2010

Patterns in Fish Community Structure in a Regulated River

Richard Davis
Virginia Commonwealth University

PATTERNS IN FISH COMMUNITY STRUCTURE IN A REGULATED RIVER

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science, Environmental Studies at Virginia Commonwealth University.

By:

RICHARD D. DAVIS
Bachelor of Science in Environmental Studies
Virginia Commonwealth University, 2007

Director: STEPHEN P. MCININCH
CENTER FOR ENVIRONMENTAL STUDIES

Virginia Commonwealth University
Richmond, Virginia
May 2010

Acknowledgements

I am very grateful for the encouragement I received from many individuals throughout the completion of this work. I would like to thank my thesis director, Dr. Stephen P. McIninch, and the members of my committee: Dr. Greg C. Garman, Dr. Paul A. Bukaveckas, and Dr. Rima B. Franklin. I am particularly thankful to Dr. Garman and Dr. McIninch for providing the opportunity of attending graduate school and working in the fisheries ecology lab. I am also grateful to the members of my lab: Dave Hopler, Casey Seelig, Matt Balazik, and Pete Sturke, for assistance in the field and entertainment in the lab. Dr. Donald Young, Drew Garey, and Dr. Johanna Kraus were particularly helpful in providing guidance with my data analyses. Jennifer Cimminelli provided assistance with the gathering of data for the GIS portion of my work. I would also like to thank Shelley Nellis, Jessica Hite, Spencer Bissett, and Adam Chupp for their much needed distractions throughout the completion of my work. Lastly, and most importantly, I would like to thank both my parents and grandparents, without them I would not be where I am today.

Table of Contents

List of Tables

Page

List of Figures

Page

Abstract

PATTERNS IN FISH COMMUNITY STRUCTURE IN A REGULATED RIVER

By Richard Dean Davis

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science, Environmental Studies at Virginia Commonwealth University.

Virginia Commonwealth University, 2010

Director: Stephen P. McIninch, Ph.D.
Center for Environmental Studies

I examined the abundance, composition, and distribution of fish communities in the lower Roanoke River, a hydropeaking system in North Carolina. Fishes were sampled at before and after peaking events over three years; 2007 to 2009. I evaluated trends in species richness, diversity, and assemblage composition. There were no significant differences in either richness or diversity suggesting consistent trends in richness and diversity throughout the study. I used non-metric multidimensional scaling (NMDS) to create a community composition model. Fish composition was noticeably greater post-peaking and changed minimally across time and event. There were no statistically significant differences in species composition among pre or post peaking samples, sites, or

years (ANOSIM $p < 0.05$). I concluded that the small amount of fish community variation observed supports the possibility that the present assemblage has adapted to a regulated flow regime, however a direct relationship between peaking and community composition cannot be established.

Additionally, fishes were sampled at three longitudinal sites during summer months of 2007 to 2009. I examined fish community composition to assess longitudinal gradients away from the source of peaking. Differences among fish species within each longitudinal site were examined by use of trophic and habitat/reproductive guilds. Statistically significant differences were detected between both trophic and reproductive guilds among sites and therefore aided in creating a pattern of longitudinal separation in community structure. The fish community of the Roanoke River between Roanoke Rapids and Hamilton does not appear to show signs of variation that may be attributed exclusively to hydropeaking. Changes in hydrology, river morphometry and topography, and habitat structure may account for the longitudinal variation observed in the community structure analyses.

The Roanoke River has been regulated for over 50 years. It is possible that the existing fish community has adapted to fluctuating flows created by seasonal hydropeaking. I concluded that in order to develop an appropriate community model and evaluate the full extent of changes in fish community characteristics over time long-term monitoring is needed in the Roanoke River.

Introduction

Rivers are one of the most diverse and important features of a continent. River corridors were seen as the pathways for the development of ancient civilizations and modern societies. As human populations increased, so too did the importance of residing on or near rivers for a supply of water and food, navigation for travel and/or commerce, and disposal of waste materials. Prior to the introduction of clean water legislation in the early 1970's, rivers were used as avenues of transport for industrial waste, contaminated human and livestock waste, and little attention was made of nutrient or pollution inputs throughout the watersheds. Industrialization and population increase has resulted in extensive ecological degradation and loss of biological diversity in river habitats within the United States (Poff et al. 1997). Rivers remain one of the most important geographic features and thus have been regulated to provide the maximum amount of goods and services. However, conflict between human use and maintaining ecological integrity continues to hinder management of large river ecosystems.

Much research has focused on the conservation of rivers due to their ecologically and economically important attributes. Within their aquatic and associated terrestrial habitats reside the majority of a region's biodiversity. Standford et al. (1996) suggest that the influence of flow regulation is possibly the most persistent change created by humans on rivers world-wide. In their natural state, rivers are dynamic conduits for the transfer of energy between terrestrial uplands and oceans. However, regulated rivers can alter this flow of energy and affect the functioning of the intact river ecosystem. River regulation may be defined as any hydrologic manipulation of the intact watershed including damming

for flood control, hydropower, navigation, and irrigation or use of river water for cooling of power plants and other industrial facilities. In most regulated rivers flow is controlled by damming and diversions with the exception of few free-flowing reaches (Dynesius and Nilsson 1994). Extensive damming fragments river systems, often leaving flow-regulated segments as the only available habitat for large-river faunal communities incapable of persisting in impounded waters (Freeman et al. 2001, Koel and Sparks 2002). As a result of alteration in river flow, freshwater ecosystems have been severely compromised.

Regulatory constraints on upstream water supply and downstream releases are the only environmental considerations presently included in reservoir operation (Jager and Smith 2008). Often reservoirs are operated without consideration of aquatic ecosystem health. Well-known detrimental effects of alteration of flow regime include: 1) impoundment of free-flowing river habitat, 2) reduced water quality in reservoirs and downstream river reaches, 3) blockage of fish movements, and 4) direct and indirect impacts on biota within the ecosystem (Jager and Smith 2008). Southern warmwater rivers are strongly influenced by hydropower facilities which operate with the goal of maximizing energy production (Jager and Smith 2008). Most energy is produced by channeling high volumes of water through turbines during periods of high electricity demand and releasing the water used through an outfall. This process, termed 'hydropeaking' creates artificial floods. Short-term fluctuations in flow increase currents and depth fluctuations cause increased turbidity, and bed and bank instability (Growns 2007) that few aquatic organisms are adapted to; though some species are more resistant to habitat variability than others (Bain et al. 1988). A peaking flow environment alters

important habitat variables during water release including depth, width, velocity, water temperature, and water quality (Cushman 1985). Hydropower dams widely affect flow volume and temporal variability and pose major challenges for conservation of native riverine fishes (Madejczyk et al. 1998, Freeman et al. 2001). Frequent changes in flow can alter habitat structure and ecosystem function within the river and its tributaries (Jager and Smith 2008). Approximation of natural flow or habitat patterns in rivers regulated by peak-load hydropower dams is clearly confounded by the short-term fluctuations inherent in peak-load operations (Freeman et al. 2001). Flow management of these systems is therefore necessary and is considered to be one of the most widespread disturbances in large rivers (Faser 1972, Ward and Stanford 1983, Bain et al. 1988).

Conserving biological resources native to large river systems increasingly depends on how flow-regulated segments of rivers are managed. Thus, studies suggest that rivers be managed to mimic pre-impacted patterns of flow as closely as possible (Bolgrien et al. 2005). In addition, regulation of rivers for hydropower often results in loss of habitat due to changing river connectivity, consequently fragmenting fish populations (Rifflart et al. 2009). Although impacts to physical habitat are well understood, the responses of fish communities are not. Several studies have examined responses by fish communities to natural levels of environmental variability (e.g. Bain et al. 1988, Nehring and Anderson 1993, Bovee et al. 1994). However the scientific community lacks knowledge of multi-year patterns of fishes depending on variability in flow regulation, particularly in the species rich rivers of the southern United States (Freeman et al. 2001).

The majority of research associated with hydrological modification has focused on the conservation and restoration of economically important fauna, such as trout and salmon (e.g. Berland et al. 2004, Connor and Pflug 2004, Flodmark et al. 2006, Bell et al. 2008). Specifically, hydrologic regime is a significant constraint on lotic fish assemblages and fish diversity. Those fishes that are not seen as economically important contribute to the overall biodiversity of the river and in most cases biodiversity decreases with the regulation of rivers (Welcomme 1994, Standford et al. 1996). Fish diversity may be linked directly to river flow but is also influenced strongly by complex biotic and abiotic processes that function across various spatial and temporal scales (Bain et al. 1988, Angermeier and Schlosser 1989, Rahel and Hubert 1991, Pegg and Taylor 2007). Extreme flow and patterns of flow variability have been shown to directly influence community structure (Meffe 1984, Bain et al. 1988, Jowett and Duncan 1990). Freeman et al. (2001) noted that some fish species downstream from large scale dams have been extirpated because they are unable to cope with altered flow and changes in water quality.

For adult fishes, normal storm events may serve as an environmental cue for spawning (Freeman et al. 2001). For anadromous species, an increase in fish mortality is seen resulting from the passage through dams and reservoirs, thus creating a loss in biodiversity (Harrison and Quinn 1989). In addition to blocking normal movements of fishes upstream and downstream, flow alteration often severs or alters the connection between the river and its floodplain. Additionally, different life stages of fish species require different hydraulic and water quality conditions which are often determined by natural states of hydrology (Bain et al. 1988, Bowen et al. 1998, Jager and Smith 2008).

For native fish assemblages the problem of hydrologic modification should be taken into consideration in order to maintain healthy fisheries in regulated rivers. There is a growing body of literature that describes changes in fish community patterns associated with regulated hydrologic conditions caused by the operations of dams (e.g. Bain et al. 1988, Bain and Boltz 1989, Martinez et al. 1994, Marchetti and Moyle 2001, Growns 2007). Modified flow regimes in regulated rivers affect fish and fish habitats, but the severity and direction of the response varies greatly (Murchie et al. 2008). It is proven to be difficult to separate specific effects of flow regulation from other anthropogenic impacts on the floodplain, such as extraction of gravel/sand, extraction of water, and pollution.).

To better understand the impact of hydropeaking on fish communities in a regulated river I investigate the Roanoke River within the Coastal Plain physiographic province of North Carolina. The low-gradient rivers that lie east of the Fall Line include some of the most diverse habitats for fishes in the United States (Jenkins and Burkhead 1994, Bolgrien et al. 2005). Flow regulation in the Roanoke River alters this natural habitat and impacts ecological health, increasing stress on the overall system (Pearsall et al. 2005).

The primary objective of my research was to quantify trends in species richness and diversity and spatially define fish community composition in the lower Roanoke River under different regulated flow regimes. My secondary objective was to assess longitudinal patterns in fish community variation away from the source of peaking. I examine spatial variation among fish communities that may be attributable to long-term changes in habitat and community composition attributable to hydropeaking. I tested the assumption of previous research that indicates negative impacts on fish assemblages due to hydrologic

modifications. An alternative hypothesis is that any differences found in fish communities temporally (pre and post-peaking) or spatially (longitudinally) may be attributable to other factors. Thus, river regulation may not have damaging effects on fish diversity and community composition. I specifically address the following questions:

1) Does hydropeaking affect species diversity and fish community composition in the channel and shallow water habitats of the Roanoke River immediately downstream from the Dominion Hydropower Station?

2) Is there a longitudinal pattern to fish community composition away from the source of peaking?

Methods

Study Area

The Roanoke River was unregulated until 1950 (Harris and Hightower 2006); however is now regulated by eight dams that control the river flow before it crosses the Fall Line to the Coastal Plain. A series of three dams sits on and just above the Fall Line: John H. Kerr Dam, Lake Gaston Dam, and Roanoke Rapids Dam (Fig. 1). The operations of these facilities are complex; Kerr Dam is operated by the United States Army Corps of Engineers (USACE) and a private energy company, Dominion Inc., operates Gaston and Roanoke Rapids (Pearsall et al. 2005). The largest of these, Kerr Dam, is primarily used for flood control but has a secondary objective of hydropower generation. Lake Gaston Dam is operated to pass Kerr water releases and is also used for hydropower generation. Roanoke Rapids Dam is located approximately 42 miles downstream from Kerr Dam and is used for hydropower generation (Pearsall et al. 2005). The Roanoke River is a 7th order

river that falls under the large river category of the river continuum framework of Vannote et al. (1980). Its basin covers 25,326 km^2, 16,276 km^2 of which are in Virginia continuing into North Carolina where it empties into the Albemarle Sound. Its mean discharge is 232m^3/s and receives 108cm in mean annual precipitation (Benke and Cushing 2005).

Sampling Sites

All sampling locations were located in the Coastal Plain physiographic province (Fig. 2). The Coastal Plain features a flat topography and is underlain by sand, silt, clay, and limestone. The location of sampling sites was selected based on habitat availability and boat accessibility. Each sampling location was sampled so as to include representative fishes associated with shallow water/margin habitat on both North and South banks as well as a mid-channel location for an overall assessment of the fish communities in all habitats of the river. One set of study sites located just upstream of Weldon, NC, were used to address the primary objective. Sampling was conducted each summer between 2007-2009 (hereafter referred to as year 1, year 2, and year 3). Three separate main-stem sampling sites (lower, middle, upper) and an additional side-channel site were sampled once prior to peaking events and once following the first peaking event of the year (Fig. 3). Sampling was conducted before summer peaking on: 30-31 May, 2007, 4 June 2008, and 29 June 2009 and after peaking on: 26 June, 2007, 30 June 2008, and 14 July, 2009 (see Appendix I for USGS hydrographs). Peaking events were described by changes in daily maximum, minimum, and mean discharge (Table 1). In year 3, the side-channel site was inaccessible due to high water levels and therefore was eliminated from any data analyses. A total of 22 community samples were collected over the course of the study.

Three additional Roanoke River sampling locations were selected for the longitudinal study. Progressing downstream, they included: 1) Weldon, 2) Scotland Neck, and 3) Hamilton (Fig. 4). Each site was sampled once yearly (years 1, 2, 3) in two sub-sections to represent 1 kilometer of sampling yielding a total of nine collections. Side-channel areas were not present and thus not sampled. GPS coordinates were taken for all sites and recorded using a Trimble GPS Unit (Appendix II).

