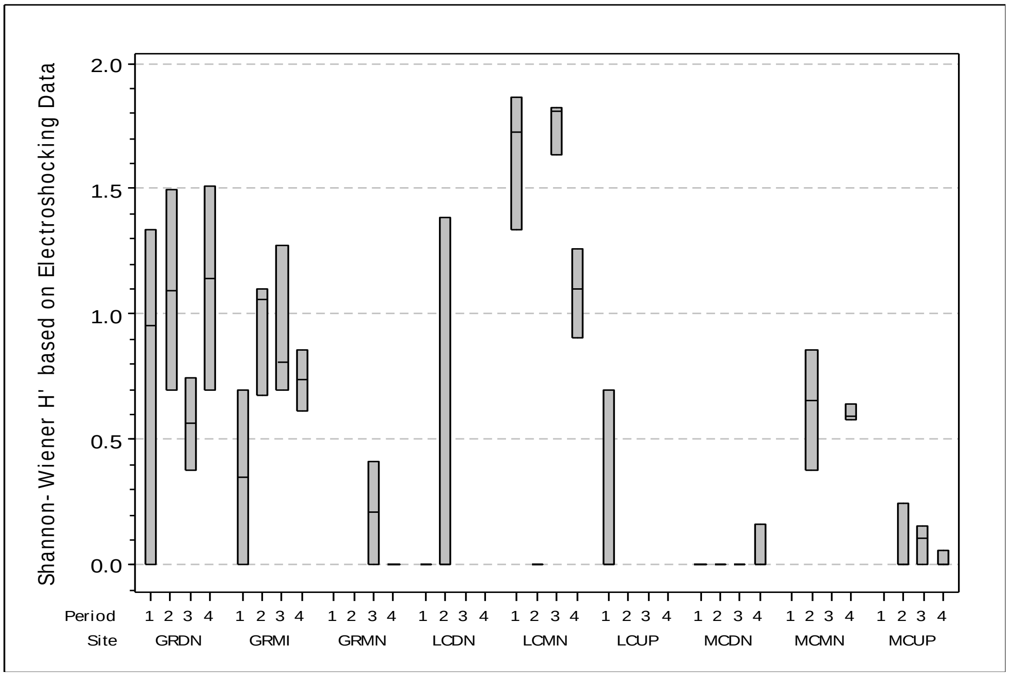


Figure 97. Boxplot of Shanon-Wiener diversity (*H'*) of fish communities sampled with a 30 ft. seine haul at each site during each period. Samples not collected at GRMN during 2010. LCUP, LCDN and MCMN not monitored during one or two sampling periods in 2011 due to drought conditions.

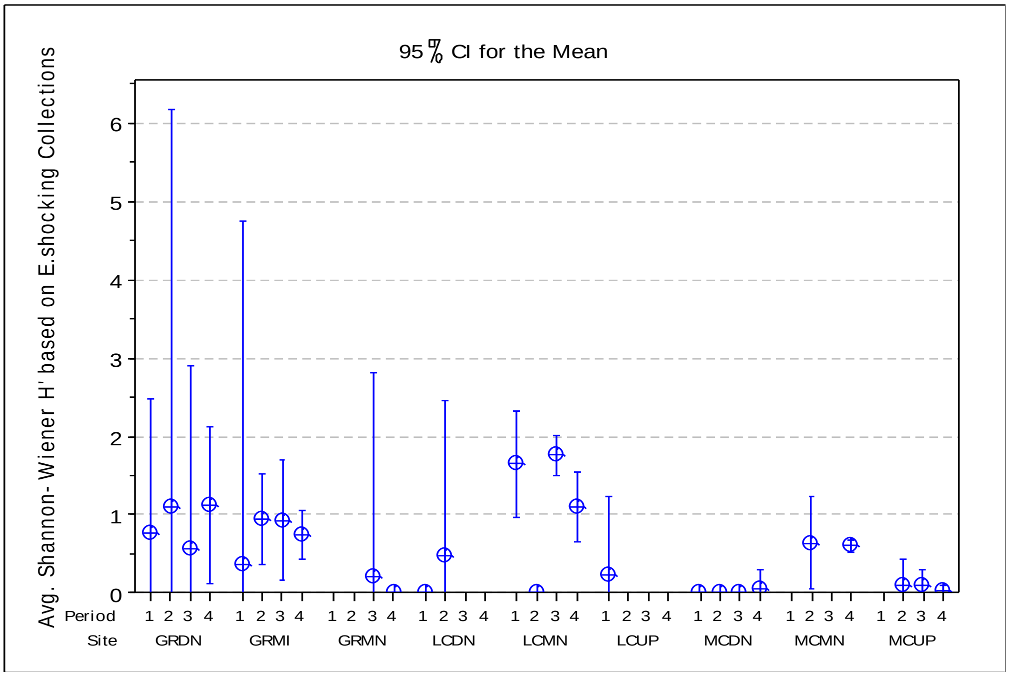


Figure 98. Ninety-five percent confidence interval plot of the average Shannon-Weiner Diversity (H') of fish communities based on electroshocking collections at each site. Samples not collected at GRMN during 2010. LCUP, LCDN and MCMN not monitored during one or two sampling periods in 2011 due to drought conditions. *H'* based on non-zero catches only

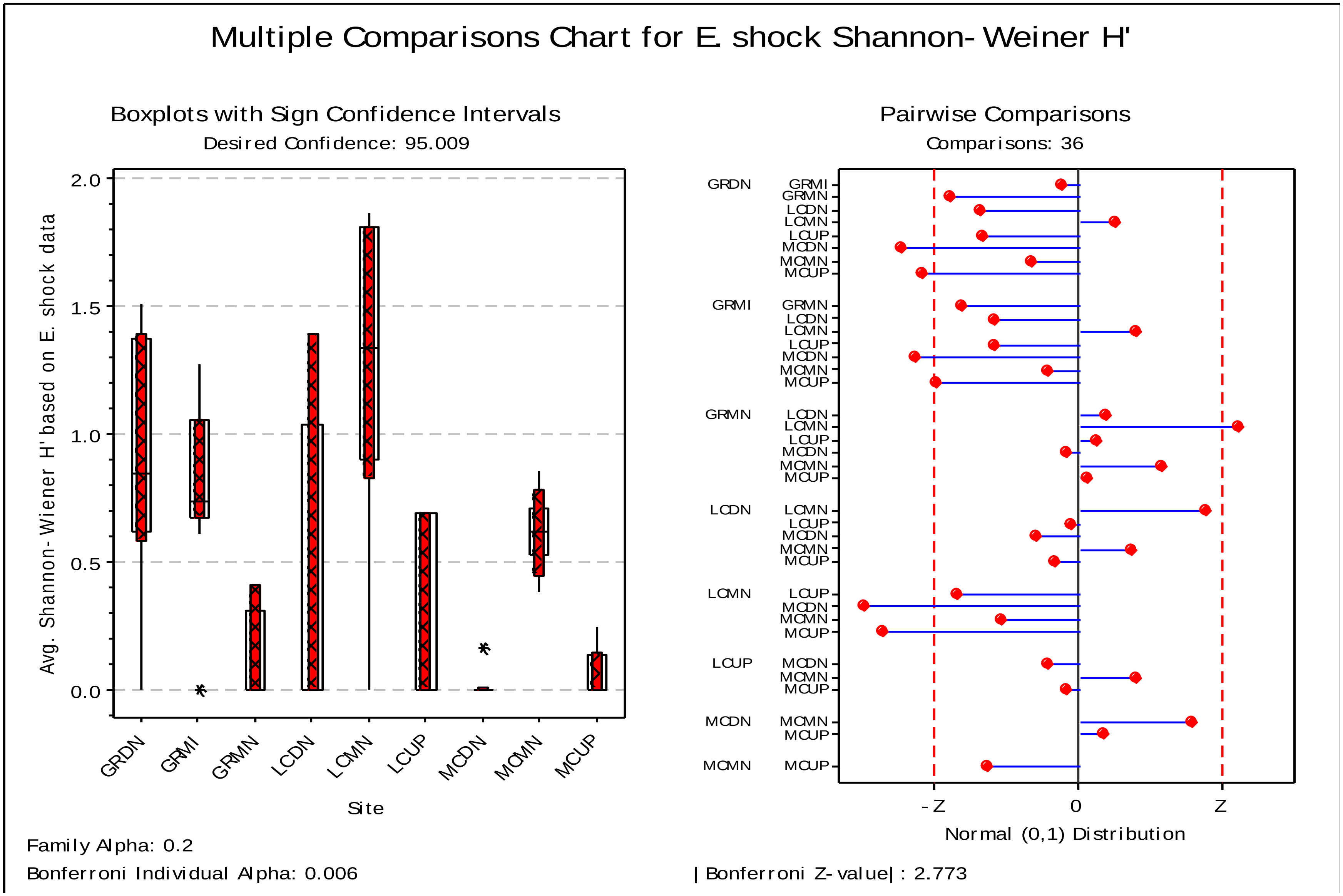


Figure 99. Results of Kruskal-Wallis One Way ANOVA with Dunn's multiple range test on Shannon-Weiner (*H'*) of fish communities based on electroshocking collections at each site during 2010 and 2011.

Table 32. Results of Kruskal-Wallis One Way ANOVA and Dunn's Multiple Range test on Shannon-Weiner Diversity (*H'*) of fish communities based on electroshocking data collected at each site during 2010 and 2011.

```
Kruskal-Wallis Test on the data
Group     N       Median  Ave Rank       Z
GRDN     10  0.848245558      45.2    2.09
GRMI     11  0.735621940      42.3    1.66
GRMN      4  0.000000000      17.4   -1.73
LCDN      4  0.000000000      24.1   -1.01
LCMN     11  1.332179045      50.8    3.28
LCUP      3  0.000000000      22.0   -1.06
MCDN      8  0.000000000      14.4   -3.00
MCMN      6  0.614388873      36.3    0.38
MCUP      9  0.000000000      18.8   -2.47
Overall  66                   33.5

H = 33.09  DF = 8  P = 0.000
H = 34.78  DF = 8  P = 0.000  (adjusted for ties)

* NOTE * One or more small samples
The following groups showed significant differences (adjusted for ties):
Groups                Z vs. Critical value       P-value
LCMN vs. MCDN         4.18124 >= 2.773           0.0000
LCMN vs. MCUP         3.80029 >= 2.773           0.0001
GRDN vs. MCDN         3.46338 >= 2.773           0.0005
GRMI vs. MCDN         3.19911 >= 2.773           0.0014
GRDN vs. MCUP         3.06457 >= 2.773           0.0022
GRMN vs. LCMN         3.05885 >= 2.773           0.0022
GRMI vs. MCUP         2.78496 >= 2.773           0.0054
```

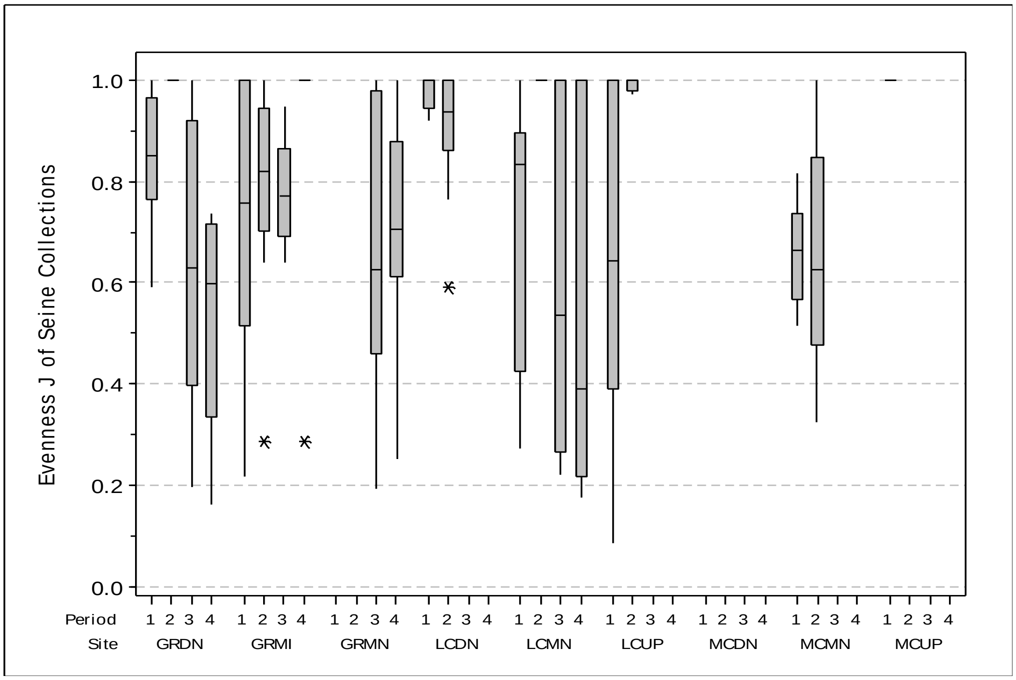


Figure 100. Evenness (*J'*) of fish communities sampled with a 30 ft. seine haul at each site during each collection. Samples not collected at GRMN during 2010. LCUP, LCDN and MCMN not monitored during one or two sampling periods in 2011 due to drought conditions. Only electroshocking was conducted at MCUP periods 3 and 4, and MCDN and MCMN periods 4.

