CHANGES IN NATIVE AQUATIC VEGETATION, ASSOCIATED FISH

ASSEMBLAGES, AND FOOD HABITS OF LARGEMOUTH BASS (*Micropterus*

salmoides) FOLLOWING THE ADDITION OF TRIPLOID GRASS CARP TO

MANAGE HYDRILLA (*Hydrilla Verticillata*) IN LAKE CONROE, TX

A Thesis

by

PATRICK ALEXANDER IRELAND

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2010

Major Subject: Wildlife and Fisheries Sciences

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Approved by:

Chair of Committee,   Frances P. Gelwick
Committee Members,   Michael Masser
                                    Michael Speed
Head of Department,   Thomas Lacher

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ABSTRACT

Changes in Native Aquatic Vegetation, Associated Fish Assemblages, and Food Habits

of Largemouth Bass (*Micropterus salmoides*) Following the Addition of Triploid Grass

Carp to Manage Hydrilla (*Hydrilla Verticillata*) in Lake Conroe, TX.

(August 2010)

Patrick Alexander Ireland, B.A., University of Mississippi

Chair of Advisory Committee: Dr. Frances P. Gelwick

Nuisance aquatic vegetation (mainly *Hydrilla Verticillata*) has become
problematic in Lake Conroe, TX. Consequently, triploid grass carp (*Ctenopharynogodon idella*) were stocked at densities sufficient to completely denude the reservoir of all
vegetation (invasive and native plants) within one year. As a result, an assessment was
designed to investigate the changes (before and after carp stocking) in the plant
assemblage among sampling stations, changes in water quality parameters, length
frequency and condition changes of Centrachid species, largemouth diet changes, and
changes in the fish assemblages among randomly selected sampling stations between
early fall 2007, when grass carp were stocked, and one year later in early fall of 2008.
The areas for sampling were based upon aquatic vegetation surveys by Texas Parks and
Wildlife during 2007 and 2008, thirteen sampling stations were randomly selected using
ArcGIS software and the percentage of water surface covered by vegetation was
recorded at each station. Within each station, fish were collected by electrofishing the
entire station for five minutes; water samples were also collected.

Largemouth bass diet did significantly change for mature (<200 mm-TL) bass as
indicated by a chi-square test. Largemouth bass from the samples were shown to

consume less sunfish and more shad by the second (post-carp) sample. This is consistent with expected results due to the removal of vegetation consequently eliminating small sunfish habitat. In similar fashion, significant length-frequency changes were seen in the second year as there were fewer smaller (juvenile) Centrachid species found in the sampling sites. Contrary to the Centrachids, length-frequency of gizzard shad significantly decreased in size by the second sampling year.

Based upon the aquatic vegetation surveys within the sampling sites of 2007 and 2008, there was an almost complete elimination of all aquatic plants following carp introduction. This result was consistent with what was expected from the carp introductions. Changes in water quality parameters (phosphorous, nitrate, nitrites, orthophosphate, chlorophyll (a)), were generally inconclusive, with the exception of nitrate which significantly increased by the second year. The water quality parameters along with other measured habitat parameters were used in the multivariate analysis.

NOMENCLATURE

BLG	Bluegill Sunfish
GZD	Gizzard Shad
HA	Hectare
LES	Longear Sunfish
LMB	Largemouth Bass
RES	Redear Sunfish
SJRA	San Jacinto River Authority
TL	Total Length
TPWD	Texas Parks and Wildlife Department
Wr	Relative Weight

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CHAPTER I

INTRODUCTION

Habitat complexity, in many reservoir systems, is a function of the amount of aquatic vegetation present in the littoral zone (Bettoli et al. 1992). Submersed aquatic plants influence both fish distribution and abundance by creating structurally complex habitats (Crowder and Cooper 1979). Evidence suggests that the morphological differences among aquatic plant species provide structural variety important to fish habitat (Dibble and Harrel 1997). In addition, much research has suggested that "intermediate" levels of aquatic macrophytes are beneficial to bluegill and largemouth bass by increasing food production via epiphytic invertebrates and reducing predation pressure (Crowder and Cooper 1982, Durocher et al. 1984, Hoyer and Canfield 1996). For example, bluegill and largemouth bass have different foraging abilities relative to plant densities, and at higher plant densities, bluegill are able to forage more successfully than largemouth bass (Savino and Stein 1982, Savino et al. 1992). The term "intermediate", is open to interpretation when considering the influence of plant density among various aquatic systems and intrinsic differences in characteristics among the plant species (e.g., different coverage density despite similar stem density or biomass). For example, in the Potomac River, fish abundance within defined levels of intermediate and high densities of aquatic plants also depended upon the time of year (Killgore et al. 1989). In general, habitat complexity provided by vegetation influences the outcome of predator-prey interactions as well as competition, and therefore fish community structure (Wiley et al. 1984, Bettoli et al. 1993). However, the meaning of 'complexity' also has various interpretations, but in most cases, habitat complexity provided by aquatic vegetation refers to the density of the physical architecture and the interstitial spaces provided by the plant material (Dibble et al. 1996).

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This thesis follows the style of Transactions of the American Fisheries Society.

Much of the research concerning fish-plant interactions has focused on the macroscale level – fish data is averaged as either standing crop (total weight), density, catch per unit effort, or percent abundance relative to total areal plant coverage within the system (Dibble et al. 1996). Typically, macroscale refers to either an entire water body or a zone within the water body (e.g., littoral zone, cove) relative to the influence of shoreline and habitat bottom characteristics (Dibble et al. 1996). The macroscale approach is generally viewed as being easier to carry out than the less-commonly used, microscale approach

People consider growth of submersed macrophytes as excessive in lakes if it limits recreation, creates an undersirable fishery, blocks navigation routes and irrigation canals, and interferes with power generation (Maceina et al. 1992). One control treatment for aquatic macrophytes in reservoir systems is the stocking of grass carp (*Ctenopharygodon idella*), a biological agent commonly used to control hydrilla *(Hydrilla verticillata)*, which these fish preferentially eat and are able to control for years after their initial stocking (Kirk et al. 2000). Many studies have indicated that grass carp can eradicate almost any aquatic plant species, if stocked at a body size sufficient to avoid their own predation and at sufficient densities (Klussmann et al. 1988, Chilton and Muoneke 1992).

The ecological and limnological changes following consumption of aquatic vegetation by grass carp have been repeatedly studied in reservoirs of the southern United States, including Lake Conroe, but effects vary greatly among systems. For example, four lakes in Florida showed no relationship between reduced macrophyte abundance and production of phytoplankton (Leslie et al. 1983). A study of water quality in Lake Conroe from 1981 – 1986 (Maceina et al. 1992) showed highly variable results, possibly related to factors such as initial plant species composition and abundance, lake morphometry, water flushing rates, internal and external nutrient loadings, sedimentation rates, and fish community structure. In general, the removal and subsequent decomposition of plant material following consumption by grass carp can lead to nutrient enrichment and consequent phytoplankton blooms (Leslie et al. 1983).

However, when conservative, incremental stocking of grass carp is combined with extensive environmental monitoring, major habitat changes and total eradication of vegetation are not likely to occur in large, mainstream impoundments (Bain 1993).

The primary purpose of this study was to document biotic and abiotic factors in Lake Conroe among sites where initial densities of non-native and native vegetation differed in the early fall, just before and one year after the reintroduction of grass carp. A similar, albeit much larger scale, study occurred in Lake Conroe between 1980 and 1986, when grass carp were initially introduced to control (eradicate) the invasive non-native plant hydrilla (*Hydrilla verticillata*) and other nuisance aquatic macrophytes. The macro-scale approach of that study yielded comprehensive results regarding the limnological and ecological changes that occurred across the entire lake. The study did not, however, provide data that would allow conclusions about the changes in the native component of vegetation and associated biotic and abiotic characteristics at smaller spatial and temporal scales. The opportunity for a study to fill this gap in knowledge arose due to the resurgence (since 2004) of nuisance levels of hydrilla coverage within Lake Conroe, and subsequent stocking of over 100,000 triploid grass carp. The original diploid grass carp were no longer in the system, and no offspring were produced in the system (Mark Webb, Texas Parks and Wildlife District Supervisor, Region 3E). The primary focus of this study is the relationships between native vegetation and fish assemblages present in the early fall across a stratified random sample of sites. In addition, I evaluated relationships among measured habitat variables (e.g., water temperature, dissolved oxygen concentration, conductivity, turbidity, chlorophyll *a*) and diet composition for the top predator largemouth bass (*Micropterus salmoides*) to identify potential mechanisms that influenced the these relationships.

The primary points for investigation are:

1) The overall changes in the plant assemblage composition in Lake Conroe and among individual sampling stations between early fall 2007, when grass carp were stocked, and one year later in the early fall 2008.

2) The changes in water quality parameters among the sampling stations between early fall 2007, when grass carp were stocked, and one year later in early fall 2008.

3) The length-frequency changes and condition changes of Centrachid species between summer 2007, when grass carp were stocked, and one year later in summer 2008.

4) The changes in the diet of largemouth bass among the sampling stations between summer 2007, when grass carp were stocked, and one year later in early fall 2008.

5) The changes in the fish assemblages among the sampling stations between early fall 2007, when grass carp were stocked, and one year later in early fall, and relationships to water quality, and habitat variables at the time of sampling.

CHAPTER II

MATERIALS AND METHODS

Study Site

Impounded in 1973, Lake Conroe is an 8,100 hectare (~20,000 ac) reservoir located in Walker and Montgomery counties, approximately 65 kilometers north of Houston, TX (Figure 1). The reservoir, managed and operated by the San Jacinto Water Authority, stores water for use by the City of Houston and a stable water level is typically maintained. It is a mainstream impoundment on the most upstream reach of the West Fork of the San Jacinto River. Lake Conroe is considered a warm monomictic reservoir that forms an anoxic hypolimnion usually in April or May that continues through August or September. The northern half of the reservoir (i.e., area north of the FM 1097 bridge) is surrounded by the Sam Houston National Forest, whereas the lower half (i.e., area south of the FM 1097 bridge) is highly developed with residential housing, lake oriented businesses, and a shoreline consisting almost entirely of bulk-head. This, in effect, creates a stark contrast between the shoreline habitats of the two halves of the reservoir.

Site Selection

Areas of vegetation in Lake Conroe recorded in the summer of 2007 by TPWD monthly vegetation surveys were delineated using ARCVIEW software (citation). The map, (Figure 2) provided by biologists at the Texas Parks and Wildlife Inland Fisheries Office in Bryan, TX showed native and non-native vegetation coverage on 1/64 acre grids at the time grass carp were stocked. From among the grids containing vegetation, ten fixed sampling stations were randomly selected, and three additional stations were selected in areas that had been specifically planted with native vegetation as part of a habitat restoration program coordinated by TPWD (Figure 2). Six stations were in the northern portion of the reservoir; four stations (5819, 1A, 2A, 3A) were along the western shoreline of the national forest within the "Caney Creek" arm (Figure 2) and the other two (9609, 6218) were located along the eastern shoreline (Figure 2). The seven stations in the southern portion of the reservoir are all located in arms that feed into the main basin of the reservoir; four along the western shoreline, and three along the eastern shoreline (Figure 2).

Figure 1. Regional location of Lake Conroe in the state of Texas.
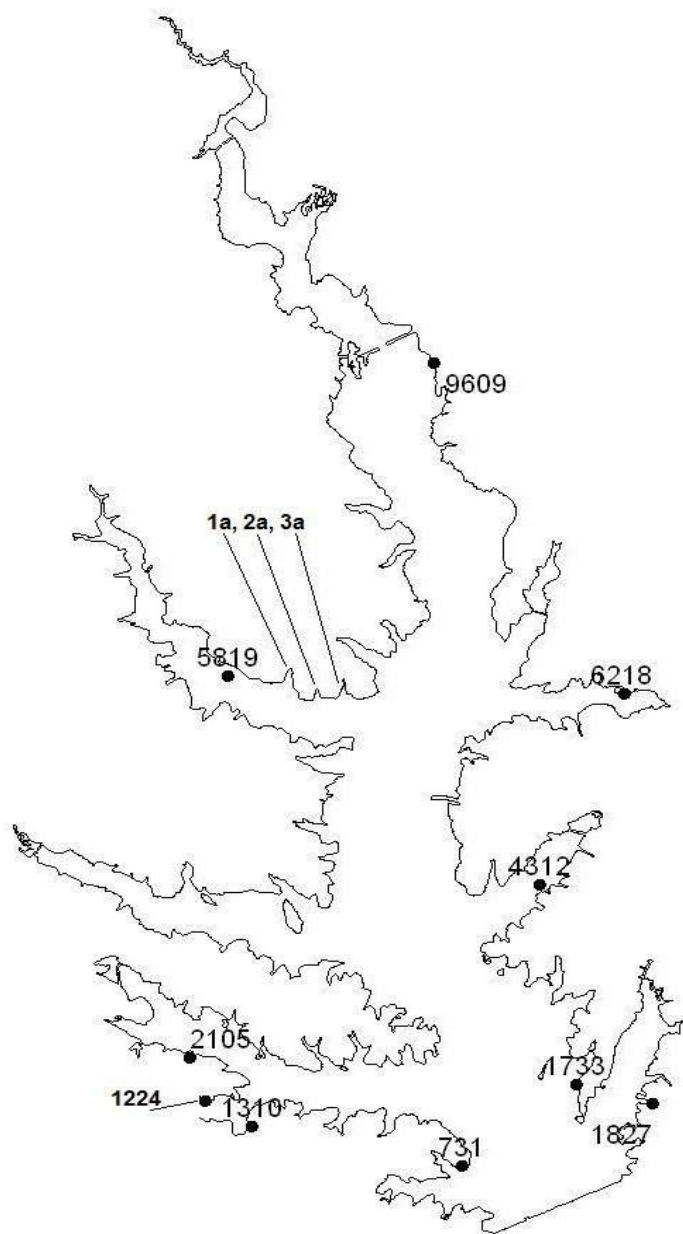
Figure 2. Randomly selected vegetated sampling stations within Lake Conroe, TX.

Field and Laboratory Data Collection

Initial fish-assemblage data were obtained in the early fall of 2007 by a five-minute electrofishing sample at each individual station. An electrofishing boat (5.5 meter Smith-Root Electrofishing Research Vessel with a Smith-Root Model 5.0 Gas Powered Boat Pulsator) provided by TPWD, was used in order to collect standardized data comparable among years and locations. The starting point for the electrofishing sample at a station was determined as follows: (1) taking GPS coordinates at the beginning and the end of the shoreline that was contained within the grid for the station, (2) going to the midpoint of the delineated shoreline and beginning the electrofishing sample, moving either right or left as determined by a coin toss.

