Connecting the Dots: A Food Web of the Lower Ogeechee River

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by

ALLISON LUTZ

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ABSTRACT

The Ogeechee is a fifth order river that originates in the Georgia Piedmont region and flows through the Coastal Plain region in the Southeastern portion of the state. The Ogeechee is one of the last unregulated rivers in Georgia; allowing for studies to occur under a natural flow regime. To my knowledge, studies that incorporate fish into ecological networks (e.g., food webs) are yet to be developed for the Ogeechee River, thus, one of the main objectives of this research was to address this knowledge gap. Five fish species were collected from June 2016 to October 2016 in order to construct a connectance food web in the Ogeechee to understand the role (i.e., trophic interactions) of major fish feeding guilds in relation to each other and to other consumer groups (i.e., macroinvertebrates) present in the river. In addition to the connectance food web, Redbreast Sunfish were collected seasonally from June 2016 to March 2017 to examine the potential for seasonal shifts in the diets of this popular sport fish. Diets of all fish were analyzed using gut content analysis and used to create a connectance food web using Cheddar, a package in RStudio. Diets were compared to composite taxa lists generated from an ongoing, two year study (2014-2016) of the Ogeechee River for four study species (Bannerfin Shiner, Redbreast, Snail Bullhead and Spotted Sucker) through diet overlap and selectivity analyses. Permutational Multivariate Analysis of Variance (PERMANOVA) and Non-metric Multidimensional Scaling (NMDS) techniques were used to compare diets across seasons for Redbreast, and across age classes for Redbreast and Snail Bullhead. Connectance of the food

web was found to be 0.285 and link density was 31.87, while the number of nodes present in the food web was 112. The Ogeechee River food web appears to be above average in terms of connectance and link density and further illustrates the dynamic nature of coastal plain, blackwater river systems. Analysis of Redbreast data shows that stomach content composition differs significantly by season when prey items were grouped by habit or order. These findings suggest that Redbreast Sunfish utilize what is available during the different seasons, thus exhibiting an opportunistic feeding strategy. This study is one of the first to construct a food web including multiple fish feeding guilds in a coastal plain, blackwater river. With these data, it is hoped that some of the knowledge gaps in food web studies in coastal plain rivers will be filled and that the information generated will facilitate future studies of trophic interactions of major consumer groups in river systems of the region.

INDEX WORDS: Food webs, Ogeechee River, Redbreast Sunfish, Macroinvertebrates, Gut content analysis

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CHAPTER 1

INTRODUCTION

The Ogeechee River is a fifth order, blackwater river that originates in the Georgia Piedmont region and flows through the Coastal Plain. This river experiences a seasonal flood pulse that inundates the adjacent flood plain of this river in the winter/spring and recedes to base flow conditions in the summer/autumn. This occurs due to evapotranspiration rates that increase during the warmer months, discharge and water levels both lower until temperatures fall during the winter months. This river is also unimpounded so natural flow still occurs here making this a good system to study blackwater coastal plain river dynamics and to do this I used fish. Fishes can alter ecosystem processes, such as the production of biomass and the cycling of nutrients, through their feeding habits (Holmlund and Hammer 1999; Gido et al. 2010). For example, grazing by herbivorous fishes can directly affect the relative amount of fine benthic organic matter (FBOM) and sediment through feeding (Power 1983) and thus, indirectly influence macroinvertebrate abundances. Grazers can also alter periphyton communities via top-down pressure and by selectively feeding on specific producer taxa. Fishes that feed on algae will have an impact on the algal community structure because of feeding pressure (Power 1983, Power and Matthews 1983, Power et al. 1988). Fishes also consume plankton and can alter their abundance and distribution (Brooks and Dodson 1965) which can cause indirect effects on algae since many plankton feed on algae. The impact on primary producer communities by fishes can greatly exceed that of macroinvertebrate grazers because herbivorous fishes are often much larger and require more energy. Additionally, fishes that are sediment ingestors (e.g., benthivores) can alter sediment accrual, nutrient cycling, and ecosystem metabolism in river systems through the consumption and disturbance of sediment (Flecker 1996; Taylor et al. 2006; McIntyre et al.

2007). For example, detritivorous fishes will consume the food source of invertebrate shredders and thus impact collector-gatherer invertebrates that feed on the by-product (fine particulate organic matter or FPOM) of the shredders' feeding mode.

Predation by fishes can also control prey populations in a top-down sense, and in extreme cases, can result in effects down to primary producers (Brönmark and Weisner 1992, Martin et al. 1992, Power 1992, Jones and Sayer 2003, Baxter et al. 2004) which makes the study of fish diets and food webs important for understanding community structure and energy flow. Fishes can also impact these systems from the bottom-up by becoming resources themselves or adding nutrients through excretion (Winemiller and Jepsen 2004). For example, in the Ogeechee, invertivorous fishes, such as Spotted Sucker or Redbreast Sunfish, could become nutrition for larger predatory fishes, and thus their density as prey can directly influence predator density. In addition to impacting predators, invertivorous fishes can also influence prey availability, resulting in shifts in the abundance, distribution, and biodiversity of benthic macroinvertebrates in rivers (Gido et al. 2010). Habitat overlap can also occur between invertivorous fishes and macroinvertebrates; as both groups use snags for habitat (Benke et al. 1985), which could cause invertebrate prey to hide in the presence of fish predators, limiting prey feeding to nighttime only (Cowan and Peckarsky 1994, McIntosh and Peckarsky 1996). This limited activity and refuge use by macroinvertebrate prey can cause lower food acquisition for the fish and thus less growth and smaller body sizes.

Fishes also experience ontogenetic shifts as they age, so a prevalence of smaller fishes can have completely different impacts on macroinvertebrates than larger fishes. Examining the interactions between fish and macroinvertebrates through gut content analysis in blackwater rivers would allow for a better understanding of energy flow between mid- (macroinvertebrates)

to top-level (fishes) consumers in these rivers. However, the fish community effects on macroinvertebrates can be variable and difficult to predict (Gido et al. 2010; Vanni 2010). Research suggests that adult fishes feed to maximize energy intake while larval fishes feed when a prey item is encountered (Griffiths 1975).

In this study, I assessed the diets of five fishes commonly found in the Ogeechee River and used these data to determine if the fishes are targeting (i.e., specializing on) specific prey items or if they exhibit an opportunistic (i.e., generalist) feeding behavior in this river. The species targeted for this study represent multiple feeding habits including a generalist carnivore, an invertivore that consumes larger invertebrates (e.g., crayfish), an omnivore, a bottom feeder, and a cyprinid invertivore. In doing so, I also examined the potential for diet overlap between the five species studied. Bowfin (*Amia calva*) are generalist carnivores and are believed to have little selectivity in their diets (Scarnecchia 1992; Boschung and Mayden 2004). Redbreast Sunfish (*Lepomis auritus*) feed mainly on invertebrates that originate on snag habitat, but will also consume crayfish and other fishes occasionally (Cooner 1981; Cooner and Bayne 1982; Boschung and Mayden 2004). Snail Bullhead (*Ameiurus brunneus*) are considered omnivorous. Although little is known about the feeding habits of *A. brunneus*, it is assumed that these fish feed in a similar manner as other bullheads which typically consume filamentous algae, larval caddisflies, snails, and small fish (Boschung and Mayden 2004). Additionally, Snail Bullhead were selected because of the paucity of recent information on diet habits (Jordan and Brayton 1878; McLane 1955), and this study will contribute new information about their diets and feeding behavior. Spotted Suckers (*Minytrema melanops*) are bottom feeders that target the invertebrates living in the shifting sand bottom in blackwater rivers. The main constituents of its diet are aquatic worms and midge larvae (White and Haag 1977). Lastly, Bannerfin Shiner

(*Cyprinella leedsi*) is a small invertivore, and it is known to eat bivalves, aquatic insects, and microcrustaceans (Marcy et al. 2005). Similar sizes of fish within each species (fishes that are older than age 0) were targeted to reduce diet variability due to body size and ontogenetic shifts in feeding behavior.

Food preference or availability likely determines the diets of the fishes sampled in this study. However, I predicted that availability will play a larger role in determining diet due to the unaltered flow and changes in water levels of the Ogeechee year round. Redbreast were sampled seasonally due to their relatively high abundance throughout the year in the Ogeechee and to determine if there are temporal shifts in their diets that can be attributed to preferential versus opportunistic feeding behavior. I also predicted that preference will play a more prominent role in larger species (e.g., Bowfin) and when prey is abundant. Thus, I anticipated that Bowfin and Snail Bullhead would mainly feed selectively and that Redbreast, Spotted Sucker and Bannerfin Shiner would mainly feed opportunistically based on what prey items are available. Spotted Suckers are bottom feeders that may not encounter as much prey as fishes that utilize snags for habitat and feeding. The shifting sand bottom of this river does not support as much invertebrate biomass compared to snags (woody debris), which can support up to 60% of total macroinvertebrate biomass at a given reach (Benke et al. 1985). This could cause them to feed whenever they find prey (i.e., feed on what is available). Fish of the genus *Cyprinella* have been previously assumed to be an opportunistic sight feeder (Boschung and Mayden 2004) and I predicted that they would follow this prior assumption. Furthermore, I hypothesized that if prey items found in Redbreast Sunfish stomachs do not differ by season then food preference is of the primary determinant of their diets. However, if fish diets differed seasonally then food availability would be indicated as the primary determining factor of diet composition. I also

hypothesized that if the frequency of prey items found in fish stomachs differ from the percent community composition of macroinvertebrates (i.e., prey) available at the sites, then preference is a driving force for the fishes in this study. If differences are present, they could suggest that these fish maximize nutrition and minimize energy expenditure to obtain prey, similar to the predictions of optimal foraging theory (McArthur and Pianka 1966; Schoener 1971).

With the diet data of these five species from different feeding guilds, a collective picture of their impact is best examined by constructing a food web. Food web studies illustrate consumer interactions, pathways of energy flow, and trophic cascades in ecosystems (Pimm et al. 1991). Consumer interactions are useful for understanding energetic pathways in ecosystems and can be determined by examining feeding relationships via gut contents, isotopic analyses or fatty acid profiling of multiple trophic levels or positions. Energy flow can also be determined by developing production models that take into account the assimilation of food items (e.g., prey) to body tissue and production of biomass (i.e., growth) by the consumers in a system. Food web studies illustrating energy flow in blackwater rivers have been conducted using macroinvertebrates (Benke et al. 2001, Benke and Wallace 2015) which are relatively easier to track as individual cohorts compared to fish. Compared to other aquatic systems, food web and energy flow studies in large floodplain river ecosystems like the Ogeechee are limited (Johnson et al. 1995). Also, food web studies of fish in blackwater rivers of the southeast US are generally lacking.

The fishes examined in this study represent five distinct feeding guilds and will allow me to determine predator-prey interactions across multiple feeding levels using gut content analyses. Although gut content analyses only provide a snapshot of what a fish has eaten on a particular day, these will show rare items and specific taxa that are consumed (Vinson and Budy 2011;

Belicka et al. 2012). Because of this, gut content analysis can provide a more accurate picture of the interactions between consumers and their resource base (e.g., predator-prey interactions), which is useful to connectance food web construction. Connectance food webs are simple food webs that have links between predator and prey, unlike quantitative food webs that take into account the relative importance of prey items. These food webs are commonly used to assess connectance, measured by dividing the number of links over the total number of possible links, a measure of ecosystem complexity. In doing this, my goal was to test for differences in connectance values based on individual taxa and trophic species present in order to examine how changing what represents the node affects overall connectance and link density. I also set out to compare the constructed food web to similar webs developed from previous studies. To do this I assembled two food webs using either taxonomic groups (genera or species) or trophic species (e.g., predator, omnivore, etc.) and compared them to other food webs from the literature.

To test for preference versus availability for the four fishes collected during non-flood pulse, calculations were performed to turn invertebrates consumed into frequencies to compare to a composite taxa list of macroinvertebrates available at the study site. To test the redbreast diet hypotheses, I looked at use versus availability using the temporal data, and I used literature and existing datasets from ongoing work in the Ogeechee River to determine availability of macroinvertebrates. To my knowledge, no study has been conducted on a large (>100 km) stretch of a coastal blackwater river that includes both fish and macroinvertebrates in the construction of a food web. Therefore, this study is the first to assemble a basic food web linking top-level consumers (e.g., fish) to mid-level consumers (e.g., macroinvertebrates) and basal resources for a blackwater river in the southeastern U.S. An overarching goal was to create a

baseline data set utilizing fish diets in the Ogeechee River that will serve as a foundation for future studies of energy flow and food webs in coastal, blackwater river systems.

CHAPTER 2

MATERIALS AND METHODS

Study Sites

I sampled six sites along a longitudinal stretch of the Lower Ogeechee River to examine the diets of five fish taxa and develop a connectance food web for the major fish guilds in the river. The sites sampled represent a change in drainage area (from upstream-most to downstream-most site): Highway 88 (88 crossing) boat launch, Highway 78 (near Wadley) boat launch, Rocky Ford boat launch, Highway 24 (near Oliver) boat launch, Highway 119 (Steel Bridge Landing near Guyton) and the Morgan's Bridge boat launch (near Ellabell) (Figure 1). These sites are also part of an ongoing, collaborative study in the Lower Ogeechee River. Furthermore, US Geological Survey (USGS) gauging stations are available at or near each site which allowed for complementary, long-term information regarding conditions (e.g., river stage, discharge rates) at times of sampling. Each site was primarily sampled during non-flood pulse months (June-October) of 2016 for the multi-taxa food web component of the study and seasonally (summer, autumn, winter, spring) for a single-taxon (i.e., Redbreast), temporal component of the study. These six sites are along an approximately 200 kilometer stretch in the Lower Ogeechee River. Land use changes minimally along this stretch with the majority of land (69%) being forest and having forestry related activities on the land (GA DNR EPD 2001).

Physiochemical Parameters

Water chemistry parameters (temperature, pH, % oxygen saturation, dissolved oxygen, conductivity, and specific conductance) were measured at each site using a YSI Professional Plus Multi-Parameter Water Quality probe (Xylem Inc., Yellow Spring Instruments, OH) at the start of each sampling event (Tables 1 and 2). Three water quality measurements were taken within the

500-meter sampling segment. Discharge and drainage area data were obtained from nearby USGS staff gauges (Table 1). These data were mainly used to justify grouping diet data from different sites on different dates based on similar water conditions. Data were also used to determine if water chemistry or discharge parameters play a role in diet across the seasons in Redbreast Sunfish.

Macroinvertebrate taxa lists

Macroinvertebrates have been collected from the same six sites during quarterly sampling dates in December, March, June and September since 2014 following standard operating procedures (SOPs) for wadeable streams (GA DNR 2007). Once collected, these are identified to the lowest taxonomic unit possible (typically genus for insect groups and order for non-insects) using taxonomic keys by Merritt et al. (2008), US EPA (1975), and Dillon et al. (2013). Composite taxa lists were assembled and macroinvertebrates from the same seasons (from the previous year) as the fish were used in determining if there is evidence of selective (maximizing energy) versus opportunistic (generalist) feeding based on the frequency of taxa present at the site. Relative abundance and frequencies of occurrence for each taxon in the composite taxa lists and in fish stomach contents were compared to assess for evidence of potential prey electivity (i.e., preference) and diet overlap between species (see *Data and Statistical Analyses*). Taxa lists and prey item lists were compiled by order/superorder level or by prey habit. Prey habit describes how a macroinvertebrate taxon behaves in its environment. For example, burrowers ‘dig’ into substrates; clingers ‘hang on’ to substrates, etc. Habit was determined from the GA Environmental Protection Division composite taxa list (GA EPD 2012); which is a modified, region-specific version of the lists developed by Barbour et al. (1999).