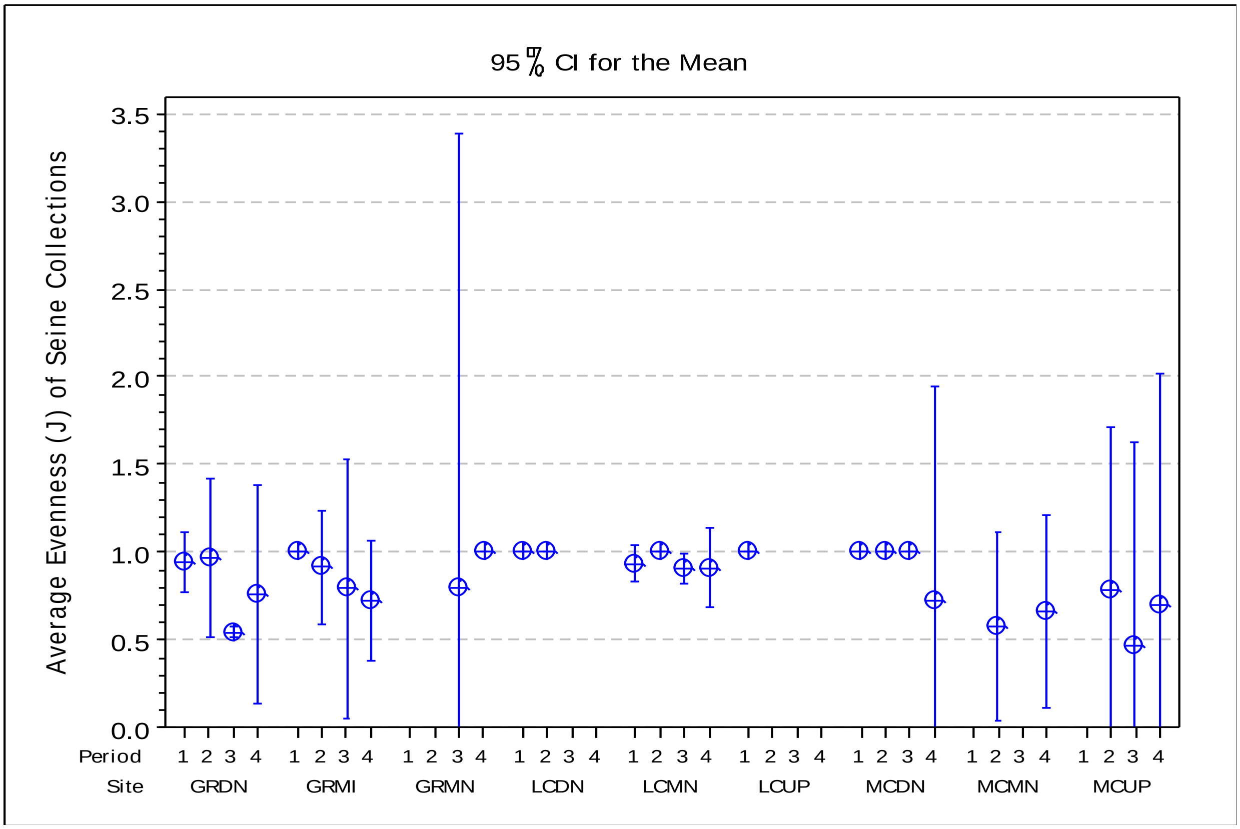


Figure 101. Ninety-five percent confidence interval plot of the average Evenness (*J'*) based on 30 ft. seine hauls collected at each site. Samples not collected at GRMN during 2010. LCUP, LCDN and MCMN not monitored during one or two sampling periods in 2011 due to drought conditions. Only electroshocking was conducted at MCUP periods 3 and 4, and MCDN and MCMN periods 4. Average J based on non-zero catches only.

Lowest median evenness (*J'*) for electrofishing collections were observed at the MCUP (periods 2-4) site (Figure 102). Evenness (*J'*) estimates were lacking for GRMN and LCUP (Periods 3-4) sites due to zero catches and insufficient data to calculate the index. Most median (E) values ranged between 0.6 and 0.9, suggesting that the distribution of specimens between taxa was often skewed with one of more taxa being numerically dominant. Average *J'* levels were very similar and many had extremely broad confidence intervals indicating these values were not statistically different (Figure 103). The only statistically significant overall difference between site median *J'* occurred between MCMN and LCDN and MCDN respectively (Figure 104 and Table 33).

The lowest median Berger Parker Index (*d*) value for seine collections was observed at the LCMN site during the first sample period (Figure 105). The remaining *d* values were generally above 0.6. This suggests most collections were dominated by a few numerically dominant taxa composing at least 60% of the total catch. Estimates of *d* were lacking for several collection periods at MCDN and MCUP due to zero catches and insufficient data to calculate the index. Based on the large confidence intervals observed for the average *d* values, there were few statistically significant differences between average *d* values by site. There were numerous collections in which no fish were captured, making it impossible to calculate (*d*). Therefore, we could not conduct the Kruskal Wallis ANOVA test for (*d*) on seine collected data.

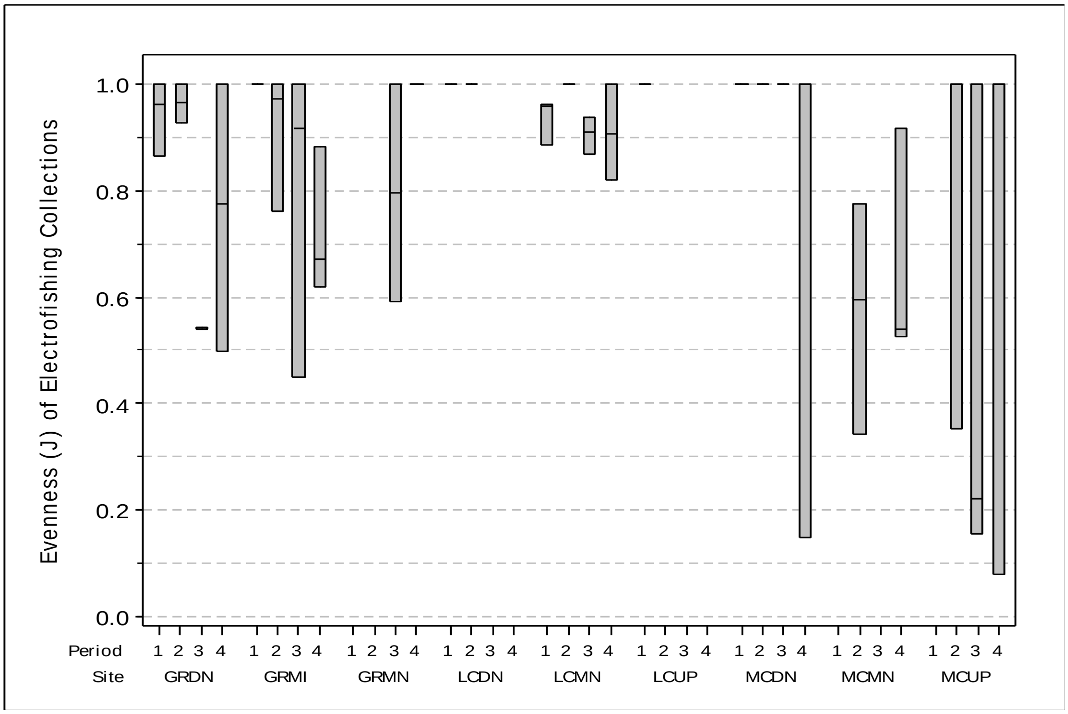


Figure 102. Evenness (*J'*) of fish communities sampled with electroshocking at each site during each collection. Samples not collected at GRMN during 2010. LCUP, LCDN and MCMN not monitored during one or two sampling periods in 2011 due to drought conditions.

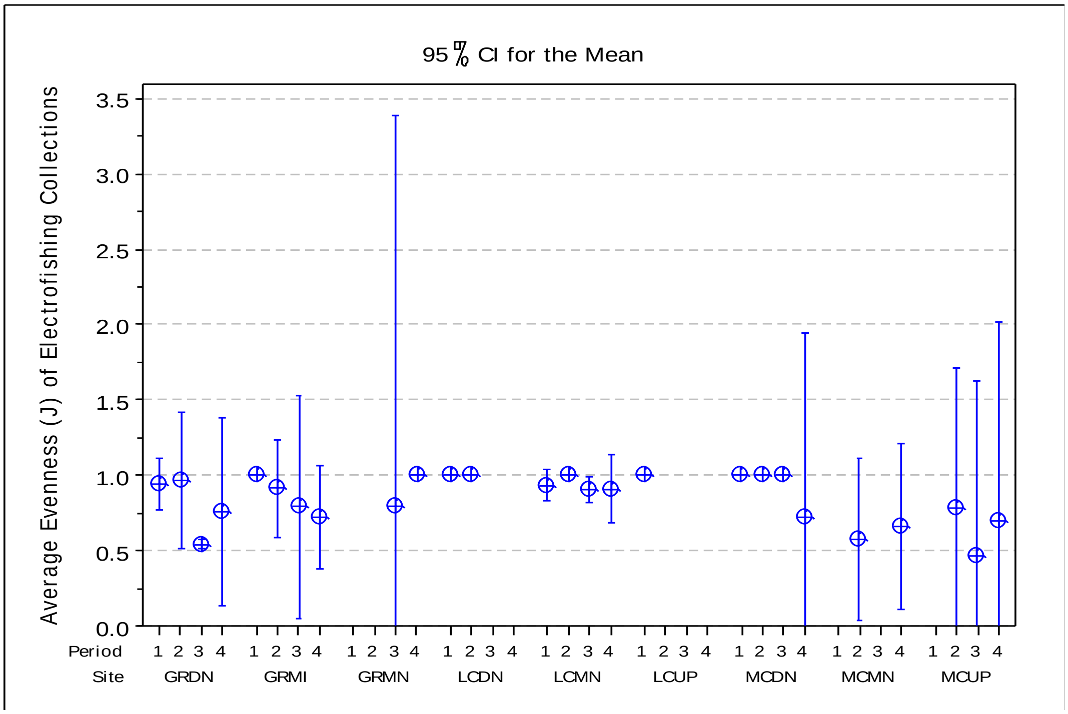


Figure 103. Ninety-five percent confidence interval plot of the average Evenness (*J'*) based on electroshocking samples collected at each site. Samples not collected at GRMN during 2010. LCUP, LCDN and MCMN not monitored during one or two sampling periods in 2011 due to drought conditions. Average J based on non-zero catches only.

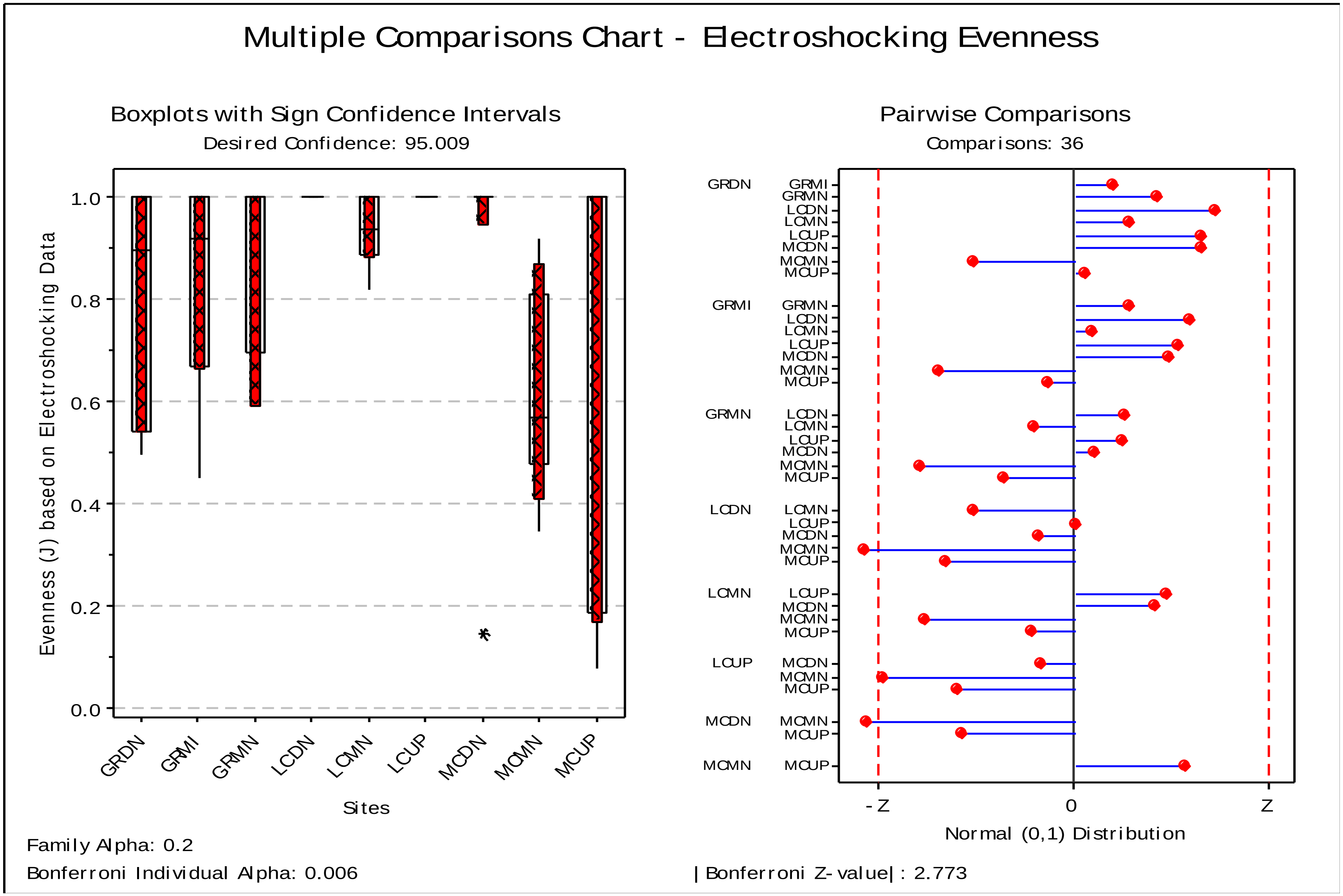


Figure 104. Results of Kruskal-Wallis One Way ANOVA with Dunn's multiple range test on Evenness (*J'*) of fish communities based on electroshocking collections at each site during 2010 and 2011.

Table 33. Results of Kruskal-Wallis One Way ANOVA and Dunn's Multiple Range test on Evenness (*J'*) of fish communities based on electroshocking data collected at each site during 2010 and 2011.

```
Kruskal-Wallis Test on the data

Group      N  Median  Ave Rank       Z
GRDN      10  0.8967      27.9   -1.00
GRMI      11  0.9183      32.2   -0.25
GRMN       4  1.0000      40.4    0.74
LCDN       4  1.0000      49.5    1.72
LCMN      11  0.9373      34.1    0.11
LCUP       3  1.0000      49.5    1.48
MCDN       8  1.0000      43.6    1.58
MCMN       6  0.5675      14.2   -2.59
MCUP       9  1.0000      29.1   -0.75
Overall   66              33.5

H = 15.06  DF = 8  P = 0.058
H = 16.62  DF = 8  P = 0.034  (adjusted for ties)

The following groups showed significant differences (adjusted for ties):

Groups                 Z vs. Critical value       P-value
LCDN vs. MCMN          2.99555 >= 2.773           0.0027
MCDN vs. MCMN          2.97872 >= 2.773           0.0029
```

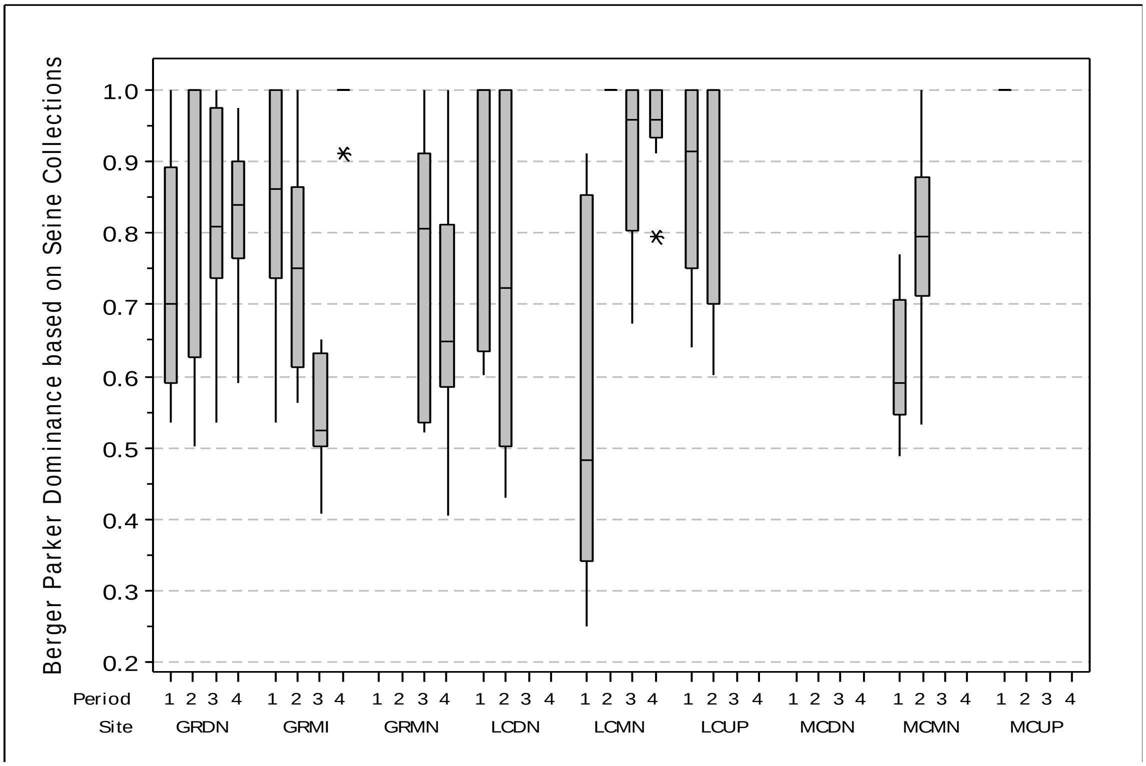


Figure 105. Berger-Parker Dominance index (*d*) based on fish communities sampled with a 30 ft. seine haul at each site during each collection. Samples not collected at GRMN during 2010. LCUP, LCDN and MCMN not monitored during one or two sampling periods in 2011 due to the drought. Only electroshocking conducted at MCUP periods 3 and 4, and MCDN and MCMN periods 4.

