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Short and Long-term Changes in the Fish Assemblages of Bayou Lacombe, Louisiana

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Short and Long-term Changes in the Fish Assemblages of Bayou Lacombe, Louisiana.

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in
Biological Sciences

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Jeffrey M. Van Vrancken.

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Dedication

I dedicate this manuscript to my fiancée, Jennifer Lanier, for her support and encouragement throughout the highs and lows of my graduate career and life in general. Thank you for listening and your unconditional love.

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Abstract

Over the past thirty-five years, anthropogenic disturbances around Bayou Lacombe have altered its fish assemblage. In 2005, the impact of Hurricane Katrina on southeast Louisiana presented me with a unique opportunity to explore the effects of a catastrophic storm on the Bayou. I explored the effects of natural and human disturbances on the Bayou's fish assemblage by electrofishing six historically sampled stations. My research goals were to determine: 1) which Bayou Lacombe fish assemblages were most resilient to the multiple effects of Hurricane Katrina, 2) if there were significant differences in the Bayou's fish assemblages over the past 35 years based on historical fish assemblage data, and 3) what are the drivers of fish assemblage change in Bayou Lacombe. I found significant differences in upstream fish assemblages before and after Hurricane Katrina in the Bayou. I also documented the disappearance of nearly all cyprinid species over the past 35 years.

Keywords: fish assemblage, Hurricane Katrina, disturbance, Bayou Lacombe, cyprinid

Introduction

Fish assemblage assessments produce important information about the overall health and stability of aquatic ecosystems while providing information about fish populations and their diversity (Araujo et al., 2000; Matthews et al., 1988). In stream systems, stability and ecological persistence of species over time are indicators of overall habitat integrity (Connell and Sousa, 1983). Although comprehensive ecological information about most stream fish assemblages is lacking, it is important to document the persistence and stability of these assemblages in order to understand the structures and functions of the system as a whole (Meffe and Berra, 1988). By comparing fish species richness, diversity, and overall species composition over spatial and temporal scales, it is possible to determine differences in fish assemblage structure and, in turn, the relative health of the aquatic ecosystems they inhabit (Madejczk et al., 1997; O'Connell et al., 2006).

There are several anthropogenic factors that can affect distributions and abundances of fishes in a given environment. Agricultural runoff, pollution, vegetation removal, vegetation change (which can lead to sedimentation), industrial disposal, channelization, and inefficient home septic systems are just some of the anthropogenic effects that can impact stream and river ecosystems (Grover and Harrington, 1966; Morisawa, 1985; Madejczyk et al., 1997). A primary focus of aquatic ecology is to understand how these drastic environmental changes alter fish assemblages (Matthews, 1998). For example, in the White River, AR, fish assemblage structure changed after the river was impounded (Quinn and Kwak, 2003). Likewise, clear cutting forests that surround a watershed may produce an effect similar to that of stream channelization, where flood volumes and total runoff are increased with shorter flood duration (Grover and Harrington, 1966; Morisawa 1985; Gordon et al., 1992). Populations of smallmouth bass (*Micropterus* *dolomieu*) in the Kankakee River, IN, drastically decreased due to an increased flow regime in 1990 that disrupted reproduction and feeding patterns (Peterson and Kwak, 1999). Deforestation of riparian zones may also lead to unstable stream banks, sedimentation, and the alteration of light and thermal regimes that further impact fish assemblages (Jones et al., 1999). When the surrounding environment is modified, changes can be expected in populations and the community dynamics of local aquatic biota (Schlosser, 1991; Lenat and Crawford, 1994; Wiley et al., 1997). Although large-scale processes in riverine systems are difficult to study empirically, knowledge of their influence is critical for developing effective management strategies (Peterson and Kwak, 1999).

Natural disturbances, such as droughts, floods, and violent storms may also alter fish assemblage structure, specifically large infrequent disturbances such as hurricanes. Cyclonic storms are thought to play as great a role in shaping a community's structure as do biological interactions such as competition and predation, which generally receive much more attention (Sousa, 1984; Resh et al., 1988; Poff and Ward, 1989). Disturbances should be defined by the nature of their damaging properties, especially the intensity and forms of their forces, along with predictability, frequency, spatial extent, and temporal duration (Lake, 2000). Unfortunately, predicting just when or where a large natural disturbance will occur is rarely possible and usually the collection of preliminary data is challenging. In coastal regions, which are prone to both anthropogenic (e.g., coastal development) and natural impacts (e.g., hurricanes), a worthwhile analytical approach to track the environmental health of aquatic ecosystems is to regularly assess fish assemblages through field surveys. Should the ecosystem be impacted, then adequate "pre-impact" data would be available for comparison as baseline information.

One such coastal aquatic ecosystem is the Lake Pontchartrain Basin in southeastern Louisiana. The estuarine and freshwater portions of this ecosystem have experienced numerous anthropogenic and natural impacts over the last century (O'Connell et al., 2004). The center of this ecosystem is Lake Pontchartrain itself, which has an average depth of 3.7 m and covers an area of about 1630 sq. km (Sikora and Kjerfve, 1985). Lake Pontchartrain is an oligohaline estuary with salinities ranging from 4 to 8 ppt year round and exhibits a microtidal environment. The salinity of Lake Pontchartrain is influenced by three connections to the Gulf of Mexico, two natural and one artificial. The original, natural connections to the marine waters are through the Rigolets Pass and Chef Menteur Pass from Lake Borgne. These tidal passes connect the eastern portions of Lake Pontchartrain to Lake Borgne which then connects to the Gulf of Mexico. The other source of marine waters is the Mississippi River Gulf Outlet (MRGO), an artificial ship channel located in the southeastern portion of Lake Pontchartrain. This artificial connection has exacerbated environmental problems already associated with this estuary (O'Connell et al., 2006). Lake Pontchartrain is an environmentally degraded system due to severe overfishing, increased runoff, shoreline alteration, industrial discharge, artificial saltwater and freshwater inputs, and past shell dredging (Francis and Poirrier, 1999; Penland et al., 2002; O'Connell et al., 2004). The primary sources of pollution to the estuary are the result of increased urban development and loss of wetland habitat. Adding to the problem is the fact that the rivers on the northshore of Lake Pontchartrain are tidally influenced. When there is a period of high water flow, tidal input may completely stop downstream movement of freshwater resulting in stagnation and complicating local pollution issues. Also, as the northshore of Lake Pontchartrain becomes more developed, the land that once supported a wetland "buffer" environment is rapidly decreasing and the current water quality problems will continue to increase. Development along the watersheds that feed directly into the Lake is primarily responsible for the pollution problems. Consequently, covering up a floodplain area with concrete eliminates the surrounding area's ability to filter out harmful pollutants. Therefore the health of the streams and rivers that flow into Lake Pontchartrain is linked to the overall condition of the entire ecosystem.

Bayou Lacombe is a small (46.1 km), slow-moving stream in St. Tammany Parish that flows south into Lake Pontchartrain (Figure 1). The riparian zones of Bayou Lacombe's headwaters have been affected by clear-cutting of pine and mixed hardwood forests, while the mouth of the Bayou is somewhat less disturbed, as a result of being within the protected boundaries of the Big Branch Marsh National Wildlife Refuge. Bayou Lacombe has been the subject of several studies starting in the 1950's to the present time. It has attracted such studies because it is a relatively simple first order stream that has endured major anthropogenic changes. Bick et al. (1953) were the first investigators to publish general observations about the fish fauna, invertebrates, and physiochemical characters of Bayou Lacombe. Bick et al. (1953) reported that during their study, upstream portions of Bayou Lacombe were dredged to facilitate drainage. Geagan (1959, 1963) was the first to report that although the physio-chemical properties of the Bayou were still distorted, the fishes that were briefly reported in Bick et al. (1953) were not severely affected by the dredging. His own research showed that the Bayou's fish assemblages could recover from an anthropogenic disturbance (Geagan, 1959, 1963). A few of the most notable experimental studies of resilience in select freshwater fishes were conducted in areas of Bayou Lacombe (Gunning and Berra, 1968, 1969; Berra, 1969; Berra and Gunning, 1970). Berra and Gunning (1970) showed that experimentally decimated areas of longear sunfish (*Lepomis megalotis*) and sharpfin chubsuckers (*Erimyzon tenuis*) were capable of repopulating an area within one year of removal, often with greater abundances. In the early

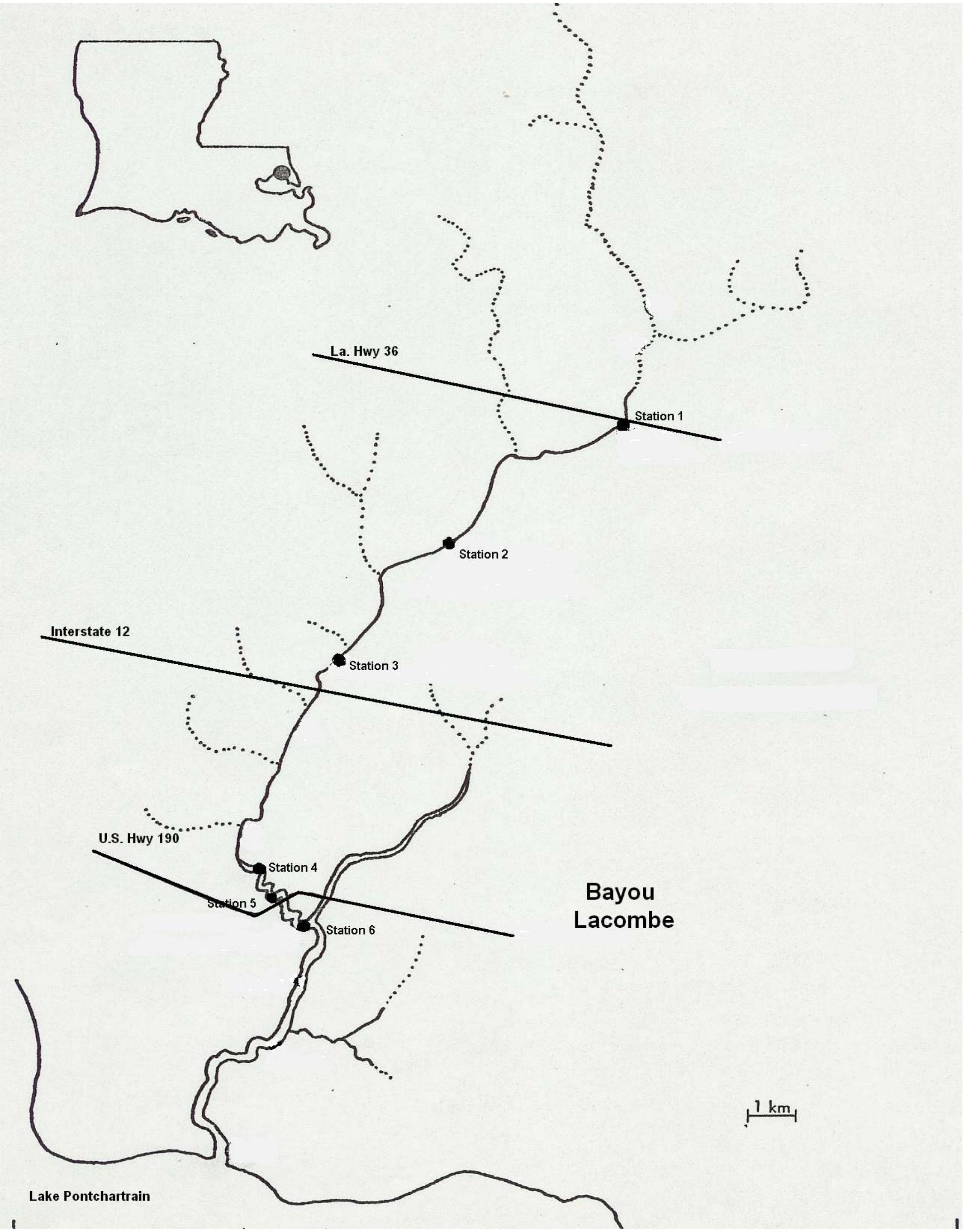

Figure 1: Map of Bayou Lacombe in St. Tammany Parish, Louisiana. Sampling stations used in the current survey are shown [Modified from Farabee (1992)].

seventies, Sobczak (1976) revisited this area and conducted his dissertation research on the physio-chemical properties that affect fish distribution in the Bayou. His exhaustive fish survey has been essential to understanding how Bayou Lacombe's fish assemblage has been changing over the past thirty-five years. Farabee (1992) also sampled this area during the late 1980's while conducting research for his master's thesis. He was the first investigator to report the extirpation of the blacktail shiner (*Cyprinella venusta*), once the most common cyprinid in the Bayou, had apparently become extirpated. His fish collections are also important because they provide a mid-point between Sobczak's thorough survey and the extensive present survey.

On August 29, 2006, Hurricane Katrina made landfall on southeastern Louisiana and the surrounding Gulf Coast areas (Figure 2). The western part of the eye, with winds in excess of 150 mph, passed directly over Bayou Lacombe. At the time of this storm, I was in the process of surveying the Bayou to assess long-term fish assemblage changes. The hurricane, although catastrophic to the human populations of southeast Louisiana and the Mississippi Gulf Coast, presented a unique opportunity to conduct a natural experiment. Specifically, I was interested in determining the resilience of stream fish assemblages to the 4.88 m (16 foot) saltwater storm surge that entered Lake Pontchartrain and impacted its freshwater tributaries (Figure 3). The storm surge backed up Bayou Lacombe and caused it to overflow into surrounding areas inundating natural floodplains and properties in reclaimed floodplains. Persistence of fish fauna after a major flooding event has been well documented (Harrell, 1978; Matthews, 1986; Fausch and Bramblett, 1991). Unlike these studies of freshwater flooding disturbances, there are little or no data available on the effects of a hurricane-induced saltwater storm surge on a freshwater stream environment. In addition to the storm surge, high winds caused trees to fall into the headwater portions of the Bayou while downstream healthy marshes were destroyed from

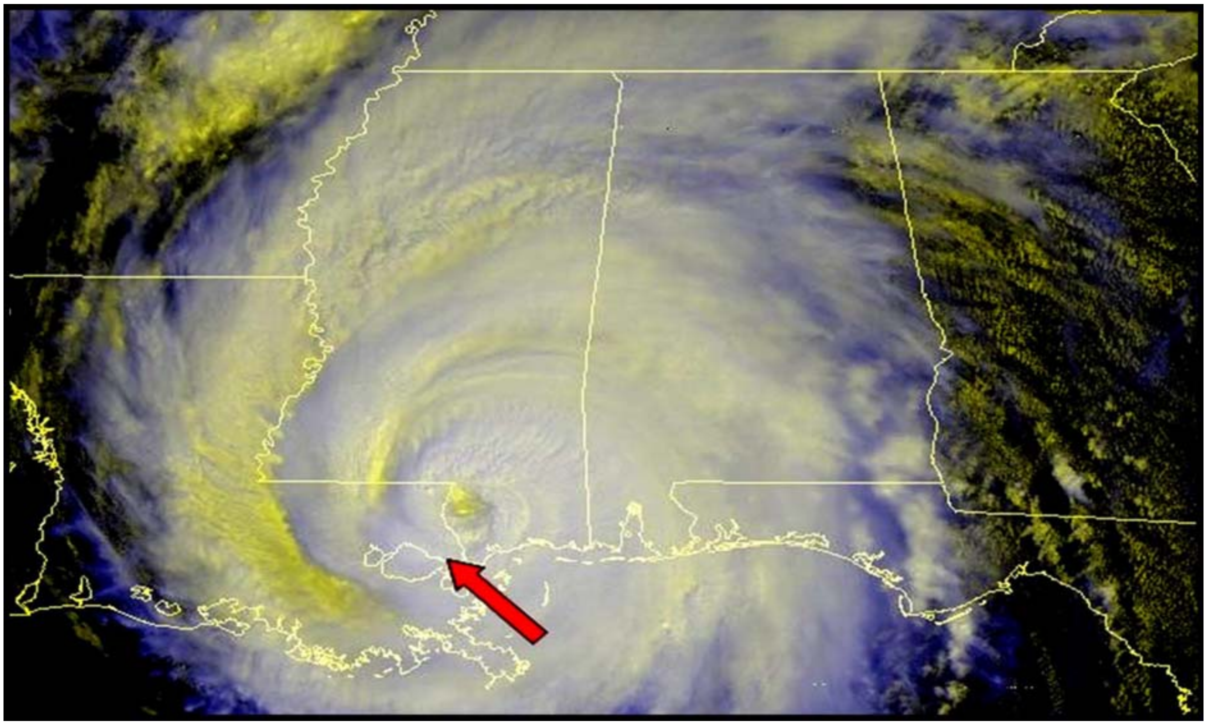

Figure 2: Hurricane Katrina's landfall on southeast Louisiana and the Gulf Coast. The arrow indicates the location of Bayou Lacombe as the western eye-wall of the storm passed over.

Figure 3: Hurricane Katrina's storm surge inundation on the northshore of Lake Pontchartrain. The contour lines represent the height of the storm surge in feet.

immense wave action. When the storm surge retreated from the northshore area of Lake Pontchartrain, there were many species of saltwater and freshwater fishes littering streets, yards, and homes. My interest was to determine if the local fish assemblages were resilient to this disturbance and if their numbers and the species compositions of their assemblages were significantly impacted, especially compared to available historical data.

The goal of the current investigation was to conduct a comprehensive assessment of the fish assemblage of Bayou Lacombe and compare the relative influence of both natural and anthropogenic impacts over short and long-term periods. I investigated fish assemblages along the entire reach of the Bayou, choosing six stations that corresponded with historical collections such that long-term comparisons in species composition could be conducted. By focusing on fish assemblages at each of these six stations, I planned to test for differences within stations over time and among stations to test the relative resilience of different assemblages. While the storm affected the entire system, saltwater inundation only occurred in the downstream portions of the Bayou while significant physical habitat alteration (i.e., tree fall damage from high winds) only occurred in upstream areas. In light of these differences, I specifically asked:

1. Which Bayou Lacombe fish assemblages were most resilient to the multiple impacts associated with Hurricane Katrina?

2. Based on comparisons with historical data from the last 35 years, were there significant changes in any Bayou Lacombe fish assemblages due to either natural or anthropogenic stressors such as hurricanes and stream modifications? And

3. If there are significant differences among fish assemblages over space and time, which particular fish species or environmental factors are associated with the differences?

Materials and Methods

For the current study, I targeted shoreline fish assemblages for my analyses. The majority of riverine fishes inhabit shallow, shoreline areas because there is usually more refugia located there (Schlosser, 1985, 1987; Bain et al., 1988; Copp, 1989; Lobb and Orth, 1991). Also, it is difficult to accurately quantify deep, main-channel fish assemblages due to the relative inaccessibility of these habitats (Mahon, 1980; Mann and Penczak, 1984). Samples taken during the current survey were collected by boat and backpack electrofishing techniques, unlike the seine sampling by Sobczak (1976) and Farabee (1992). The fish assemblage samples are likely representative of their respective periods because sampling for all three studies was conducted along shoreline habitats. My choice of electrofishing as a collection method was based on its effectiveness. It is considered the single most comprehensive and effective type of sampling fishes in riverine and stream habitats (Vincent, 1971; Novotny and Priegel, 1974; Davis et al., 1996; Barbour et al., 1999; Simon and Sanders, 1999; Allen-Gil, 2000). Although electrofishing targets certain fish species more effectively than others (i.e., larger fish provide a larger contact area for electrical current than smaller species), it proved to be the best method of sampling during post-Katrina samples since the Bayou was littered with fallen trees following the storm. The debris would have made effective seining impossible. Electrofishing was conducted in all samples pre/post-Hurricane Katrina and sampling effort remained constant. The assessment of fish assemblages among the three surveys is comparable. However, when comparing samples taken during the current study with those samples from past studies, there are possible biases associated with using different collection methods.

