M. effects of land use and habitat on stream fish assemblages in tributaries of the lower Bogue Chitto watershed, Washington Parish, Louisiana

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M. EFFECTS OF LAND USE AND HABITAT ON STREAM FISH ASSEMBLAGES IN TRIBUTARIES OF THE LOWER BOGUE CHITTO WATERSHED, WASHINGTON PARISH, LOUISIANA

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Abstract

My research focused on how fish communities are responding to watershed land use and instream habitat in tributaries of the Lower Bogue Chitto River. To address this question I electrofished and seined 10 sites in four tributaries of the Bogue Chitto River a total of 4 times each over the course of 15 months in 2007 and 2008. I characterized habitat by measuring water flow, water depth, substrate size, woody debris, temperature, and dissolved oxygen, and quantified heterotrophic plate counts, nutrients, and chlorophyll *a* concentrations at the end of the sampling period each year. Watershed land cover was measured with 2001 USGS Land use/Land cover data, and my analysis focused on cultivated cropland and pasture land, as well as forested and herbaceous wetlands.

Many of the most common fishes responded positively to differences in stream characteristics, particularly increased nitrate and agricultural development, and decreased wetlands, which are typically characteristic of anthropogenic stream impacts. Other fishes responded to increased flow and substrate size, which appeared to characterize less disturbed stream conditions. Overall, fish diversity was negatively associated with distance from the mainstem Bogue Chitto River. These results suggest that in nutrient limited systems, some fishes respond positively to anthropogenic alterations, and that watershed-based characteristics are more important than local habitat variables in predicting fish assemblage composition and abundance in these streams.

Introduction

Habitat degradation is among the greatest threats to biodiversity in the modern world (Vitousek et al. 1997). For lotic ecosystems, past (Harding et al. 1998) and current land use within the watershed has been shown to strongly influence in-stream habitat (Allan and Flecker 1993; Jowett et al. 1996). Allochthonous material from the surrounding watershed provides energy and nutrients for aquatic macroinvertebrates, and the structure of stream fish assemblages is sometimes best explained from spatial factors working at broad scales (Flinders et al. 2008). Due to the complexity of biotic and abiotic interactions within streams, between streams and adjacent riparian areas, and within the watershed, stream assessment and management programs must consider interactions at multiple spatial scales (Noss 1990; Richards et al. 1996; Cooper et al. 1998; Fausch et al. 2002). Changing land use within a watershed has been shown to alter in-stream communities, often favoring the tolerant species (Lussier et al. 2008), and continuing patterns of urbanization and agricultural change are projected to have further negative effects on lotic ecosystems throughout the U.S. (Sickle et al. 2004).

In most stream systems, water quality is most strongly influenced by regional scale factors, whereas stream habitat is most influenced by local factors (Wang et al. 2003; Moerke and Lamberti 2006). On the reach scale, fish distribution and abundance have been shown to be influenced by several in-stream variables (Jackson et al. 2001; Li and Gelwick 2005; Smiley and Dibble 2005), including stream volume (Inoue and Nakano 2001; Hitt and Angermeier 2008), substrate composition (Waters 1995; Cyterski and Barber 2006) canopy cover, instream vegetation, water temperature (Smith and Kraft 2005), flow velocity (Freeman et al. 1988; Meffe and Sheldon 1988; Lammert and Allan 1999), and turbidity (Waters 1995).

Percentage of agricultural cover in the upstream watershed and at other spatial scales have been shown to have strong linear relationships with in-stream water chemistry (Tong and Chen 2002; Buck et al. 2004), and habitat heterogeneity (Richards et al. 1996), as well as direct effects on benthic invertebrate community structure (Lenat and Crawford 1994; Harding et al. 1999), all of which would be expected to influence the abundance and species composition of the resident fish community. Habitat heterogeneity is often reduced in agriculturally-dominated watersheds, which results in a depauperate fish community (Park et al. 2006). Croplands also increase local concentrations of nutrients, and influence nutrient retention downstream (Ulen et al. 2004; Bernot et al. 2006). Although the areal extent of agricultural lands in a watershed should be taken into account when assessing stream health, the effects of agricultural land use on stream structure and function are highly variable. In some cases, agricultural development or forest clearing does not impact stream function until the magnitude of land use change reaches a threshold (Jones et al. 2001; Kaller and Hartman 2004). Beyond this threshold, agricultural land development can have a significant negative influence on the species composition (Moerke and Lamberti 2006), overall abundance, and diversity of downstream fish communities (Orrego et al. 2009). Other studies have found that although agricultural practices can have deleterious effects on fish communities in adjacent streams, other factors are important as well, and areas of extensive agricultural land use may not necessarily be associated with a degraded fish community (Meador and Goldstein 2003). In some cases, agricultural land use can increase fish diversity and abundance in adjacent streams (Pinto et al. 2006), with increased nutrient concentrations promoting algal production, an important food source for invertebrates and some groups of fishes (Singkran and Meixler 2008).

Similar to agricultural development, the loss of forest cover associated with advancing urbanization can also lower the diversity of local fish assemblages in adjacent streams (

Vondracek et al. 2005; Diana et al. 2006; Scott 2006; Burcher et al. 2008; Hrodey et al. 2008; Lorion and Kennedy 2009). Municipal land development significantly increases sediment run-off (Cyterski and Barber 2006; Roy et al. 2007), and the associated increases in the area extent of impervious surfaces (roads, parking lots, etc.) not only results in flashy stream hydrographs (Jones et al. 2000), but has been shown to be an indicator of land use impacts on stream fishes (Wang et al. 2001). High flow variability has been linked to fish assemblage composition (Oberdorff et al. 2001), with small-bodied fishes most often affected by the rapid flow changes characteristic of flashy-hydrograph streams (Bain et al. 1988).

Land cover is also importantly, but indirectly related to stream biota through abiotic pathways (Hynes 1970; Hanchet 1990; King et al. 2005a; Gido et al. 2006; Wilson and Xenopoulos 2008), affecting fishes through changes to in stream nutrient levels (Johnson et al. 1997), dissolved oxygen concentrations (Morgan et al. 2006), sediment runoff patterns (Scott et al. 1994), and in-stream physical habitat structure (Bojsen and Barriga 2002). Land development accelerates erosion rates, affecting stream bed composition by decreasing mean substrate particle size and shifting the fish community to silt-tolerant species (Schweizer and Matlack 2005; Sutherland et al. 2002). Loss of forest cover in riparian as well as adjacent upland areas can affect stream fish habitat in several ways, including loss of woody debris and destabilization of stream banks and instream habitat (Stauffer et al. 2000; Talmage et al. 2002; Brazner et al. 2005). Loss of woody debris inputs can significantly reduce aquatic insect diversity and abundance (Iwata et al. 2003; Potter et al. 2005; Muenz et al. 2006), reducing energy sources available to insectivorous fishes (Esteves et al. 2008) and influencing fish size (Koehn and O'Connor 1994). Unstable and eroding banks with fine substrates can result in channel narrowing, which is usually associated with lower biodiversity and stream health (Heitke et al. 2006; Smiley and Dibble 2008). In several studies, channel width and depth have been reported

to be directly related to the presence, survival, and size composition of fishes present in a stream (Wang et al. 2003; Grenoullillet et al. 2004; Dauwalter et al. 2008; Murray and Innes 2008; D'Ambrosio et al. 2009). Stable habitat conditions are important for maintaining fish community diversity (Angermeier and Schlosser 1989; Rathert et al. 1999; Diana et al. 2006) and enhancing juvenile fish survival (Freeman et al. 2001). Changes in sediment input and hydrograph characteristics can alter substrate composition, with significant impacts on benthic macroinvertebrates (Richards and Host 1993; Strand and Merrit 1997; Kaller and Hartman 2004), availability of fish forage (Waters 1995; Jowett et al. 1996), and reproduction of lithophillic spawners (Brown 1975; Snyder et al. 2003; Helms and Feminella 2005).

Protection of wider riparian zones (Keim and Schoenholtz 1999; Quinn 2005) and an emphasis on protecting headwaters and lower-order watersheds (Lee et al. 2002; Ekness and Randhir 2007) have been suggested as strategies to alleviate the effects of watershed development on streams. In highly disturbed streams, it has been found that fish recolonization often occurs shortly after less disturbed stream conditions have been reestablished through the use of best management practices (Martin-Smith et al. 1999; Moore and Palmer 2005). In Louisiana, most farmers comply with BMP recommendations (Kaller et al. 2002), although the effectiveness of BMP implementation in protecting fish communities in altered watersheds have not been examined.

Many stream fishes are habitat specialists (Hynes 1970; Gorman and Karr 1978), and changes in habitat complexity from riparian alterations, particularly a reduction in woody debris abundance, can reduce the microhabitat diversity that is needed to support high fish community richness (Angermeier and Karr 1984; Beechie and Sibley 1997; Scott and Helfman 2001). Loss and alteration of favorable stream habitat characteristics, which is often tied to poor land use protection of adjacent streams, often favors fishes that are trophic, reproductive, and habitat

generalists. In contrast, less-impacted streams tend to support more specialist species (Weaver and Garman 1994; Poff and Allan 1995) such as darters, which have been shown to be sensitive to changes in stream bed characteristics (Tipton et al. 2004). Increases in the magnitude or frequency of watershed disturbances can result in local extinctions or extirpations of species (Lowe 2002), which should be reflected in assessments of fish community structure.

Because of a significant movement of residents from New Orleans, Louisiana, the Florida parishes on the north shore of Lake Pontchartrain are undergoing rapid urbanization, with significant changes in local land use (Templet 2004). Streams in this area are in the Eastern Gulf Coastal Plain ecoregion (Isphording and J. F. Fitzpatrick 1992) or Terrence Uplands, (DeWalt 1997), and are characterized by fine substrates, low-gradients, and low concentrations of dissolved substances (Felley 1992). Other than a few historical fish collections (Douglas 1974), and one that took place in the main river (Stewart et al. 2005) there is little data to assess potential biotic changes in these Terrace Upland streams resulting from this rapid development. Stream fishes have long been considered a potential bio-indicator of watershed and stream disturbance (Karr 1981), and fishes in these coastal plain streams may be sensitive to changing watershed conditions. Most of the research on land-use and habitat effects on stream fish community structure has been done in more northern-latitude systems (Heitke et al. 2006; Moerke and Lamberti 2006; Lussier et al. 2008), or in warm water streams in the Midwest or along the Atlantic coast (Angermeier and Karr 1984; Bart 1989; Jones III et al. 1999; Cyterski and Barber 2006; Wang et al. 2007; Hrodey et al. 2008; Wilson and Xenopoulos 2008). The goal of this project is to apply the principles and methods of watershed disturbance-fish community research to Louisiana coastal streams by examining the relationships among land use, stream habitat, water quality characteristics, and fish community structure in the Bogue Chitto watershed in southeastern Louisiana. In addition to significant tracts of agricultural and

forested land, the Bogue Chitto watershed encompasses the municipality of Franklinton, and provides an excellent study location to examine watershed-fish community associations in a warm water, coastal plain stream system.

Specifically, my objectives are to identify effects of catchment disturbance and in-stream habitat on fish community structure in the Bogue Chitto River watershed, and attempt to gauge the usefulness of fish as a potential bio-indicator of disturbance. By determining how various land uses affect in-stream habitat and fish community structure, it will also allow managers to better develop and implement BMP programs that address specific land use practices.