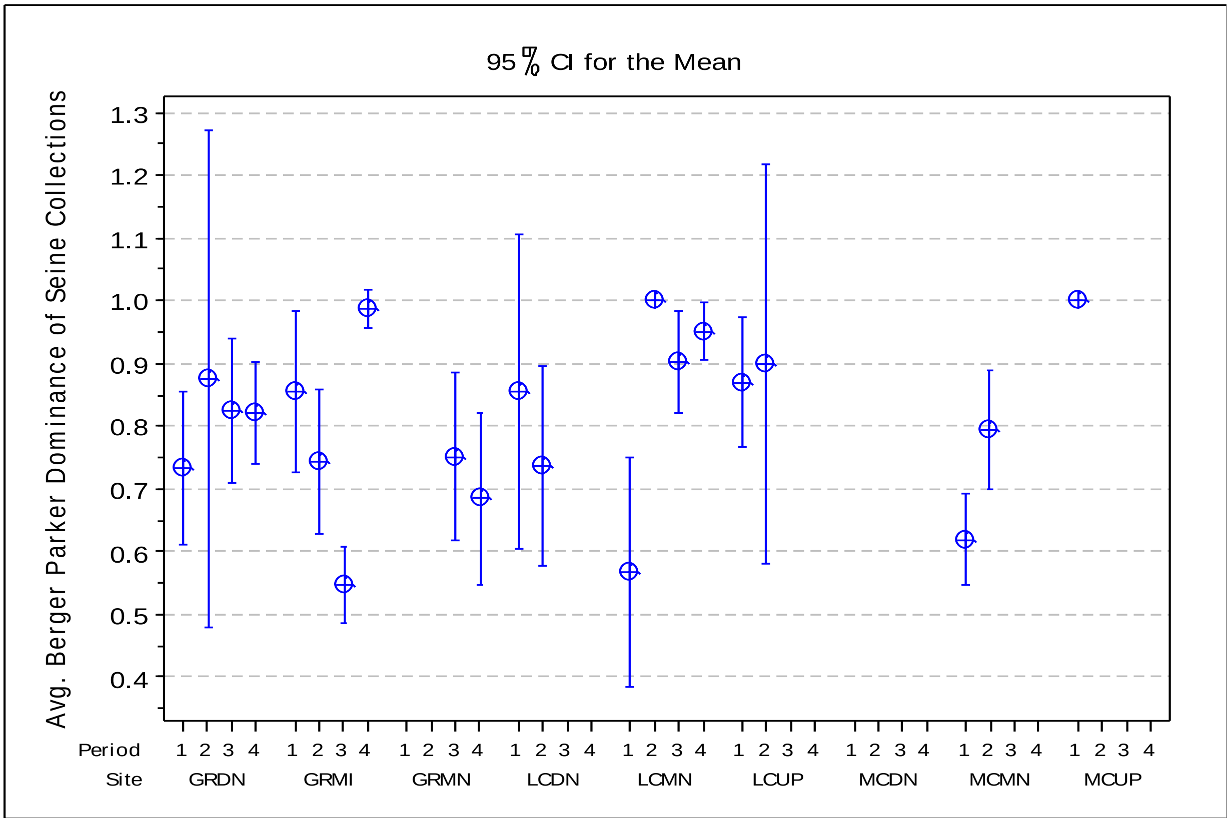


Figure 106. Ninety-five percent confidence interval plot of the average Berger-Parker Dominance Index (*d*) based on 30 ft. seine hauls collected at each site. Samples not collected at GRMN during 2010. LCUP, LCDN and MCMN not monitored during one or two sampling periods in 2011 due to drought conditions. Only electroshocking was conducted at MCUP during periods 3 and 4, and MCDN and MCMN period 4. Average *d* based on non-zero catches only

Median Berger Parker Index (*d*) values based on electrofishing data were generally greater than 0.5 at most sites (Figure 107). Lowest values of (*d*) occurred at the LCMN site during sampling periods 1, 3 and 4. The other sites exhibited very similar median and average *(d)* values and/or possessed wide confidence intervals of the mean (Figure 107 and 108). Statistically significant differences in *(d)* between MCMN and GRDN, GRMI and LCMN sites; and MCDN and GRDN, LCMN; MCUP and GRDN; GRMI and LCMN were observed (Figure 109 and Table 34).

Many of the measured fish community metrics showed significant cross correlation with other metrics derived from both seine and electrofishing (Table 35). The weakest correlations were between gear types (seine and electroshocking) versus within gear type metrics. This indicates that each method of collecting fish community data is mutually exclusive, non-duplicative, and supportive of the overall assessment. We also found that multiple fish community metrics were correlated with various environmental variables (Table 36). The strongest correlations ($r > .55$ or $r < -0.55$) occurred between electroshocking Berger Parker Indices *d* and sediment size (rank), and % emergent vegetation; electroshocking Shannon Weiner diversity *(H')* and sediment size, electroshocking total numbers and chlorophyll-a and total alkalinity. Additional strong correlations were observed between seine *d* and % bank vegetation.

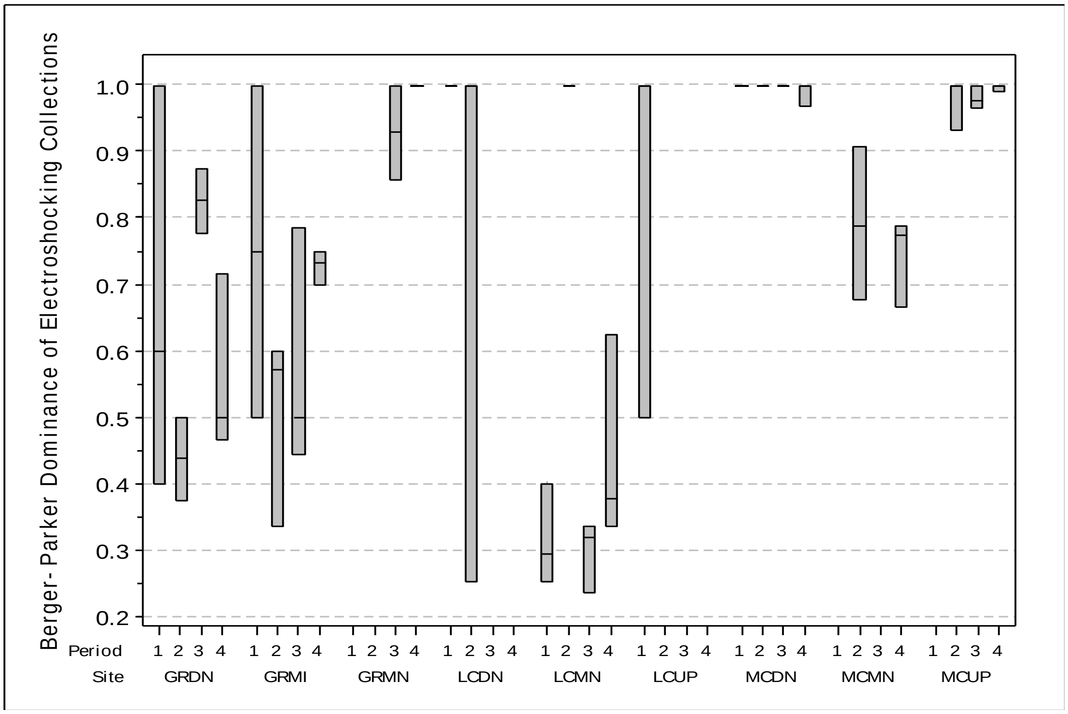


Figure 107. Berger-Parker Dominance (*d*) index based on fish communities sampled electroshocking at each site during each collection. Samples not collected at GRMN during 2010. LCUP, LCDN and MCMN not monitored during one or two sampling periods in 2011 due to drought conditions.

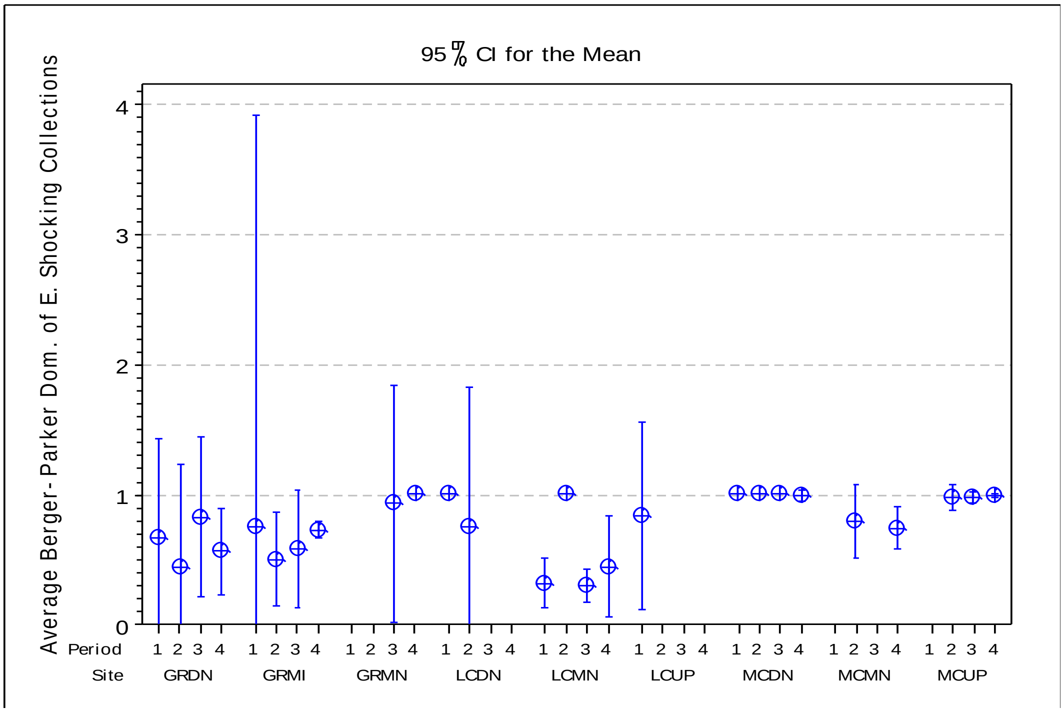


Figure 108. Ninety-five percent confidence interval plot of the average Berger-Parker Dominance Index (*d*) based on electroshocking collections at each site. Samples not collected at GRMN during 2010. LCUP, LCDN and MCMN not monitored during one or two sampling periods in 2011 due to drought conditions. Average values based on non-zero catches only.

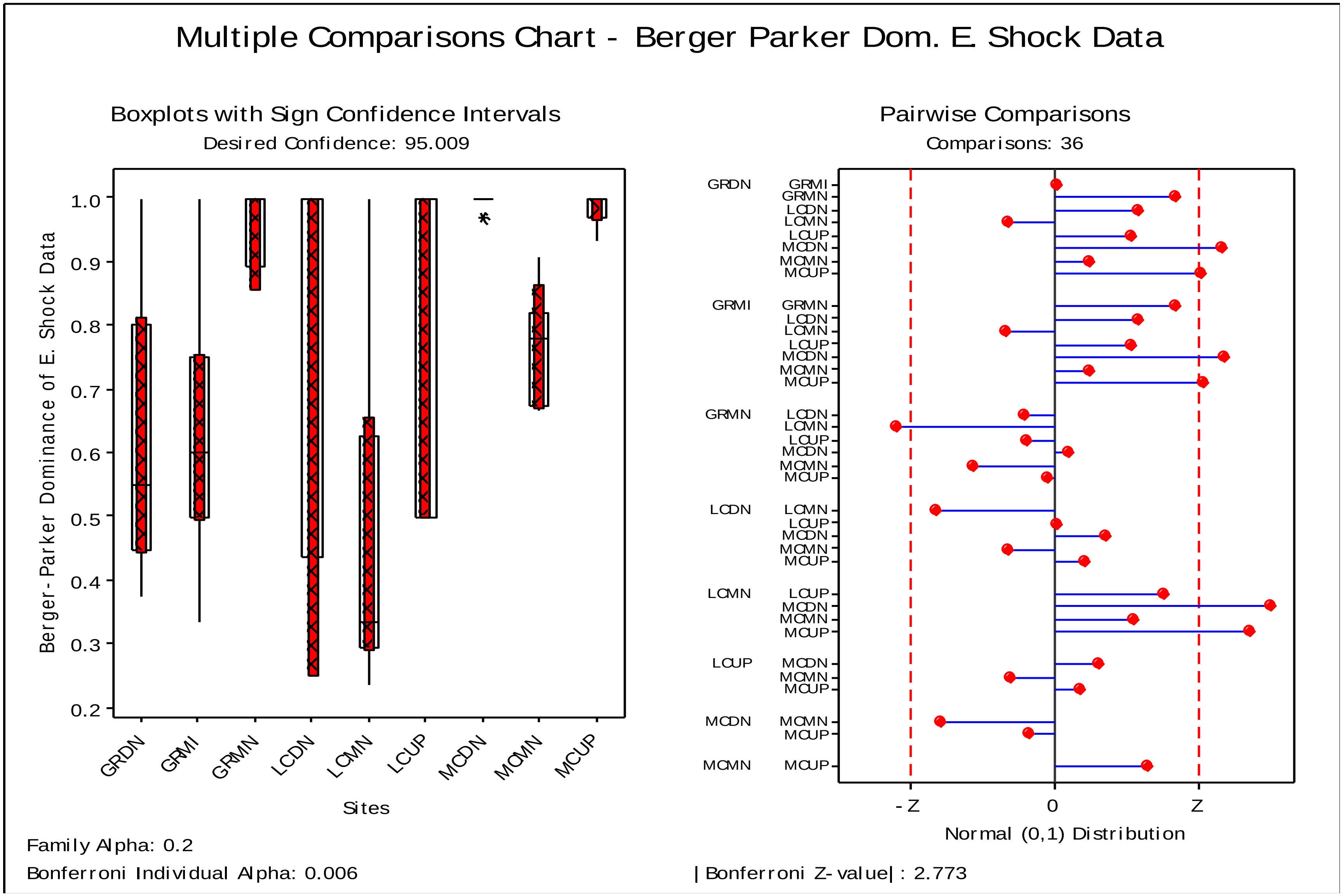


Figure 109. Results of Kruskal-Wallis One Way ANOVA with Dunn's multiple range test on Berger-Parker Dominance Index (*d*) of fish communities based on electroshocking collections at each site during 2010 and 2011.

