DIETS OF THREE SUNFISH SPECIES IN LAKE CONROE, TEXAS, BEFORE AND AFTER GRASS CARP INTRODUCTION

A Thesis

by

MATTHEW L. SIFUENTES

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

December 2009

Major Subject: Rangeland Ecology and Management

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Approved by:

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	Fred E. Smeins
Committee Member,	Michael P. Masser
Head of Department,	Steven G. Whisenant

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ABSTRACT

Diets and Summer Habitat Associations of Three Sunfish Species in Lake Conroe, Texas, Before and After Grass Carp Introduction. (December 2009)

Matthew L. Sifuentes, B.S., The University of Texas at San Antonio

Co-Chairs of Committee: Dr. Frances P. Gelwick
Dr. Fred E. Smeins

Hydrilla (*Hydrilla verticillata*) is an invasive aquatic plant that grows quickly across shallow freshwater habitats. It is a problem for recreational users of lakes and landowners. Grass carp (*Ctenopharynogodon idella*) is an effective biological control agent that preferentially consumes and can control the spread of hydrilla. However, grass carp also will consume other vegetation, which influences aquatic communities via direct and indirect interactions that can change food and habitat availability and use by various species. Aquatic plants influence habitat and types of prey used by sunfish (*Centrarchidae*), which must also avoid their own predators. Prey use among sunfish species depends on density and taxonomic identity of both prey and vegetation. This was a one-year analysis of stomach contents from three common species of invertivorous sunfish: bluegill (*Lepomis macrochirus*), longear sunfish (*Lepomis megalotis*), and redear sunfish (*Lepomis microlophus*). Thirteen sampling stations were randomly selected using ArcGIS software. Percentage of water surface covered by vegetation was recorded at each station. A five-minute electrofishing sample was performed within the littoral zone early morning in late September. The stomach contents of all targeted sunfish (N=489) showed high percentages of diet overlap pre- (0.77-0.92) and post- (0.83-0.88) introduction of grass carp. Multivariate analysis showed total explained variation (15.5%) in sunfish diet composition was ($P < 0.05$) correlated significantly with sunfish species (6.67%), percent surface vegetation coverage (3.97%), and sampling periods pre- versus post-introduction of grass carp (2.13%). Prey-specific abundance showed that all sunfishes displayed a generalized feeding strategy in both sampling periods. Diets of each sunfish species showed differences in abundance (by volume) and occurrence (among individual fish) of prey items between sampling periods. Levin's standardized index of diet breadth for all sunfish species decreased from pre- (0.12) to post-introduction (0.05). Results imply that vegetation control by grass carp influenced the diets and feeding strategies of three cohabitating sunfish species. These findings may help fisheries biologists to plan future management actions that influence assemblages of aquatic plants and macroinvertebrates, herbivorous fish, invertivorous prey-fish, and piscivorous game fish, to promote a healthy and balanced ecosystem for Lake Conroe stakeholders.

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I would like to specially thank my friends at the Texas Parks and Wildlife Department, Inland Fisheries Office in Bryan, TX, Mark Webb, Bill Johnson, and Mike Gore. Mark, you are truly an example of a fisheries biologist who enjoys what they do. I thank you for the advice, recommendations, and fun talk that we have had. To Bill and Mike, where would Patrick and I be without the guidance and funny criticism from you both? You both make sampling a whole lot of fun. Thank you all so much.

I would also like to thank my partner in crime on this project, Patrick Ireland, and former lab partner, A.J. Vale, for their help with this project. These guys have put a lot of work into this project and they should be recognized for their hard work. Thanks!

Special thanks goes out to my friends, faculty, and staff of both the Department of Ecosystem Science and Management and the Department of Wildlife and Fisheries

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To save the best for last, thanks to my great parents and family members for their encouragement and support. You all mean a great deal to me and I would not be where I am today if it were not for your love, support, and friendships. Thank you all.

NOMENCLATURE

B/CS	Bryan/College Station
LCA	Lake Conroe Association
SJRA	San Jacinto River Authority
TAMU	Texas A&M University
TPWD	Texas Parks and Wildlife Department

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1. INTRODUCTION

Fish, invertebrates, and plants can indicate lake ecosystem health because species vary in their tolerances across a range of environmental regimes and associated abiotic and biotic factors. Primary producers at the base level of aquatic systems provide food and habitat resources to invertebrates and fish at higher trophic levels. Populations of fish and invertebrate species are often associated positively with vegetated habitats, where aquatic plant morphology and structural complexity may influence predator-prey interactions (Dibble et al. 1996; Keast 1984).Vegetation-dwelling invertebrates are important food organisms for juvenile and adult fishes, particularly in lakes with a limited benthic prey base, because macroinvertebrate species composition is strongly influenced by habitat structure and water quality (Merritt and Cummins 1996). Moving to higher trophic levels, a healthy assemblage of small-bodied prey fish sustains a healthy predator assemblage, which attracts human anglers among other top level consumers. This web of species is dynamically balanced through interactions both positive and negative. In order to produce and maintain a healthy aquatic system, many small-scale interactions must be understood well enough to predict the direction (and when possible the outcome) of management activities intended to attain those goals, and more specific measurable objectives such as production of goods and services to humans.

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

2. PROBLEM

Hydrilla *Hydrilla verticillata* (Royle) is a submerged aquatic plant that can grow quickly and spread across aquatic habitats. It causes problems for both recreational users of these habitats and riparian landowners, and influences interactions among members of the aquatic community. Hydrilla is native to Asia, but has become widespread throughout North America. It was first discovered in the United States in Florida in 1960 and within the last 45 years has colonized over 690 water bodies within 190 drainage basins of 21 states (Langeland 1996; Jacono and Richerson 2007). Hydrilla provides shelter, breeding habitat, and epiphytic forage for numerous fish and aquatic macroinvertebrates (Killgore et al. 1998). However, high densities are not beneficial to a fishery because hydrilla can out-compete native vegetation, and lead to reductions in angler access, fish foraging success, invertebrate abundance, and water quality (Martin and Shireman 1976).

3. STUDY SITE

Lake Conroe (Figure 1) is an 8,498 hectare impoundment of the West Fork of the San Jacinto River in Walker and Montgomery counties, TX. The lake was formed in 1973 and shortly thereafter, hydrilla became established, and recurring problems for lake managers followed. In 1979, hydrilla reached its peak surface coverage of approximately 1,821 hectares. Grass carp *Ctenopharyngodon idella*, a non-native species introduced for biocontrol of hydrilla, has been studied in southern reservoirs of North America, where hydrilla is among their preferred food plants (Allen and Wattendorf 1987; Wattendorf and Anderson 1987; Klussmann et al. 1988). The Texas Parks and Wildlife Department (TPWD) and the San Jacinto River Authority (SJRA) have carried out multiple actions to control hydrilla at Lake Conroe. In 1981 and 1982, approximately 270,000 diploid (non-sterile) grass carp were stocked into the reservoir (75 fish per vegetative hectare; Chilton and Muoneke 1992), and by 1983 all vegetation had been removed. Over time, grass carp abundance declined through natural and harvest mortality, and no recruitment was detected (M. Webb, TPWD, personal communication). In 1996, vegetation surveys conducted by TPWD showed that hydrilla had reappeared in Lake Conroe across a total of 351 hectares. Localized spraying of chemical herbicides was minimally effective as a single method of control; therefore, in 2007 an integrated pest management (IPM) plan was developed by TPWD and SJRA to control the spread of hydrilla. The IPM plan consisted of chemical, physical, and biological controls, which included the stocking of 86,000 triploid (sterile) grass carp (9.1 to 55 fish per vegetative hectare) (M. Webb, TPWD, unpublished data).