Fish Sampling

Fish sampling was conducted under IACUC I16013 and adapted from the standard methods for sampling warm water fish in wadeable and non-wadeable streams outlined by EPA Field Operations Manuals and the Georgia Department of National Resources (GA DNR) SOPs (US EPA 2013a, 2013b; GA DNR 2005). Five 100 meter segments were sampled for approximately eleven minutes on one side of the river bank. Right or left bank was chosen randomly for the first segment then alternated for the following four segments. Fish were then processed after the completion of sampling a segment. All segments were at least 100 meters above the bridge or landing (i.e., boat ramp) present at each site. The voltage to be used was determined from water quality measures (e.g., conductivity) taken before the first segment was sampled. Fish were sampled in June, September and October (one site sampled later due to water levels being too low in September) of 2016 or quarterly (redbreast only; summer (June), autumn (September), winter (December), spring (March) in 2016-2017) using pulsed DC boat or backpack electrofishing techniques targeting taxa in specific feeding guilds (Gerking 1994; Goldstein and Simon 1999). During the summer, at Rocky Ford, the water level was too low to allow for boat access, thus a backpack electrofisher was used to sample this site. In addition, the 88 Crossing site was not sampled during fall due to low water levels that prevented boat access. However, this site was not sampled with a backpack electrofisher because it is too deep for wading. The species targeted in sampling events were a general carnivore, Bowfin (*Amia calva*), an omnivore Snail Bullhead (*Ameiurus brunneus*), a bottom feeder Spotted Sucker (*Minytrema melanops*), an invertivore Redbreast Sunfish (*Lepomis auritus*), and minnow invertivore Bannerfin Shiner (*Cyprinella leedsi*). All fish captured were identified to species, measured and weighed in the field. Electrofishing techniques have the potential to bias stomach contents results due to targeting larger bodied individuals as well as the potential for fishes shocked to regurgitate some of their food

(Zale et al. 2012). Large, piscivorous fishes tend to have higher regurgitation rates than other fishes (Bowen 1996; Sutton et al. 2004). Regurgitation rates have the potential to be higher in summer as well (Treasurer 1988; Sutton et al. 2004).

Sample Sizes and Fish Diet Analyses

An initial target of 10 individuals of each target species was aimed for collection at each site (n = 60 per site, n=300 total for all sites). However, due to size/age range limitations, a smaller sample size was achieved for most of the species targeted. All species fell short, with Bowfin (n=36), Snail Bullhead (n=40), Spotted Sucker (n=38), Bannerfin Shiner (n=50) and Redbreast Sunfish (with the exception of summer sampling), n_{summer}=60, n_{autumn}=47, n_{winter}=34, and n_{spring}=49 respectively. The initial sample size for the Redbreast seasonal analysis was determined using a power analysis with an estimated medium effect size value (0.5) taken from Cohen (1988). The power for a sample size of 60 for each group was 91.2 percent. The reason this was higher than 80 percent was to account for empty stomachs and/or being unable to collect the full sample size. With my sample sizes, the power was calculated to be 81.1 percent, which is still within the 80 percent desired threshold (Cohen 1988).

Snail Bullhead, Bowfin and Spotted Sucker were kept on ice in the field and stored in a freezer upon return to the laboratory until further processing. Stomachs of all specimens collected were removed in the laboratory and preserved in 10% formalin. Stomachs from Spotted Suckers were removed according to Rybczynski et al. (2008) which is to the first 180º bend in the stomach due to the lack of a true stomach in catostomid fishes. Contents from Spotted Sucker stomachs were agitated to suspend prey items, then subsampled (1-10%, depending on amount of ethanol that was used to wash contents into a conical tube; larger fish required more ethanol) and counted in a Sedgewick-Rafter counting chamber similar to Hyslop (1980). For Bannerfin Shiner, fish were

placed directly into 10% formalin, after euthanasia with clove oil, for 24-48 hours and then transferred to 70% ethanol at the laboratory where stomachs were extracted to the first 180º bend due to a lack of a true stomach. Contents were then subsampled and counted in a Sedgewick-Rafter counting chamber (Hyslop 1980). Stomach contents of all fish were identified to the lowest practical taxonomic level and categorized as terrestrial or aquatic. Snail Bullhead were the only species to eat aquatic plants/algae and a plant category was used with only this fish.

No fishes of the age zero size class were collected, as the aim was to collect fish from the age 1-3 size classes to prevent large differences being observed due to ontogenetic feeding shifts. Fish size ranges from age 1-3 were estimated per Boschung and Mayden (2004). Analyses to examine for diet differences between age classes were performed for Snail Bullhead and Redbreast Sunfish. Snail Bullhead ages were estimated from a study on Flat Bullhead (a related species) by Olmstead and Cloutman (1979). Redbreast ages were estimated from Sammons and Maceina (2009). Size ranges for Snail Bullhead ages were: age 1 (97-152 mm), age 2 (153-191 mm), age 3 (192-225 mm), age 4 (226-255 mm), age 5 (256-270 mm), age 6 (271-286 mm) and age 7 (287 mm and above). Size ranges for Redbreast ages were: age 2 (90-120 mm), age 3 (121-190 mm) and age 4 (190 mm and above). In addition to fish sampling conducted in the summer, Redbreast Sunfish were also collected and their stomachs were removed in the field during quarterly sampling (summer 2016, autumn 2016, winter 2016, and spring 2017) at each site for assessment of temporal patterns in diets (target of n=60 per season, actual sample size was n=190 total including those collected during summer sampling). Stomach contents of Redbreast Sunfish were analyzed as described above.

Food Webs

Connectance food webs were constructed using stomach content data from all fishes (June 2016-March2017) and macroinvertebrate assemblage data (June 2014-March 2015) generated for the river. I used data generated as part of an ongoing, collaborative study (Assessment of Hydrological, Biological, and Environmental Components of the Lower Ogeechee River Ecosystem) in the river to establish links between potential food resources and the feeding guilds targeted. Macroinvertebrate and fish datasets have been developed for an approximately two-year period prior to my study. These baseline datasets were used to establish linkages between consumers and resources not directly observed during my sampling or difficult to identify from assessment of stomach contents. The first food web utilized species or genera level organisms and the second one was broader and used trophic species (e.g., shredder, omnivore, etc.). Constructing trophic webs is the more common practice than species/genera webs (Dunne et al. 2002a). However, they typically include multiple sizes of fish to incorporate ontogenetic shifts which we did not measure, so I included both webs in order to address any potential over- or underestimation of food web metrics to get an estimated range for the food web metrics described below. Food webs were constructed using the Cheddar package in RStudio (Version 0.99.902). The package calculated connectance, total number of links, and link density, as per Bersier et al. (2002), which allowed for assessment of stability of the ecosystem based on literature values. Connectance and link properties both correspond to the number of species in the web and number of trophic links. Connectance, or directed connectance, corresponds to the number of actual links divided by the number of total possible links (number of species squared) between species in a food web; and link density is measured by dividing number of links by number of species in a web (Bersier et al. 2002). Fish diet data and macroinvertebrate data collected the previous year were used to expand the food web developed

in this study. The macroinvertebrate taxa list was used to extrapolate invertebrates from the family level to the genus level. For example, if the dragonfly family Aeshnidae (Odonata) was found in a stomach, then the genus *Boyeria* and *Basiaeschna* were considered possible prey items of that fish as both genera are present in the system. Macroinvertebrate diets were estimated using functional feeding groups (FFGs) and a previous study (Benke and Wallace 2015). The constructed food web was compared to food webs available in the literature in order to determine the structure and function of this specific network in relation to other systems commonly studied.

Data and Statistical Analyses

Frequency of occurrence was calculated for each prey group for each fish species by dividing the number of stomachs an item was present in over total number of fish stomachs analyzed (excluding empty stomachs). Frequency of occurrence was compared to percent by number which was calculated by dividing the number of a prey item group over the total number of prey items found in all the stomachs. This comparison was made by graphing frequency of occurrence against percent by number, following Costello (1990) and Alcaraz and García-Berthou (2007), in order to describe prey importance and feeding strategy for the fishes. Chesson's α (W) values were also calculated for each prey item grouping in order to describe prey selectivity (Vanderploeg and Scavia 1979a). This index was selected due to the large number of rare prey items, it is similar to Ivlev's forage ratio (Ivlev 1961) but it is normalized so that the sum of all ratios in a sample equals one. The normalization allows for representing the predator's perception of the value of a prey item in relation to its abundance and other food types available. Values below 1/n indicate negative selection and values above 1/n indicate positive selection, with n representing the number of prey groups being analyzed. A better measure,

according to Lechowicz (1982), would have been relativized electivity (Vanderploeg and Scavia 1979b), however, this was not used due to the large number of zeros in the data set representing rare prey items. Niche breath, or diet overlap (i.e., niche overlap; φ) was calculated for each species pairing based on equations in Lawlor (1980) and Winemiller (1989).

Statistical analyses were carried out in RStudio (Version 0.98.1079) and PRIMER-E (version 7; PRIMER-E Ltd., Plymouth, UK). Non-metric multidimensional scaling (NMDS) ordination techniques were used to visualize the relationships between redbreast stomach assemblages across the seasons and age classes for Snail Bullhead and redbreast. These plots were assembled based on a Bray-Curtis similarity matrix (Bray and Curtis 1957). Redbreast diets were compared seasonally using Permutational Multivariate Analysis of Variance (PERMANOVA) (Anderson and Walsh 2013) alongside the NMDS. Similarity Percentages (SIMPER) analyses were used to identify each taxon's contribution to any observed patterns of dissimilarity (in the case of comparisons) and similarity (within an assemblage/season) (Clarke 1993). Age class analyses of diets were performed for Snail Bullhead and Redbreast using NMDS and PERMANOVA techniques as well. These tests are non-parametric and based on permutated data, and are adequate for multivariate data.

CHAPTER 3

RESULTS

Water Quality Parameters

Flow levels in the Ogeechee River fluctuate through the year due to flood pulse with the highest flow levels seen in spring followed by winter and the lowest flows being observed during fall and summer months. Temperature (°C) was highest during summer sampling, followed by fall, spring, and winter. Dissolved oxygen (mg/L) was lowest during the summer sampling events and ranged from 5.62 to 8.62. Higher values of dissolved oxygen were observed with higher levels of flow. Potential of hydrogen (pH) ranged from 6.27 ± 0.26 in winter to 7.13 ± 0.18 during summer. Conductivity values were highest during the summer (103.16 ± 22.45 μS/cm) and lowest (52.46 ± 7.22 μS/cm) during the winter.

Gut Content Analyses

The total number of unique prey items found in fish stomachs during Summer/Fall sampling varied by fish species and ranged from as few as 4 to as many as 52 prey items (Figure 2). Bowfin had the least amount of prey items consumed out of all the fish species, with only four different items/item groups (Figure 3). Furthermore, fish that were consumed by bowfin were often unidentifiable because many distinguishing features had been digested. Aside from fish, crayfish were the most common prey item found in Bowfin stomachs (Figure 3). Spotted Sucker were second in terms of least amount of different prey items found in stomachs, with a total of nineteen different taxa (11 when grouped by order/superorder; Figure 2a, Table 3). The most common prey items found in Spotted Sucker stomachs were Chironominae midges followed closely by Cladocerans (Figure 4). Bannerfin Shiner had a total of twenty prey items (10 when grouped by order/superorder or category; Figure 2, Tables 3-4). The most common

prey items found in Bannerfin Shiner stomachs were Chironominae followed by Hydropsychidae caddisflies (Figure 5). Snail Bullhead were the only fish to have a substantial amount of plant material (e.g., filamentous algae) found in their stomachs with some specimen's stomachs only filled with plant material (Table 4). The total count for number of prey items was twenty-seven (14 when grouped by order/superorder or category; Figure 2, Tables 3-4); the most common prey items were plant material followed by Viviparidae snails (Figure 6). The filamentous algae consumed by these fish may have been consumed incidentally in pursuit of snails because both prey items cling to hard substrates.

Redbreast Sunfish had the highest number of prey items out of all of the fish species targeted (16 when grouped by order/superorder or category), even when only comparing fall and summer samples to the rest of the fish (Figure 7). The total number of unique prey items during fall and summer for Redbreast was fifty-two (Figure 2). The grand total of unique prey items (i.e., different taxa) found in Redbreast stomachs for all sampling periods was sixty-four. The most common prey items found in Redbreast stomachs during summer and fall were Chironominae followed by Oligochaeta. During winter and spring, the most common prey items were Baetidae and Isonychiidae mayflies. It is important to note that the total counts for number of unique prey items for each fish species grouped unidentifiable prey and terrestrial prey as a single prey item. Total counts are likely higher than what is listed, but the order of the fish in terms of number of prey items would likely be the same (Redbreast>Snail Bullhead>Bannerfin Shiner>Spotted Sucker>Bowfin).

Prey Selectivity and Diet Overlap

Prey selectivity was measured for all of the fish species in this study using Chesson's α values (Tables 5 and 6). For the fish sampled during non-flood pulse, Snail Bullhead and Spotted

Sucker had the highest number (3) of prey items that were positively selected for. Snail Bullhead selected for Megaloptera, Odonata and Plecoptera prey groups and Spotted Sucker selected for Cladocera, Collembola and Oligochaeta. For Redbreast Sunfish, during flood-pulse times they appeared to select for a higher number of prey items. For example, Redbreast positively selected for three prey items in winter, however, this number increased to positive selection of six prey items during spring when water levels and discharge are highest. The prey items selected for during winter were Coleoptera, Lepidoptera, and terrestrial prey while the items selected for during spring included Bivalvia, Hirudinea, Plecoptera, Trichoptera and terrestrial prey. Bowfin and Bannerfin Shiner also positively selected prey items. Bowfin positively selected for Decapoda, which were all crayfish, and Odonata which represented the single family Macromiidae. Bannerfin Shiner only selected for one prey item group, Lepidoptera. Significant diet overlap (electivity-based) was classified as greater than 0.5 according to Winemiller (1989) and only occurred between the Snail Bullhead-Bannerfin Shiner pairing and the Redbreast Sunfish-Bannerfin Shiner pairing (Table 7).

Food Web Metrics

Connectance of the species food web was found to be 0.285 and link density was 31.9 links/species, while the number of nodes present in this web was estimated at 112. It is important to note that these estimates include the interactions between predatory macroinvertebrates and other macroinvertebrates in this system and are not limited to the five fish taxa examined. In the constructed food web shown (Figure 8), I have removed the predatory macroinvertebrate interactions to only highlight the interactions between fish and their prey. Connectance of the trophic species web was 0.148, link density was 2.67 and number of nodes in this web was 18

(Figure 9). These estimates do not include drastically different fish size classes or different instars of aquatic insects that feed at different levels.