During the current survey, the upper reaches of Bayou Lacombe (i.e., Stations 1-3) were electrofished using a Smith-Root backpack DC electrofisher. All three sampling stations coincided with historical stations sampled by Sobczak (1976) and Farabee (1992). Electrofish sampling proceeded under the bridge at the station and continued upstream so that downstream flow reduced problems with netting visibility. Electrofishing at each station lasted 45 minutes during which all habitats, including riffles, runs and pools were sampled. Water quality parameters (temperature, salinity, specific conductance, percent saturation and dissolved oxygen) were also taken at the end of each collection using a Yellow Springs Instruments model 85 meter. Specimens of large species were identified in the field and released. Small, more abundant species were put on ice or fixed in 10% buffered formalin and returned to the laboratory for processing. Processing included identifying each specimen to species, counting the number of specimens per species, calculating the total weight of each species, and measuring a standard length range.

Fishes at the three downstream sampling stations (i.e., Stations 4-6) were collected with a Coeffelt model DC electrofisher by boat. Stations 4 and 6 coincided with downstream historical stations sampled by Sobczak (1976) and Farabee (1992). So that the electrofishing collections could be standardized, a two-hundred meter reach was established (with length determined by a GPS unit) and electrofished using a single-pass technique. All structures within the reach (fallen trees, marsh balls, fishing docks, etc.) were targeted for sampling and these non-linear efforts were included in calculating the total distance sampled. After a reach had been sampled, electrofishing was continued on the opposite side of the channel with the identical approach. Finally after that reach was sampled, a single-pass of the electroshock boat was conducted directly down the middle of the channel to collect any open water species that may have not been caught along the banks. Therefore, an individual sample consisted of three electrofishing passes: one along each of two banks and a single pass through the mid-channel. Total distances electrofished were recorded and averaged about 800-1000 total meters per sample. Flotemersch (2004) found that daytime electrofishing distances of 800 m in non-wadeable streams less than 4 m deep were sufficient enough to characterize local fish assemblages. GPS start and stop positions were taken at each station using a Garmin GPS-Map76C. Stream widths were measured using a one hundred meter measuring tape and stream depth was measured using a weighted graduated rope. Sampling procedures for the current study were repeated after Hurricane Katrina and after the debris were removed from the upstream portions of the Bayou.

Station Descriptions

To accurately assess historical assemblage changes over time in each of the regions of Bayou Lacombe, I chose six sampling stations that were common to both Sobczak’s (1976) and Farabee’s (1992) surveys. Herein I will refer to these efforts as Sobczak’s study and Farabee’s study, respectively. Sobczak’s study in the early 1970’s sampled ten stations. The northern-most three (his Stations 1, 2, and 3) were not accessible for Farabee and myself during our respective surveys. Therefore, the northern-most station common to all three studies was Highway 36 (Station 1; Figure 1). Downstream, the area near Highway 434 is the next station common to all three studies (Station 2; Figure 1). Further downstream is the Krentel Road area (Station 3; Figure 1) and it is the southern-most upstream station common to all studies. During the 1970’s, Sobczak established a station at the Interstate 12 overpass (his Station 7). This was not easily accessible for Farabee or myself either, so it was not sampled for the current survey. Sobczak’s next station (his Station 8) was in Bayou Lacombe adjacent to the Louisiana Department of Wildlife and Fisheries fish hatchery. This station was not accessible to Farabee but was accessible in the current study via electrofishing boat and is the northern-most of the downstream stations (Station 4; Figure 1). I established Station 5 (Figure 1) for the current study so that three upstream stations could be compared to three downstream stations. It was not sampled in either Sobczak’s or Farabee’s study. Finally, the area near the Main Street boat launch (Station 6; Figure 1) is common to all three studies and is the southern-most downstream station. Sobczak and Farabee also collected data from a common station at the mouth of Bayou Lacombe where it enters with Lake Pontchartrain. This station was not sampled in the current study because the conductivity of the Lake was too high (due to high salinity) to attempt monthly electrofishing samples.

Station 1: GPS Location (30 25.281’, 89 51.465’) Highway 36 Bridge located in northern Lacombe, Louisiana [stream width: 4.5m, stream depth: 0.3m to 1m]

This is the northern-most upstream sampling station common to all three fish surveys. In the 1973-1975 survey, Sobczak sampled here monthly for a period of 24 months. Farabee also sampled monthly for a period of 12 months from 1988-1989. During the current fish assemblage survey, monthly sampling started in June 2005 until Hurricane Katrina interrupted sampling in late August 2005 (n = 3). Monthly sampling continued again following the storm from June 2006 to September 2006 (n = 4). Samples were also conducted from October 2006 to May 2007 after the debris was removed from the Bayou (n = 6). Samples could not be taken in January and May 2007 due to dangerously high waters resulting from extended periods of local heavy rainfall.

Station 2: GPS Location (30 23.666’, 89 53.621’) Highway 434 Bridge located in northern Lacombe, Louisiana [stream width: 6.7m, stream depth: 0.3m to 1m]

This station is considered the middle upstream station sampled common to the three most recent fish surveys. Sobczak seined this station once a month for a period of 24 months from 1973-1975. Farabee had conducted monthly seining samples 12 times here from 1988-1989. Electrofishing surveys were conducted here during the summer months of 2005 (n = 3), from June 2006 to September 2006 (n = 4), and following the debris removal from October 2006 to May 2007 (n = 6). Again, January and May 2007 samples were not taken due to dangerously high waters. Fish habitats during the current survey consisted mainly of small fallen shrubs, sunken logs, and sparse patches of SAV, particularly *Cabomba* sp.

Station 3: GPS Location (30 21.904’, 89 55.398’) Kremlin Bridge located on Krentel Road in Lacombe, Louisiana [stream width: 10.9m, stream depth: 0.3m to 1m]

Station 3 was the southern-most upstream station in the current study and was sampled monthly by Sobczak from 1973-1975 for a total of 24 samples. Sobczak had described the station as having healthy sand bars. In comparing pictures from his work with my own observations at the station, it is apparent that these healthy sand bars no longer exist. Farabee sampled this station monthly as well in his 1988-1989 fish survey for a total of 12 samples but made no mention of theses features. During the current survey, sampling was conducted at Station 3 from June 2005 to August 2005 (n = 3). Sampling resumed starting in June 2006 to September 2006 (n = 4). Fish assemblage samples were also taken here following the debris removal from October 2006 to May 2007 (n = 6). Again, high water precluded sampling during the months of January and May 2007.

Station 4: GPS Location (30 19.084', 89 56.357'). Bayou Lacombe near Louisiana Department of Wildlife and Fisheries fish hatchery [stream width: 24.3m, stream depth: 0.3m to 5.9m]

Station 4 is the northern-most downstream station and is common to the Sobczak and the current surveys only; Farabee did not sample this station due to its inaccessibility. Sobczak seined this area once a month intermittently from 1973-1975 for a total of 10 samples. Although his samples are few, they are important for comparisons to the current study. Bayou Lacombe is a slow moving and tidally influenced by nearby oligohaline waters of Lake Pontchartrain. On several occasions I observed that strong tides altered water quality conditions dramatically on a month-to-month basis. For the current study, this area was sampled monthly by boat electrofishing, before Hurricane Katrina (n =2) and monthly after the storm (n = 12). My observations suggest that Station 4 changed little physically due to storm impacts, but this assumption may be biased because the Bayou is much wider here than in the upstream stations and habitat changes may have been less noticeable.

Station 5: GPS Location (30 18.772’, 89 56.012’). Located approximately one mile north of the Main Street boat launch but just south of Highway 190 Bridge in Lacombe, Louisiana [stream width: 36.5m, stream depth: 0.3m to 5.9m]

Station 5 was only sampled in the current study. It was sampled prior to Hurricane Katrina (n = 2) and following the storm from June 2006 to May 2007 (n = 12). This station was not located near a bridge or any roads, so it was not easily accessible in past studies by foot. This station was established during the current study due to relative ease of boat electroshocking and the lack of local boat traffic, which can disturb sampling. Station 5 is important to the pre-Katrina, post-Katrina, and post-debris removal sampling of the current study. Three historic upstream stations were sampled and two historic downstream stations were sampled. This station was chosen for convenience and so that three upstream stations could be compared to each other temporally and three downstream stations could be compared temporally.

Station 6: GPS Location (30 18.557’, 89 55.709’). Main Street boat launch near downtown Lacombe, Louisiana [stream width: 57.9m, stream depth: 0.3m to 4.3m]

This station was sampled during all three studies. Sobczak seined this station intermittently during his survey from 1973-1975 for a total of 11 monthly samples. Farabee also seined this station monthly from 1988-1989 for a total of 12 samples. During the current fish assemblage survey, Station 6 was boat electrofished prior to Hurricane Katrina (n = 2) and following the Hurricane from June 2006 to May 2007 (n = 12). Historically, Sobczak captured numerous freshwater species at Station 6. During the current study, only freshwater species that could tolerate temporary periods of brackish water salinity were captured here. Primary freshwater fishes were not represented at Station 6 during the current survey.

Data Analysis

2005-2007 Pre/Post-Hurricane Katrina and Post-Debris Removal Study

Fish assemblage samples from the summer of 2005, before Hurricane Katrina, and those from the summer of 2006, after Hurricane Katrina, were compared using assemblage analysis procedures in the PRIMER (Plymouth Routines in Multivariate Ecological Research) 5.2.2 statistical package (Clarke and Warwick, 2001). Fish assemblages sampled after debris removal from upstream stations in late September were compared to those before the debris was removed to determine if fish assemblages were resilient to this disturbance. Although it is likely that there may be some seasonal migration among stations may have influenced these analyses because sampling was continued through fall, winter, and spring months, it should be noted that this type of bias will be minimal in the short (46.1 km) Bayou Lacombe system; primary freshwater fishes can only migrate downstream so far within the system to avoid the brackish waters near the mouth. Water quality variables were compared between the two periods primarily to determine if water quality changed from post-Katrina samples to post-debris removal samples. All tests were conducted at the $\alpha = 0.05$ significance level.

Upstream and downstream fish assemblage data (numbers of individuals per species) during the various periods in the current study were compared using analysis of similarity (ANOSIM, $\alpha = 0.05$). R-values in ANOSIM of 1.000 represent complete dissimilarity. Similarity matrices were generated for fish assemblages by square root transforming the raw abundance data and calculating Bray-Curtis similarity indices for each pair-wise assemblage comparison (Bray and Curtis, 1957). Individual station fish assemblages were also compared throughout the current study using the same techniques. If significant differences were found among assemblages, non-metric multidimensional scaling (MDS) plots were conducted to visually explore how samples compared. All stress values on MDS plots were less than 0.24. Stress values below 0.24 indicate that Euclidian distance among samples in NMS space and Bray-Curtis similarity can be strongly represented in two-dimensional images (Clarke and Warwick, 2001). Similarity percentages (SIMPER) were also calculated using raw abundance data in PRIMER to observe which species were contributing to the change in assemblage data (Clarke and Warwick, 2001). SIMPER testing allows one to see the similarities and dissimilarities within sampling stations or among sampling periods.

Using Microsoft Excel statistical package, I conducted one-way analysis of variance (ANOVA) tests to see if there were significant differences in water temperature, salinity, specific conductance, percentage saturation and dissolved oxygen at each station per period of disturbance. All tests were conducted at the $\alpha = 0.05$. These tests were conducted to determine if fish assemblages were experiencing significant changes in local environmental conditions. Only natural variables among like stations were compared. For complete upstream comparisons, only the three northern most stations (Stations 1-3) were included in analyses. For complete downstream comparisons, only the three southern most stations (Stations 4-6) were included in any analyses. Using PRIMER statistical package, I also performed a BIOENV routine to see which of the natural variables influenced the fish assemblage the most. The environmental data was averaged and square-root transformed. This information was used to form a similarity matrix based on normalized Euclidian distance. This matrix was then compared to the fish assemblage matrix by calculating Spearman rank correlation coefficients. The BIOENV test determines the relationship among assemblage data and environmental variables measured (Clarke and Ainsworth, 1993; Clarke and Warwick, 2001).

Historical Bayou Lacombe Fish Assemblage Change: 30 Year Study

Comparisons among three periods (Sobczak 1973-1975, Farabee 1988-1989, and the current study, 2005-2007) were conducted using PRIMER. Although the number of samples varied among periods of their respective investigation, the robust non-parametric techniques of PRIMER allow for an accurate comparison of fish assemblages. It is important to note that fish assemblage data only from like stations were used for comparisons. Also, it is important to remember that although sampling methods differ from current samples compared to those from past samples, there still are shifting fish assemblage trends in Sobczak's seining data and Farabee's seining data. The current electrofishing samples follow similar patterns.

Fish assemblage data from the three time periods were compared using analysis of similarity (ANOSIM, $\alpha = 0.05$). Stations were compared individually to observe fish assemblage change over time. Similarity matrices were created after all data was square root transformed and Bray-Curtis similarity indices were calculated for each pair wise comparison (Bray and Curtis, 1957). If significant differences were found among fish assemblages, non-metric multidimensional scaling plots were performed to observe change over time. Similarity percentages (SIMPER) among fish assemblages were also calculated in order to determine which species were contributing to the change in assemblage data. The BIOENV procedure was not conducted on the historical data since water quality from field notes of past studies was unavailable.

Results

Part 1: 2005-2007 Pre/Post-Hurricane Katrina and Post-Debris Removal Study

A total of 8676 fishes, comprising 17 Families, 28 genera and 42 species, were collected during the current study (Table 1). During this study, Bayou Lacombe experienced considerable natural and anthropogenic disturbances. Pre-Hurricane Katrina samples were conducted in the Bayou during the summer 2005 and post-Hurricane Katrina samples were conducted during the summer 2006. Following the upstream debris removal (sometime between September 2006 samples and October 2006 samples), sampling continued for another eight months in order to have twelve months of data. Comparisons of environmental variables (i.e., water temperature, salinity, specific conductance, percent saturation and dissolved oxygen) among sampling periods were conducted to determine if the respective disturbance significantly altered water quality (Tables 2 and 3). The BIOENV procedure was used to determine which environmental variables were strongly associated with fish assemblages at each of the six stations (Table 4).

Bayou Lacombe Station 1: Highway 36

Observations at this station suggest its surrounding riparian and aquatic habitats were likely the most disturbed of all six sampling stations during the current survey. The eastern banks of the Bayou appear particularly degraded. Once dense pine forest, which is still present on the western side of the Bayou, had been recently clear-cut (Figure 4). This area appears now as mixed brush and tree stumps. The period during which the forest was clear-cut is not certain, but when samples started in June 2005, pine tree stumps were smoldering after fires were set sometime before, presumably to destroy the remaining underbrush. Water clarity remained very low at Station 1 throughout the current survey, even during periods of low flow (Figure 5).

Table 1: Complete species list from current 2005-2007 fish assemblage survey of Bayou Lacombe.

Family	**Genus**	**Species**	**Station 1**	**Station 2**	**Station 3**	**Station 4**	**Station 5**	**Station 6**
Lepisosteidae	*Atractosteus*	*spatula*	0	0	0	1	0	2
	Lepisosteus	*oculatus*	1	2	4	65	49	25
	Lepisosteus	*osseus*	0	0	0	2	1	1
Amiidae	*Amia*	*calva*	0	0	0	4	2	4
Anguillidae	*Anguilla*	*rostrata*	0	5	4	6	11	9
Cluepidae	*Brevoortia*	*patronus*	0	0	0	3	32	1
	Dorosoma	*cepedianum*	0	0	0	9	6	1
	Dorosoma	*petenense*	0	0	0	16	7	18
Esocidae	*Esox*	*americanus*	104	29	14	0	0	0
Cyprinidae	*Notemigonus*	*crysoleucas*	0	0	2	1	2	0
	Notropis	*texanus*	0	0	8	0	0	0
Catostomidae	*Minytrema*	*melanops*	20	70	15	28	16	6
	Erimyzon	*sucetta*	14	0	0	0	0	0
	Erimyzon	*tenuis*	64	5	0	0	0	1
Ictaluridae	*Ictalurus*	*furcatus*	0	0	0	4	0	7
	Ameiurus	*natalis*	25	20	25	3	2	2
	Ameiurus	*melas*	2	0	0	0	0	3
	Ameiurus	*nebulosus*	0	0	0	1	0	0
Aphredoderidae	*Aphredoderus*	*sayanus*	143	177	211	12	1	0
Fundulidae	*Fundulus*	*chrysotus*	0	0	0	0	0	1
	Fundulus	*nottii*	28	4	5	3	0	1
	Fundulus	*olivaceus*	2	10	98	14	0	0
	Fundulus	*grandis*	0	0	0	0	1	0
	Lucania	*parva*	0	1	3	25	1	8
Poeciliidae	*Gambusia*	*affinis*	13	37	63	0	4	0
	Heterandria	*formosa*	0	0	0	3	0	0
Atherinidae	*Labidesthes*	*sicculus*	0	1	11	270	328	75
	Menidia	*beryllina*	0	0	0	20	405	292
Elassomatidae	*Elassoma*	*zonatum*	275	132	44	0	0	0
Centrarchidae	*Centrarchus*	*macropterus*	2	1	0	0	0	0
	Pomoxis	*nigromaculatus*	0	0	0	6	0	2
	Micropterus	*salmoides*	96	102	54	282	292	210
	Lepomis	*gulosus*	12	16	18	21	32	57
	Lepomis	*megalotis*	187	286	405	7	2	4
	Lepomis	*symmetricus*	4	0	0	0	0	0
	Lepomis	*miniatus*	9	71	73	67	165	135
	Lepomis	*macrochirus*	34	82	133	437	543	513
	Lepomis	*microlophus*	0	0	0	320	142	103
	Lepomis	*marginatus*	14	4	0	0	0	0
Percidae	*Etheostoma*	*parvipinne*	18	2	1	0	0	0
Mugilidae	*Mugil*	*cephalus*	0	0	0	87	51	44
Soleidae	*Trinectes*	*maculatus*	0	0	0	5	9	10
	Total	***Individuals***	**1067**	**1057**	**1191**	**1722**	**2104**	**1535**

Table 2: Environmental variables and significant differences using one-way Analysis of Variance (ANOVA) calculated within stations and between samples conducted before and after Hurricane Katrina. Water quality samples for Stations 4-6 was combined since the stations were very close together (all were located within a 2.5 km range of the Bayou).

Environmental Variable	Station 1	Station 2	Station 3	Stations 4-6
water temperature (^oC)	NS	NS	NS	NS
salinity (ppt)	NS	NS	NS	< 0.001
specific conductance (uS)	NS	NS	NS	< 0.001
percent saturation (%)	NS	NS	< 0.001	NS
dissolved oxygen (mg/L)	NS	0.039	< 0.001	NS

Table 3: Environmental variables and significant differences using one-way ANOVA calculated within stations and between samples conducted before and after the debris removal from Bayou Lacombe. Water quality samples for Stations 4-6 was combined since the stations were very close together (all were located within a 2.5 km range of the Bayou).

Environmental Variable	Station 1	Station 2	Station 3	Stations 4-6
water temperature (^oC)	0.009	0.003	< 0.001	< 0.001
salinity (ppt)	NS	NS	NS	0.004
specific conductance (uS)	NS	0.007	0.05	0.002
percent saturation (%)	NS	NS	0.02	NS
dissolved oxygen (mg/L)	NS	NS	0.007	NS

Table 4: Environmental variables most associated with fish abundances among stations according to BIOENV.

Bayou Lacombe Station	Number of Variables	Spearman Correlation	Environmental Variables
Station 1	3	0.519	water temp., sp. cond., % saturation
Station 2	3	0.428	water temp., sp. cond., DO
Station 3	4	0.455	water temp., sp. cond, % saturation, DO
Station 4	2	0.389	water temp., sp. cond
Station 5	2	0.373	water temp., sp. Cond
Station 6	1	0.163	water temp.