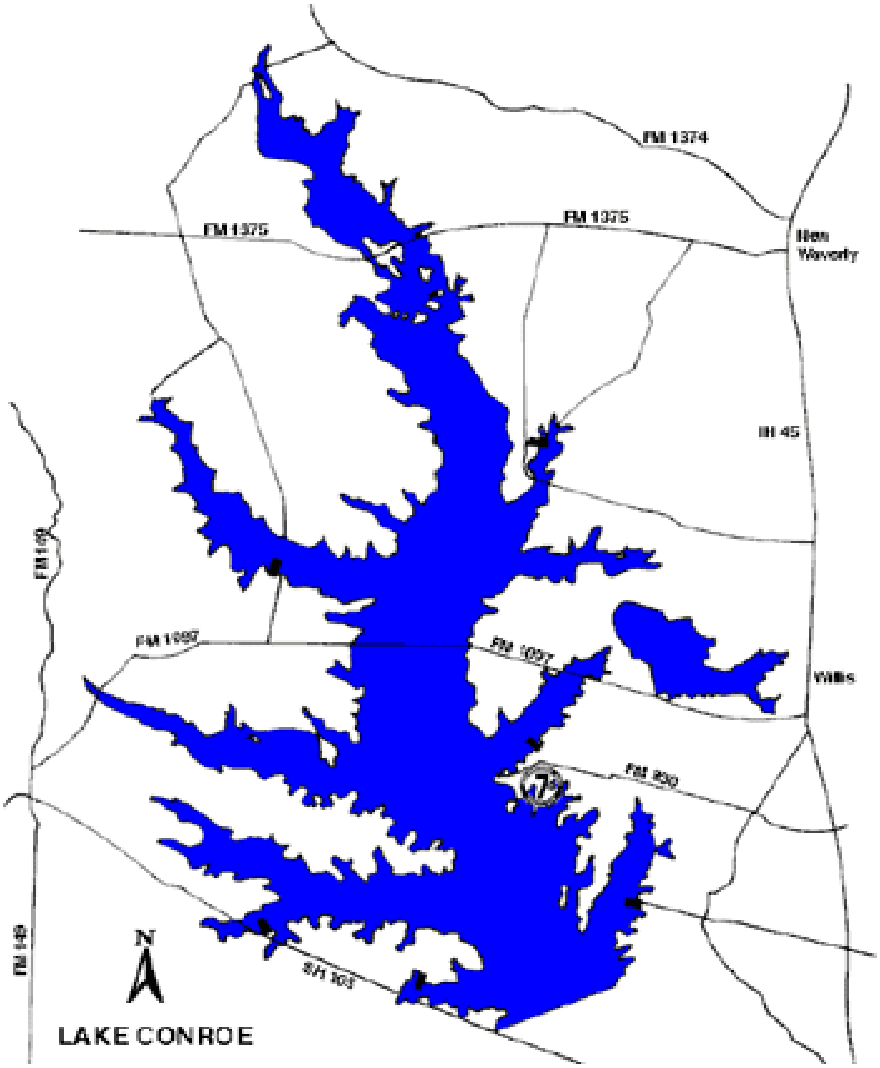


Figure 1. Map of Lake Conroe, TX.

4. PURPOSE AND HYPOTHESIS

The purpose of this project is to evaluate the indirect effects of stocking triploid grass carp to control hydrilla in Lake Conroe, TX on the diets of three of the most common sunfish species in the system: bluegill (*Lepomis macrochirus*), longear sunfish (*Lepomis megalotis*), and redear sunfish (*Lepomis microlophus*). Sunfish, family *Centrarchidae*, are often studied to identify ecological consequences of species interactions because of their wide range of food types and habitat associations (Robinson et al. 1993). The hypothesis tested is:

H_o: Pre- and Post- introduction of grass carp has no effect on diets within and between the sunfish species as related to:

a) diet breadth
b) feeding strategies
c) relative importance of prey types

Several alternative outcomes can be anticipated. With the removal of aquatic vegetation by grass carp, there could be a corresponding decrease in the abundance and types of available prey previously associated with that vegetation (Werner et al. 1983; Orth and van Montfrans 1984). In addition, the relative efficiency of foraging by each sunfish species depends on both the abundance and behavior of various types of prey (e.g., ability to avoid predators), as well as the ability of sunfish to detect prey and maneuver within and near habitat structure provided by vegetation, while avoiding their own predators (Werner and Hall 1976, 1977; Mittelbach 1984, 1988). Many studies have shown the positive correlation between sunfishes abundance and vegetation cover (Ware and Gasaway 1978; Wiley et al. 1984; Noble 1986; Scott 1993). Thus, abundance of sunfish species, as well as their diets may change as grass carp remove vegetation and change the parameters that influence foraging success, competitive interactions among sunfish species, and predator-prey relationships.

5. METHODS

Field Design/Sampling

Thirteen stations throughout Lake Conroe were sampled once each year during autumn (late September 2007/2008), just before and one year after grass carp were stocked (55 per vegetative hectare). Ten stations were randomly selected using ArcGIS software (Booth and Mitchell 2004) and three additional stations were randomly selected in areas undergoing restoration of native vegetation (*Vallisneria americana*). All stations were classified into categories of percent vegetation cover across the surface of the water during sampling as follows: heavy (>60%); moderate (60-10%); and light (<10%).

Electrofishing is a desired sampling tool for capturing fish within the shallow littoral zone (Reynolds 1996). To standardize the effort, a five-minute boat electrofishing sample was taken at constant speed to cover a similar transect distance within the littoral zone of each station (calculated from GPS coordinates recorded in the field) A Smith-Root electrofishing research vessel equipped with a Smith-Root Model 5.0 pulsator (GPP) was used during the early morning between 0900 and 1200 hours (cst). Depth was averaged and recorded. All sunfish that surfaced were the focus of netting efforts. Fish were identified, weighed and measured, and placed on ice, transported to the laboratory, and frozen for further processing.

Stomach Content Analysis

The true stomach (from the esophagus to the anterior portion of the intestine) of each sunfish was removed and its contents were processed. Prey items were viewed through a dissecting microscope (from 0.80x to 4.00x) and identified to the lowest practical taxonomic level using Merrit and Cummins (1996), Pennak (1989), and Thorp and Covich (2001). The contents grouped by taxon were considered as a single prey type, and distributed as a 1-mm-thick layer in a gridded (1x1 mm) Petri dish and the number of 1-mm thick grid squares that were covered by a prey type was recorded.