Seasonal Redbreast Analyses

PERMANOVA for Redbreast, when prey was grouped by order/superorder or habit, revealed that there were significant differences among seasons (Order: pseudo-$F_{3,161}$=4.263, P=0.001; Habit: pseudo-$F_{3,162}$=3.093, P=0.001). SIMPER revealed low (18.91-29.93) similarity based on broad groups (order or superorder level) for each season (Table 8). During summer and fall Trichoptera were the highest contributor to similarity (38.7 and 19.7 percent, respectively) within those seasons. In winter, Coleoptera contributed the most to assemblage similarity at 36.4 percent. During spring, Ephemeroptera had the highest contribution to assemblage similarity at 39.5 percent. Interestingly, Coleoptera contributed second highest (18.5 percent) in fall before it became the top contributor to similarities in winter. A similar trend was seen for Ephemeroptera from winter (26.3 percent) to spring. Slightly higher similarity values were observed when prey items were grouped by habit (29.3-39.1). As for habit, clingers contributed the most to assemblage similarity for both summer and fall (31.7 and 46.5 percent respectively). In winter, burrowers contributed the most to assemblage similarities at 31.6 percent. In spring, swimmers contributed the most to similarity at 40.8 percent (Table 8). NMDS of diets based on each season did not reveal any visual trends, likely due to the large sample size, for either order/superorder or habit groupings of the prey items (Figures 10 and 11).

Age Class Analyses

For Snail Bullhead, plant material was found in the greatest number of stomachs (13 out of 31 total) compared to other diet items. The most abundant items in terms of numbers across all fish were viviparid snails and chironomid midges. Diet did not differ between the age classes

represented in this study based on either prey item habit or group (PERMANOVA pseudo-$F_{6,24}$ =1.0435, P=0.41; pseudo-$F_{6,24}$=1.3084, P=0.142). For Redbreast Sunfish, PERMANOVA revealed there were no significant differences when prey was grouped by habit between different age classes (pseudo-$F_{2,157}$=1.433, P=0.18). However, when prey items were grouped by order between different age classes, there were significant differences between age class diets (pseudo-$F_{2,153}$=1.853, P=0.036) (Figure 8). SIMPER age class analysis based on order groupings revealed that Trichoptera had the highest contribution to similarity at 41.5 percent for the age 2 fish. Ephemeroptera had the highest contribution to both age 3 and age 4 fish at 23.9 and 31.1 percent. Diptera influenced dissimilarities between age groups, except for the age 3 versus age 4 comparison where Ephemeroptera contributed most to dissimilarities in diet composition (Table 11). When prey items were grouped by habit, clingers drove similarities within each age class (38.15, 31.69 and 46.86 percent in order from age 2 to age 4; Table 10). Clingers contributed the most to the dissimilarities between age 2 and age 3; Swimmers contributed the most between age 2 and age 4 as well as between age 3 and age 4. Age 2 fish appeared to mainly consume smaller prey (e.g., Chironomidae) and the older fish (age 3 and 4) added larger prey into their diets (e.g., Decapoda, Coleoptera and Odonata). However, all of the ages appeared to target Chironomidae (Table 6). Age 1 was excluded from analyses due to a low sample size (n=1). NMDS showed no visible trends in the data, likely due to the large sample size for either order/superorder groupings or habit (Figures 12 and 13).

CHAPTER 4

DISCUSSION

This study was the first, to my knowledge, to examine the diets of these study species within the Lower Ogeechee River and include them within the context of prey availability. Of the five taxa studied, only Bowfin and Bannerfin Shiner diets differed from prey availability. The differences observed in Bowfin diets are likely due to their feeding behavior which focused mainly on fish and crayfish. There was also a high percentage of empty Bowfin stomachs encountered (~50%), the highest percentage out of all of the fish species collected. It is likely that these fish are eating more fish species than observed in the gut content analysis due to their piscivorous nature (Boschung and Mayden 2004). A possible explanation for the high percentage of empty stomachs is that the breeding season for these fish is in late May and early June, and many of the Bowfin were collected during early June in this study. They may be eating less in order to direct more of their energy to reproduction instead of feeding. Also, large, piscivorous fishes tend to have higher regurgitation rates than other fishes when subject to electrofishing (Bowen 1996; Sutton et al. 2004).

The Bannerfin is also known to sight feed on drifting macroinvertebrates (Boschung and Mayden 2004). A reason for the difference between the diets and availability is the high amount of Trichoptera consumed by Bannerfin Shiner. A study by Benke et al. (1991) found that Trichoptera represented a substantial portion (14.5%) of the invertebrate drift throughout the year at a site in the Lower Ogeechee River. Although caddisflies are well represented in the macroinvertebrate samples used to generate the composite list of available prey items, their densities fall in comparison to other taxa with shorter life-span and quick turnover (e.g., Diptera). Furthermore, the prey list would most closely represent macroinvertebrate prey assemblages as

standing stock densities, which likely differ from the assemblage of drifting invertebrates as some of the taxa included would not exhibit this behavior (e.g., Oligochaeta, Gastropoda, Crayfish, etc.) Furthermore, most of the Trichoptera found within the stomachs were Hydropsychidae, which constituted a major portion of the biomass of the drift samples taken by Benke et al. (1991). Another common family consumed was Leptoceridae, which was found to contribute substantially to density but not to biomass by Benke et al. (1991). Drift quantities for the Ogeechee were some of the highest ever reported in the literature (Benke et al. 1991), so sight feeding is likely influencing the differences between diet and availability in my data. Thus, availability of invertebrate drift is likely impacting Bannerfin Shiner diet.

The other three fish species (Snail Bullhead, Spotted Sucker, and Redbreast Sunfish) exhibited no differences between prey item consumption and amount of prey available, which could suggest that availability is impacting these fish diets and that they are feeding more generally. Snail Bullheads prefer swift flowing rocky bottom streams (Yerger and Relyea 1968), which helps explain the 28 prey items found in the clinger habit category. Prey items of this fish follow what has been previously found (Jordan and Brayton 1878; McLane 1955; Boschung and Mayden 2004). Previous studies on various species of Catostomatidae revealed similar diets that consisted mainly of cladocerans, copepods and chironomids (White and Haag 1977; Boschung and Mayden 2004), which supports my findings. The Spotted Suckers stomachs in this study also contained a lot of sand, indicating they are feeding on the sandy bottoms of this river. The midges they consume are likely species that dwell in the sand and are probably different species than the ones that Redbreast or Bannerfin Shiner consume, which are probably snag dwelling midges. Redbreast Sunfish in the Ogeechee River also appear to follow what has been known about their diets (Coomer et al. 1977; Cooner 1981; Cooner and Bayne 1982; Benke et al. 1985).

They are known to be a species that consumes almost any type of macroinvertebrate (Boschung and Mayden 2004), so it was expected that they would consume the highest number of different prey items. Preference versus availability analyses may be limited due to macroinvertebrates only being classified at the order level. Although the macroinvertebrate communities used to develop the composite list of available prey items were from a previous year of study in the river, it is unlikely that the relative densities of dominant prey item groups would change from year to year. Furthermore, the two years have exhibited similar patterns in hydrology and water chemistry, thus it is unlikely that macroinvertebrate communities differ in such a way to bias the results of my study. In addition, a study by Benke et al. (1991) observed similar trends at the order level across years, so general patterns in this study would likely be similar. It is also worth mentioning that for four of the fish species studied samples were only taken during non-flood pulse times, thus it is possible that the diets of these fish would shift as different habitats (e.g., the floodplain), and with them different prey items, become available.

A study by Floeter and Temming (2003) found that prey availability is often the driver of diet composition, however the relationship between preference and availability is complex and includes factors like predation risk, prey defenses and food capture efficiency. Also, when prey abundances are high, fish are more likely to target the largest size prey for maximizing energy gains and minimizing expenditures (Werner and Hall 1974), which follows predictions of optimal foraging theory as described by Schoener (1971). Four of the fish species in this study appeared to use what is available, which supports the findings of similar studies. For example, a study by Worischka et al. (2015) found that fish preferred to eat prey that is abundant. Additionally, a study by Eggleton and Schramm (2004) stated that during a low water year, in a river flood plain system, catfish select low energy, but highly abundant prey. The fishes observed

in the study by Eggleton and Schram (2004) also exhibited little prey selection and they concluded that consumption reflected the availability in the habitat.

Seasonal differences in Redbreast Sunfish diets suggest that preference is not the main factor of diet selection year-round and that instead the diets are influenced by prey availability. Macroinvertebrate communities are constantly changing within the course of a year. Redbreast diets in this study appear to follow trends observed for another local river, the Satilla River in southeast Georgia. The Satilla flows completely within the coastal plain, and similar to the Ogeechee, is not impounded. In a study by Benke et al. (1984), standing stock biomass was measured for a variety of insects within the Satilla River at two sites (e.g., upper and lower). I compared Redbreast diet data and the data from the lower site from the 1984 study and found similarities in Redbreast diet composition as observed by Benke et al. (1984). This comparison must be taken with reservations because these data were collected from a different river and over thirty years ago. However, general trends (Ordinal level) may be more comparable to our data than specific trends (Familial level), which is why the comparison was made. For instance, Trichoptera biomass (g/m^2) from the 1984 study peaked in the summer and remained steady until winter. Trichoptera was also the least consumed prey group during the winter when levels were lowest. Coleoptera peaked in late spring into the summer and was low the rest of the year (with a slight peak in the winter months); Redbreast consumed the highest amount of Coleoptera in the winter. Diptera had peaks in late summer, fall and late winter; Redbreast in this study consumed high (24%-33%) amounts of Diptera in two (fall and summer) of the three seasons as the peaks in the 1984 study. Plecoptera had peaks in winter and late spring/early summer. Redbreast consumed a high amount of Plecoptera in the spring and followed the trend seen in the 1984 study. Any discrepancies between the biomass peaks from Benke et al. (1984) and this study are

likely due to the Satilla being completely within the Coastal Plain, unlike the Ogeechee which originates in the Piedmont region. Temperature likely plays the biggest role in differences, some insect orders may emerge earlier in the Satilla due to temperatures being slightly higher since it is south of the Ogeechee (Ward et al. 2005). This comparison provides further evidence that Redbreast diets follow general availability trends within the Ogeechee River.

Two common generalizations about food webs are the link-species scaling law and the hyperbolic connectance law (Cohen and Newman 1988). The link-species scaling law states that the expected number of trophic links is directly proportional to the number of trophic species, in community webs with a moderate number of trophic species. The hyperbolic connectance law states that the product of the number of species and connectance is approximately constant, again in webs with a moderate number of trophic species. Many of the food webs (>200) measured to date have been compiled into a data bank (ECOWeB, Cohen 2010), most have been relatively small (<19 species), and 95% of the food webs have fewer than 40 species included (Goldwasser and Roughgarden 1993). Since many food webs have been small, many of the generalizations may not hold true for full scale communities (Polis 1991). Compared to other webs, my species level food web is large (119 nodes); however my trophic species web falls below the average size of a web in the ECOWeB database. The food web constructed in this study revealed a high level of connectance compared to other food webs assembled in the past for different habitat types (Martinez 1992; Dunne et al. 2002a, 2002b). Martinez (1992) stated that high levels of consumer diversity can cause high connectance, and that is a possible explanation for the high connectance value for this food web.   This study has placed Southeastern Coastal Plain rivers as one of the more diverse and connected aquatic food webs measured to date. The food web in this study could underestimate the true connectance of the system as well because we may not be

collecting all of the insects present in this system during macroinvertebrate sampling. Macroinvertebrates were only collected using one method, jab sampling, and it is likely that certain macroinvertebrates that are rare or do not inhabit the areas where samples are collected from were missed. However, macroinvertebrates found in the gut content analysis were extrapolated to the genus level using the composite taxa list to account for some of the possible missing links. The reason I extrapolated was to create a more accurate connectance food web in order to see broad structure of this system. Gut content analysis is limited because it only examines a "snap-shot" on one day, and typically isotopic analyses are better suited in determining diet over time (Belicka et al. 2012). However, gut content analysis was better suited for this study because more unique trophic links could be observed this way. Isotopic analyses place organisms in relation to other organisms but it isn't possible to construct a connectance food web this way. Another reason for underestimation is not including every single fish species in this system or not finding all of the potential prey items in the fish stomachs. Each year the quarterly sampling has captured at least one new fish species or macroinvertebrate genus.

The species food web I constructed likely overestimates the level of connectance as I estimated macroinvertebrate feeding based on functional groups (Merritt et al. 2008; GA DNR 2012) and by using a dataset developed from a study conducted over 30 years prior to this one in which a quantitative food web was developed from estimates of gut contents (Benke and Wallace 2015). These consumer interactions may misrepresent the true complexity of the current food web as certain predatory macroinvertebrates may not consume all the prey items available or may shift their feeding strategies based on developmental stages. The trophic species web is likely to underestimate values because I did not take diets from multiple size classes of fish and the macroinvertebrate feeding estimations were only based on late instar insects, fully-, or near

fully-developed aquatic macroinvertebrates. Using both the webs gives a range of values within which, the true food web metric values likely fall.

My results indicate that Snail Bullhead, regardless of age class, feed on similar prey items. This could be due to the cryptic nature of this species (Boschung and Mayden 2004). However, age class differences were observed for Redbreast Sunfish when prey items were grouped by order but not by habit. This could suggest that there is no major shift in feeding behavior between age classes, however, each age class may feed on different types of macroinvertebrates most likely due to an ontogenetic shift. I have determined that prey availability is the main factor driving diets for most of the fishes in this study. The major exception being the Bowfin, but that is likely due to their primarily piscivorous feeding behavior or due to limitations set forth by my sampling method when compiling prey availability lists (for all other fish taxa studied) or when assessing diet composition given that Bowfin resulted in the largest proportion of empty stomachs. In addition, all of the fish species studied, except for Redbreast Sunfish, were collected only during the summer and fall. It would be interesting for a future study to look at seasonal changes for these other fishes. Perhaps some of the fish species differ in diet selection from the proportion of available prey in certain seasons, thus exhibiting a more selective feeding behavior that targets high quality prey. The food web generated in this study has placed the Ogeechee River as one of the most highly connected food webs measured to date. Previous studies have shown that the Ogeechee River has a high amount of invertebrate biomass and production (Benke et al. 1991; Benke and Wallace 1997; Benke 1998, Benke and Wallace 2015), which likely lends to the high connectance of this food web. In the future, isotopic analyses at different trophic levels may help determine whether this food web accurately reflects connectance between predatory macroinvertebrates and their prey. Even with the

potential under- or overestimation of connectance, the value for the Ogeechee River is still likely to be high when compared to other food webs.

Table 1: Physical and chemical characteristics of the six sites in the Lower Ogeechee River. Physical: latitude, longitude, drainage area, average annual discharge, and average annual river stage from 2016 (January 2016-December 2016). Chemical: pH, conductivity, dissolved oxygen and temperature averaged across sampling times (June 2016-March 2017).