Fish Sampling

Main-stem sampling events were conducted using Smith-Root boat electrofishing gear, and side-channel sites were collected using Smith-Root backpack electrofishing gear. Electrofishing settings (voltage/amperage) were set according to conditions of the day (e.g. water temperature, conductivity) for both gear types. Main-stem river collections were made while electrofishing in a downstream direction for approximately 500 meters of habitat per site for each of 2 margins (north and south banks) and the main channel. An additional 500 meter collection was made at each main-stem site while using low-frequency electrofishing. This methodology was employed to target catfishes and was more effective for the sampling of these species. Each 500 meter collection was timed and recorded upon completion. Stream and river lengths were measured using a Bushnell laser rangefinder. Stunned fishes were dipped from the river and placed into a live-well to recover from the initial shock. Upon completion of each segment, fishes were identified to species, checked for parasites and other anomalies, and enumerated prior to being released downstream of the sampling area. Some fishes, such as longnose gar (*Lepisosteus osseus*) and common carp (*Cyprinus carpio*), were enumerated without capture to avoid handling

large fishes. Only those fishes within reachable distance were counted as 'captured'. Side-channel fish sampling was performed in an upstream direction for approximately 150 meters. Fishes were captured with dip nets and placed into buckets for recovery. All fish collections followed Virginia Commonwealth University Institutional Animal Care and Use Committee (IACUC) protocol AD20042. Unidentified fish were preserved (using 10% buffered formaldehyde) and identified in the lab.

Data Analysis

In order to address the primary objective, fish species diversity (Shannon diversity index), evenness, and richness were calculated and compared from data collected during pre-peaking and post-peaking periods at three sampling sites (Upper, Middle, Lower). Additionally, fish community composition was compared between pre and post-peaking samples using Non-metric multidimensional Scaling (NMDS). Corresponding analyses of community differences between pre and post-peaking assemblages were compared using an analysis of similarity (ANOSIM).

For the second objective, longitudinal variation was analyzed using NMDS. In addition, life history aspects were used to develop function guilds for an additional approach to explaining longitudinal variability.

The Shannon index of diversity (Shannon 1948) was used in order to compare species diversity between pre and post-peaking sampling events. The following formula was used to calculate the Shannon index of diversity:

$$H' = - \sum (p_i \ln p_i)$$

Both species richness and evenness were calculated for individual sites for each year. Species richness values were calculated by combining all collections within each sampling site and compiling a list of all species. Species evenness (J') was derived using the Shannon H' value from each sampling site using the formula:

$$J' = H' / H'_{max}$$

Species richness and diversity were analyzed for normal distribution using a Levene's test. A paired-sample t-test was used in order to determine if variation in mean species diversity and mean species richness existed between pre and post-peaking communities. A two-factor analysis of variance (ANOVA) was used to assess annual variation between pre and post-peaking species diversity and species richness. An additional two-factor ANOVA was performed to determine if variation existed among sites between pre and post-peaking species diversity and species richness. Post-hoc comparisons of relative abundance were made using Tukey's multiple comparison procedure. It is important to note that the side-channel sites were eliminated from the ANOVA's due to their significantly different fish communities (stream-like fish communities). Upon inspection of both two-factor ANOVA's the side-channel sites were significantly different from all of the main-stem sites. Because of the possibility of misinterpretation, these sites were then eliminated from the data set.

Non-metric multidimensional Scaling (NMDS) using PC-ORD version 4.0 (McCune and Medford 1999) with the Bray-Curtis distance measure was used to examine how fish assemblage composition varied among pre and post-peaking. NMDS is well suited for non-normal data and does not assume linear relationships among variables

(McCune et al. 2002). NMDS begins by plotting a matrix of resemblance coefficients and then finding the set of coordinates for each assemblage that most closely approximates the relationships indicated by the resemblance matrix. This procedure plots similar assemblages closer together and dissimilar assemblages farther apart. To complement the ordination analysis results, analysis of similarity an (ANOSIM) using PAST version 1.9 (Hammer et al. 2001) with the Bray-Curtis distance measure was used to analyze fish species composition among the pre and post-peaking samples. For this analysis data were pooled among all years. ANOSIM is a non-parametric tool proposed by Clarke (1993) which provides a test of variability between two or more groups of sampling units.

Community samples were combined for each site (Upper, Middle, Lower) among each year. Side-channel samples were not analyzed for this portion of the study. Species that accounted for less than 5% of the data were eliminated in order to minimize the effect of rare species in my analysis. Eliminated species include golden redhorse (*Moxostoma erythrurum*), Atlantic needlefish (*Strongylura marina*), and walleye (*Sander vitreus*). Data were Log_{10} transformed in order to conserve species abundances and ordinated using NMDS to develop a model of community composition. Multivariate analyses were performed using both transformed abundance and proportional abundance. The results presented minor differences and therefore only the transformed abundance data were presented.

Similar multivariate methods were used in order to address longitudinal variability. In addition, differences among species within each longitudinal site were examined by use of trophic and habitat/reproductive guilds. This approach is structured on the notion that

communities are built from groups of species that share certain similarities, either ecological or phylogenetic (Blondel 2003). The term "guild" refers to a group of species that share a common resource (Root 1967). Guild can also refer to groups of species that occupy similar niches without regard to taxonomic position (Blondel 2003). Specific trophic and reproductive guilds were established (see Appendix III & IV) and fish were placed into respective guilds based on life history information obtained from Jenkins and Burkhead (1994) and Menhinick (1991) (Appendix V). Since some species may occupy multiple trophic guilds, guild assignment was based on their dominant habits. These life style metrics are indicators of how important habitat structure and function are at a given site and therefore can be used to indicate which guilds are most successful.

A one-factor ANOVA was utilized in order to assess longitudinal variability and spatial variation differences (among sites) of relative abundance in trophic and reproductive guild structure. Post-hoc comparisons of relative abundance were made using Tukey's multiple comparison procedure. All analyses, except NMDS and ANOSIM, were conducted using SPSS version 17.0. An alpha level of 0.05 was used for all statistical analyses.

Results

Does hydropeaking affect species diversity and fish community composition in the channel and shallow water habitats of the Roanoke River immediately downstream from the Dominion Hydropower Station?

A total of 5,496 fishes was captured between years 1 and 3 at Roanoke Rapids representing 13 families and 38 species. Of those, 1,965 were captured in the pre-peaking sampling events and 3,531 in the post-peaking events (Tables 2 & 3). The most numerous

fish encountered in pre-peaking samples was gizzard shad (*Dorosoma cepedianum*), followed by shorthead redhorse (*Moxostoma macrolepidotum*) and common carp (*Cyprinus carpio*). Six species were encountered in pre-peaking sampling events only, including: quillback (*Carpiodes cyprinus*), golden redhorse (*Moxostoma erythrurum*), blue catfish (*Ictalurus furcatus*), Atlantic needlefish (*Strongylura marina*), walleye (*Sander vitreus*), and rosyface shiner (*Notropis rubellus*). The most numerous fish encountered in post-peaking sampling events was shorthead redhorse (*Moxostoma macrolepidotum*), followed by gizzard shad (*Dorosoma cepedianum*) and American eel (*Anguilla rostrata*). Southern flounder (*Paralichthys lethostigma*) was the only exclusive species captured in post-peaking sampling events. American shad (*Alosa sapidissima*) were present in eight samples during pre-peaking collections and most likely reflect adults at the end of their spawning run. The absence of adults during the post-peaking collections may be attributed to their anadromous life style. The single post-peaking occurrence is a collection of a small young of the year specimen.

Species diversity varied among site, year, and pre/post-peaking sampling events. In most cases, the most abundant species varied between sites for pre and post-peaking sampling events. The highest species diversity was found at the lower sites with the exception of one sampling event during year 1 when the upper site contained the highest species diversity (Tables 4 - 6). In addition, species evenness was consistently the highest among the lower sites for all years and all sampling events.

The diversity indices for all sites were summed for each year in order to obtain mean species diversity for each year among each sampling event. There was no significant

difference in mean species richness between pre and post-peaking samples ($p > 0.05$) nor mean species diversity between pre and post-peaking samples ($p > 0.05$). There was no annual variation in mean species richness or diversity between pre and post-peaking samples ($p > 0.05$) (Fig. 5 & 6). There was no significant difference in species richness or species diversity among sites between pre and post-peaking samples ($p > 0.05$) (Fig. 7 & 8).

Community Analysis

Ordinations for pre/post-peaking sites yielded a two-dimensional solution that accounted for 83% (47% and 36%, respectively) of the variation in fish assemblage composition among pre and post-peaking communities. The final stress for the two-dimensional solution was 0.09. This value represents a low to moderate amount of distortion of the original distance matrix, based on the guidelines described in the literature (Clarke 1993, McCune et al. 2002). Pre and post-peaking assemblages separated mostly on the first axis (Fig. 9). The greatest amount of separation was seen between the upper sites while the lower and middle sites were relatively similar in composition (Fig. 10). Although visually interesting, there were no significant differences in species compositions among peaking samples, sites, or years (ANOSIM $p > 0.05$).

Is there a longitudinal pattern to fish community variation away from the source of peaking?

There was a total of 2,965 fishes captured between years 1 and 3 representing 14 families and 38 species (Table 7). The most numerous fish encountered over the three year period was white catfish (*Ameiurus catus*), followed by eastern silvery minnow

(*Hybognathus regius)* and satinfin shiner (*Cyprinella analostana*). There were four species encountered in the longitudinal portion of the study which were not encountered in the pre/post-peaking part of the study, which were: bay anchovy (*Anchoa mitchilli*), alewife (*Alosa pseudoharengus*), swallowtail shiner (*Notropis procne*), and grass carp (*Ctenopharyngodon idella*).

Community Analysis

Ordinations for longitudinal community structure yielded a two-dimensional solution that accounted for 93% (47% and 46%, respectively) of the variation in fish assemblage composition. The final stress for the two-dimensional solution was 0.12. This value represents a low to moderate amount of distortion of the original distance matrix. There was separation between the upper (Weldon), middle (Scotland Neck) and lower (Hamilton) sites (Fig. 11).

Guild Associations

Trophic Comparisons

Omnivores were the dominant trophic guild at both Hamilton and Scotland Neck, whereas general carnivores dominated Weldon (Fig. 12). Mean proportions of general carnivores, planktivores, general invertivores, and insectivores were statistically significantly different among sites ($p < 0.05$) (Table 8). Unexpectedly, the mean proportion of detritivores did not significantly differ among sites. This was anticipated due to the high capture of eastern silvery minnow (*H. regius*) at the upper site (Weldon) during year 1 of the study.

Reproductive/Habitat Comparisons

The mean proportion of the marine spawners was highest at Weldon. At Scotland Neck, the mean proportion of broadcast spawners was highest, and at Hamilton the mean proportion of crevice spawners was highest (Fig. 13). Mean proportions of reproductive guilds were statistically significantly different among sites ($p < 0.05$). Post-hoc analyses revealed all guilds, with the exception of nest and benthic spawners, were significantly different among sites (Table 9).

Discussion

Peaking Relationships and Community Composition

The fish assemblage in the Roanoke River did not appear to be influenced by changes in hydrology associated with hydropeaking. The lack of association between altered river hydrology and fish assemblages either suggests that peaking has little to no effect on fish assemblages in the lower Roanoke, or that other potential influences on fish ecology, have a greater influence than altered flow regimes. Changes in species richness or species diversity were not apparent between pre and post-peaking samples. Both assemblages showed a high degree of richness for the region, and a high diversity index (Jenkins and Burkhead 1994). In only one of the four sampling regions was there a dominant species that may have impacted species diversity. The middle stretch was dominated by gizzard shad (*D.cepedianum)* and in some cases the collection of all individuals was not possible. The high density of this fish in this sampling region is likely due to the location of a warm outfall from a local paper plant. Gizzard shad may be attracted to such areas due to the constant suspension of particles, plankton, and other

organisms on which they feed (Dave Hopler, personal comm.). The flow of water across the adjacent floodplain is thought to be one of the key factors in describing both diversity and composition (Poff and Allan 1995) and the regulation of rivers removes this component out of the biotic interactions within the region (Pegg and Taylor 2007). Some life history characteristics (i.e. anadromy) and seasonal variation in species habitat preference may explain variation in communities among the samples.

Poff (1997) suggested that hydrological variables limit species distribution and composition, and that substantial changes in hydrology can lead to different assemblage structure. In the present study, hydrological variables were not measured, which makes it difficult to determine if changes in hydrology affected composition of fish communities. Fish species composition and diversity are directly linked to biotic and abiotic processes that function across various scales of space and time (Pegg and Taylor 2007). Livingston et al. (1982) and Hughes et al. (1987) provided insight into the interacting biotic temporal processes involving rates of evolutionary speciation and dispersal within regulated river systems. Such patterns are shown to influence species diversity within an among river systems. The Roanoke River has been regulated for 50 years and it is possible that the existing fish community has adapted to the fluctuating flows of peaking events. Ecological paradigms such as the natural flow paradigm (Poff et al. 1997) are based on the importance of flooding regimes and the interaction of the river and floodplain habitats. The small amount of fish community variation observed during the three-year study period supports the possibility that the present assemblage has adapted to a regulated flow regime.

In this study, there was a visual difference between pre and post-peaking community composition in the upper regions sampled. There is a distinct area of rapids in the upper region creating in the separation between habitats of the main-stem river. In the pre-peaking sampling events, some species were present due to higher levels of water. In the post-peaking sampling events the level of water was significantly lower, increasing the likelihood of fishes becoming stranded in the pools beneath the rapids. Given that abundance depended on year and event (pre vs. post), it is not surprising that there were visual differences in assemblage composition. Angermeier and Schlosser (1989) suggest that in a system that frequently fluctuates between physically harsh and benign conditions, species composition and abundance may remain in continual flux due to immigration/emigration dynamics. It is possible that during peaking flows fishes have adapted and therefore find refuge outside the main-stem river within tributaries. Other considerations are that fishes have adapted their diet and/or feeding because of peaking events, and additionally have altered their behaviors to cope with flows during peaking events. While the Roanoke River experiences substantial oscillation of flow during peaking season, the persistence of species in sampling events prior and subsequent to peaking suggests that these dynamics are not significantly impacting the extant fish community.