Absolute and Proportional Volume

Absolute volume of each prey type within each stomach was quantified by calculation. The number of grid squares was converted to volume (ml) by calculating the mean number of squares covered by 1-ml of water spread to 1-mm thickness across the grid, based on five replicates (Coefficient of Variation = 10%). The absolute volume was calculated using the following equation

$$V_{ij} = (X_i)\ 0.0183$$

where V_i is absolute volume of prey item i in fish j , X_i is the number of squares covered by prey item i , and 0.0183 is the calculated mean volume of a 1-mm thick square.

Proportional volume is an index that identifies the proportion a single prey type contributes to the stomach content (Hyslop 1980). Proportional volume was calculated using the following equation:

$$PV_j = (V_{ij}/V_j)$$

where PV is proportional volume of each prey item i in fish j , V_{ij} is the absolute volume of prey item i in fish j , and V_j is the total volume of all prey items in fish j .

Frequency of Occurrence

Frequency of occurrence for each prey type was based on its presence or absence in stomachs of each sunfish species in each sample. Values range from 0 to 1, with values closest to 0 indicating that a prey type is most rare and values closest to 1 indicating it is most common. 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 sunfish species, J_i is number of fish containing prey item, *i* , and P is the number of fish stomachs that contained food. Frequency occurrence is an index that represents how common a prey item is in the diet of each sunfish species in a sample, and describes the uniformity with which groups of fish include prey items in their diet, but does not quantify their importance.

Prey-Specific Abundance

Prey-specific abundance is a graphical technique that relates prey abundance to its frequency of occurrence. It is a modification by Amundsen et al. (1996) of the model of Costello (1990) (Figure 2). A combination of two diet measures can explain three concepts related to predation: feeding strategy, relative importance of each prey type, and diet variability (Figure 3). Prey-specific abundance was calculated using the following equation:

$$P_i = (\sum S_i/\sum S_{ti})\ 100,$$

where P equals prey-specific abundance (volume), *i* is prey type, S is the mean abundance (volume) of the prey type across sampled stomachs, and *ti* equals the total abundance (volume) of a prey type across all predators that contain the prey type.

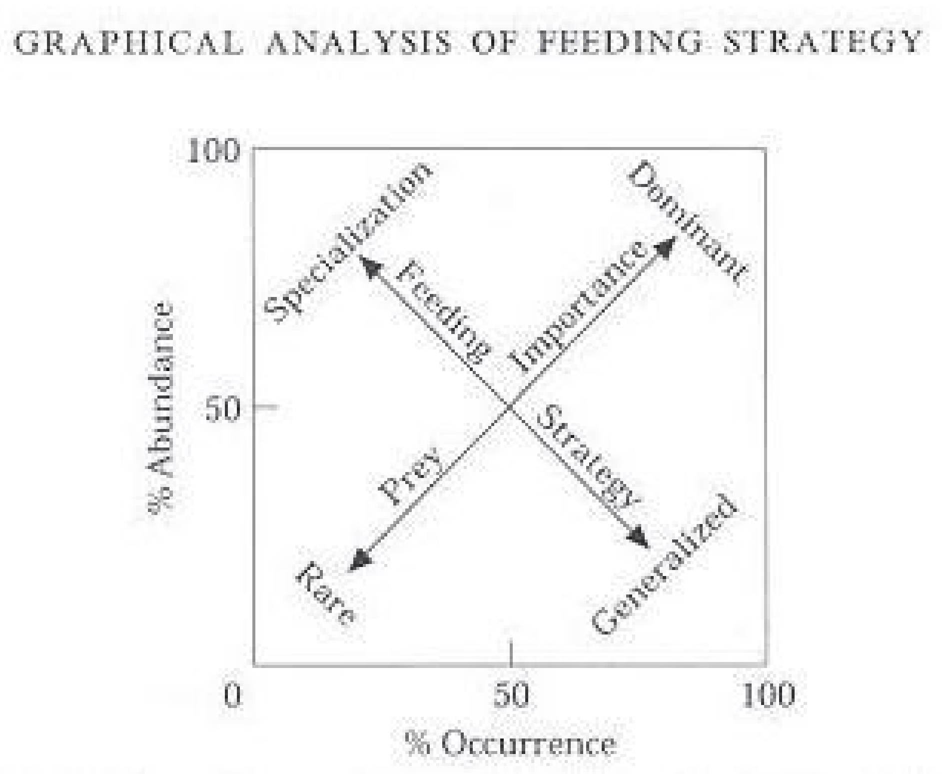


Figure 2. The explanatory diagram from the Costello (1990) method.

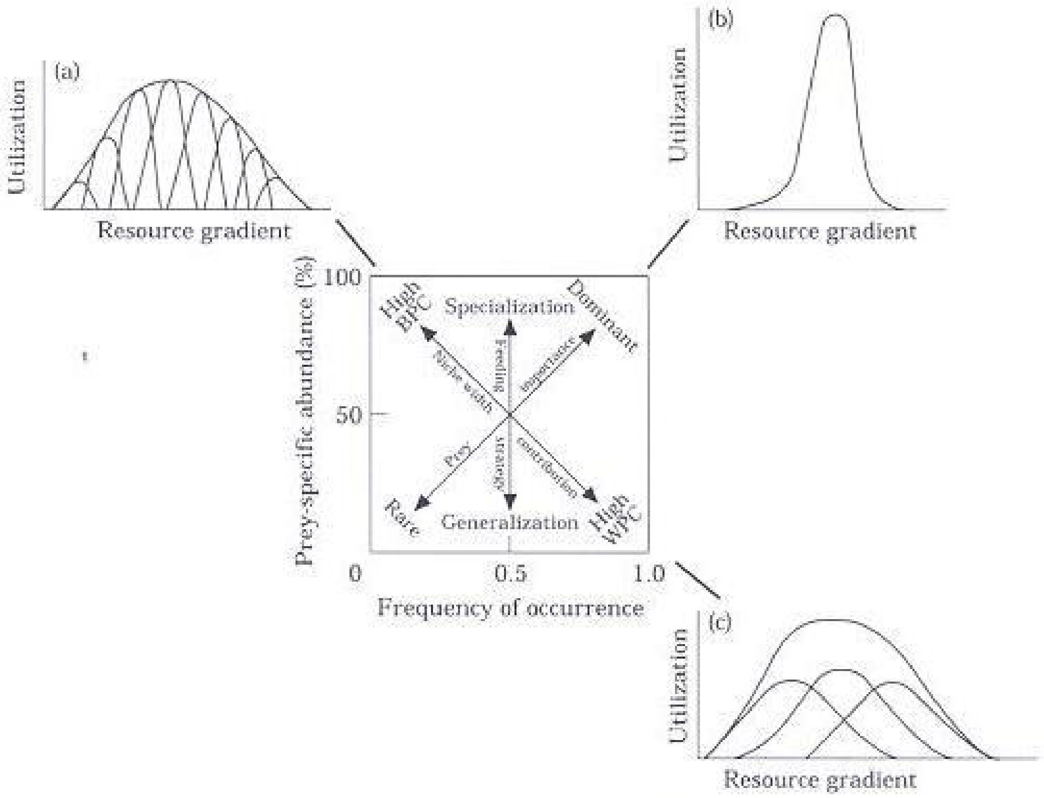


Figure 3. Explanatory diagram for interpretation of feeding strategy, niche width contribution and prey importance based on prey-specific abundance for a group of fish. Niche utilization curves show (a) high between-phenotype component to niche width, (b) narrow niche width and (c) high within-phenotype component.