Site Name	**Latitude**	**Longitude**	**Drainage Area (km^2)**	**Avg. Discharge (m^3/s)**	**Avg. Stage (m)**	**pH**	**Cond (µS/cm)**	**DO (mg/L)**	**Temp (C°)**
88 Crossing	33.0460	-82.6052	1,173.19	10.97	2.80	6.5	49.85	7.76	15.3
Wadley	32.8724	-82.3179	3,470.58	34.00	0.85	6.86	64.15	8.32	17.17
Rocky Ford	32.6495	-81.8429	5,050.48	49.92	1.81	7.07	92.06	7.28	19.22
Oliver	32.4965	-81.5570	6,138.27	59.55	2.92	6.74	89.25	6.38	21.06
Highway 119	32.2982	-81.4516	6,863.47	66.37	2.04	6.74	82.79	7.00	19.77
Morgan's	32.0800	-81.3856	7,692.27	73.40	2.16	6.65	76.99	6.85	20.08

Table 2: Water Quality data (Temperature (ºC), Dissolved Oxygen Saturation (%), Dissolved Oxygen (mg/L), Conductivity (S/m), Specific Conductance (µS/cm), and pH) with standard deviations within each season of sampling, averaged across the six study locations.

Season	Temp (°C)	DO (%)	DO (mg/L)	SPC (µS/cm)	Cond. (S/m)	pH
Summer	26.83 ± 2.03	70.43 ± 6.98	5.65 ± 0.62	97.61 ±18.4	103.16 ± 22.45	7.13 ± 0.18
Fall	23.98 ± 2.76	74.16 ± 6.77	6.28 ± 0.81	92.35 ± 15.72	90.0 ± 11.9	6.81 ± 0.28
Winter	11.83 ± 1.87	75.82 ± 7.07	8.26 ± 1.13	70.11 ± 8.93	52.46 ± 7.22	6.27 ± 0.26
Spring	13.41 ±2.7	81.84 ± 5.15	8.62 ±1.01	79.87 ± 18.01	62.97 ± 17.26	6.85 ± 0.36

Table 3: Frequency of occurrence of prey item groups in fish diets during non-flood pulse sampling times (June-October 2016).

Prey item	Bannerfin Shiner	Spotted Sucker	Snail Bullhead	Bowfin
Acari	0.00	1.82	3.23	0.00
Cladocera	0.00	16.36	0.00	0.00
Coleoptera	0.00	3.64	6.45	0.00
Collembola	0.00	7.27	0.00	0.00
Copepoda	0.00	29.09	0.00	0.00
Crayfish	0.00	0.00	19.35	86.67
Diptera	42.50	100.00	32.26	0.00
Elmidae	5.00	7.27	0.00	0.00
Ephemeroptera	30.00	0.00	12.90	0.00
Fish	0.00	0.00	12.90	53.33
Lepidoptera	2.50	0.00	0.00	0.00
Megaloptera	0.00	0.00	3.23	0.00
Mollusca	5.00	14.55	12.90	0.00
Odonata	0.00	0.00	16.13	13.33
Oligochaeta	2.50	45.45	0.00	0.00
Peracarida	0.00	1.82	0.00	6.67
Plant Material	0.00	0.00	51.61	0.00
Plecoptera	2.50	0.00	6.45	0.00
Shrimp	2.50	0.00	0.00	0.00
Terrestrial Prey	7.50	0.00	25.81	0.00
Trichoptera	97.50	1.82	16.13	0.00

Table 4: Percent diet composition of the five study species when comparing aquatic invertebrates to other food sources (terrestrial, aquatic plant and fish).

Prey Item	Spotted Sucker	Snail Bullhead	Bannerfin Shiner	Redbreast	Bowfin
Aquatic Invertebrates	100	63	97	92	74
Plant Material	0	19	0	0	0
Terrestrial Prey	0	12	2	8	0
Fish	0	4	0	0	26

Table 5: Comparison of Chesson's α (W) values for fish species sampled during non-flood pulse, (-) represents negative prey selection and (+) represents positive prey selection.

Taxa	Spotted Sucker	Selection	Snail Bullhead	Selection	Bannerfin Shiner	Selection	Bowfin	Selection
Amphipoda	5.76E-09	-	4.54E-06	-	1.89E-07	-	0.018	-
Bivalvia	6.04E-05	-	0.022	-	0.00037	-	1.70E-05	-
Cladocera	0.96	+	0.025	-	0.0011	-	0.045	-
Coleoptera	2.26E-06	-	0.0084	-	1.55E-07	-	6.63E-06	-
Collembola	0.038	+	0.025	-	0.0011	-	0.045	-
Copepoda	5.90E-04	-	8.14E-05	-	3.39E-06	-	0.00015	-
Decapoda	7.42E-09	-	0.039	-	0.00068	-	0.70	+
Diptera	5.30E-05	-	0.013	-	0.0014	-	1.72E-06	-
Ephemeroptera	5.43E-06	-	0.014	-	0.0015	-	5.34E-06	-
Gastropoda	2.62E-09	-	0.035	-	7.99E-05	-	3.68E-06	-
Hemiptera	2.07E-08	-	1.63E-05	-	6.78E-07	-	2.91E-05	-
Hirudinea	6.52E-09	-	5.14E-06	-	2.14E-07	-	9.18E-06	-
Hydrachnidae	2.99E-06	-	0.0056	-	2.05E-07	-	8.78E-06	-
Isopoda	1.98E-06	-	6.49E-06	-	2.70E-07	-	1.16E-05	-
Lepidoptera	3.20E-05	-	0.025	-	0.98	+	0.045	-
Megaloptera	1.60E-07	-	0.14	+	5.26E-06	-	0.00023	-
Odonata	2.18E-08	-	0.098	+	7.15E-07	-	0.14	+
Oligochaeta	3.74E-05	+	2.42E-06	-	0.0012	-	4.33E-06	-
Plecoptera	2.91E-07	-	0.52	+	0.0089	-	0.00041	-
Trichoptera	1.32E-06	-	0.025	-	0.0059	-	7.75E-06	-

Table 6: Comparison of Chesson's α (W) values for Redbreast Sunfish sampled quarterly, (-) represents negative prey selection and (+) represents positive prey selection (SU=summer 2016, FL=fall 2016, WN=winter 2016, SP=spring 2017).

Taxa	Redbreast SU	Selection	Redbreast FL	Selection	Redbreast WN	Selection	Redbreast SP	Selection
Amphipoda	0.0015	-	0.00016	-	0.00011	-	0.0019	-
Bivalvia	0.0046	-	0.016	-	0.0098	-	0.17	+
Cladocera	0.022	-	0.0082	-	0.0054	-	0.017	-
Coleoptera	0.014	-	0.014	-	0.072	+	0.0041	-
Collembola	0.013	-	0.0082	-	0.011	-	0.034	-
Copepoda	0.0077	-	0.0013	-	0.00045	-	0.00095	-
Decapoda	0.00070	-	0.0024	-	0.0014	-	0.0025	-
Diptera	0.016	-	0.0070	-	0.0029	-	0.0054	-
Ephemeroptera	0.028	-	0.0063	-	0.0077	-	0.047	-
Gastropoda	0.00062	-	0.0071	-	0.0037	-	0.022	-
Hemiptera	0.00096	-	0.00040	-	0.0027	-	0.0063	-
Hirudinea	0.00018	-	0.0023	-	0.0036	-	0.068	+
Hydrachnidae	0.00092	-	0.00014	-	8.52E-05	-	0.00086	-
Isopoda	0.0022	-	0.0076	-	0.0099	-	0.0040	-
Lepidoptera	0.013	-	0.0082	-	0.27	+	0.019	-
Megaloptera	0.023	-	0.0046	-	0.027	-	0.019	-
Odonata	0.033	-	0.012	-	0.013	-	0.15	+
Oligochaeta	0.019	-	0.0018	-	0.00072	-	0.0084	-
Plecoptera	0.067	+	0.067	+	0.013	-	0.11	+
Trichoptera	0.039	-	0.026	-	0.0059	-	0.069	+
Terr. Prey	0.69	+	0.80	+	0.54	+	0.24	+

Table 7: Diet overlap (φ) values between different fish species in this study. Significant diet overlap occurs at φ values above 0.5.

Fish species 1 (j)	**Fish species 2 (k)**	$\varphi_{j,k}$	$\varphi_{k,j}$
Spotted Sucker	Snail Bullhead	0.01	0.08
Spotted Sucker	Bannerfin Shiner	0.04	0.01
Spotted Sucker	Redbreast Sunfish	0.02	0.01
Spotted Sucker	Bowfin	0	0
Snail Bullhead	Bannerfin Shiner	0.75	0.13
Snail Bullhead	Redbreast Sunfish	0.36	0.16
Snail Bullhead	Bowfin	0.49	0.20
Bannerfin Shiner	Redbreast Sunfish	0.57	1.43
Bannerfin Shiner	Bowfin	0.17	0.02
Redbreast Sunfish	Bowfin	0.04	0.04

Table 8: Similarity Percentages (SIMPER) estimates of average abundance, average similarity, and percent contribution of prey items in Redbreast Sunfish diets by season.

Season	Grouping	Taxon	Avg. Abundance	Avg. Similarity	% Contribution
Summer	Order/Superorder	Trichoptera	1.02	9.45	38.65
Summer	Order/Superorder	Diptera	0.97	5.58	22.82
Summer	Order/Superorder	Terr. Prey	0.42	3.15	12.89
Fall	Order/Superorder	Trichoptera	0.46	3.73	19.72
Fall	Order/Superorder	Coleoptera	0.51	3.5	18.53
Fall	Order/Superorder	Ephemeroptera	0.55	3.3	17.46
Fall	Order/Superorder	Diptera	0.61	3.01	15.91
Winter	Order/Superorder	Coleoptera	0.9	9.75	36.43
Winter	Order/Superorder	Ephemeroptera	0.71	7.04	26.33
Winter	Order/Superorder	Terr. Prey	0.49	3.04	11.38
Spring	Order/Superorder	Ephemeroptera	1.72	11.82	39.48
Spring	Order/Superorder	Trichoptera	0.98	8.07	26.95
Spring	Order/Superorder	Plecoptera	0.79	3.32	11.11
Summer	Habit	Clinger	0.98	9.49	31.67
Summer	Habit	Burrower	1.21	7.3	24.36
Summer	Habit	Climber	0.71	5.23	17.44
Fall	Habit	Clinger	0.93	13.62	46.51
Fall	Habit	Burrower	0.81	6.86	23.42
Fall	Habit	Sprawler	0.37	2.42	8.26
Winter	Habit	Burrower	1.02	11.54	31.57
Winter	Habit	Clinger	1.02	10.88	29.75
Winter	Habit	Swimmer	1.02	9.7	26.54
Spring	Habit	Swimmer	1.7	15.96	40.8
Spring	Habit	Clinger	1.69	14.63	37.41

Table 9: Frequency of occurrence of prey item groups in redbreast diets across four sampling seasons.

Prey item group	Redbreast Summer	Redbreast Fall	Redbreast Winter	Redbreast Spring
Acari	3.70	0.00	0.00	0.00
Cladocera	1.85	0.00	0.00	0.00
Coleoptera	38.89	51.28	67.74	13.95
Collembola	0.00	0.00	0.00	2.33
Decapoda	0.00	10.26	6.45	9.30
Diptera	77.78	53.85	38.71	44.19
Ephemeroptera	31.48	43.59	64.52	100.00
Hirudinea	0.00	0.00	0.00	4.65
Lepidoptera	0.00	9.00	19.35	0.00
Megaloptera	3.70	0.00	3.23	0.00
Mollusca	18.52	23.08	41.94	41.86
Odonata	18.52	17.95	19.35	18.60
Oligochaeta	7.41	2.56	0.00	6.98
Peracarida	14.81	5.13	12.90	46.51
Plecoptera	0.00	12.82	6.45	55.81
Pupae	1.85	5.13	3.23	4.65
Terrestrial Prey	42.59	41.03	51.61	18.60
Trichoptera	90.74	43.59	25.81	100.00

Table 10: List and total number of prey items (Taxa) found in Redbreast Sunfish diets grouped by different age classes (2, 3, 4).

Taxa	Age 2	Age 3	Age 4
Odonata	2	30	12
Peracarida	18	30	93
Terrestrial Prey	7	51	20
Aquatic insect	1	0	0
Ephemeroptera	14	158	163
Trichoptera	30	135	53
Diptera	148	108	23
Cladocera	1	0	0
Decapoda	0	7	5
Coleoptera	16	113	14
Acari	1	1	0
Oligochaeta	0	126	1
Plecoptera	3	62	19
Mollusca	16	35	23
Pupae	2	5	0
Megaloptera	1	2	0
Lepidoptera	1	3	3
Collembola	1	0	0
Hirudinea	0	2	0

Table 11: Similarity Percentages (SIMPER) estimates of average abundance, average similarity, and percent contribution of prey items in Redbreast Sunfish diets by age class.

Age	Grouping	Taxon	Avg. Abundance	Avg. Similarity	% Contribution
Age 2	Order/Superorder	Trichoptera	0.83	10.44	41.46
Age 2	Order/Superorder	Diptera	1.32	7.09	28.15
Age 2	Order/Superorder	Mollusca	0.45	2.58	10.24
Age 3	Order/Superorder	Ephemeroptera	0.78	5.23	23.9
Age 3	Order/Superorder	Trichoptera	0.72	4.73	21.6
Age 3	Order/Superorder	Coleoptera	0.56	3.47	15.83
Age 3	Order/Superorder	Diptera	0.6	2.77	12.66
Age 4	Order/Superorder	Ephemeroptera	1.22	7.06	31.1
Age 4	Order/Superorder	Trichoptera	0.78	6.01	26.47
Age 4	Order/Superorder	Terr. Prey	0.43	4.18	18.41
Age 2	Habit	Clinger	1.09	11.56	38.15
Age 2	Habit	Burrower	1.27	7.58	25.04
Age 2	Habit	Climber	0.48	5.23	17.28
Age 3	Habit	Clinger	1.16	10.11	31.69
Age 3	Habit	Burrower	0.99	8	25.08
Age 3	Habit	Swimmer	0.76	7.14	22.38
Age 4	Habit	Clinger	1.24	15.42	46.86
Age 4	Habit	Swimmer	1.27	5.75	17.47
Age 4	Habit	Burrower	0.65	5.06	15.4