Table 34. Results of Kruskal-Wallis One Way ANOVA and Dunn’s Multiple Range test on Berger Parker Dominance Index (BPI) of fish communities based on electroshocking data collected at each site during 2010 and 2011.

```
Kruskal-Wallis Test on the data
Group     N  Median  Ave Rank      Z
GRDN     10  0.5500      23.9  -1.72
GRMI     11  0.6000      24.1  -1.78
GRMN      4  1.0000      49.6   1.73
LCDN      4  1.0000      41.5   0.86
LCMN     11  0.3333      16.3  -3.25
LCUP      3  1.0000      42.0   0.78
MCDN      8  1.0000      52.7   3.02
MCMN      6  0.7805      30.5  -0.40
MCUP      9  1.0000      48.1   2.45
Overall  66              33.5

H = 31.37  DF = 8  P = 0.000
H = 32.98  DF = 8  P = 0.000  (adjusted for ties)

* NOTE * One or more small samples
The following groups showed significant differences (adjusted for ties):
Groups                Z vs. Critical value       P-value
LCMN vs. MCDN         4.18021 >= 2.773           0.0000
LCMN vs. MCUP         3.77114 >= 2.773           0.0002
GRMI vs. MCDN         3.28683 >= 2.773           0.0010
GRDN vs. MCDN         3.24124 >= 2.773           0.0012
GRMN vs. LCMN         3.04658 >= 2.773           0.0023
GRMI vs. MCUP         2.84756 >= 2.773           0.0044
GRDN vs. MCUP         2.80776 >= 2.773           0.0050
```

Table 35. Significant correlation analysis between fish community metrics.

E. Shock Metric 1	E. Shock Metric 2	Correlation	p-value
d	Cum. Taxa	-0.86	0.0000
J'	Tot. No.	-0.55	0.0033
H'	*d*	-0.98	0.0000
H'	Cum. Taxa	0.88	0.0000
H'	No. Taxa	0.92	0.0000
No. Taxa	*d*	-0.85	0.0000
No. Taxa	Cum. Taxa	0.92	0.0000
Seine Metric 1	**Seine Metric 2**	**Correlation**	**p-value**
BPI	Cum. Taxa	-0.66	0.0013
J'	Cum. Taxa	-0.53	0.0128
J'	No.Taxa	-0.70	0.0004
H'	*d*	-0.98	0.0000
H'	Cum. Taxa	0.73	0.0002
H'	No.Taxa	0.89	0.0000
No. Taxa	*d*	-0.80	0.0000
No. Taxa	Cum. Taxa	0.86	0.0000
Total No.	No.Taxa	0.40	0.0455
Seine Metric	**E. Shock Metric**	**Correlation**	**p-value**
Cum.Taxa	BPI	-0.63	0.0015
Cum.Taxa	Cum. Taxa	0.60	0.0016
Cum.Taxa	*H'*	0.62	0.0022
Cum.Taxa	No. Taxa	0.56	0.0035
J'	No. Taxa	-0.49	0.0232
No. Taxa	Cum.Taxa	0.46	0.0194
No. Taxa	*H'*	0.57	0.0056
No. Taxa	No. Taxa	0.48	0.0150

Table 36. Significant correlation analysis between fish community metrics and environmental variables.

E. Shock Metric	Variable	Correlation	p-value
d	Sed. Rank	-0.63	0.0006
d	% Emerg. Veg.	0.52	0.0070
d	Bank Slope	-0.40	0.0403
Cum. No. Taxa	Sed. Rank	0.51	0.0043
Cum. No. Taxa	pH	0.51	0.0045
Cum. No. Taxa	% Emerg. Veg.	-0.47	0.0104
Cum. No. Taxa	NH4-N	-0.45	0.0141
Cum. No. Taxa	Bank Slope	0.43	0.0203
Cum. No. Taxa	% Impervious	0.39	0.0386
J'	Total Alkalinity	-0.49	0.0117
J'	% Run	0.42	0.0324
J'	D.O.	0.41	0.0371
J'	NH4-N	0.41	0.0386
J'	Sp. Cond.	-0.40	0.0403
J'	% Pool	-0.40	0.0437
H'	Sed. Rank	0.56	0.0028
H'	% Emerg. Veg.	-0.47	0.0150
H'	pH	0.39	0.0470
No. Taxa	pH	0.49	0.0064
No. Taxa	NH4-N	-0.46	0.0128
No. Taxa	AvgSedRank	0.41	0.0283
No. Taxa	Air. Temp	0.40	0.0337
Tot. No.	Chl-a	0.63	0.0003
Tot. No.	Total Alkalinity	0.60	0.0005
Tot. No.	% Pool	0.53	0.0033
Tot. No.	Sp. Cond.	0.51	0.0044
Tot. No.	% Run	-0.51	0.0047
Tot. No.	O-P	0.44	0.0170
Tot. No.	Velocity	-0.43	0.0186
Tot. No.	Air. Temp	0.41	0.0267
Tot. No.	% Shading	-0.39	0.0368
Tot. No.	NH4-N	-0.38	0.0432
Seine Metric	**Variable**	**Correlation**	**p-value**
d	% Benk Veg.	-0.59	0.0047
d	NO2+3	-0.47	0.0323
Cum. No. Taxa	% Emerg. Veg.	-0.58	0.0024
Cum. No. Taxa	Sed. Rank	0.45	0.0253
Cum. No. Taxa	Chl-a	-0.45	0.0257
Cum. No. Taxa	Bank Slope	0.43	0.0303
Cum. No. Taxa	pH	0.43	0.0307
J'	Sp. Cond.	-0.55	0.0094
J'	Total Alk.	-0.52	0.0156
J'	D.O.	0.52	0.0160
J'	Air Temp	-0.46	0.0342
J'	TSS	0.43	0.0492
H'	% Bank Veg.	0.60	0.0040
H'	Air Temp	0.48	0.0263
No. Taxa	Chl-a	-0.48	0.0141

Finally, we observed relatively strong (r > 0.60) correlations between selected fish community metrics and benthic invertebrate community metrics (Table 37). The strongest correlations were observed between evenness (J') based on electroshock collected fish community and benthic community number of taxa, cumulative number of taxa, and (*H'*).

Table 37. Significant correlation coefficients between fish and benthic community metrics.

Fish Metric	Benthic Metric	Correlation	p-value
E. shock Cum. Taxa	Benthic Tot. No.	0.37	0.0475
E. shock *J'*	Benthic *d*	0.44	0.0259
E. shock *J'*	Benthic No. Taxa	-0.67	0.0002
E. shock *J'*	Benthic Cum. Taxa	-0.69	0.0001
E. shock *J'*	Benthic *H'*	-0.64	0.0004
E. shock No. Taxa	Benthic Tot. No.	0.38	0.0394
E. shock Tot. No.	Benthic *H'*	0.51	0.0049
E. shock Tot. No.	Benthic No. Taxa	0.55	0.0019
Seine No. Taxa	Benthic *J'*	-0.47	0.0168

The species composition and total catch for all collection gear (seines and electrofishing) is presented in Table 38 and 39. Catches overall were composed of 29 taxa totaling 10,124 fish. Overall catches were dominated by several species including *Gambusia affinis*, mosquitofish (7,711, 76.2%), *Lucania goodei*, bluefin killifish (562, 5.5%) and *Poecilia latipinna*, sailfin molly (481, 4.8%). Both mosquitofish and sailfin molly are considered species tolerant of poor water quality (TCEQ 2007). Bluefin killifish is an introduced species, native to Florida. It was first recorded in Texas in 1998 in a constructed wetland that discharged into the Guadalupe, River, in Guadalupe County, near Victoria, Texas (Gallaway et al. 2008). Another introduced species, *Oreochromis* spp., tilapia, was also collected at the GBMI site during the second and GRMN site during third sampling period (Table 38 and 39). Finally, another introduced species that has established itself in urban streams, the armored catfish *Pteroplicthys* spp., was collected at GRDN during period 4 and GRMN during periods 3 and 4 (Hubbs et al. 2008). Ten of the fish taxa collected during the study period were considered "tolerant' species (Linam et al. 2002; TCEQ 2007)

Fish community IBI metrics indicated that the majority of restoration sites were classified as having intermediate aquatic life use during most collections (Figure 110). Only GRDN period 4 and LCMN period 1 and 3 had high aquatic life use designations. A low aquatic life use designation was assigned to GRMI period 2, GRMN periods 3 and 4, LCDN period 1, and MCMN period 4.

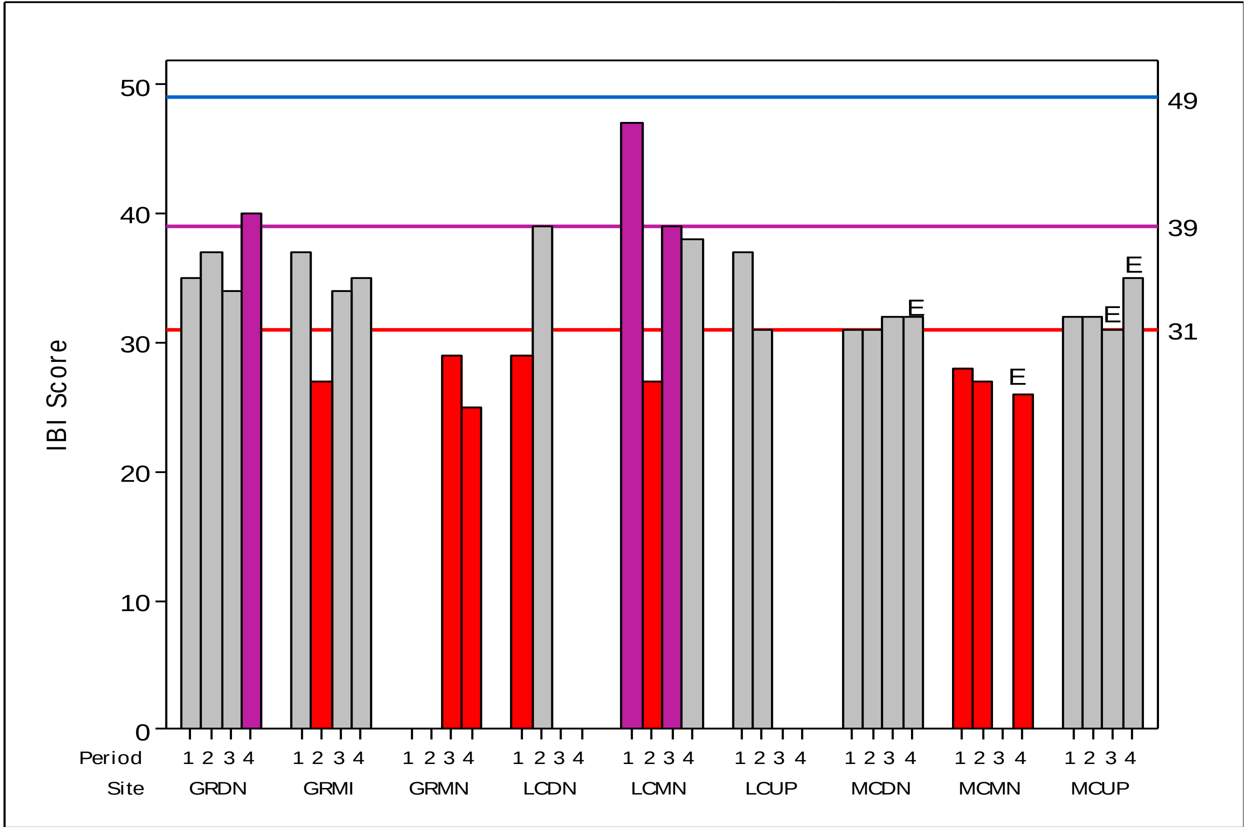


Table 38. Fish collection data used to calculate IBI metrics during each collections in 2010. Numbers in second row refer to sampling period. GRMN not sampled during 2010.