Figure 4: Downstream view of Station 1. The eastern banks (left side of picture) have been severely clear-cut.

Figure 5: Upstream view at Station 1 during a low flow period. The surrounding riparian habitat has dramatically changed since Sobczak's 1973-1975 survey.

Just north of the bridge at the Highway 36 station, an emergent plant (*Myriophyllum* sp.) dominated the waterway. Many chubsuckers (*Erimyzon* spp.) were found here throughout the current survey. Numerous chain pickerel (*Esox americanus*) were found here prior to Hurricane Katrina but appeared less abundant after the storm. I found almost no submersed aquatic vegetation (SAV) in this area except for one small isolated patch of *Cabomba* sp. that had been present before Hurricane Katrina. After the storm, the habitat changed severely. It proved to be fairly difficult to maneuver around and between fallen trees, which over time captured debris flowing downstream. To keep the habitats where sampling occurred as natural as possible, paths were cleared around the debris so that fish assemblages change could still be monitored pre/post-Katrina with as little influence from our surveying efforts as possible (Figures 6 and 7). Electrofishing proved to be the best method of sampling here since it would have been nearly impossible to thoroughly sample the area with seines as Sobczak and Farabee did in their earlier surveys. Beginning in September 2006, the debris from the Highway 36 Bridge southwards was removed by contractors paid by the Federal Emergency Management Agency (FEMA). Since samples were always conducted from the bridge upstream, the debris produced by Hurricane Katrina's winds remained throughout the rest of the survey at Station 1. This was not the case with the other upstream stations, Stations 2 and 3. There was hardly any sand or gravel found at Station 1 during the current survey. My observations suggest that the historic substrates reported by Sobczak have been since covered with mud and silt from runoff associated with clear-cutting the forests adjacent to the Bayou.

A total of 1067 fishes were captured at Station 1 in fourteen monthly samples. Fish assemblages collected during the summers before and after Hurricane Katrina were significantly different (ANOSIM, $R = 1.000$, $p = 0.029$) with the composition of fish assemblages exhibiting

Figure 6: Fallen trees in upstream portions of the stream made sampling difficult. Here a large tree blocks the upstream sampling at Station 1.

Figure 7: In order to reduce impacts as much as possible, paths were cleared around the fallen debris so that sampling could commence with a minimum of human interference.

no overlap (Figure 8). There was essentially no similarity between sampling periods. Numbers of grass pickerel (*Esox americanus*), goldstripe darter (*Etheostoma parvipinne*), and longear sunfish (*Lepomis megalotis*) declined after the storm (Table 5). However, numbers of pygmy sunfish (*Elassoma zonatum*) and pirate perch (*Aphredoderus sayanus*) increased (Table 5). No significant differences in water quality measurements were found between time periods, but there was a large increase in habitat complexity due to numerous fallen trees and accumulated debris.

When the debris was removed from the Bayou, Station 1 fish assemblages again changed significantly (ANOSIM, R = 0.647, p = 0.001) with species compositions becoming somewhat intermediate between pre- and post-storm assemblages (Figure 8). The abundance of *L. megalotis* and *Fundulus notti* both increased after the debris was removed. Numbers of *E. zonatum* also increased after the debris removal, while abundances of *A. sayanus* markedly decreased during this same period. The abundance of sharpfin chubsuckers, *Erimyzon tenuis*, also decreased following the disturbance. Water temperature was the only environmental variable at Station 1 found to be significantly different (ANOVA, p = 0.009) between post-storm and post-debris removal samples. This was probably due to seasonal changes among sampling periods.

Pre-Katrina fish assemblages were also significantly different (ANOSIM, R = 0.728, p = 0.012) from post-debris removal fish assemblages. Although numbers of *L. megalotis* are similar between sampling periods (Table 5), abundances of other local fish species changed drastically. For example, numbers of *Esox americanus* and *Etheostoma parvipinne* were markedly reduced following the storm and debris removal. On the other hand, abundances of *E. zonatum* and *A. sayanus* increased following the disturbances. Water temperature, specific conductivity, and

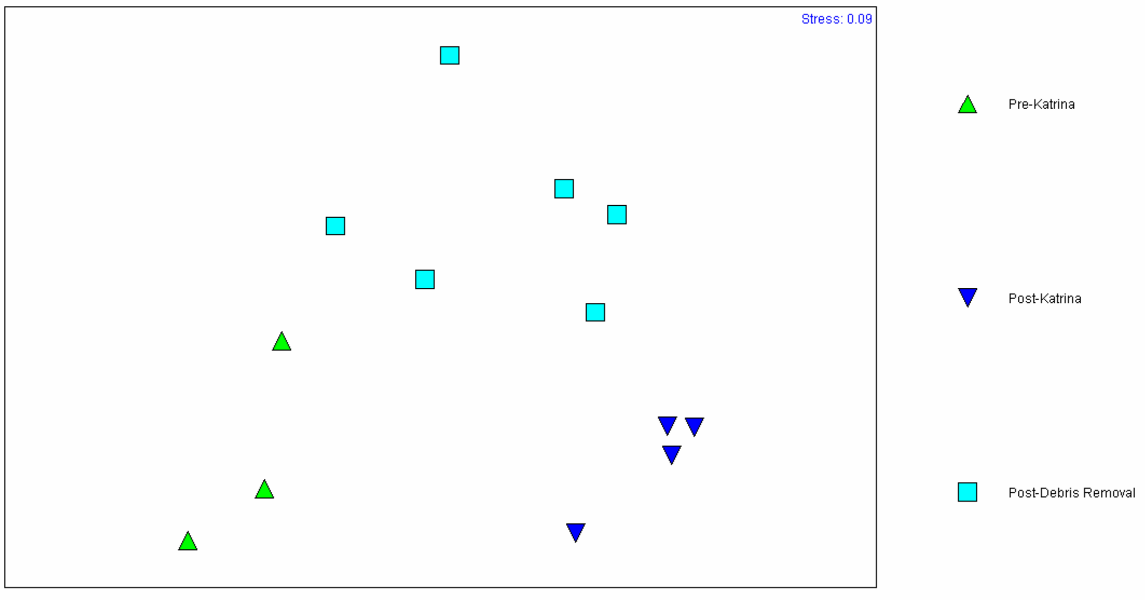

Figure 8: Non-metric Multidimensional Scaling (MDS) plot of fish assemblage samples taken at Station 1 during all three periods of collections (pre-Katrina, post-Katrina and post-debris removal samples). Distances between shapes represent similarities (i.e., closer shapes in MDS space represent similar species and abundances of fishes captured among samples).

Table 5: Analysis of Similarity (ANOSIM) and Similarity Percentages (SIMPER) for fishes collected at Station 1 during the three periods of sampling in the current Bayou Lacombe fish assemblage survey. Only the top five species associated with the greatest change between sampling periods are listed.

Time Period Comparison	R-value	p-value	Species	Pre-Event Mean Abundance	Post-Event Mean Abundance	Contrib. %
pre-Katrina vs. post-Katrina	1.000	0.029	*Elassoma zonatum*	0.00	19.00	15.87
			Aphredoderus sayanus	1.67	21.75	13.28
			Esox americanus	22.33	6.00	8.30
			Etheostoma parvipinne	5.33	0.25	7.60
			Lepomis megalotis	16.33	4.50	7.57
post-Katrina vs. post-debris removal	0.647	0.001	*Elassoma zonatum*	19.00	33.17	11.91
			Lepomis megalotis	4.50	20.00	10.09
			Erimyzon tenuis	10.00	3.00	8.95
			Aphredoderus sayanus	21.75	8.50	8.41
			Fundulus notti	0.25	3.67	6.39
pre-Katrina vs. post-debris removal	0.728	0.012	*Elassoma zonatum*	0.00	33.17	19.01
			Esox americanus	22.33	2.17	13.81
			Etheostoma parvipinne	5.33	0.17	8.40
			Aphredoderus sayanus	1.67	8.50	7.02
			Lepomis megalotis	16.33	20.00	3.03

percent saturation were the environmental variables that had the strongest association with changes in fish assemblage structures during the three periods of sampling (BIOENV, r = 0.519).

Bayou Lacombe Station 2: Highway 434

The banks at Station 2 appeared less impacted than those at Station 1 during pre-Katrina sampling (Figure 9). Other than a few houses located approximately 60 m (200 feet) from the Bayou, the surrounding riparian areas appeared relatively stable. This situation changed, though, when winds from Hurricane Katrina (exceeding 150 mph) blew numerous pine trees and other smaller trees into the Bayou. Based on these impacts, Station 2 appeared to suffer the most severe habitat change as a result of Hurricane Katrina (Figure 10). Numerous fallen mature pine trees were very difficult to maneuver around and could not be removed by field sampling crews during the current study. As with Station 1, we cleared paths so that monthly electrofishing could continue. Over time, the large downed trees restricted debris from flowing downstream, causing the accumulation of large amounts of decaying material. The presence of these debris dams likely reduced local levels of dissolved oxygen after the hurricane. In response to this debris accumulation, sometime prior to the October 2006 sampling, local contractors removed all blockages in Bayou Lacombe from Highway 36 to the Interstate 12 (Figure 1). To remove the debris, contractors cleared a fifty-foot wide path along the banks so that tractors could gain access to the waterway (Figure 11). During subsequent monthly sampling, the lack of trees allowed more light onto the local aquatic habitats. As with similar stream systems, it is possible that the removal of trees adjacent to the Bayou will increase local water temperatures and the chance of future algal blooms. The contractors’ efforts removed all of the post-Katrina debris along with some submerged logs that were present prior to the storm. These activities reduced available habitats for fishes in the upstream portions of the Bayou. Although turbidity measures

Figure 9: Downstream view at Station 2 before Hurricane Katrina. This picture was taken during a low flow period and the water was constantly turbid.

Figure 10: A rather large debris dam at Station 2 after Hurricane Katrina. Station 2 had the most tree damage from the storm. Backpack electrofishing this station proved to be very difficult.

Figure 11: A trail cleared out on the eastern banks at Station 2 so that FEMA contractors could maneuver their equipment around to pull the debris out of Bayou Lacombe.

were not taken in the current survey, I observed markedly lower water clarity after the debris was removed. Low water clarity is often attributed to the lack of a natural buffer on the banks of streams. Intact riparian zones typically filter out sediments and organic debris that can enter streams after heavy rainfalls.

Station 2 was the most disturbed station before and after Hurricane Katrina. Sampling at Station 2 was problematic due to numerous pine trees that fell into the Bayou at this locality, but my use of electrofishing proved to be the correct choice for sampling disturbed habitats such as these. A total of 1057 fishes were captured at Station 2. Fish assemblages collected before and after the storm were significantly different (ANOSIM, R = 1.000, p = 0.029) with the composition of fish assemblages exhibiting no overlap (Figure 12). Three species of the sunfish genus *Lepomis* (*L. megalotis*, *L. gulosus*, and *L. macrochirus*) declined after the storm (Table 6). During the same period, though, *E. zonatum* and *A. sayanus* increased in abundance (Table 6). These changes in fish abundances coincided with a significant (ANOVA, p = 0.039) decline in dissolved oxygen (DO) and an increase of habitat complexity at Station 2 due to the large numbers of fallen trees and a build-up of debris.

After the debris was removed from the Bayou, fish assemblages at Station 2 again changed significantly (ANOSIM, R = 0.575, p = 0.019) with species composition being somewhat intermediate between pre- and post-storm assemblages (Figure 12). The number of *L. megalotis* increased after the debris was removed. Red spotted sunfish, *L. miniatus*, and the spotted sucker, *Minytrema melanops*, also became relatively abundant. Water temperature and specific conductivity were the only environmental variables that were found to be significantly different (ANOVA, p = 0.003 and p = 0.007, respectively) after the debris was removed from Station 2.

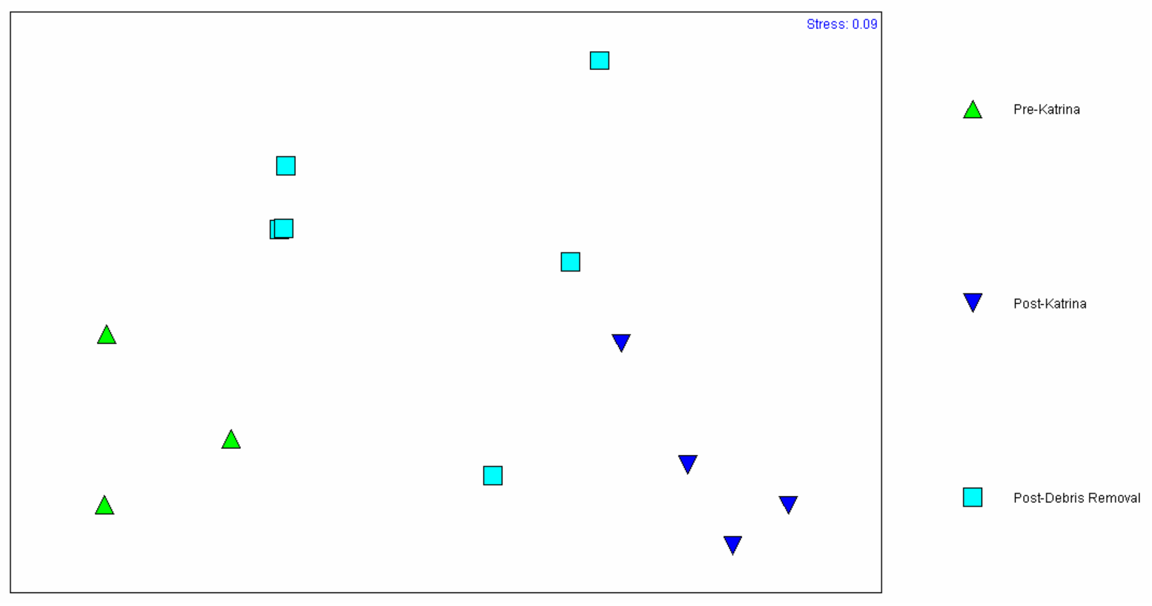

Figure 12: MDS plot of fish assemblage samples taken at Station 2 during all three periods of collections.

Table 6: ANOSIM and SIMPER for fishes collected at Station 2 during the three periods of sampling in the current Bayou Lacombe fish assemblage survey. Only the top five species associated with the greatest change between sampling periods are listed.

Time Period Comparison	R-value	p-value	Species	Pre-Event Mean Abundance	Post-Event Mean Abundance	Contrib. %
pre-Katrina vs. post-Katrina	1.000	0.029	*Lepomis megalotis*	43.33	5.25	17.25
			Elassoma zonatum	0.33	13.00	12.00
			Aphredoderus sayanus	4.67	20.50	8.76
			Lepomis gulosus	3.67	0.00	7.02
			Lepomis macrochirus	12.67	4.00	5.73
post-Katrina vs. post-debris removal	0.575	0.019	*Lepomis miniatus*	0.00	10.83	14.20
			Lepomis megalotis	5.25	22.50	13.03
			Elassoma zonatum	13.00	13.17	11.62
			Minytrema melanops	2.25	10.00	9.43
			Aphredoderus sayanus	20.50	13.50	8.36
pre-Katrina vs. post-debris removal	0.370	0.036	*Lepomis macrochirus*	12.67	4.67	10.59
			Elassoma zonatum	0.33	13.17	10.06
			Minytrema melanops	0.33	10.00	9.48
			Lepomis megalotis	43.33	22.50	8.68
			Aphredoderus sayanus	4.67	13.50	7.66

Pre-Katrina assemblages were also significantly different (ANOSIM, R = 0.370, p = 0.036) from post-debris removal assemblages (Table 6) but the relatively low R-value (R = 0.370) illustrates that the fish assemblage at Station 2 are possibly returning to a pre-Katrina species composition (Figure 12). This assemblage cyclicity suggests a level of recovery (Matthews, 1998), but there is still some seasonal variation in the fishes sampled. Numbers of *L. macrochirus* and *L. megalotis* captured after the debris removal were markedly lower than those collected before the storm (Table 6). In contrast, *E. zonatum*, *A. sayanus*, and *M. melanops* exhibited high numbers both before Hurricane Katrina and after the debris removal. For Station 2 water temperature, specific conductivity, and dissolved oxygen had the strongest association with changes in fish assemblage structure during all three periods of sampling (BIOENV, r = 0.428).

Bayou Lacombe Station 3: Krentel Road

The forested areas surrounding Station 3 appeared healthy and rich with vegetation before Hurricane Katrina. During pre-Katrina samples, there were numerous submerged logs and small fallen trees into the Bayou that provided habitat for fishes. Very little submersed aquatic vegetation, in particular *Cabomba* sp., was found at Station 3 during the current study. The sand and gravel bottoms described by Sobczak in 1976 are no longer as he described them. The substrate, prior to Hurricane Katrina, consisted primarily of mud and water-logged debris (i.e., leaves and branches). As with Station 2, many large pine trees fell into the Bayou after the storm, though the blockages they created were not nearly as severe as those described at Station 2. Again, we cleared paths to sample around the newly formed habitat to minimize disturbing the sampled habitats. In late September 2006, contractors removed debris from this area as well. The healthy vegetation left unscathed by Hurricane Katrina on the east bank of Station 3 was destroyed from tractors maneuvering fallen trees and debris out of the Bayou (Figure 13). Observed water clarity in post-debris removal samples appeared once again to be low due to increased runoff. The covering canopy of trees was also very much reduced. During sampling conducted post-debris removal, I noticed a more open canopy at Station 3 rather than a more closed canopy. Once again, not only did workers remove jammed debris caused by Hurricane Katrina, they also removed some of the water-logged submerged trees that were there years before the storm impacted the area. Fish habitat was markedly reduced after the debris removal (Figure 14).

A total of 1191 fishes were captured at Station 3 among all three sampling periods. Fish assemblages collected before and after the storm were significantly different (ANOSIM, $R = 1.000$, $p = 0.029$) with the composition of fish assemblages exhibiting no overlap (Figure 15). Numbers of the spotted topminnow, *Fundulus olivaceus,* and *L. megalotis* declined after the storm and no *N. texanus* were collected in subsequent sampling (Table 7). Only abundances of *A. sayanus* and *E. zonatum* increased after Hurricane Katrina (Table 7). The changes in fish abundances coincided with significant (ANOVA, both $p < 0.001$) declines in dissolved oxygen and percent saturation and an increase in habitat complexity at Station 3 due to the large numbers of fallen trees and accumulation of debris behind log jams.

Following the debris removal from the Bayou, the fish assemblage at Station 3 again changed significantly (ANOSIM, $R = 0.282$, $p = 0.038$). Species composition was found to be somewhat intermediate of pre-Katrina and post-Katrina fish assemblages (Figure 15). Abundances of *L. megalotis*, *L. miniatus*, and *F. olivaceus* increased after the debris removal (Table 7). Abundances of *A. sayanus* and the yellow bullhead, *Ameiurus natalis*, both declined after debris removal (Table 7). At Station 3, water temperature, percent saturation, and dissolved

Figure 13: A cleared trail by FEMA contractors at Station 3.

Figure 14: An upstream view of Station 3. Much of the habitat that was here before Hurricane Katrina was removed as well.