Due to the patchy nature of aquatic vegetation, the electrofishing boat ran, as best as possible, along the immediate outside of the vegetated edge of the habitat while two persons, each using a standard-size dipnet (0.6 cm mesh, 43 cm deep, and 2.13 meters long), collected all fish that surface (TPWD 1998). Although an exhaustive approach, such as the use of cove rotenone, is desirable when assessing actual fish density at a sampling station, such an approach was deemed logistically unfeasible for this study. Instead, the 5-min electrofishing period was chosen because it yields adequate data to quantify the relative abundance of fishes present, given that this method has the least bias of standardized reservoir-sampling gears (Reynolds 1996). Furthermore, sampling precision has been shown to be very good for electrofishing; in particular, electrofishing has shown less variability and less effort (in terms of time)compared to rotenone in the sampling of juvenile and adult largemouth bass(Tate et al. 2003). Following the 5-min sample, all collected fish were placed in one or more plastic bags, labeled with the sampling station number and date, then placed on ice, and processed (within 18 hrs) at the laboratory.

All collected fish were identified (to species level), counted, and total length of each fish was measured to the nearest millimeter. However, instead of measuring individual lengths for threadfin shad *Dorosoma petenense,* gizzard shad *Dorosoma*

cepedianum, inland silverside *Menidia berryllina,* and brook silverside *Labidesthes sicculus,* (considered to be common prey species), individuals of each species were counted into categories of 2.5-mm increments (inch groups). Individual weight in grams (g) was measured for all Centrarchid species, catfishes, and other large-bodied (> 80 mm TL) fishes. The stomach from each largemouth bass *Micropterus salmoides* was removed, placed in an individual plastic bag (labeled to identify individual fish, sampling station, and date), and frozen for diet analysis, carried out in the laboratory of Fran Gelwick (Department of Wildlife and Fisheries Sciences, Texas A&M University, College Station, TX). For each stomach, all contents were identified to the lowest practical taxon (generally species for fish and other vertebrate prey, and genus or family for macroinvertebrates and zooplankton). Volume by taxon was recorded as milliliters of water displaced in a volumetric cylinder (for large-bodied taxa), or number of calibrated cells of uniform depth. Body condition was quantified for each largemouth bass by calculating the relative weight (Wr). A mean Wr of 100 for a broad range of size-groups within a population reflects ecological and physiological optimality (Anderson and Neumann 1996).

At the time of each electrofishing sample at each station detailed notes and photographs were taken at the station. Vegetation was first recorded as the presence of each plant species at the station. Then a visual estimate of the total percentage of the surface area coverage (nearest 5%) of each plant at the station was recorded and then summed in order to have a total vegetation coverage of each station. Also, immediately following the electrofishing run at each sampling station, water temperature (^{o}C), pH, total dissolved solids (TDS), conductivity (μSiemens), and dissolved oxygen (mg/L and percent saturation) were measured using a Yellow Springs Instrument (YSI-85) probe submerged at the center of the distance sampled. Turbidity was measured as Secchi-disk depth (cm) at each station. Water samples for chemical analysis were collected just below (approximately 10 cm) the surface at each station using acid-washed Nalgene bottles. Nitrates, nitrites, orthophosphate, chlorophyll *a*, and ammonia, were measured using a HACH spectrophotometer based upon methods found in Handbook of Common

Methods in Limnology (Lind 1985, HACH 2002). Predominant habitat categories recorded as present or absent at each collection station were as follows: rock (largest diameter > 25 cm), gravel (largest diameter < 5 cm), sand (smaller than gravel but larger than clay) macrophytes, rooted trees, undercut banks, bare bottom, soft clay and shale and whether the shoreline was "bulkheaded" or natural shoreline. All water quality and habitat data were recorded for use in habitat analysis and as potential explanatory variables in a multivariate analysis of the fish assemblage (see Data Analysis, *Fish Assesmblage / Multivariate*).

Data Analysis

Vegetation

The vegetation coverage at each station in 2007 and 2008 was categorized based upon three levels of surface coverage by plants. Sites that had surface coverage of 85-100% were designated "Heavy", surface coverage between 30-80% were designated "Moderate", and stations with a surface coverage of 0-25% were designated "Light". These three categories were used as variables in other analyses for this project. In addition, the 2007 and 2008 TPWD surveys of total reservoir vegetation coverage and species richness were utilized to compare total reservoir vegetation coverage to that for sampling stations.

Water Quality and Habitat Characteristics

To relate changes in water quality to vegetation removal, each of the measured nutrient parameters (nitrates, nitrites, orthophosphate, chlorophyll *a*, and ammonia) were averaged across stations by sampling year. To test for significant differences, all values for between year comparisons were run utilizing an independent samples t-test using SPSS 15.0; statistical significance was set at a tablewise alpha probability level ≤ 0.05. In addition, because the parameters may be linked thus creating a multiple statistical

inference problems, a sequential Bonferroni correction was used to increase statistical power and reduce the potential of a Type I error (Holme 1970, Rice 1989). The sequential Bonferroni is used to retain a prescribed familywise error rate α in an analysis involving more than one comparison (thus, the error rate for each comparison is more stringent than α.)

Length Frequency / Abundance

       I tested for effects of vegetation removal on length frequency distributions for total lengths (TL) measured for individuals of species in the family Centrarchidae (largemouth bass, redear sunfish, bluegill sunfish, and longear sunfish) and for gizzard shad (family Clupeidae). The mean TL (a measure of central tendency) was also calculated for each fish species for 2007 and 2008. The TL of each of the four Centrachid species and for gizzard shad were summarized into length-frequency distributions (1.0-cm TL intervals). Interval width was determined by maximum fish length; as suggested by Anderson and Neumann (1996), 1.0-cm intervals for species that reach 30-cm, 2.0-cm intervals for species reaching 60-cm, and 5.0-cm for species reaching 150-cm. Gizzard shad were summarized by inch-group (2.5 cm). All samples were separated by year for analyses. Statistical analyses were performed with the SPSS 15.0 statistical analysis program (SPSS 2005). Two independent sample Kolmogorov-Smirinov (K-S) tests were used to test for differences in length-frequency distribution (across all stations) between the summer 2007 and summer 2008 for each of the fish species. The K-S test is a popular nonparametric method to determine differences in length frequencies, as length-frequency data oftentimes deviate substantially from normal (Neuman and Allen 2007). The K-S test includes no underlying assumptions about data distribution and is appropriate for multi-modal and skewed length frequency data. Furthermore, the K-S test is sensitive to differences in the shape and location of the data. In regards to the two years of length data for the Lake Conroe fish samples, a significant difference in location would indicate an overall shift in the mean-length of

the fish population. A significant difference in shape would indicate that the distribution of the fish lengths has changed.

In order to test for differences in shape, the sample data must be centered around the mean in order to remove the effect of location. This is accomplished by subtracting the mean value for the sample from each individual data point within that sample. The SPSS statistical software calculates the following: a K-S statistic (Z), the largest absolute distance between cumulative distribution functions (D), and significance level (P) for sample data and centered sample data. The null hypothesis (Ho) is rejected (at the alpha probability level ≤ 0.05) when the Z surpasses a critical value, provided by the SPSS statistical software.

Gablehouse categories of increasing length: Stock, Quality, Preferred, Memorable, and Trophy, from Weithman's fish-quality world-record length relationship were also used to summarize length data, and to calculate an index of community structure (i.e., proportional stock density) commonly used to describe the relative quality of fish size distribution for recreational management (Gablehouse 1984). The proportional stock density index (PSD) is the percentage of stock length fish that are quality length or greater (Willis et al. 1993) and comparison of this index to desired objective ranges can be used to evaluate population size structure. Proportional stock density indices are binomially distributed but can be approximated by the normal distribution (Gustafson 1988) to estimate 95% confidence intervals (CI) if values are not too close to either 0 or 100, or if the sample size is large (PSD as decimal fraction × number of stock length fish in a sample < 5.0).

Condition (Relative Weight)

Relative weight (Wr) values are used to evaluate the physiological well being of individual fish (Anderson and Neumann 1996, Pope and Kruse 2007). Relative weight (Wr) indices are calculated by comparing fish weight when captured to a length-specific standard weight (Ws) inferred from a weight-length regression fit to the 75th percentile of weights at species-specific total-length intervals from pooled weight-length data

across the species geographical range (Anderson and Neumann 1996, Pope and Kruse 2007). This method was used to calculate Wr for largemouth bass, bluegill sunfish, and redear sunfish in Lake Conroe. Longear sunfish were excluded because slope and intercept parameters could not be found for this species for this area of the country. To test for length related patterns in condition, largemouth bass, bluegill, and redear were subdivided into Gablehouse length categories (by year) and the mean Wr value of each category was calculated. In addition, a 95% confidence interval was calculated around the mean for each length category by year.

The statistical properties of relative weight data have been debated. Ratio data, such as Wr, tends to exhibit heteroscedasticity, leptokurtosis, and skewness in its distribution that make assumptions of normality implausible and violate the assumptions of common statistical tests (Pope and Kruse 2007). However, mean comparison tests such as the two-sample t-test (or the nonparametric equivalent, Mann-Whitney test) or multiple-comparison tests such as ANOVA can be used to examine length-related or interpopulation trends. However, statistical analysis was not performed on the relative weight data because the mean values appeared to change very little between 2007 and 2008.

Largemouth Bass Stomach Content Analysis

Presence or absence of a food item within a stomach is recorded and then the proportion of the fish that contained one or more items of a given food type is calculated to obtain the frequency of occurrence for that food type. The frequency of occurrence was calculated using the following equation:

$$O_i = J_i \, / \, P$$

where O_i is frequency of occurrence in the sample for a bass species, J_i is number of fish containing prey item i, and P is the number of fish stomachs that contained food. Frequency of occurrence (FO) was used to evaluate how often a particular prey type was eaten and to indicate the extent to which fish in samples functioned as a singular feeding unit (Bowen 1996, Chipps and Garvey 2007). Prior to analysis, the largemouth bass were divided into two size groups; juvenile ($\leq$199 mm) and mature ($\geq$200 mm). The segregation of the bass into two categories is based upon the knowledge that different sized bass utilize different food resources. This is most pronounced in the feeding habits of young-of-year juvenile bass which primarily consume invertebrates. At a certain length, however, the young-of-year switch from invertebrates to a diet consisting primarily of fish. Other studies have indicated that the switch to piscivory occurs at approximately 50 mm of length (Olson 1996). The exact length at which this food resource switch occurs, however, can vary depending upon many ecological influences (including, vegetation coverage). I deemed that it was impractical to determine the size at which this switch occurred in my study due to the low sample size of these small fish in 2008, and the high proportion of empty stomachs among these fish in both years. Consequently, without knowing the approximate length the switch to piscivory occurs, it is likely that the greater numbers of larger below 200 mm fish in 2008 could bias the between year comparisons of diet. Despite this limitation, some comparisons could still be made between sampling years utilizing diet data of juvenile bass, mature bass, and the percentage of empty stomachs. To do this, a nonparametric Chi-square statistic was used to test for between-year differences in the proportion of largemouth bass stomachs that contained a specific prey type. The chi-square test was performed using the "Crosstabs" function in SPSS (2 x 2 table with one degree of freedom) by which the frequency of stomachs containing a specific food item were compared between years. The basis for the expected values were the sum of the prey-type counts for both years and the sum of the stomachs containing another food item for both years. In addition, the use of frequency of occurrence (FO) yields a comprehensive qualitative description of diet

composition, which may subsequently be related to vegetation coverage and other habitat variables.

Fish Assemblage / Multivariate

Multivariate methods provide an objective approach to identifying patterns in species assemblages and their relationships with environmental conditions (Jackson et al. 2001). Redundancy analysis (RDA) was used to summarize variation in the fish assemblages collected by electrofishing, and to infer relationships among environmental parameters and assemblage structure of Lake Conroe. The multivariate analysis was performed with CANOCO version 4.5 (cite). The species included for analysis were limited to those whose overall abundance was at least 5% of all fishes (10 species) collected across 2007 and 2008. The largemouth bass were differentiated into two size categories ($\geq$149 mm and $\leq$150 mm) to identify any ontogenetic differences in their ecology and habitat use. RDA is a multivariate ordination and regression method by which the relationships among multiple response (dependent / species) and environmental (explanatory, independent) variables are determined by constraining the canonical ordination axes to be linear combinations of explanatory variables (ter Braak and Smilauer 2002). The explanatory variables for ordination of the electrofishing catch were as follows: type of vegetation (torpedo grass, hydrilla, willow, American lotus, spatterdock), water quality parameters (conductivity, ammonia, total dissolved solids, dissolved oxygen, orthophosphate), and water depth. Significant variables that had variance inflation values > 5.0 were deemed to be highly collinear with other variables and were removed from the final canonical model.

However, some of these were, subsequently included as supplementary variables (i.e., passive variables for which their post-hoc correlation with explanatory axes are used to plot their relationships to other variables, but do not influence the ordination model). The correlation coefficients for explanatory variables and canonical axes were interpreted as significant if their t-value was > |2.1|. Monte Carlo permutations (499 permutations, using a split-plot design with time as the within plot factor and sampling stations as the whole plot factor) were also performed with CANOCO. The test statistic for non-permuted data was compared to the test statistic determined from random permutation (using the split-plot design) of the species data. The F-ratio was used to test (P-value ≤ 0.5) the null hypothesis that the variation in distribution of species data among samples was unrelated to the variation in explanatory data (ter Braak and Smilauer 2002).

CHAPTER III

RESULTS

Vegetation Changes in Lake Conroe

The eventual stocking rate of grass carp was approximately 125 fish per vegetated hectare (approximate stocking density may be lower due to natural mortality of the carp, estimated at 32% per year), and sufficient to visibly alter the vegetation coverage, and change plant distributions within Lake Conroe. It should be noted that the grass carp were incrementally stocked between March 2006 and February 2008 (Table 1). The surveys by TPWD of the reservoir as a whole (Figures 3 and 4), showed a dramatic reduction in all aquatic vegetation between 2007 and 2008, corresponding with the stocking of grass carp. In July of 2007, TPWD surveys indicated that hydrilla occupied a total of 717 hectares (as either "topped out" at the surface, or submerged below the surface). By the summer of 2008, TPWD surveys indicated that less than 1 hectare of hydrilla remained in the reservoir, resulting in a total reduction of 716 hectares; > 99% reduction in previously measured coverage in 2007. A similar trend was observed for the native aquatic vegetation in Lake Conroe. The summer survey of 2007 indicated a total of 437 hectares of all native vegetation (regardless of species). By the summer of 2008, this number had been reduced to 61 hectares; 86% reduction of previous coverage.

Table 1. Dates and numbers of grass carp stocked
into Lake Conroe, TX.