Methods

Study Area

My research focused on fish communities inhabiting streams in the Bogue Chitto watershed, which comprises roughly the western half of Washington Parish, Louisiana. Prior to European settlement, Washington Parish was dominated by longleaf pine forests. However, commercial logging in the 1890's significantly reduced the areal extent of forested land, and the Bogue Chitto watershed currently includes substantial tracts of agricultural land (Smith 2004).

My study sites in the upper Bogue Chitto drainage extended from the town of Franklinton to the northern border of the parish at the Mississippi state line. All of my sites were chosen based on their proximity to each other in order to minimize geographical barriers to fish dispersal, as well as geologic differences among study reaches. Within this area, I identified 10 sites located in 1^{st} through 3^{rd} order streams that were of similar width and depth, easily accessible from nearby bridge crossings, and amenable to sampling with seines and electrofishing equipment. Study locations included three sites each along Silver and Deer Lick creeks, and two sites each on Lawrence and Hayes creeks (Table 1; Figure 1). Each site was sampled in the summer and fall of 2007, and spring and summer of 2008. The 10 sites provided a range of different habitat types, as well as different densities of riparian forestland, intensities of agricultural development, and levels of human disturbance (Figure 2).

Sampling Protocols

Habitat. On each sampling date, I confirmed that the streams were in base flow conditions, which was based upon visual inspection. Streams were always sampled at least 3 days after a rain event to reduce the stochastic effects of weather on fish distribution and abundance. I used calibrated YSI 6820 V2 or Hydrolab Quanta *in situ* water quality monitors to

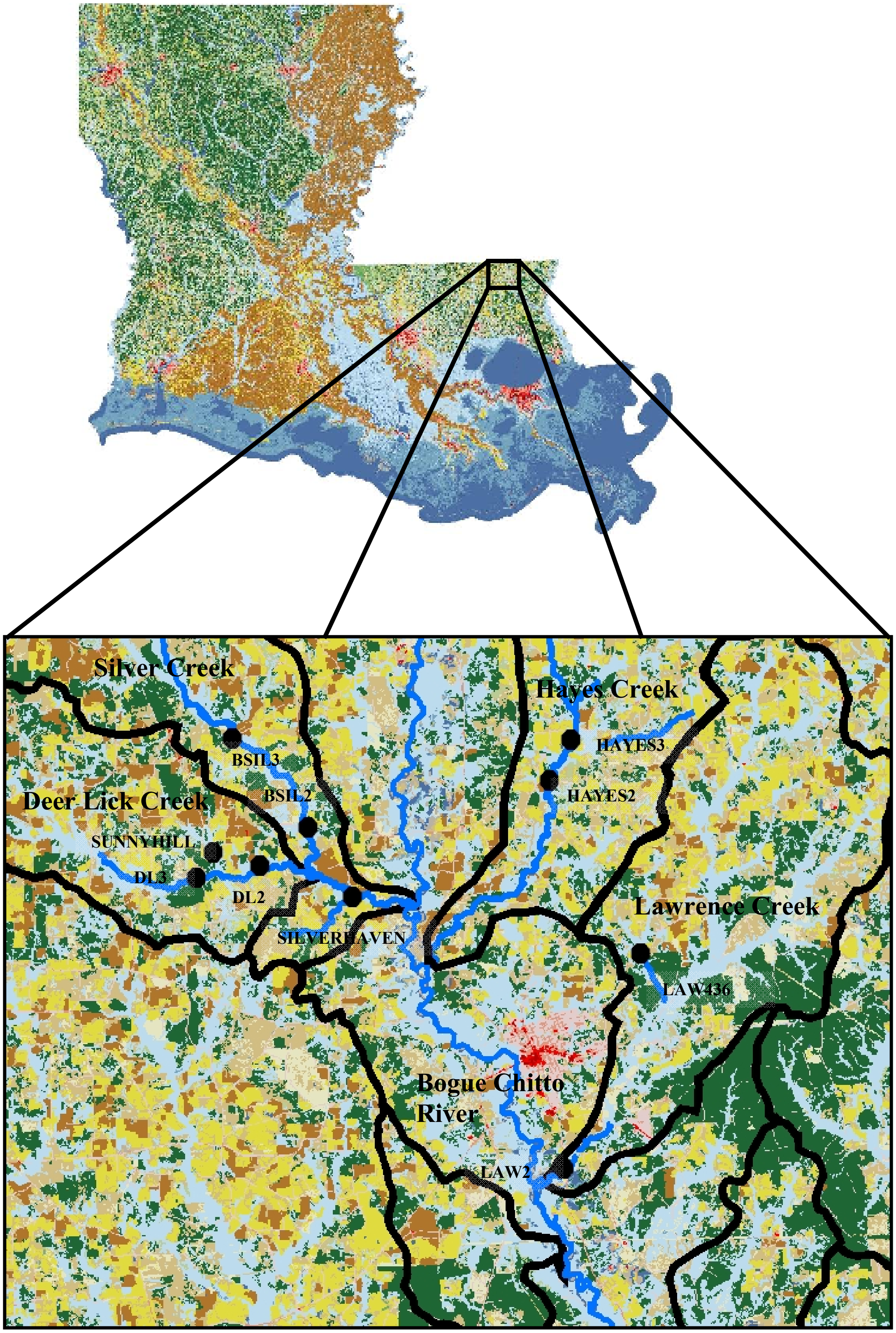

Figure 1: Locations of the 10 study sites in Washington Parish, Louisiana, USA, that were sampled in 2007 and 2008.

Table 1: List of sites and their respective X,Y coordinates (NAD 1983 UTM Zone 16N). Coordinates measured with a Garmin 60CS.

SITE	X	Y
BSIL2	763576.2	3424696
BSIL3	760715.2	3428104
DL2	761751.4	3423248
DL3	759364.7	3422787
HAYES2	772745.4	3426474
HAYES3	773571.8	3428045
LAW2	773257.2	3411768
LAW436	776174.5	3419945
SILVERHAVEN	765266.7	3422066
SUNNYHILL	759997.4	3423773

Figure 2: Examples of different habits provided by the study streams: 1) Lower Lawrence Creek, open exposed sandy bottom; 2) Upper Hayes Creek, low flow with obvious human impacts; 3) Upper Lawrence Creek, low flow with large amounts of woody debris; and 4) Big Silver Creek (2^{nd} order), high flow, with larger substrate.

record temperature, dissolved oxygen (DO), specific conductance, and pH, and then divided each site into two 50-100 m reaches spaced about 50 meters apart. I measured width (m, tape measure), depth (cm; 1.2 m wading rod), flow (cm/sec, Sontek Flowtracker Handheld ADV), substrate particle size, and amounts of woody debris at points located at 25, 50, and 75% of the stream width along perpendicular transects spaced every ten meters throughout each reach.

Substrate was visually characterized on a 1-4 scale based on increasing particle size from sand (1) to rubble (4), and pieces of woody debris within a 0.5-m radius of each point were counted.

Fish Community Composition. Each reach was blocked with a 13-m seine (6-mm mesh) to prevent fishes from leaving the reach. Fishes were subsequently collected with three 10-m drags of a 5-m seine (6-mm mesh), and then one upstream pass with a Smith-Root LR-24 backpack electrofishing unit. I used the multi-gear approach to minimize sampling bias associated with using only one type of gear, and because seining was often more effective in capturing smaller fish, whereas the electrofishing unit is better for collecting fish in complex habitat (Dauble and Gray 1980). Other fishes that could be field identified were measured and released, whereas individuals that could not be identified were preserved in alcohol and returned to the laboratory, for identification according to Ross (2001) or Douglas (1974).

Water Chemistry. Water samples were taken at the end of each of the four field seasons, brought back to the laboratory on ice, and analyzed for biochemical oxygen demand (BOD), ammonia, nitrite, nitrate, total nitrogen, orthophosphate, total carbon, inorganic carbon, organic carbon, dissolved organic carbon, heterotrophic bacteria, fecal coliform bacteria, suspended solids, volatile solids and chlorophyll-*a*. All water samples were analyzed following procedures outlined in the American Public Health Associations' Standard Methods for the Examination of Water and Wastewater (2005) except for nitrite and nitrate, which were analyzed with the USEPA-approved diazotization method and cadmium reduction method, respectively. Biochemical oxygen demand was assessed over a 20-day period instead of the standard five days because much of the organic material in these waters takes a substantial period of time to break down. Carbon analyses were conducted with a Shimadzu TOC-V Combustion analyzer.

Land Use Data. Land use data were collected from U. S. Geological Survey 2001 land use and land cover (LULC) maps. Watershed land use was applied to each upstream delineated

watershed based on Louisiana Department of Environmental Quality (LDEQ) sub-segments, or was manually delineated based on the 2004 LDEQ Elevation map. Potential scale differences in watershed effects on stream fish community composition were assessed by also quantifying land use in buffer zones of 1.6 km and 500 m upstream from each sampling site, as these spatial scales had been used in previous land use studies (Wang et al. 1997). Land use and buffer zone areas within each watershed were measured on a GIS map (ERSI ArcMap 9.3) with the Hawths tools 3.27 extension clip raster by polygons II function.

Data Analysis. To be sure most species of the area were captured I created a species accumulation curve based on the *Mau Tau* method using Colwell (1997). For the statistical analyses of fish community-habitat-land use relationships, the two reaches at each site were combined, and width, depth, flow, and substrate size were averaged to characterize each site. I analyzed the data with several methods to address the overall goal of assessing the links between stream habitat, watershed land use, and stream fish community composition in the study streams.

Due to missing values attributed to malfunctions of water quality probes in the field and analytical equipment in the laboratory, I was forced to eliminate pH, turbidity, total nitrogen, organic nitrogen, NH_4, total suspended solids, and total volatile suspended solids from the dataset. Early PCA revealed nitrite to be driven by an outlier, and was therefore also eliminated from further analyses. Total carbon, total organic carbon, and dissolved organic carbon were all highly correlated (>0.90), so I retained only TOC for further analysis, because it had the highest correlation with the first principle component. After an initial PCA, inorganic carbon was also eliminated as it was correlated with only a single principle component and its inclusion in the model actually decreased the amount of variation explained by 2% (Härdle and Simar 2007).

I used a principle component analysis (PCA) with varimax rotation on the mean width, depth, flow, and substrate size, nutrient, and land use data at each site, retaining principle

components (PCs) with eigenvalues greater than 1.0 for further analysis (Johnson 1998). I also examined the variable loadings to detect autocorrelation among the different buffer zone scales, which was not evident in the data. I then used a multivariate analysis of variance (MANOVA) to test for significant relationships among seasons, habitat and land-use variables (PCs), and the abundances of fish species (expressed as number of individuals per m^2) that comprised 93% of the individuals collected during the study. For PCs that were significantly related to the abundance of one or more fishes, I used analysis of variance (ANOVA) to test for significant relationships between fish species abundance and variables with factor loadings greater than 0.5. I also used separate ANOVAs to examine relationships between the PCs, seasons, and Shannon-Weiner diversity and absolute abundance. Once those relationships were determined, I used further ANOVAs to examine relationships between the variables highly correlated with the PCs (> 0.5) and Shannon-Weiner diversity and absolute abundance.