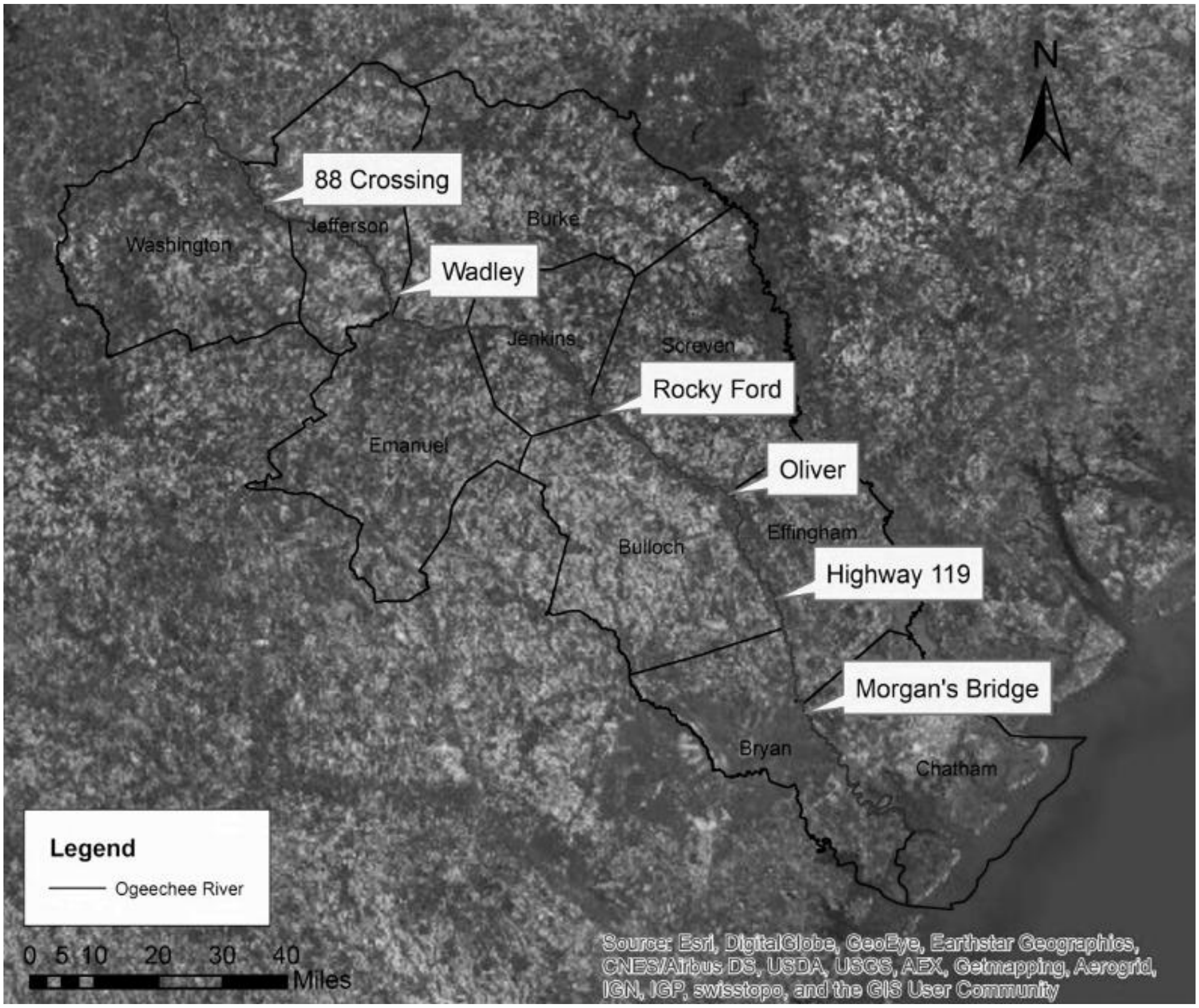

Figure 1: Map of the Lower Ogeechee River in southeastern Georgia depicting the six sampling locations along a ~200 kilometer stretch of the river.

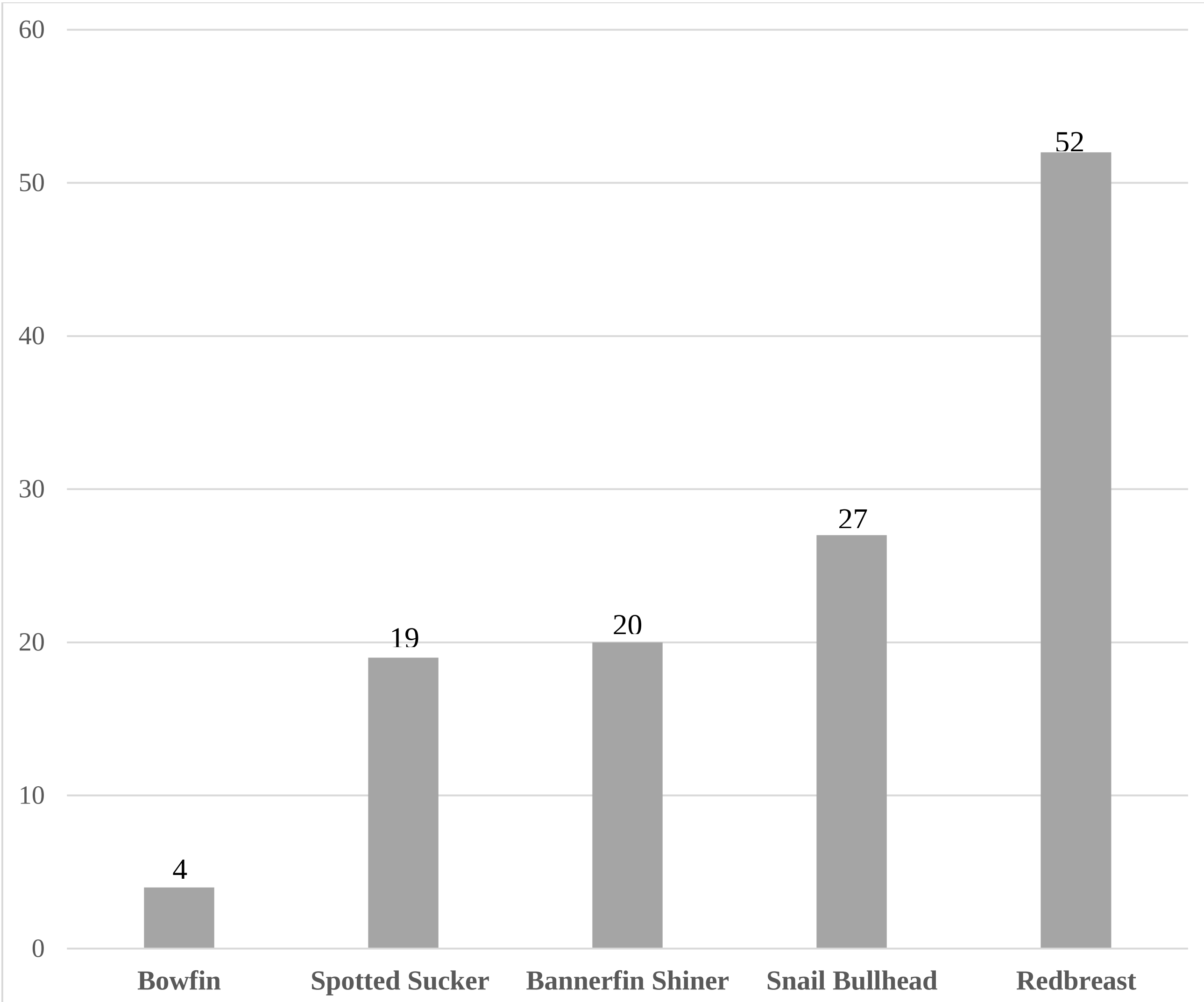

Figure 2a: Number of unique prey item groups (order or superorder) for each fish species in the study. Redbreast Sunfish numbers are only from non-flood pulse sampling in summer and fall 2016.

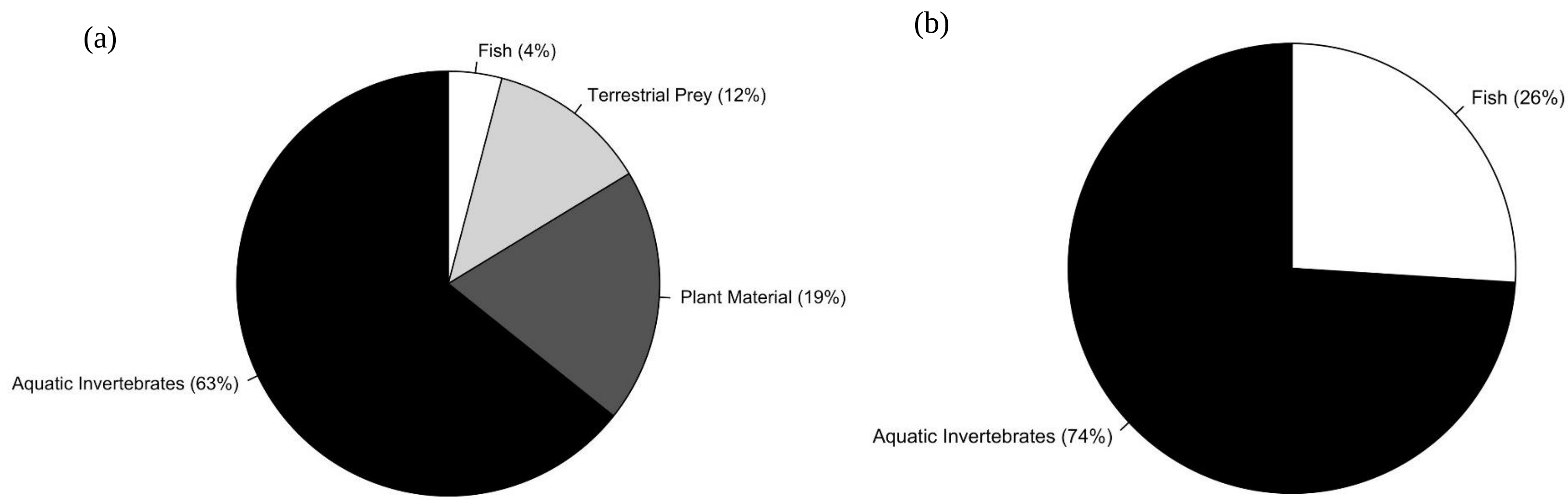

Figure 2b: Diet composition of Snail Bullhead (a) and Bowfin (b) including percentages of non-aquatic invertebrates.

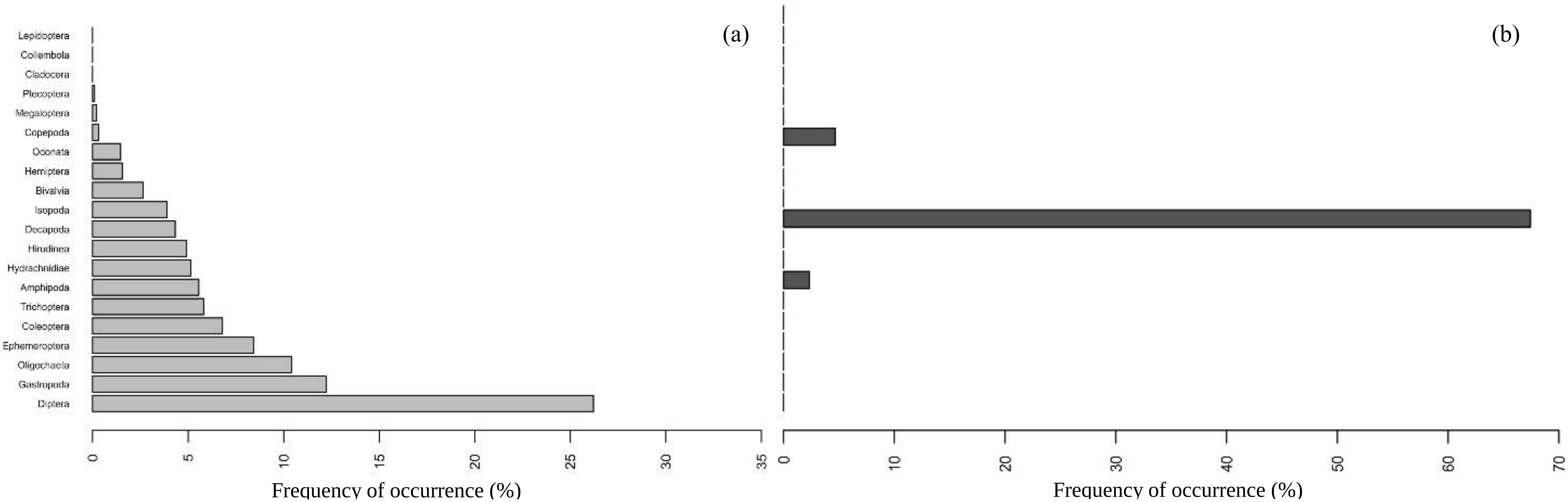

Figure 3: Percentage of each prey item available determined from composite taxa lists (a) is compared against the diets of all Bowfin (b). Note the change in scale, prey axis goes to 70 while available axis goes to 35.

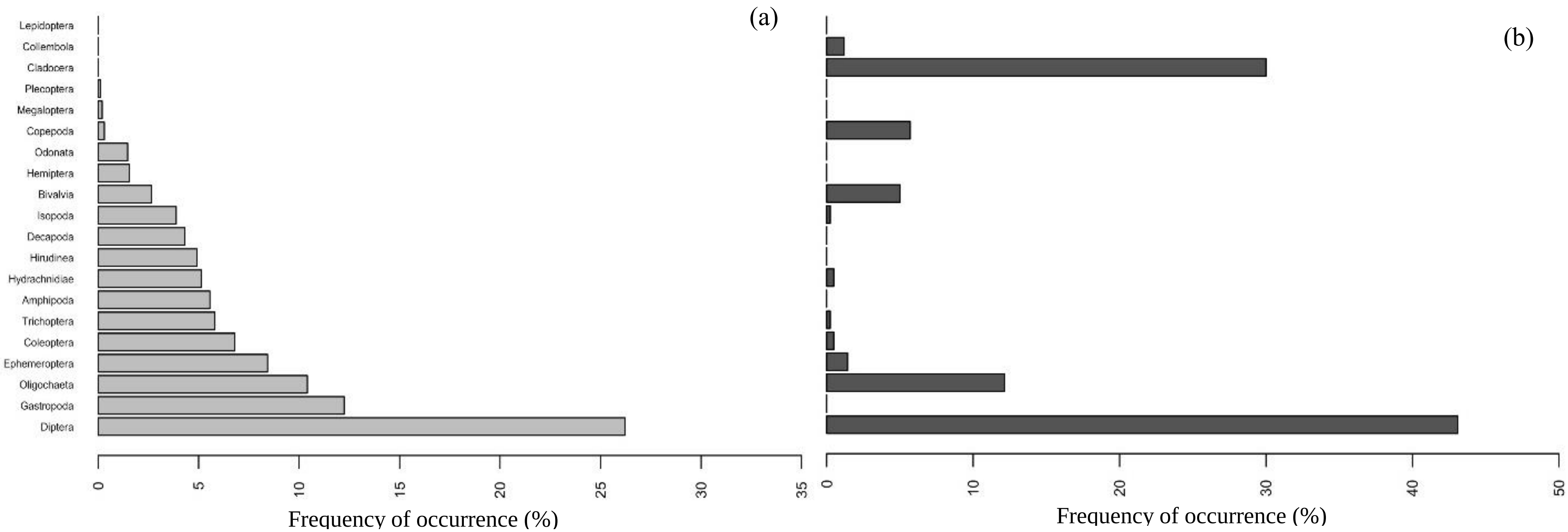

Figure 4: Percentage of each prey item available determined from composite taxa lists (a) compared against the diets of all Spotted Sucker (b). Note the change in scale, prey axis goes up to 50 while available axis goes to 35.