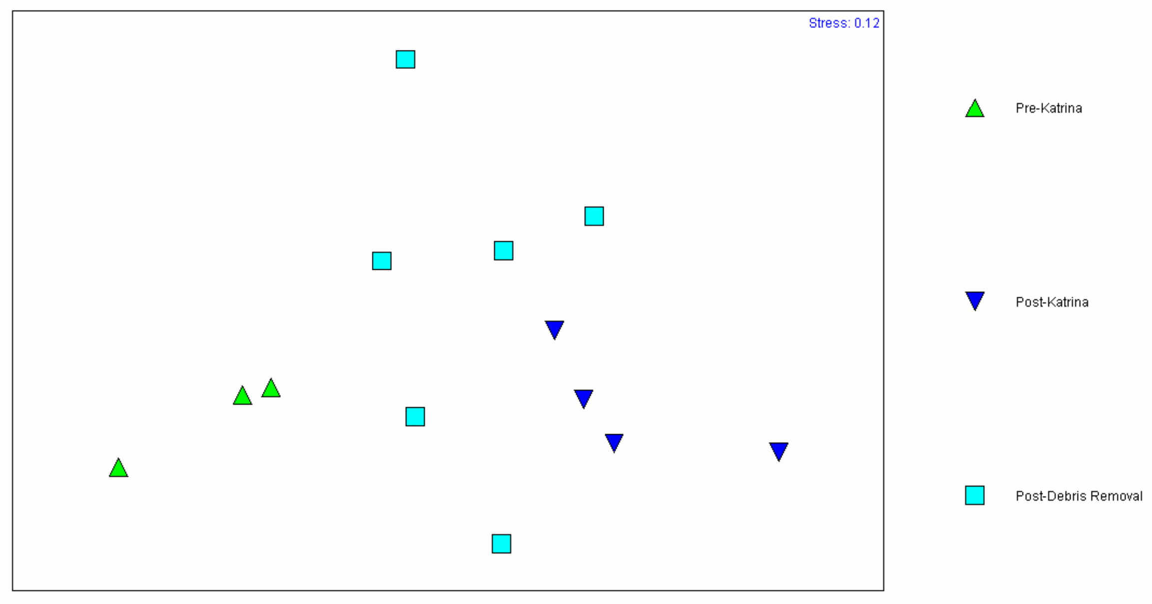

Figure 15: MDS plot of fish assemblage samples taken at Station 3 during all three periods of collections.

Table 7: ANOSIM and SIMPER for fishes collected at Station 3 during the three periods of sampling in the current Bayou Lacombe fish assemblage survey. Only the top five species associated with the greatest change between sampling periods are listed.

Time Period Comparison	R-value	p-value	Species	Pre-Event Mean Abundance	Post-Event Mean Abundance	Contrib. %
pre-Katrina vs. post-Katrina	1.000	0.029	*Aphredoderus sayanus*	6.00	30.50	12.96
			Fundulus olivaceus	18.00	2.50	11.70
			Lepomis megalotis	40.00	18.00	9.82
			Notropis texanus	2.67	0.00	6.46
			Elassoma zonatum	0.67	4.50	5.85
post-Katrina vs. post-debris removal	0.282	0.038	*Aphredoderus sayanus*	30.50	11.83	17.08
			Lepomis megalotis	18.00	35.50	10.63
			Ameiurus natalis	4.75	1.00	8.44
			Lepomis miniatus	3.50	9.50	8.03
			Fundulus olivaceus	2.50	5.67	6.64
pre-Katrina vs. post-debris removal	0.562	0.012	*Fundulus olivaceus*	18.00	5.67	11.45
			Lepomis miniatus	0.67	9.50	10.53
			Lepomis megalotis	40.00	35.50	8.85
			Notropis texanus	2.67	0.00	7.62
			Aphredoderus sayanus	6.00	11.83	7.00

oxygen were the environmental variables that were found to be significantly different (ANOVA, $p < 0.001$, $p = 0.02$, and $p = 0.007$, respectively) after the debris was removed.

Pre-Katrina fish assemblages were also significantly different (ANOSIM, $R = 0.562$, $p = 0.012$) from post-debris removal assemblages (Table 7). Although there is some seasonal variation in fish assemblage samples, the assemblage is possibly recovering from storm disturbance after the debris was removed from the Bayou (Figure 15). Numbers of *L. megalotis* collected after the debris removal closely resemble those collected before the storm (Table 7). Abundances of *L. miniatus* and *A. sayanus* increased after the disturbance events (Table 7). Marked declines in *F. olivaceus* were observed between sampling periods and *N. texanus* was never sampled again after the storm (Table 7). Water temperature, specific conductivity, percent saturation, and dissolved oxygen had the strongest association with changes in fish assemblage structure among all three periods of sampling at Station 3 (BIOENV, $r = 0.455$).

Bayou Lacombe Station 4: Fish Hatchery

The land surrounding Station 4 remained relatively unharmed from Hurricane Katrina's winds (Figure 16). This station, however, was submerged by saltwater for some time after the storm due to the high storm surge that entered Lake Pontchartrain. The same cypress and pine trees were present at all periods of sampling in the current study. Aquatic habitat here was littered with cypress knees, submerged logs, and small trees whose branches dipped into the water, providing shade and habitat. Submerged vegetation was somewhat healthier here with areas of thick freshwater coontail, *Ceratophylum demersum*. Other than the water quality of the Bayou, Station 4 appeared to be unaffected by the removal of debris upstream. Because the waterway was not completely blocked, contractors did not remove the few fallen trees this far

Figure 16: Upstream view of Station 4.

downstream. Since the stream width here is much wider than that upstream, the fallen trees did not pose a threat to debris buildup or water backup.

A total of 1722 fishes were collected at Station 4. Fish assemblages collected before and after the storm were not significantly different (ANOSIM, R = 0.750, p = 0.067) even though the composition of fish assemblages exhibited no overlap (Figure 17). Abundances of *M. salmoides*, *L. macrochirus*, and *L. microlophus* all markedly increased in the summer following the storm (Table 8). Numbers of *L. miniatus* and *M. cephalus* slightly increased after the disturbance (Table 8). Salinity and specific conductivity were the environmental variables that were found to be significantly different (ANOVA, both $p < 0.001$) between the pre-storm and post-storm sampling periods.

After the debris was removed from the upstream portions of the Bayou, fish assemblages at Station 4 changed significantly (ANOSIM, R = 0.551, p = 0.002) with species compositions being somewhat dissimilar to pre- and post-storm assemblages (Figure 17). Abundances of the brook silverside, *L. sicculus*, markedly increased following the debris removal (Table 8). Numbers of *L. microlophus*, *M. cephalus*, and *L. oculatus* also increased during this time (Table 8). Only numbers of *M. salmoides*. decreased after the debris was removed from the Bayou (Table 8). Water temperature, salinity, and specific conductance were the environmental variables that were found to be significantly different (ANOVA, $p < 0.001$, $p = 0.004$, and $p = 0.002$, respectively) between sampling periods.

Significant differences (ANOSIM, R = 0.892, p = 0.022) were found between pre-Katrina and post-debris removal samples as well. Species abundances of *L. microlophus*, *L. sicculus*, *L. oculatus*, *L. macrochirus*, and *M. cephalus* all increased following the natural and anthropogenic disturbances (Table 8). For Station 4 water temperature and specific conductivity had the

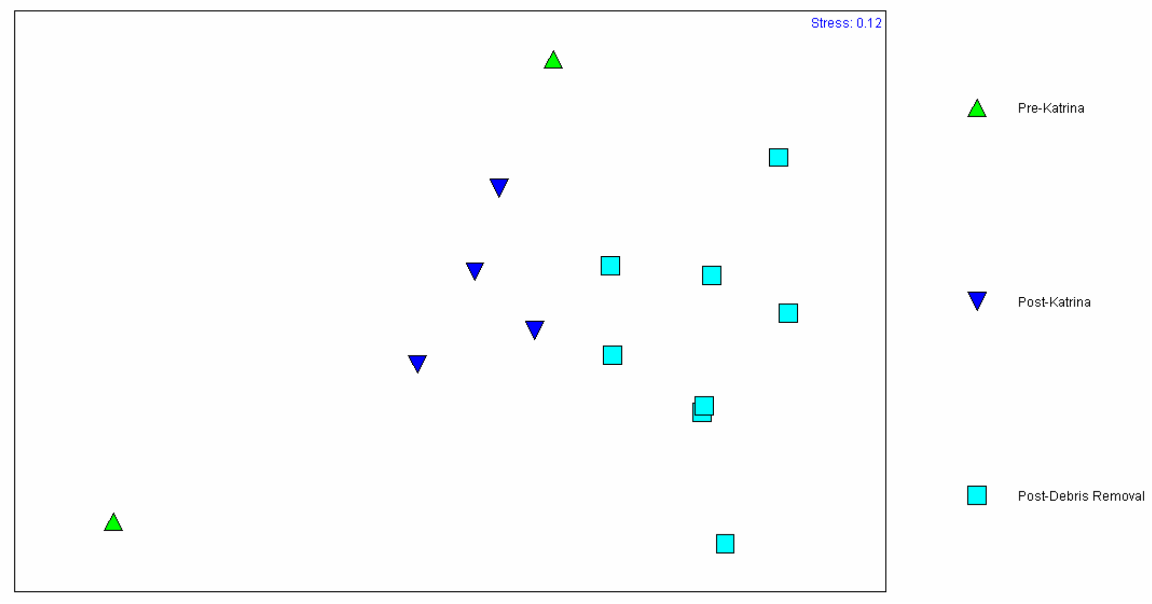

Figure 17: MDS plot of fish assemblage samples taken at Station 4 during all three periods of collections.

Table 8: ANOSIM and SIMPER for fishes collected at Station 4 during the three periods of sampling in the current Bayou Lacombe fish assemblage survey. Only the top five species associated with the greatest change between sampling periods are listed.

Time Period Comparison	R-value	p-value	Species	Pre-Event Mean Abundance	Post-Event Mean Abundance	Contrib. %
pre-Katrina vs. post-Katrina	0.750	0.067	*Micropterus salmoides*	8.50	39.00	14.94
			Lepomis macrochirus	10.50	38.75	14.19
			Lepomis microlophus	1.00	12.25	12.81
			Lepomis miniatus	4.50	6.00	7.44
			Mugil cephalus	1.50	4.75	7.37
post-Katrina vs. post-debris removal	0.551	0.002	*Labidesthes sicculus*	1.00	32.63	15.63
			Micropterus salmoides	39.00	13.63	9.05
			Lepomis microlophus	12.25	33.63	8.05
			Mugil cephalus	4.75	8.13	7.58
			Lepisosteus oculatus	1.00	7.63	6.63
pre-Katrina vs. post-debris removal	0.892	0.022	*Lepomis microlophus*	1.00	33.63	16.05
			Labidesthes sicculus	2.50	32.63	13.56
			Lepisosteus oculatus	0.00	7.63	9.16
			Lepomis macrochirus	10.50	32.63	8.27
			Mugil cephalus	1.50	8.13	6.11

strongest association with changes in fish assemblage structure during all three periods of sampling (BIOENV, r = 0.389).

Bayou Lacombe Station 5: Extra downstream samples

This station also remained relatively unscathed from Hurricane Katrina, although the saltwater storm surge penetrated this area (Figure 18). The cypress and pine trees that surrounded Station 5 prior to Hurricane Katrina remain there currently. Available fish habitats consisted of a few submerged logs, numerous cypress knees, and some tree branches. Other potential fish habitats included beds of SAV, which were dominated by widgeon grass, *Ruppia martima*.

The fish assemblage at Station 5 remained relatively stable throughout the sampling periods. A total of 2104 fishes were collected at this station. Fish assemblages collected before and after the storm were not significantly different (ANOSIM, R = 0.179, p = 0.400) even though the assemblages exhibited no overlap (Figure 19). Numbers of *M. salmoides*, *M. beryllina*, *B. patronus*, and *L. microlophus* all increased after the storm (Table 9). Only abundances of *L. macrochirus* slightly decreased after the storm (Table 9). These slight changes in abundances show the resilience of these fishes to significant (ANOVA, both $p < 0.001$) increases in salinity and specific conductance found at Station 5 a year after the storm.

Following the debris removal from the Bayou, fish assemblages at Station 5 changed significantly (ANOSIM, R = 0.432, p = 0.018) with species composition being very different from pre- and post-storm assemblages (Figure 19). There were marked increases in the abundances of silversides, *L. sicculus* and *M. beryllina* (Table 9). Numbers of *M. salmoides*, *L. macrochirus*, and *B. patronus* all became relatively less abundant (Table 9). Water temperature, salinity, and specific conductivity were the environmental variables that were found to be

Figure 18: Upstream view of Station 5.

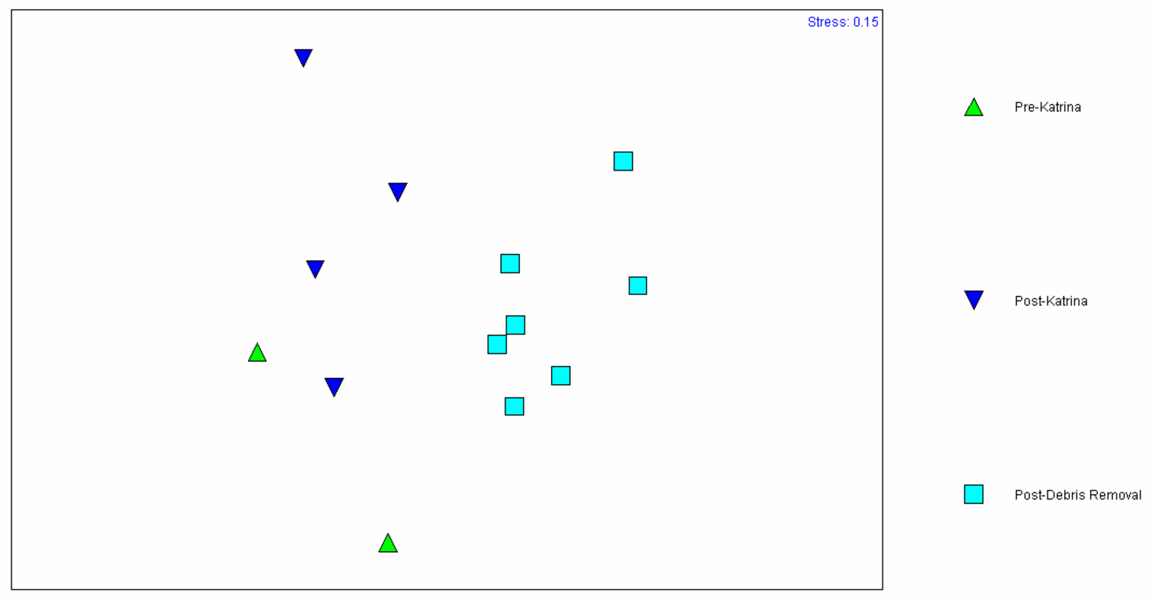

Figure 19: MDS plot of fish assemblage samples taken at Station 5 during all three periods of collections.

Table 9: ANOSIM and SIMPER for fishes collected at Station 5 during the three periods of sampling in the current Bayou Lacombe fish assemblage survey. Only the top five species associated with the greatest change between sampling periods are listed.

Time Period Comparison	R-value	p-value	Species	Pre-Event Mean Abundance	Post-Event Mean Abundance	Contrib. %
pre-Katrina vs. post-Katrina	0.179	0.400	*Micropterus salmoides*	8.50	41.25	14.62
			Menidia beryllina	0.50	17.00	14.02
			Lepomis macrochirus	53.50	44.75	11.28
			Brevoortia patronus	0.00	7.75	9.66
			Lepomis microlophus	1.00	7.25	8.74
post-Katrina vs. post-debris removal	0.432	0.018	*Labidesthes sicculus*	0.00	40.25	16.77
			Menidia beryllina	17.00	42.00	12.76
			Micropterus salmoides	41.25	13.75	9.31
			Lepomis macrochirus	44.75	32.13	7.78
			Brevoortia patronus	7.75	0.13	7.08
pre-Katrina vs. post-debris removal	0.466	0.089	*Labidesthes sicculus*	3.00	40.25	16.64
			Menidia beryllina	0.50	42.00	12.96
			Lepomis macrochirus	53.50	32.13	11.57
			Lepomis microlophus	1.00	13.88	11.11
			Lepisosteus oculatus	0.00	5.88	8.36

significantly different (ANOVA, $p < 0.001$, $p = 0.004$, and $p = 0.002$, respectively) after the debris was removed from the upstream portions of the Bayou.

Pre-Katrina fish assemblages were not significantly different (ANOSIM, $R = 0.466$, $p = 0.089$) from post-debris removal assemblages. Abundances of silversides, *L. sicculus* and *M. beryllina*, *L. microlophus*, and *L. oculatus* markedly increased between the periods of sampling (Table 9). Only numbers of *L. macrochirus* showed slight decreases in abundance (Table 9). Water temperature and specific conductivity had the strongest association with changes in fish assemblage structure during the three periods of sampling at Station 5 (BIOENV, $r = 0.373$).

Bayou Lacombe Station 6: Main Street

This station is surrounded by old, healthy cypress and pine trees with numerous small shrubs intermixed underneath the canopy (Figure 20). Along with Stations 4 and 5, this station appeared minimally impacted by Hurricane Katrina, even though the saltwater storm surge submerged this area for some time. The aquatic habitat consisted of numerous cypress knees with many shaded areas provided by trees and an occasional fallen tree. The trees that fell after Hurricane Katrina were not removed in November 2006 because they did not interfere with the water flow or boat traffic. The SAV included a combination of both *R. maritima* and *C. demersum*.

Of all stations, the fish assemblages at Station 6 were the most resilient to both natural and anthropogenic disturbances. At Station 6, a total of 1535 fishes were collected. Fish assemblages collected before and after Hurricane Katrina were not significantly different (ANOSIM, $R = 0.357$, $p = 0.200$) although the species composition exhibited no overlap (Figure 21). Abundances of *M. salmoides*, *L. microlophus*, and the hogchoker, *Trinectes maculatus*, increased after Hurricane Katrina (Table 10). Numbers of *L. macrochirus* and *L. miniatus* only

Figure 20: Upstream view of Station 6.

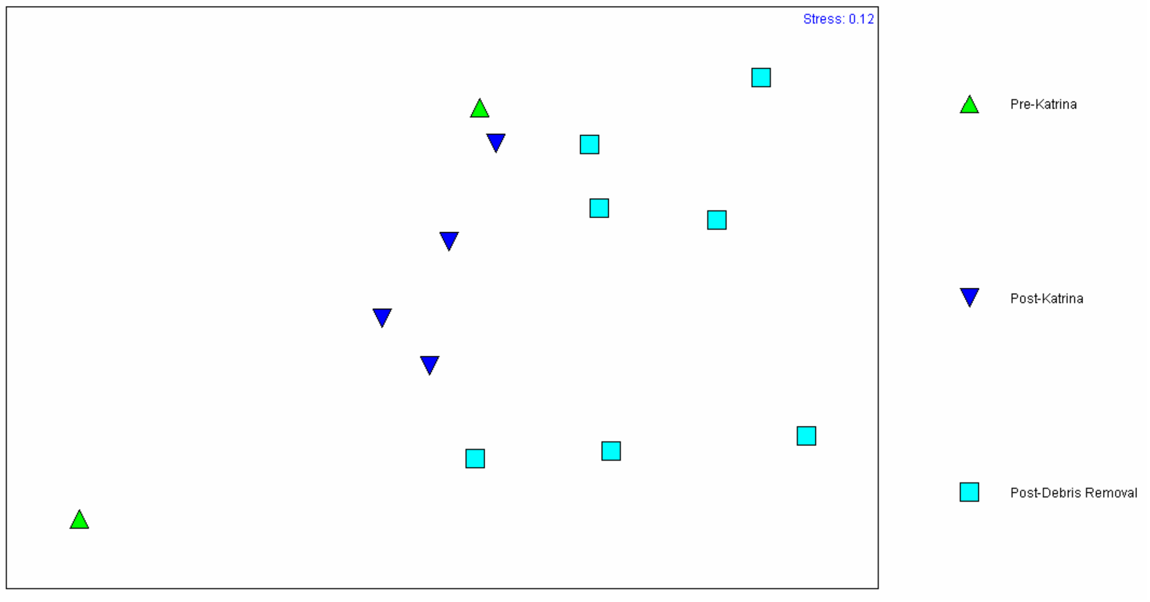

Figure 21: MDS plot of fish assemblage samples taken at Station 6 during all three periods of collections.