Date	Number Stocked	Total Stocked
3/15/2006	4,330	4,330
8/20/2006	9,311	13,641
10/23/2006	13,800	27,441
2/22/2007	10,000	37,441
4/22/2007	23,386	60,827
10/18/2007	25,364	86,191
1/15/2008	15,575	101,766
2/22/2008	33,474	135,240

The 13 sampling stations in 2007 showed varying degrees of macrophyte coverage and species richness. In 2007, there were four stations characterized as heavily vegetated, which contained *Ceratophyullum dersum* (coontail), *Vallinsinaria americana* (tapegrass), and *Panicum repens* (torpedograss). It should be noted that *Hydrilla verticillata* (hydrilla) was present throughout the reservoir and within many of the sampling stations. In addition, all stations characterized as "heavy" had no bulkheadconstruction and were located in the northern end of the reservoir (surrounded by the Sam Houston National Forest). By 2008, corresponding with the overall reduction in vegetation seen throughout the reservoir, the 13 sampling stations exhibited a similar trend in vegetation reduction in that all the stations were essentially void of plants by the 2008 sampling (Table 2). Every sampling station in 2008 showed an almost complete removal of aquatic macrophytes as compared to 2007. Even coverage by species that were deemed unpalatable to grass carp (e.g., torpedograss, bulrush, American lotus) was reduced. In particular, among the heavily vegetated stations in 2007, coontail, tapegrass, torpedograss, and hydrilla were essentially absent, leaving a bare surface on the bottom of the shoreline by the summer of 2008. Thus, reducing the habitat complexity previously due to interstitial spaces between the matrix of submerged plants, and exposing the bottom sediments that were covered in decaying plant material.

Lake Conroe
Hydrilla
July 2007

***Note: Lake level at time of survey was at normal pool elevation of 201 ft.

Previous hydrilla amounts from May 2007 survey:

Little Lake Creek= 592.36 acs.
Lewis Creek= 274.36 acs.
Caney Creek= 471.93 acs.

Most of the hydrilla located was topped out. Overall biomass seems to be decreasing with many holes appearing in mats.

5 ac. patch of Elodea was discovered in Caney Creek.***

Surveyed by:
Mike Gore, Bill Johnson, Kelsey Gocke, and Patrick Ireland

07/09, 07/10, 07/11, 07/16, 07/17, 07/18, 07/23, 07/24, 07/25, 07/30, 07/31

1775.90 acres of hydrilla

Little Lake Creek= 553.08 acs. of hydrilla
Lewis Creek= 294.65 acs. of hydrilla
Caney Creek= 564.33 acs. of hydrilla

Hydrilla
Topped Out
Submersed
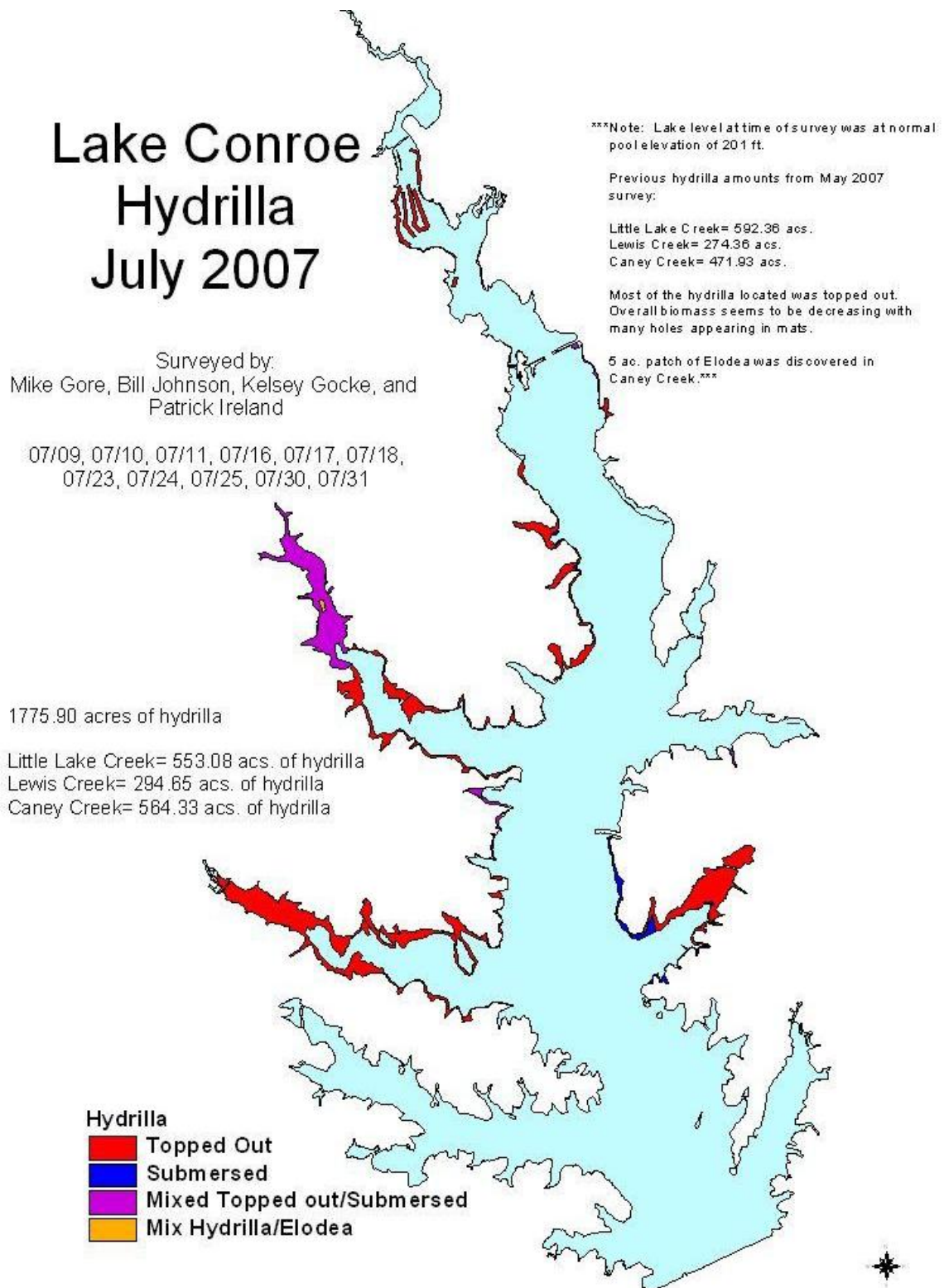Mixed Topped out/Submersed
Mix Hydrilla/Elodea

Figure 3. TPWD survey map of hydrilla infestation in Lake Conroe in July 2007.

Lake Conroe
Hydrilla
July 2008

Surveyed by:
Mike Gore, Bill Johnson,
Patrick Ireland, Kelsey Gocke

07/29,07/30,07/31,08/06,08/07,
08/11,09/08
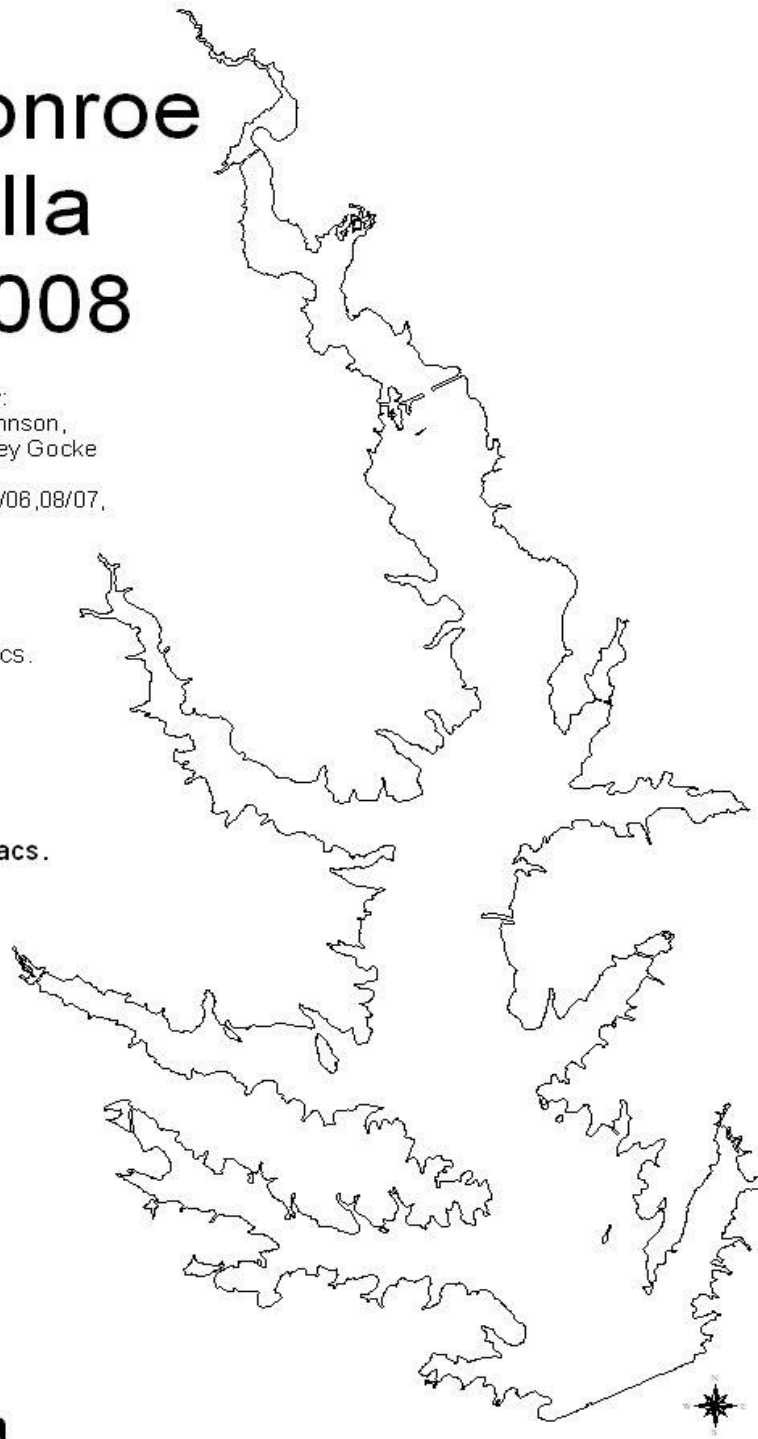
MSL= 199.9 acs.

Hydrilla= 1.3 acs.

Hydrilla

Figure 4. TPWD survey map of hydrilla infestation in Lake Conroe in July 2008.

Table 2. Plant species and vegetation coverage in the 13 sampling stations in Lake Conroe. Values are percent of water surface coverage for each species and total summation of the coverage by year. Measurements were visually estimated to the nearest 5%. The (*) symbol indicates a non-native plant that has become naturalized within the site.

Station ID	Ceratophyullum dersum		Ludwigia hexapetala		Nelumbo lutea		Nuphar lutem		Potamogeton illinoeinsis		Scirpus pungens		Vallinsinaria americana		Typha latifolia		Arundo donax *		Panicum repens *		Hydrilla verticillata *		Total Vegetation Coverage	
	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008
1A	30%	-	-	-	-	-	-	-	-	-	-	-	-	-	10%	-	-	-	25%	5%	30%	-	>95%	5%
5819	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5%	-	<5%	-	50%	5%	40%	-	>95%	5%
3A	-	-	-	-	-	-	-	-	-	-	-	-	15%	-	-	-	<5%	-	50%	5%	10%	-	85%	5%
2A	-	-	-	-	50%	-	5%	-	-	-	5%	-	5%	-	10%	-	-	-	10%	5%	-	-	90%	5%
9609	10%	-	-	-	-	-	-	-	-	-	-	-	-	-	5%	-	-	-	40%	-	10%	-	65%	0
6218	20%	-	-	-	-	-	-	-	30%	-	-	-	-	-	-	-	-	-	-	-	10%	-	60%	0
1224	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	40%	-	-	-	40%	0
1827	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	30%	-	-	-	30%	0
731	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5%	-	-	-	5%	-	-	-	10%	0
4312	-	-	5%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5%	-	10%	0
1733	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5%	-	-	-	-	-	-	-	5%	0
2105	-	-	-	-	-	-	-	-	-	-	-	-	5%	-	-	-	-	-	-	-	-	-	5%	0
1310	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5%	-	-	-	5%	0

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Habitat Description and Water Quality Changes in Lake Conroe

Mean nitrate levels between 2007 and 2008 were significantly different (P = 0.001) with a mean value of 0.18 mg/L in 2007 and a mean value of 0.73 mg/L in 2008 (Table 3). All other chemical water quality parameters, however, were very similar in 2007 and 2008 (Table 3). It should be noted that all sampling occurred on a single day for both years with the first water samples being collected at approximately 8 AM and continuing to the early afternoon. Consequently, variables that have diurnal fluctuations such as pH and dissolved oxygen may be affected by the sampling time.

Abiotic habitat variables varied in many respects across sampling stations (Table 4). Mean secchi depths were similar between years; however, the heavily vegetated areas in 2007 appeared to have less-turbid water than the all other sites. In particular, the heaviest vegetated areas in 2007 had a mean secchi visibility of 67.5 cm which was far greater than the lightly vegetated sites found in 2007 and 2008. Water depths ranged between 0.5 and 2.5 meters, and bulkhead was or was not present along shorelines (Table 4). In addition, specific conductivity, dissolved oxygen, water temperature, pH, and total dissolved solids appeared to be similar across sampling years. These measured parameters are also used as explanatory variables in the multivariate analysis of fish assemblages.

Table 3. Water parameters measured in Lake Conroe. Measurements were collected in 2007 and 2008 at 20 cm depth. P values for nutrient comparisons given.

Parameter	Summer 2007 Mean Values			Summer 2008 Mean Values			2007 Total Mean Value	2008 Total Mean Value	P
	Heavy	Moderate	Light	Heavy	Moderate	Light			
Physical									
Sample Size	4	4	5	-	-	13			
Water Temperature (°C)	25.38	25.33	26.1	24.2	25.1	24.7	25.38	24.94	
Sp. Conductivity (mS/cm³)	215	215	215	235	235	235	215	235	
TDS (mg/L)	.140	.139	.139	.12	.12	.11	0.139	0.12	
Turbidity (secchi cm)	67.5	38	57	70	75	55	54.23	67	
Chemical									
Dissolved Oxygen (mg/L)	6.15	7.3	7.31	7.3	6.14	7.3	6.95	6.91	
pH	7.8	7.9	8.1	7.2	7.4	7.5	7.97	7.4	
Nitrates (mg/L)	0.23	0.2	0.14	0.53	0.45	0.73	0.18	0.73	0.001
Nitrites (mg/L)	0.003	0.004	0.003	0.004	0.001	0.0004	0.003	0.0017	0.497
Ammonia (mg/L)	0.09	0.1	0.1	0.12	0.13	0.1	0.1	0.12	0.74
Orthophosphate	0.04	0.15	0.05	0.19	0.12	0.15	0.08	0.15	0.075
Biological									
Chlorophyll (a) (µg/L)	64	68	65	68	71	75	65	71	0.785

Table 4. Abiotic shoreline habitat conditions and coordinates for sampling locations at each station.