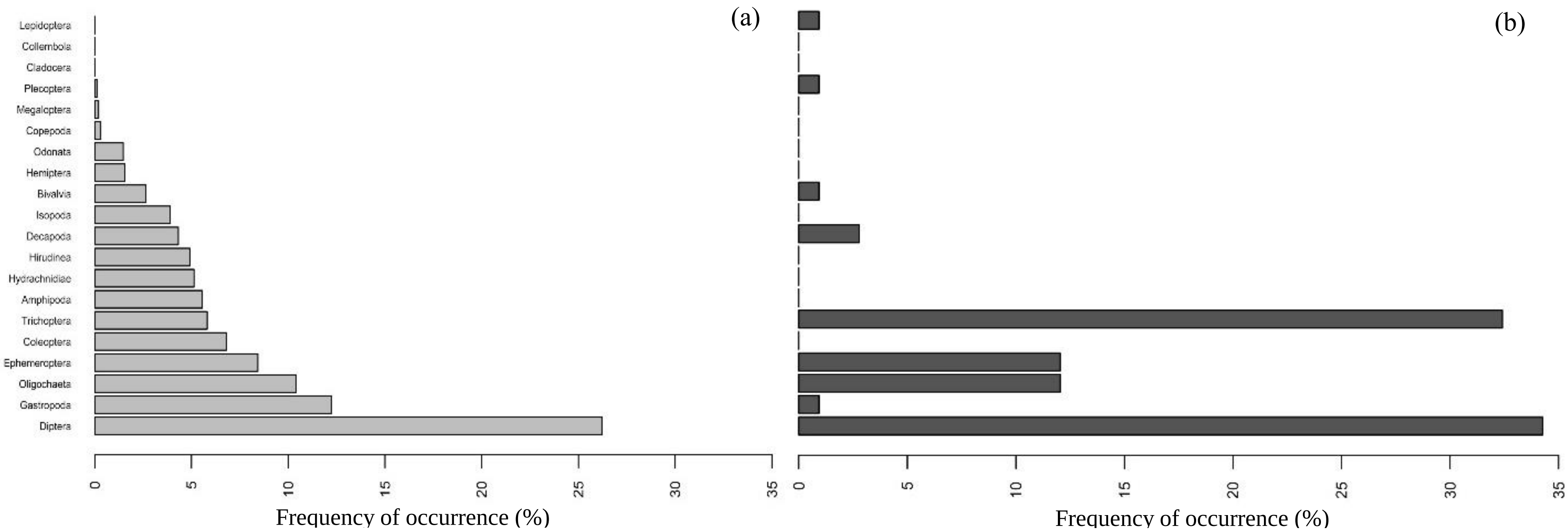

Figure 5: Percentage of each prey item available determined from composite taxa lists (a) compared against the diets of all Bannerfin Shiner (b).

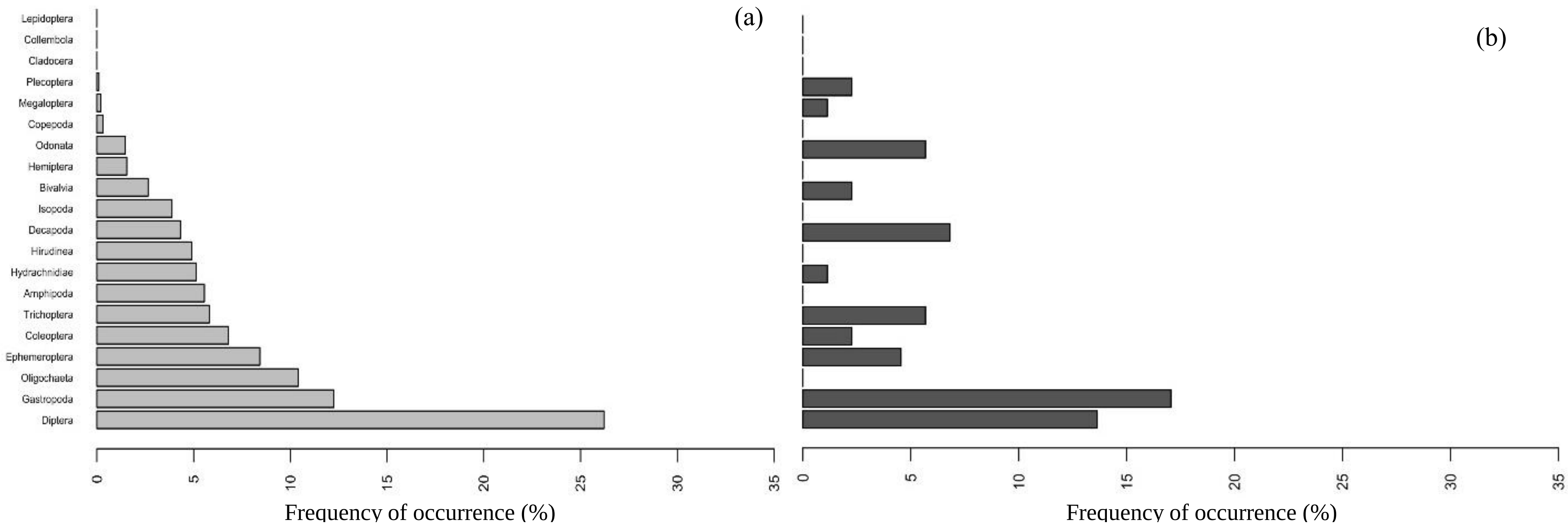

Figure 6: Percentage of each prey item available determined from composite taxa lists (a) compared against the diets of all Snail Bullhead (b).

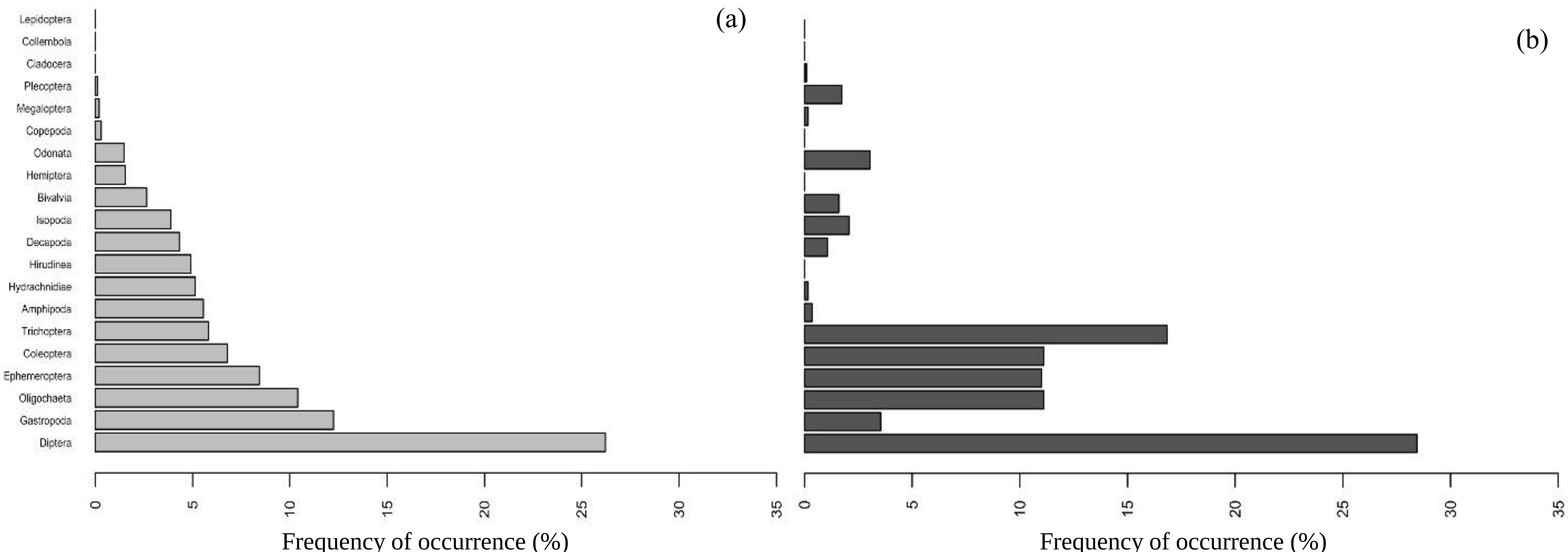

Figure 7: Percentage of each prey item available determined from composite taxa lists (a) compared against the diets of all Redbreast Sunfish (b).

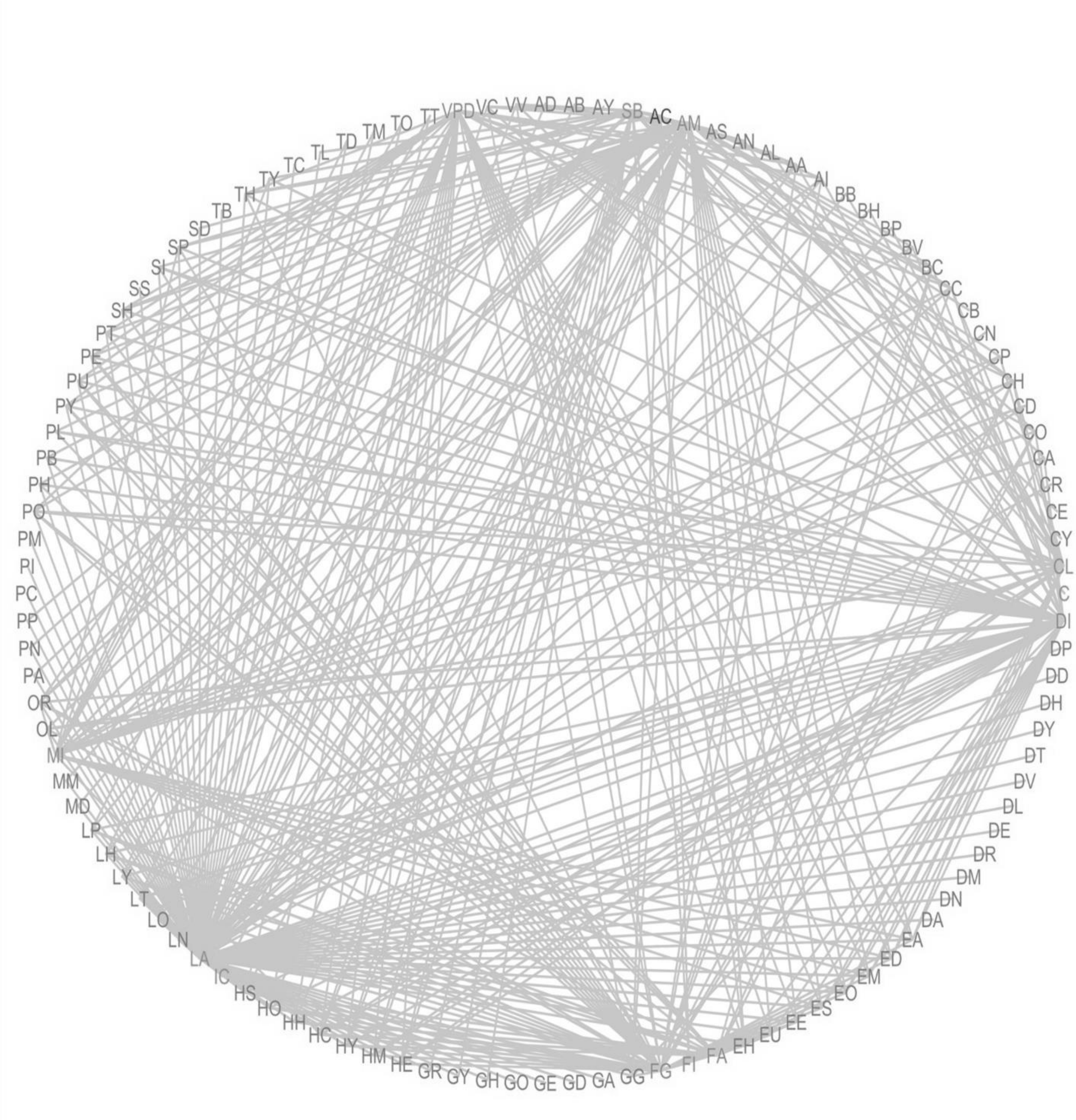

Figure 8: Connectance food web of the Lower Ogeechee River; macroinvertebrate interactions are not included to facilitate interpretability. Abbreviated names are included in Appendix F.

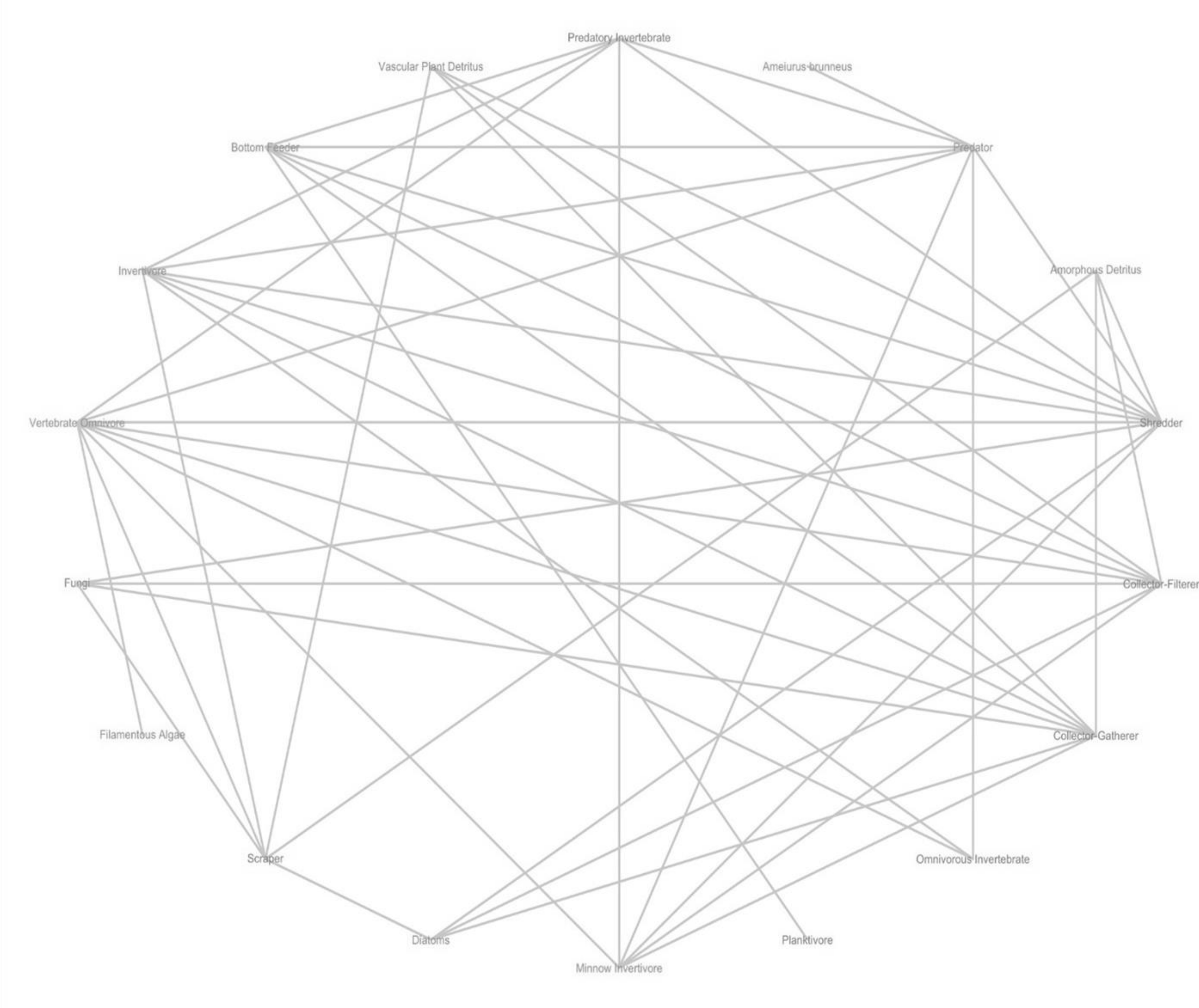

Figure 9: Connectance food web of the Lower Ogeechee River using trophic species.