Table 10: ANOSIM and SIMPER for fishes collected at Station 6 during the three periods of sampling in the current Bayou Lacombe fish assemblage survey. Only the top five species associated with the greatest change between sampling periods are listed.

Time Period Comparison	R-value	p-value	Species	Pre-Event Mean Abundance	Post-Event Mean Abundance	Contrib. %
pre-Katrina vs. post-Katrina	0.357	0.200	*Lepomis macrochirus*	40.50	41.00	16.75
			Micropterus salmoides	12.50	23.00	10.92
			Lepomis microlophus	0.00	3.00	9.03
			Lepomis miniatus	11.00	9.00	7.94
			Trinectes maculatus	0.00	1.75	6.67
post-Katrina vs. post-debris removal	0.135	0.185	*Menidia beryllina*	0.25	36.68	13.12
			Lepomis macrochirus	41.00	33.50	11.36
			Micropterus salmoides	23.00	11.63	8.21
			Labidesthes sicculus	1.00	8.13	6.97
			Lepomis microlophus	3.00	11.38	6.68
pre-Katrina vs. post-debris removal	0.429	0.139	*Menidia beryllina*	0.00	36.38	12.26
			Lepomis macrochirus	40.50	33.50	12.04
			Lepomis microlophus	0.00	11.38	9.63
			Lepomis miniatus	11.00	9.63	7.46
			Micropterus salmoides	12.50	11.63	7.37

slightly increased between sampling periods (Table 10). The fish assemblages collected at this station before and after the storm were resilient to the significant (ANOVA, both $p < 0.001$) increases in salinity and specific conductance associated with the storm surge and its aftermath.

After the debris was removed from the upstream portions of Bayou Lacombe, fish assemblages at Station 6 again were not significantly different (ANOSIM, $R = 0.135$, $p = 0.185$) with species composition remaining somewhat similar to post-Katrina assemblages (Figure 21). Numbers of *M. beryllina*, *L. sicculus*, and *L. microlophus* increased in abundance following the debris removal (Table 10). Abundances of *L. macrochirus* and *M. salmoides* decreased during the same time period (Table 10). At Station 6 water temperature, salinity, and specific conductance were the environmental variables that were found to be significantly different (ANOVA, $p < 0.001$, $p = 0.004$, and $p = 0.002$, respectively) after the debris was removed from upstream portions of the Bayou.

Pre-Katrina assemblages were also not significantly different (ANOSIM, $R = 0.429$, $p = 0.139$) from post-debris removal assemblages (Table 10). Abundances of *M. beryllina* and *L. microlophus* markedly increased (Table 10). In contrast, *L. macrochirus*, *L. miniatus*, and *Micropterus salmoides* exhibited similar numbers both before Hurricane Katrina and after the upstream debris removal (Table 10). For Station 6 water temperature was the only environmental variable that had a slight association with fish assemblage structure during all three periods of sampling (BIOENV, $r = 0.163$).

Part 2: 33-Year Historical Bayou Lacombe Fish Assemblage Change

In order to reduce spatial variation, only fish assemblage samples taken from similar stations in Sobczak's, Farabee's, and my studies were compared for historical comparisons (Tables 11, 12, and 13). Mosquito fish (*Gambusia affinis*) and largemouth bass (*Micropterus*

Table 11: Sobczak's species list for Stations 1-4 and Station 6 during the 1973-1975 fish survey.

Family	**Genus**	**Species**	**Station 1**	**Station 2**	**Station 3**	**Station 4**	**Station 6**
Lepisosteidae	*Atractosteus*	*spatula*	0	0	0	0	0
	Lepisosteus	*oculatus*	0	0	0	0	1
	Lepisosteus	*osseus*	0	0	0	0	0
Amiidae	*Amia*	*calva*	0	0	0	0	0
Anguillidae	*Anguilla*	*rostrata*	0	0	0	0	0
Cluepidae	*Dorosoma*	*cepedianum*	0	0	0	0	0
	Dorosoma	*petenense*	0	0	0	0	2
Esocidae	*Esox*	*americanus*	6	2	2	1	0
Cyprinidae	*Notemigonus*	*crysoleucas*	2	1	0	0	0
	Cyprinella	*venusta*	15	281	1264	811	524
	Opsopoeodus	*emiliae*	0	0	0	58	30
	Notropis	*texanus*	107	109	394	33	22
Catostomidae	*Minytrema*	*melanops*	3	0	3	0	0
	Erimyzon	*sucetta*	35	9	0	0	0
	Erimyzon	*tenuis*	78	38	1	0	0
Ictaluridae	*Ictalurus*	*punctatus*	0	0	0	0	1
	Ictalurus	*furcatus*	0	0	0	0	0
	Ameiurus	*natalis*	5	0	0	0	0
	Ameiurus	*melas*	0	0	0	0	0
	Ameiurus	*nebulosus*	0	0	0	0	0
	Pylodictis	*olivaris*	0	0	0	0	1
Aphredoderidae	*Aphredoderus*	*sayanus*	10	8	0	0	0
Fundulidae	*Fundulus*	*chrysotus*	2	0	0	0	2
	Fundulus	*nottii*	69	11	12	0	0
	Fundulus	*olivaceus*	247	388	438	106	38
	Lucania	*parva*	0	0	0	0	0
Cyprinidontidae	*Cyprinodon*	*variegatus*	0	0	0	0	0
Poeciliidae	*Poecilia*	*latipinna*	0	0	0	0	3
	Gambusia	*affinis*	121	229	170	48	84
Atherinidae	*Labidesthes*	*sicculus*	82	76	434	50	571
Elassomatidae	*Elassoma*	*zonatum*	50	17	5	0	0
Centrarchidae	*Centrarchus*	*macropterus*	0	0	0	0	0
	Pomoxis	*nigromaculatus*	0	0	0	0	0
	Micropterus	*salmoides*	17	18	29	7	29
	Lepomis	*gulosus*	17	4	0	2	1
	Lepomis	*megalotis*	182	97	599	321	86
	Lepomis	*symmetricus*	0	0	0	0	0
	Lepomis	*miniatus*	8	0	0	0	2
	Lepomis	*macrochirus*	18	21	44	15	211
	Lepomis	*microlophus*	0	0	0	33	1
	Lepomis	*marginatus*	2	1	0	0	1
Percidae	*Etheostoma*	*chlorosoma*	0	0	0	11	0
	Etheostoma	*fusiforme*	27	4	0	0	0
	Etheostoma	*parvipinne*	3	0	0	0	0
	Species	**Totals**	**23**	**18**	**13**	**13**	**19**

Table 12: Farabee's species list from Stations 1-4 and Station 6 during the 1988-1989 fish survey.

Family	**Genus**	**Species**	**Station 1**	**Station 2**	**Station 3**	**Station 4**	**Station 6**
Lepisosteidae	*Atractosteus*	*spatula*	0	0	0	N/A	0
	Lepisosteus	*oculatus*	0	0	0	N/A	1
	Lepisosteus	*osseus*	0	0	0	N/A	0
Amiidae	*Amia*	*calva*	0	0	0	N/A	0
Anguillidae	*Anguilla*	*rostrata*	0	0	0	N/A	0
Cluepidae	*Dorosoma*	*cepedianum*	0	0	0	N/A	0
	Dorosoma	*petenense*	0	0	0	N/A	25
Esocidae	*Esox*	*americanus*	7	2	0	N/A	0
Cyprinidae	*Notemigonus*	*crysoleucas*	0	0	0	N/A	1
	Cyprinella	*venusta*	0	0	0	N/A	0
	Opsopoeodus	*emiliae*	0	0	0	N/A	15
	Notropis	*texanus*	16	12	194	N/A	0
Catostomidae	*Minytrema*	*melanops*	0	0	1	N/A	0
	Erimyzon	*sucetta*	0	0	0	N/A	0
	Erimyzon	*tenuis*	33	33	1	N/A	0
Ictaluridae	*Ictalurus*	*punctatus*	0	0	0	N/A	1
	Ictalurus	*furcatus*	0	0	0	N/A	0
	Ameiurus	*natalis*	0	0	0	N/A	0
	Ameiurus	*melas*	0	0	0	N/A	0
	Ameiurus	*nebulosus*	0	0	0	N/A	0
	Pylodictis	*olivaris*	0	0	0	N/A	0
Aphredoderidae	*Aphredoderus*	*sayanus*	5	2	0	N/A	0
Fundulidae	*Fundulus*	*chrysotus*	0	0	0	N/A	4
	Fundulus	*nottii*	22	26	1	N/A	2
	Fundulus	*olivaceus*	1	15	41	N/A	90
	Lucania	*parva*	0	0	1	N/A	0
Cyprinidontidae	*Cyprinodon*	*variegatus*	0	0	0	N/A	1
Poeciliidae	*Poecilia*	*latipinna*	0	0	0	N/A	0
	Gambusia	*affinis*	64	29	266	N/A	71
Atherinidae	*Labidesthes*	*sicculus*	43	16	171	N/A	1035
Elassomatidae	*Elassoma*	*zonatum*	9	3	8	N/A	0
Centrarchidae	*Centrarchus*	*macropterus*	0	0	0	N/A	0
	Pomoxis	*nigromaculatus*	0	0	0	N/A	0
	Micropterus	*salmoides*	1	2	7	N/A	33
	Lepomis	*gulosus*	6	4	1	N/A	6
	Lepomis	*megalotis*	29	60	102	N/A	137
	Lepomis	*symmetricus*	0	0	0	N/A	0
	Lepomis	*miniatus*	8	4	2	N/A	15
	Lepomis	*macrochirus*	11	39	36	N/A	522
	Lepomis	*microlophus*	1	0	1	N/A	30
	Lepomis	*marginatus*	3	1	0	N/A	3
Percidae	*Etheostoma*	*chlorosoma*	0	0	0	N/A	0
	Etheostoma	*fusiforme*	0	0	0	N/A	3
	Etheostoma	*parvipinne*	37	4	0	N/A	0
	Species	**Totals**	**17**	**16**	**15**	**N/A**	**19**

Table 13: Van Vrancken's species list from Stations 1-4 and Station 6 during the current 2005-2007 fish survey.

Family	**Genus**	**Species**	**Station 1**	**Station 2**	**Station 3**	**Station 4**	**Station 6**
Lepisosteidae	*Atractosteus*	*spatula*	0	0	0	1	2
	Lepisosteus	*oculatus*	1	2	4	65	25
	Lepisosteus	*osseus*	0	0	0	2	1
Amiidae	*Amia*	*calva*	0	0	0	4	4
Anguillidae	*Anguilla*	*rostrata*	0	5	4	6	9
Cluepidae	*Dorosoma*	*cepedianum*	0	0	0	9	1
	Dorosoma	*petenense*	0	0	0	16	18
Esocidae	*Esox*	*americanus*	104	29	14	0	0
Cyprinidae	*Notemigonus*	*crysoleucas*	0	0	2	1	0
	Cyprinella	*venusta*	0	0	0	0	0
	Opsopoeodus	*emiliae*	0	0	0	0	0
	Notropis	*texanus*	0	0	8	0	0
Catostomidae	*Minytrema*	*melanops*	20	70	15	28	6
	Erimyzon	*sucetta*	14	0	0	0	0
	Erimyzon	*tenuis*	64	5	0	0	1
Ictaluridae	*Ictalurus*	*punctatus*	0	0	0	0	0
	Ictalurus	*furcatus*	0	0	0	4	7
	Ameiurus	*natalis*	25	20	25	3	2
	Ameiurus	*melas*	2	0	0	0	3
	Ameiurus	*nebulosus*	0	0	0	1	0
	Pylodictis	*olivaris*	0	0	0	0	0
Aphredoderidae	*Aphredoderus*	*sayanus*	143	177	211	12	0
Fundulidae	*Fundulus*	*chrysotus*	0	0	0	0	1
	Fundulus	*nottii*	28	4	5	3	1
	Fundulus	*olivaceus*	2	10	98	14	0
	Lucania	*parva*	0	1	3	25	8
Cyprinidontidae	*Cyprinodon*	*variegatus*	0	0	0	0	0
Poeciliidae	*Poecilia*	*latipinna*	0	0	0	0	0
	Gambusia	*affinis*	13	37	63	0	0
Atherinidae	*Labidesthes*	*sicculus*	0	1	11	270	75
Elassomatidae	*Elassoma*	*zonatum*	275	132	44	0	0
Centrarchidae	*Centrarchus*	*macropterus*	2	1	0	0	0
	Pomoxis	*nigromaculatus*	0	0	0	6	2
	Micropterus	*salmoides*	96	102	54	282	210
	Lepomis	*gulosus*	12	16	18	21	57
	Lepomis	*megalotis*	187	286	405	7	4
	Lepomis	*symmetricus*	4	0	0	0	0
	Lepomis	*miniatus*	9	71	73	67	135
	Lepomis	*macrochirus*	34	82	133	437	513
	Lepomis	*microlophus*	0	0	0	320	103
	Lepomis	*marginatus*	14	4	0	0	0
Percidae	*Etheostoma*	*chlorosoma*	0	0	0	0	0
	Etheostoma	*fusiforme*	0	0	0	0	0
	Etheostoma	*parvipinne*	18	2	1	0	0
	Species	**Totals**	**21**	**21**	**20**	**24**	**23**

salmoides) were excluded from statistical analyses. *G. affinis* were observed in large numbers (approximately 30 to 40 individuals) during the current fish assemblage survey but were not sampled effectively by electrofishing. *M. salmoides* were also excluded from statistical analyses because the Louisiana Department of Wildlife and Fisheries (LDWF) confirmed stocking this species in the Bayou during the spring of 2005 and 2006 (Howard Rogillio, pers. comm.). The LDWF was unable to tell me exactly just how many *M. salmoides* were stocked into the Bayou since their stocking ponds were flooded from Hurricane Katrina's storm surge. Environmental variable data (i.e., dissolved oxygen, salinity, etc.) from Sobczak's study and Farabee's study were unavailable for comparisons.

Bayou Lacombe Station 1: Highway 36

Fish assemblages collected during Sobczak's study and Farabee's study were significantly different (ANOSIM, R = 0.571, p = 0.001) with the composition of fish assemblages exhibiting no overlap (Figure 22). Numbers of *L. megalotis*, *E. tenuis*, *F. olivaceus*, and most cyprinid species (specifically *N. texanus*) declined over this fifteen-year period (Table 14). However, during the same period the abundance of *E. parvipinne* increased (Table 14). The comparison between Farabee's study and the current study revealed significant differences (ANOSIM, R = 0.708, p = 0.001) with no overlap in assemblage data (Figure 22). Numbers of *Elassoma zonatum*, *L. megalotis*, *A. sayanus*, and *Esox americanus* all increased during the fifteen-year period between samples (Table 14). Only the abundance of *L. sicculus* declined during this same time period at Station 1 (Table 14). The fish assemblages collected in Sobczak's study were also significantly different (ANOSIM, R = 0.763, p = 0.001) than the assemblage samples collected in my current fish assemblage survey. Again, there is no overlap of fish assemblage samples between sampling periods (Figure 22). Abundances of *Elassoma*

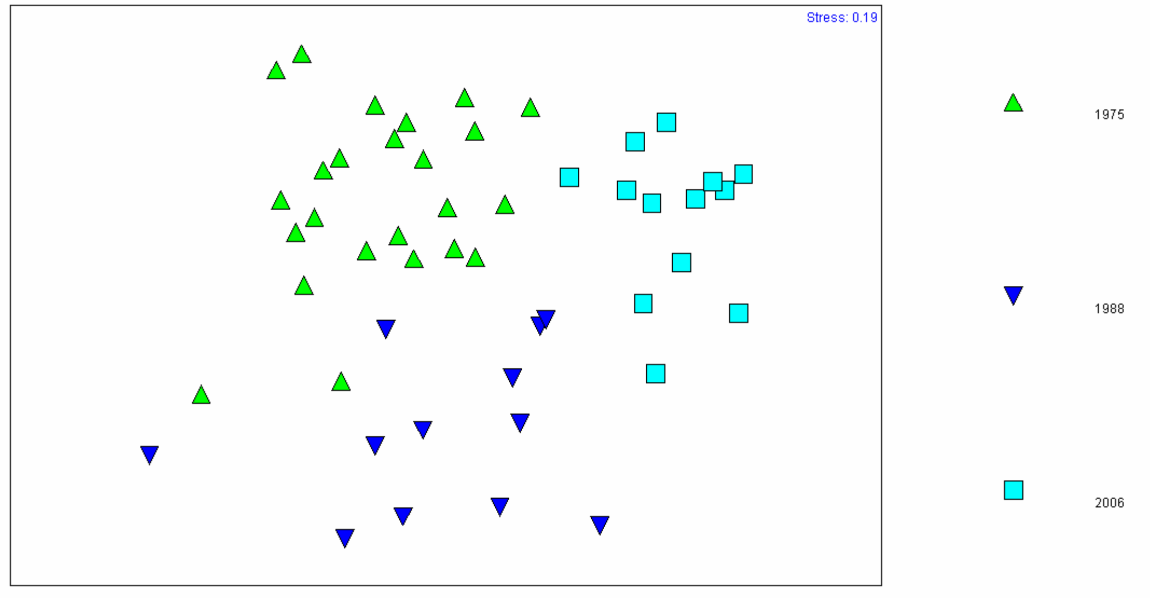

Figure 22: Non-metric Multidimensional Scaling (MDS) plot of fish assemblage samples taken at Station 1 during all three periods of collections (Sobczak's 1973-1975 survey, Farabee's 1988-1989 survey and the current 2005-2007 survey).

Table 14: Analysis of Similarity (ANOSIM) and Similarity Percentages (SIMPER) for fishes collected at Station 1 during the three periods of sampling for historical comparisons. Only the top five species associated with the greatest change between sampling periods are listed.

Time Period Comparison	R-value	p-value	Species	Pre-Event Mean Abundance	Post-Event Mean Abundance	Contrib. %
1973-1975 vs. 1988-1989	0.571	0.001	*Fundulus olivaceus*	10.29	0.08	14.76
			Lepomis megalotis	7.58	2.42	9.24
			Notropis texanus	4.46	1.33	7.52
			Etheostoma parvipinne	0.13	3.08	7.06
			Erimyzon tenuis	3.25	2.75	7.00
1988-1989 vs. 2005-2007	0.708	0.001	*Elassoma zonatum*	0.75	21.25	12.10
			Lepomis megalotis	2.42	14.38	10.22
			Aphredoderus sayanus	0.42	11.00	10.07
			Esox americanus	0.58	8.00	8.42
			Labidesthes sicculus	3.58	0.00	4.95
1973-1975 vs. 2005-2007	0.763	0.001	*Elassoma zonatum*	2.08	21.15	10.59
			Fundulus olivaceus	10.29	0.15	9.17
			Aphredoderus sayanus	0.42	11.00	9.01
			Esox americanus	0.25	8.00	8.13
			Notropis texanus	4.46	0.00	5.61

zonatum, *A. sayanus*, and *Esox americanus* increased over the thirty-year time period (Table 14). Over this same time period, numbers of *F. olivaceus* and *N. texanus* markedly decreased (Table 14).