Longitudinal Patterns in Community Composition

Large river ecosystems naturally exhibit a certain degree of community differentiation from upstream to downstream (McClelland et al. 2006). The longitudinal sites separated in the ordination results, however for most community analyses, including

NMDS, the minimum sample size recommended is ten sample units (McCune et al. 2002). Even in these circumstances, it is apparent that there was some degree of longitudinal variation away from the source of peaking. Minimal change occurred in the fish species composition at each site between years. Faunal persistence existed at each reach between years. This would suggest that Roanoke River fishes demonstrate persistence across several years of rapidly changing hydrologic conditions (Ross et al. 1985, Matthews 1986).

Strange et al. (1992) suggested that the mechanisms by which fish communities develop and stabilize are particularly hard to determine due to contrasting life histories of fish species. Changes in biotic and abiotic interactions play an important role in determining fish community structure, especially between the upper and lower river regions. Fishes more tolerant of waters with higher sediment loads should be present in greater abundance farther downstream where these conditions exist. Further investigations into the fish community through guild associations gave some insight into the structure of the present community. It was observed that general carnivores dominated the upper regions whereas omnivores and insectivores dominated the middle and lower regions. Sunfishes such as redbreast sunfish (*L. auritus*) and bluegill (*L. macrochirus*) dominated the upper regions where there are more rocky areas for hiding and nesting. White catfish (*A. catus*) and gizzard shad (*D. cepedianum*) dominated the middle and lower region. These areas are characteristic of moderate flow with typical meandering of the river. In addition, both the middle and lower regions are topographically similar in that they are characterized by more sand/silt bottoms. Satinfin shiner (*C. analostana*), a minnow that feeds on drifting items in the water column, was increasingly abundant in the lower region.

An interesting feature of the upper region is the number of sucker species (*Moxostoma spp*.) that occur throughout the study. Suckers do not thrive in heavily silted or anaerobic river bottoms. In the Roanoke River, constant fluctuations in flow disturb the river bottom and in most cases sucker species would not be tolerant of such conditions. However, these species were abundant in the upper region. The trophic guilds were equally represented among the three sampling regions within the three-year period.

Marine spawners accounted for a significantly higher proportion of abundance in the upper region than in the middle or lower region due to the high abundance of American eel (*A. rostrata*). The middle and lower regions were characterized by broadcast and nest spawners. This can be explained by the time of year that sampling took placed for the longitudinal study (mid-late July). Late summer spawners such as white catfish (*A. catus*) influenced the proportion of nest spawners in the lower region. Additionally, more of these fishes were caught in the middle and lower regions, aiding in the increase of nest and broadcast spawners.

A degree of community differentiation was apparent when using guild associations creating a longitudinal separation pattern in community structure that suggests well-developed patterns of community composition under the constraints of rapid hydrologic variability. The fish community of the Roanoke River between Weldon and Hamilton did not show signs of variation that may be attributed exclusively to hydropeaking. Longitudinal variation in hydrology, river morphometry and topography, and habitat structure may account for the variation seen in community structure.

Conclusions

Bain et al. (1988) suggested that the effects of flow regulation operate as a main structuring agent for fish abundance, diversity, and composition. Understanding fish community structure within regulated rivers has implications for conservation and biodiversity. In the Roanoke River, the constant environmental variability would predictably create variability in community structure and a reduction in species diversity, however, I found mixed results. Persistence of species and the consistency in number of individuals over time was evident among sites. In few cases were there species that were captured on a single occurrence. Though mean species richness and diversity were not statistically significantly different, the numbers of fishes caught in the post-peaking sampling events were markedly higher, leaving the interesting question of whether this is a sampling bias, or the possibility that fishes are more tolerant to rapid variability than expected. The fish community showed consistent longitudinal patterns of abundance such that community attributes did not markedly differ over time. As with any aquatic system, trophic and reproductive success is important in determining the structure of the community. I found that a degree of community differentiation was apparent when using guild associations, suggesting a longitudinal pattern of community structure away from the source of peaking.

The role of environmental variables (i.e. temperature, dissolved oxygen, conductivity) and their relationship in constraining fish community structure was not observed in this study. Growns and Marsh (2000) used 300 variables describing differing aspects of river hydrology to characterize modified flows. By doing so, they were able to

relate changes in hydrology to changes in fish community structure. In addition, the temporal scale of this study is abbreviated compared to other studies on regulated river systems. McCleelland et al. (2006) were able to detect longitudinal differences in fish community structure on the Illinois River using a fifteen year dataset. They concluded that without the proper management these types of systems would experience a shift in production and an overall reduction in biodiversity.

The Roanoke River represents a complex, rapidly changing environment that fishes must adapt to in order to survive. There appears to be no changes in diversity or composition that can be solely attributed to hydropeaking. It is highly likely that the existing fish community has adapted to fluctuating flows of peaking events. Considering the Roanoke River has been regulated for some 50 years, it is possible that the fishes that are most sensitive to hydropeaking impacts have long been extirpated. Thus, the small amount of community variation during the three-year study period supports the possibility that the present assemblage has adapted to the regulated flow. Further investigations into the tributaries of the Roanoke River should be evaluated in order to determine the broad scale effects of hydropeaking. I find that the number of fishes captured post-peaking compared to pre-peaking is alarming, and therefore conclude that the fish community is not stabilized. However, I cannot relate hydropeaking directly to this cause. Therefore, long-term monitoring is needed in the Roanoke River to evaluate the full extent of changes in fish community characteristics over time.

References

Angermeir P.L. and I.J. Schlosser. 1989. Species-area relationships for stream fishes. *Ecology* 70: 1450-62.

Bain, M.B., Finn, J.T., and H.E. Booke. 1988. Streamflow regulation and fish community structure. *Ecology* 69: 382-392

Bain, M.B. and J.M. Boltz. 1989. Regulated streamflow and warmwater stream fish; a general hypothesis and research agenda. *U.S. Fish and Wildlife Service Biolgical Report* 89(18), Washington, USA.

Bell, E., Kramer, S., Zajanc, D. and J. Aspittle. 2008. Salmonid fry stranding mortality associated with daily water level fluctuations in Trail Bridge Reservoir, Oregon. *Fisheries Management* 28: 1515-1528

Benke, A.C. and C. E. Cushing. 2005. Rivers of North America. Elsevier Academic Press, Burlington, Massachusetts, USA.

Berland, G., Nickelsen, T. Heggenes, J., Okland, F., Thorstad, E.B, and J. Halleraker. 2004. Movements of wild Atlantic salmon parr in relation to peaking flows below a hydropower station. *River Research and Applications* 20(8): 957-966

Blondel, J. 2003. Guilds or functional groups: Does it matter? *Oikos* 100: 223-231.

Bolgrien, D.W., Angradi, T.R., Schweiger, E.W. and J.R. Kelly. 2005. Contemplating the assessment of great river ecosystems. *Environmental Monitoring and Assessment* 103: 5-20

Bovee, K. D., Newcomb, T. J., and T.G. Coon. 1994. Relations between habitat variability and population dynamics of bass in the Huron River, Michigan. *National Biological Survey Report,* 22, 19 pp.

Bowen, Z.H., Freeman, M.C., and K.D Bovee. 1998. Evaluation of generalized habitat criteria for assessing impacts of altered flow regimes on warmwater fishes. *Transactions of the American Fisheries Society* 127: 455-468.

Clarke, K.R. 1993. Non-parametric multivariate analysis of changes in community structure. *Australian Journal of Ecology* 18: 117-143

Connor, E. and D.E. Pflug. 2004. Changes in the distribution and the density of pink, chum, and Chinook salmon spawning in the upper Skagit River in response to flow management measures. *Fisheries Management* 24(3): 835-852

Cushman, R.M. 1985. Review of ecological effects of rapidly varying flows downstream from hydroelectric facilities. *North American Journal of Fisheries Management* 5: 330-339

Dynesius, M. and C. Nilsson. 1994. Fragmentation and flow regulation of river systems in the northern third of the world. *Science* 266: 753-762.

Flodmark, L.E.W, Forseth, T. L., Abee-Lund, J.H., and L.A. Vollestad. 2006. Behavior and growth of juvenile brown trout exposed to fluctuating flow. *Ecology of Freshwater Fish* 15: 57-65

Fraser, J.C. 1972. Regulated discharge and the stream environment. *River Ecology and Management*: 264-286. Academic Press, New York, New York, USA.

Freeman M.C., Bowen, Z.H., Bovee, K.D. and E.R. Irwin. 2001. Flow and habitat effects on juvenile fish abundance in natural and altered flow regimes. *Ecological Applications* 11(1): 179-190

Growns, I. and N. Marsh. 2000. Characterizations of flow in regulated and unregulated streams in eastern Australia. Cooperative Research Centre for Freshwater Ecology, Tech Report 3/2000

Growns, I. 2007. The influence of changes to river hydrology on freshwater fish in regulated rivers of the Murray-Darling basin. *Hydrobiologia* 596: 203-211.

Hammer, O., Harper, D.A.T., and P. D. Ryan, 2001. PAST: Paleontological Statistics Software Package for Education and Data Analysis. Palaeontologia Electronica 4(1): 9pp.

Harris, J.E. and J.E. Hightower. 2006. Relative abundance of migratory fishes within a restored braided-channel habitat below the Roanoke Rapids Dam. North Carolina Cooperative Fish and Wildlife Research Unit. Year 2005 Report. North Carolina State University.

Harrison, S. and J.F. Quinn. 1989. Correlated environments and the persistence of metapopulations. *Oikos* 56: 293-298

Hutchinson, G.E. 1959. Homage to Santa Rosalia or why are there so many kinds of animals? *American Naturalist* 93: 145-159

Hughes, R., Rexstad, E., and C.E. Bond. 1987. The relationship of aquatic ecoregions, river basins and physiographic provinces to the ichthyogeographic regions of Oregon. *Copeia* 423-432.

Jager, H.I. and B.T Smith. 2008. Sustainable reservoir operation: Can we generate hydropower and preserve ecosystem values? *River Research Applications* 24: 340-352.

Jenkins, R. E and N. M. Burkhead. 1994. Freshwater Fishes of Virginia. American Fisheries Society, Bethesda, Maryland, USA.

Jowett, I. and M.J. Duncan. 1990. Flow variability in New Zeland rivers and its relationship to in-stream habitat and biota. *New Zealand Journal of Marine and Freshwater Research* 24: 305-317

Koel, T.M. and R.E. Sparks. 2002. Historical patterns of river stage and fish communities as criteria for operations of dams on the Illinois River. *River Research Applications* 18:3-19.

Livingston, D.A., Rowland, M. and P.E. Bailey. 1982. On the size of African riverine fish faunas. *American Zoologist* 22: 361-369

Lubchenco, J., Olson, A. M., Brubaker, L. B., Carpenter, S. R., Holland, M. M., Hubbell, S. P., Levin, S. A, MacMahon, J. A., Matson, P. A., Melillo, J. M., Mooney, H. A., Peterson, C. H., Pulliam, H. R., Real, L. A., Regal, P. J. and P. G. Riser. 1991. The sustainable biosphere initiative: An ecological research agenda. *Ecology* 72(2): 371 -412.

Madejczyk, J.C., Mundahl, N.D. and R.M. Lehtinen. 1998. Fish assemblages of natural and artificial habitats within the channel border of the upper Mississippi River. *American Midland Naturalist* 139: 296-310

Matthews, W.J. 1986. Fish faunal structure in an Ozark stream: stability, persistence, and a catastrophic flood. *Copeia* 1986(2): 388-397.

Marchetti, M.P. and P.B. Moyle. 2001. Effects of flow regime on fish assemblages in a regulated California stream. *Ecological Applications* 11(2): 530-539.

Martinez, P.J., Chart, T.E., Trammell, M.A., Wulschleger, J.G. and E.P. Bergersen. 1994. Fish species composition before and after construction of a main stream reservoir on the White River, Colorado. *Environmental Biology of Fishes* 40: 227-239.

McCune, B., Grace, J.B., and D.L. Urban. 2002. Analysis of Ecological Communities. MjM Software Designs, Gleneden Beach, Oregon, USA.

McCune, B. and M.J. Medford. 1999. PC-ORD. Multivariate analysis of ecological data. Version 4.0. MjM Software, Gleneden Beach, OR.

McClelland, M.A., Pegg, M.A., and T.W. Spier. 2006. Longitudinal patterns of the Illinois River waterway fish community. *Freshwater Ecology* 21(1): 91-99

Meffe, G.K. 1984. Effects of abiotic disturbance on coexistence of predator-prey fish species. *Ecology* 65(5): 1525-1534.

Menhinick. E.F. 1991. The freshwater fishes of North Carolina. North Carolina Wildlife Resource Commission, Raleigh, North Carolina.

Murchie, K.J., Hair, K.P.E., Pullen, C.E., Redpath, T.D., Stephens, H.R., and S.J. Cooke. 2008. Fish response to modified flow regimes in regulated rivers: research methods, effects, and opportunities. *River Research and Applications* 24: 197-217

Nehring R.B. and R.M. Anderson. 1993. Determination of population-limiting critical salmonid habitats in Colorado streams using the Physical Habitat Simulation System. *Rivers* 4: 1–19

Pearsall, S.H., McCrodden, B.J. and P.A. Townsend. 2005. Adaptive management of flows in the lower Roanoke River, North Carolina, USA. *Environmental Management* 35(4): 353-367

Pegg, M.A. and R.M. Taylor. 2007. Fish species diversity among spatial scales of altered temperate rivers. *Journal of Biogeography* 34: 549-558.

Poff, N.L. 1997. Landscape filters and species traits: towards mechanistic understanding and prediction of stream ecology. *Journal of North American Benthological Society* 16: 391-409

Poff, N.L., Allen, J.D., Bain, M.B., Karr, J.R., Prestegaard, K.L., Richter, B.D., Sparks, R.E., and J.C. Stromberg. 1997. The Natural Flow Regime. *BioSience* 47(11): 769-784

Poff, N.L. and J.D. Allan. 1995. Functional organization of stream fish assemblages in relation to hydrological variability. *Ecology* 76: 606-627.