Species	Tolerance	Trophic	Non-Native	GRDN	GRDN	GRMI	GRMI	LCDN	LCDN	LCMN	LCMN	LCUP	LCUP	MCDN	MCDN	MCMN	MCMN	MCUP	MCUP
				1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Dorosoma cepedianum	*T*	*O*		0	0	0	0	0	0	3	0	10	0	0	0	0	0	0	0
Cyprinella lutrensis	*T*	*IF*		55	0	0	0	0	1	7	0	0	0	0	0	0	0	0	0
Cyprinella venusta		*IF*		0	1	0	0	0	28	19	0	0	0	0	0	0	0	0	0
Notemigonus crysoleucas	*T*	*IF*		0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
Notropis atrocaudalis		*IF*		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pimephales vigilax		*IF*		14	0	0	2	0	0	18	0	0	0	0	0	0	0	0	0
Erimyzon sucetta		*O*		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ameiurus natalis		*O*		0	1	0	0	1	0	5	2	0	0	0	0	0	0	0	1
Ameiurus melas	*T*	*O*		0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0
Noturus gyrinus	*I*	*IF (benthic)*		0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Pteroplichthys spp.		*H*	*X*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aphredoderus sayanus		*IF*		0	0	0	0	0	1	6	0	0	0	0	0	0	0	0	0
Fundulus notatus		*IF*		0	0	0	0	0	14	176	0	0	0	0	0	0	0	0	0
Lucania goodei			*X*	0	0	0	0	0	0	0	0	0	0	0	0	522	35	0	0
Gambusia affinis	*T**	*IF*		42	22	134	37	8	4	22	2	284	8	0	5	1,018	352	1,740	91
Poecilia latipinna	*T*	*O*		3	0	9	0	0	5	0	0	0	0	0	0	78	70	0	0
Labidesthes sicculus	*I*	*IF*		0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0
Menida beryllina		*IF*		0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0
Elassoma zonatum		*IF*		0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Lepomis sp. (juvenile)				0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0
Lepomis auritus		*IF*		0	2	0	3	0	0	0	0	0	0	0	0	0	0	0	0
Lepomis cyanellus	*T*	*P*		1	3	0	3	0	1	2	0	0	0	0	0	0	0	0	0
Lepomis gulosus	*T*	*P*		0	0	1	0	0	0	2	0	1	0	0	0	0	0	0	0
Lepomis humilis		*IF*		0	1	18	6	0	0	3	0	0	0	0	0	0	0	0	0
Lepomis macrochirus	*T*	*IF*		0	1	0	6	7	1	4	0	17	2	0	0	36	0	0	0
Lepomis megalotis		*IF*		6	1	4	8	0	3	9	0	0	0	1	0	0	0	0	0
Lepomis microlophus		*IF*		0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Micropterus sp.		*P*		0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Micropterus punctulatus		*P*		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Micropterus salmoides		*P*		2	1	1	0	0	0	4	0	10	1	0	0	0	0	0	0
Pomoxis annularis		*P*		0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Etheostoma chlorosomum		*IF (benthic)*		0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
Cichlasomo cyanoguttatum		*IF*		1	0	1	6	0	0	0	0	0	0	0	0	0	0	0	0
Oreochromis sp.	*T*	*O*	*X*	0	0	0	31	0	0	0	0	0	0	0	0	0	0	0	0
Unknown				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Number all Gear				124	33	169	112	16	62	289	4	333	11	1	5	1,655	457	1,740	92
No. Fish Species				8	9	8	10	3	11	17	2	8	3	1	1	5	3	1	2

Table 39. Fish collection data used to calculate IBI metrics during each collection in 2011. Numbers in second row refer to sampling period. E = only electroshocking data collected.

Species	Tolerance	Trophic	Non-Native	GRDN	GRDN	GRMI	GRMI	GRMN	GRMN	LCMN	LCMN	MCDN	MCDN	MCMN	MCUP	MCUP	2010-11
				3	4	3	4	3	4	3	4	3	4,E	4, E	3, E	4, E	Total
Dorosoma cepedianum	*T*	*O*		0	0	0	0	0	0	0	0	0	0	0	0	0	13
Cyprinella lutrensis	*T*	*IF*		8	10	0	0	0	0	0	0	0	0	0	0	0	81
Cyprinella venusta		*IF*		0	0	0	0	0	0	5	5	0	0	0	0	0	58
Notemigonus crysoleucas	*T*	*IF*		0	0	0	0	0	0	0	0	0	0	0	0	0	2
Notropis atrocaudalis		*IF*		0	0	0	0	0	0	0	0	0	1	0	0	0	1
Pimephales vigilax		*IF*		0	2	0	0	74	81	0	0	0	0	0	0	0	191
Erimyzon sucetta		*O*		0	0	0	0	0	0	0	1	0	0	0	0	0	1
Ameiurus natalis		*O*		0	4	0	0	1	1	2	1	0	0	0	0	0	19
Ameiurus melas	*T*	*O*		0	0	0	0	0	0	0	0	0	0	0	0	0	8
Noturus gyrinus	*I*	*IF (benthic)*		0	0	0	0	0	0	0	0	0	0	0	0	0	1
Pteroplichthys spp.		*H*	*X*	0	1	0	0	14	4	0	0	0	0	0	0	0	19
Aphredoderus sayanus		*IF*		0	0	0	0	0	0	3	1	0	0	0	0	0	11
Fundulus notatus		*IF*		0	0	0	0	0	0	34	20	0	0	0	0	0	244
Lucania goodei			*X*	0	0	0	0	0	0	0	0	0	0	2	2	1	562
Gambusia affinis	*T**	*IF*		859	541	113	38	277	224	263	990	196	98	98	82	163	7,711
Poecilia latipinna	*T*	*O*		163	114	0	1	4	8	0	0	0	0	26	0	0	481
Labidesthes sicculus	*I*	*IF*		0	0	0	0	0	0	0	0	0	0	0	0	0	5
Menida beryllina		*IF*		0	0	0	0	0	0	0	0	0	0	0	0	0	3
Elassoma zonatum		*IF*		0	0	0	0	0	0	0	0	0	0	0	0	0	1
Lepomis sp. (juvenile)				0	0	0	0	0	0	0	0	0	0	0	0	0	10
Lepomis auritus		*IF*		0	1	4	0	0	0	6	0	0	0	0	0	0	16
Lepomis cyanellus	*T*	*P*		0	6	44	0	0	0	13	5	0	1	0	0	0	79
Lepomis gulosus	*T*	*P*		1	1	0	1	0	0	0	0	0	0	0	0	0	7
Lepomis humilis		*IF*		0	0	0	0	0	0	0	0	0	0	0	0	0	28
Lepomis macrochirus	*T*	*IF*		1	1	6	6	0	0	11	3	0	0	0	0	0	102
Lepomis megalotis		*IF*		12	64	94	27	2	4	9	8	0	0	0	0	0	252
Lepomis microlophus		*IF*		0	1	2	0	0	0	1	0	0	0	0	0	0	5
Micropterus sp.		*P*		0	0	0	0	0	0	0	0	0	0	0	0	0	1
Micropterus punctulatus		*P*		0	0	4	0	0	0	0	0	0	0	0	0	0	4
Micropterus salmoides		*P*		4	3	9	2	0	0	0	2	0	0	0	0	0	39
Pomoxis annularis		*P*		0	0	0	0	0	0	0	0	0	0	0	0	0	1
Etheostoma chlorosomum		*IF (benthic)*		0	0	0	0	0	0	0	0	0	0	0	0	0	3
Cichlasomo cyanoguttatum		*IF*		0	1	61	0	0	62	0	0	0	0	0	0	0	132
Oreochromis sp.	*T*	*O*	*X*	0	0	0	0	0	1	0	0	0	0	0	0	0	32
Unknown				1	0	0	0	0	0	0	0	0	0	0	0	0	1
Total Number all Gear				1049	750	337	75	372	385	347	1036	196	100	126	84	164	10,124
No. Fish Species				8	14	9	6	6	8	10	10	1	3	3	2	2	29

Table 40. Calculated fish IBI metric scores based on seine and electrofishing collections.

Site	Date	Gear	Period	No. Taxa. Score	No.Native Cyprinids Score	No. Bent. Invertivore Spp. Score	No. Sunfish Spp. Score	No. Intolerant Spp. Score	% Indiv. As Tolerant Spp. w/o ms Score	% of Indiv. As Omnivore Score	% Indiv. As Invertivore Score	No. Fish/Seine Haul Score	No. Fish/Min. E. Shock Score	Average Gear Score	% Indiv. Non-Native Spp. Score	% Indiv. With Disease & Anomaly Score	Total IBI Score	ALU
GRDN	7/21/2010	S&E	1	3	3	1	3	1	5	3	5	1	1	1	5	5	35	Intermediate
GRDN	9/2/2010	S&E	2	3	1	1	5	1	5	5	5	1	1	1	5	5	37	Intermediate
GRDN	6/10/2011	S&E	3	3	1	1	3	1	5	3	5	3	1	2	5	5	34	Intermediate
GRDN	7/29/2011	S&E	4	5	3	1	5	1	5	3	5	1	3	2	5	5	40	High
GRMN	6/15/2011	S&E	3	3	1	1	1	1	5	1	5	1	1	1	5	5	29	Limited
GRMN	8/1/2011	S&E	4	3	1	1	1	1	5	1	5	1	1	1	1	5	25	Limited
GRMI	7/21/2010	S&E	1	3	1	1	5	1	5	5	5	1	1	1	5	5	37	Intermediate
GRMI	9/2/2010	S&E	2	5	1	1	5	1	3	1	3	1	1	1	1	5	27	Limited
GRMI	6/10/2011	S&E	3	3	1	1	5	1	5	5	5	1	3	2	1	5	34	Intermediate
GRMI	7/29/2011	S&E	4	3	1	1	3	1	5	5	5	1	1	1	5	5	35	Intermediate
LCDN	7/6/2010	S&E	1	1	1	1	1	1	3	5	5	1	1	1	5	5	29	Limited
LCDN	9/7/2010	S&E	2	5	3	3	3	1	5	5	5	1	1	1	3	5	39	High
LCMN	7/12/2010	S&E	1	5	5	3	5	3	5	5	5	1	1	1	5	5	47	High
LCMN	9/14/2010	S&E	2	1	1	1	1	1	3	5	3	1	1	1	5	5	27	Limited
LCMN	6/14/2011	S&E	3	5	1	1	5	1	5	5	5	1	1	1	5	5	39	High
LCMN	8/3/2011	S&E	4	5	1	1	3	1	5	5	5	3	1	2	5	5	38	Intermediate
LCUP	7/6/2010	S&E	1	3	1	1	3	3	5	5	5	1	1	1	5	5	37	Intermediate
LCUP	9/7/2010	S&E	2	1	1	1	1	1	5	5	5	1	1	1	5	5	31	Intermediate
MCDN	5/17/2010	S&E	1	1	1	1	1	1	5	5	5	1	1	1	5	5	31	Intermediate
MCDN	8/27/2010	S&E	2	1	1	1	1	1	5	5	5	1	1	1	5	5	31	Intermediate
MCDN	6/13/2011	S&E	3	1	1	1	1	1	5	5	5	1	3	2	5	5	32	Intermediate
MCDN	7/28/2011	E	4	1	1	1	1	1	5	5	5	1	3	2	5	5	32	Intermediate
MCMN	5/21/2010	S&E	1	3	1	1	1	1	5	5	3	3	1	2	1	5	28	Limited
MCMN	8/27/2010	S&E	2	1	1	1	1	1	5	3	5	1	5	3	1	5	27	Limited
MCMN	7/28/2011	E	3	1	1	1	1	1	5	1	5	1	3	2	3	5	26	Limited
MCUP	5/17/2010	S&E	1	1	1	1	1	1	5	5	5	3	1	2	5	5	32	Intermediate
MCUP	8/27/2010	S&E	2	1	1	1	1	1	5	5	5	1	3	2	5	5	32	Intermediate
MCUP	6/13/2011	E	3	1	1	1	1	1	5	5	5	3	3	3	3	5	31	Intermediate
MCUP	7/28/2011	E	4	1	1	1	1	1	5	5	5	5	5	5	5	5	35	Intermediate

(w/o mf = without mosquitofish; E – electroshocking, S - seine)

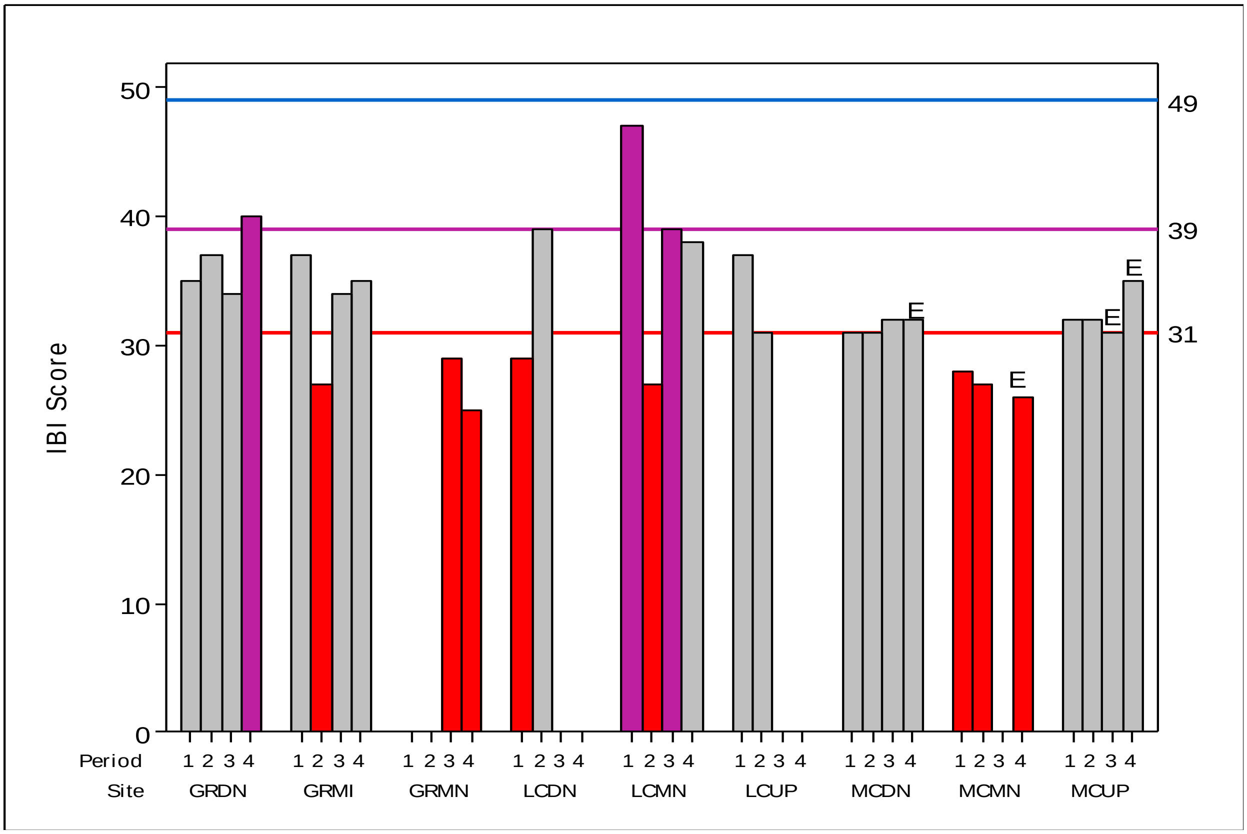


Figure 110. Summary of fish IBI scores based on combined seine and electrofishing collections. Aquatic life use >49 exceptional (blue bars); 39-48 High (purple bars); 31-38 Intermediate (gray bars); < 31 Limited (red bars). Sample periods 1 and 2 = 2010 collections; 3 and 4 = 2011 collections. Samples not collected at GRMN during 2010. LCUP, LCDN and MCMN not monitored during one or two sampling periods in 2011 due to drought conditions. E = ranking based on electroshocking data only.

The metric scores that exhibited the strongest most significant ($p <= 0.01$) correlations with the overall IBI score were number of fish taxa, number of native cyprinids, number of benthic invertivores, number of intolerant species and percent of individuals as non-native species (Table 41). In addition, we observed significant ($p <= 0.05$) correlations between total IBI scores and percent individuals as tolerant species, percent individuals as omnivores and percent individuals as invertivores. Stepwise regression conducted indicated four metric variable scores including number of sunfish species, percent individuals as non-native species, number of benthic invertivore species, and percent individuals as intolerant species explained the majority of variation ($r^2 = 0.9061$) in total IBI scores. The estimated linear model is provided below.