				Coordinates			
	Depth	Bulkhead	Substrate	BEGIN		END	
Heavy Sites				start	stop	start	stop
1A	1.5	no	silt	30°45'72.2"	95°60'85.2"	30°45'77.6"	95°60'87.4"
5819	1.21	no	sand	30°46'118	95°63'088	30°46'183	95°63'17.9"
3A	1.5	no	silt	30°45'89	95°62'075	30°46'001	95°62'012
2A	2.44	no	silt	30°45'587	95°61'415	30°45'714	95°61'378
Moderate							
9609	1.06	no	sand	30°52'123	95°59'202	30°52'205	95°59'248
6218	2.04	yes	gravel	30°45'812	95°55'147	30°45'817	95°55'095
1224	2.4	no	silt	30°37'505	95°63'673	30°37'511	95°63'65
1827	1.5	no	gravel	30°38'364	95°54'382	30°38'397	95°54'28
Light							
731	1.83	yes	sand	30°36'575	95°58'677	30°36'505	95°58'622
4312	2.13	yes	clay	30°41'958	95°56'653	30°41'932	95°56'57.9
1733	1.06	no	sand	30°38'712	95°55'795	30°38'666	95°55'89.4"
2105	1.83	yes	silt	30°38'475	95°63'76	30°38'491	95°63'738
1310	1.95	yes	gravel	30°37'181	95°62'372	30°37'265	95°62'444

Length Frequency Changes for Centrarchid Species and Gizzard Shad in Lake Conroe

In order to increase sample size and size structure representativeness, length frequency distributions of largemouth bass, redear sunfish, bluegill, longear sunfish, and gizzard shad were pooled by species across all vegetation categories in 2007 and 2008. Thus, comparisons were made between the two years (pre-carp versus post-carp) and not within vegetation categories.

Largemouth Bass

For electrofishing 2007 (N = 128) and electrofishing 2008 (N = 62), K-S tests indicated a significant difference in location (D = 2.071; $P < 0.05$) between the two sampling seasons. The K-S test did not, however, show any significant difference in shape (D = .737; $P > 0.05$) (Figure 5). Mean total length for Largemouth bass in 2007 was 183.5 mm. In 2008, mean total length for largemouth bass was 265.5 mm. These results indicate that the size of largemouth bass across all sites increased in overall length from 2007 to 2008, but the overall shape of the distribution did not change. The size shift of greatest magnitude occurred at approximately 100 mm (Figure 5), where 50% of the sampled largemouth bass were smaller than 100 mm in 2007, but in 2008, they constituted less than 6% of total largemouth bass sampled.

The PSD values for largemouth bass samples in both 2007 and 2008 were in the generally acceptable range of 40-80 (Table 5) that is consistent with a balanced largemouth bass and bluegill management strategy (Willis et al. 1993). The above noted shift in length frequency distribution was reflected only as the greater percentage of fish ≤ stock-sized in 2007 than in 2008 (Table 4) suggesting that relative abundance of juvenile fish in Lake Conroe was lower in 2008.
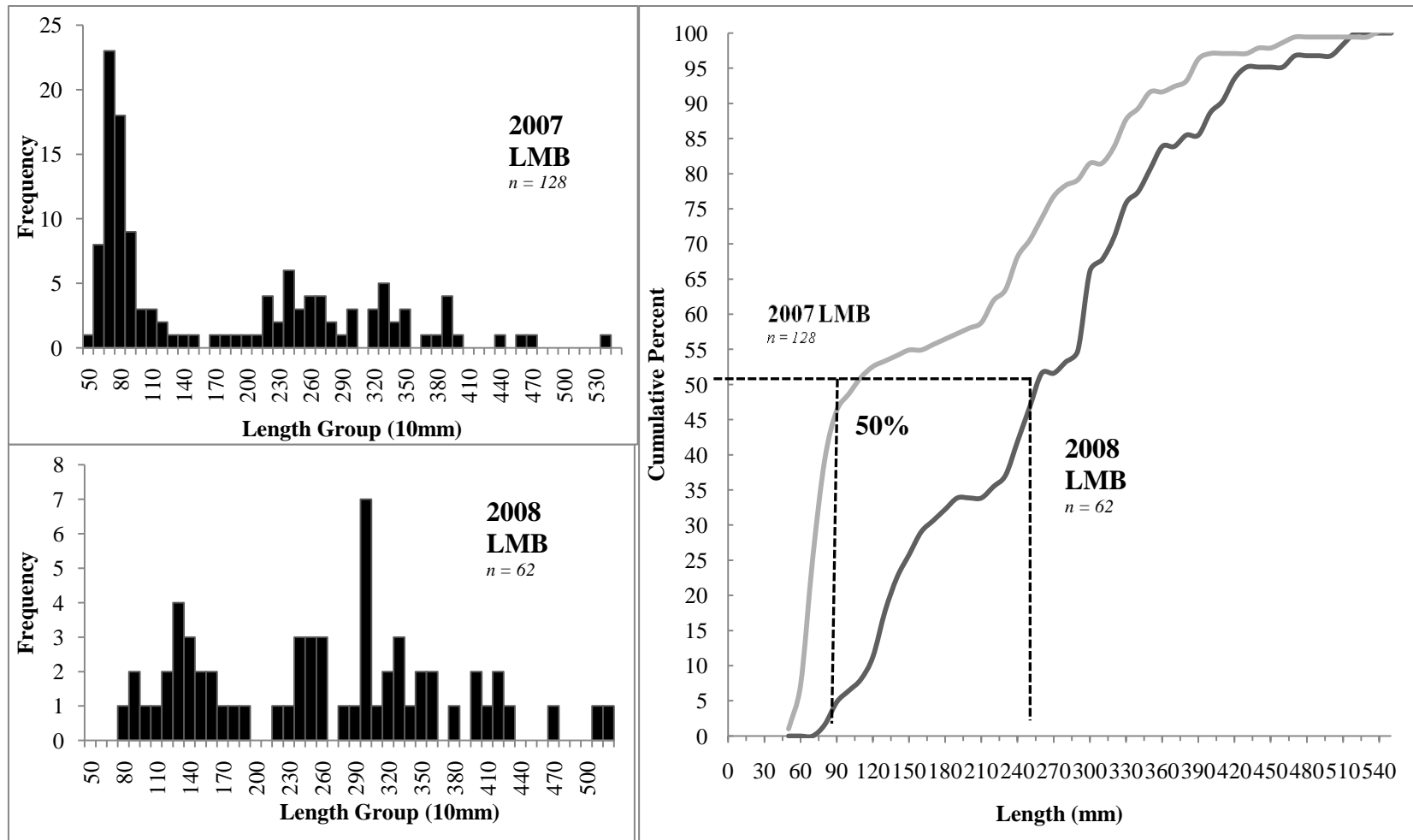
Figure 5. Absolute-length frequency histogram and cumulative-frequency distribution of largemouth bass sampled by electrofishing in 2007 and 2008 in Lake Conroe. Dashed lines represent the sizes of fish at the 50% threshold.

Table 5. Largemouth bass stock density indices and CPUE. Proportional stock densities (PSD), number of stock length largemouth bass (N), 95% confidence intervals of stock-length largemouth bass caught by electrofishing. CPUE of bluegill, redear sunfish, and longear sunfish separated by year.

	Year	Effort (min)	PSD±95% C.I.	N	CPUE (Fish/hr) Stock (≥ 200-mm TL)	Total
Largemouth bass	2007	65	49± 11	55	68	118
	2008	65	68±14	40	19	57
Bluegill	2007	65				381
	2008	65				43
Redear Sunfish	2007	65				96
	2008	65				30
Longear Sunfish	2007	65				128
	2008	65				35

Bluegill

For bluegill captured in 2007 (N = 381) and 2008 (N = 43), K-S tests for length-frequency distributions (Figure. 6) indicated a significant between-year difference in location (D = 1.514; P = .020), and shape (D = 3.491; P = 0.000). Mean total length for bluegill in 2007 was 100.1 mm, and in 2008 was 136.1 mm, indicating that mean length of bluegill in Lake Conroe had increased. In addition, overall CPUE of bluegill was lower in 2008 (Table 4), suggesting their lower relative abundance in the reservoir.

Redear Sunfish

For redear sunfish captured in 2007 (N = 96) and 2008 (N = 31), K-S tests for length-frequency distributions (Figure 7) indicated a significant between-year difference in location (D = 4.685; P = 0.000) and shape (D = 3.873; P = 0.000). Mean total length for redear sunfish in 2007 was 114.5 mm, and in 2008 was 177 mm, indicating that mean length of redear sunfish in Lake Conroe had increased. However, the shape of the distribution also changed; in 2007, 70% of redear sunfish captured were < 130 mm (Figure 7), but in 2008, there were no fish < 130 mm captured. In addition, the overall catch of redear was substantially lower in 2008 (Table 4), again suggesting there lower relative abundance in the reservoir.

Longear Sunfish

For longear sunfish captured in 2007 (N = 129) and 2008 (N = 40), K-S tests for length-frequency distributions (Figure 8) indicated a significant between-year difference in location (D = 1.601; P = 0.012) but not in shape (D = 1.344; P = 0.054). Mean total length for longear sunfish in 2007 was 99.47 mm, and in 2008 was 108.23 mm, indicating no significant changes in size distribution of longear sunfish in Lake Conroe.

 In 2007, approximately 50% of longear sunfish captured were < 80 mm (Figure 7), but in 2008, however, 50% of longear were <95 mm. In addition, the overall catch of longear was substantially lower in 2008. (Table 4), again suggesting their lower relative abundance in the reservoir.

Gizzard Shad

There were 109 gizzard shad collected in 2007. The same number of gizzard shad were also collected during the 2008 sampling. This may indicate that grass carp had little impact on the abundance of gizzard shad due to their continued abundance following carp introduction. The K-S tests indicated a significant difference in location ($D = 2.167$; $P = 0.000$) and shape ($D = 1.49$; $P = 0.024$) between the two sampling seasons. Mean total length for gizzard shad in 2007 was 201 mm and in 2008 was 183 mm. Contrary to the trend of decrease in size of small Centrarchids in 2008, gizzard shad showed an increase in abundance of smaller fish in 2008, most evident for inch-groups (Figure 9). In 2007, eight fish were ≤ 76.2 mm-TL (≤ 5 inches), as compared to 2008, when there were 38 fish in this size group.

Figure 6. Absolute-length frequency histogram and cumulative-frequency distribution of bluegill sampled by electrofishing in Lake Conroe in 2007 and 2008.