Postel, S., and S. Carpenter. 1997. Freshwater ecosystem services. Pages 195-214 *In* Daily, G.C., ed. Nature's Services: Societal Dependence on Natural Ecosystems. Washington (DC): Island Press.

Rahel, F.J. and W.A. Hubert. 1991. Fish assemblages and habitat gradients in rock mountain-great plains stream: biotic zonation and additive patterns of community change. *Transactions of the American Fisheries Society* 120: 319-332

Richter, B.D., Matthews, R., Harrison, D.L., and R. Wigington. 2003. Ecologically sustainable water management: Managing river flows for ecological integrity. *Ecological Apps*. 13(1): 206-224

Rifflart, R., Carrel, G., Coarer, Y.L., and B.N. Fontez. 2009. Spatio-temporal patterns of fish assemblages in a large regulated alluvial river. *Freshwater Biology* 54: 1544-1559

Root R.B. 1967. The niche exploitation pattern of the blue-gray gnatcatcher. *Ecological Monographs* 37: 317-350

Ross, S.T., Matthews, W.J. and A.A. Echelle. 1985. Persistence of stream fish assemblages: effects of environmental change. *The American Naturalist* 126(1): 24-40.

Shannon, C.E. 1948. A mathematical theory of communication. *Bell System Technical Journal* 27: 379–423 and 623–656

Stanford, J.A., Ward, J.V., Liss, W.J., Frissell, C.A., Williams, R.N., Lichatowich, J.A., and C.C. Coutant. 1996. A general protocol for restoration of regulated rivers. *Regulated Rivers: Research and Management* 12: 391-413

Strange, E.M., Moyle, P.B. and T.C. Foin. 1992. Interactions between stochastic and deterministic processes in stream fish community assembly. *Environmental Biology of Fishes* 36: 1-15.

Vannote, R.L., Minshall, G.W., Cummings, K.W., Sedell, J.R., and C.R. Cushing. 1980. The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences* 37: 130-37.

Welcomme, R.L. 1994. The status of large river habitats. *In Rehabilitation of Freshwater Fishes*, CowX IG (ed.). Fishing News Books: Oxford, 11-20

Table 1. Summary of minimum, maximum, and mean discharge (m^3/s) during peaking events.

	Discharge (m^3/s)		
Peaking Duration	Minimum	Maximum	Mean
6/18/2007	79	595	186
6/19/2007	79	595	230
6/20/2007	80	580	151
6/16/2008	80	416	127
7/13/2009	64	422	94
7/14/2009	63	422	85

Table 2. Summary of fishes captured pre-peaking at Roanoke Rapids.

Family	Genus/species	Common name	Pre Peaking (# of individuals)		
			2007	2008	2009
Lepisosteidae	*Lepisosteus osseus*	longnose gar	27	44	21
Amiidae	*Amia calva*	bowfin	14	4	0
Anguillidae	*Anguilla rostrata*	American eel	43	35	15
Clupeidae	*Alosa aestivalis*	blueback herring	0	5	7
	Alosa sapidissima	American shad	22	54	7
	Dorosoma cepedianum	gizzard shad	60	178	123
	Dorosoma petenense	threadfin shad	0	0	3
Cyprinidae	*Cyprinella analostana*	satinfin shiner	15	27	6
	Cyprinus carpio	common carp	97	21	23
	Hybognathus regius	eastern silvery minnow	0	1	0
	Notropis rubellus	rosyface shiner	0	0	13
	Notropis amoenus	comely shiner	2	61	0
	Notropis hudsonius	spottail shiner	2	30	2
Catostomidae	*Carpiodes cyprinus*	quillback	2	1	2
	Erimyzon oblongus	creek chubsucker	0	1	2
	Moxostoma macrolepidotum	shorthead redhorse	133	73	140
	Moxostoma erythrurum	golden redhorse	1	0	0
	Moxostoma pappillosum	V-lip redhorse	4	3	1
	Moxostoma collapsum	notchlip redhorse	11	36	22
Ictaluridae	*Ameiurus catus*	white catfish	49	47	45
	Ameiurus platycephalus	flat bullhead	7	4	3
	Ameiurus nebulosus	brown bullhead	1	0	0
	Noturus insignis	margined madtom	7	3	2
	Ictalurus furcatus	blue catfish	0	0	1
	Ictalurus punctatus	channel catfish	24	12	8
Mugilidae	*Mugil cephalus*	striped mullet	36	21	14
Belonidae	*Strongylura marina*	Atlantic needlefish	1	0	0
Moronidae	*Morone americana*	white perch	0	1	1
	Morone saxatilis	striped bass	10	16	5
Centrarchidae	*Micropterus salmoides*	largemouth bass	28	25	16
	Lepomis auritus	redbreast sunfish	39	32	30
	Lepomis macrochirus	bluegill	11	4	1
	Lepomis microlophus	redear sunfish	3	1	0
Percidae	*Sander vitreus*	walleye	1	0	0
	Perca flavescens	yellow perch	2	1	3
	Percina roanoka	Roanoke darter	31	13	0
	Etheostoma olmstedi	tessellated darter	8	4	0
Paralichthyidae	*Paralichthys lethostigma*	southern flounder	0	0	0

Table 3. Summary of fishes captured post-peaking at Roanoke Rapids.

Family	Genus/species	Common name	Post-peaking (# of individuals)		
			2007	2008	2009
Lepisosteidae	*Lepisosteus osseus*	longnose gar	16	34	9
Amiidae	*Amia calva*	bowfin	29	21	3
Anguillidae	*Anguilla rostrata*	American eel	64	255	236
Clupeidae	*Alosa aestivalis*	blueback herring	1	0	0
	Alosa sapidissima	American shad	0	2	0
	Dorosoma cepedianum	gizzard shad	197	95	267
	Dorosoma petenense	threadfin shad	9	91	0
Cyprinidae	*Cyprinella analostana*	satinfin shiner	13	9	1
	Cyprinus carpio	common carp	46	93	41
	Hybognathus regius	eastern silvery minnow	0	2	57
	Notropis rubellus	rosyface shiner	0	0	0
	Notropis amoenus	comely shiner	0	21	0
	Notropis hudsonius	spottail shiner	7	0	14
Catostomidae	*Carpiodes cyprinus*	quillback	0	0	0
	Erimyzon oblongus	creek chubsucker	1	0	0
	Moxostoma macrolepidotum	shorthead redhorse	125	158	313
	Moxostoma erythrurum	golden redhorse	0	0	0
	Moxostoma pappillosum	V-lip redhorse	16	5	2
	Moxostoma collapsum	notchlip redhorse	43	32	93
Ictaluridae	*Ameiurus catus*	white catfish	37	27	38
	Ameiurus platycephalus	flat bullhead	0	7	24
	Ameiurus nebulosus	brown bullhead	2	0	0
	Noturus insignis	margined madtom	1	5	6
	Ictalurus furcatus	blue catfish	0	0	0
	Ictalurus punctatus	channel catfish	22	27	73
Mugilidae	*Mugil cephalus*	striped mullet	19	112	19
Belonidae	*Strongylura marina*	Atlantic needlefish	0	0	0
Moronidae	*Morone americana*	white perch	1	1	1
	Morone saxatilis	striped bass	10	6	4
Centrarchidae	*Micropterus salmoides*	largemouth bass	34	110	38
	Lepomis auritus	redbreast sunfish	59	154	131
	Lepomis macrochirus	bluegill	13	21	14
	Lepomis microlophus	redear sunfish	5	4	3
Percidae	*Sander vitreus*	walleye	0	0	0
	Perca flavescens	yellow perch	4	5	0
	Percina roanoka	Roanoke darter	9	30	4
	Etheostoma olmstedi	tessellated darter	5	11	3
Paralichthyidae	*Paralichthys lethostigma*	southern flounder	0	9	2

Table 4. Shannon Index of Diversity calculations for 2007 pre and post-peaking sampling events.

	Pre-peaking				Post-peaking			
Assemblage structural index	Lower	Middle	Upper	Side-channel	Lower	Middle	Upper	Side-channel
Richness								
Species	23	20	22	8	16	21	21	7
Family	11	12	11	5	10	11	11	5
Diversity								
Shannons H'	2.63	2.53	2.41	1.72	2.40	2.10	2.61	1.34
Evenness								
Based on H'	0.84	0.84	0.78	0.83	0.86	0.69	0.85	0.69

Table 5. Shannon Index of Diversity calculations for 2008 pre and post-peaking sampling events.

	Pre-peaking				Post-peaking			
Assemblage structural index	Lower	Middle	Upper	Side-channel	Lower	Middle	Upper	Side-channel
Richness								
Species	23	19	18	10	22	21	22	7
Family	10	10	10	5	11	11	12	5
Diversity								
Shannons H'	2.70	1.75	2.31	1.90	2.57	2.30	2.13	1.56
Evenness								
Based on H'	0.86	0.60	0.80	0.82	0.83	0.75	0.69	0.80

Table 6. Shannon Index of Diversity calculations for 2009 pre and post-peaking sampling events (+ = did not sample due to hydrological conditions).

	Pre-peaking				Post-peaking			
Assemblage structural index	Lower	Middle	Upper	Side-channel	Lower	Middle	Upper	Side-channel
Richness								
Species	16	19	20	+	15	19	23	+
Family	7	10	10		10	10	12	
Diversity								
Shannons H'	2.27	1.94	2.03	+	2.01	1.93	2.04	+
Evenness								
Based on H'	0.82	0.66	0.68	+	0.74	0.66	0.65	+

Table 7. Summary of fishes captured at three longitudinal sites (Weldon, Scotland Neck, and Hamilton).

Family	Genus/Species	Common name	Occurrence (# of individuals)		
			2007	2008	2009
Lepisosteidae	*Lepisosteus osseus*	longnose gar	85	42	53
Amiidae	*Amia calva*	bowfin	23	9	8
Anguillidae	*Anguilla rostrata*	American eel	30	42	29
Engraulidae	*Anchoa mitchilli*	bay anchovy	0	3	13
Clupeidae	*Alosa aestivalis*	blueback herring	5	2	8
	Alosa sapidissima	American shad	10	28	19
	Alosa pseudoharengus	alewife	6	0	0
	Dorosoma cepedianum	gizzard shad	45	72	109
	Dorosoma petenense	threadfin shad	2	10	1
Cyprinidae	*Cyprinella analostana*	satinfin shiner	114	140	157
	Cyprinus carpio	common carp	53	58	33
	Ctenopharyngodon idella	grass carp	0	0	1
	Hybognathus regius	eastern silvery minnow	326	57	109
	Notemigonus crysoleucas	golden shiner	1	1	0
	Notropis rubellus	rosyface shiner	0	0	3
	Notropis amoenus	comely shiner	6	9	3
	Notropis hudsonius	spottail shiner	15	6	70
	Notropis procne	swallowtail shiner	1	3	0
Catostomidae	*Carpiodes cyprinus*	quillback	1	0	0
	Moxostoma macrolepidotum	shorthead redhorse	31	30	31
	Moxostoma pappillosum	V-lip redhorse	4	3	2
	Moxostoma collapsum	notchlip redhorse	34	10	15
Ictaluridae	*Ameiurus catus*	white catfish	88	250	188
	Ameiurus platycephalus	flat bullhead	1	2	0
	Noturus insignis	margined madtom	0	2	2
	Ictalurus furcatus	blue catfish	5	26	5
	Ictalurus punctatus	channel catfish	39	13	18
Mugilidae	*Mugil cephalus*	striped mullet	36	15	5
Belonidae	*Strongylura marina*	Atlantic needlefish	0	2	6
Moronidae	*Morone americana*	white perch	25	1	0
	Morone saxatilis	striped bass	4	0	11
Centrarchidae	*Micropterus salmoides*	largemouth bass	25	23	22
	Lepomis auritus	redbreast sunfish	49	21	15
	Lepomis macrochirus	bluegill	42	5	14
	Lepomis microlophus	redear sunfish	2	3	2
	Pomoxis nigromaculatus	black crappie	0	2	1
Percidae	*Perca flavescens*	yellow perch	1	1	0
Paralichthyidae	*Paralichthys lethostigma*	southern flounder	4	8	0

Table 8. Mean proportion of trophic guilds for longitudinal sites throughout all years sampled. Differences among guilds were compared using a one-factor ANOVA. Values with the same superscript letters are considered to have no significant differences between sites.

	Site		
Trophic Guild	Weldon	Scotland Neck	Hamilton
Piscivores	0.13[a]	0.13[a]	0.11[a]
General Carnivores	0.23[a]	0.11[ab]	0.05[b]
Planktivores	0.04[a]	0.14[ab]	0.19[b]
Omnivores	0.20[a]	0.32[a]	0.29[a]
General Invertivores	0.14[a]	0.07[ab]	0.00[b]
Insectivores	0.06[a]	0.15[ab]	0.28[b]
Detritivores	0.20[a]	0.08[a]	0.08[a]

Table 9. Mean proportion of reproductive guilds for longitudinal sites throughout all years sampled. Differences among guilds were compared using a one-factor ANOVA. Values with the same superscript letters are considered to have no significant differences between sites.