Fish IBI Score = 7.913 + 1.67 (Number of Sunfish Species) + 1.42 (% individuals as non-native species) + 3.74 (Number of benthic invertivore species) + 2.30 (% individuals as tolerant species).

Variables that improved the model only marginally ($\Delta\ r^2 \leq 3$ for each additional variable) included percent individuals as omnivores, number of native cyprinid species, average gear score, number of taxa, and percent individuals as invertivores.

Table 41. Results of rank correlation analysis between various fish IBI community metric scores. Only significant ($p \leq 0.05$), r values reported. Cells highlighted in yellow are significant at the $p \leq 0.01$ level.

Metric Scores	No. Taxa. Score	No.Native Cyprinids Score	No. Bent. Invert. Spp. Score	No. Sunfish Spp. Score	No. Intolerant Spp. Score	% Indiv. As Tolerant Spp. w/o ms Score	% of Indiv. As Omnivore Score	% Indiv. As Invertivore Score	No. Fish/Seine Haul Score	No. Fish/Min. E. Shock Score	Average Gear Score	% Indiv. Non-Native Spp. Score	% Indiv. With Disease & Anomaly Score	Total IBI Score
No. Taxa. Score														
No.Native Cyprinids Score	0.505													
No. Bent. Invert. Spp. Score	0.437	0.785												
No. Sunfish Spp. Score	0.793	0.409												
No. Intolerant Spp. Score		0.490	0.463											
% Indiv. As Tolerant Spp. w/o ms Score														
% of Indiv. As Omnivore Score														
% Indiv. As Invertivore Score														
No. Fish/Seine Haul Score														
No. Fish/Min. E. Shock Score	-0.390													
Average Gear Score									0.747	0.838				
% Indiv. Non-Native Spp. Score							0.412	0.391						
% Indiv. With Disease & Anomaly Score														
Total IBI Score	0.590	0.655	0.553	0.672	0.498	0.368	0.448	0.391				0.465		

We also observed significant correlations between the various fish IBI metrics (Table 41). This indicates that many of these metrics measure some component of the same traits of the community (e.g. dominance, diversity etc). The benthic and fish IBI scores exhibited no significant correlation (Spearman's rank correlation $r_s = 0.121$, $p = 0.533$) (Figure 111). This suggests that each method provides supplementary information and cannot be used exclusively to rank the aquatic life use at a site. Benthic scores generated lower scores more often than higher or equal fish IBI scores.

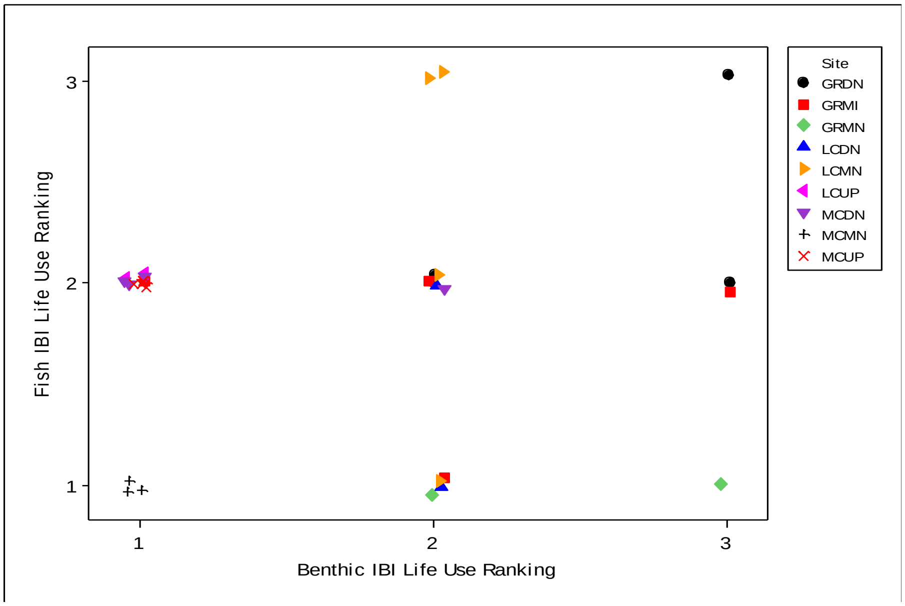


Figure 111. Plot of fish versus benthic aquatic life use rankings (1 = limited, 2 = intermediate, 3 = high, 4 = exceptional). Rank correlation results: $r_s = 0.121$, $p = 0.533$

Many of the fish community indices measured during this study were also significantly correlated with environmental variables (Table 42). For example, electrofishing catch rates were positively correlated with water temperature, specific conductance, chlorophyll-*a*, orthophosphates and percent pool coverage in the study reach. Electrofishing catch rates were also negatively correlated with percent shading, stream velocity, and percent runs in the study reach. Interestingly seine catch rates were not correlated with any environmental variable listed. The number of taxa in seine and electrofishing collections were both negatively correlated with chlorophyll-*a* and average stream width respectively. The Shannon Weiner Fish community diversity (*H'*) calculated from electrofishing collections was positively correlated with NO_{2+3}-N and negatively correlated with NH_4-N. In contrast, the Berger Parker dominance index (*d*) (a measure of dominance by a single species) was negatively correlated with NO_{2+3}-N but positively correlated with ammonia nitrogen. Stream shading was positively correlated with fish community evenness (*J'*) obtained from electrofishing and seine fish samples. Cumulative number of fish taxa collected by seines was positively correlated with large (higher sediment score) size. Cumulative number of fish taxa as calculated from both collection methods was negatively correlated with percent bottom covered by emergent vegetation, which may imply a reduction in gear efficiency.

Fish community metrics also exhibited significant correlations with some benthic community indices (Table 43). Strong negative correlations existed between fish community Evenness (*J'*) based on electrofishing collections and several benthic diversity metrics. This suggests fish communities dominated by a few species negatively influenced benthic community diversity.

Cluster analysis yielded 6 site cluster groupings based on the composition of fish taxa collected at each site by electrofishing (Figure 112). The MCMN period 1, MCUP period 1, and LCUP period 2 collections represented unique “singleton” groups. Cluster 4 consisted of GRMI, LCMN and GRDN collected primarily during various periods. Cluster 5 consisted primarily of two subgroups including Mason Creek collections and the second subgroup represented by a variety of sites and sampling periods. The final cluster 6 consisted mostly of sites sampled during period 1, with the exception of GRMI period 4.

Results of NMDS analyses further elucidated the similarity of sites based on similarity between sites (Figure 113). The NMDS ordination indicated that most sites were similar in species composition based on electrofishing data, with only MCUP period 1, MCDN period 1, and LCUP period 2 appearing to differ substantially from the other sites.

Table 42. Results of correlation analysis between various fish metrics and environmental variables. Only significant, p ≤ 0.05, r values reported. Cells with bold italic text are significant at the p ≤ 0.01 level.

	Total Number of Fish		Number of Taxa		Shannon Diversity H'		Pielou's Evenness		Berger Parker Dominance		Cumulative Number of Species		Total IBI
	Seine (per haul)	E. Shock (per min.)	Seine	E. Shock	Seine	E. Shock	Seine	E. Shock	Seine	E. Shock	Seine	E. Shock	Both Gears
Water Temp.		0.361											
pH						0.393					0.443	**0.512**	
Specific Cond.		***0.514***					***-0.553***	-0.405					
Diss. Oxygen							0.519	0.411					
Secchi Disk													
NTU													
Chlorophyll-a		***0.628***	-0.484								**-0.527**		
Ortho-P		0.440											
NO3&NO2									-0.468				
TSS							0.434						
Flow													-0.379
% Shading		-0.389											**0.538**
Sediment Size						***0.562***	***0.562***			***-0.628***	0.446	***0.514***	0.388
% Sub. Veg.													
% Emerg. Veg.						-0.472				***0.516***	**-0.608**	***-0.468***	
Thalweg Depth (m)													
Thalweg Velocity		-0.434											
Avg. Width (m)				-0.362									-0.379
% Pool		***0.528***						-0.399					
% Run		***-0.510***						0.421					
% Riffle													
Watershed (hectare)													
% Impervious												0.386	

Table 43. Significant ($p < 0.01$) correlations between fish and benthic community indices.

Fish Metric	Benthic Metric	Correlation	p-value
E. shock Cum. Taxa	Benthic Tot. No.	0.37	0.0475
E. shock *J'*	Benthic *d*	0.44	0.0259
E. shock *J'*	Benthic No. Taxa	-0.67	0.0002
E. shock *J'*	Benthic Cum. Taxa	-0.69	0.0001
E. shock *J'*	Benthic *H'*	-0.64	0.0004
E. shock No. Taxa	Benthic Tot. No.	0.38	0.0394
E. shock Tot. No.	Benthic *H'*	0.51	0.0049
E. shock Tot. No.	Benthic No. Taxa	0.55	0.0019
Seine No. Taxa	Benthic *J'*	-0.47	0.0168

Examination of site clusters identified by cluster analysis of electrofishing data revealed distinct patterns in selected community metrics (Figure 114). Most site clusters had very low levels of total number of fish and number of fish taxa with the exceptions of the cluster 4 grouping, which exhibited higher catch rates and highest species richness, the cluster 5 grouping, which had highest catch rates and lower species richness, and the cluster 6 grouping, which had very low catch rates and lower species richness.

Electrofishing collections overall were numerically and frequently dominated by four species including *Gambusia affinis*, *Lepomis megalotis*, *Cichlasoma cyanoguttatum*, and *Poecilia latipinna* (Figure 115). The Greens Bayou sites were frequently dominated by *Lepomis megalotis* and *Cichlasoma cyanoguttatum.* In contrast, the Little Cypress Creek sites had the most diverse collections, seldom being dominated by one or more fish species. Finally, the Mason Creek sites were primarily numerically dominated by *Gambusia affinis*.

Cluster analysis of seine collections yielded 4 site cluster groupings based on the composition of fish taxa (Figure 116). The MCUP period 1, and MCDN periods 4 and 2 collections represented unique “singleton” groups. In contrast, cluster 4 consisted of all remaining seine collections. The NMDS ordination indicated that most sites were similar in species composition based on seine collections (Figure 117). Only collections from MCDN periods 1, 2 and 4, and MCUP period 2 appeared to substantially differ in species composition. Examination of site clusters revealed distinct patterns in selected community metrics based on seine collections (Figure 118). Site clusters had very low levels of total number of fish and number of fish taxa with the exception of the cluster 4 grouping, which exhibited a wide range of catch rates and species richness.

Seine collections overall were numerically and frequently dominated by four species including *Gambusia affinis*, *Lucania goodei*, *Fundulus notatus*, and *Poecilia latipinna* (Figure 119). The Greens Bayou site complex collections were frequently dominated by *Gambusia affinis.* The Little Cypress Creek complex varied in composition with some collections being dominated by *Fundulus notatus*. Finally, the Mason Creek site complex collections either yielded no catch or were dominated by *Gambusia affinis*, and/or *Lucania goodei* and *Poecilia latipinna*.

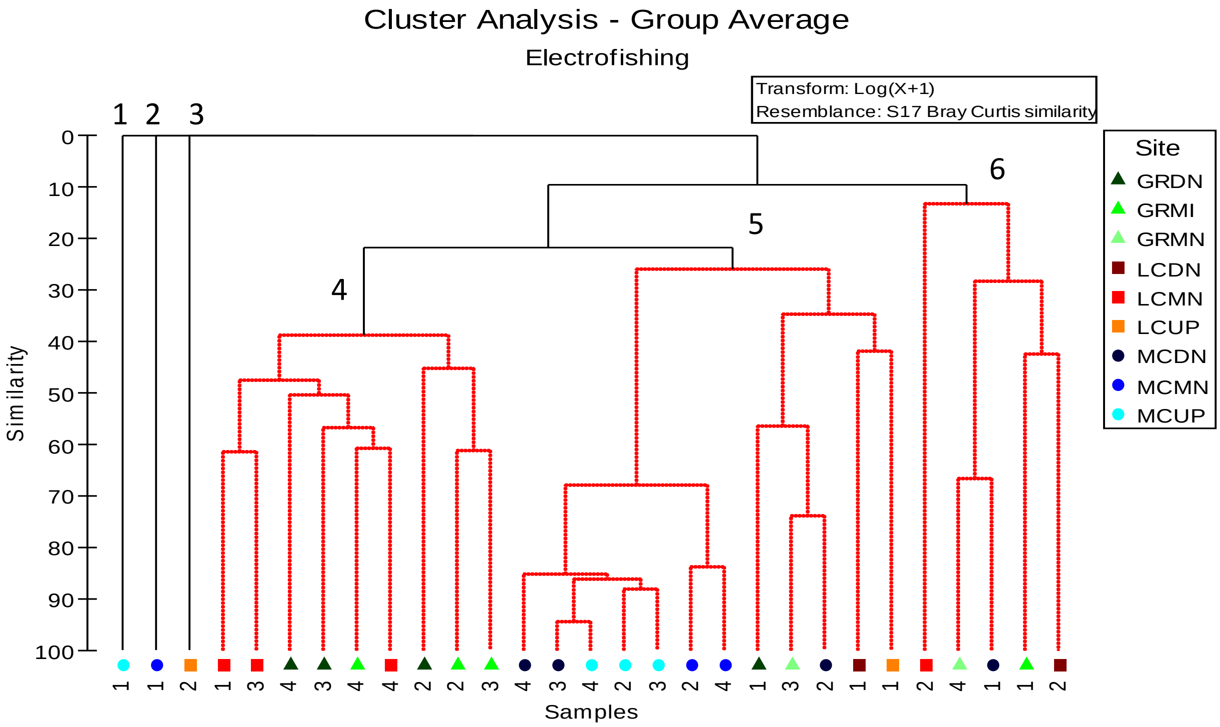


Figure 112. Cluster analysis of collections based on similarity of fish community data collected during electrofishing. Conducted using Bray Curtis Similarity index and log (X+1) transformed data in PRIMER v. 6. Groups determined using the SIMPROF test. Collections connected by a red line are not significantly different in community structure. Numbers on dendrogram axis denote sampling period (1, 2 = 2010; 3, 4 = 2011). Numbers above dendrogram refer to cluster groupings.