Results

<u>Fishes</u>

Fishes, habitat data and water quality measurements were collected during 39 trips to the 10 sample sites in the summers of 2007 and 2008 (Table 2). However, freezer malfunction in the fall of 2008 damaged four samples, resulting in 35 fish samples that could be used in further analyses. These samples yielded 5,865 individuals representing 45 species, with the total number of fishes collected in each stream ranging from 179 (LAW436, 2 collections) to 997 (DL3, 4 collections). A total of 16 species made up more than 1% of the total number of fishes collected, but most collections were dominated by striped shiner *Luxilus chrysocephalus*, Longear sunfish *Lepomis megalotis*, and cherryfin shiner *Lythrurus roseipinnis*, which comprised about 52 % of the total number of fishes sampled in the 10 streams (Table 3). The striped shiner was by far most abundant in the Deer Lick Creek watershed, particularly at sites SUNNY HILL and DL3. These two sites also yielded high abundances of cherryfin shiners and longear sunfish, although both of these fishes were also present in relatively high densities in the Hayes creek watershed. The SUNNY HILL site had the highest average CPUE, with BSIL3 exhibiting the lowest CPUE. Abundance was not closely tied to diversity, as the fish community at the SILVERHAVEN site exhibited both the highest and lowest diversities, depending on the season sampled. Examination of species accumulation curves revealed that LAW2, DL2, BSIl3, SILVERHAVEN and HAYES3 appeared to be leveling off after 4 samples, whereas sites BSIL2, DL3, LAW436, HAYES2, and SUNNYHILL still appeared to be increasing in species number with each successive sample (Figure 3).

<u>Habitat</u>

Mean temperatures in all streams during the 2007 and 2008 sampling periods ranged between 20 and 23^{o}C, and all streams exhibited relatively high DO levels (typically > 5.0 mg/l)

Table 2: Sampling date, site, stream, area (square meters electrofished), total number of fishes collected (Number), catch per unit effort (CPUE, Number/1,000 m^2), and fish community diversity (Shannon-Weaver) in tributaries of the upper Bogue Chitto River, Washington Parish, LA, during 2007 and 2008.

DATE	SITE	Stream	Area	Number	CPUE	Diversity
8/6/2007	BSIL2	Big Silver	958.5	260	271.3	4.6
10/19/2007	BSIL2	Big Silver	1110	209	188.3	4.6
3/2/2008	BSIL2	Big Silver	1136	108	95.1	4.8
7/16/2008	BSIL2	Big Silver	1136	284	250.0	4.7
5/29/2007	BSIL3	Big Silver	2031.2	62	30.5	4.1
10/10/2007	BSIL3	Big Silver	1874	94	50.2	4.0
3/24/2008	BSIL3	Big Silver	1985.1	124	62.5	4.1
7/23/2008	BSIL3	Big Silver	1985.1	118	59.4	4.1
8/16/2007	SILVERHAVEN	Big Silver	3016.3	128	42.4	4.5
10/31/2007	SILVERHAVEN	Big Silver	2642	204	77.2	4.3
4/17/2008	SILVERHAVEN	Big Silver	1527.8	147	96.2	4.9
8/29/2008	SILVERHAVEN	Big Silver	2642	49	18.5	3.6
7/26/2007	DL2	Deer Lick	1723.3	89	51.6	4.4
10/5/2007	DL2	Deer Lick	2068.8	109	52.7	4.0
4/10/2008	DL2	Deer Lick	1805	153	84.8	4.2
6/28/2007	DL3	Deer Lick	1142.4	219	191.7	4.0
10/2/2007	DL3	Deer Lick	979	183	186.9	3.8
3/16/2008	DL3	Deer Lick	1459	261	178.9	3.9
8/21/2008	DL3	Deer Lick	1459	334	228.9	3.8
6/21/2007	HAYES2	Hayes	1458	286	196.2	4.3
9/28/2007	HAYES2	Hayes	1325.5	79	59.6	4.2
4/1/2008	HAYES2	Hayes	1449	148	102.1	3.9
8/15/2008	HAYES2	Hayes	1325.5	113	85.3	3.6
6/11/2007	HAYES3	Hayes	1092.1	131	119.9	4.1
9/21/2007	HAYES3	Hayes	812	111	136.7	3.9
3/20/2008	HAYES3	Hayes	1164.5	112	96.2	3.9
7/9/2007	LAW2	Lawrence	1825.2	118	64.7	4.7
8/31/2007	LAW2	Lawrence	1759	75	42.6	4.4
3/19/2008	LAW2	Lawrence	2422	66	27.3	4.2
8/8/2008	LAW2	Lawrence	2422	139	57.4	4.7
9/14/2007	LAW436	Lawrence	1135.5	104	91.6	4.7
3/3/2008	LAW436	Lawrence	1066	75	70.4	4.1
5/24/2007	SUNNY HILL	Sunny Hill	983	239	243.1	4.2
9/7/2007	SUNNY HILL	Sunny Hill	1032	268	259.7	4.1
2/14/2008	SUNNY HILL	Sunny Hill	1139.5	357	313.3	4.2

Table 3: Total number and percentage of total of total abundance of fishes collected in tributaries of the upper Bogue Chitto River, Washington Parish, LA, during 2007 and 2008.

Species	**Common name**	**Total collected**	**% Total Abundance**
Icthyomyzon gagei	Southern Brook Lamprey	55	0.94
Lepisosteus oculatus	Spotted gar	3	0.05
Anguilla rostrata	American Eel	4	0.07
Cyprinella venusta	Blacktail Shiner	103	1.76
Luxilus chrysocephalus	Striped Shiner	1560	26.61
Lythrurus roseipinnis	Cherryfin shiner	822	14.02
Nocomis Leptocanthus	Bluehead chub	216	3.68
Notropis longirostris	Longnose shiner	107	1.83
Notropis texanus	Weed shiner	11	0.19
Notropis winchelli	Clear chub	333	5.68
Opsopodeodus emilae	Pugnose minnow	2	0.03
Pteronotropis signipinnis	Flagfin shiner	3	0.05
Erimyzon oblongus	Creek chub sucker	22	0.38
Erimyzon tenuis	Sharpfin chubsucker	139	2.37
Hypentelium nigricans	Northern hog sucker	115	1.96
Moxostoma poecilurum	Blacktail redhorse	122	2.08
Ameiurus natalis	Yellow bullhead catfish	17	0.29
Noturus funebris	Black madtom	38	0.65
Noturus leptacanthus	Speckled madtom	33	0.56
Noturus miurus	Brindled madtom	7	0.12
Noturus nocturnus	Freckled madtom	18	0.31
Esox americanus	Grass Pickerel	10	0.17
Esox niger	Chain pickerel	1	0.02
Aphredoderus sayanus	Pirate perch	146	2.49
Fundulus olivaceus	Blackspotted topminnow	195	3.33
Gambusia affinis	Western mosquito-fish	55	0.94
Labidesthes sicculus	Inland silverside	5	0.09
Ambloplites ariommus	Shadow bass	102	1.74
Lepomis cyanellus	Green sunfish	18	0.31
Lepomis gulosus	Warmouth	32	0.55
Lepomis macrochirus	Bluegill sunfish	163	2.78
Lepomis megalotis	Long-ear sunfish	639	10.90
Lepomis microlophus	Red-ear sunfish	1	0.02
Lepomis miniatus	Red-spotted sunfish	132	2.25
Micropterus punctulatus	Spotted bass	44	0.75
Micropterus salmoides	Largemouth bass	2	0.03
Elassoma zonatum	Pygmy sunfish	6	0.10
Ammocrypta beani	Naked sand darter	7	0.12
Ammocrypta vivax	Scaly sand darter	2	0.03
Etheostoma chlorosoma	Bluntnose darter	5	0.09
Etheostoma histrio	Harlequin darter	54	0.92
Etheostoma stigmaeum	Speckled darter	42	0.72
Etheostoma swaini	Gulf darter	164	2.80
Percina sciera	Dusky darter	16	0.27
Percina nigrofasciata	Black-banded Darter	267	4.55

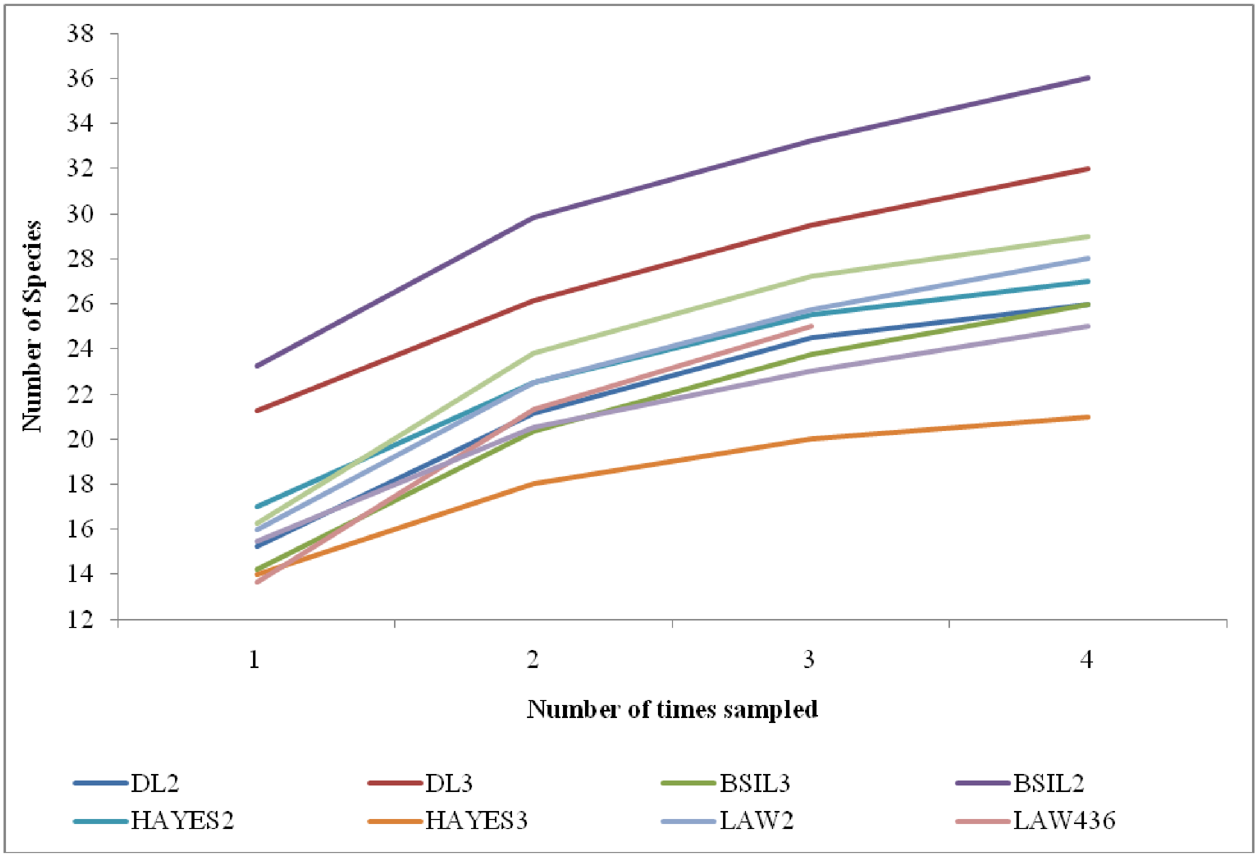

Figure 3: *Mau Tau* method species accumulation curves (Colwell 1997) for tributaries of the Bogue Chitto River sampled 4 times from summer of 2007 to summer of 2008.

during both years. Sample sites ranged from 5.5 to 13.9 m in width, but all streams were of similar depths, with mean values ranging from 40 to 55 cm (Table 4). Although average flow velocities ranged up to 0.26 m/sec, mean current speeds at most of the sites were less than half this value. Substrates were typically dominated by sand, although gravel patches were evident at BSIL2, BSIL3, LAW2, SILVERHAVEN, and SUNNY HILL. Woody debris was common at most sites, but was particularly abundant at HAYES2. Overall, the LAW2 site in the Lawrence Creek watershed exhibited the highest DO concentrations, greatest flow rates, and largest substrate sizes.