Figure 7. Absolute-length frequency histogram and cumulative-frequency distribution of redear sunfish sampled by electrofishing in 2007 and 2008 in Lake Conroe.
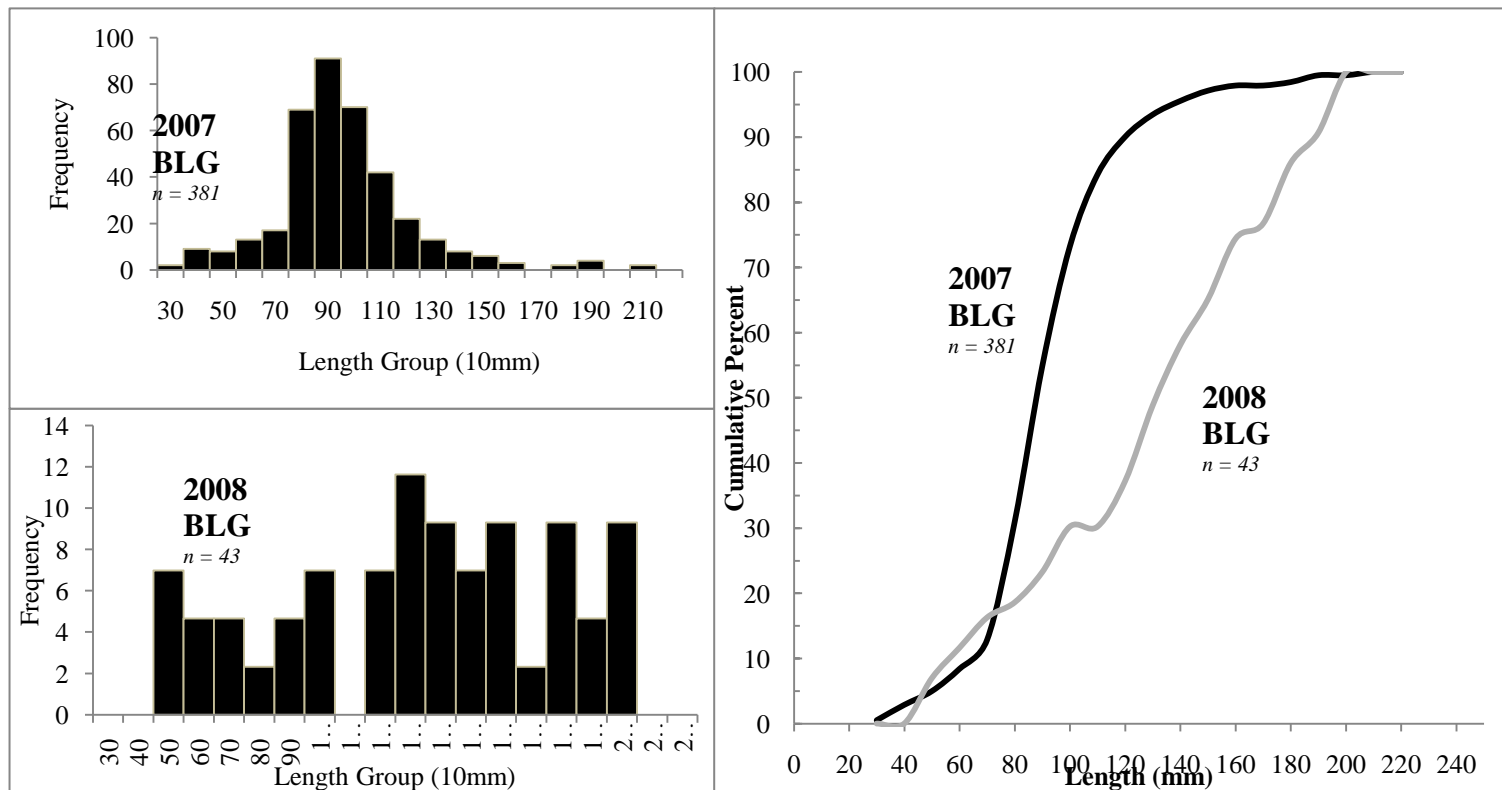
Figure 8. Absolute length-frequency histogram and cumulative-frequency distribution of longear sunfish sampled by electrofishing in Lake Conroe 2007-2008.
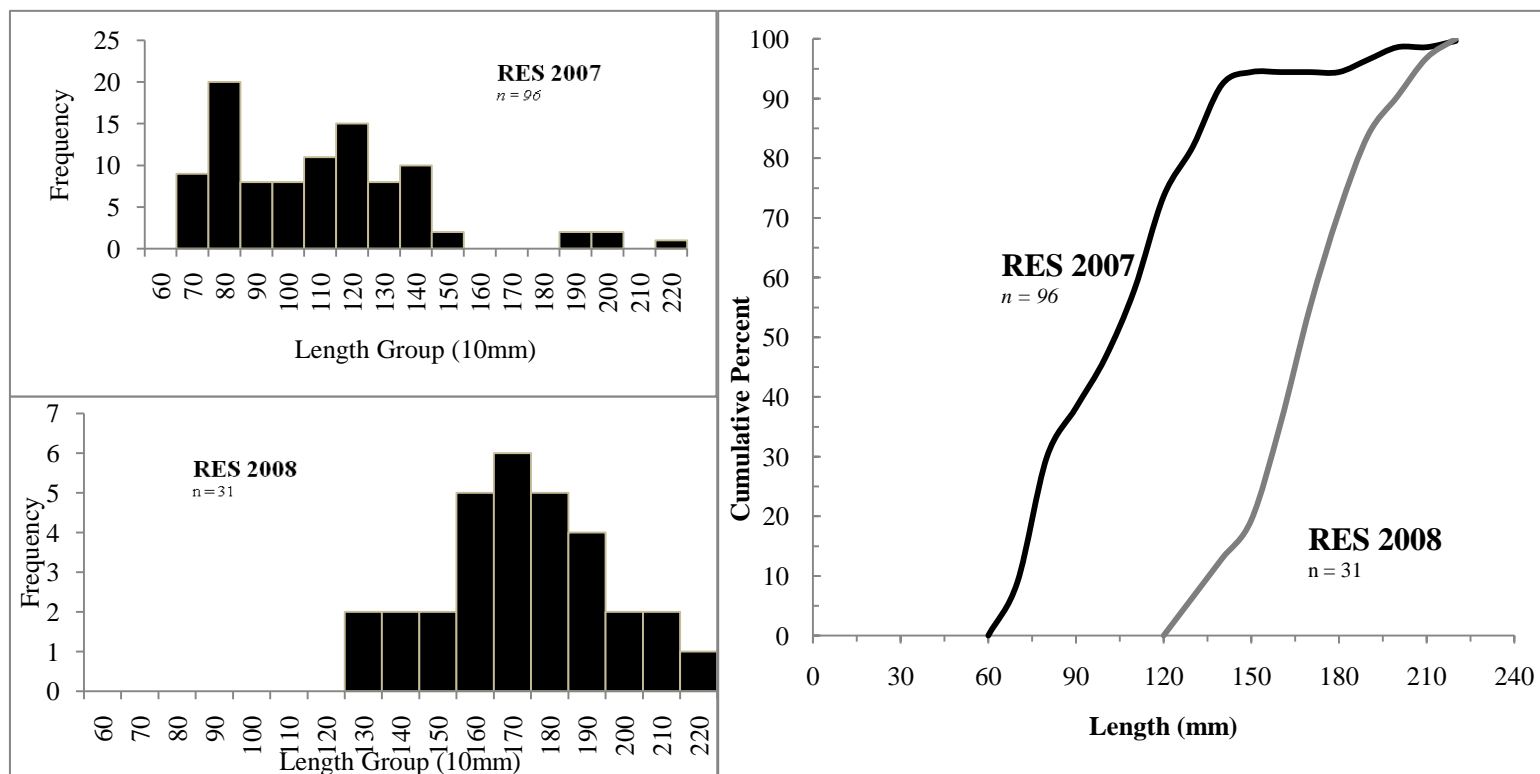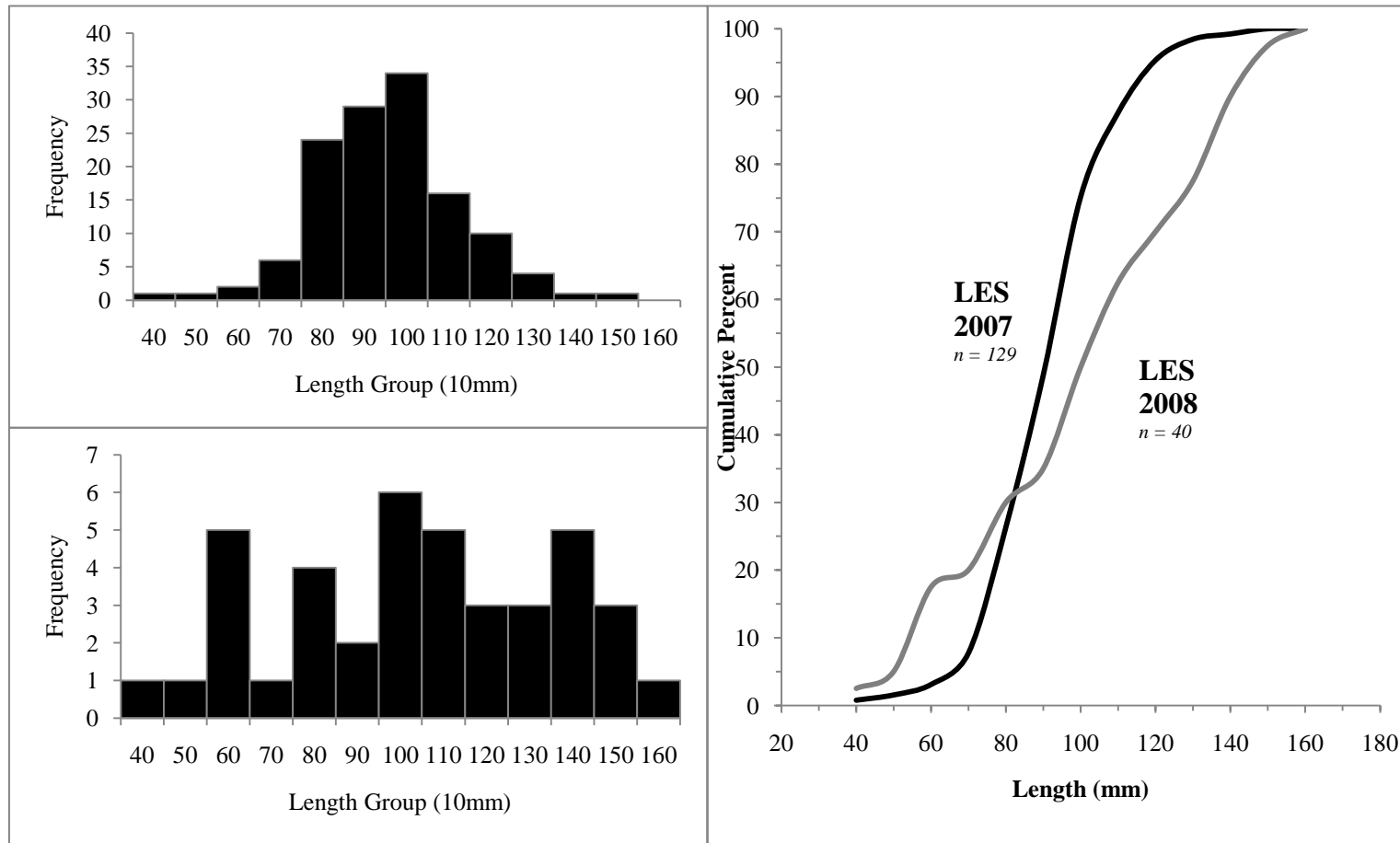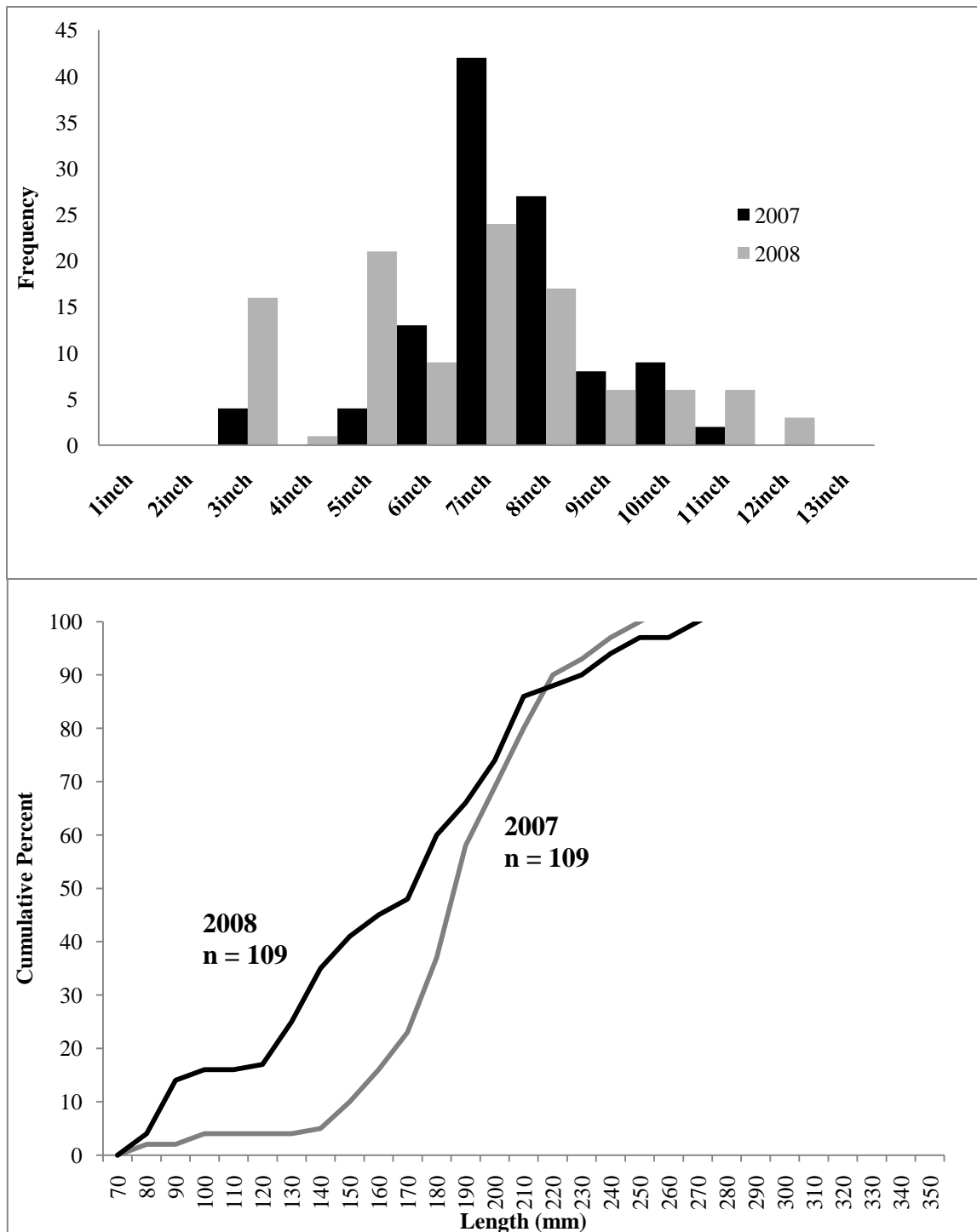
Figure 9. Distribution of gizzard shad by inch-group (top) and cumulative length frequency (bottom) collected by electrofishing in late summer 2007 and 2008 in Lake Conroe.

Largemouth Bass Diet in Lake Conroe

Stomach contents were examined from a total of 189 largemouth bass collected in 2007 (n=128) and 2008 (n=61) in Lake Conroe. Length of largemouth bass was stratified into two categories (sub-stock and stock sized and greater) to evaluate the influence of size on changes in feeding patterns between 2007 and 2008. For purposes of the analysis, all substock-sized fish were designated as juvenile, whereas stocked-sized and greater fish were designated as mature. Of the fish sampled in 2007, 73 were sub-stock sized ($\leq$199 mm, TL) and 55 were stock sized and greater ($\geq$200 mm, TL) in length. In 2008, fewer fish were captured and therefore fewer examined; 21 were sub-stock sized ($\leq$199 mm, TL) and 40 were stock sized and greater ($\geq$200 mm, TL) in length. A total of 411 food items representing two major prey types (7 vertebrate taxa, 10 invertebrate taxa) were found in largemouth bass stomachs (Table 6 and Table 7). For the analysis and diet calculations, the prey types were pooled into 12 taxonomic groups (Table 7).

Diets of mature largemouth bass ($\geq$200 mm-TL) consisted exclusively of fish, primarily *Lepomis* sunfish and shad. Other fish prey, including mosquitofish, logperch, silversides, and various shiners (family Cyprinidae) were rarely encountered. In addition, no evidence of cannibalism was found in stomachs from either 2007 or 2008. A chi-square test for between year difference was conducted on mature ($\geq$200 mm, TL) largemouth bass stomachs that contained shad (*Dorosoma* sp.) and stomachs that contained Centrachid sunfish. The analysis indicated that the numbers of sunfish in the stomachs of the mature largemouth bass differed significantly between years (Table 8). In 2007, sunfish comprised 40% of the food items in mature largemouth bass stomachs; in 2008, sunfish comprised only 13%. The largemouth bass stomachs that contained shad, however, did not differ significantly between pre- and post-carp samples (Table 8), comprising 50% in 2007 and 63% in 2008. Similarly, percentage of empty stomachs (no food types present) did not differ significantly between years; 45% in 2007 and 57% in 2008.

Due to the very low sample size of juvenile (sub-stock) largemouth bass in 2008, it was deemed unfeasible to make statistical comparisons of diets between the two sampling years. In addition, there were no largemouth bass collected that were < 80 mm-TL in 2008, whereas this size range made up > 40% of the largemouth bass collected in 2007. Thus, important length related diet changes between the years could not be evaluated fully for these fish (e.g., average length at which a switch to piscivory occurred, or potential change in food types for largemouth bass < 80 mm-TL). Despite these constraints, but as expected, aquatic invertebrates comprised a large proportion of the diets of sub-stock sized largemouth bass in both years. In addition, data indicated an increase in the consumption rate of fish in 2008 as compared to 2007 (Table 7 and Figure 10). However, because few age-0 largemouth bass were collected in 2008 and because larger fish are known to be more piscivorous, the observed increase in number of stomachs containing fish in the 2008 sample due to a higher percentage of larger fish cannot be discerned from that due to any possible change in food habits between years.