Diet Breadth

Diet breadth indicates trophic niche space, and was calculated using Levins (1968) Index:

$$B_j = (1)/(\sum P^2_{ij})$$

where B_j is Levin's index for consumer species j , p_{ij} is the volumetric fraction of prey item i in the total diet of consumer species j. Diet breadth was standardize in order to make comparisons on a scale of 0 to 1 based on Hurlbert (1978) by using the following equation:

$$B_{Aj} = (B_j - 1) / (n - 1)$$

where B_{Aj} is Levin's standardized niche breadth for consumer species j, B_j is as defined above, and n is the total number of resource states (prey types). Values of B_{Aj} range from 0 to 1, indicating minimum or maximum niche breadth, respectively.

Diet Overlap

Similarity of sunfish diets between species (and within species between time periods) was calculated as Pianka's (1973) index of niche overlap using the following equation:

$$O_{jk} = (\sum^{n} p_{ij} \cdot p_{ik}) / (\sqrt{\sum p^{2}_{ij} \sum p^{2}_{ik}})$$

where O_{jk} is Pianka's measure of niche overlap between species j and species k, p_{ij} is the proportion of resource i across the total resources (volume) used by species j, p_{ik} is the proportion of resource i across the total resources used by species k, and n is the total number of resource states (prey types). Values of O_{jk} equal to 0 represent no overlap and values equal to 1 represent complete overlap. The values are symmetrical when comparing two species (i. e., overlap of species A onto species B is identical to overlap of species B onto species A).

Multivariate Analysis

Multivariate analysis of stomach contents was performed using the Canonical Community Ordination software (CANOCO, ter Braak and Smilauer 2002). I ran a canonical correspondence analysis (CCA) to correlate variation in data for community diet composition as the dependent variables that could be explained by variation in data for independent variables (ter Braak 1986). Dependent variables were mean proportions of each prey type in stomachs of each combination of sunfish species and collection period at each station. Independent variables were categorical variables (e.g., Bluegill-Pre, Bluegill-Post) The algorithm was a reciprocal weighted average using Chi Square distance (ter Braak 1986) to calculate optimal distributions for dependent variables that maximized the variation among all samples and was constrained to be linearly correlated with the independent variables (i.e., canonical axes were orthogonal gradients calculated as linear combinations of all independent variables),

Sample period was strongly intercorrelated (variance inflation factor score > 10) with percent vegetation coverage and grass carp stocking in initial models. Therefore, the latter two independent variables were treated as post-hoc, supplemental variables, so as to evaluate their relationships to the variation in diet composition, yet not inflate significance of F-tests for the final canonical model. Significance tests were based on Monte Carlo randomizations and a repeated measures design (i.e., randomizations were carried out within, but not across stations). Thus, supplemental variables were not part of the final canonical model. Instead, their correlations with the resulting ordination scores for the dependent variables on the canonical axes were calculated. The two supplemental variables were category of grass carp stocking (Pre-GCarp, and Post-GCarp), and the continuous variable percent vegetation (% Vegetation was converted to a proportion and arcsine-transformed). All relationships among dependent, independent and supplemental independent variables were visualized as a bi-plot for common trends.

6. RESULTS

The number of fish stomachs included in the analyses depended on number of sunfish collected across stations and sampling periods. Stations with large numbers of fish were sub-sampled (Bowen 1996), and a minimum of ten fish were selected from each length group for each species, at each station, and each sample period. Length groups were formed so that equal proportions across the three sunfish species and the minimum of ten fish per length group were maintained. A total of 372 sunfishes were analyzed in the pre-grass carp sample (total length): 203 bluegill (37-213mm), 90 longear sunfish (48-150mm), and 79 redear sunfish (70-208mm). A total of 117 sunfishes were analyzed in the post-grass carp sample: 43 bluegill (51-205mm), 40 longear sunfish (40-163mm), and 34 redear sunfish (110-222mm). There were 3 fish (89, 103, 112 mm) that had an empty stomach in the pre-grass carp sample and 3 fish (80, 170, 204 mm) that had an empty stomach in the post-grass carp sample. A total of 22 prey taxa were identified across all stomachs. Unidentifiable and digested material was included in the absolute and percent volume calculations, but prey-specific indices for these categories were not calculated. Table 1 shows the depths and percent surface vegetation coverage for each site.

Table 1. Total percent surface vegetation coverage for all sites for pre- and post-grass carp samples. Average depths are shown and were the same from pre- to post- samples because water levels did not change.

Station	Depth (ft)	Total % Surface Vegetation Coverage (Pre)	Total % Surface Vegetation Coverage (Post)
1A	5	95	5
5819	4	94	5
3A	5	82	5
2A	8	80	15
9609	3.5	65	0
6218	6.7	55	0
1224	8	40	0
1827	5	30	0
731	6	10	0
4312	6.5	6	0
1733	4	5	0
2105	6	5	0
1310	6	3	0

Multivariate Analysis

Species identity, pre- and post-grass carp time period, and percentage surface vegetation at sample sites together explained 15.5%, and variation among sites contributed an additional 34% of the total variation in diet composition in fish stomachs (Table 2). Monte Carlo Randomization Tests confirmed significance for the first axis (eigenvalue = 0.118, F-ratio = 5.660, P-value = .0020) and all canonical axes (eigenvalue =0.233, F-ratio = 2.601, P-value = 0.0020). The first axis (horizontal) explained 13% of the total variation and the second axis (vertical) explained an additional 6% of the residual variation remaining after covariation due to sites was removed. The third axis explained 4% of the total variation and the fourth axis explained an additional 2%.

Therefore, the biplot of only the first two axes (19%) representing diet composition among the sunfish species is presented (Figure 4). Centroids (centers of multivariate distribution) for explanatory variables are plotted for combinations of sunfish species and sampling time (e.g., BluegillPre, RedearPost).

The closer proximity of a centroid (for both dependent and independent variables) to an axis indicates its higher correlation with the axis and centroids for independent variables that are plotted farther from the intersection of the axes, contribute most strongly to the gradient along the axis. Bluegill diets in the pre-carp samples were associated with amphipods and trichopterans (lower left quadrant of Figure 4). Bluegill diets in the post-carp samples (upper left quadrant of Figure 4) were associated with vascular vegetation (stems, leaves). Longear sunfish diets in the pre- and post-grass carp samples (lower right quadrant of Figure 4) were similarly associated with nematodes, chironomid pupae (ChironP), chironimid larvae (ChironL), and trichopterans. Redear sunfish diets in the pre-grass carp samples (lower left quadrant of Figure 4) were similarly associated with amphipods and trichopterans, as were bluegill diets in the pre-carp samples. However, redear sunfish diets in the post-carp samples were associated with hard-bodied prey items such as gastropods, and sphaerid clams (upper right quadrant of Figure 4). Seeds, dipterans, algae, and ostracods were all positively associated with increasing coverage of the water surface by vegetation (lower left quadrant of Figure 4).