Table 4: Means (± standard deviation, below) of habitat variables measured from 2007-2008 in tributaries of the upper Bogue Chitto watershed during 2007 and 2007. Data includes flow, depth, substrate [categorized as 1 (silt), 2 (sand), 3 (gravel), and 4 (cobble)] and woody debris, which was quantified as the average number of pieces per transect

SITE	DO (mg/l)	Temperature (°C)	Width (m)	Depth	Flow (m/sec)	Substrate	Woody debris
BSIL2	8.50	21.85	11.55	49.34	0.26	2.44	1.04
	±0.62	±1.58	±0.50	±1.78	±0.028	±0.04	±0.138
BSIL3	7.50	21.87	10.92	55.53	0.11	2.35	2.50
	±0.14	±0.19	±0.55	±1.54	±0.011	±0.04	±0.128
DL2	6.83	22.90	11.58	50.32	0.10	2.04	0.49
	±0.30	±1.20	±0.63	±1.44	±0.006	±0.05	±0.149
DL3	7.12	22.01	7.11	40.80	0.13	2.10	4.59
	±0.12	±0.04	±0.49	±1.08	±0.007	±0.02	±0.159
HAYES2	7.15	20.76	8.26	53.61	0.09	1.97	3.95
	±0.23	±0.94	±1.20	±3.03	±0.003	±0.02	±0.29
HAYES3	7.32	21.80	5.51	55.52	0.13	2.08	3.56
	±0.33	± 1.20	±1.37	±4.10	±0.027	±0.01	±0.388
LAW2	10.42	23.47	10.40	43.19	0.26	2.57	0.504
	±0.37	±0.67	±1.23	±3.70	±0.015	±0.02	±0.44
LAW436	6.20	21.69	6.03	41.22	0.12	1.87	4.23
	±0.60	±1.36	±1.62	±5.32	±0.010	±0.05	±0.62
SILVERHAVEN	8.91	20.98	13.89	46.79	0.18	2.44	8.30
	±0.29	±1.46	±0.88	±1.77	±0.016	±0.02	±0.03
SUNNY HILL	6.95	23.47	5.78	48.43	0.15	2.35	5.47
	±0.55	±1.56	±0.68	±3.23	±0.046	±0.06	±0.33

<u>Water Quality</u>

Nitrogen levels were relatively consistent among the study streams (nitrate 0.1523 to 0.1155, nitrite 0.0035-0.0050 mg/l; Table 5). Phosphorus appeared to be somewhat elevated in BSIL3 and SUNNY HILL, whereas TOC was relatively consistent among streams. Fecal coliform counts, although variable, appeared to divide the study streams into two groups, with lower values for the Lawrence Creek sites (LAW2 and LAW436), SILVERHAVEN, and SUNNY HILL, and higher values for the remaining sites in Big Silver (BSIL2, BSIL3), Deer Lick (DL2, DL3), and Hayes creeks (King et al. 2005b). These data were not mirrored by the heterotrophic plate counts, which were highly variable within and among streams, ranging from 3480 to 28,150 colonies per ml. Chlorophyll *a* values were relatively consistent among streams,

with mean values ranging from 20-60 µg/l, as were total volatile solids, which ranged from about 0.009 to 0.025 mg/l. Biochemical oxygen demand values were remarkably consistent, ranging from 4.03 to 4.95 for eight of the ten streams.

Table 5: Water chemistry (mean ± standard error, below) determined for each sampling site in tributaries of the upper Bogue Chitto River measured at the end of each field season in 2007 and 2008. Data include orthophosphate (Ortho-P), total organic carbon (TOC), fecal coliform counts (FC), heterotrophic plate counts (HPC), chlorophyll *a* (Chl-*a*), total volatile solids (TVS), and 20-day biochemical oxygen demand (BOD-20).

SITE	**Nitrate (mg/l)**	**Ortho-P (mg/l)**	**TOC (mg/l)**	**FC (per 100ml)**	**HPC (per ml)**	**Chl-*a* (ug/l)**	**TVS (mg/l)**	**BOD-20 (mg/l)**
BSIL2	0.1155	0.34	4.86	1362	10501.3	43.31	0.0094	4.79
	±0.0164	±0.05	±0.54	±337.2	±1625.7	±33.90	±0.007	±0.61
BSIL3	0.1098	0.61	5.68	1647	8001.3	29.96	0.0095	4.89
	±0.0182	±0.09	±0.33	±417.0	±1444.4	±27.90	±0.010	±1.41
DL2	0.1215	0.37	4.35	225.5	5781.3	14.90	0.0209	4.91
	±0.0151	±0.06	±0.35	±8.11	±877.3	±11.90	±0.015	±0.87
DL3	0.1208	0.31	4.18	151	7036.3	20.31	0.0175	4.66
	±0.0151	±0.07	±0.57	±11.25	±1115.7	±11.05	±0.013	±0.69
HAYES2	0.1095	0.30	3.88	281.5	4623.8	31.94	0.0218	4.95
	±0.0134	±0.02	±0.68	±25.97	±513.4	±25.20	±0.017	±1.56
HAYES3	0.1155	0.26	5.81	275	3480.5	60.67	0.0506	6.38
	±0.0105	±0.05	±0.68	±18.51	±602.4	±56.80	±0.054	±2.46
LAW2	0.1358	0.33	4.77	135.8	7713.8	33.34	0.0188	4.44
	±0.0089	±0.05	±0.34	±23.33	±2470.5	±43.00	±0.011	±1.04
LAW436	0.1523	0.36	5.73	83	7141.7	45.31	0.0250	4.85
	±0.0311	±0.09	±0.17	±15.89	±3654.9	±39.01	±0.003	±2.52
SILVERHAVEN	0.1223	0.80	5.80	1064.5	10961.3	22.39	0.0106	5.51
	±0.0272	±0.21	±0.35	±256.0	±2250.2	±13.90	±0.006	±1.31
SUNNYHILL	0.1425	0.71	5.13	284	28150.0	47.21	0.0139	4.03
	±0.0291	±0.05	±0.39	±64.14	±4715.5	±19.80	±0.011	±1.89

<u>Watershed Characteristics</u>

Of the 10 sampling sites, LAW2 was closest to the main channel of the Bogue Chitto River (250 m), whereas LAW436 was the furthest at 3.95 km (Table 6). SILVERHAVEN had the largest watershed (17,7612 ha), whereas the upstream site LAW436 had the smallest. HAYES2 had the most pasture land at 26.7%, whereas SUNNYHILL had the most cultivated cropland (23%). LAW2 had the lowest percentage of basin wide agricultural land at a combined 22.4%. At the 1.6-km scale, DL3 had the highest percentage of forested land at 38%, whereas

just downstream, DL2 had the least forested land at 2.3%. SILVERHAVEN had the largest percentage of cultivated cropland (33.2%), and HAYES2 had the most pasture land. At the 500-m buffer scale, DL3 again had the highest percentage of forested land (21.3%), HAYES3 had the most pasture land, and BSIL3 had the most cultivated cropland.

<u>Habitat , Water Quality, and Land Use PCA</u>

Results of the PCA on the 25 habitat, water quality, and land use variables yielded 8 principle components with eigenvalues greater than 1.0 that together accounted for 80% of the variance in the dataset (Table 7). Principle component 1 contrasted sites that differed in several important habitat measurements, including flow velocity, substrate, DO levels, and distance from the river mainstem. In contrast, PC2 seemed to be related to disturbance, with high correlations for nitrate, cultivated crops, and pasture. Principle component 3 was related to smaller scale watershed land use, having strong correlations with 500-m and 1.6-km forest, and 1.6-km cultivated crops and pasture, whereas PC4 was related to HPC, temperature, and phosphate.

Table 6: Distance of each study site from the Bogue Chitto River main channel (Dist), as measured in accordance with Berkman et. al. (1986) percentage of Cultivated cropland (CC), Pasture land (PAS), and Forested (FS) within 500-m and 1.6-km buffers upstream from each site, and land use percentages and size for each basin. Land use data were collected from U. S. Geological Survey 2001 land use and land cover (LULC) maps. Watershed land use was applied to each upstream delineated watershed based on Louisiana Department of Environmental Quality (LDEQ) sub-segments, or was manually delineated based on the 2004 LDEQ Elevation map.

		500-m buffer			**1.6-km buffer**			**Basin**		
Site	**Dist (km)**	**CC**	**PAS**	**FS**	**CC**	**PAS**	**FS**	**CC**	**PAS**	**Size (ha)**
BSIL2	1.55	0.0	19.3	7.0	0.8	6.3	17.5	14.1	18.6	5958
BSIL3	3.25	28.0	0.0	0.7	10.1	15.1	14.6	16.4	16.7	4532
DL2	2.10	18.4	14.3	0.0	11.3	24.2	2.3	14.9	19.2	9920
DL3	3.75	0.0	8.7	21.3	0.0	10.0	38.6	15.2	19.5	7770
HAYES2	3.05	0.0	18.8	9.8	0.0	29.5	9.1	2.2	26.7	5234
HAYES3	3.60	0.0	28.7	0.0	8.7	19.1	10.0	2.3	26.5	4228
LAW2	0.25	0.0	0.0	10.7	0.0	12.8	14.1	4.5	17.9	13301
LAW436	3.95	0.0	23.6	1.9	3.65	18.5	11.7	8.9	25.7	1257
SILVERHAVEN	0.85	0.3	12.3	0.0	33.2	23.4	5.3	14.2	19.0	17612
SUNNY HILL	2.60	0.0	18.9	15.4	22.0	19.7	14.7	23.0	18.5	1120

Principle component 5 was related to BOD and chlorophyll, PC6 reflected stream differences in fecal coliform levels and TOC concentrations. The last two PCs reflected differences in reach-scale habitat among streams, including woody debris abundance (PC7) and depth (PC8).

Table 7: Correlations of each of the 25 land-use, habitat and water chemistry variables with each of the eight principle components (PC) with eigenvalues over 1.0. Highlighted values in each PC are those variables with correlations greater than 0.50. TVS= total volatile solids, Ortho-P= orthophosphate, TOC=total organic carbon, BOD-20= 20-day biochemical oxygen demand, FC= fecal coliform counts, and HPC=heterotrophic plate counts. Distance of each study site from the Bogue Chitto River main channel (Dist), as measured in accordance with Berkman et. al. (1986) percentage of Cultivated cropland (CC), Pasture land (PAS), and Forested (FS) within 500-m and 1.6-km buffers upstream from each site, and land use percentages and size for each basin.