Another temporal trend was observed as a decrease in the percentage of several invertebrate taxa in largemouth bass stomachs. For example, odonates (immature damselfly larvae), chironomids, scuds, and other invertebrates were less frequent in stomachs sampled in 2008 as compared to 2007, but also be attributed to lower numbers of juvenile-size largemouth bass in 2008 (Table 7). Within 2007, odonates were a frequent diet item, however, a chi-square test showed no significant difference between the high-density and low-density vegetated sites. Again, this could be due to the low sample size (5) of fish that contained odonates in 2007 for low- versus high-density vegetated sites. The percentage of empty stomachs, however, did differ significantly between the two years (Table 8). Empty stomachs for these juvenile bass were observed in significantly lower numbers than expected in bass collected in 2008 (Table 8). In 2007, 18% of the stomachs were empty; in 2008, 57% of the stomachs were empty.

Table 6. Prey items found in the stomachs of largemouth bass in Lake Conroe, 2007 and 2008.

Amphipoda	**Fishes**	**Hemiptera**
	Atherinidae	
Diptera	*Menidia beryllina*	Unknown Hemiptera
	Labidesthes	
Chironomidae	*sicculus*	
Diptera adult	Centrachidae	**Miscellaneous**
Diptera pupae	*Lepomis spp.*	plant matter
	Clupeidae	**Odonata**
	Cyprinidae	Anisoptera
	Percidae	Zygoptera
	Poeciliidae	
	Unknown	**Zooplankton**
		Cladocera

Table 7. Quantitative description of largemouth bass diet. Stomach contents, represented by percent frequency of occurrence (FO), of 189 largemouth bass collected by electrofishing from Lake Conroe in late summer of 2007 and 2008. Percent frequency of occurrence is separated into sub-stock, and stock-sized and greater length categories to identify length-related changes in diet.

| | Summer 2007 | | | | | | Summer 2008 | | | | | |
| | **Sub-Stock** | | | **≥Stock Size** | | | **Sub-stock** | | | **≥Stock Size** | | |
Food Item	No. of fish with item	FO	# of prey	No. of fish with item	FO	# of prey	No. of fish with item	FO	# of prey	No. of fish with item	FO	# of prey
Aquatic Invertebrates												
Odonata	31	51.7	65	0	0.0	0	1	11.1	4	0	0.0	0
Chironomids	9	15.0	59	0	0.0	0	1	11.1	7	0	0.0	0
Ostrocoda	1	1.7	1	0	0.0	0	0	0.0	0	0	0.0	0
Hemiptera	2	3.3	3	0	0.0	0	0	0.0	0	0	0.0	0
Scuds	19	31.7	178	0	0.0	0	0	0.0	0	0	0.0	0
Unknown	3	5.0	5	0	0.0	0	0	0.0	0	0	0.0	0
Fishes		21.7			100.0			88.9			100.0	
Sunfish	1	1.7	1	12	40.0	12	0	0.0	0	3	15.0	3
Silversides	1	1.7	1	3	16.7	5	2	22.2	2	0	0.0	0
Shad	8	13.3	8	13	40.0	15	5	44.4	5	14	70.0	18
Shiners	1	1.7	1	0	0.0	0	0	0.0	0	0	0.0	0
Logperch	0	0.0	0	0	0.0	0	0	0.0	0	1	5.0	2
Mosquitofish	1	1.7	1	0	0.0	0	0	0.0	0	0	0.0	0
Unknown	2	3.3	2	8	13.3	8	2	22.2	2	3	15.0	3
No. of largemouth examined	73			55			21			40		
No. of stomachs with food	60			30			9			20		
% empty stomachs	17.8			45.45			57.1			57.1		
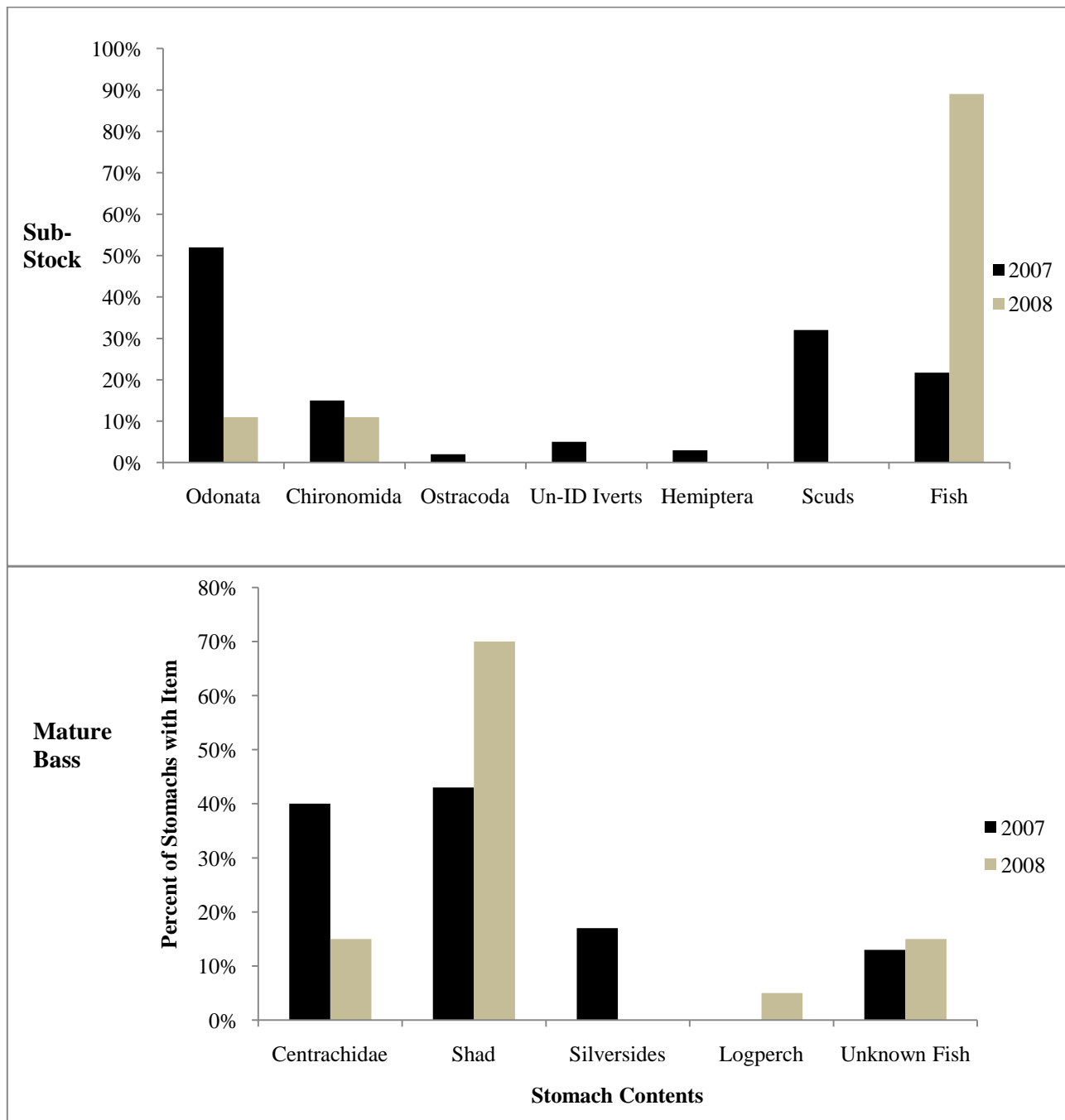
Figure 10. Percentage of stomachs that contained one or more of the specified food items from bass sampled in 2007 and 2008.

Table 8. Chi-square results for between-year differences in the frequency of stomachs that contained particular prey taxa, or were empty of largemouth bass in 2007 and 2008. Results for between-year differences in diets of mature fish are shown for stomachs that contained sunfish, shad, or were empty and for juvenile fish that were empty; results for juvenile fish in 2007 are for differences between vegetation coverage categories in frequency of stomachs that contained odonates. Expected values for number of prey items are in parentheses.

Mature Bass (Bass $\geq$ 200 mm TL), n=95

Prey	2007	2008	X^2	*P*
Sunfish	12 (18.7)	3 (6.3)	4.574	0.032
Shad	15 (16.7)	14 (12.3)	0.963	0.326
Empty	25 (26.1)	20 (18.9)	0.192	0.683

Juvenile Bass Empty Stomachs (Bass $\leq$ 200 mm, TL), n=24

Empty	13 (18.5)	12 (6.5)	8.717	0.003

2007 Juvenile Bass (Bass $\leq$ 200 mm, TL), n=28

Prey	High 2007	Low 2007	X^2	*P*
Odonata	23 (23.8)	5 (4.2)	0.335	0.562

Condition (2007-2008)

Mean values for Wr were calculated for largemouth bass, bluegill, and redear sunfish in each collection in 2007 and 2008. However, low sample sizes did not justify calculation of separate mean values for each vegetation coverage category. Generally, mean Wr values for all three species were within the range (95-105) for a fish considered to be in optimal condition (Anderson and Neumann 1996, Pope and Kruse 2007). The largemouth bass of preferred length collected in 2007 and largemouth bass of memorable length collected in 2008, both had Wr > 105 (Table 9). However, due to low sample sizes of these two length categories, caution is used when interpreting these results. Overall in Lake Conroe, it appears that mean values for Wr of largemouth bass were similar in both collection years, despite vegetation removal. Similar to the largemouth bass, bluegill also displayed mean Wr in all length categories that were well within the optimal range, or at the high end of the optimal range (Table 8). Except for length categories with small samples sizes, Wr values appeared to have changed little between collection years. For redear sunfish, mean Wr for combined stock and quality length group (pooled to increase sample size) was also within the optimal range, albeit closer to the lower threshold of 95 (Table 9). In addition, there also appeared to be no substantial change between years in Wr values for the combined stock and quality length group of redear sunfish. Substock sized redear sunfish sampled in 2007 had a mean Wr of 88, which is below optimal (Table 9). No substock sized redear sunfish were collected in the 2008 sample for comparisons to 2007.

Table 9. Sample size, mean Relative Weight (Wr) and 95% confidence interval around mean for three Centrachid species in Lake Conroe sampled by electrofishing in 2007 and 2008.

		Summer 2007		Summer 2008	
	Length Category	n	Mean Wr ± 95% CI	n	Mean Wr ± 95% CI
Largemouth Bass	Substock	4	104 ± 4.5	6	99 ± 8
	Stock	27	97 ± 3.4	14	97 ± 3.3
	Quality	17	103 ± 5.75	16	99 ± 4.4
	Preferred	8	109 ± 7.2	7	101 ± 8.4
	Memorable	1	100	2	112 ± 38
Bluegill	Stock	314	101 ± .45	17	101 ± 4.2
	Quality	14	103 ± 5.1	13	105 ± 5.4
	Preferred	2	95 ± 14	3	102 ± 9.6
Redear Sunfish	Substock	37	88 ± 3.55	0	
	Stock & Quality	58	95 ± 2.8	30	95 ± 4.6

Table 10. Fish species collected by electrofishing in Lake Conroe. Years in which a species was collected are in parentheses.

Atherinidae	**Clupeidae**	**Lepisosteidae**
		Lepisosteus oculatus
Labidesthes sicculus (2007)	*Dorosoma cepedianum* (2007/2008)	(2007/2008)
Menidia beryllina (2007/2008)	*Dorosoma petenense* (2007/2008)	
		Moronidae
Catostomidae	**Cyprinidae**	*Morone chrysops* (2008)
Minytrema melanops (2007/2008)	*Cyprinella venusta* (2007/2008)	
	Cyprinus carpio (2007)	**Percidae**
Centrachidae	*Pimephales vigilax* (2007/2008)	*Percina caprodes* (2007)
Pomoxis annularis (2007)	*Ctenopharyngodon idella* (2007/2008)	
Pomoxis nigromaculatis (2007)	*Notemigonous chrysoleucas* (2007/2008)	**Poeciliidae**
Micropterus punctulatus (2008)		
Micropterus salmoides (2007/2008)		*Gambusia affinis* (2008)
Lepomis megalotis (2007/2008)	**Fundiliade**	
Lepomis machochirus (2007/2008)	*Fundulus chrysotus* (2007)	**Sciaenidae**
Lepomis microlphus (2007/2008)		*Aplodinotus grunniens* (2007)
	Ictaluridae	
	Ictalurus punctatus (2007/2008)	
	Ameirus natalis (2007)	
	Ameirus melas (2007/2008)	
	Ictalurus furctatus (2008)	

Table 11. Total electrofishing effort, and catch per unit effort of non-Centrachid forage species in summer 2007 and 2008 in Lake Conroe TX.

YEAR	Total Effort (minutes)	Inland Silverside	Brook Silverside	Gizzard Shad	Threadfin Shad	Blacktail Shiner	Bullhead Minnow	Golden Shiner
2007	65	37	12	109	1407	14	4	127
2008	65	73	0	109	1492	33	11	0

Fish Community Composition and Multivariate Analysis

A total of 27 species of fish representing 12 families were collected by electrofishing in summer of 2007 and 2008 (Table 10). The relative abundances of Centrachid species, golden shiners, and brook silversides each declined from 2007 to 2008 in our collections (Table 11). Conversely, the relative abundances of blacktail shiners, bullhead minnows and inland silversides each increased in 2008, whereas relative abundances of both threadfin and gizzard shad were similar in each year.

The Redundancy Analysis summarized the relationships among the distribution of relative abundances of fish species among sampling stations, and explanatory variables associated with each station. Both the first (major) canonical axis and all canonical axes combined, explained a significant amount of the variation in the species data matrix (Axis 1 = 67%, F-ratio = 30.813, p = 0.008; all canonical axes combined = 70%, F-ratio = 3.545, p-value = 0.01). The first two RDA axes explained 69.6% of the variation in the species data matrix, and 89.4% of the variation in the species-environment correlations (Figure 11).