	Site		
Reproductive Guild	Weldon	Scotland Neck	Hamilton
Broadcast	0.19[a]	0.40[b]	0.29[ab]
Nest	0.30[a]	0.27[a]	0.34[a]
Marine	0.17[a]	0.08[ab]	0.03[b]
Crevice	0.04[a]	0.13[ab]	0.28[b]
Benthic	0.17[a]	0.06[a]	0.06[a]
Benthic/gravel	0.13[a]	0.06[ab]	0.00[b]

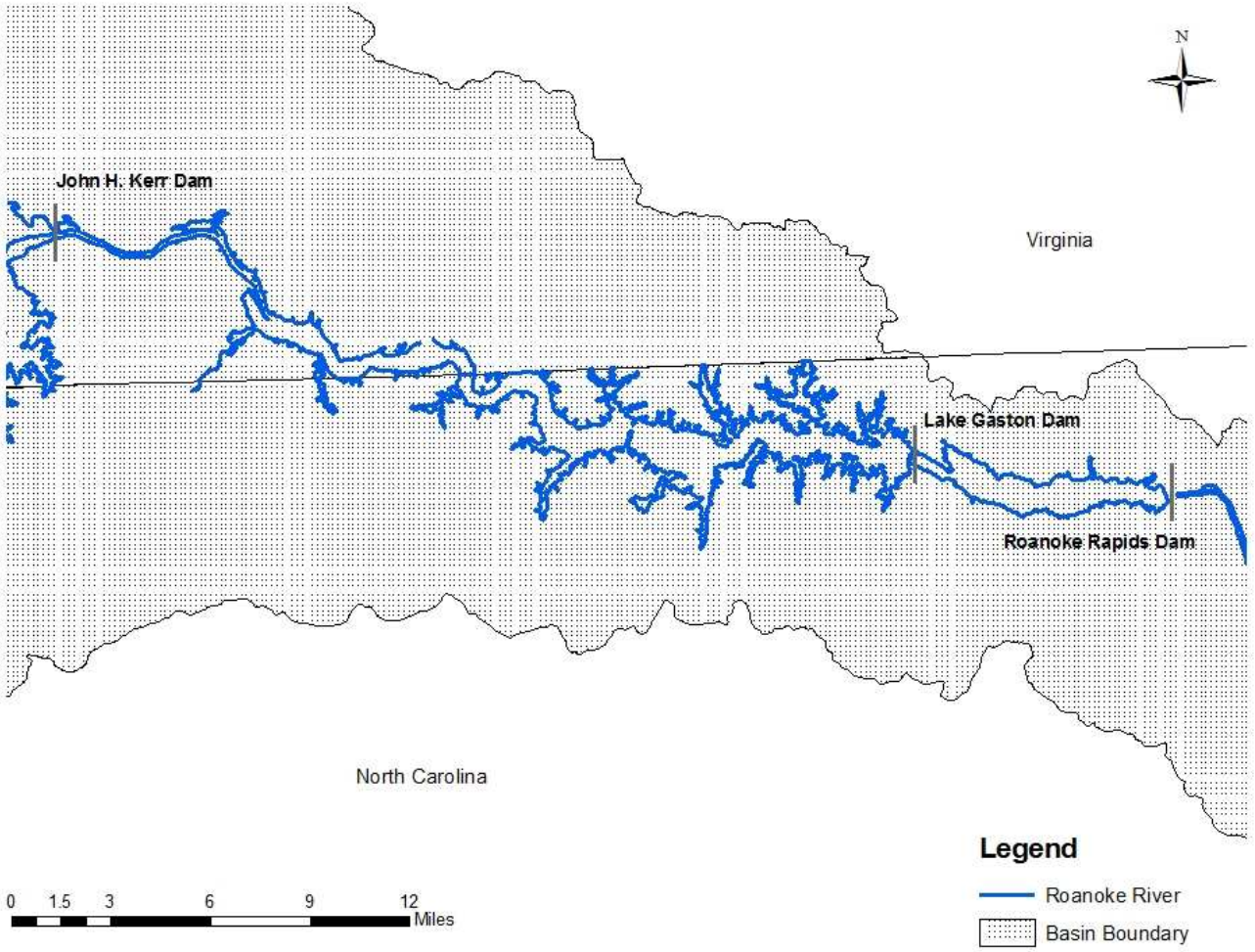


Figure 1: Map displaying three large scale dams (John H. Kerr Dam, Lake Gaston Dam and Roanoke Rapids Dam) on the lower Roanoke River.

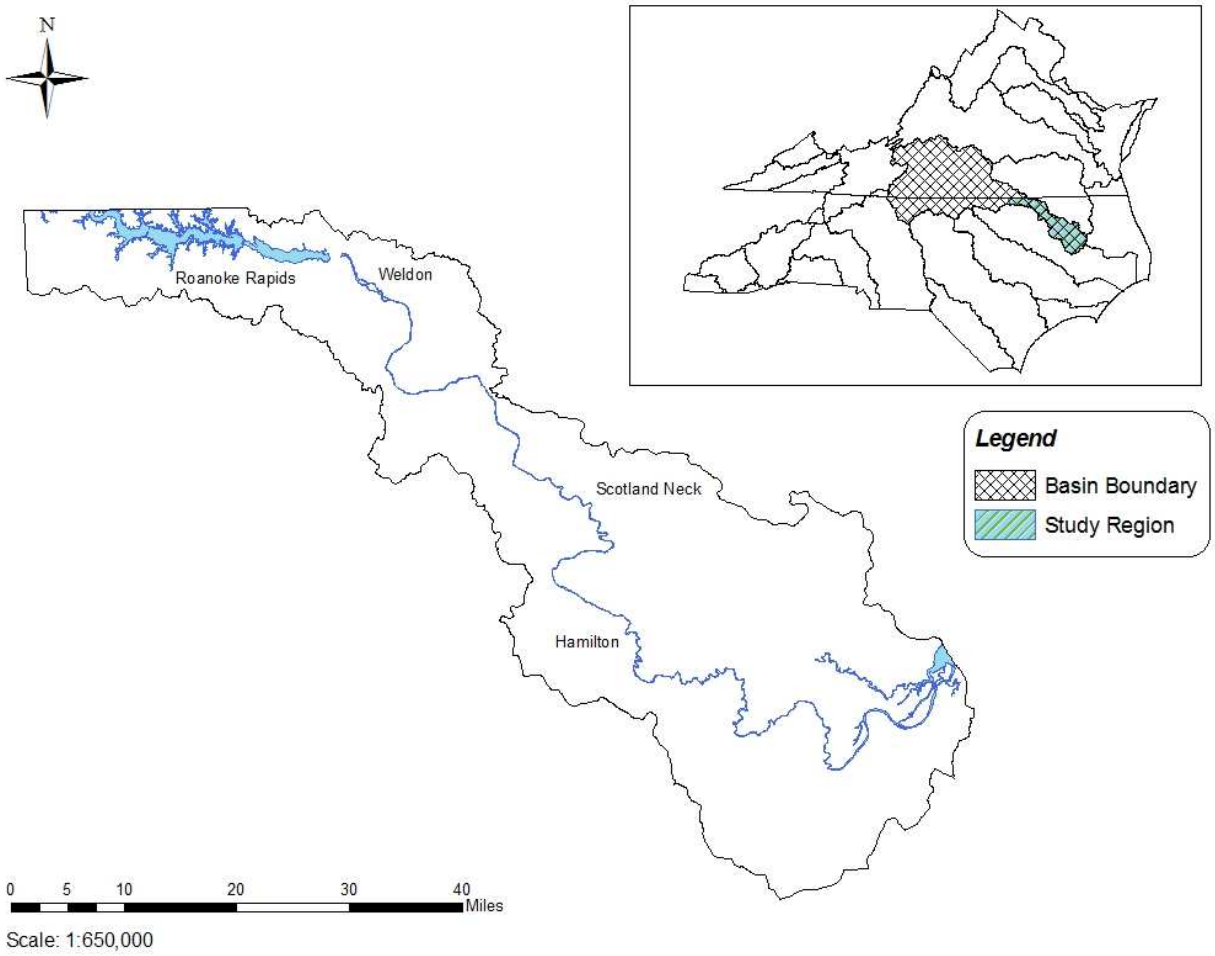


Figure 2. Map of lower Roanoke River watershed and study region.

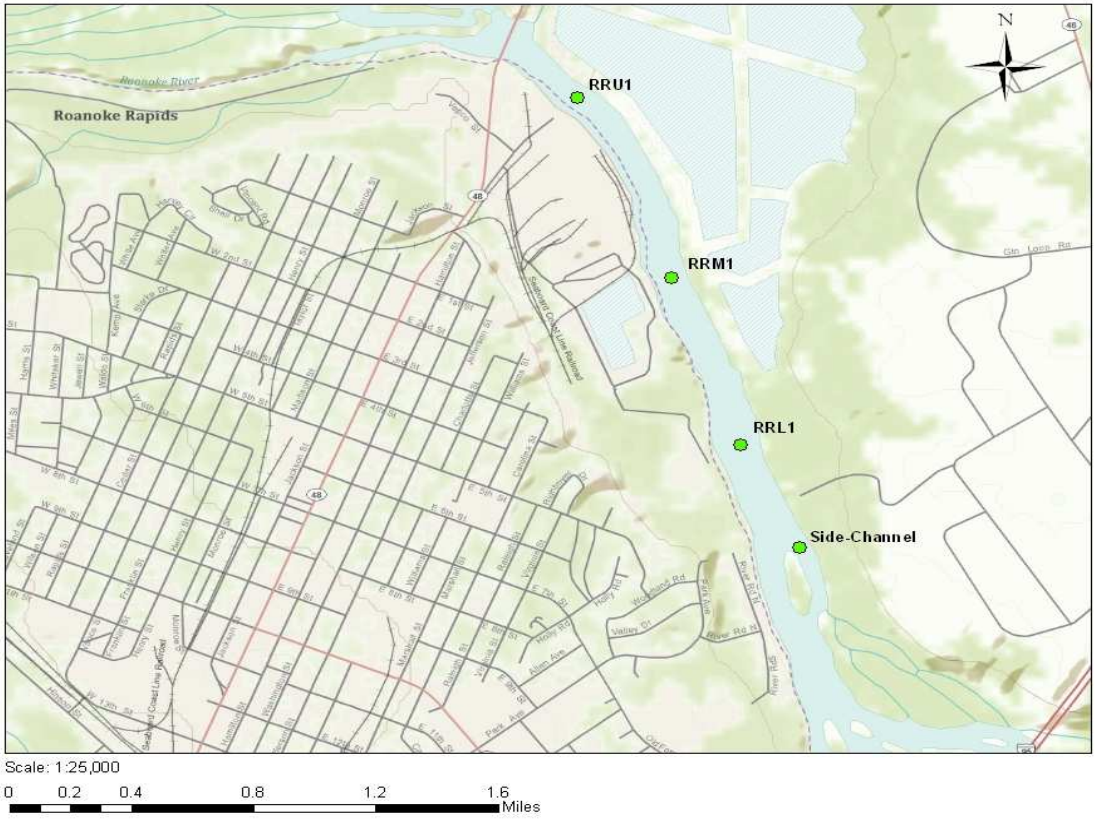


Figure 3. Lower Roanoke River sampling sites for pre/post-peaking data collection (RRL1 = lower, RRM1 = middle, RRU1 = upper, RRSC1 = side channel).

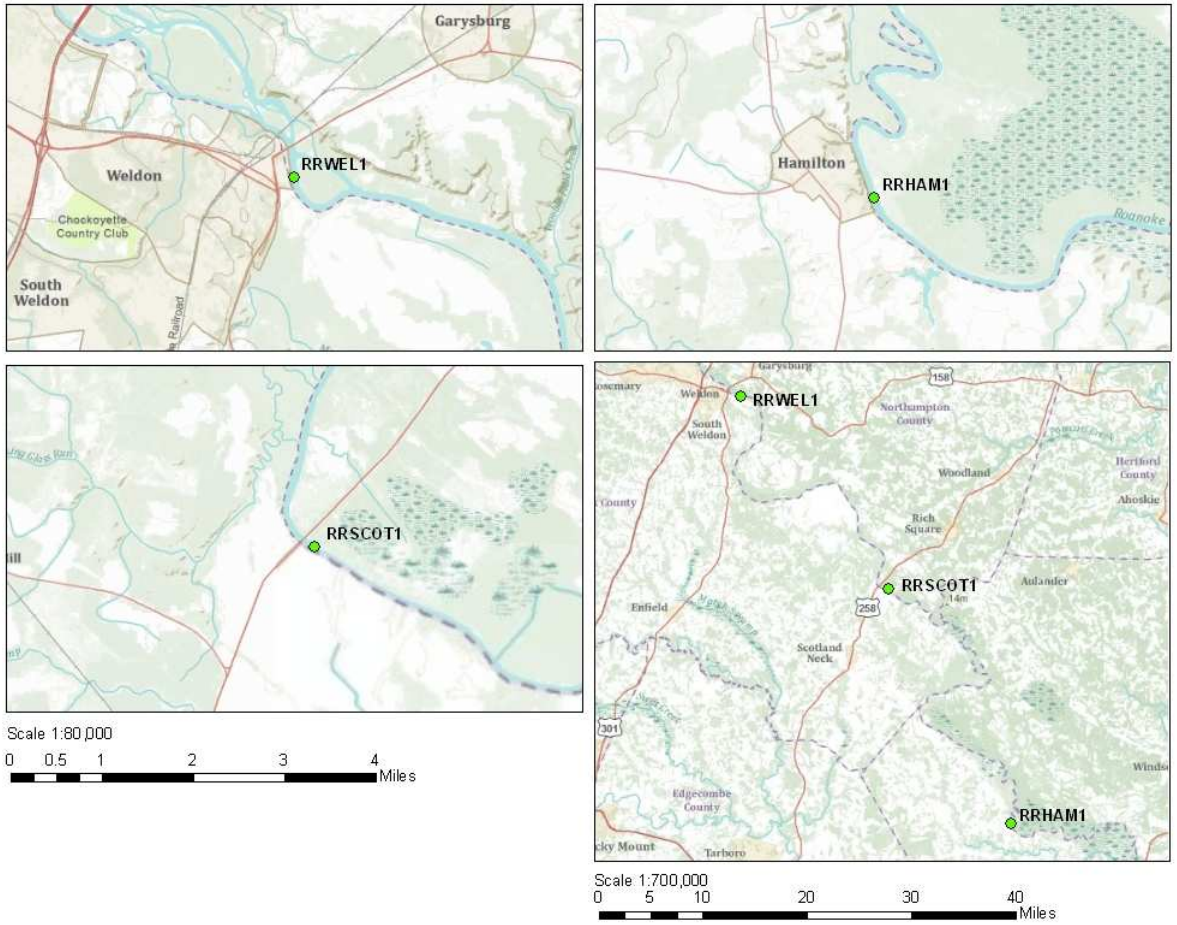


Figure 4. Lower Roanoke River sampling sites for longitudinal data collection (RRWEL = Weldon, RRSCOT = Scotland Neck, RRHAM = Hamilton).