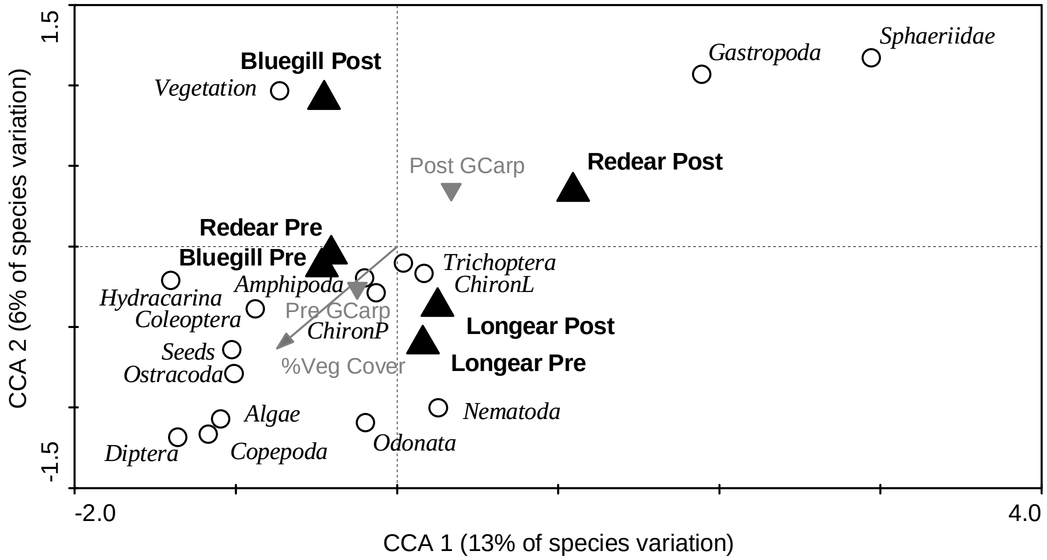


Figure 4. Joint plot showing the relationships on the first and second canonical axes for combinations of three sunfish species and pre-/post-grass carp introduction (i.e., Bluegill Post; filled up triangles). The centroids for prey items (open circles) are plotted according to their correlation with the canonical axes. Supplemental explanatory variables are plotted as centroids for sample periods pre- and post-introduction of grass carp (filled grey down triangles), and as a vector indicating the direction of increasing percentage of surface vegetation cover (grey arrow).

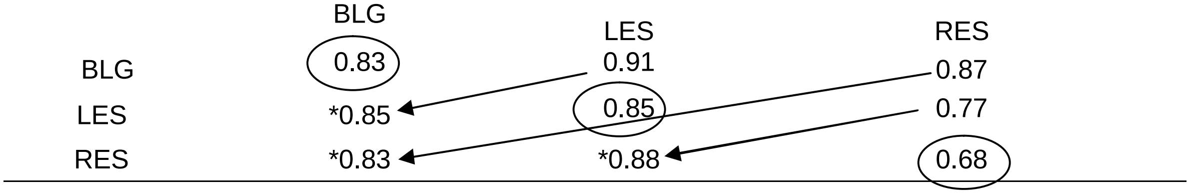
Table 2. Variance decomposition of variables used in the canonical correspondence analysis. Sites were used as blocks to prevent their variance from being factored into the total explained variation. Shared is the variation due to the overlap of all variables.

Variables	Unique Variation	Eigenvalue	% Variation	F-ratio	P-value
Total		1.409	100.00		
	Fish Species	0.094	6.67	2.639	0.002
	% Vegetation	0.056	3.97	3.158	0.008
	Pre-/Post- Carp	0.03	2.13	1.665	0.014
	Shared	0.039	2.77		
Total Explained		0.219	15.54	3.081	0.002
	Site (blocks)	0.478	33.90		

Diet Overlap and Breadth

All overlaps had high values (> 0.75) in pre- and post-grass carp samples (Table 3). Longear sunfish and redear sunfish were the only between species pair for which overlap was higher in the post-grass carp stocking period. Within-species diet overlaps between grass carp stocking periods were lowest for redear sunfish (0.68). Diet breadths of all sunfish species decreased from pre- to post-grass carp periods (Table 4). Redear sunfish had the greatest decrease (0.09) in diet breadth and longear sunfish had the smallest decrease (0.04). Average diet breadth of all species was higher during pre- (0.12) than post- (0.05) introduction of grass carp.

Table 3. Diet overlap values among sunfish species calculated using Pianka's (1973) index. Asterisks indicate comparisons between species in post-grass carp samples, and comparisons without asterisks are from pre-grass carp samples. Values for within species comparisons (circles) are between pre- and post-grass carp samples. Direction of arrows show values from pre- to post-grass carp samples for two species.



	BLG	LES	RES
BLG	0.83	0.91	0.87
LES	*0.85	0.85	0.77
RES	*0.83	*0.88	0.68

Table 4. Levin's (1968) diet breadths of bluegill, longear sunfish, and redear sunfish were pre- and post-introduction of grass carp. Values were standardized using Hurlbert (1978) method.

Sampling Period	LevBrthStnd BLG	LevBrthStnd LES	LevBrthStnd RES	Average
Pre	0.15	0.08	0.13	0.12
Post	0.07	0.04	0.04	0.05
Difference	0.09	0.04	0.08	0.07

Prey-Specific Abundance

The mean prey-specific abundance index was calculated across all stations for each combination of sunfish species and grass carp stocking period, and all sunfish showed a generalist feeding strategy (Figures 5, 6, and 7). Associations between diet composition, sunfish species, and sampling periods support the common trends identified in the canonical multivariate analysis. In bluegill diets, chironimid larvae and vegetation were both the most common and abundant prey types; shifts in frequency of occurrence from pre- to post-grass carp samples were related to decrease in ostracods, seeds, and trichopterans versus increase in chironomic pupae (Figure 5). Before the introduction of grass carp, longear sunfish displayed a generalist feeding strategy of chironimid pupae, ostracods, vegetation, and trichopterans, with a specialization on chironimid larvae. After the introduction of grass carp, the feeding strategy of longear sunfish (Figure 6) consited of a high specialization of chironimid larvae and a low occurrence of all previously common prey items. In pre-carp samples, redear sunfish (Figure 7) showed a generalization of multiple prey items (vegetaton, trichopterans, ostracods, chironimid pupae, and seeds) with a high specialization in chironimid larvae. In post-carp samples, there was a reduction in the occurrence of vegetation and ostracoda and an increase in chironimid pupae, sphaerids, and gastropods. Furthermore, chironimid larvae were more common and abundant as seen with all other sunfish species.