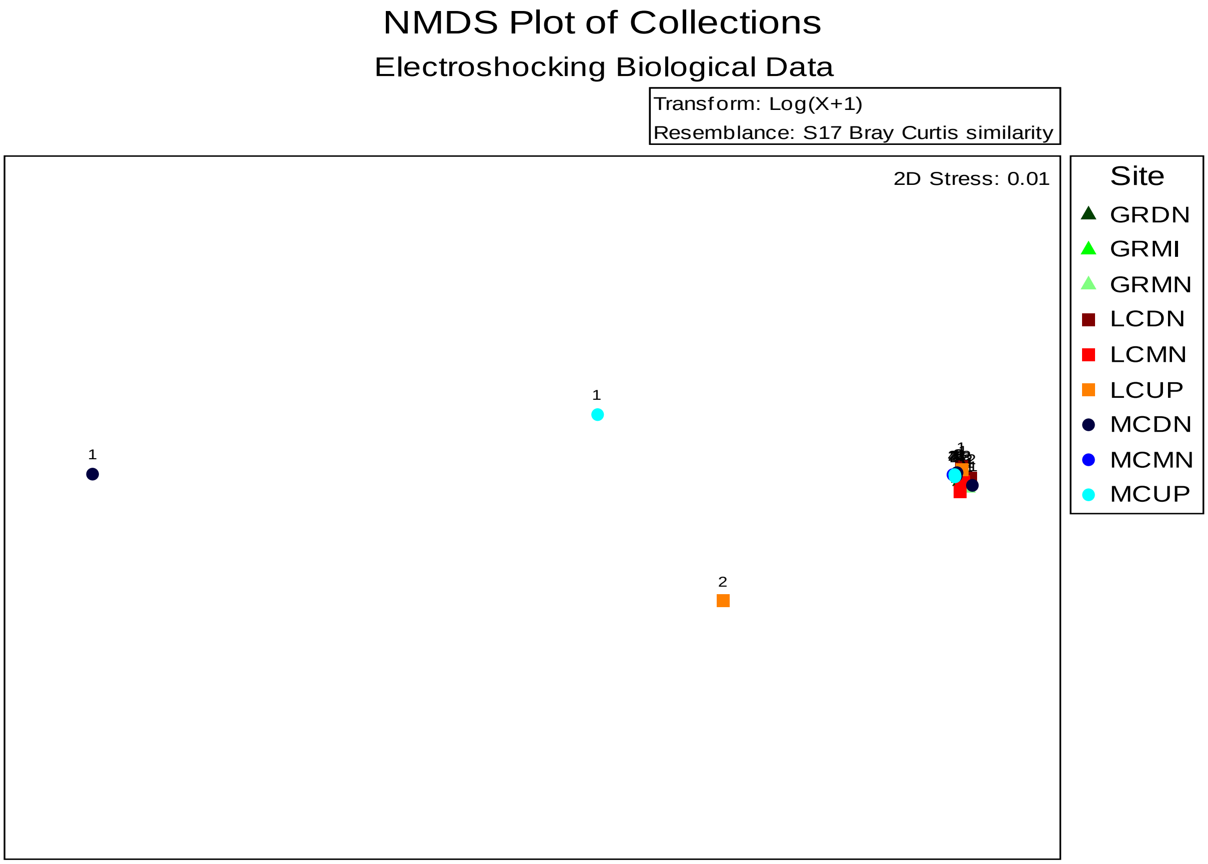


Figure 113. Results of NMDS classification of fish communities collected during electrofishing. Conducted using PRIMER v. 6. Numbers denote sampling period (1, 2 = 2010; 3, 4 = 2011).

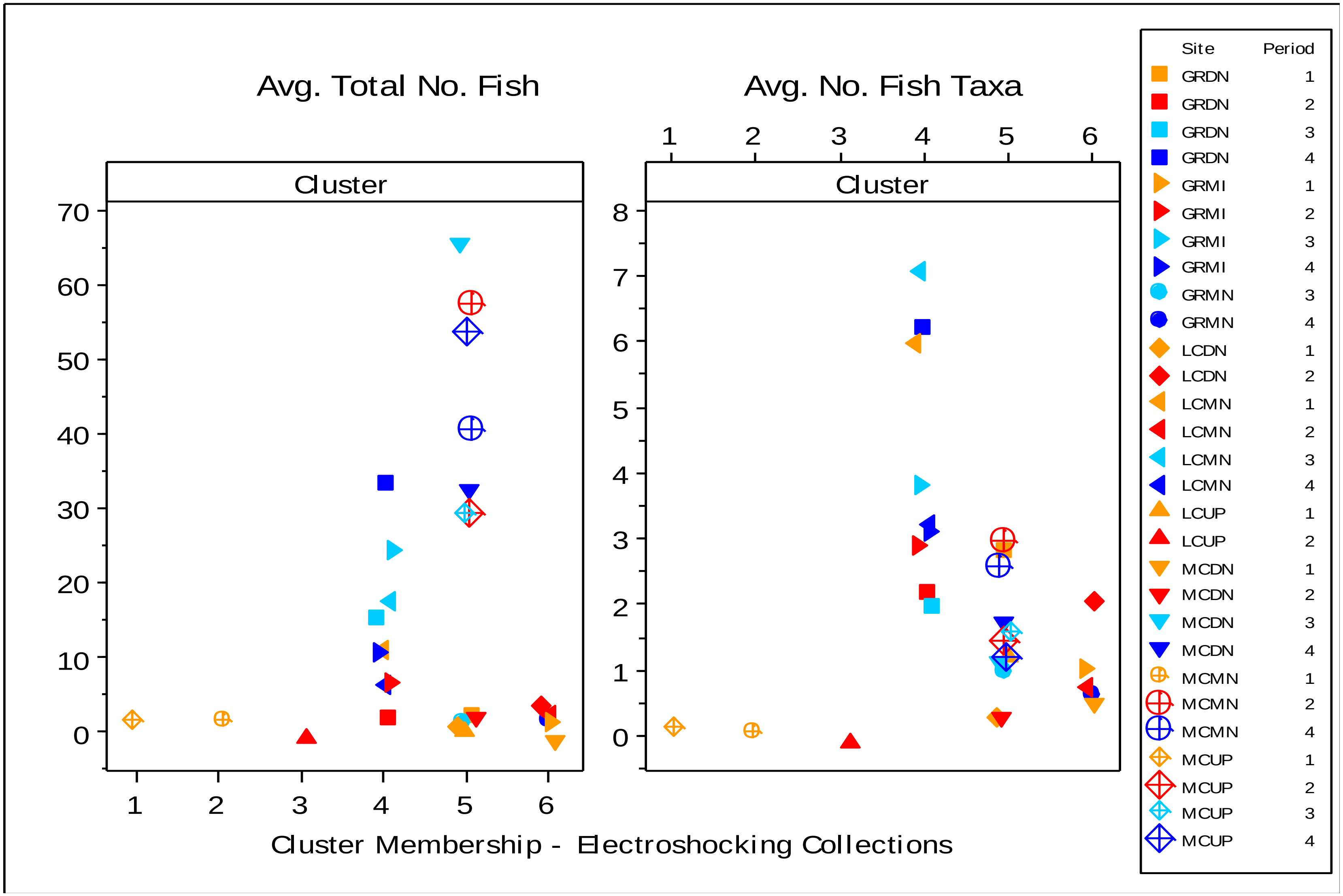


Figure 114. Average total number of fish and number of taxa collected during electrofishing collections classified by cluster analysis membership.

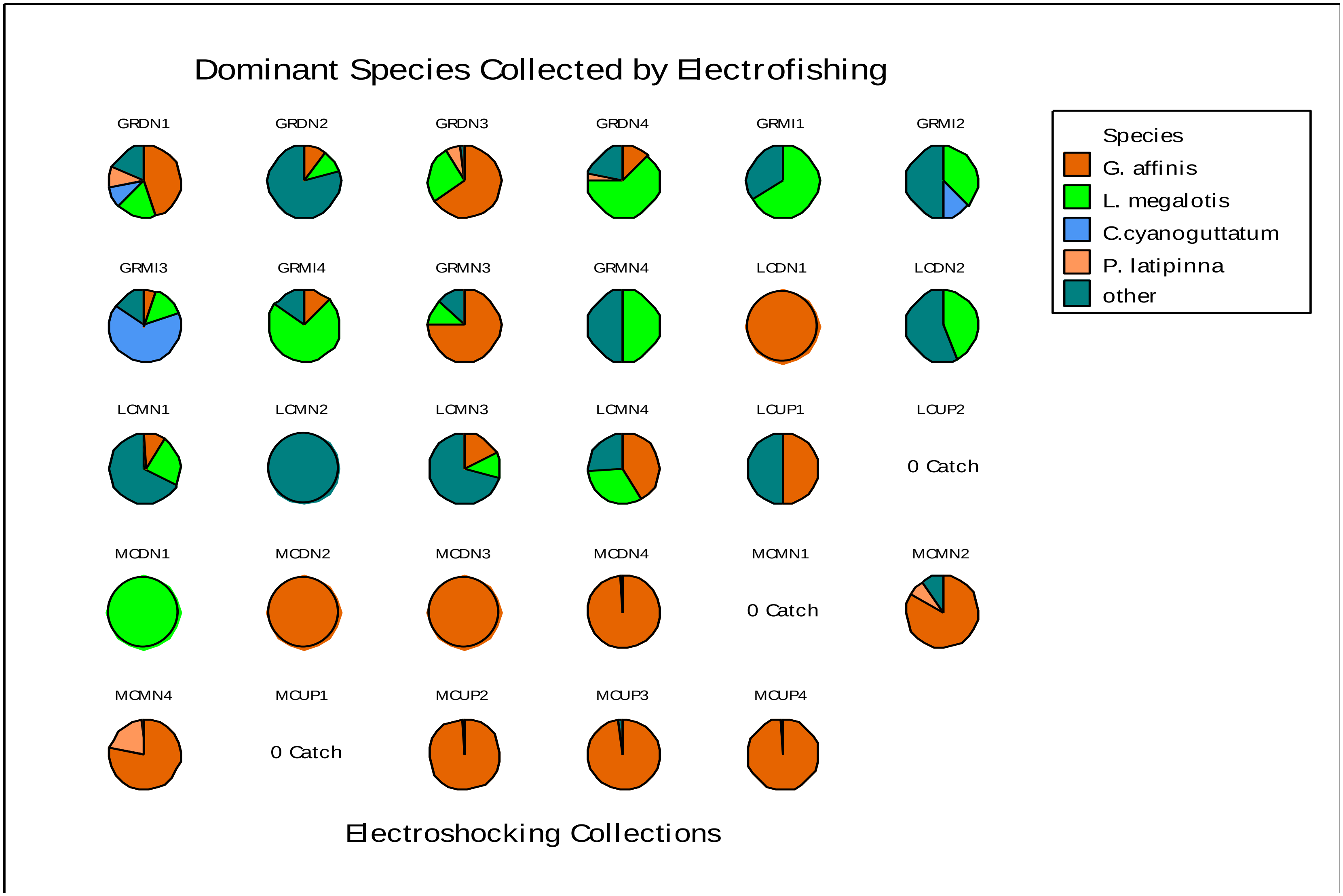


Figure 115. Dominant fish taxa and composition collected during each period at each site. Numbers refer to collection periods. 1, 2 = 2010; 3, 4 = 2011. Only taxa compromising greater than 5% of the catch are reported.

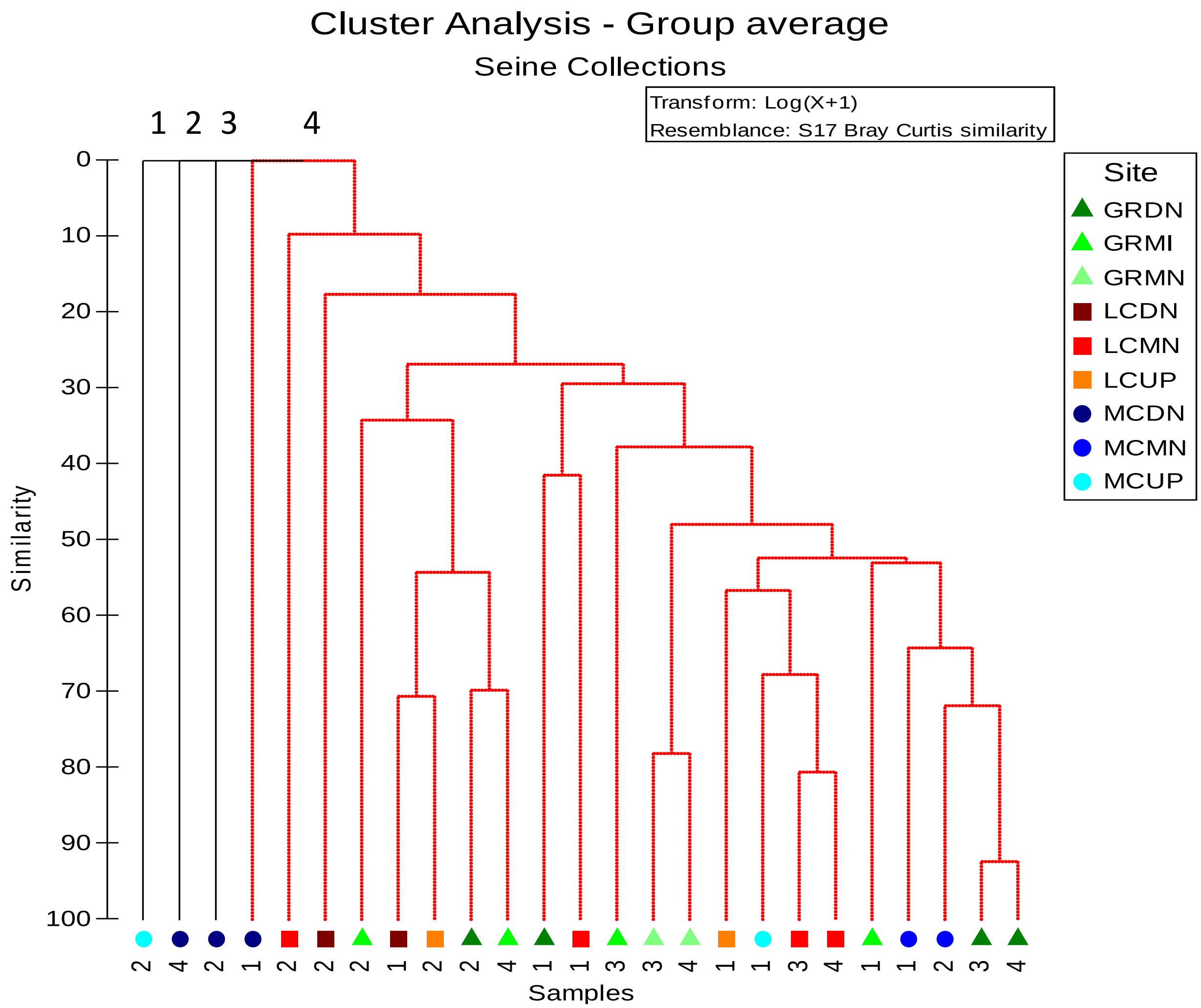


Figure 116. Cluster analysis of collections based on similarity of fish community data collected during seine collections. Conducted using Bray Curtis Similarity index and log (X+1) transformed data in PRIMER v. 6. Groups determined using the SIMPROF test. Collections connected by a red line are not significantly different in community structure. Numbers on dendrogram axis denote sampling period (1, 2 = 2010; 3, 4 = 2011). Numbers above dendrogram refer to cluster groupings.