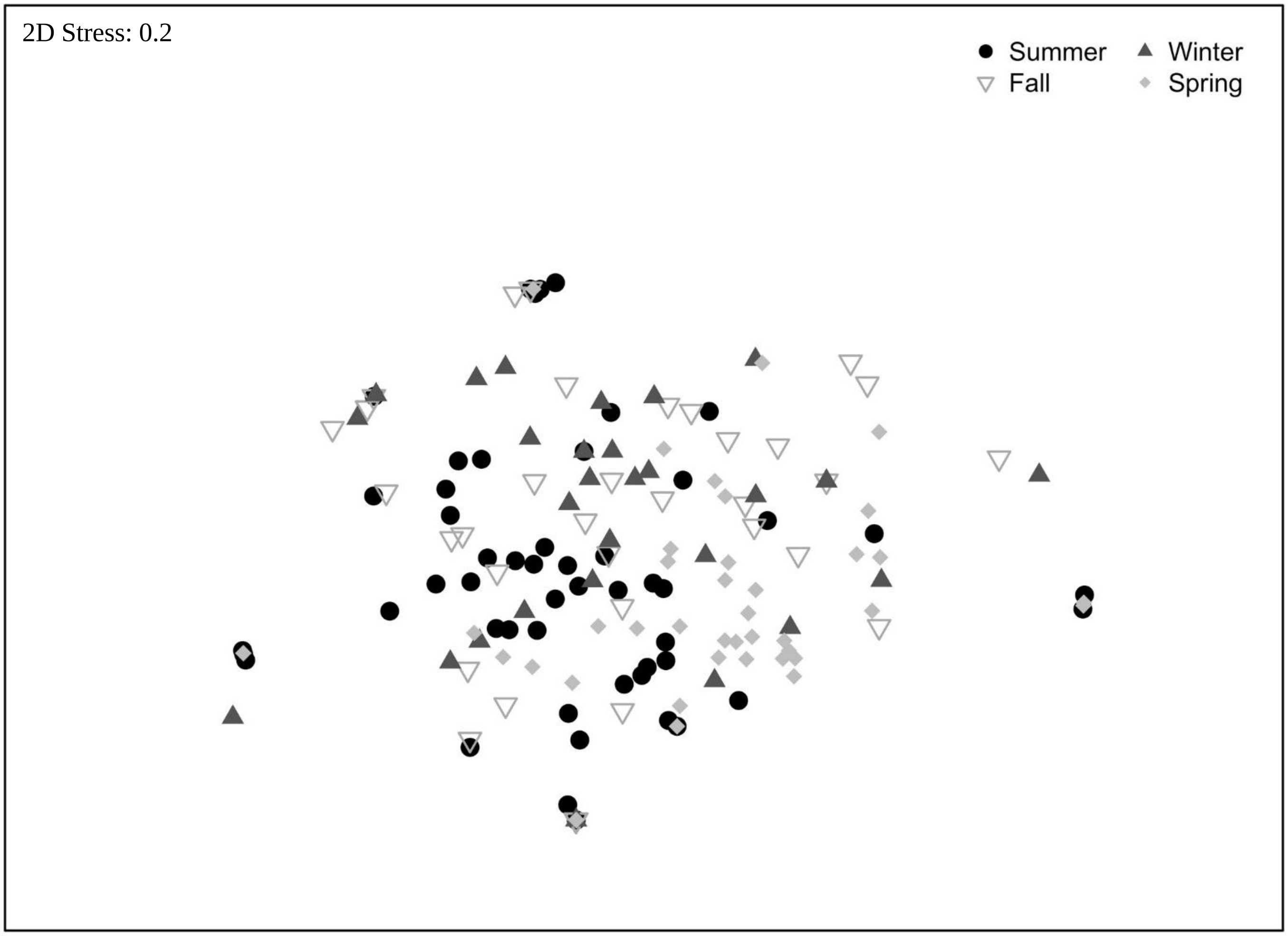

Figure 10: Non-metric Multidimensional Scaling (NMDS) ordination plots depicting Redbreast Sunfish diets by season when prey items were grouped by order or superorder.

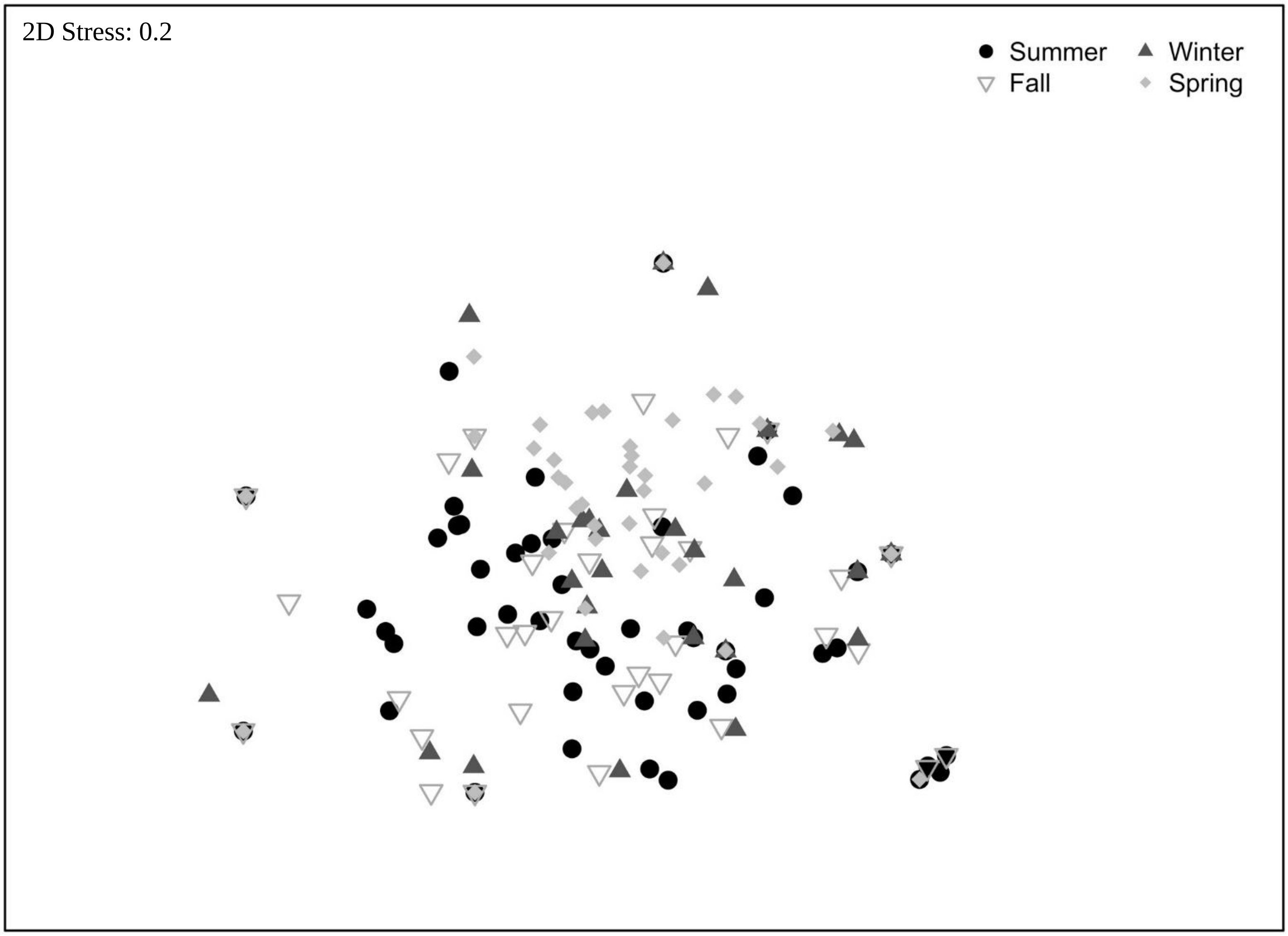

Figure 11: Non-metric Multidimensional Scaling (NMDS) ordination plots depicting Redbreast Sunfish diets by season when prey items were grouped by habit.

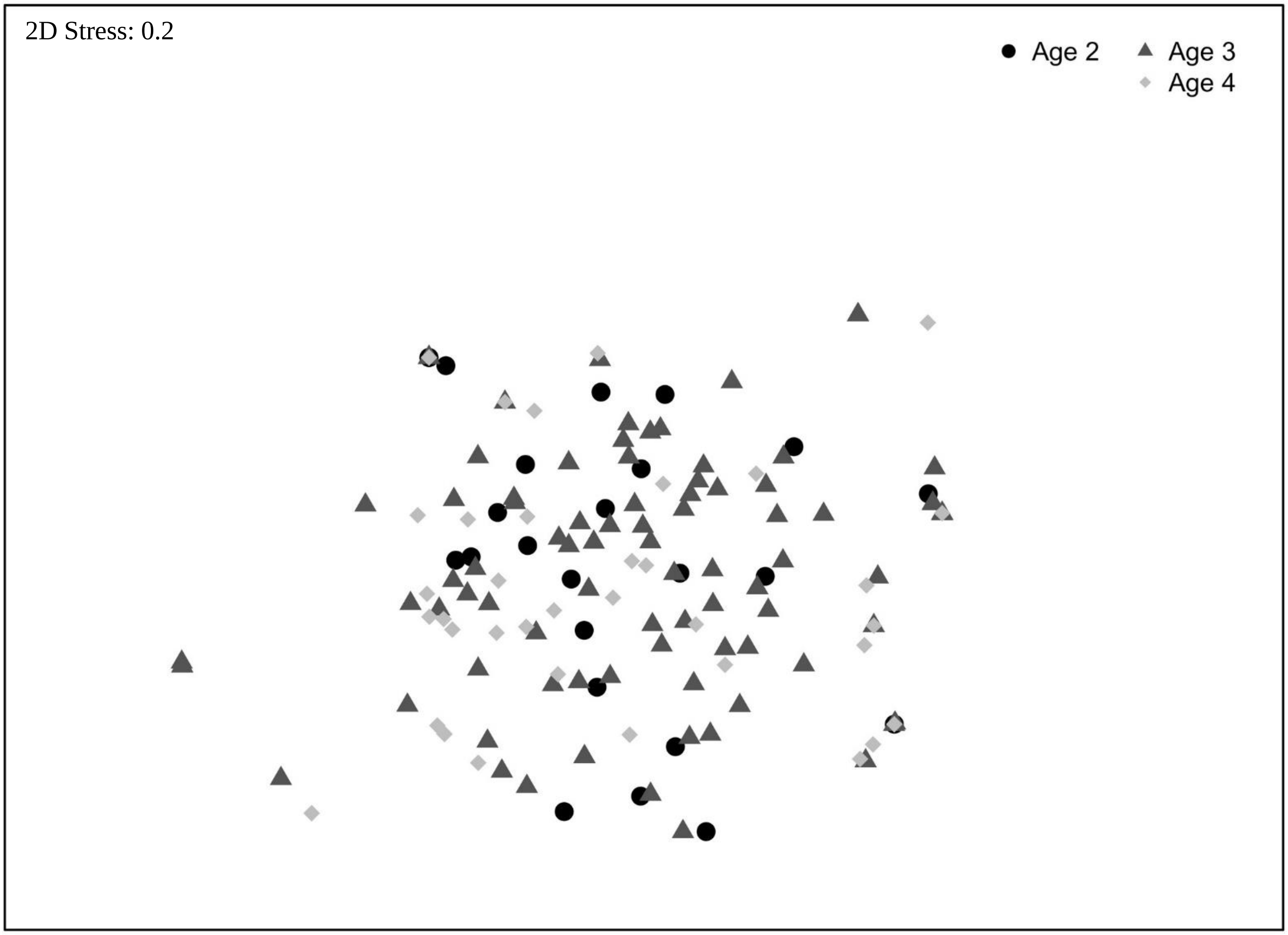

Figure 12: Non-metric Multidimensional Scaling (NMDS) ordination plots depicting Redbreast Sunfish diets by age class when prey items were grouped by order or superorder.

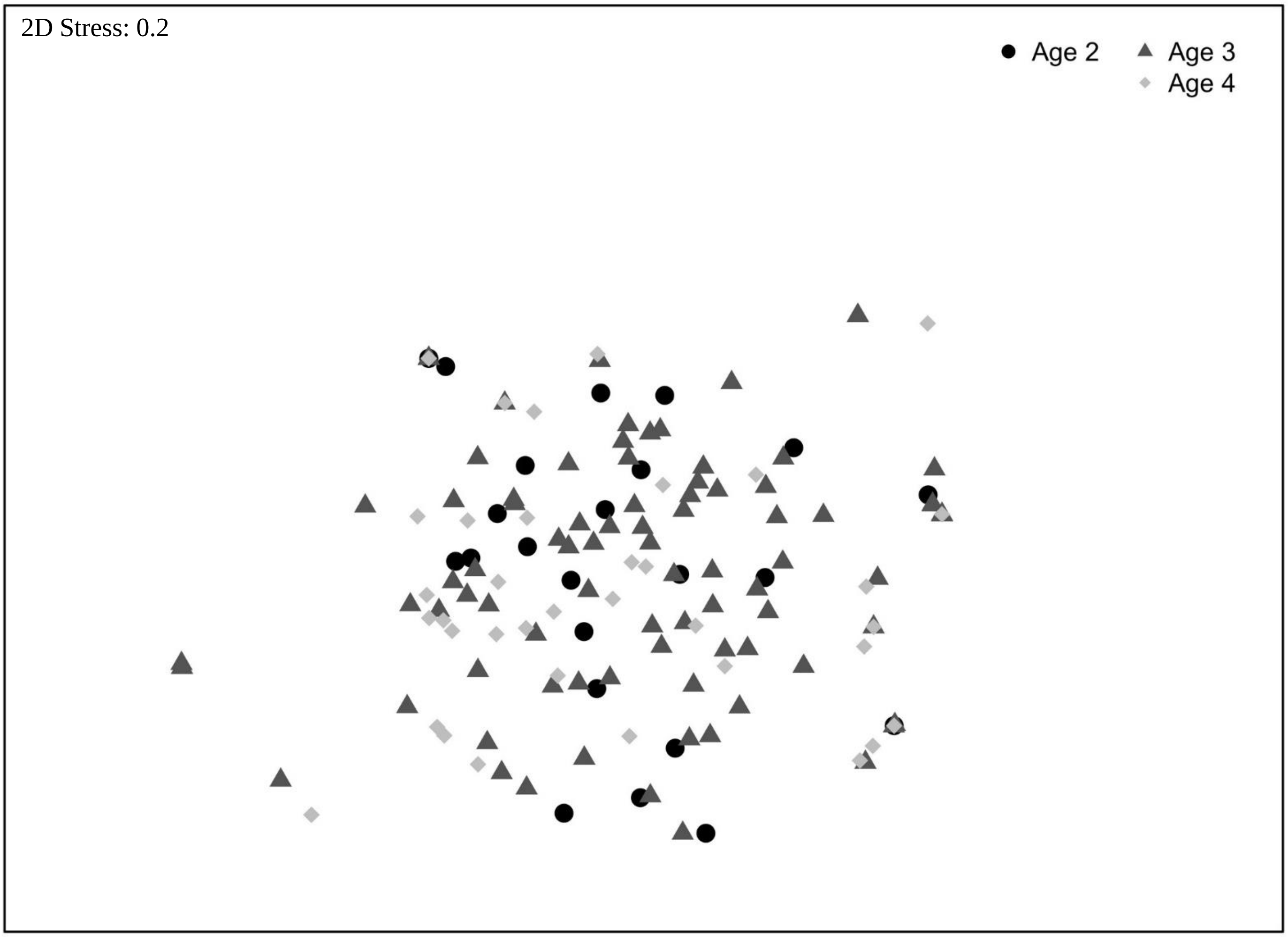

Figure 13: Non-metric Multidimensional Scaling (NMDS) ordination plots depicting Redbreast Sunfish diets by age class when prey items were grouped by habit.