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
Percent of variance explained	22.68	13.37	11.49	8.67	7.8	6.91	4.86	4.37
Distance From Main Channel (km)	**0.87**	-0.09	0.16	-0.07	-0.11	10	0.06	-0.05
Fine Substrate	**0.85**	-0.21	0.07	-0.14	0.22	-0.18	-0.04	-0.03
Flow (m/sec)	**-0.64**	-0.19	0.28	0.25	0.33	-0.02	0.17	0.22
Dissolved Oxygen (mg/l)	**-0.77**	-0.12	0.12	-0.34	-0.11	-0.07	0.12	0.09
Sand/Coarse substrate	**-0.86**	0.28	-0.05	0.12	0.14	0.20	0.06	0.0
Nitrate (mg/l)	-0.11	**0.85**	0.06	0.09	-0.10	0.06	0.11	-0.08
Basin-wide Cultivated Crops	-0.01	**0.82**	0.15	0.34	-0.02	0.20	0.20	0.08
Total Volitile Solids	0.20	**-0.52**	-0.10	-0.01	-0.43	0.03	0.22	-0.42
Basin-wide Pasture	**0.54**	**-0.70**	-0.20	-0.11	-0.14	-0.26	0.15	0.03
1.6-km Evergreen Forest	0.17	0.14	**0.95**	-0.05	-0.01	0.05	0.00	-0.09
500-m Evergreen Forest	0.06	0.22	**0.79**	0.12	0.05	-0.37	0.10	-0.13
1.6-km Cultivated Crops	-0.19	0.35	-0.48	0.37	-0.14	0.09	0.49	0.32
1.6-km Pasture	0.31	-0.05	**-0.74**	0.03	-0.05	-0.30	0.17	0.15
Heterotrophic Plate Count (# per ml)	-0.13	0.23	0.09	**0.82**	0.13	-0.14	0.03	0.03
Ortho-P	-0.06	0.12	-0.15	**0.62**	0.28	0.31	0.07	0.08
Temperature (°C)	0.07	0.03	0.02	**0.73**	-0.03	0.06	-0.48	-0.19
Width	-0.36	0.21	-0.20	-0.29	-0.30	0.03	0.12	-0.49
BOD-20	0.16	-0.37	-0.09	0.13	**-0.72**	0.05	-0.01	0.17
Chlorophyll-a (ug/l)	0.02	-0.18	-0.02	0.02	**0.85**	0.13	0.12	0.01
500m Cultivates Crops	0.12	0.48	-0.38	-0.20	-0.11	0.46	-0.43	-0.06
500m Pasture	0.44	-0.46	-0.18	0.20	0.22	-0.18	0.40	0.10
Fecal Coliform (# per 100 ml)	-0.22	0.05	-0.04	0.08	0.27	**0.84**	0.09	0.09
Total Organic Carbon (TOC)	-0.05	-0.41	-0.10	-0.05	0.13	**-0.66**	-0.03	-0.07
Wood	0.02	0.09	-0.02	-0.16	0.06	0.05	**0.83**	-0.12
Depth	-0.04	-0.10	-0.23	0.03	-0.02	0.11	-0.06	**0.84**

Bi-plots of site scores revealed several differences among sampling sites for the eight PCs retained from the analysis. Sites were relatively evenly spaced along PC1, with most of the samples within sites clustered together (Figure 4). Site LAW2 exhibited low PC1 scores relative to most of the other sites, most likely due to its proximity to the main river. Sites were also dispersed fairly evenly along PC2, likely reflecting differences in the proportions of agricultural and pastoral land use in their watersheds. Samples within sites clustered together along PC3, which was to be expected given the importance of the static landscape variables in this PC (Figure 5). However, there was considerable spread among sites along this axis, likely reflecting between-site differences in land use at the three spatial scales. Although there was less spread among sites along PC4, several sites exhibited substantial differences in scores among samples, which likely reflected seasonal and annual differences in temperatures, orthophosphate levels, and heterotrophic plate counts.

The plot of PC5 and PC6 (Figure 6) revealed large differences among and within sites, particularly for SUNNYHILL, BSIL3 and HAYES3. Again, I interpret the spread along PC5 as a reflection of seasonal and annual differences in primary production (chlorophyll *a*) and organic decomposition (BOD-20) among samples, and the among-site and within-site variability along PC6 as temporal changes in TOC and FC levels. Most of the sites were clustered fairly close together along PC7 and PC8, although seasonal variation within sites was evident for both PC7 (likely tied to woody debris abundance, e.g., SUNNYHILL and SILVERHAVEN) and PC8 (likely tied to depth, e.g., HAYES3).

<u>Relationships Among Abundant Fish Species and Habitat PCs</u>

Results of the MANOVA on the top 20 species that comprised 93% of the total fishes collected during the study indicated significant relationships between the PCs and the

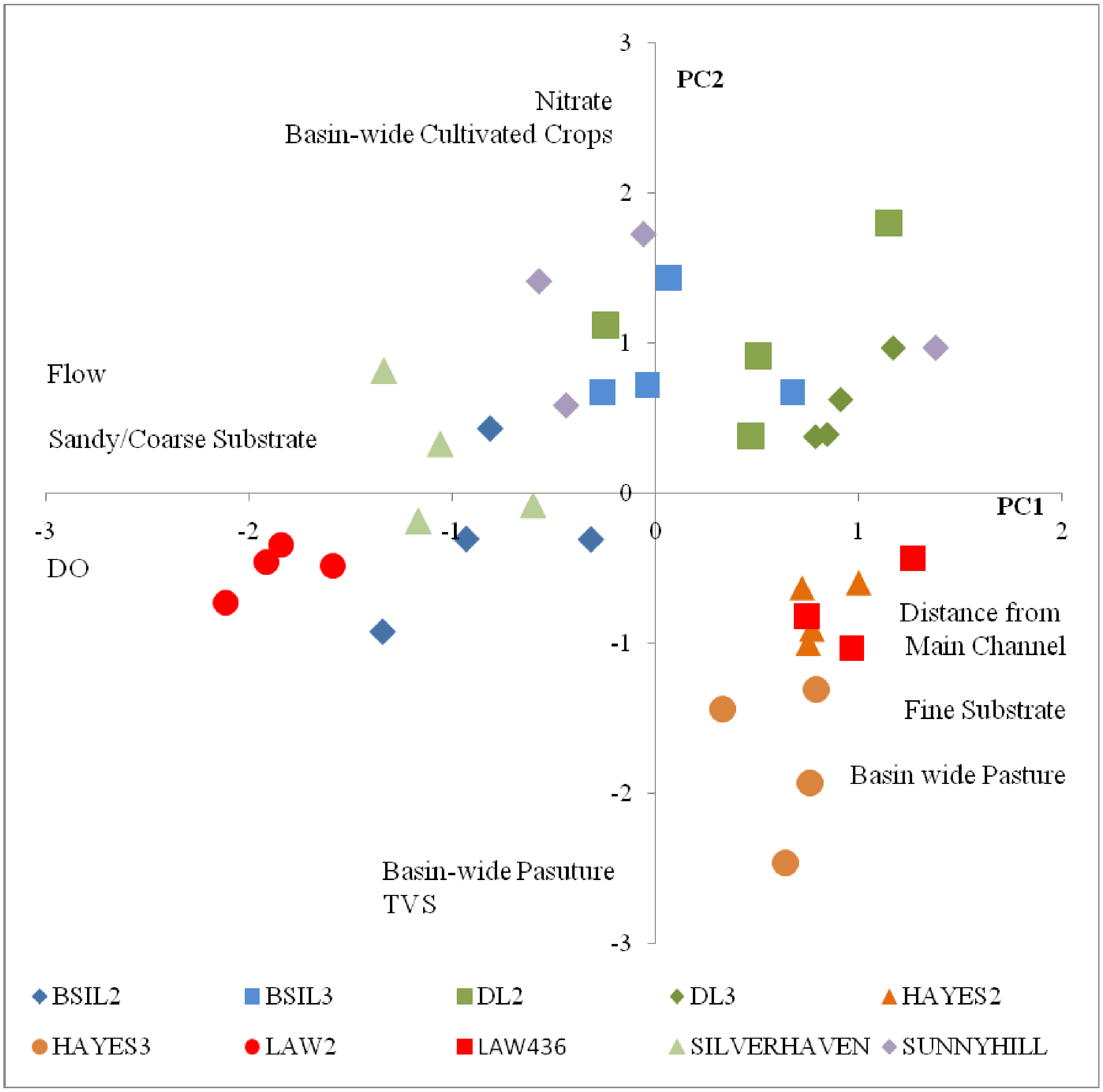

Figure 4. Site scores on PC1 and PC2 from the PCA of 25 habitat, water quality, and landscape variables for the 10 southeastern Louisiana streams sampled during 2007-2008.