Bayou Lacombe Station 2: Highway 434

At Station 2 fish assemblages collected during Sobczak's and Farabee's studies were significantly different (ANOSIM, R = 0.562, p = 0.001). The composition of fish assemblages exhibited no overlap (Figure 23). Abundances of *F. olivaceus* and all cyprinids, such as *C. venusta* and *N. texanus*, markedly decreased over the fifteen-year period between samples (Table 15). In addition, numbers of *L. sicculus* also decreased, though only slightly (Table 15). In contrast, abundances of *L. macrochirus* increased over the same period (Table 15). When fish collected during Farabee's study and my study were compared significant differences (ANOSIM, R = 0.757, p = 0.001) were found and the fish assemblages did not overlap (Figure 23). Numbers of *A. sayanus*, *L. megalotis*, *E. zonatum*, and *L. miniatus* all increased over the 15-year gap between studies (Table 15). During this same time, abundances of *N. texanus* decreased at Station 2 (Table 15). The fish assemblages sampled in Sobczak's study were also significantly different (ANOSIM, R = 0.904, p = 0.001) than the fish assemblages sampled in my current survey. There is, again, no overlap of fish assemblage samples between the thirty-year sampling periods (Figure 23). Abundances of *A. sayanus* and *L. megalotis* markedly increased over this period between samples (Table 15). Similar to Station 1 results, *F. olivaceus* and all minnows, specifically *C. venusta* and *N. texanus*, decreased during this same time period (Table 15). In fact, the absence of *C. venusta* from current fish assemblage samples confirms the extirpation of *C. venusta* from Station 2.

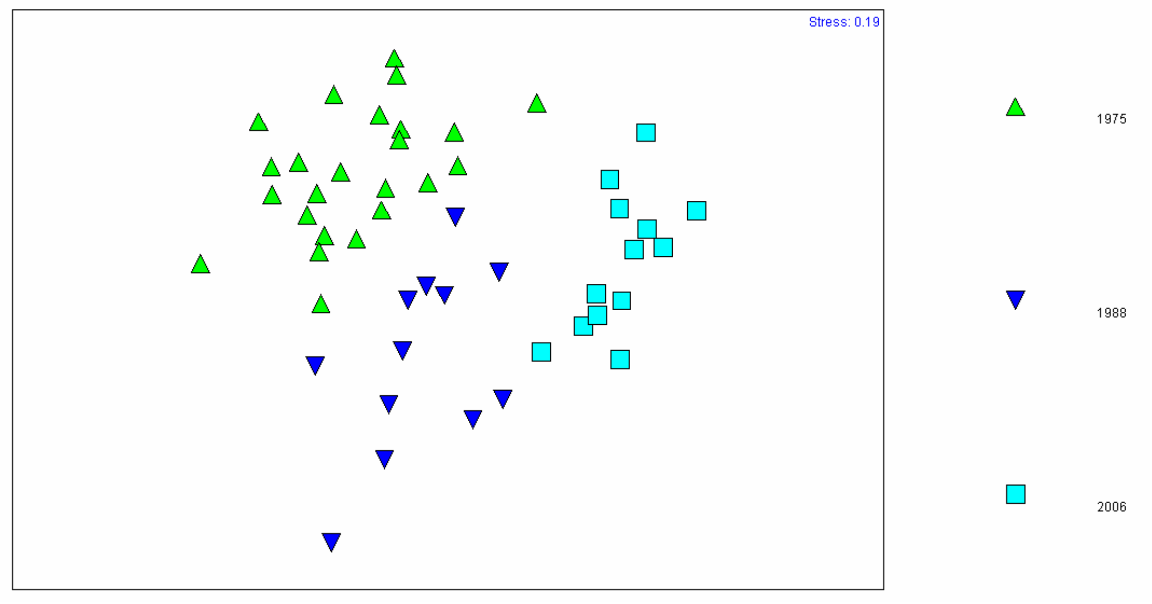

Figure 23: MDS plot of fish assemblage samples taken at Station 2 during all three periods of collections (Sobczak's 1973-1975 survey, Farabee's 1988-1989 survey and the current 2005-2007 survey).

Table 15: ANOSIM and SIMPER for fishes collected at Station 2 during the three periods of sampling for historical comparisons. Only the top five species associated with the greatest change between sampling periods are listed.

Time Period Comparison	R-value	p-value	Species	Pre-Event Mean Abundance	Post-Event Mean Abundance	Contrib. %
1973-1975 vs. 1988-1989	0.562	0.001	*Cyprinella venusta*	11.71	0.00	15.97
			Fundulus olivaceus	16.00	1.58	15.97
			Notropis texanus	4.54	1.00	7.90
			Lepomis macrochirus	0.88	3.25	6.80
			Labidesthes sicculus	3.17	1.33	6.65
1988-1989 vs. 2005-2007	0.757	0.001	*Aphredoderus sayanus*	0.17	13.62	13.10
			Lepomis megalotis	5.00	22.00	10.84
			Elassoma zonatum	0.25	10.15	8.86
			Lepomis miniatus	0.33	5.46	6.94
			Notropis texanus	1.00	0.00	5.53
1973-1975 vs. 2005-2007	0.904	0.001	*Aphredoderus sayanus*	0.33	13.62	10.01
			Fundulus olivaceus	16.00	0.77	9.88
			Lepomis megalotis	4.04	22.00	9.76
			Cyprinella venusta	11.71	0.00	8.97
			Notropis texanus	4.54	0.00	4.89

Bayou Lacombe Station 3: Krentel Road

Fish assemblage samples collected during Sobczak's study and Farabee's study were significantly different (ANOSIM, R = 0.639, p = 0.001) with the composition of fish assemblages exhibiting some overlap (Figure 24). Abundances of *L. megalotis*, *F. olivaceus*, and *L. sicculus* showed slight declines between the sample periods (Table 16). Numbers of *N. texanus* were relatively unchanged over the 15-year period (Table 16). In contrast, Farabee never captured *C. venusta* during his study from the late 1980's (Table 16). When comparing fish assemblages collected from Farabee's study with the assemblages collected in my study significant differences (ANOSIM, R = 0.627, p = 0.001) between samples were found. Unlike when comparing Sobczak's fish assemblage samples with Farabee's samples, there was no overlap in fish assemblage samples between Farabee's study and my own study (Figure 24). Abundances of *L. megalotis*, *A. sayanus*, and *F. olivaceus* increased over the fifteen-year gap in fish assemblage samples at Station 3 (Table 16). Abundances of *N. texanus* and *L. sicculus* were markedly lower in my current samples as compared to those from Farabee's study at this station (Table 16). After comparing fish assemblage samples collected during Sobczak's study and my current study significant differences (ANOSIM, R = 0.883, p = 0.001) again were found and the composition of fish assemblages showed no overlap (Figure 24). Abundances of *A. sayanus* and *L. megalotis* increased over the thirty-year period between samples (Table 16). Numbers of *N. texanus* and *L. sicculus* markedly decreased during the same period (Table 16). Also, the most abundant species, *C. venusta*, sampled by Sobczak in the 1970's at Station 3 never occurred in any samples during the current study. The absence of this species in current fish assemblage samples confirms the extirpation of *C. venusta* from Station 3.

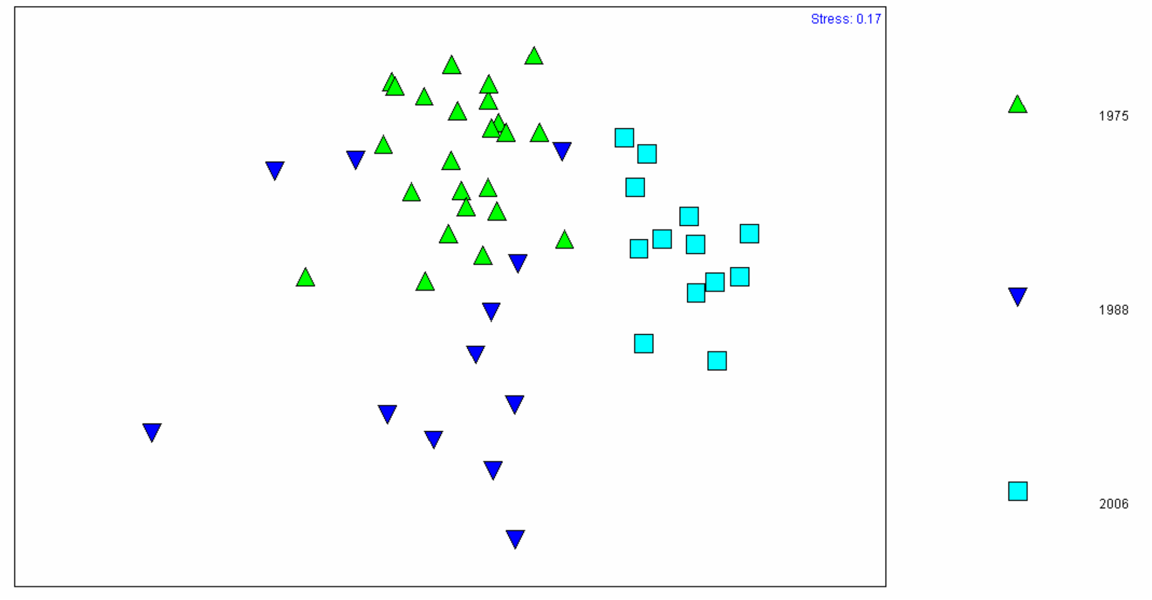

Figure 24: MDS plot of fish assemblage samples taken at Station 3 during all three periods of collections (Sobczak's 1973-1975 survey, Farabee's 1988-1989 survey and the current 2005-2007 survey).

Table 16: ANOSIM and SIMPER for fishes collected at Station 3 during the three periods of sampling for historical comparisons. Only the top five species associated with the greatest change between sampling periods are listed.

Time Period Comparison	R-value	p-value	Species	Pre-Event Mean Abundance	Post-Event Mean Abundance	Contrib. %
1973-1975 vs. 1988-1989	0.639	0.001	*Cyprinella venusta*	52.67	0.00	24.80
			Lepomis megalotis	24.96	8.50	13.70
			Fundulus olivaceus	18.25	3.42	13.33
			Notropis texanus	16.42	16.17	11.53
			Labidesthes sicculus	18.08	14.25	11.27
1988-1989 vs. 2005-2007	0.627	0.001	*Lepomis megalotis*	8.50	31.15	13.23
			Aphredoderus sayanus	0.00	16.23	12.33
			Notropis texanus	16.17	0.62	8.60
			Labidesthes sicculus	14.25	0.85	8.40
			Fundulus olivaceus	3.42	7.54	6.74
1973-1975 vs. 2005-2007	0.883	0.001	*Cyprinella venusta*	52.67	0.00	18.49
			Aphredoderus sayanus	0.00	16.23	10.43
			Notropis texanus	16.42	0.62	8.80
			Labidesthes sicculus	18.08	0.85	8.06
			Lepomis megalotis	24.96	31.15	6.95

Bayou Lacombe Station 4: Fish Hatchery

Fish assemblage samples collected during Sobczak's and my current studies were significantly different (ANOSIM, R = 0.981, p = 0.001) with the composition of fish assemblages exhibiting no overlap (Figure 25). The majority of centrarchid species, specifically *L. macrochirus*, *L. microlophus*, *L. miniatus*, and *L. gulosus*, increased in abundance over the thirty-year interval between studies (Table 17). However, *L. megalotis* numbers markedly decreased during this same time period (Table 17). Also, showing increases in abundance were *L. oculatus* and *M. melanops*. All cyprinids, such as *C. venusta*, *O. emiliae*, and *N. texanus*, were never captured at Station 4 during the current survey (Table 17). In addition, *F. olivaceus* numbers markedly decreased.

Bayou Lacombe Station 6: Main Street

Fish assemblages collected during Sobczak's study and Farabee's study were significantly different (ANOSIM, R = 0.508, p = 0.001) with the composition of fish assemblages exhibiting no overlap (Figure 26). Numbers of *L. sicculus*, *L. macrochirus*, *F. olivaceus*, and *L. megalotis* increased during the fifteen-year interval between fish assemblage samples at Station 6 (Table 18). Similar to the other stations sampled by Sobczak and Farabee, *C. venusta* were never captured in Farabee's study at Station 6 (Table 18). When the fish assemblages collected during Farabee's study and my study were compared significant differences (ANOSIM, R = 0.784, p = 0.001) again were found and the fish assemblage compositions did not overlap (Figure 26). The abundance of *L. sicculus* markedly decreased during the fifteen-year interval between studies (Table 18). Numbers of *L. macrochirus*, *L. megalotis*, and *F. olivaceus* also decreased between sampling periods (Table 18). Only the inland silverside, *Menidia beryllina*, increased between sampling periods (Table 18). The fish

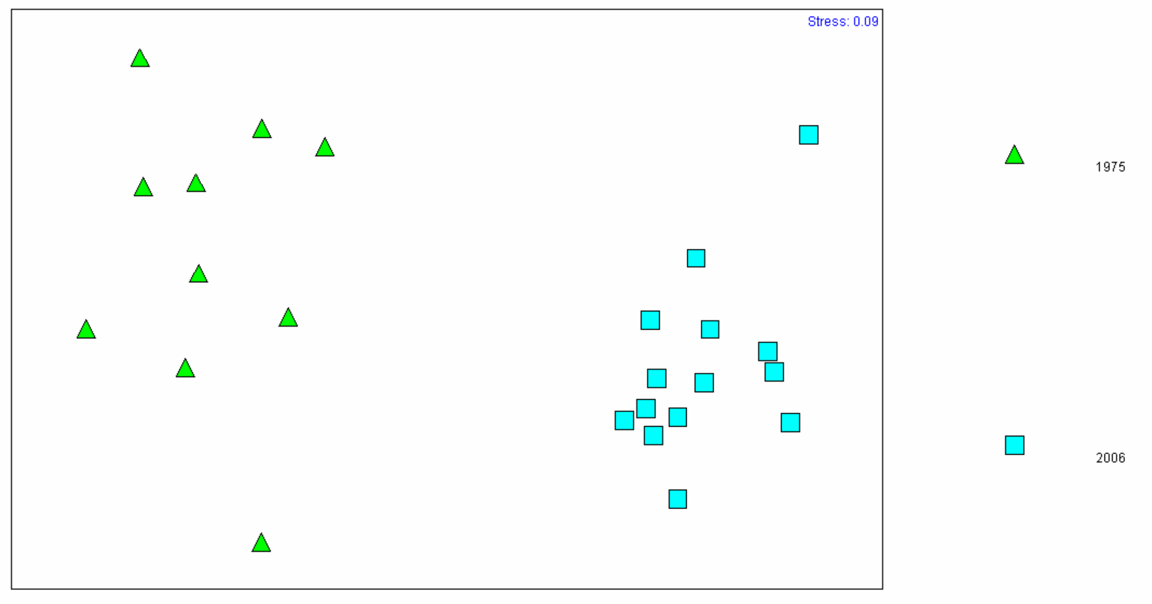

Figure 25: MDS plot of fish assemblage samples taken at Station 4 during only Sobczak's 1973-1975 survey and the current 2005-2007 survey. Farabee was unable to sample this site in his 1988-1989 survey.

Table 17: ANOSIM and SIMPER for fishes collected at Station 4 during only Sobczak's study and the current study because Farabee did not sample Station 4. Nearly all of the species captured during both periods of sampling are listed.

Time Period Comparison	R-value	p-value	Species	Pre-Event Mean Abundance	Post-Event Mean Abundance	Contrib. %
1973-1975 vs. 2005-2007	0.981	0.001	*Cyprinella venusta*	81.10	0.00	13.66
			Lepomis megalotis	32.10	0.50	11.25
			Lepomis macrochirus	1.50	31.21	10.96
			Lepomis microlophus	3.30	22.86	8.87
			Micropterus salmoides	0.70	20.14	8.65
			Labidesthes sicculus	5.00	19.29	6.25
			Fundulus olivaceus	10.60	1.00	5.96
			Lepomis miniatus	0.00	4.79	4.38
			Lepisosteus oculatus	0.00	4.64	3.79
			Opsopoeodus emiliae	5.80	0.00	3.28
			Minytrema melanops	0.00	2.00	2.23
			Notropis texanus	3.30	0.00	2.14
			Lepomis gulosus	0.20	1.50	2.02

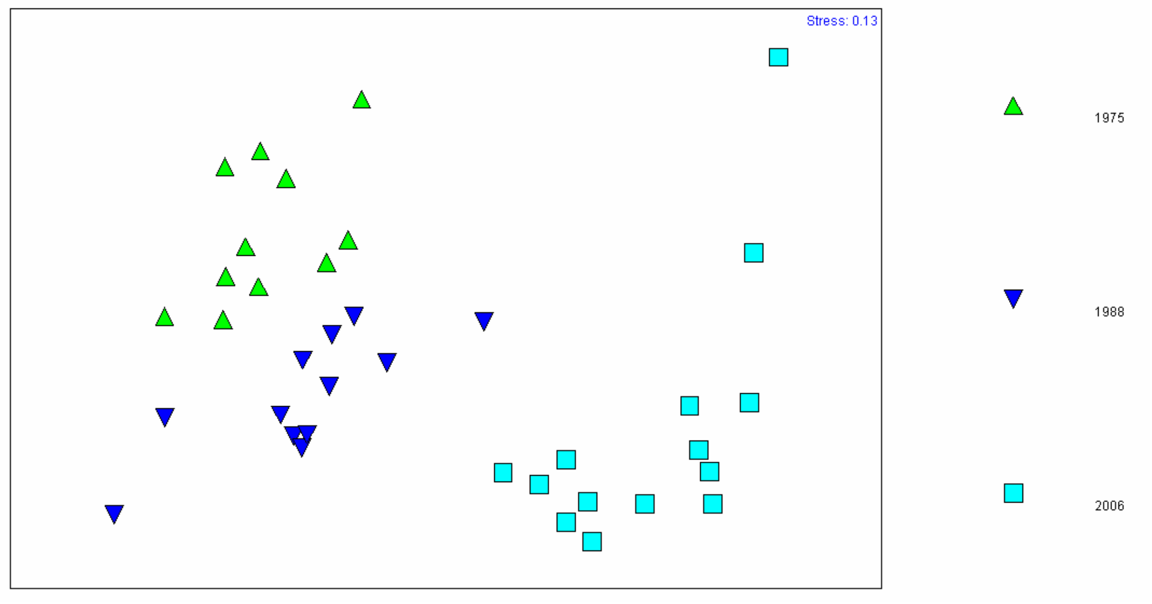

Figure 26: MDS plot of fish assemblage samples taken at Station 6 during all three periods of collections (Sobczak's 1973-1975 survey, Farabee's 1988-1989 survey and the current 2005-2007 survey).

Table 18: ANOSIM and SIMPER for fishes collected at Station 6 during the three periods of sampling for historical comparisons. Only the top five species associated with the greatest change between sampling periods are listed.

Time Period Comparison	R-value	p-value	Species	Pre-Event Mean Abundance	Post-Event Mean Abundance	Contrib. %
1973-1975 vs. 1988-1989	0.508	0.001	*Cyprinella venusta*	47.64	0.00	21.17
			Labidesthes sicculus	51.73	86.25	15.74
			Lepomis macrochirus	19.18	43.50	13.22
			Fundulus olivaceus	3.45	7.50	5.42
			Lepomis megalotis	7.82	11.42	5.11
1988-1989 vs. 2005-2007	0.784	0.001	*Labidesthes sicculus*	86.25	5.36	21.05
			Lepomis macrochirus	43.50	36.64	9.68
			Lepomis megalotis	11.42	0.29	7.67
			Fundulus olivaceus	7.50	0.00	7.22
			Menidia beryllina	4.42	20.86	6.60
1973-1975 vs. 2005-2007	0.920	0.001	*Cyprinella venusta*	47.64	0.00	14.90
			Labidesthes sicculus	51.73	5.36	13.43
			Lepomis macrochirus	19.18	36.64	7.16
			Lepomis miniatus	0.18	9.64	6.43
			Lepomis megalotis	7.82	0.29	6.20

assemblages collected in Sobczak's study were also significantly different (ANOSIM, R = 0.920, p = 0.001) than the assemblage samples collected in my current fish assemblage survey. Again, there is no overlap of fish assemblage samples between sampling periods (Figure 26). Abundances of *L. sicculus* and *L. megalotis* decreased between the thirty-year sampling periods (Table 18). In contrast, numbers of *L. macrochirus* and *L. miniatus* increased during the same time period (Table 18). *Cyprinella venusta* was never sampled here during the current study (Table 18), verifying the extirpation of this species whose first disappearance was noted in Farabee's study.