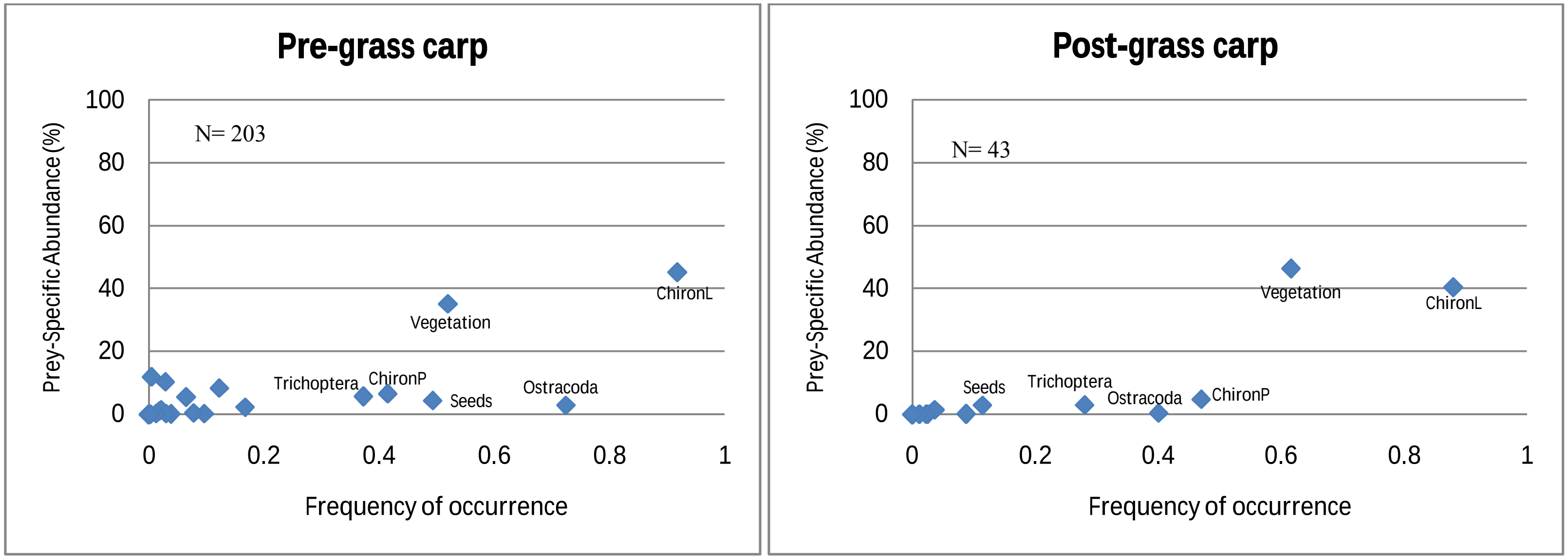


Figure 5. Plots of mean frequency of occurrence versus mean prey-specific abundance for each prey type identified in bluegill stomachs in pre- and post-grass carp samples. N = number of stomachs. The most common prey types are labeled for comparison. Both populations displayed a generalized feeding strategy (i.e., prey types primarily distributed across the bottom half of the plot).

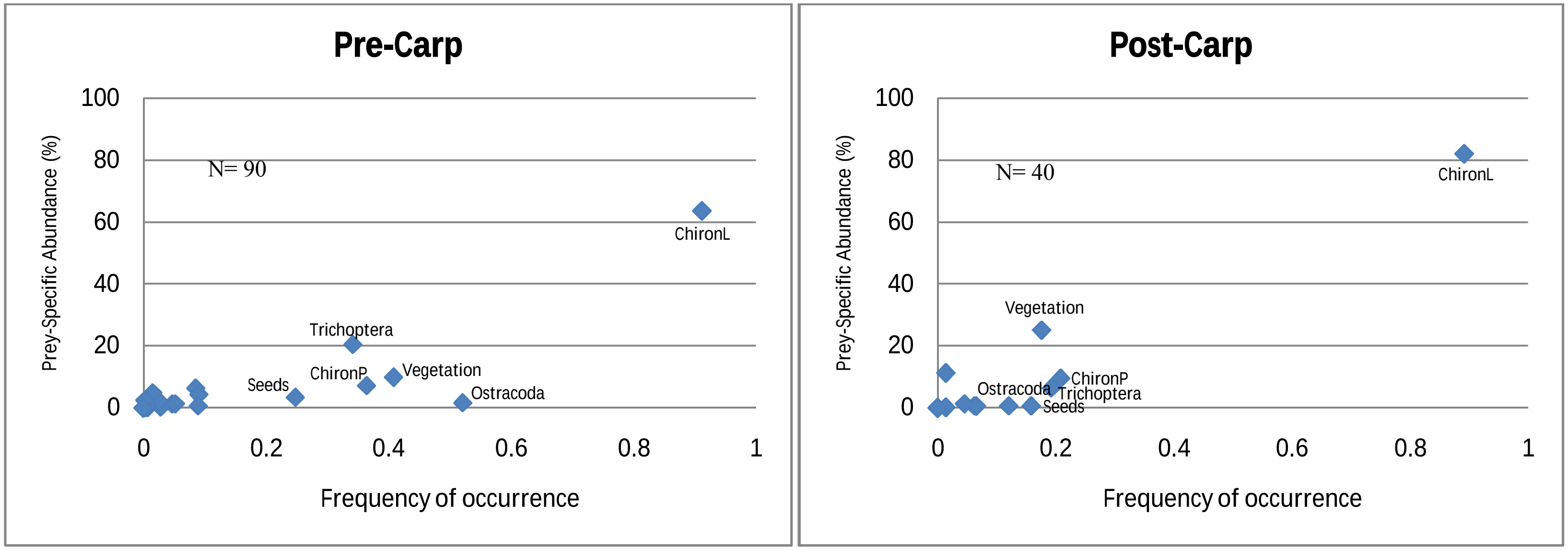


Figure 6. Plots of mean frequency of occurrence versus mean prey-specific abundance for each prey type identified in longear sunfish stomachs in pre- and post-grass carp samples. N = number of stomachs. The most common prey types are labeled for comparison. The pre-carp populations displayed a generalized feeding strategy (i.e., prey types primarily distributed across the bottom half of the plot). The post-carp population specialized in Chironimid larvae (upper right corner). All other prey items became less common and rare (lower left corner).