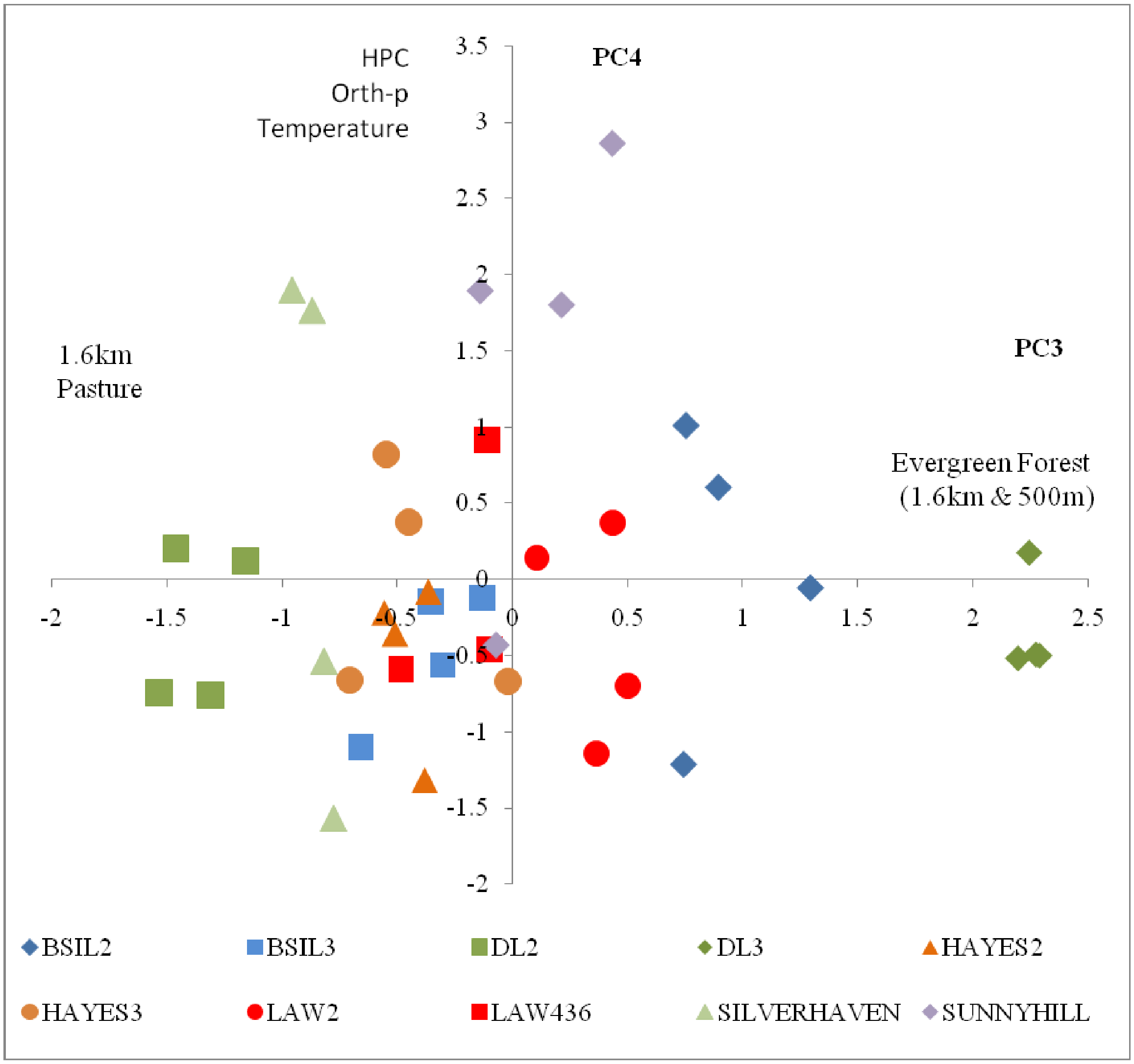

Figure 5. Site scores on PC3 and PC4 from the PCA of 26 habitat, water quality, and landscape variables for the 10 southeastern Louisiana streams sampled during 2007-2008.

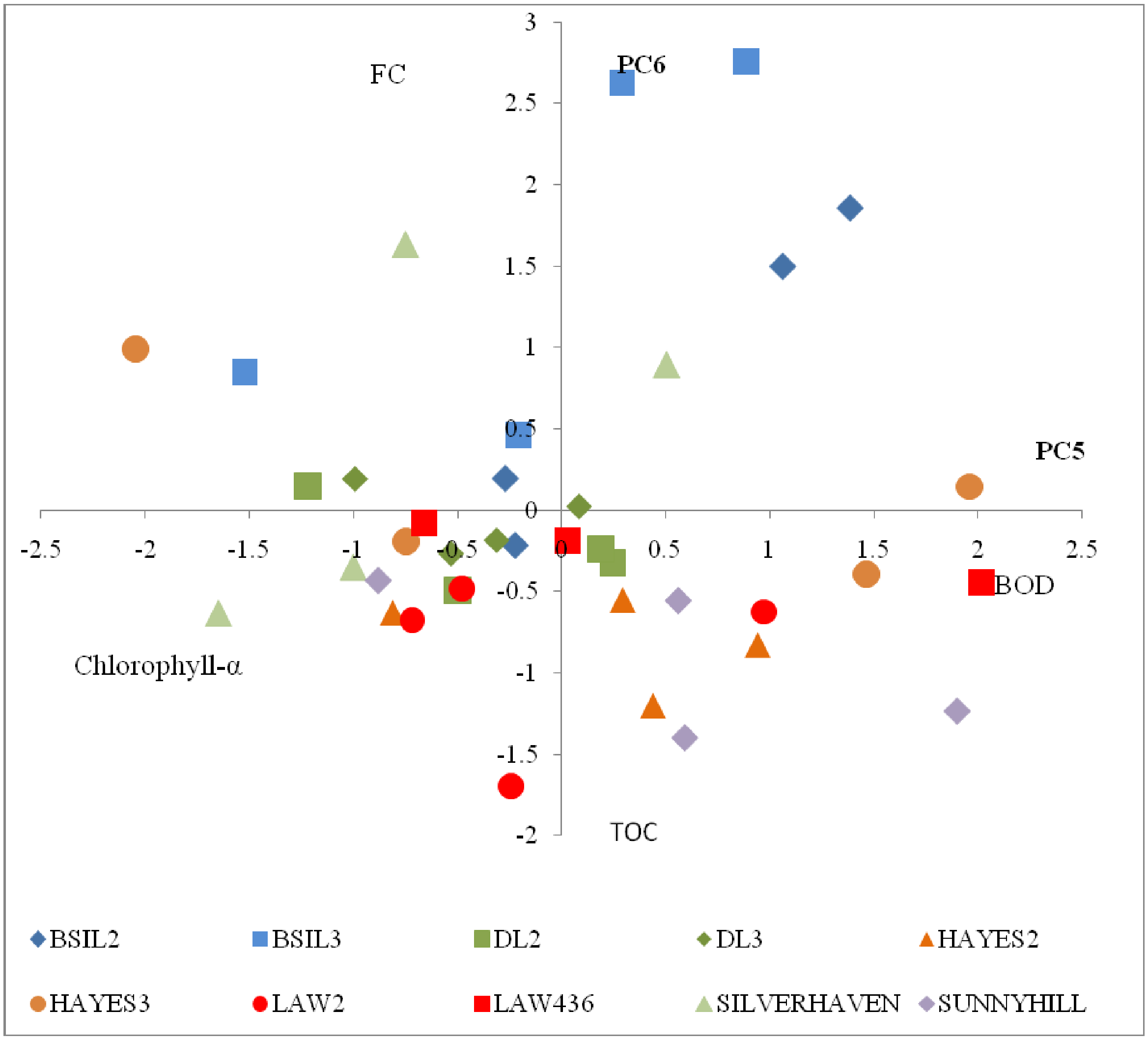

Figure 6. Site scores on PC5 and PC6 from the PCA of 26 habitat, water quality, and landscape variables for the 10 southeastern Louisiana streams sampled during 2007-2008.

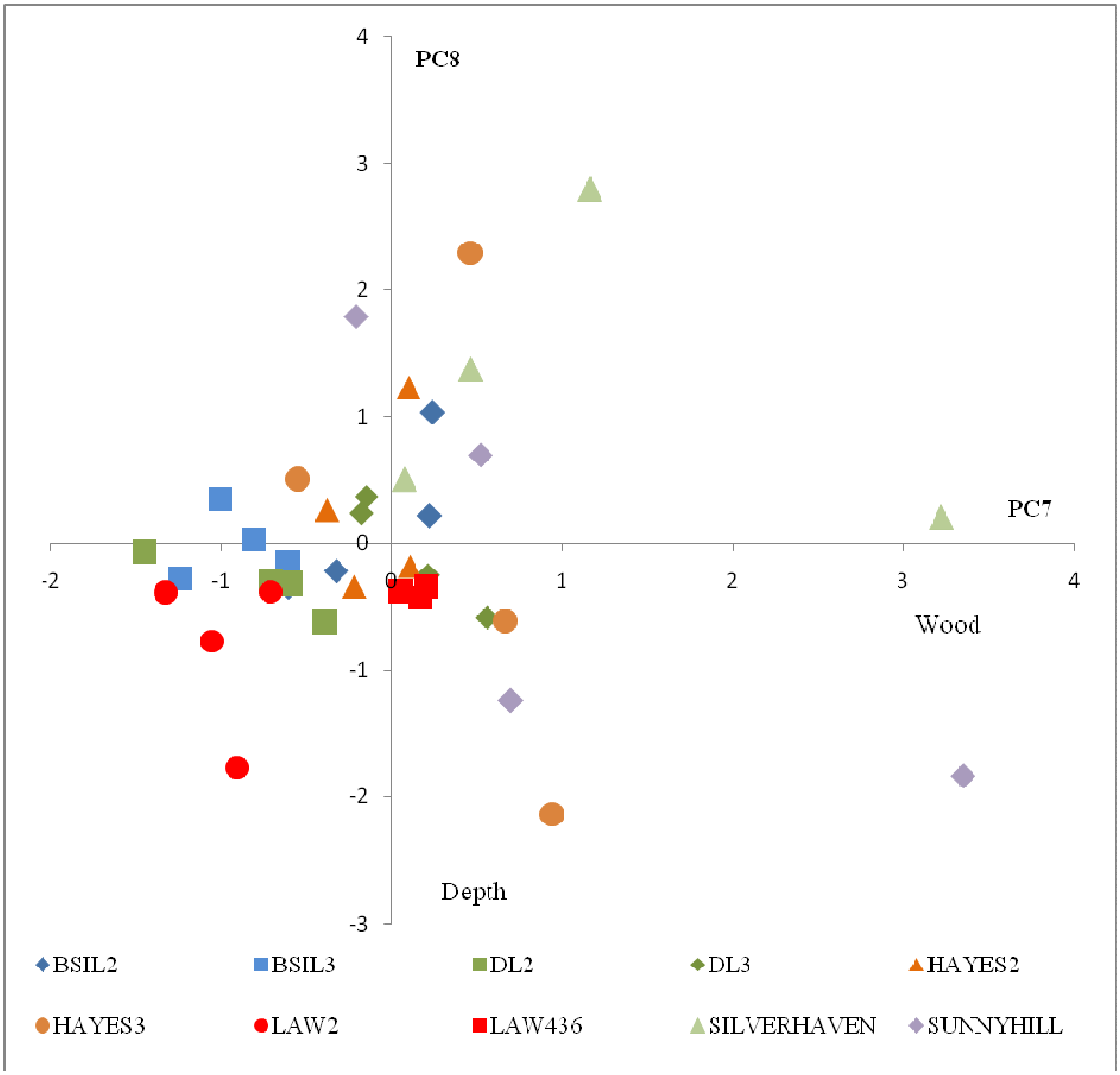

Figure 7. Site scores on PC7 and PC8 from the PCA of 26 habitat, water quality, and landscape variables for the 10 southeastern Louisiana streams sampled during 2007-2008.

abundances of southern brook lamprey, gulf darter, striped shiner, cherryfin shiner, bluehead chub, pirate perch, blacktail shiner, redspotted sunfish, shadow bass, northern hogsucker and blacktail redhorse. Blacktail redhorse was the only fish to show seasonal differences in abundance (P=0.0177), being less abundant in the fall, indicating that seasonal changes in fish abundance and distribution did not significantly affect the analyses.

Habitat PC1 showed significant positive relationships with the abundance of striped shiners, cherryfin shiners, and pirate perch, and a negative relationship with blacktail shiners, shadow basses, redspotted sunfishes, and blacktail redhorse (Table 8). Results of ANOVAs on the abundance of these species and the variables that were highly correlated (>0.5) on PC1 [(+)distance from main river, (-) DO, (-) flow, (-)substrate,(+) %Basin wide pasture] revealed that distance from the Bogue Chitto River was positively associated striped shiner abundance (P=0.0099), and negatively associated with blacktail shiner abundance (P=0.0031). PC2 [(+) Nitrate, (+) Basin-wide cultivated crops, (-) Basin-wide pasture, (-) TVS], showed a positive relationship with the abundance of striped shiners and bluehead chubs. More specifically, ANOVAs revealed positive relationships between basin-wide cultivated crops and the abundances of striped shiners (slope = 1.30, P=0.0142) and bluehead chubs (slope = 0.93, P = 0.0100), and between basin-wide pasture and the abundance of striped shiners (slope = 1.97, P=0.0160).