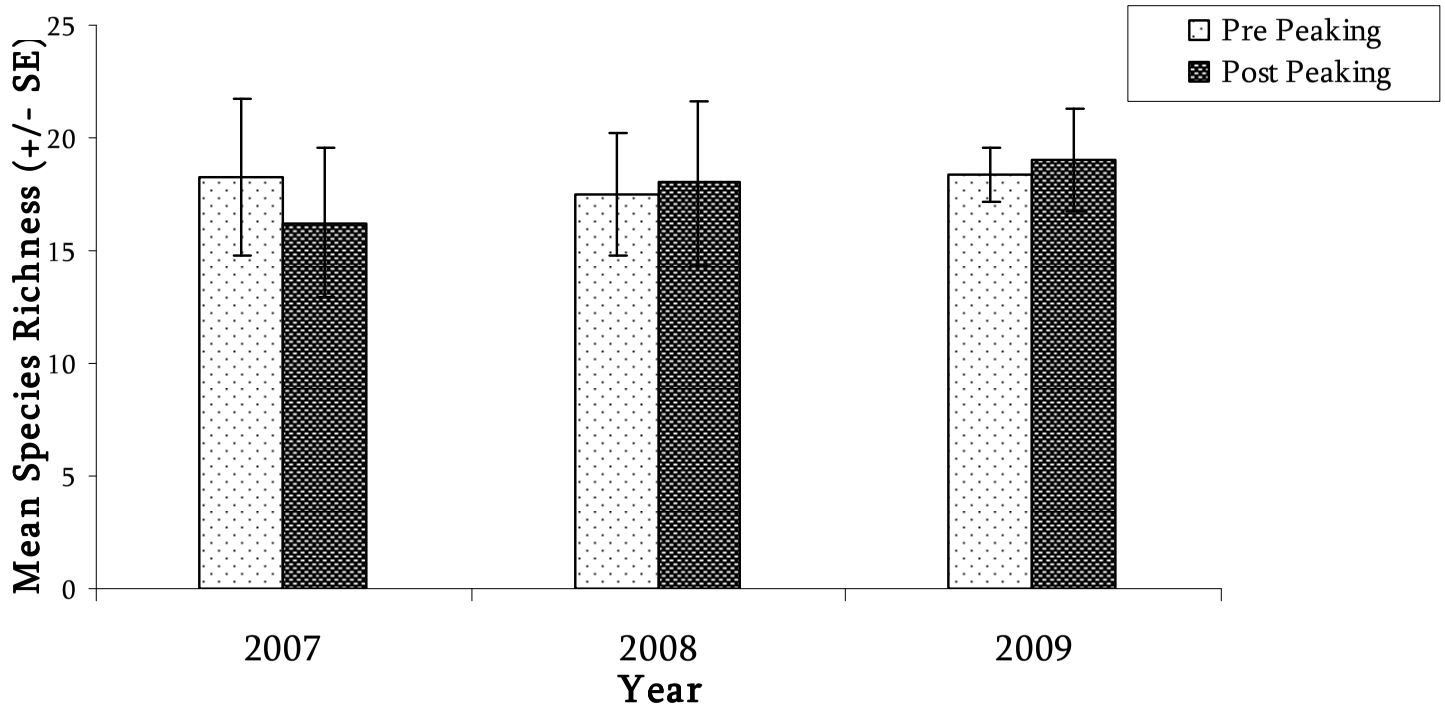


Figure 5. Bars representing mean and standard error of species richness for pre and post-peaking sampling events at Roanoke Rapids from 2007 to 2009.

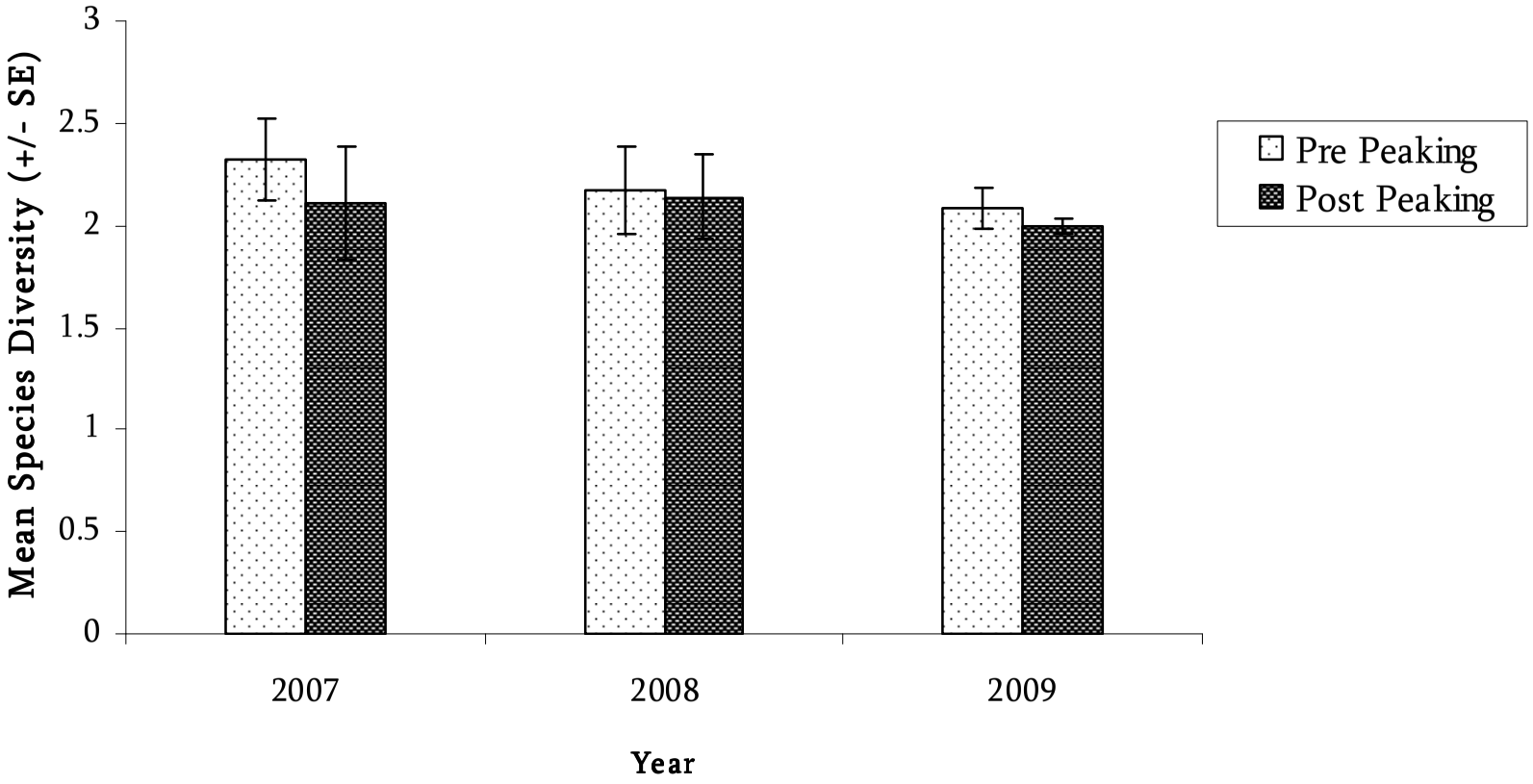


Figure 6. Bars representing mean and standard error of species diversity for pre and post-peaking sampling events at Roanoke Rapids from 2007 to 2009.

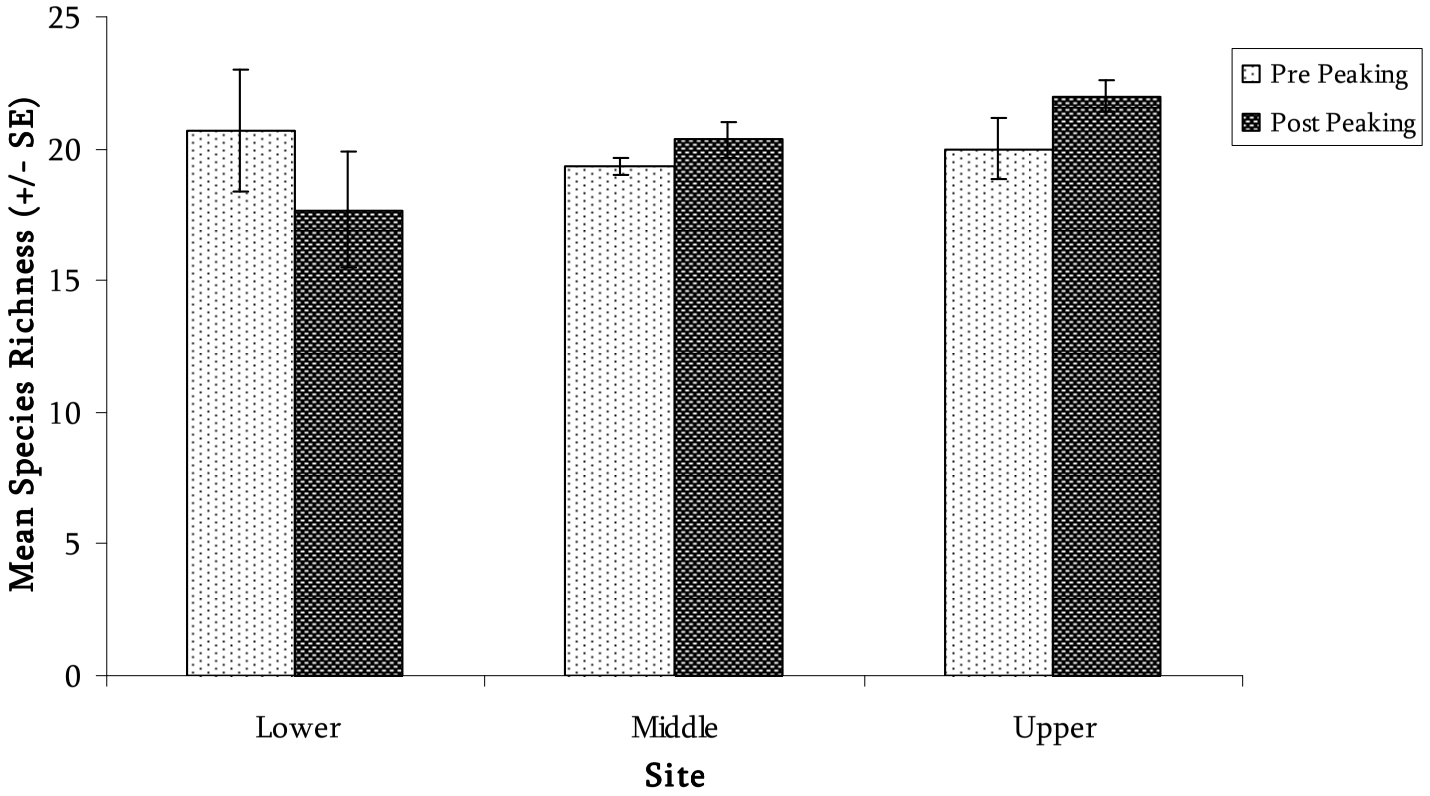


Figure 7. Bars representing mean and standard error of species richness for pre and post-peaking sampling events at lower, middle, and upper sampling sites at Roanoke Rapids.

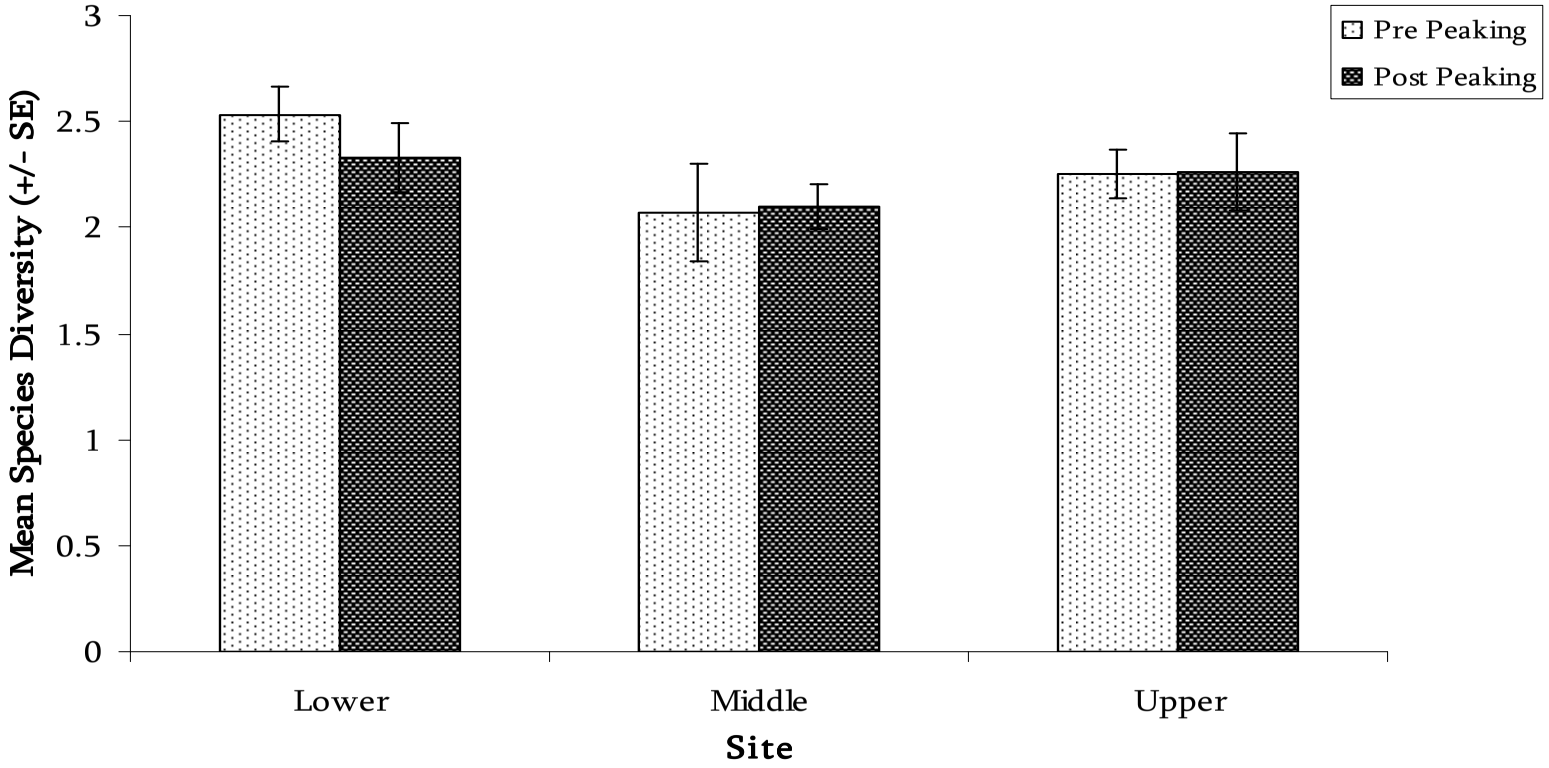


Figure 8. Bars representing mean and standard error of species diversity for pre and post-peaking sampling events at lower, middle, and upper sampling sites at Roanoke Rapids.