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APPENDIX A

COMPOSITE GUT CONTENT PREY ITEM LIST FOR REDBREAST SUNFISH

Taxa	Summer	Autumn	Winter	Spring	Total
Aeshnidae	4	0	0	1	5
Amphipoda	4	0	0	4	8
Aquatic Lepidoptera	0	0	7	0	7
Baetidae	4	3	1	84	92
Baetiscidae	0	0	0	8	8
Brachycentridae	1	0	2	0	3
Caenidae	5	3	0	0	8
Cambaridae	0	3	3	3	9
Capniidae	0	0	0	1	1
Ceratopogonidae	18	8	0	1	27
Chironominae	145	31	2	15	193
Cladocera	1	0	0	0	1
Collembola	0	0	0	1	1
Cordulegastridae	4	0	0	0	4
Corduliidae	0	0	1	1	2
Corydalidae	0	0	1	0	1
Dipseudopsidae	3	3	0	3	9
Dytiscidae	7	11	16	3	37
Elmidae	28	18	51	0	97
Ephemerellidae	0	1	0	3	4
Ephemeridae	2	18	20	1	41
Gomphidae	5	1	4	5	15
Gyrinidae	1	3	1	3	8
Heptageniidae	18	4	9	49	80
Hirudinea	0	0	0	2	2
Hydrachnidae	2	0	0	0	2
Hydropsychidae	12	8	1	18	39
Hydroptilidae	15	3	9	16	43
Isonychiidae	0	0	0	84	84
Isopoda	4	7	74	49	134
Leptoceridae	45	10	0	7	62
Leptohyphidae	2	2	0	9	13
Leptophlebiidae	0	0	0	5	5
Limnephilidae	7	0	0	18	25
Macromiidae	1	1	8	2	12
Oligochaeta	123	1	0	3	127
Orthocladinae	2	0	0	1	3
Palaemonidae	1	1	0	1	3
Perlidae	2	4	0	42	48
Perlodidae	0	1	1	31	33
Philopotamidae	17	3	0	6	26

Phryganeidae	0	0	0	1	1
Physidae	1	2	2	8	13
Planoorbidae	1	1	1	3	6
Polycentropodidae	14	0	1	4	19
Pteronarcyidae	0	1	0	0	1
Sialidae	2	0	0	0	2
Simulidae	0	3	0	0	3
Sphaeridae	5	5	2	1	13
Tabanidae	0	1	0	0	1
Tanypodinae	17	5	0	5	27
Tipulidae	2	1	15	2	20
Viviparidae	2	10	10	6	28
Unidentified† Anisoptera	0	5	0	0	5
Unidentified Bivalvia	0	0	1	4	5
Unidentified Coleoptera	1	0	2	0	3
Unidentified Diptera	2	0	6	4	12
Unidentified Ephemeroptera	1	2	0	0	3
Unidentified Gastropoda	0	0	0	1	1
Unidentified Odonata	1	0	0	0	1
Unidentified Plecoptera	1	0	2	0	3
Unidentified Pupae	2	2	1	2	7
Unidentified Trichoptera	2	1	2	1	6
Terrestrial Prey	31	19	18	6	74

†Unidentified means that the prey item was too destroyed to identify it to a lower taxonomic level

APPENDIX B

COMPOSITE GUT CONTENT PREY ITEM LIST FOR SNAIL BULLHEAD, SPOTTED SUCKER AND BANNERFIN SHINER

Taxa	**Snail Bullhead**	**Spotted Sucker**	**Bannerfin**
Baetidae	0	1	2
Caenidae	1	2	1
Cambaridae	4	0	0
Ceratopogonidae	2	28	3
Chironominae	5	132	21
Cladocera	0	126	0
Collembola	0	5	0
Copepoda	0	24	0
Cordulidae	2	0	0
Corydalidae	1	0	0
Cyprinidae	1	0	0
Elmidae	2	2	2
Ephemeridae	2	0	0
Gyrinidae	1	0	0
Heptageniidae	1	0	4
Hydrachnidae	1	2	0
Hydropsychidae	2	0	20
Hydroptilidae	0	1	0
Isopoda	0	1	0
Lepidoptera	0	0	1
Leptoceridae	0	0	9
Macromiidae	1	0	0
Oligochaeta	0	51	13
Orthocladinae	2	6	0
Palaemonidae	2	0	0
Perlidae	1	0	0
Philopotamidae	0	0	1
Pleuroceridae	0	0	1
Polycentropodidae	1	0	0
Simulidae	0	0	10
Sphaeridae	0	18	1
Tanypodinae	3	11	3
Tipulidae	0	1	0
Viviparidae	15	0	0
Plant Material	16	0	0
Terrestrial Prey	10	0	2
Unidentified† Bivalvia	2	2	0
Unidentified Decapoda	0	0	1

Unidentified Diptera	0	3	0
Unidentified Ephemeroptera	0	3	6
Unidentified Fish	3	0	0
Unidentified Odonata	2	0	0
Unidentified Plecoptera	1	0	1
Unidentified Trichoptera	1	0	5

†Unidentified means that the prey item was too destroyed to identify it to a lower taxonomic level

APPENDIX C

COMPOSITE GUT CONTENT PREY ITEM LIST FOR BOWFIN

Taxa	Count (Summer and Autumn)
Amphipoda	1
Cambaridae	29
Unidentified† Fish	10
Ictaluridae	1
Macromiidae	2

†Unidentified means that the prey item was too destroyed to identify it to a lower taxonomic level

APPENDIX D

TABLE OF ALL SIMPER VALUES FOR REDBREAST SEASONAL ANALYSES

Taxon	Grouping	Season	Avg. Abundance	Avg. Similarity	Similarity SD	% Contribution	% Cumulative
Trichoptera	Order	Summer	1.02	9.45	0.62	38.65	38.65
Diptera	Order	Summer	0.97	5.58	0.51	22.82	22.82
Terr. Prey	Order	Summer	0.42	3.15	0.29	12.89	12.89
Trichoptera	Order	Autumn	0.46	3.73	0.28	19.72	19.72
Coleoptera	Order	Autumn	0.51	3.5	0.31	18.53	38.24
Ephemeroptera	Order	Autumn	0.55	3.3	0.37	17.46	55.7
Diptera	Order	Autumn	0.61	3.01	0.34	15.91	71.61
Coleoptera	Order	Winter	0.9	9.75	0.61	36.43	36.43
Ephemeroptera	Order	Winter	0.71	7.04	0.58	26.33	62.76
Terr. Prey	Order	Winter	0.49	3.04	0.36	11.38	74.14
Ephemeroptera	Order	Spring	1.72	11.82	0.83	39.48	39.48
Trichoptera	Order	Spring	0.98	8.07	0.61	26.95	66.43
Plecoptera	Order	Spring	0.79	3.32	0.49	11.11	77.53
Clinger	Habit	Summer	0.98	9.49	0.59	31.67	31.67
Burrower	Habit	Summer	1.21	7.3	0.56	24.36	56.02
Climber	Habit	Summer	0.71	5.23	0.45	17.44	73.46
Clinger	Habit	Autumn	0.93	13.62	0.68	46.51	46.51
Burrower	Habit	Autumn	0.81	6.86	0.51	23.42	69.93
Sprawler	Habit	Autumn	0.37	2.42	0.29	8.26	78.19
Burrower	Habit	Winter	1.02	11.54	0.71	31.57	31.57
Clinger	Habit	Winter	1.02	10.88	0.68	29.75	61.32
Swimmer	Habit	Winter	1.02	9.7	0.64	26.54	87.86
Swimmer	Habit	Spring	1.7	15.96	0.97	40.8	40.8

Clinger	Habit	Spring	1.69	14.63	0.99	37.41	78.21

APPENDIX E

TABLE OF ALL SIMPER VALUES FOR REDBREAST AGE CLASS ANALYSES

Taxon	**Grouping**	**Age**	**Avg. Abundance**	**Avg. Similarity**	**Similarity SD**	**% Contribution**	**% Cumulative**
Trichoptera	Order	2	0.83	10.44	0.58	41.46	41.46
Diptera	Order	2	1.32	7.09	0.65	28.15	69.61
Mollusca	Order	2	0.45	2.58	0.32	10.24	79.85
Ephemeroptera	Order	3	0.78	5.23	0.48	23.9	23.9
Trichoptera	Order	3	0.72	4.73	0.39	21.6	45.5
Coleoptera	Order	3	0.56	3.47	0.35	15.83	61.33
Diptera	Order	3	0.6	2.77	0.37	12.66	73.98
Ephemeroptera	Order	4	1.22	7.06	0.56	31.1	31.1
Trichoptera	Order	4	0.78	6.01	0.51	26.47	57.57
Terr. Prey	Order	4	0.43	4.18	0.32	18.41	75.98
Clinger	Habit	2	1.09	11.56	0.74	38.15	38.15
Burrower	Habit	2	1.27	7.58	0.62	25.04	63.19
Climber	Habit	2	0.48	5.23	0.37	17.28	80.48
Clinger	Habit	3	1.16	10.11	0.64	31.69	31.69
Burrower	Habit	3	0.99	8	0.61	25.08	56.77
Swimmer	Habit	3	0.76	7.14	0.52	22.38	79.15
Clinger	Habit	4	1.24	15.42	0.89	46.86	46.86
Swimmer	Habit	4	1.27	5.75	0.46	17.47	64.34
Burrower	Habit	4	0.65	5.06	0.43	15.4	79.73

APPENDIX F

KEY TO THE ABBREVIATED NAMES OF THE CONNECTANCE FOOD WEB

Abbreviation	**Taxon**
AD	Adult dragonfly
AB	Aeshnidae *Basiaeschna*
AY	Aeshnidae *Boyeria*
SB	*Ameiurus brunneus*
AC	*Amia calva*
AM	Amorphous Detritus
AS	Anisoptera
AN	Ant
AL	Aquatic Lepidoptera
AA	Asellidae *Asellus*
AI	Asellidae *Lirceus*
BB	Baetidae *Baetis*
BH	Baetidae *Heterocloeon*
BP	Baetidae *Procloeon*
BV	Bivalvia
BC	Brachycentridae *Brachycentrus*
CC	Caenidae *Caenis*
CB	Cambarus spp.
CN	Centipede
CP	Ceratopogonidae
CH	Chironominae
CD	Cladocera
CO	Collembola
CA	Copepoda
CR	Cordulegastridae *Cordulegaster*
CE	Corduliidae *Epitheca*
CY	Corydalidae *Nigronia*
CL	*Cyprinella leedsi*
C	Cyprinidae
DI	Diatoms
DP	Dipseudopsidae *Phylocentropus*
DD	Dytiscidae *Dytiscus*
DH	Dytiscidae *Heterosternuta*
DY	Dytiscidae *Hydroporus*
DT	Dytiscidae *Hydrotrupes*

DV	Dytiscidae *Hydrovatus*
DL	Dytiscidae *Laccophilus*
DE	Dytiscidae *Liodessus*
DR	Dytiscidae *Lioporeus*
DM	Dytiscidae *Matus*
DN	Dytiscidae *Nebrioporus*
DA	Dytiscidae *Neoporus*
EA	Elmidae *Ancyronyx*
ED	Elmidae *Dubiraphia*
EM	Elmidae *Macronychus*
EO	Elmidae *Optioservus*
ES	Elmidae *Stenelmis*
EE	Ephemerellidae *Ephemerella*
EU	Ephemerellidae *Eurylophella*
EH	Ephemeridae *Hexagenia*
FA	Filamentous Algae
FI	Unidentified Fish
FG	Fungi
GG	Gammaridae *Gammarus*
GA	Gomphidae *Arigomphus*
GD	Gomphidae *Dromogomphus*
GE	Gomphidae *Erpetogomphus*
GO	Gomphidae *Gomphus*
GH	Grasshopper
GY	Gyrinidae *Dinetus*
GR	Gyrinidae *Gyrinus*
HE	Heptageniidae *Epeorus*
HM	Heptageniidae *Maccaffertium*
HY	Hydrarachnidae
HC	Hydropsychidae *Cheumatopsyche*
HH	Hydroptilidae *Hydroptila*
HO	Hydroptilidae *Ochrotrichia*
HS	Hydroptilidae *Stactobiella*
IC	Ictaluridae
LA	*Lepomis auritus*
LN	Leptoceridae *Nectopsyche*
LO	Leptoceridae *Oecetis*
LT	Leptoceridae *Triaenodes*
LY	Leptohyphidae *Tricorythodes*
LH	Limnephilidae *Hydatophylax*

LP	Limnephilidae *Pycnopsyche*
MD	Macromiidae *Didymops*
MM	Macromiidae *Macromia*
SS	*Minytrema melanops*
OL	Oligochaeta
OR	Orthocladinae
PA	Perlidae *Attaneuria*
PN	Perlidae *Neoperla*
PP	Perlidae *Perlesta*
PC	Perlodidae *Clioperla*
PI	Perlodidae *Isoperla*
PM	Perlodidae *Malirekus*
PO	Philopotamidae *Chimarra*
PH	Physidae *Physa*
PB	Planorbidae
PL	Pleuroceridae
PY	Polycentropodidae *Cyrnellus*
PU	Polycentropodidae *Neureclipsis*
PE	Polycentropodidae *Polycetropus*
PT	Pteronarcyidae *Pteronarcys*
SH	Shrimp
SS	Sialidae *Sialis*
SI	Simulidae *Simulium*
SP	Sphaeridae *Sphaerium*
SD	Spider
TB	Tabanidae
TH	Talitridae *Hyallela*
TY	Tanypodinae
TC	Terrestrial Coleoptera
TL	Terrestrial Lepidoptera
TD	Tipulidae *Dicranota*
TM	Tipulidae *Molophilus*
TO	Tipulidae *Ormosia*
TT	Tipulidae *Tipula*
VPD	Vascular Plant Detritus
VC	Viviparidae *Campeloma*
VV	Viviparidae *Viviparus*