Habitat PC3 [(+) forest cover 1.6km, and 500m buffer, (-) cultivated crops, and (-)pasture 1.6km buffer] showed significant positive relationships with the abundance of gulf darters, striped shiners, blue head chubs, shadow basses, black banded darters, northern hog suckers, and blacktail redhorse (Table 9). The ANOVAs revealed negative relationships between 1.6-km pasture land and abundances of gulf darters (P=0.0045), shadow basses (P=0.0171), northern

hog suckers (*P*=0.0321), and blacktail redhorse (*P*=0.0039). In addition, blacktail redhorse abundance was negatively associated with the proportion of forested land in the 1.6-km buffer (*P*=0.0245), whereas striped shiner abundance was positively associated with the proportion of forested land at both the 500-m (*P*=0.0392) and 1.6-km (*P*=0.0086) scales.

Table 8. Significant relationships between PC1(distance from main river, DO, flow, substrate, %Basin wide pasture) and the abundance of fishes collected in southeastern Louisiana streams in 2007 and 2008.

Species	**Slope with PC1**	***P*-value**
Striped shiner	13.92	0.0001
Cherryfin shiner	6.76	0.0075
Pirate perch	1.02	0.0171
Shadow bass	-0.74	0.0123
Blacktail shiner	-1.39	0.0012
Redspotted sunfish	-0.99	0.0376
Blacktail redhorse	-0.88	0.0057

Table 9: Significant relationships between PC3 (forest cover 1.6km, and 500m buffer, and pasture 1.6km buffer) and the abundance of fishes collected in southeastern Louisiana streams in 2007 and 2008.

Species	**Slope with PC3**	***P*-value**
Gulf Darter	2.41	0.0106
Striped shiner	18.64	<0.0001
Cherryfin shiner	6.48	0.0087
Bluehead chub	3.48	0.0012
Shadow Bass	0.63	0.0279
Black banded Darter	1.24	0.0399
Northern Hogsucker	1.58	0.0026
Blacktail Redhorse	0.77	0.0128

Relationships Among Abundance and Diversity and the Habitat PCs

The ANOVA of total fish abundance and the eight habitat PCs produced significant positive relationships with PC2 [(+) nitrate, (+) basin-wide cultivated crops, (-) basin-wide pasture, *P*=0.0231], PC3 [(+) 1.6-km forest, (+) 500m forest, (-) 1.6-km pasture, *P*=0.0001], PC4 [(+) HPC, (+) Ortho-P, (+) Temperature, *P*=0.0196], and PC7 [(+) Wood, *P*=0.0059]. Further analyses revealed positive significant relationships between total abundance and basin-wide cultivated crops (*P*=0.0266), basin-wide pasture (*P*<0.0001), and 500-m forest (*P*=0.0073), and a significant negative relationship with 1.6-km pasture (*P*=0.0012).

Shannon-Weiner diversity was significantly related to PC1 (*P*=0.0017). The ANOVA of diversity and the variables highly correlated with PC1 [(+) Distance from main river, (+) fine substrate, (+) %Basin wide pasture, (-) DO, (-) Flow, (-) Sand/coarse substrate] yielded a significant negative relationship between diversity and site distance from the Bogue Chitto River (Figure 8, *P*=0.0498).

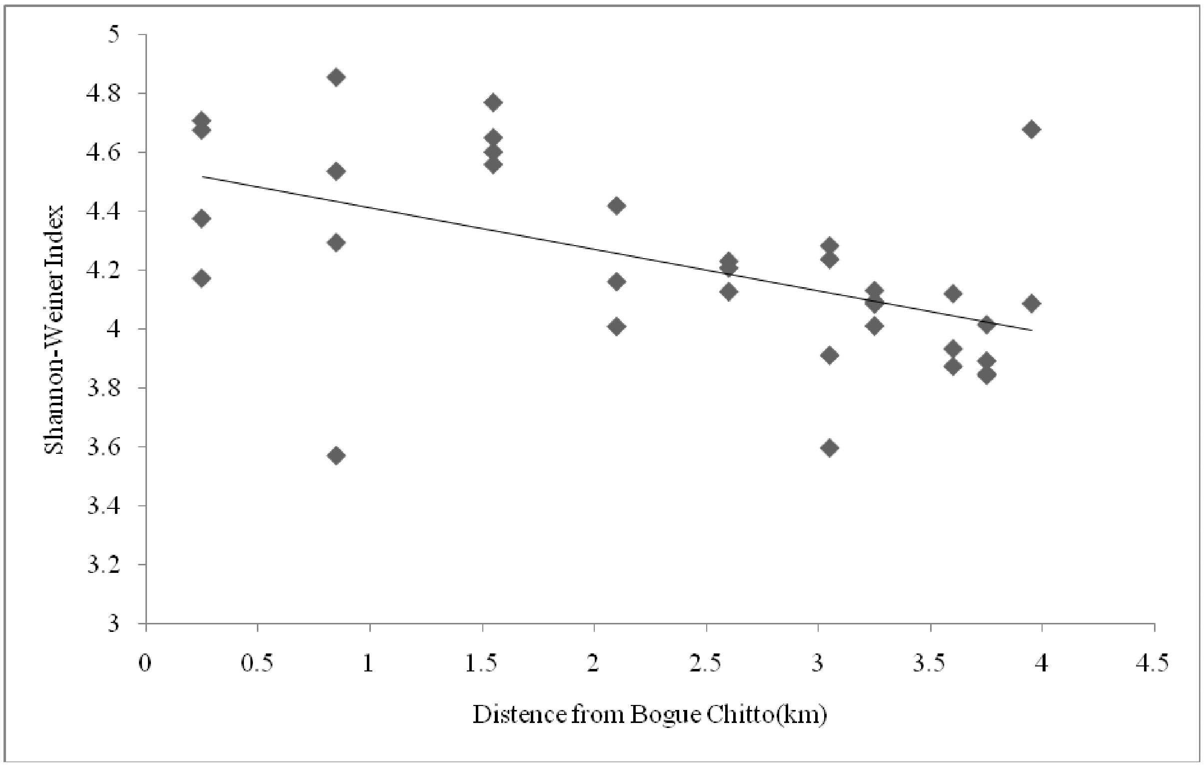

Figure 8: Shannon-Weiner diversity indices of fish samples taken from tributaries of the Bogue Chitto River plotted against distance from the main river (r^2 =0.29, p=0.0498).

Discussion

Streams in the Bogue Chitto River supported a higher species richness than other coastal plain streams in similar ecoregions (Paller 1994; Smiley et al. 2005). Overall, the fish communities in these streams were dominated by striped and cherryfin shiners, as well as longear sunfish. The tributary stream fish communities differed substantially from 1998 collections in the main channel of the Bogue Chitto River, which were dominated by blacktail shiner (56.7% of relative abundance; Stewart et al. 2005), a species that comprised only 1.76% of the fishes collected in this study (Table 2).

Habitat characteristics of the coastal plain streams were similar to those found in other systems within the eastern Gulf coastal plains ecoregion, with DO ranging from 5-9 mg/l, flow from 0.11 to 0.26 m/s, and substrates being composed mostly of sand (Felley 1992). With the exception of SUNNYHILL, these streams were also chemically similar to other streams in their ecoregion, with low levels of nutrients and dissolved substances (Felley 1992). As with most of the watersheds in this region, land use was dominated by forests and agricultural lands. Louisiana landowners typically follow the state's voluntary BMP's, leaving stream side riparian zones relatively undisturbed (Kaller et al. 2002). In the 500-m buffer around the sample sites there was some agricultural development, but never more than a combined 33% of the land area (Table 5). Forests made up a large part of the land use in all of the watersheds, and the lack of variation in forested area likely kept this from being a significant variable in the models of fish abundance (Table 5). Although Washington Parish is known for its timber industry, and parts of the Lawrence creek watershed are owned by timber companies, there was no evidence of clearcutting or drastic changes to the foliage around the study sites during the sampling period. Basin-wide cultivated land use also differed among streams by only 21% and pastureland by

10% (Table 5), which is a smaller range than has been included in other studies (Lammert and Allan 1999; Buck et al. 2004; Diana et al. 2006; Heitke et al. 2006), and again could explain why no direct relationship between agricultural intensity and fish community composition was found.

Physicochemical Characteristics of Sampling Sites

Results of the PCA indicated substantial separation among sites and clumping within sites along the first two principle components, suggesting consistent differences in habitat and water quality among the ten sites as well as seasonal and annual similarities in overall physicochemical conditions within each site. The PCs appeared to be readily interpretable based on correlations between the PCs and the habitat, water quality, and landscape variables.

Of the PCs that exhibited relationships with stream fish abundance, I interpreted PC1 as a stream order component, based on positive correlations with flow, substrate size, DO, and negative correlations with distance from the Bogue Chitto River and Basin-wide pasture area (Table 7). Flow velocity, both high and low, has been shown to be a significant factor influencing stream fish communities (Freeman et al. 1988; Meffe and Sheldon 1988; Lammert and Allan 1999). Larger substrate sizes have also shown to favor certain species, such as sculpin, although substrate composition appears to be less important to generalist species like brown bullhead and largemouth bass (Smith and Kraft 2005).

PC2 appeared to be related to basin-wide cropland versus pasture land, with stream nitrate levels apparently reflecting the proportion of cropland in the watershed. In many tropical ecoregions, agricultural run-off accounts for 50% of the nitrogen in adjacent waterways (Borbor-Cordova et al. 2006), and agricultural land use and water-borne nitrate levels (as well as other nutrients; (Ulen et al. 2004; Bernot et al. 2006) in nearby streams have been correlated in other studies (Johnson et al. 1997). Principle component 3 was positively correlated with the

proportions of forested land in the 500-m and 1.6-km buffers, and negatively correlated with the proportion of pastureland in the 1.6-km buffer, and appeared to reflect mid-scale land use or condition of the riparian zone.

Principle component 4 [(+) HPC, (+) Ortho-P, (+) Temperature] appeared to be a related to stream respiration, perhaps influenced by human habitation within the riparian buffer of a stream. The similar correlations for heterotrophic plate counts and ortho-phosphate are not surprising given that heterotrophic bacteria are often phosphorous limited (Kirchman 1994; Basu and Pick 1997).

Woody debris abundance was highly correlated with PC7, which I interpreted as an allochonous input component. Woody debris is an important component of habitat complexity and is often an important factor in the maintenance of diverse fish communities (Angermeier and Karr 1984; Talmage et al. 2002). In addition to its value as cover and a velocity refuge, woody debris is also known to be important habitat for many stream macroinvertebrates (Iwata et al. 2003; Potter et al. 2005; Muenz et al. 2006), which are important food sources for fishes in these streams (Ross 2001). Even though depth varied little within or among streams, PC8 indicated that there was a significant amount of seasonal or annual variability in depth, at least over this limited range.

Fish Species Abundance Patterns in Relation to the Habitat PCs

Striped Shiner. (+PC1, +PC2, +PC3). The striped shiner decreased in abundance as sites got closer to the Bogue Chitto River, and this species appears to be associated with low-order agricultural streams. The striped shiner has been shown to be abundant in backwater habitats of the Pearl River system (Baker and Ross 1981), probably reflecting a preference for lower flow velocity, finer substrate habitats, as indicated by the negative association with PC1. The positive

associations with PC1 (+ Basin-wide pasture) and PC2 (- Basin-wide pasture) suggest that striped shiners are more strongly associated with agricultural streams. This species has been reported to tolerate heavily silted habitats (Schweizer and Matlack 2005), indicating it can withstand at least moderate disturbance within the watershed.