Discussion

Relative Resilience of Fish Assemblages: Upstream Stations

Hurricane Katrina significantly impacted upstream fish assemblages in Bayou Lacombe. Although the saltwater storm surge did not penetrate the upstream portions of Bayou Lacombe, the extremely high winds caused a different type of disturbance for these fishes and the habitats. The effects of fallen trees and increasing leaf litter were probably not sufficient enough to alter the fish assemblage initially, similar to the findings of Schaefer et al. (2006) in their fish assemblage study of the upstream portions of Black Creek, MS, soon after Hurricane Katrina's impact. But the build-up of debris behind fallen trees over weeks and months did significantly reduce dissolved oxygen in the narrow, upper portions of Bayou Lacombe creating an hypoxic environment. Fishes that could not tolerate this extended period of low dissolved oxygen, such as *L. macrochirus* and *L. megalotis*, likely moved downstream or died. Various species of the genus *Lepomis* are able to tolerate periods of low dissolved oxygen, though these fishes are unable to occupy habitats frequently or continuously experiencing low dissolved oxygen (Lewis, 1970). As a result, species that could tolerate low dissolved oxygen and occupy habitats with high concentrations of organic debris, such as *A. sayanus* and *E. zonatum* (Pflieger, 1975; Boschung and Mayden, 2004), became very abundant. These species may have also become more numerous because of the lack of predators, such as *Micropterus salmoides* and *E. americanus*. In addition, no *E. parvipinne*, the only darter species collected, were sampled following the storm. It is possible that this species may not have been sampled effectively given the electrofishing sampling bias and poor water visibility. Paerl et al. (2001) found increased mortality of benthic species due to low dissolved oxygen and/or salinity stress in their studies following three hurricanes in a lagoonal estuary. The weed shiner, *Notropis texanus*, also was never captured again after the storm. The disappearance of *N. texanus* may be the result of reduced refuge from downstream salinity and upstream low dissolved oxygen. Even though there is some seasonal migratory variation, after the debris was removed from the Bayou, upstream fish assemblage began recovering to the pre-Katrina assemblage (Figure 27). Fish assemblage recovery from effects of lasting low dissolved oxygen is not well documented. Hynes (1960) showed longitudinal recovery of stream biota from low dissolved oxygen caused by sewage discharge. The most abundant upstream fish species prior to Hurricane Katrina, *L. megalotis*, is well-known for its ability to re-establish in prior habitats of Bayou Lacombe after being removed from these areas (Berra, 1969; Gunning and Berra, 1969; Berra and Gunning, 1970).

While the removal of debris from the Bayou by FEMA contractors helped to increase water flow and decrease the build-up of decaying organic material, the impacts of mechanically clearing bank vegetation to access the Bayou for debris removal were significant and appear to be long-lasting (Van Vrancken, *pers. obs.*). The canopy that once provided shade to the Bayou on the eastern banks no longer exists and the increased exposure to sunlight may raise water temperatures, further disturbing the aquatic community. Not only has the canopy disappeared, but the natural buffer to runoff has vanished as well. Now organic debris and sediments flow directly into the Bayou after heavy rains.

Information on hurricane effects on small coastal streams is lacking. My review of the current literature suggests that there have been no studies on first order streams that have been exposed to multiple impacts from one hurricane. Dolloff et al. (2004) documented the impacts of habitat destruction caused by high winds from Hurricane Hugo on the fish populations of an

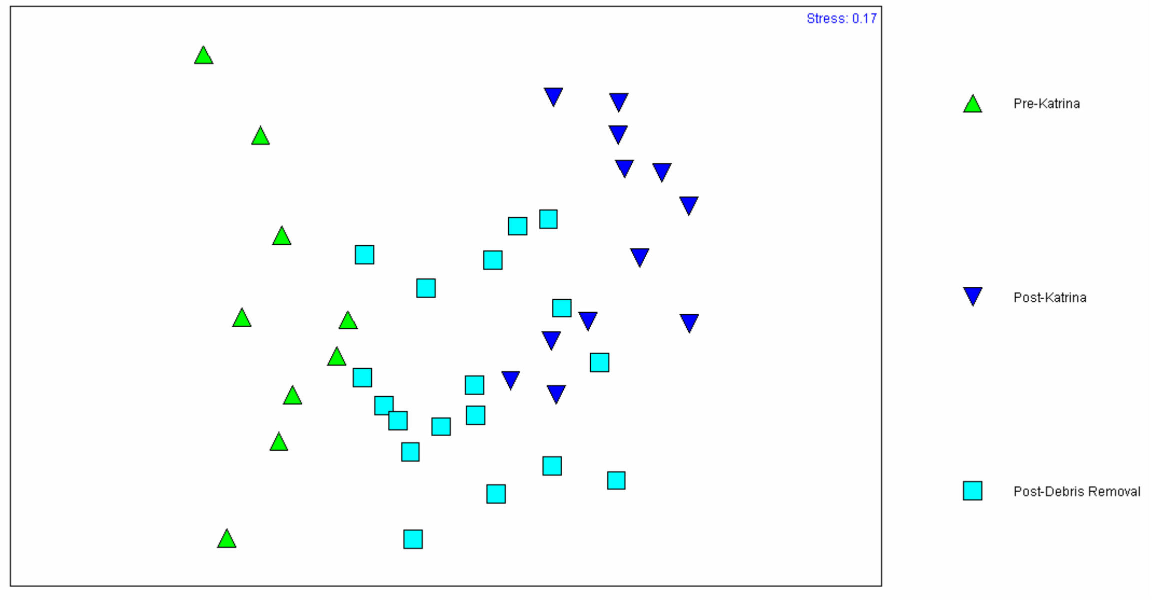

Figure 27: All upstream samples from the current 2005-2007 study. Pre-Katrina and post-Katrina samples are completely separated. Post-debris removal samples are shown migrating from being more similar to post-Katrina samples to becoming more similar to pre-Katrina fish assemblages. This is showing visually that the Bayou is in fact recovering to pre-Katrina fish assemblages.

Appalachian watershed. There have also been fish assemblage studies regarding the effects of saltwater tidal surge on estuarine environments (Paperno et al., 2006; Blanke, 2006). In all of the pre- and post-storm estuarine fish assemblage studies, the storm surge itself seemed to have minimal, if any, impact on the fish assemblages. Estuarine fishes are saltwater tolerant and have more places to flee in the event of disturbance (Keup and Bayless, 1964; Paperno et al., 2006). Bayou Lacombe is unique in the fact that the lower reaches were submerged by a large saltwater tidal surge while upstream portions of the Bayou sustained habitat damage from unrelenting gale-force winds. Freshwater fishes in a small waterbody, such as Bayou Lacombe, have limited areas to seek refuge during large storm events (especially if the western eye-wall of a hurricane passes directly over-head) and significant impacts on their populations should be expected.

Schaefer et al. (2006) sampled freshwater fishes in the months following Hurricane Katrina in the nearby Pascagoula River and some of its tributaries in southern Mississippi. Fish assemblages in downstream stations experienced significant change directly after the storm due to the overwhelming storm surge. Upstream fish assemblages were unchanged and sustained similar habitat destruction as Bayou Lacombe's upstream portions. These results are opposite of what I observed in Bayou Lacombe. In samples conducted a year after the storm, I found that there was no difference in downstream fish assemblages and significant upstream fish assemblage changes. The initial saltwater storm surge impacts on downstream areas, as documented by Schaefer et al. (2006), and hypoxic conditions due to debris decay in smaller portions upstream, as supported in the current study, are enough to significantly change fish assemblages. My study was different from Schaefer et al. (2006) in that sampling was conducted a year after the storm event and was contained within one tributary of Lake Pontchartrain, rather than a large river (Pascagoula River) with numerous freshwater tributaries. Bayou Lacombe has limited places and refuges for freshwater fishes to flee in the event of a large disturbance. Located to the south is Lake Pontchartrain, a brackish water estuary, while 46.1 km to the north are intermittent headwaters. Baseline data are very important to draw conclusions about large infrequent disturbances such as Hurricane Katrina. Although there were few samples conducted before the storm, this information was imperative in understanding how a small system's fish assemblage responded to a catastrophic event. Short and long-term data sets play a crucial role in understanding fish assemblage shifts.

Relative Resilience of Fish Assemblages: Downstream Stations

While Hurricane Katrina's storm surge penetrated the lower portions of Bayou Lacombe and likely displaced fishes and created hypoxic environments (Buck, 2005; Schaefer et al., 2006), my results suggest that the local fish assemblages were resistant to these impacts and the significant increase in salinity that was present in these habitats the following summer. This is no surprise given that the lower portions of Bayou Lacombe are subject to daily tidal flux from the brackish waters of Lake Pontchartrain. Again this is different from Schaefer et al. (2006), who found that in the lower portions of the Pascagoula River and Black Creek showed large changes in fish assemblage composition in the months following Hurricane Katrina. Other studies on hurricane impacts on estuarine fish assemblages have been documented and have showed relatively small differences in pre- and post-storm assemblage data (Hutchinson and Williams, 2003; Paperno et al., 2006; Blanke, 2006). All of the species collected from downstream samples (primarily centrarchids) in the current study can tolerate temporary periods of high salinity brackish water (i.e., 15-20 ppt) and can easily survive in salinities of 8 ppt or less (Keup and Bayless, 1964). Hutchinson and Williams (2003) have shown that inter-tidal communities can respond quickly to severe tropical disturbances, and they suggest that seasonal temperature variations have more of a long-lasting effect on community structure than infrequent severe natural disturbances.

Unlike the downstream sampling conducted in the summer after Hurricane Katrina that showed no significant differences in fish assemblages, the continued downstream sampling after the debris dams were removed did show significant differences in assemblages, supporting the seasonal temperature variation theory suggested by Hutchinson and Williams (2003). In the colder months of sampling, similar species were collected but in very different relative abundances than those taken during summer months. For example, at Station 5 many more *Menidia beryllina* were captured during the winter samples because *M. beryllina* are known to reproduce in shallow, heavily vegetated areas during this time (Hubbs, 1982; Middaugh and Hemmer, 1992; Boschung and Mayden, 2004). Similarly, *Labidesthes sicculus* reproduce in late August. The young remain in deepwater channels until they reach approximately 60mm in length, which occurs mid-Winter (Hubbs, 1921; Nelson, 1968; Pflieger, 1975; Boschung and Mayden, 2004). It is during mid-winter samples that this species became more abundant in current downstream Bayou Lacombe samples. Abundances of *M. salmoides* dropped during winter samples since they tended to seek refuge in deeper portions of the waterway in colder temperatures. The altering abundances of fishes in Bayou Lacombe due to seasonal change were documented in Farabee's (1992) thesis. His autumn and winter abundances of silversides (*M. beryllina* and *L. sicculus*) and *M. salmoides* reflect those of current autumn and winter sample data. All of the downstream fishes captured in the most recent fish survey conducted in Bayou Lacombe have a relatively high tolerance to the influence of brackish water according to Pflieger (1975) and Boschung and Mayden (2004). The difference in salinity tolerance of Bayou

Lacombe fish species is more than likely responsible for the clear separation of downstream and upstream fish assemblages (Figure 28).

Historical Bayou Lacombe Fish Assemblage Changes

The results of the current study confirm the extirpation of *C. venusta* from Bayou Lacombe. Farabee (1992) was the first investigator to recognize the disappearance of *C. venusta* from Bayou Lacombe in his fish assemblage study from the late 1980's. His data represent a "midpoint" in time between Sobczak's study and my current 2005-2007 study. My results are consistent with a pattern of changing fish assemblages in Bayou Lacombe as recognized by these earlier studies. My analyses show that fish assemblages have changed significantly in Bayou Lacombe over the past 35 years. The extirpation of *C. venusta*, once the most abundant species in this system, may have been a species-specific event, but my analyses suggest that all minnow species in the Bayou have decreased over time. The basic trend is that all cyprinids (minnows) are decreasing over time and all centrarchids (sunfishes) are increasing over time. Because Sobczak's and Farabee's field notes were unavailable for water quality comparisons, I was unable to link possible environmental changes to these species shifts. This makes definite answers to the fish assemblage trends unclear. However, there have been some local events that provide possible insight into why the fish assemblages of Bayou Lacombe have changed.

The habitat surrounding Bayou Lacombe has been considerably altered over the past 25 years. GIS data, courtesy of Luis Martinez (personal comm.), shows the land use change of the northshore area surrounding Bayou Lacombe (Figures 29 and 30). Developing land along the waterway decreases the natural "buffer" zone in the surrounding area and can lead to increased runoff and sedimentation (Weaver and Garman, 1994; Jones et al., 1999; Wang et al., 2001; Tabit and Johnson, 2002; Snyder et al., 2003; Wang et al., 2003). Sedimentation can alter the

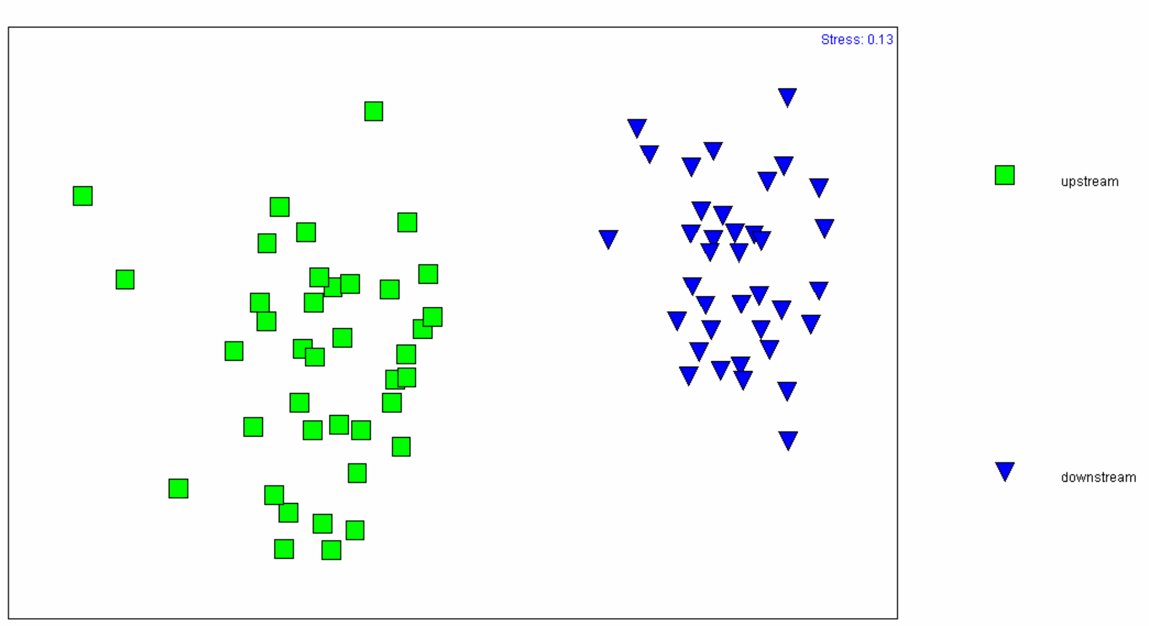

Figure 28: Samples from 2005-2007 throughout Bayou Lacombe. There is a clear separation among upstream and downstream fish assemblage samples.

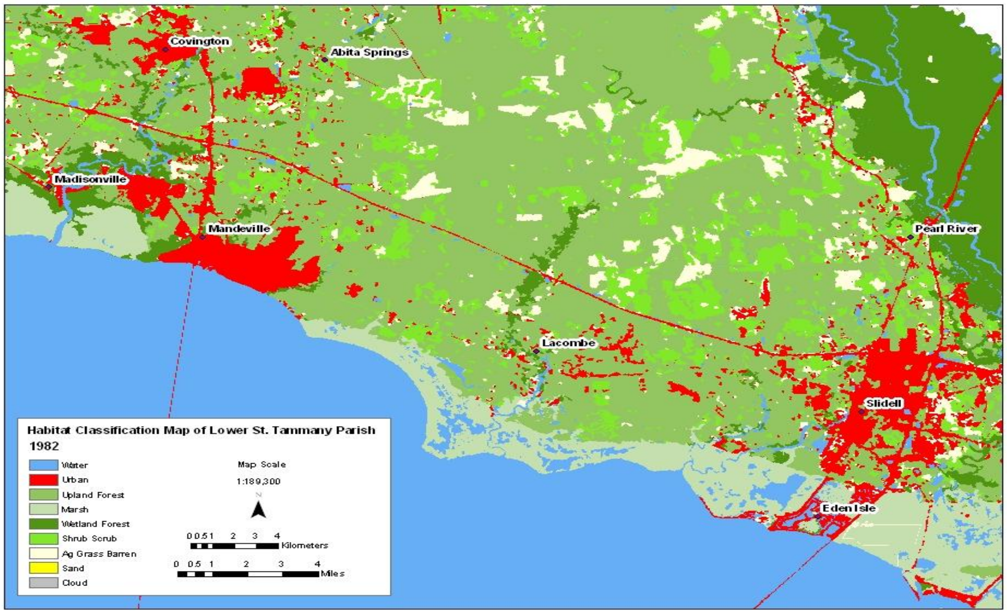

Figure 29: GIS image of developed areas around lower St. Tammany Parish in 1982. Notice the development (red areas) around Bayou Lacombe in the center of the picture. (Image courtesy of Luis Martinez)

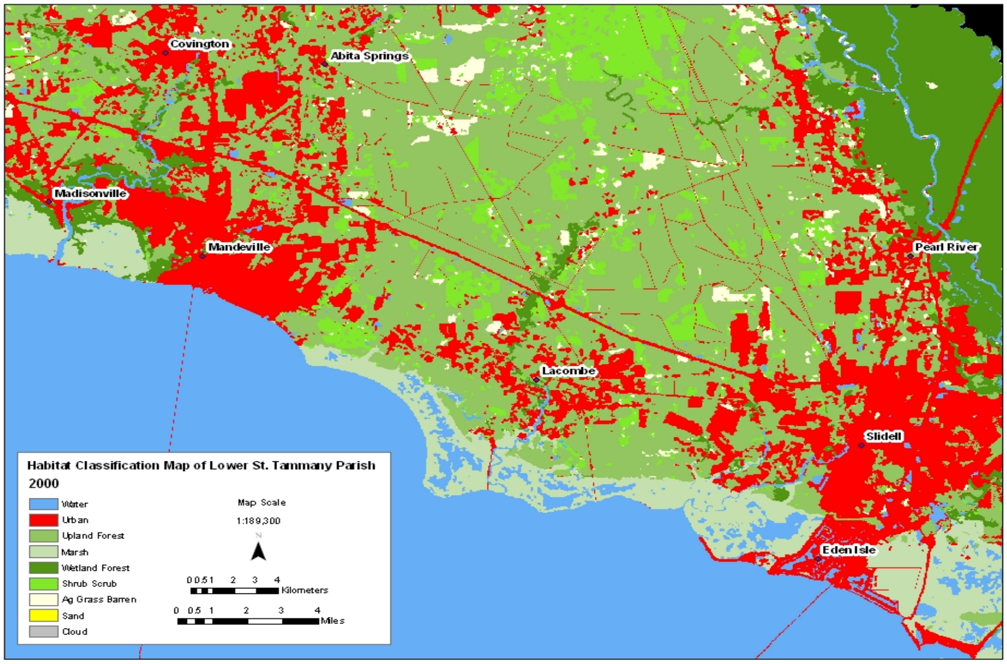

Figure 30: GIS image of same St. Tammany Parish area in 2000. Notice how much the once small town of Lacombe has developed in just 18 years. This has had an impact on the fish assemblage of Bayou Lacombe. (Image courtesy of Luis Martinez)

reproductive habitat of some fishes, especially crevice spawners like *C. venusta*. Burkhead and Jelks (2001) have demonstrated how increasing levels of suspended sediments lead to decreasing levels of reproductive success in the crevice spawner *C. trichroistia*. Similarly, increased stream discharge due to larger amounts of runoff can negatively impact male-female insemination in *C. venusta* (Baker et al., 1994). In the upstream areas, Farabee (1992) had reported a large area of clear-cutting. With the technological advances in satellite imagery, I was able to capture an aerial glimpse of the entire Bayou using GOOGLE Earth (version 7.0). Just to the south of Station 1 in Bayou Lacombe there are two large areas where land has been clear-cut to the Bayou and north of Station 3, a large sand mining pit is located (Figure 31). This destroyed habitat along with the development of houses and neighborhoods along the remaining portions of Bayou Lacombe could have altered aquatic habitat over the past 35 years. Weaver and Garman (1994) discovered that urbanization and clear-cut logging were primarily responsible for the decrease in abundances of nearly all fishes in a stream during their thirty-two year historical fish assemblage study comparisons. Weaver and Garman (1994) have also proposed that although gradual urbanization is usually a low-intensity disturbance, urbanization over long periods of time can produce results similar to those of one high-intensity disturbance when studying fish assemblage alterations. Sobczak (1976) did not report any clear-cutting in his station observations, just a few houses along the midstream portions of the Bayou. Bick et al. (1953) and Sobczak (1976) did, however, report that even during high flow periods Bayou Lacombe remained relatively clear with low turbidity. This was probably due to a somewhat less disturbed riparian habitat and mixed sand and gravel stream bottoms reported in their studies. The same could not be said about pre-Hurricane Katrina environmental assessments characterizing the stream bottom in the current study. The bottom was often composed of decaying leaf litter and mud mixed with