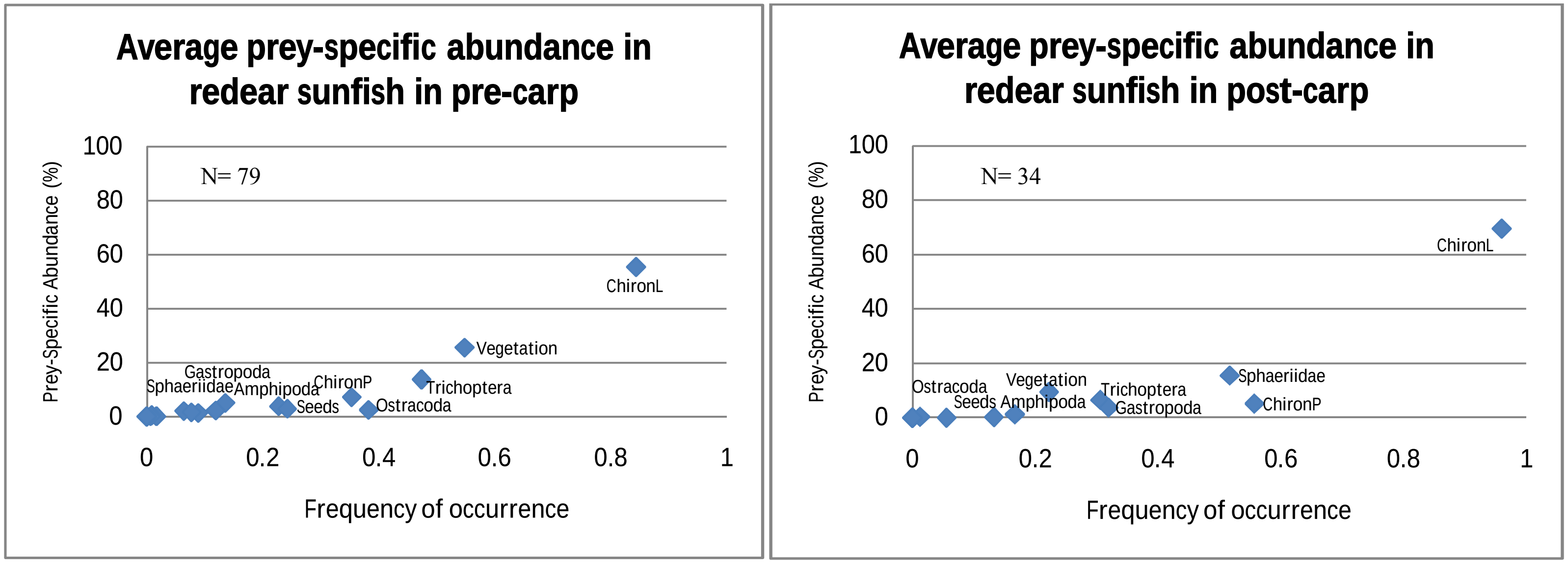


Figure 7. Plots of mean frequency of occurrence versus mean prey-specific abundance for each prey type identified in redear sunfish stomachs in pre- and post-grass carp samples. N = number of stomachs. Both population displayed a generalized feeding strategy (prey items associated in the lower half of the plot). Both population specialized in chironimid larvae (positioned in the upper right corner). Hard-bodied prey items (gastropoda, sphaeriidae) became more common and abundant in the post-carp population.

Total length of fish versus average total volume of stomach contents for each sunfish specie was plotted (Figures 8, 9, 10) to compare overall stomach fullness of similar size sunfish from both sampling periods. Bluegills (Figure 8) from pre-carp showed a higher slope (0.143) than bluegills in post-carp samples (0.116). Longear sunfish (Figure 9) had a higher slope in pre-carp samples (0.103) than in post-carp samples (0.057). Redear sunfish (Figure 10) in post-carp sample (0.066) had a slightly higher slope value than pre-carp (0.062).

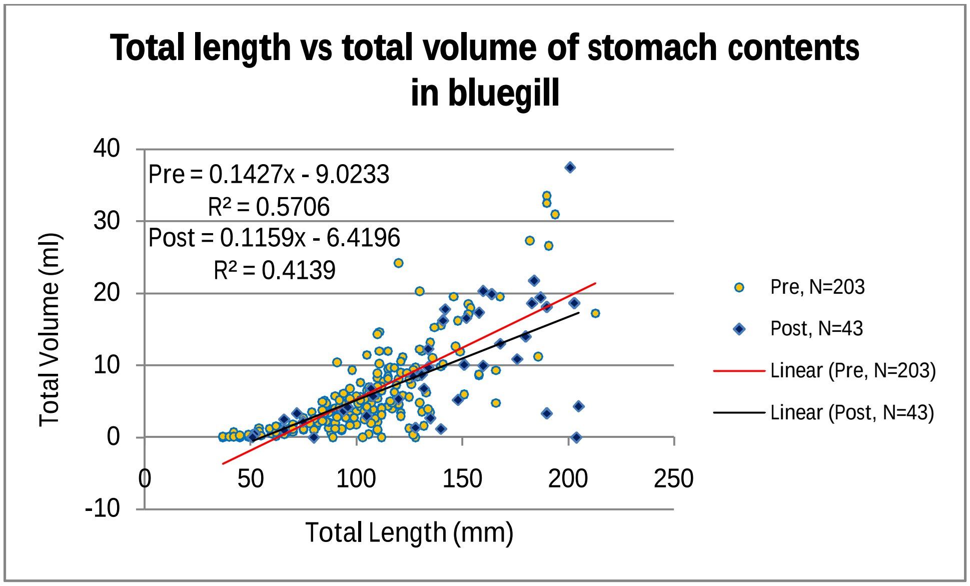


Figure 8. Total length versus total volume of stomach contents of bluegills pre- and post-carp introduction. The trendline for the post-carp population show a lower slope value (0.116) than the pre-carp population (0.143). Both R^2 values were moderate for pre- (.571) and post- (.414) populations.

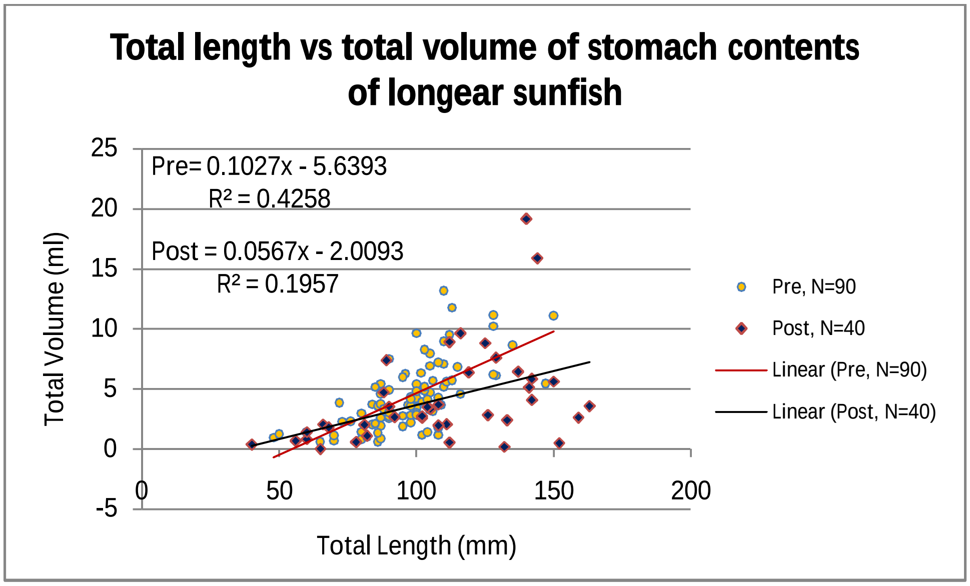


Figure 9. Total length versus total volume of stomach contents of longear sunfish pre- and post-carp introduction. Slope was greater for the pre-carp (0.103) population than the post- (0.057) carp population. R^2 was moderate for pre- (0.426) but low for post- (0.196) carp populations.