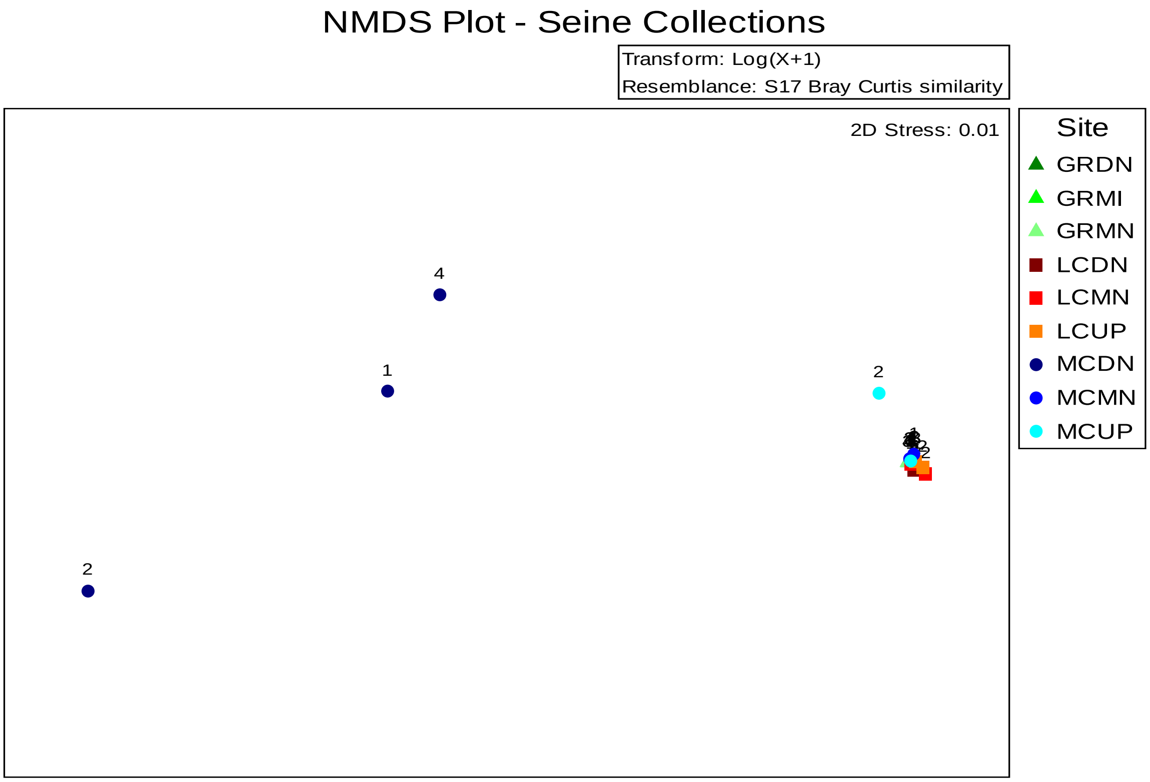


Figure 117. Results of NMDS classification based on fish community data collected during seine collection efforts. Conducted using PRIMER v. 6. Numbers denote sampling period (1, 2 = 2010; 3, 4 = 2011).

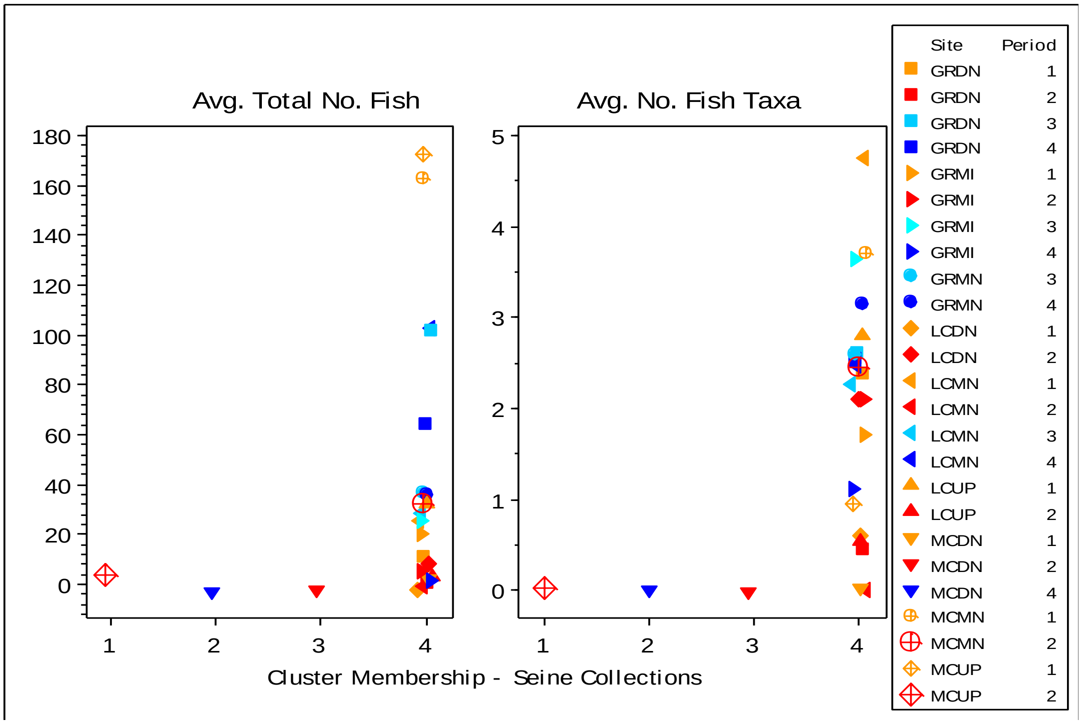


Figure 118. Average total number of fish and number of taxa collected during seine collections classified by cluster analysis membership.

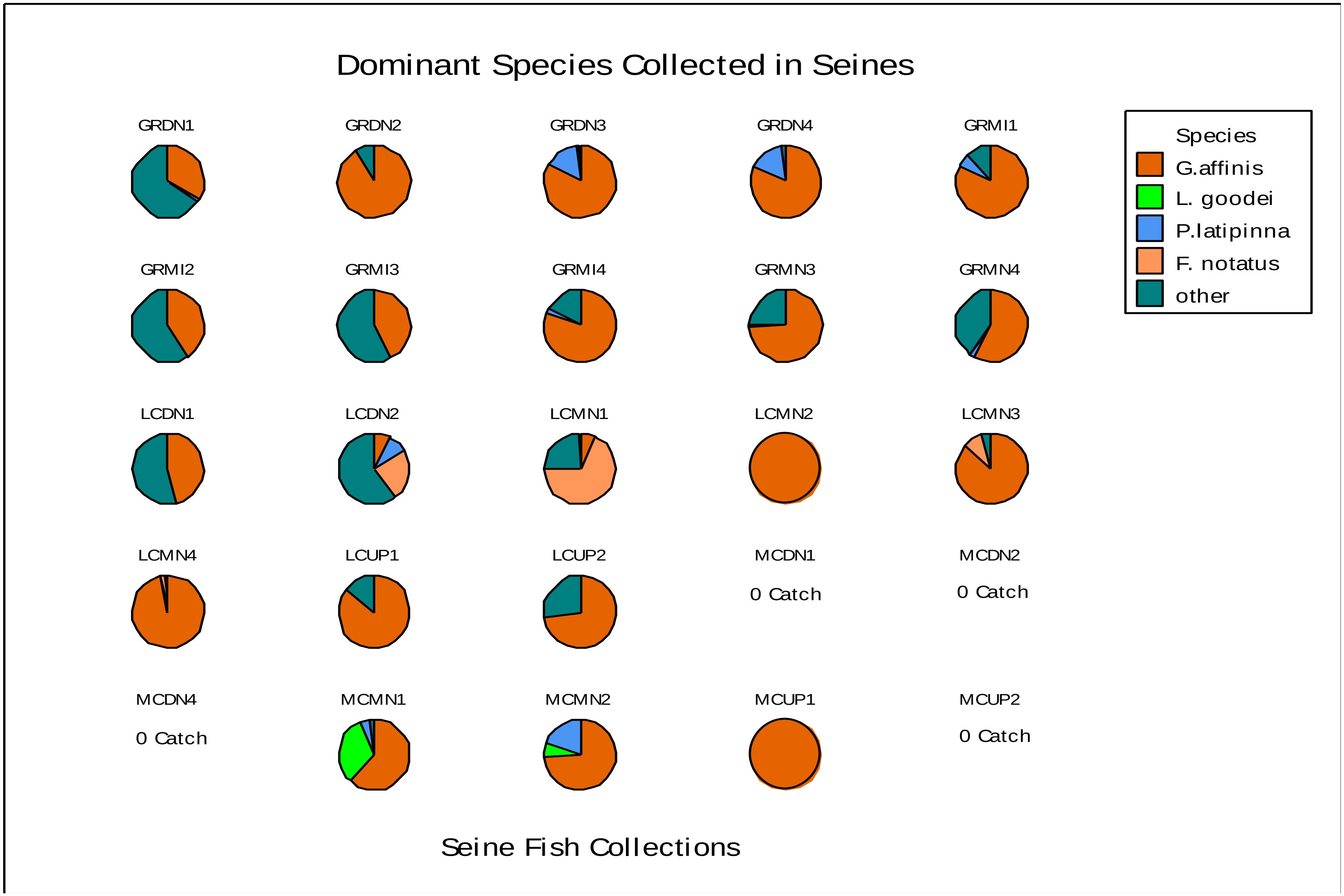


Figure 119. Dominant fish taxa and composition collected during each period at each site. Numbers refer to collection periods. 1, 2 = 2010; 3, 4 = 2011. Only taxa compromising greater than 5% of the catch are reported.

Conclusions and Recommendations

This report documents the first comprehensive study of the stream biota, water quality and macrohabitat associated with three existing and future restoration sites including the Little Cypress Creek (L100-00-00), Mason Creek (T101-01-00), and Greens Bayou (P138-00-00) sites. The site with the lowest aquatic life use designation based on both benthic invertebrates and fish during each collection was the Mason Creek Mainstem site. The Little Cypress Creek Mainstem site generally had intermediate and high aquatic life use designations. The Greens Bayou mainstem site exhibited low aquatic life use based on fish community data, and intermediate to high aquatic life use based on benthic invertebrates. In addition, the Greens Bayou mainstem sites seldom exceeded the aquatic life use designations at the associated tributary sites. Based on these limited data the greatest expected increase in aquatic life use after future management efforts would likely occur at the Little Cypress Creek sites. Improvement at the tributaries on the Greens Bayou site may be limited by the “seed” stock of organisms found in the mainstem channel.

The Mason Creek sites were unique in that they were existing sites that were constructed upstream of and drain into a created wetland pond. Therefore, the aquatic life use at these sites may be limited by flow regime due to their location higher in the watershed and limited drainage area. Furthermore, the downstream mainstem site possessed limited habitat value and streamflow. At the time of the 2010 survey, the MCUP site had also been impacted by construction of an illegal dam that backed up water and created lentic type pond habitat. This stagnant pond provided ideal habitat for many “stress tolerant” invertebrates which thrive best in depositional areas. Also, the lack of sufficient flows and partial barriers to movement may have resulted in reduced recruitment of fish. The barrier was removed in February 2011. However, during 2011 monitoring drought conditions were present, confounding any possible comparison between years associated with removal of the dam. Seining was not possible during 2011 due to lack of sufficient water and thick vegetation. Based on electrofishing data alone, there did not appear to be a major difference at MCUP in species composition or community metrics between years and the adjacent non-impounded downstream site (MCDN). Aquatic life use, based on benthic aquatic surveys, was consistently designated as “limited” for MCUP, even after removal of the dam. The downstream (MCDN) and mainstem (MCMN) sites had either limited (most frequently) or intermediate aquatic life use designations.

The majority of restoration sites exhibited relatively low stream velocity and flows, low periphyton production, and lacked significant riffle habitat. In some oxygen levels were also depressed (< 4 mg/l). The combination of these factors and their correlation with various aquatic community metrics can result in limited carrying capacity for benthic and fish communities due to insufficient flows for aeration and resulting settling of fine silts and clays. The control sites did in general have higher flows and dissolved oxygen levels. This was most noticeable at the Little Cypress Creek upstream in comparison to the mainstem site in 2010. However, these local control sites have in most cases been channelized, which has resulted in reduced amounts of stream meanders, riparian buffer zones (shading and plant detritus input), instream vegetation used by organisms as food and cover, and deposition of fine silts due to altered flow regime and the loss of riffle habitat.

Based on the results of our study of the proposed HCFCD restoration sites, it appears that each of the restoration sites have limited to intermediate quality aquatic communities. The benthic and fish communities are both dominated by stress tolerant species. The level of stress causing this effect is due to various physical and water quality traits observed in many highly modified urban streams including:

- Past channelization which cut off meanders
- Reduced or eliminated connectivity with the watershed
- Altered flow regime
- Reduced reaeration
- Concurrent losses or reduction in the diversity of various types of macrohabitat needed by aquatic organisms.

As the Harris County Flood Control District improves these streams through active restoration it will be interesting to see how the stream aquatic communities respond to increase connectivity with adjacent waterbodies and possible increased flows. We highly recommend that future validation monitoring be conducted at each of the future restoration sites for a period of several years post restoration implementation to evaluate the response of the stream in terms of geomorphology, hydrology, water chemistry and aquatic communities. This will provide enough data, over a range of possible precipitation and hydrological regimes, to evaluate with sufficient confidence whether the reconnected stream segment has recovered many of the structural and functional components that support aquatic life.

The extent of recovery at the reconnected and restored stream segments will be limited to the attainable levels of aquatic resources within the watershed, hence the need to monitor control sites within the stream system. Based on our data, the mainstem site of Little Cypress Creek has the highest aquatic life use and therefore reconnection of the LCUP and LCDN sites should lead to better improvement than the Greens Bayou sites.

Another issue that may influence ultimate attainment of restoration goals is the presence of invasive species. During this study we encountered several invasive fish species, one of which had been seldom encountered in Texas. Highly urban areas in general are at higher risks of exposure to invasive species due the greater likelihood of release of aquarium and aquaculture specimens. Both the Greens Bayou and to a lesser extent the Mason Creek sites are at risk of invasion of introduced exotic species. The Mason Creek site which is fairly isolated had one species of native exotic fish. The only other documented introduction of this species, *Lucania goodei*, was associated with wetland restoration project in the Guadalupe River. We propose to conduct follow up studies in Mason Creek to determine whether this population will establish itself and or expand its range.

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APPENDIX 1: CALIBRATION DATA

Electronic Supplement

APPENDIX 2: FIELD AND LAB DATA

Electronic Supplement

APPENDIX 3: PHOTOGRAPHIC RECORD

Electronic Supplement

APPENDIX 4: GOOGLE EARTH INTERACTIVE MAP

Electronic Supplement