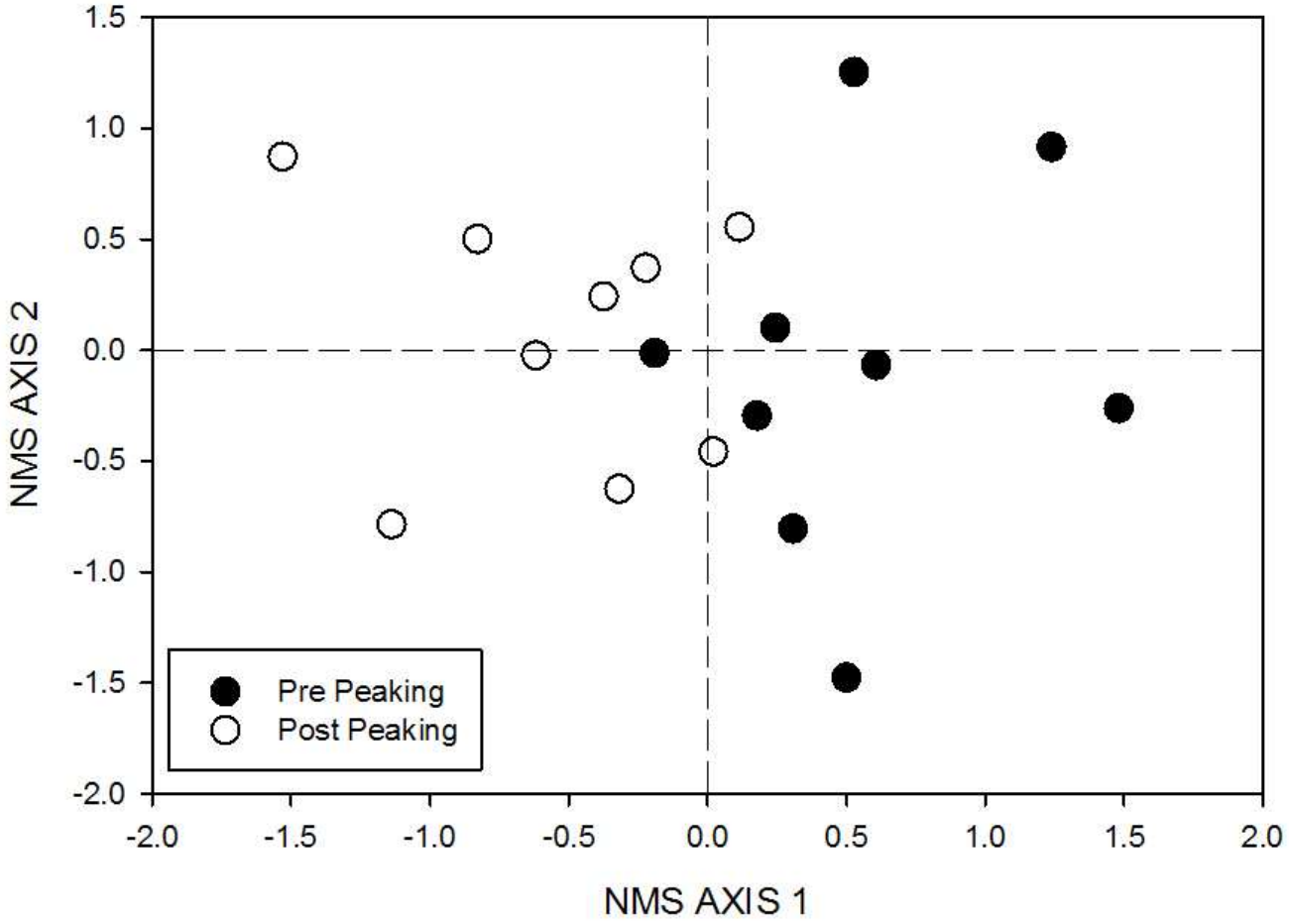


Figure 9. Non-metric multidimensional scaling (NMDS) ordination of pre and post-peaking sampling events at Roanoke Rapids based on Log transformed abundance data.

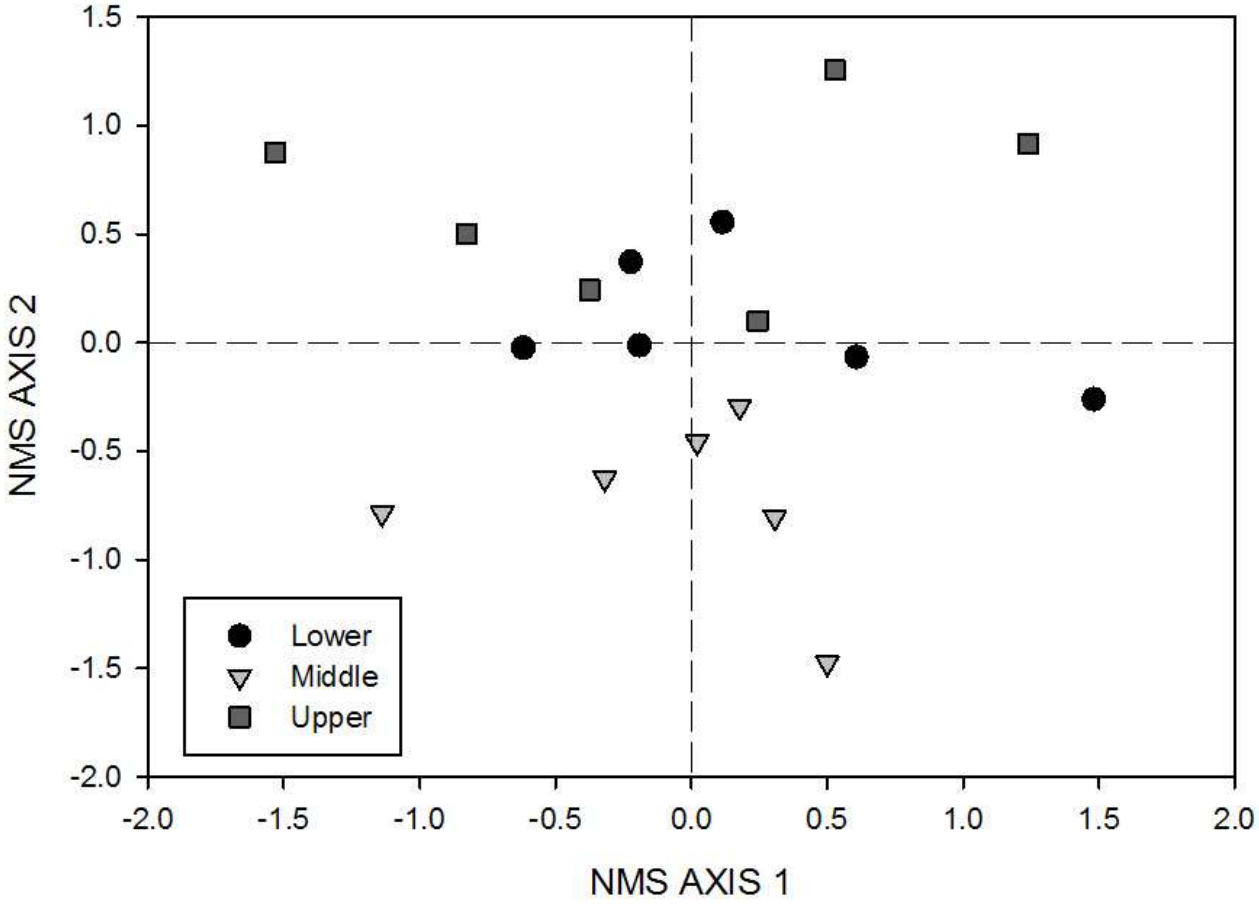


Figure 10. Non-metric multidimensional scaling (NMDS) ordination of lower, middle, and upper sampling sites at Roanoke Rapids based on Log transformed abundance data.

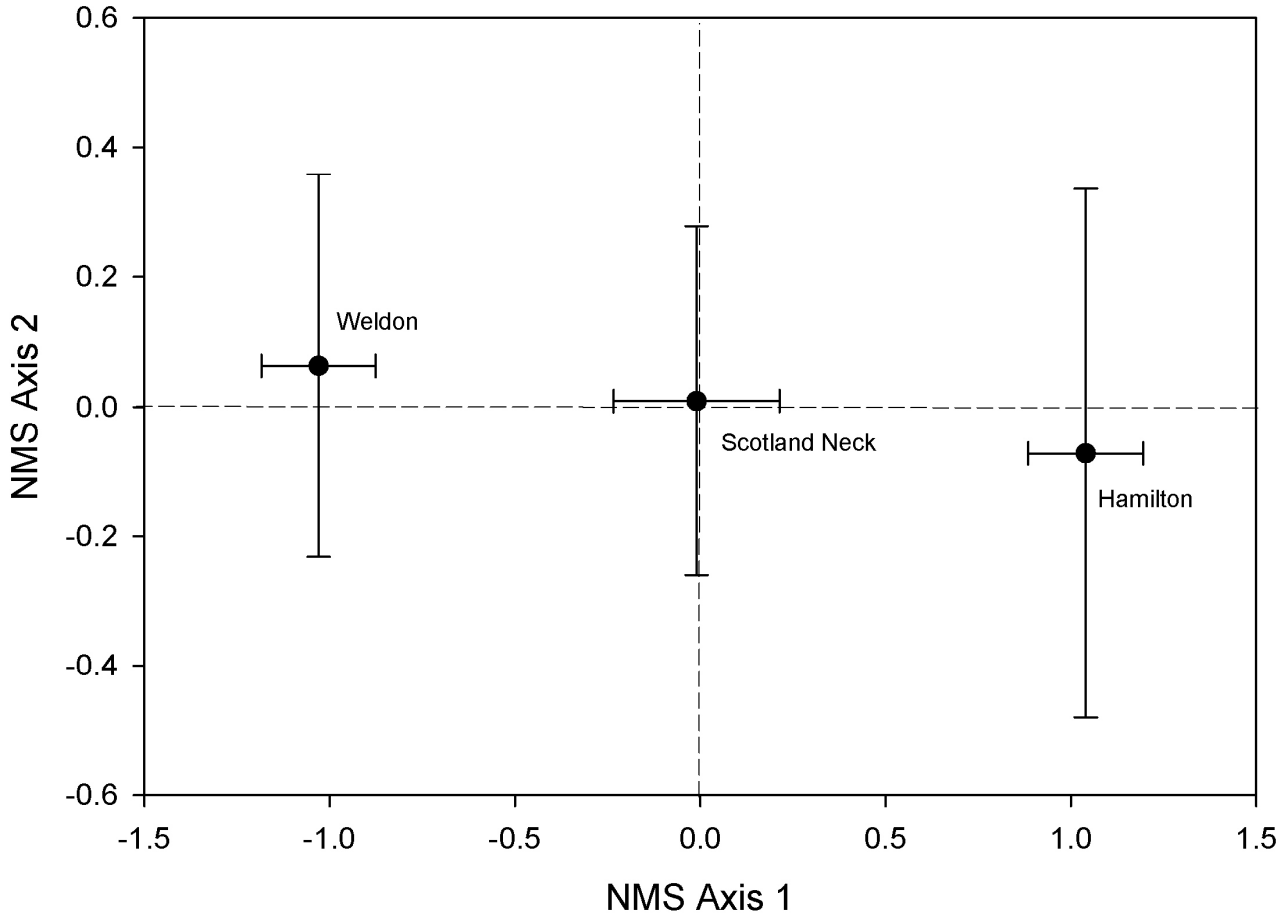


Figure 11. Non-metric multidimensional scaling (NMDS) ordination (mean +/- standard error of axis scores) of nine longitudinal sampling events based on Log transformed abundance data. Ordination points are a result of each all collections at each station.