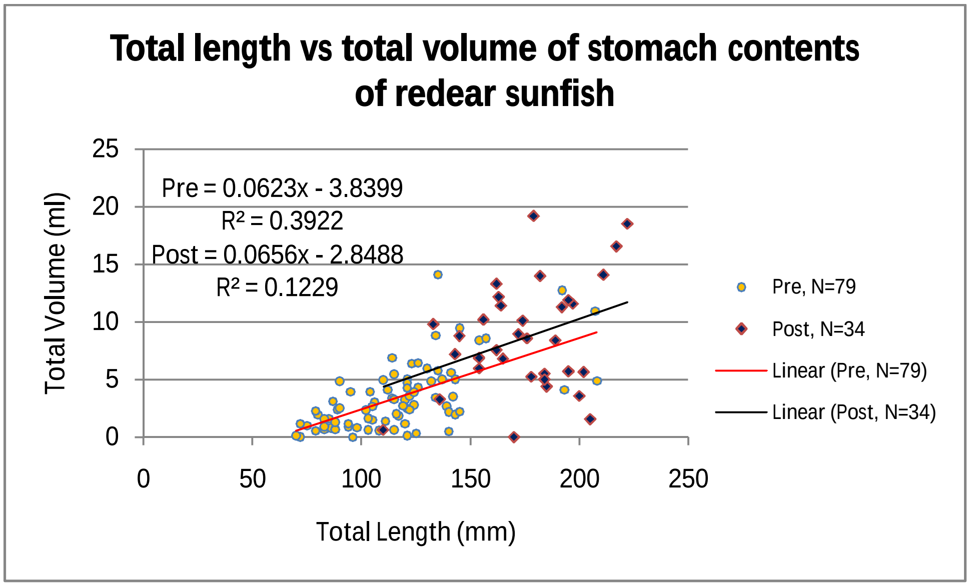


Figure 10. Total length versus total volume of stomach contents of redear sunfish pre- and post-carp introduction. Slope was similar for pre- (0.062) and post- (0.066) carp populations. R2 was moderate for pre- (0.392) and low for post- (0.123) carp populations.

7. DISCUSSION AND CONCLUSION

The results from this study gave many implications on how how vegetation removal can affect the feeding strategies and prey availability of sunfishes. The overlap in diet between different sunfish species was high in both sampling periods and decreased minimally across sampling periods despite high decreases in surface vegetation coverage. Some studies considered values greater than .75 to indicate high overlap (Matthews et al. 1982; Matthews and Hill 1980). Low overlap or a substanstial difference in resource use has been considered to be less than 0.40 (Ross 1986). Average diet breadth of all sunfishes were greater in pre- (0.12) than post- (0.05) carp samples. These numbers could imply a wider range of prey items available or consumed in higher proportions in the pre-carp samples rather than in post-carp samples. The prey-specific abundance indices displayed the overall generalized feeding strategies among all sunfishes. All sunfishes showed a high consumption of chironimid larvae pre- and post-carp samples, which shows their high importance in sunfish diets. Bluegills diet did not change much in their diet from pre- to post-grass carp introduction. Vascular vegetation slightly increased in abundance and occurrence from pre- to post- samples. Studies have shown vegetation to be a big component of bluegill’s diets (Forbs and Richardson 1920; Engel 1987; Seaburg and Moyle 1964; Keast 1985). However, one could question whether bluegills were purposely eating vegetation for nutritional content or if consumption was incidental when foraging within the vegetation for associated prey items. Longear sunfish showed a higher specialization on chironimid larvae from pre- to post-carp samples in the pre-specific abundance indices. This feeding strategy was further supported by the ordination diagram (Figure 4) by showing a higher association between ChironL and Longear Post than with Longear Pre. Longear sunfish from pre- and post- samples had a high overlap value (0.85) and the smallest change in diet breadth (0.04) of all species. Overall, longear sunfish diets and feeding strategy did not change much. A few studies have shown longear sunfish to be minimally affected by the removal of vegetation (Laughlin and Werner 1980; Layzer and Clady 1991). The multivariate analysis showed different associations between prey items and both populations of redear sunfish. RedearPre were associated with amphipods and trichopterans while RedearPost were highly associated with hard-bodied prey items such as gastropods and sphaerids. The prey-specific abundance indices also confirmed this relationship with the increase of occurrence and abundance of gastropods and sphaerids along with the reduction of other prey items such as vegetation, trichopterans, and ostracods. Diet overlap within pre- and post-sample redear sunfish (0.68) were the lowest of all overlap indices. Overall, redear sunfish consumed different proportions of similar prey items in their diets across sampling periods. The disappearance of vegetation could have exposed more benthic prey items to redear sunfish that are known to forage efficiently in benthic habitats. Other studies explain how vegetation complexity can reduce the foraging efficiency of sunfish (Crowder and Cooper 1982; Mittlebach 1984). Many studies have also shown how redear sunfish are more molluscivorous than other sunfishes and specialize in feeding on hard bodied prey items like gastropods and sphaeriidae (Huckins 1997, Lauder 1983, Mittlebach 1984, Wainwright and Lauder 1992).

The overall populations of sunfish captured during sampling declined from pre- (608) to post- (117) carp samples. Other studies experienced similar declines in sunfish due to the introduction of grass carp for hydrilla control (Forester and Lawrence 1978; Klussmann et al. 1988; Bettoli et al. 1993). This could be due to the decrease in the amount of vegetation and the increase accessibility of forage for predatory fishes. Studies have shown that macrophytes can provide fish and invertebrates with food and shelter (Werner et al. 1983; Orth and van Montfrans 1984). The decline in sample size could also be due to the relocation of sunfish populations to other suitable and beneficial habitat due to the reduction in vegetation cover and prey availability. These factors could also lead to an increase in competition due to limiting resources.

There were a few things that could have led to more accurate results and assumptions. There was a high variation among sites (33.9%) as shown in Table 2. Other variables could have been included in the analysis to account for the variation. Macroinvertebrate samples within the vegetation could have allowed us to compare prey availability with the prey items consumed. Multiple samples per year could have given more accurate conclusions about feeding strategies and prey preferences if the question of how seasonality could have affected feeding behavior. A control site could have allow us to make comparisons across sampling periods in terms of vegetation structure, macroinvertebrate abundance, and population sizes. Figures 8, 9, and 10 gave little insight to the availability of prey items in both populations based upon relative fullness of stomach of sunfishes of similar sizes in both sampling periods. My partner, Patrick Ireland, is studying the changes in length-frequency distribution of all sunfish, including largemouth bass (*Micropterus salmoides*), and will analyze the condition of all populations sampled. A comparative study with the results from his study and this study could give insight to other variables such as second level predator-prey interactions and the influence of habitat structure and prey populations on the feeding characteristics of cohabitating predators.

Stomach content analysis is important in fisheries management. Identification of food preferences can help fisheries managers determine the prey base for sport fishes, evaluate habitat improvement efforts, as well as determining the biological integrity of a water body (Rabeni 1996). This study can give insight to a lower level of predator-prey interactions and predator-predator interactions that are often overlooked in fisheries management plans (Noble 1986). Results showed the effects of introducing grass carp for vegetation control on the feeding associations and strategies of three cohabitating sunfish species. These findings may help fisheries biologists plan future management actions that influence assemblages of aquatic plants and macroinvertebrates, herbivorous fish (grass carp), invertivorous prey-fish (sunfishes), and piscivorous game fish (largemouth bass), to promote a healthy and balanced ecosystem for Lake Conroe stakeholders.

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