Axis 1 represents an ecological gradient related to shoreline category, coverage by aquatic plants species, and water quality variables, whereas Axis 2 depicts the temporal changes in these variables relative to grass carp introduction (Figure 11). Abundances of the two shad species were strongly positively correlated with the first axis, which was positively correlated with sampled stations that had bulkhead along the shoreline, deeper water, higher dissolved oxygen concentrations (DO), higher orthophosphorus concentrations, and greater coverage by American lotus and spatterdock (right side of Figure 11). In contrast, these variables were negatively correlated with samples at stations that had natural shoreline, and greater coverage by willow, and higher water conductivity and ammonia concentrations (left side of Figure 11). Longer sunfish, bluegill and golden shiner were only weakly positively correlated with the first axis, and all other species were weakly negatively correlated it. In contrast, all species except for the two shad species were more strongly correlated with

differences between pre- and post-grass carp introductions depicted along axis 2. Stations sampled before grass carp were introduced (upper half of Figure 11) were correlated most strongly with abundances of bluegill and golden shiner, and less strongly with redear and longear sunfish and both size classes of largemouth bass. Pre-grass carp samples also had stronger positive correlations with coverage by torpedo grass and hydrilla, and higher concentrations of total dissolved solids (TDS). Whereas after grass carp were introduced (lower half of Figure 11), samples were negatively correlated with those variables and abundances of those species, and positively contained with abundances of inland silverside and blacktail shiner.

Blacktail shiners and inland silversides were negatively correlated with axes 1 and 2 (lower left quadrant in Figure 11) and positively correlated with specific conductivity and ammonia. In addition, these two species are negatively correlated with the pre-grass carp period (2007) and more closely associated with the post-grass carp period (2008) along with more bulk-headed habitat. In opposite trend, bluegill, longear sunfish, and golden shiners were positively associated with the pre-grass carp period along with total dissolved solids and two plant species (spatterdock and American lotus).

Redear sunfish and largemouth bass (both size classes) were negatively correlated with axis 1 but positively correlated with axis 2 (upper left quadrant in Figure 11). These species were associated with pre-grass carp conditions (2007) and were highly correlated with hydrilla, torpedograss, willow, and a natural (non-bulkheaded) shoreline. In contrast, threadfin shad and gizzard shad show an association with post-grass carp (2008) along with a bulk-headed shoreline, increasing depth, high dissolved oxygen and increasing ortho-phosphate. In addition, the strength of the threadfin shad abundance gradient represented by the longer species arrow in the triplot is greatest among all species.

Table 12. Species and variable codes used in the redundancy analysis are presented with definitions.

Species codes	Definition
LMB+150	Largemouth bass $\geq$ 150 mm
LMB-149	Largemouth bass $\leq$ 149 mm
RE Sunfish	Redear Sunfish
Bluegill	Bluegill
LE Sunfish	Longear Sunfish
Golden Shiner	Golden Shiner
BlkTail Shiner	Blacktail Shiner
Inland Silver	Inland Silverside
Threadfin Shad	Threadfin Shad
Gizzard Shad	Gizzard Shad

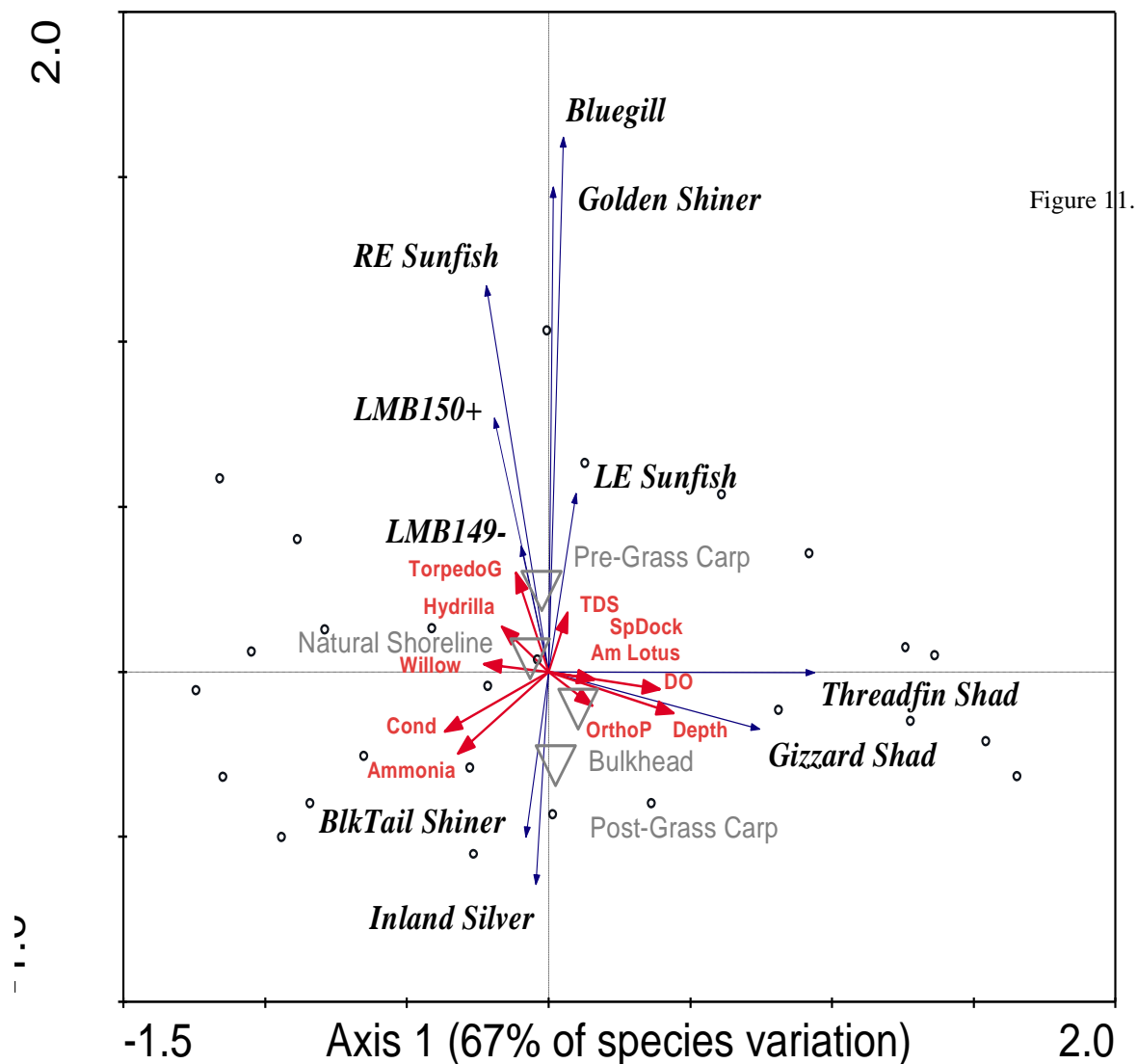| Variable Codes	Definition
Torpedo G	Torpedo Grass
Hyrdilla	Hyrdilla
Willow	Willow
Cond	Conductivity
Ammonia	Ammonia
TDS	Total Dissolved Solids
SpDock	Spattedock
AmLotus	American Lotus
DO	Dissolved Oxygen
OrthoP	Orthophosphate
Depth	Depth

Figure 11. Ordination tri-plot for the RDA of fish assemblage data collected by electrofshing in the summer of 2007 and 2008 in Lake Conroe, TX. Relationships are depicted for fish relative abundances (blue arrows depict direction of increase for each species) among individual samples (open circles), and correlations of fish abundances with environmental variables (red arrows depict direction of increasing value for continuous variables; grey triangles are centroids of distribution for samples categorized by shoreline as bulkhead or natural shoreline, and by year as pre- or post-grass carp introduction) Axes use symmetric scaling of scores for species and explanatory variables. Centroids closer to an axis, and arrows that form more acute angles with an axis are more strongly correlated with that axis.

CHAPTER IV

DISCUSSION AND CONCLUSION

Vegetation Changes in Lake Conroe

In 1981-1982, when grass carp (diploid) were first introduced into Lake Conroe, their density was roughly 74 fish per vegetated hectare, or 270,000 grass carp per 3,600 ha of aquatic vegetation (90% of which was *Hydrilla verticillata*). It then took approximately 3 years before aquatic vegetation was nearly eliminated from the reservoir. The re-stocking rate in 2007 was roughly 125 fish per vegetated hectare (90,000 fish per 715 ha of hydrilla) was sufficient to quickly rid the lake of nearly all plant species, even those that had been deemed (from previous research) to be unpalatable to grass carp (Fowler and Robson 1978, Pine and Anderson 1991, Chilton and Muoneke 1992). The reduction in these plant species (many of which were not present in Lake Conroe during the 1980s) between 2007 and 2008, is less easily explained as due to consumption by grass carp. If water containing a mixed plant community is stocked with grass carp, these fish can alter the species diversity by removing palatable plants, leaving those they do not eat, particularly emergent plants, to spread (Fowler and Robson 1978). But, such a result was not evident during the 2007-2008 study period, in which all plants showed a large-scale reduction.

A better correspondence with our results, is reported in four reservoirs studied in Florida, into which grass carp were stocked at the rate of 50/ha in order to control hydrilla. In that study, the result was a possible eradication of hydrilla, along with a dramatic reduction in almost all plant species considered less-palatable to grass carp (Leslie et al. 1983). It seems reasonable that a very dense initial stocking of grass carp will hasten the reduction in all plant species, thus reducing the time frame in which unpalatable species could grow and spread. Thus, what could be considered as understocking of grass carp would result in less control of (nuisance) vegetation because

growth by unpalatable forms could compensate for consumption of palatable species (Fowler and Robson 1978, Chilton and Muoneke 1992). In my study of Lake Conroe, it was particularly interesting to observe the effect of grass carp on the emergent, shoreline grass species, *Panicum repens* (torpedo grass). This plant is native to Australia, but naturalized along shoreline habitat in many aquatic systems in the southern United States, and dominated nearly all the natural shoreline of Lake Conroe that lacked bulkhead. During the 2008 sampling, it was evident that grass carp had used the emergent torpedo grass as a food resource. I observed plants that had been shredded and removed along the shallowest areas of the shoreline. Other studies have reported that torpedograss is consumed by grass carp when other more palatable plants are no longer available (Osborne 1981, Van Dyke et al. 1984). It seems plausible that grass carp continue to switch food resources as sources of their more favorable plants became exhausted (i.e. as hydrilla became scarce, grass carp switched to the less desirable species, eventually consuming torpedo grass). I note, however, that some reduction of the less-palatable species in the summer of 2007, also could be attributed to the application of aquatic herbicide by personnel working for the San Jacinto River Authority and Texas Parks and Wildlife. Exact locations for herbicide applications were not documented, nor which species of plants were targeted and affected. Ultimately, changes in the plant assemblage composition as well as coverage between summer2007 and summer 2008 included almost complete removal of vegetation, rather than a shift in relative abundances among plant species.

Water Quality Changes in Lake Conroe and Habitat Description

Sampling at each site only once during each of the sampling seasons may not be sufficient to document the indirect effects that grass carp may have on the physical, chemical, and biological characteristics of Lake Conroe because large seasonal and diel fluctuations in the values of the measured parameters occur in large impoundments

(Maceina et al. 1992). The two point temporal sampling schedule does not allow detection of change in these patterns. Systematic monitoring of these variables at a finer temporal scale (seasonal or monthly over multiple years) would better detect direction and magnitude of changes in trends such as for multiple water quality parameters. However, the significant increase in nitrate levels from 2007 to 2008 is consistent with the ecological hypothesis that nutrients previously sequestered in macrophytes were released back into the reservoir water column as macrophytes were consumed by grass carp (Reddy and De Busk 1985, Takamura et al. 2003). However, the static measure of nutrient levels in a reservoir at any point in time reflects only the current balance of dynamic input and loss rates (Leslie et al. 1983, Klussmann et al. 1988). The time frame for this balancing process to occur in Lake Conroe is unknown, but could be presumed to be rapid if water is continuously being discharged at the dam. However, factors such as external supply of nutrients have likely changed the dynamics of this process, given that shoreline development around Lake Conroe has increased since the 1980s. The increase from 2007 to 2008 in water clarity (i.e., increase in secchi depth) is contrary expectations of algal blooms being fed by the release of nutrients from vegetation via its consumption by grass carp. However, this may be a transient phase, given that the previous stocking of grass carp in Lake Conroe in the 1980's, was followed by a steady decrease in water clarity over a six–year period.

Length Frequency Changes

Largemouth Bass, Bluegill, Redear Sunfish, Longear Sunfish and Gizzard Shad

The length distribution of a fish population at any point in time reflects the dynamic balance among recruitment, growth, and mortality, linked to both the biotic and abiotic environments (Miranda 2007). Thus, the observed decrease in relative abundance and increase in mean size and shift in length frequency among Centrarchid species captured at the sampling station between 2007 and 2008 should reflect the influence that

aquatic vegetation has on these fishes. For example, size-structure of *Lepomis* sunfish and *Micropterus* bass populations are both positively and negatively related to plant abundance, and optimum conditions vary across studies (Forester and Lawrence 1978, Durocher et al. 1984, Dibble et al. 1996). For example, younger and smaller fish (such as juvenile bluegill) become more abundant as plant density increases (Barnett and Schneider 1974, Dibble et al. 1996) and likewise, decrease when the plants are removed (Pothoven and Vondracek 1999). Therefore, I expected the observed changes in length-frequency and relative abundances of Centrarchid fishes, and that these changes would correspond with the vegetation removal observed from 2007 to 2008 in Lake Conroe. Such changes are consistent with ecological theory of community interactions and the various functional roles of aquatic vegetation.

The role of aquatic vegetation as a structural refuge is logically consistent with the grater abundance of juvenile largemouth bass and sunfishes across the sampling stations in Lake Conroe prior to grass carp introduction. Aquatic vegetation was ubiquitous along the shoreline of the reservoir in 2007. Even a very heterogenous, patchy distribution implies that fishes captured at only "lightly" vegetated stations are likely to be influenced by its structure at some spatial or temporal scale. Likewise, the decreased abundance of smaller sized Centrachids in collections after grass carp were stocked could be due to increased predation rates as vegetative cover was consumed (Mittlebach 1981). Through structural complexity, the aquatic plants reduce predation risk by mediating the extent to which predators and their prey interact (Werner 1974, Savino and Stein 1982, Miranda and Hodges 2000). This protection, critical to smaller fishes, is due to relative cost to piscivores of increased search, encounter, and capture times, as well as reduced rates of encounter, attack, and capture, and generally reduced swimming velocities of the larger piscivores (Anderson 1984, Diehl 1988, Dibble et al. 1996). Additional benefits to smaller fishes come from the structural complexity that plants provide as habitat for their epiphytic macroinvertebrate prey (Schramm and Jirka 1989). The dynamics of these interactions were not directly investigated in my project. However, the large decline in 2008 of juvenile largemouth bass (<200 mm-TL), juvenile

bluegill (<80 mm-TL), juvenile redear sunfish (<70mm-TL), and longear sunfish (<80 mm-TL) could indicate increased predation pressure on juvenile (young-of–the-year) fish. For example, during the 1980s Lake Conroe study, the decrease in redear sunfish abundance was hypothesized (but not tested) as due to a drop in recruitment rates following vegetation removal (Bettoli et al. 1993). It may be that once the vegetation was removed, redear sunfish populations are less able than those of bluegill and longear sunfish to persist in the presence of strong predation by largemouth bass (Swingle 1949).