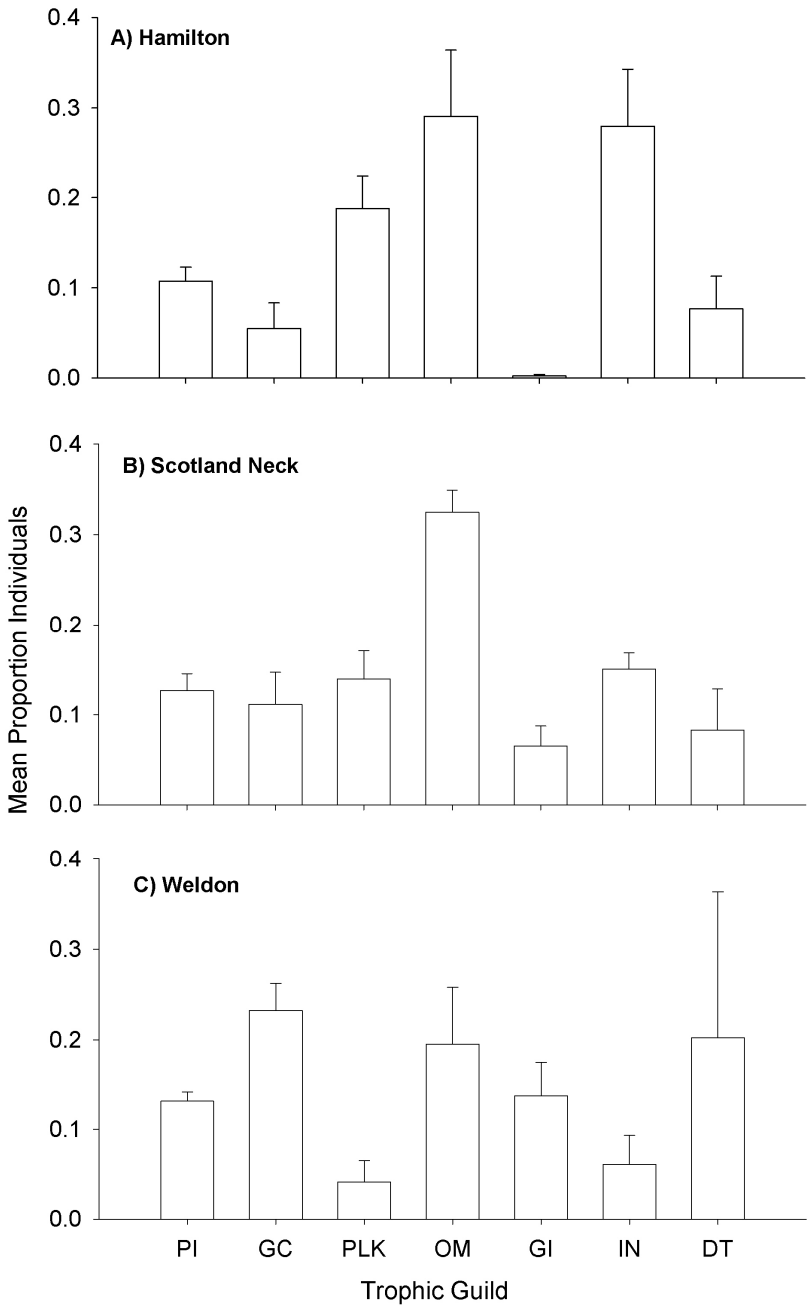


Figure 12: Bars representing mean and standard error of proportion of trophic guilds represented at longitudinal sampling sites. (PI – piscivore, GC – general carnivore, PLK – planktivore, OM – omnivore, GI – general invertivore, IN – insectivore, DT – detritivore)

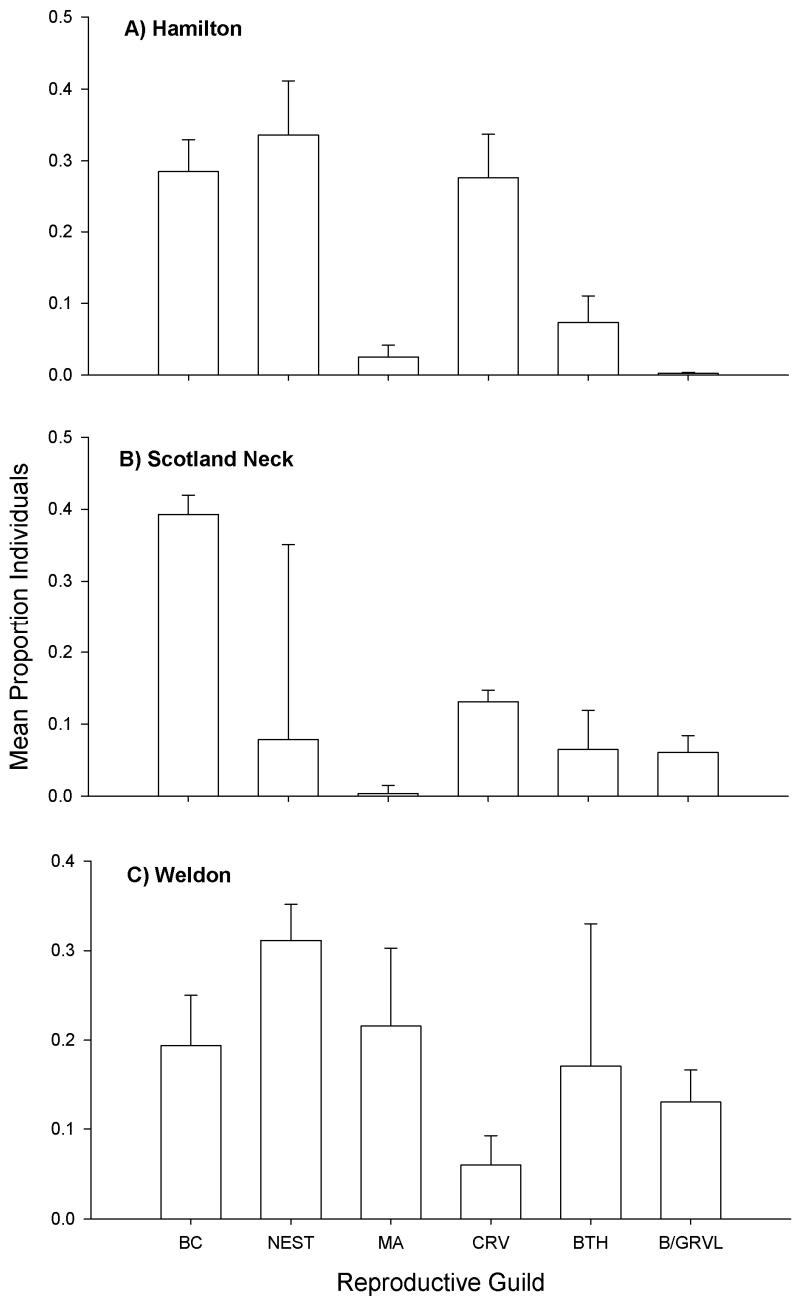
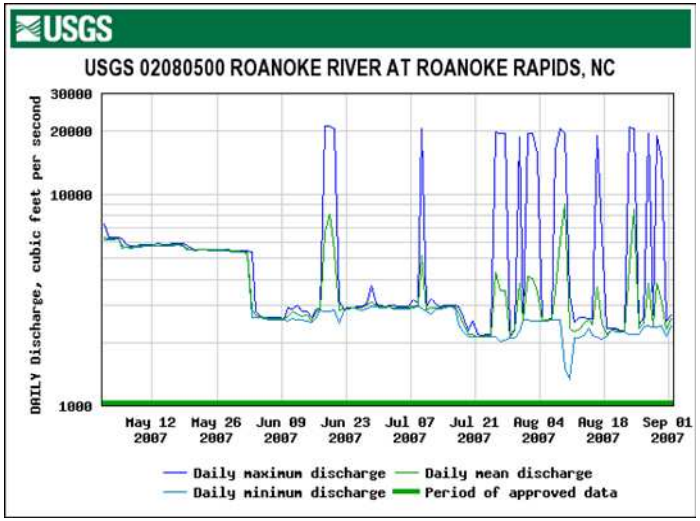


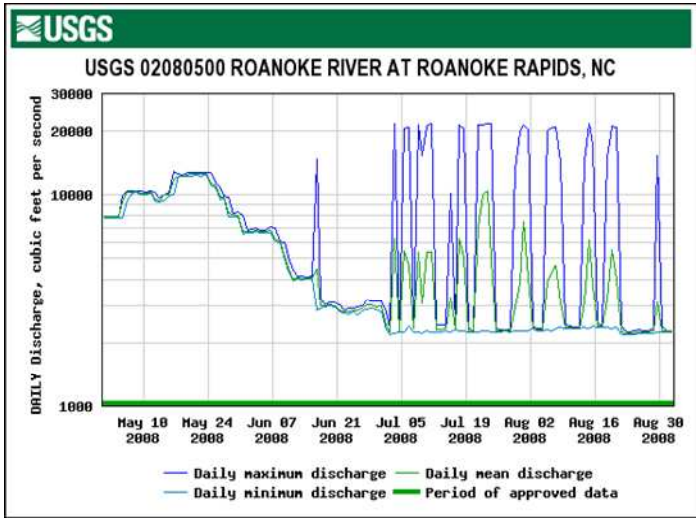
Figure 13: Bars representing mean and standard error of proportion of reproductive guilds represented at longitudinal sampling sites. (BC - broadcast spawner, NEST – nest producer, MA – marine spawner, CRV – spawns in crevices of rocks and woody debris, BTH - general benthic spawners, B/GRVL – benthic spawners over gravel substrates).

Appendix I: USGS Hydrographs displaying discharge data for sampling periods a)2007, b)2008, c) 2009

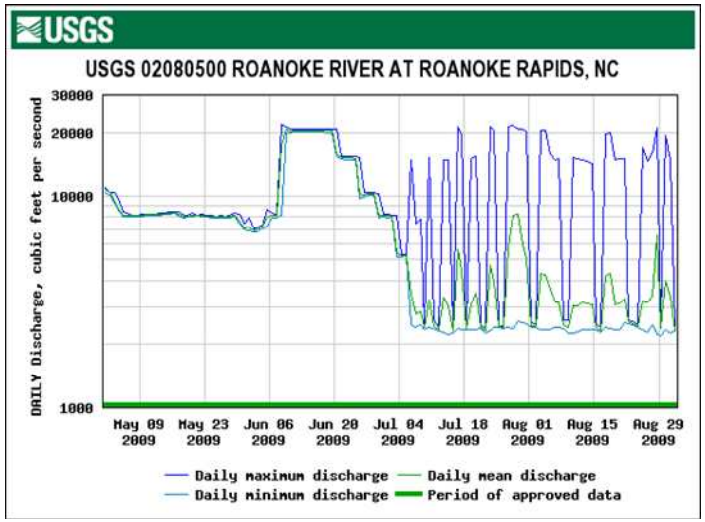
A) 2007



B) 2008



C) 2009



Appendix II: Site code and coordinates for sampling locations.

Site	Site Code	River Basin	Latitude	Longitude
Roanoke Rapids Lower	RRL1	Roanoke	36.453619	77.630081
Roanoke Rapids Middle	RRM1	Roanoke	36.465200	77.634639
Roanoke Rapids Upper	RRU1	Roanoke	36.479350	77.641831
Roanoke Rapids Side Channel	RRSC1	Roanoke	36.452458	77.626931
Weldon	RRWEL1	Roanoke	36.426496	77.590049
Scotland Neck	RRSCOT1	Roanoke	36.202285	77.369054
Hamilton	RRHAM1	Roanoke	35.936966	77.198659

Appendix III: Trophic guilds

Guild	Abbreviation	Description
Planktivore	PLK	feeds primarily on plankton
General Carnivore	GC	diet primarily consists on feeding of other animals
General Invertivore	GI	feeds primarily on invertebrates
Piscivore	PI	feeds primarily on other fishes
Insectivore	IN	feeds primarily on insects and invertebrates
Omnivore	OM	diet primarily consists on feeding of other animals and plant material
Detritivore	DT	feeds on detritus (decomposing organic matter)

Appendix IV: Reproductive guilds

Guild	Abbreviation	Classification
Broadcast	BC	release eggs usually during mass spawning events once a year into open water
Nest	NEST	nests are built and eggs are released within nests, usually involves parent care/guarding of gametes
Marine	MA	Non residents which spawn in estuaries or ocean
Crevice	CRV	release eggs into rocks, woody debris, and other crevice areas for protection
Benthic	BTH	adhesive eggs are released and fall to the substrate where they are fertilized by the males
Benthic/gravel	B/GRVL	adhesive eggs are released in rock/gravel substrate where they are fertilized by the males

Appendix V: Trophic and reproductive guild assignments.

Family	Genus/Species	Common name	Reproductive Guild	Trophic Guild
Lepisosteidae	*Lepisosteus osseus*	longnose gar	BC	PI
Amiidae	*Amia calva*	bowfin	NEST	PI
Anguillidae	*Anguilla rostrata*	American eel	MA	GC
Engraulidae	*Anchoa mitchilli*	bay anchovy	MA	PLK
Clupeidae	*Alosa aestivalis*	blueback herring	BC	PLK
	Alosa sapidissima	American shad	BC	PLK
	Alosa pseudoharengus	alewife	BC	PLK
	Dorosoma cepedianum	gizzard shad	BC	PLK
	Dorosoma petenense	threadfin shad	BC	PLK
Cyprinidae	*Cyprinella analostana*	satinfin shiner	CRV	IN
	Cyprinus carpio	common carp	BC	OM
	Ctenopharyngodon idella	grass carp	BC	GI
	Hybognathus regius	eastern silvery minnow	BTH	DT
	Notemigonus crysoleucas	golden shiner	BC	PLK
	Notropis rubellus	rosyface shiner	unknown	IN
	Notropis amoenus	comely shiner	unknown	IN
	Notropis hudsonius	spottail shiner	BC	OM
	Notropis procne	swallowtail shiner	BTH	GI
Catostomidae	*Carpriodes cyprinus*	quillback	BTH	DT
	Moxostoma macrolepidotum	shorthead redhorse	B/GRVL	GI
	Moxostoma pappillosum	v-lip redhorse	B/GRVL	GI
	Moxostoma collapsum	notchlip redhorse	B/GRVL	GI
Ictaluridae	*Ameiurus catus*	white catfish	NEST	OM
	Ameiurus platycephalus	flat bullhead	unknown	OM
	Noturus insignis	margined madtom	NEST	GI
	Ictalurus furcatus	blue catfish	NEST	PI
	Ictalurus punctatus	channel catfish	NEST	GC
Mugilidae	*Mugil cephalus*	striped mullet	MA	DT
Belonidae	*Strongylura marina*	Atlantic needlefish	BC	OM
Moronidae	*Morone americana*	white perch	BC	GC
	Morone saxatilis	stripped bass	BC	PI
Centrarchidae	*Micropterus salmoides*	largemouth bass	NEST	PI
	Lepomis auritus	redbreast sunfish	NEST	GC
	Lepomis macrochrius	bluegill	NEST	GC
	Lepomis microlophus	redear sunfish	NEST	GC
	Pomoxis nigromaculatus	black crappie	NEST	PI
Percidae	*Perca flavescens*	yellow perch	NEST	GC
Paralichthyidae	*Paralichthys lethostigma*	southern flounder	MA	GC

VITA

Richard Dean Davis was born on May 29, 1985 in Philadelphia, Pennsylvania, U.S.A. Richard graduated from Thomas Dale High School in 2003 and received a Bachelors of Science in Environmental Studies from Virginia Commonwealth University in 2007. After completion of his degree, Richard worked for the Virginia Department of Game and Inland Fisheries for one year before enrolling in the Environmental Science Masters program at VCU.