Cherryfin Shiner. (+PC1, +PC3). This was the second most abundant species in the study, and based on previous reports and the results of my analyses, cherryfin shiners appear to be similar to striped shiners in their preference for low-flow habitats (Ross 2001) and their tolerance of heavy silt loads (Schweizer and Matlack 2005). However, in contrast to striped shiners, cherryfin shiners were more abundant in streams with higher levels of forest cover in the watershed, and this species may be less tolerant of agriculturally-related stream impacts.

Bluehead Chub. (+PC2, +PC3). Bluehead chub abundance was positively associated with forested and cultivated cropland streams, and negatively associated with pastureland streams. The positive association between bluehead chub abundance and percent watershed forest cover has been reported previously (Kennen et al. (2005). This species is known to be omnivorous (Sheldon and Meffe 1993), and the positive relationship with PC2 (high nitrate levels) may be related to stream productivity and food availability, a relationship that has been shown for other species such as brook trout (Baldigo and Lawrence 2001). It is interesting that bluehead chub abundance was not negatively associated with PC1, as larger substrate sizes are an important part of the reproductive ecology of these pebble-mound builders (Ross 2001).

Blacktail Redhorse. (-PC1, +PC3). Based on the highly correlated variables in PC1 and PC3, I would characterize the blacktail redhorse as a larger stream specialist characteristic of higher-flow, larger substrate habitats with intact riparian zones, which is consistent with previous reports of blacktail redhorse preferences for intermediate-sized streams with moderate flow

(Ross 2001). This was the only species I collected that exhibited seasonal differences in abundance, with much lower densities in the fall. Previous reports have shown the blacktail redhorse to be a highly mobile species, traveling considerable distances to spawn (Bahm 2007) and overwinter in higher stream-order pools (Ross 2001).

Northern Hog Sucker. (+PC3). This species was positively associated with greater amounts of forested land within the 500-m and 1.6-km buffers and less pastureland within the 1.6-km buffer, suggesting that northern hog suckers may be sensitive to disturbances within the riparian zone. They are also known to be detritivores (Ross 2001), and their abundance patterns may also partially reflect detrital inputs from the surrounding riparian zone.

Blacktail Shiner. (-PC1) This species was most abundant at sites with high flow, high DO levels, and larger substrates that were located closer to the main river channel (Table 9). Stewart (2005) described this species as being highly abundant in the Bogue Chitto River, but less common in tributary streams. As such, the blacktail shiner is likely a larger-stream specialist in the Gulf coast plain (Ross 2001), preferring deeper pools and glides that were not common at most of my study sites.

Pirate Perch. (+PC1, -PC2). As evidenced by the negative relationship with PC2 and the positive relationship with PC1, increased pirate perch abundance appears to be associated with low-flow pool and backwater habitats in productive streams (Monzyk et al. 1997; Ross 2001).

Blackbanded Darter. (+PC3). Although blackbanded darter abundance was not related to PC7 (woody debris), the positive association PC3 may still reflect habitat complexity and greater inputs of wood from forest-dominated riparian zones. This species is known to prefer habitats with increased amounts of cover (Ross et al. 1987), and fewer blackbanded darters might be expected at sites with significant riparian clearing for agriculture or pastureland.

Gulf Darter. (+PC3). Similar to northern hog suckers and blackbanded darters, Gulf darter abundance was also higher in streams with higher proportions of forested land near the stream. This species is known to feed mostly on aquatic insects such as chironomids and mayflies (Ruple et al. 1984), and a woody dominated riparian zone may provide allochthonous debris that promotes production of aquatic insect prey.

Redspotted Sunfish. (-PC1). Analyses suggested that abundance of redspotted sunfish may be related to stream size and location, with a preference for larger habitats closer to the main river that are characterized by higher flows and larger substrates. This is contrast to the habitat preferences reported be Ross et. al. (1987), who reported that this species was most abundant in fine-substrate streams with high levels of vegetative cover. Very few macrophytes were encountered in my study streams, but structurally complex habitats may have been available from accumulations of small woody debris. The redspotted sunfish is known to feed primarily on benthic insects and crustaceans (Desselle et al. 1978).

Shadow Bass (-PC1, +PC3) The shadow bass is a cryptic centrachid known for using cover and occupying areas around the mouths of tributary streams (Ross 2001). In this study abundance of shadow bass increased with stream size, and was again associated with the amount of forested land in the riparian zone, suggesting that this species prefers higher order streams with less disturbance of streamside habitats.

Abundance and Diversity Patterns in Relation to Habitat PCs

Abundance. Total fish abundance was positively related to PC2, PC3, PC4, and PC7, which I interpreted as contrasting sites differing in watershed agricultural development, including the amount of cropland (PC2), pastureland (PC3), productivity (PC4). Analyses also revealed significant relationships between fish abundance and both basin-wide and 1.6-km

pastureland, but interestingly, this relationship was negative at the 1.6-km scale and positive at the basin-wide scale. I believe this demonstrates the potential importance of land use scale on fish-watershed analyses, and how variables measured at different scales can apparently have different relationships with fish communities in adjacent streams. The positive relationship with the amount of forest 500 meters upstream from the site likely reflects the important role intact riparian zones can play in maintaining healthy fish communities (Gregory et al. 1991; Jones III et al. 1999; Iwata et al. 2003; Ekness and Randhir 2007; Richardson and Danehy 2007; Lorion and Kennedy 2009). However, total fish abundance may not be directly related to the level of stream disturbance. Tolerant fish species are often found in abundance in disturbed sites (Fausch et al. 1990), and in warm water systems, human disturbance has been reported to affect habitat diversity in such a way that overall fish abundance increases (Langeani et al. 2005; Pinto et al. 2006), with little evidence of degraded fish community composition (Meador and Goldstein 2003).

Of the species I analyzed, only two showed a relationship with PC2 (Basin-wide cultivated crops), and agriculture has been reported to have little effect on the biotic integrity of local fish communities in streams with little agricultural development within the stream buffer (Fitzpatrick et al. 2001), which was characteristic of most of my study streams. The total abundance relationship with PC2 may have simply been related to stream productivity (nitrate levels), but if that were the case, I would have expected similar positive correlations with chlorophyll *a,* which was not evident in the analyses. Because the fish communities I sampled were populated by similar species that ranged from relatively intolerant cyprinids to highly tolerant centrarchids, it was not unexpected that an analysis of total abundance would not have yielded many significant relationships. Unless stream conditions were inhospitable, which did

not seem to be the case for any of my samples, I would have expected that some subset of the fish community would have been able to exploit the available habitat conditions and remain abundant.

Diversity. In contrast to total abundance, Shannon-Wiener diversity index was significantly related to variables that I would have expected to be characteristic of least disturbed stream habitat, such as higher flow velocities, DO concentrations, and substrate particle sizes. Moreover, diversity showed a significant inverse relationship with distance to the mainstem Bogue Chitto River. Stream order has been tied to increasing richness in studies of other warm water streams (Mathews et al. 1992; Osbourne et al. 1992; Pyron and Lauer 2004; Langeani et al. 2005), as well as cool water streams (Sullivan et al. 2006), and my results support the trend of increasing diversity (species number) as stream systems increase in size. Interestingly, some authors have argued that high species richness is indicative of healthy communities associated with undisturbed sites (Karr 1981). However, the SUNNYHILL site, which had the highest levels of basin wide agricultural land use (cropland plus pasture), nitrite, and HPC, all of which can be associated with human disturbance, also had the highest CPUE, and some of the highest diversities of any of the sites in the study (Table 2). These results emphasize that relationships (or lack thereof) between stream environments and the abundance, richness, and diversity of the resident fish community need to be evaluated against the species composition of the community when drawing conclusions regarding stream impairment, as is standard protocol for current fish-based bioassessments (Karr 1981; Fausch et al. 1990; Minns et al. 1996).

Effects of Land Use on Fish Assemblage

The objective of this study was to examine the effects of land use and habitat variables on stream fishes in a relatively restricted geographic area in southeastern Louisiana. Diversity and

many of the species were related to PC1, suggesting stream size and order strongly influence the abundance of most of the common species. These relationships have been reported in other studies (Mathews et al. 1992; Pyron and Lauer 2004; King et al. 2005a; Langeani et al. 2005; Sullivan et al. 2006; Grubbs et al. 2007), and seems to follow the river continuum concept (Cushing and Allan 2001). However, land use relationships among the sites that were evident in PC2 and PC3 did have a significant effect on the abundances of several species, as well as overall abundance. With the exception of Basin-wide pasture, all of these land use categories had ranges greater than 20%, with 1.6-km cultivated cropland having a range of 33% (Table 6). There appeared to be a detectable significant effect of agriculture on fish community structure in these streams, which has also been reported for fish communities in cool water streams (Buck et al. 2004; Richards et al. 1996). It is possible that these fishes were responding to slightly higher levels of agricultural land use and its effects on elevated levels of nitrate, but if this were true I would have expected the relationship to be apparent with other variables related to site productivity, such as increased chlorophyll-α. Interestingly, FC levels, which could certainly be associated with agricultural run-off from domesticated livestock, did not correlate highly on PC2 or PC3, and Basin-wide pasture, even with the limited variability among the study streams, was related to increased overall fish abundance (Tables 8 and 12). In this ecoregion, streams are known to have low nutrient levels (Felley 1992), and it may be that small increases in nutrients from agricultural run-off may be increasing productivity, resulting in increased fish abundance.

Pastureland has been well documented to have negative impacts on waterways (Belsky et al. 1999; Allan 2004; Casatti et al. 2006; Ferreira and Casatti 2006; Bayley and Li 2008), and although positively associated with the abundance of striped shiners, was negatively associated with the abundances of several other species in my study streams (gulf darter, shadow bass,

northern hog sucker, and blacktail redhorse). According to Hilty and Merenlender (2000) and Karr and Chu (1999), a good set of indicator taxa comes from different taxonomic groups and are complimentary, so that multiple types of disturbance are each indicated by different groups of taxa. In this study it appeared that the percentage of pastureland in the watershed negatively impacted several fishes, while simultaneously positively impacting another species at a smaller spatial scale (1.6 km).

Summary

Based on the results of my study, it is apparent that both watershed characteristics and reach-scale variables (including stream size) are influencing the composition of fish communities in the Bogue Chitto River watershed. Diversity was directly related to distance from the riverine source, suggesting that determinations of community health based on a criterion such as diversity may need to consider stream size in addition to watershed and reach-scale habitat variables. Of the 11 species that showed significant relationships with the PCs, 7 were associated with PC1 (both positive and negative associations), and 8 were positively associated with PC3. Relationships with PC1 appeared to contrast species based on stream size and local habitat conditions (headwater species in slower pool habitats versus higher-order species in habitats with higher flows and substrate sizes), whereas the consistently positive relationships with PC3 (by species that were both positively and negatively associated with PC1) suggested an overriding importance of forest cover in determining the species composition of the fish community in Bogue Chitto streams.

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Vita

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