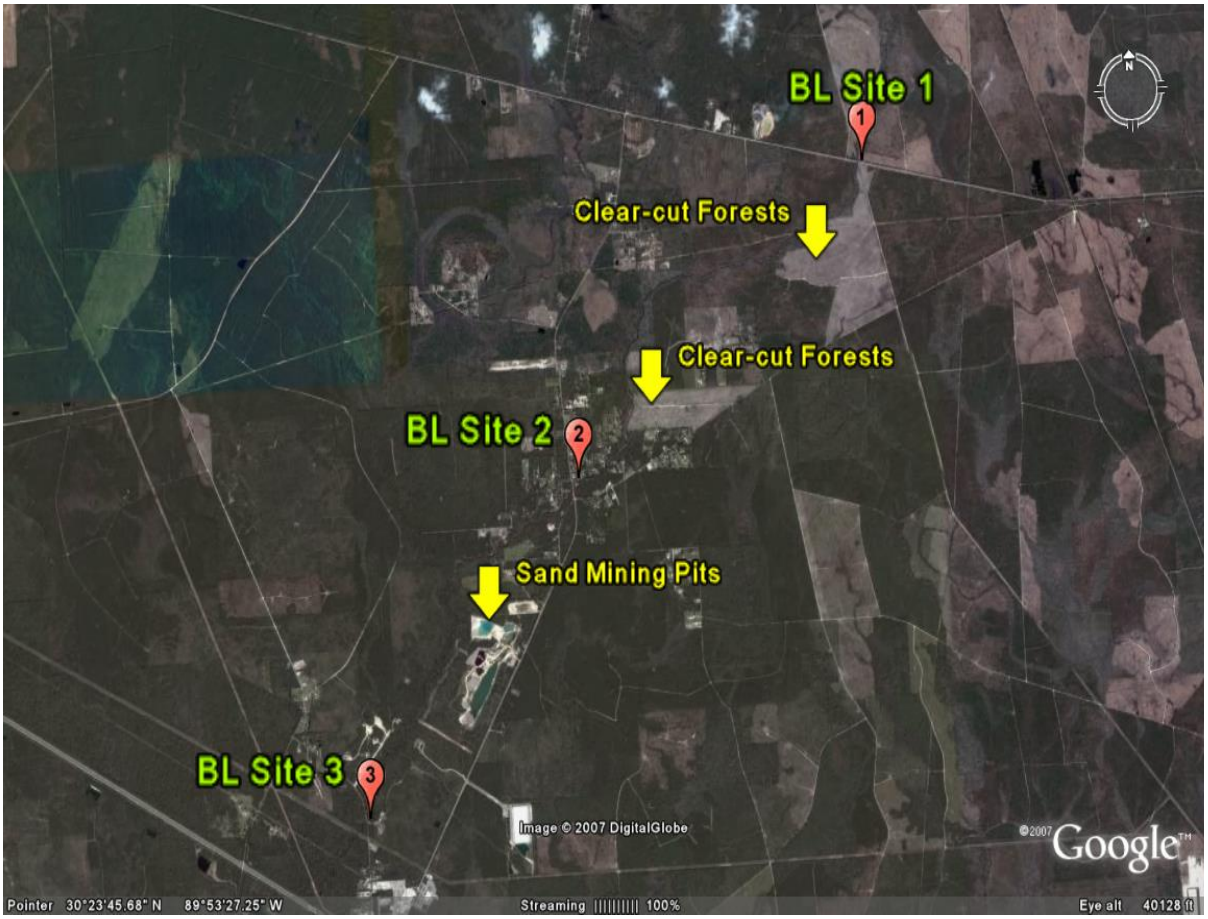

Figure 31: Satellite image of upstream stations at Bayou Lacombe. Two large areas of clear-cut logging can be seen in between Station 1 and Station 2. Between Stations 2 and 3 are several large sand mining pits near Bayou Lacombe.

occasional sandy areas. I observed, for example, that gravel could be felt as my feet sank through the detritus. In some areas the decaying leaf litter was so thick that when stepped on large gas bubbles would surface. Needless to say, water clarity and turbidity were continuously an issue while electrofishing even during low flow periods.

Clear-cutting can have severe effects on aquatic habitat. This is particularly evident at Station 2. Before Hurricane Katrina, this station had the most in-stream habitat. This station had numerous riffles, runs, and pools with plenty of sunken logs and tree branches over-hanging the Bayou providing shade and cover. This station was the most disturbed after Hurricane Katrina. When the debris was removed from the Bayou, the fish assemblage began recovering to its pre-Katrina composition. The assemblage will never fully recover, however, because the entire aquatic habitat is essentially destroyed. The sunken logs that were there prior to the storm were removed with the recently fallen trees. The canopy along the eastern bank was almost completely destroyed. Lack of canopy cover can negative bottom-up trophic effects as shown by Robinson and Minshall (1986). Station 2 is essentially just a run and riffle habitat now. The relatively deep pools located at Station 2 are currently filled in with sand from runoff. The entire station that I used to sample is approximately less than 0.25 m deep during periods of low flow now. There is no in-stream habitat and sand from the banks washes directly into the Bayou every time it rains there. Species richness has been proven to be highly correlated with instream habitat (Angermeier and Karr, 1984; Gorman and Karr, 1978; Benke et al., 1985; Schlosser, 1982; Shields et al. 1994). Meffe and Sheldon (1988) found that fish assemblages in blackwater South Carolina streams responded strongly to habitat structure. They found that the local habitat structure, such as depth, width, stream velocity and percent cover, is a good indicator of the local assemblage structure. If this “template” that they created holds true, then it is almost certain that the fish assemblage at Station 2 in Bayou Lacombe will never fully recover from the natural and anthropogenic disturbances that have drastically altered the aquatic habitat.

In addition to succumbing to massive amounts of human development and urbanization, the downstream portions of Bayou Lacombe's fish assemblage are largely influenced by the brackish waters of Lake Pontchartrain. The downstream fish assemblages of the Bayou currently represent species that can tolerate euryhaline environments. Although the salinity of Lake Pontchartrain has not altered significantly in recent times, the salinity of the Lake is slowly increasing over time (Thompson and Fitzhugh, 1985; Sikora and Kjerfve, 1985). The gradual increase in salinity may not be sufficient enough to impact the fishes that occupy Lake Pontchartrain but it may be enough to influence freshwater fishes in a slow moving, tidally influenced Bayou, such as Bayou Lacombe. The brackish water lake is a barrier to freshwater fish dispersal among nearby tributaries.

In electrofishing samples conducted in the Tangipahoa River, a river whose confluence is in the northwestern portion of Lake Pontchartrain, *C. venusta* and *N. texanus* were consistently captured in large numbers along with a variety of other freshwater fishes. I noticed, however, that samples approaching the mouth of the river captured lower numbers of *C. venusta* and *N. texanus*. In fact, no cyprinids were captured in salinities greater than 2 ppt. The Tangipahoa River is a very large river with numerous tributaries. Minnows seem to prefer inhabiting complete freshwater environments. Sobczak's fish assemblage study of Bayou Lacombe in the seventies strongly resembles what I found in the Tangipahoa River in current samples (Figure 32). The Lake was fresher back then and hence, fresher waters, than the present time, would have been tidally pushed into the lower portions of Bayou Lacombe. Bayou Lacombe has little refuge from increasing salinity. The increased salinity in combination with increased

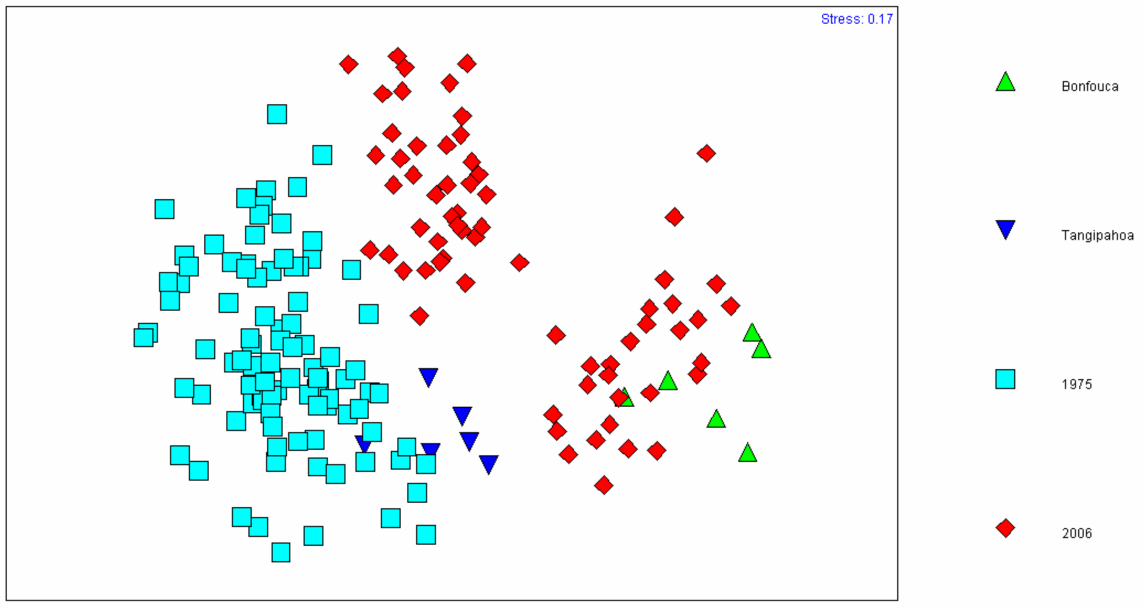

Figure 32: MDS plot showing the relationship of two other tributaries of Lake Pontchartrain as compared to past and present samples in Bayou Lacombe. Bayou Bonfouca, a tributary that's confluence with the lake is closer to the natural tidal passes, strongly resembles present Bayou Lacombe samples. The Tangipahoa River, a third order river that's confluence is in the northwestern part of the lake, more resembles samples collected from past studies.

sedimentation may have led to the demise of the majority of cyprinids in Bayou Lacombe. *Notemigonus crysoleucas* is the only cyprinid still found in the Bayou and has been noted to withstand prolonged periods of moderate salinity (Boschung and Mayden 2004). *N. crysoleucas* may be re-introduced into the Bayou by bait release from the nearby fish hatchery. *Labidesthes sicculus*, the brook silverside, is the only other "minnow-like" abundant fish left in Bayou Lacombe and it is quite salt tolerant (Pflieger, 1975; Boschung and Mayden, 2004).

Further supporting the theory of increased salinity determining Bayou Lacombe's downstream fish assemblage change over time is the fact that the fish assemblage is almost identical to that of Bayou Bonfouca (Figure 32). Bayou Bonfouca is a small, slow-moving Bayou located in Slidell, Louisiana. Its confluence with Lake Pontchartrain is approximately five miles from the mouth of Bayou Lacombe. Therefore, Bayou Bonfouca is much more tidally influenced from the Rigolets and Chef Menteur tidal passes. Bayou Bonfouca is slightly more euryhaline (6 to 12 ppt), whereas Bayou Lacombe is more oligohaline (0.5 to 5 ppt). In electrofishing samples conducted in Bayou Bonfouca, the salinity was consistently 2 to 4 ppt higher than that of Bayou Lacombe (personal obs.). The fish assemblages of both Bayous were highly similar. Although numerous centrarchids (i.e., *Lepomis macrochirus*, *Lepomis miniatus* and *Lepomis microlophus*) were captured in Bayou Bonfouca, no longear sunfish, *Lepomis megalotis*, were captured in any samples conducted there. This is similar to present samples made in the lower reaches of Bayou Lacombe. Only seven *L. megalotis* were captured in all fourteen present study samples. This is much lower than the 407 captured by Sobczak (1976) at the same stations using only seines. It may be as simple an explanation that *L. microlophus*, *L. macrochirus* and *L. miniatus* are just out-competing *L. megalotis* since those species were found in greater abundance in present downstream samples than in the past. Or it may be that those species are more salt tolerant than *L. megalotis*. There is no simple explanation but I believe that the rising salinity of Lake Pontchartrain, albeit a very small change, is enough to influence the migration of fishes in Bayou Lacombe. *L. megalotis* has been captured in salinities of 10 ppt (Boschung and Mayden, 2004), but its survivability for prolonged periods of time in higher salinities has never been documented. More studies need to be conducted to fully understand a freshwater fish's tolerance to brackish water influence.

The effects of Hurricane Katrina on current downstream fish assemblages support the rising Lake salinity theory as well. Similar to the high resistance exhibited by estuarine fishes in their responses to saltwater surge impacts from hurricanes, the downstream fish assemblage of Bayou Lacombe were shown to be the most resistant to the lasting effects of a saltwater storm surge. Although the upstream portions of the Bayou were affected by factors other than saltwater, the before and after comparisons of fish assemblages show that the upstream fish assemblage is much more sensitive to environmental change. I here suggest that *N. texanus* has become completely extirpated during this time. The longear sunfish, *L. megalotis*, was never sampled again in the eleven monthly downstream samples following the storm. Its abundance significantly decreased in upstream samples following the storm, but quickly arose again when the debris was cleared out of the Bayou. Darters, such as *E. parvipinne*, were never sampled again upstream after the storm. I would not consider them completely extirpated yet since I used electrofishing techniques in sampling and water quality remained low after the storm. These fishes, including *C. venusta*, are in no danger of becoming extinct species. They are highly abundant in other local streams and rivers across the southeastern U.S. (Pflieger, 1975; Boschung and Mayden, 2004). The significance of this study is to show how short-lived catastrophic events and long-term anthropogenic development can drastically alter fish assemblages.

Although there is no obvious answer to why Bayou Lacombe's fish assemblage has shifted from a minnow-dominated assemblage to a sunfish-dominated one, the overwhelming physical evidence of habitat alteration surrounding the Bayou's banks and gradual salinity increasing of tidally influenced waters from Lake Pontchartrain provide some explanation for the transformation. Destroying buffer habitat along the banks of a waterway seems to never lead to positive outcomes for the majority of aquatic organisms. From past environmental assessments of the Bayou Lacombe area, it is clear that the underwater substrate has changed markedly from gravel and sandy bottoms to detritus and muddy bottoms. It is possible that the reproductive habitat of the minnows has become severely impaired over the past thirty-five years. This in combination with increasing downstream salinities creates a very confined area where *C. venusta* and *N. texanus* can successfully reproduce and survive. However, with the decrease in cyprinids, the centrarchids (*Lepomis* spp.) were possibly able to take advantage of the reduced competition for food and space, therefore increasing their abundances over time. Centrarchids are capable of building nests for successful reproduction even if conditions are not ideal. In any event, it is obvious that the mystery underlying Bayou Lacombe's fish assemblage alterations remains unsolved. This study, however, has addressed many questions concerning short-term fish assemblage responses to natural and anthropogenic perturbations and long-term fish assemblage shifts.

Conclusions

The Lake Pontchartrain estuary is a unique study area because of the phenomenal rate of land loss, both from natural and anthropogenic disturbances, in coastal Louisiana as compared to other estuaries nationwide (Walker et al., 1987; Penland et al., 1990; Penland and Ramsey, 1990). Gradual increases in the salinity of Lake Pontchartrain are to be anticipated due to relative sea level rise, subsidence and the destruction of barriers to saline waters of the Gulf of Mexico due to large infrequent storms (Walker et al., 1987; Penland et al., 1990; Penland and Ramsey, 1990), such as Hurricane Katrina. The oligohaline waters of Lake Pontchartrain are a natural barrier to dispersal of *Cyprinella venusta* from the Tangipahoa River. Over the past four years I was fortunate enough to conduct fish surveys at the Chandeleur Islands with other Nekton Research Laboratory crew. I was able to see first hand the destructive power of two hurricanes at the Chandeleur Islands (Hurricane Ivan 2004 and Hurricane Katrina 2005) after they made landfall. The barrier islands are the first line of defense against a catastrophic storm surge. Nearly 40% of the islands have disappeared due to Hurricane Katrina (GIS data, Luis Martinez, personal comm.). It is to be expected that the now smaller barrier will allow more salt water to influence the Biloxi Marsh and consequently, Lake Pontchartrain. Historically, Lake Pontchartrain was exposed to annual spring floods of the Mississippi River. The large amounts of freshwater were great enough to replenish soils and flush out the lake, helping to maintain low salinities, if any salinity at all. Although the lake is exposed to the freshwater flooding with the periodical opening of the Bonnet Carre Spillway, the brief openings are short-lived and therefore, do not have much of a replenishing effect on the Lake Pontchartrain area. With the leveeing of the river and disappearing barriers to saltwater, it is inevitable that the Lake Pontchartrain's salinity will continue to rise.

In addition to understanding why the Bayou's fish assemblage was changing over the past 30 years, I witnessed dramatic fish assemblage change in just 2 years. Natural disasters play a very important role in shaping a stream's fish assemblage. Species in low abundance are at high risk of becoming extirpated. Freshwater fish species in first order streams that cannot tolerate prolong periods of brackish water or low dissolved oxygen are also at risk of becoming extirpated from their respective system.

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Vita

Jeffrey Michael Van Vrancken was born August 25, 1979, in New Orleans, Louisiana. His parents, Edward and Rita Van Vrancken, raised him along with his sisters, Michelle and Lauren, and his brothers, Duane and Kevin, in Slidell, Louisiana. Jeffrey spent most of his adolescent life outdoors exploring the local wooded areas and small waterways. In 1995, he started working at Delta Pet Center in Slidell, Louisiana. He spent ten years there working and educating the public about reptiles and fishes from around the world. While working 30 to 40 hours a week, Jeffrey received his Bachelor's degree in Science from the University of New Orleans in 2003. Little did he know that he would also meet his future fiancée, Jennifer Lanier, at the pet store. The couple has been together for over five years now and plans on getting married within the next couple of years. They have two dogs, Lucas Oswald and Zachary Taylor, and would like to have children in the future.