In addition to the protection that aquatic vegetation provides to fishes, is the increased abundance and diversity of macroinvertebrates prey that attract juvenile fishes. Macroinvertebrate abundance and diversity are higher in patches of aquatic plants than in unvegetated areas because at this finer grain of spatial complexity, leaves and stems provide substrate for their attachment and protection from their predators (Dibble et al. 1996). Therefore, I reasoned that the removal of aquatic plants in Lake Conroe would cause juvenile Centrachids to not only seek suitable habitat structure, but use a different range of food resources (possibly more benthic oriented) that would be more readily available once plants were removed. However, another study in Lake Conroe concurrent with mine (Sifuentes 2009) showed that three sunfish species (bluegill, longear sunfish, and redear sunfish) had a high degree of diet overlap and showed little change in diet from 2007 to 2008. Thus, these sunfishes may have abandoned these areas in search of protective structure. In contrast, in a study in the Atchafalaya Basin, showed that age-0 largemouth bass had significantly different diets that corresponded with variation in aquatic vegetation coverage (Mason 2002).

The roles as refugia and forage provisioning are important factors in potential explanations for changes in the relative abundance and length-frequency distributions of centrarchid fishes following the removal of virtually all the aquatic vegetation within the sampling stations, and Lake Conroe as a whole. However, I am cautious when interpreting these results due concerns about small sample sizes, particularly from the small abundances of fish in the 2008 samples. Samples of 75 – 100 individuals of largemouth bass and samples of 130 – 160 individuals of bluegill were needed to

accurately estimate population mean abundance (Vokoun et al. 2001, Miranda 2007). The abundances of species collected in 2008 were well below those referenced values which, in turn, could affect the accuracy of the K-S tests. In addition, because data for all stations were combined to increase sample sizes, inter-station comparisons within year were not made. Therefore, length-frequency differences due to vegetation density could not be tested.

A final comment about the low relative abundance of Centrachids in 2008 concerns their predator-avoidance behavior. When bluegills observe a foraging bass, they move out of range (or into thick vegetation) and remain motionless (Savino and Stein 1989). It seems possible that the noise of the electrofishing boat could elicit this predator-avoidance response. Thus, in the 2007 (pre-carp) sample, if the Centrachids (including juvenile bass) sought shelter and remained motionless in the thickest, most protected, vegetated areas, they may have been concentrated and more readily collected. In contrast, during the 2008 sampling after grass carp introduction, the presence of the electrofishing boat might have caused the fish to disperse from the stations, reducing their capture rate. Thus, mechanisms contributing to lower catches in 2008, are unconfirmed, but an expected result based on published studies.

The possible mechanisms influencing the size shift in the gizzard shad population are less well discussed in the literature than for Centrachids. Individual gizzard shad growth rates should be related to the trophic status of the reservoir, and accordingly influence size structure. Length distributions of gizzard shad in Florida were skewed towards smaller individuals in eutrophic lakes (Kautz 1982). Eutrophic waters may produce higher abundances of gizzard shad that could depresses individual growth through density dependent mechanisms (DiCenco et al. 1996). Thus, the mean decrease in size (total length) of gizzard shad in Lake Conroe after grass carp stocking, corresponds with such a scenario of planktonic algal blooms triggered by the large scale removal of aquatic vegetation and release of nutrients via their consumption. Although changes in water quality parameters in Lake Conroe were inconclusive regarding grass carp introduction, a transition to a more eutrophic state would be expected to produce an

increase in planktonic algal biomass, which would drive secondary production by gizzard shad (Bettoli et al. 1990). Contrary to this scenario, however, the Lake Conroe study from 1980-1986 reported an increase (rather than the expected decrease) in the abundance of large-sized gizzard shad after the removal of macrophytes, although, it was attributed to a strong 1979 year-class becoming fully susceptible to the gear (gill-nets) (Klussmann et al. 1988). Since I did not age the gizzard shad in my study, the possible effect of year-class strength is not known. Ultimately, correct interpretation of the change in size distribution of gizzard shad from 2007 to 2008, would require additional data for a variety of influential factors, such as internal and external nutrient fluxes, year-class strength, predator abundances, condition of adults, competition between other planktivores (e.g., threadfin shad).

Largemouth Bass Diet

Largemouth bass are considered versatile and opportunistic predators, that consume a wide variety of prey types depending upon their availability (Maceina and Murphy 1989, Sammons and Maceina 2006). The predominance of shad in the stomachs of largemouth bass for both 2007 and 2008 is not surprising given that they were the most abundant forage species encountered in my samples. In addition, shad (in particular, the small bodied gizzard shad and the smaller-bodied threadfin shad) are extremely vulnerable to predation by largemouth bass (Conley et al. 2004). First, their small, soft-bodied morphology may reduce energy cost due to handling time as compared to that for coarse finned and deep-bodied fishes such as sunfish. Second, shad species are typically the most abundant forage species found in many reservoirs of the southern U.S. and consequently are a major prey type in the diet of piscivorous fishes (Noble 1981). However, in Lake Conroe the significant decrease in the frequency of consumption by largemouth bass of Centrachid sunfishes after vegetation removal, may have related to the dramatic change in habitat structure . Two circumstances may have led to this pattern. First, it is reasonable that the removal of macrophytes caused a

restructuring of the forage base in that there were fewer juvenile sunfish and more shad within the habitat (as was evident in the relative abundances in the electrofishing samples). Second, the diet shift may be due to the reduced habitat complexity changing foraging efficiency of largemouth bass. Macrophyte structure impedes foraging efficiency by creating physical barriers to fish movement and visual prey detection (Kovalenko et al. 2009). During the Lake Conroe study in the 1980s, largemouth bass similarly increased their consumption of shad after grass carp removed hydrilla, and abundances of sunfish decreased, as shad increased (Bettoli et al. 1992, 1993). Such diet switches are a part of an adaptive behavior pattern in that switching among prey items, increases the probability that individuals will survive under changing circumstances influencing growth and fitness (Gerking 1994). Interestingly, despite the relative increase in abundance of blacktail shiners and bullhead minnows (family Cyprinidae) following vegetation removal, no minnows were encountered in the mature bass stomachs from either sampling year, though some may have been included in the category of digested "unidentifiable fish". The absence of minnows also may be attributable to either an insufficient sample of largemouth bass stomachs, or an indication that the overall abundance of minnows (despite the increase) was not sufficient to constitute a noticeable portion of the diet. Absence of age-0 largemouth bass from stomach contents suggests that cannibalism did not occur or was rare during our sampling. However, like the Cyprinids, age-0 largemouth bass could have been included among the digested remains of unidentifiable fishes.

A study in Florida found a higher percentage of empty stomachs of largemouth bass in vegetated lakes than unvegetated lakes, by which it was inferred that food consumption rates were higher in unvegetated lakes (Cailteux et al. 1998). Although the percentage of empty stomachs for mature bass in Lake Conroe did not change between sampling years, these results may be influenced by the complicated diel cycle of behavior exhibited by Centrachid fishes. For my project fish were sampled in both years from mid-morning through early afternoon, which may not coincide with the feeding cycle of adult bass. A study in Florida found that largemouth bass divided their time

between resting offshore primarily during the daytime, and time spent near-shore, where foraging presumably occurred during dusk and other low-light periods (Sammons and Maceina 2005). Although largemouth bass were captured during electrofishing, it is possible that many had not been recently feeding, thus increasing the percentage of empty stomachs as compared to collections near dusk, closer to peak feeding activities.

In regards to the juvenile largemouth bass, age-0 fish, typically > 40-50 mm TL, begin to increase their consumption of fish (Chew 1974). This diet transition from invertebrates to fish allows young-of-the-year largemouth bass to maximize growth rates and increases first-year survival (Timmons et al. 1980, Keast and Eadie 1985, Olson 1996). Although it was impractical (given the relatively few fish < 80 mm TL in the 2008 sample) to determine the average size at which this diet switch occurred in the Lake Conroe population, the increase in FO from 22% to 89% fish could indicate that these juvenile bass were relying more on fish as prey, than they were on invertebrates. In addition, the decrease in FO from 52% to 11% for Odonates may also mirror this trend because the previous vegetated habitat was more suitable for such macroinvertebrate prey (Merritt and Cummings 1996).

Centrarchid Body Condition

Relative weight is intended to estimate the short-term physiological condition of a fish and is primarily influenced by food availability and seasonal changes in gonadal development (Pope and Kruse 2007). Values below 95 are associated with inadequate prey availability, and the severity of the deficiency increases with the downward deviation from this benchmark (Anderson and Neumann 1996, Pope and Kruse 2007). The relatively high Wr values (> 95) for almost all size classes of largemouth bass, bluegill, and redear sunfish in Lake Conroe for both sampling years suggest that prey was sufficient and available. Therefore, despite vegetation removal, all size classes maintained good body condition. However, these fish species are typically spring spawners, and may have been in a weight gain period of their seasonal cycle (thus

improving body condition) during the late summer sampling for this study and thus, experiencing a seasonal increase in food consumption rate (Rice et al. 1983), rather than responding to a change in prey availability.

Other studies have reported differing results in regards to Wr values and vegetation removal. In Arkansas, condition factors for bluegills, redear sunfish and largemouth bass were reported as generally improved after removal of aquatic vegetation (Bailey 1978). Largemouth bass are also reported to undergo reduction in Wr attributed to reduced foraging efficiency during periods of peak hydrilla infestation (Colle and Shireman 1980). The dynamics governing these changes, however, may also be sensitive to the initial coverage levels, and, in particular, space in the water column occupied by plants.

Multivariate Fish Data

When looking at a fish community, there is the implicit assumption that the associations arise from biotic factors, abiotic factors, or a combination of the two (i.e., that the community composition is not random). Therefore, in looking at the fish community (in this study, the 10 most commonly collected fish species) within the sampling stations in Lake Conroe, it is important to be aware of the important variables related to reservoir conditions. Reservoirs are considered hybrid systems having both lotic and lentic properties. Typically, it would be expected that the upstream reaches of the reservoir would contain more riverine habitat, whereas downstream it would more resemble a natural lake. Thus, reservoirs exhibit longitudinal gradient that may strongly influence the distribution of its fish community in space and time. However, if the localized habitat conditions have a larger effect than longitudinal position, then physical habitat may be the best predictor of the fish community structure (Gido et al. 2002). In this study, the localized habitat parameters (such as the presence or absence of specific plant species) are the focus of my investigation regarding the "who is where" aspect of this project.

The first two RDA axes summarizing the data set explained 69% of the variation in fish species distribution among samples (Table 10). Overall, it appears that the littoral zone fish community within the sampling stations of Lake Conroe are somewhat predictable based upon gradients in related environmental parameters. The four species of Centrarchids (largemouth bass, redear sunfish, longear sunfish, and bluegill) along with golden shiners were more strongly associated with with conditions prior to grass carp introductions. In particular, their association with greater coverage by hydrilla and torpedograss (the two most abundant plant species), and presence of natural shoreline. Smaller (<150-mm TL) largemouth bass abundances are positively correlated with vegetation coverage (Tate et al. 2003) and are expected to decrease with the removal of the vegetation (Shireman et al. 1985, Bettoli et al. 1992). This is confirmed by (Miranda and Pugh 1997), reporting that intermediate levels of aquatic vegetation maximized the abundance of juvenile largemouth bass entering the winter season, and their abundance was positively correlaed with the amount of vegetation coverage in their habitat. Explaining the dynamics of these associations, however, can become quite complex due to a number of influential variables.

The association in my study among bluegill, longear sunfish and golden shiners with conditions prior to grass carp introduction (particularly, coverage by spatterdock and American lotus) was more closely associated with deeper, and open-water, conditions associated with bulkhead, than the natural shoreline and shallower habitats associated with largemouth bass and redear sunfish. Typically after hatching, longear sunfish, redear sunfish, and largemouth bass remain in shallow littoral habitats (Meals and Miranda 1991). Bluegill may leave the littoral zone upon hatching, but typically return once they have reached 11-25 mm TL (Werner 1967). Given that the majority of the bluegill and longear sunfish captured in Lake Conroe were juveniles (most were captured in 2007 samples), the correlation with the specified plant species could relate to their protective cover and substrate for production of macroinvertebrate food resources (as discussed in detail in the preceding sections). Their association with golden shiners is less obvious. During the 1980 to 1986 study of Lake Conroe, golden shiner density and

biomass were variable but neither consistent nor statistically significant (Klussmann et al. 1988). Golden shiners spawn over vegetation where their eggs adhere until hatching; their foraging on invertebrates and zooplankton is generally oriented toward the water surface (Robison and Buchanana 1988) Thus, the cover and shade provided by leaves of spatterdock and American lotus would not only enhance their foraging success, but also reduce predation by wading and diving birds (Gawlik 2002). Alternatively, as a schooling species, their strong association may also be related to their concentrated abundance in these habitats, and therefore ease of collection.

Unlike the Centrachid species, threadfin and gizzard shad were correlated with samples taken after grass carp introduction, and along bulkhead shorelines. In addition, threadfin shad and gizzard shad were associated with deeper as well as open water, higher orthophosphate concentrations, and higher dissolved oxygen. During the Lake Conroe study from 1980 to 1986, both threadfin and gizzard shad increased in abundance and biomass following the removal of macrophytes (Klussmann et al. 1988). This increase could be linked to consumption of macrophytes by grass carp, which would re-route energy and nutrients into phytoplankton in the limnetic zone, thus benefiting planktivores such as shad (Bettoli et al. 1990). The association of the two shad species with depth and bulkhead habitat reflects their limnetic habitat use. In addition, the association with higher orthophosphate may indicate nutrients released into the water column that are otherwise incorporated into plants and adsorbed onto sediment particles (Gosselink and Mitsch 2007). The association of blacktail shiner and inland silverside with samples after grass carp were stocked may share characteristics with shads. Blacktail shiners were the most abundant minnow species captured in both years. However, in the 2008 sample, they were substantially more abundant. In addition, in the 2007 sample before grass carp were stocked, they were associated with "lightly" vegetated stations. This corresponds with the results of the study of Lake Conroe from 1980 to 1986, which reported significant increase in blacktail shiner after the removal of macrophytes. The association of blacktail shiner and silverside to less-vegetated conditions may related to their successful foraging techniques on terrestrial insects at the

water's surface (blacktail shiners), and suction feeding on zooplankton in open habitat (inland silverside), which would reduce competition with small sunfish (Klussmann et al. 1988).

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