FRESHWATER FISHERIES RESEARCH

ANNUAL PROGRESS REPORT

F-63

January 1, 2004 – December 31, 2004

Jim Bulak
Research Coordinator, Freshwater Fisheries

Division of Wildlife and Freshwater Fisheries
D. Breck Carmichael, Deputy Director

TABLE OF CONTENTS

STATEWIDE RESEARCH 1

Development of Reservoir-Specific Management Models 1

Assessing Hybridization Among Native and Introduced Black Bass Species in the Savannah River Drainage 3

Table 1. Morphological characters scored for redeye bass, spotted bass and potential hybrids collected in 2004. 4

Table 2. Number of black bass collected from Savannah drainage reservoirs in 2004. Catch is listed by species as identified in the field; REB = redeye bass, SPB = spotted bass, LMB = largemouth bass, SMB = smallmouth bass, HYB = potential hybrid. 4

Table 3. Number of black bass collected from Savannah drainage streams in 2004. Catch is listed by species as identified in the field; REB = redeye bass, SPB = spotted bass, LMB = largemouth bass, HYB = potential hybrid. 5

Table 4. Genetic markers in development at University of South Carolina for distinguishing black bass species. 6

A Genetic Survey of Crappie Populations in South Carolina 8

Table 1. Number of crappie collected by population (BLC = black crappie, WTC = white crappie, HYB = hybrid) for 2001 genetic survey. 8

Table 2. Measures of genetic variability for South Carolina crappie populations as calculated from 30 loci examined. The first five populations listed represent black crappie collected. Marion (WTC) is white crappie collected from Lake Marion. 9

Figure 1. Roger's genetic similarity dendogram for South Carolina black crappie populations surveyed in 2001. 10

Zoogeography of Centrarchidae of the South Atlantic Slope 12

Contribution of South Carolina and Georgia stocked hybrid bass in Lakes Hartwell and Thurmond 13

Table 1. Hybrid striped bass gill net collections from Lake Thurmond in 2003-04, South Carolina and Georgia combined. Catch is listed by age and mesh. 14

Table 2. Hybrid striped bass gill net collections from Lake Hartwell in 2003-04, South Carolina and Georgia combined. Catch is listed by age and mesh. 14

Table 3. Striped bass gill net collections from Lake Thurmond in 2003-04. Catch is listed by age and mesh. 15

Evaluation of hooking mortality and recovery of striped bass held in flow-through live-release tubes 16

Table 1. Mortality (percent) for striped bass caught and released, or caught stored in live-release tubes and then released in Lake Murray, South Carolina. The number of fish (N) that were tagged and released is given in parentheses. Residence times varied and are rounded to the nearest hour. 16

Figure 1. Relation of hematological characteristics (y) to residence time (x) for striped bass angled from Lake Murray, South Carolina. Spring-caught fish are represented by solid circles and summer-caught fish are represented by open circles. Regression equations and r^2: cortisol (spring) $y = -0.0003x^2 + 0.172x + 7.296$, $r^2 = 0.46$; cortisol (summer) $y = -0.0005x^2 + 0.259x + -0.169$, $r^2 = 0.65$; glucose (spring) $y = -0.0024x^2 + 1.118x + 116.05$, $r^2 = 0.35$; glucose (summer) $y = -0.0024x^2 = 0.989x + 102.78$, $r^2 = 0.50$; lactate (spring) $y = -0.0012x^2 + 0.498x + 57.33$, $r^2 = 0.24$; lactate (summer) $y = -0.0039x^2 + 1.511x + 37.292$, $r^2 = 0.74$; osmolality (summer) $y = -0.0009x^2 + 0.359x + 347.80$, $r^2 = 0.56$. 18

Piedmont Stream Survey – Broad River basin 20

Table 1. Sites sampled within the Broad River drainage during fall 2004. 20

Figure 1. Sites sampled in the Broad River Drainage during fall, 2003 and 2004. 21

Table 2. Fish species collected from Broad River tributaries during fall, 2004, and their conservation concern status based on the Comprehensive Wildlife Conservation Plan. 23

Analysis of 2003 Stream Survey Data 24

Table 1. Major river drainages and ecoregions sampled in the 2003 Stream Survey. Codes for each drainage and ecoregion are used in subsequent tables and figures. 24

Table 2. Selected abiotic variables measured at 50 sites during the 2003 SC Stream Survey. Ecoregion and drainage codes are found in Table 1, ELEV is site elevation in feet, LENGTH is length of sampled stream segment in meters, WIDTH is mean channel wetted width (m), DEPTH is mean water depth (m), DEP-SD is the standard deviation of all depth measurements, CONDUC is water conductivity (S/cm), and PH is water pH. Dashes represent missing values. 25

Table 3. Summary statistics for 50 sites sampled for fish in 2003 SC Stream Survey (all passes combined). Sum is total number of fish collected, Sp. Rich is species richness, Even is assemblage evenness, and H Divers is Shannon-Weiner diversity. 27

Figure 1. Plot of species scores on two ordination axes produced by nonmetric multidimensional scaling illustrates a gradient in species composition. Species with similar scores co-occur. For example, associations of greenfin shiner, spottail shiner, and seagreen darter through blackbanded darter, dusky shiner, and warmouth to sawcheek darter, tadpole madtom and flier are apparent. 30

Figure 2. Plot of site scores on the two NMS axes illustrates site similarities in terms of fish fauna. The two dimensional space is defined by the fish species scores depicted in Figure 1, so sites located in a similar region of the graph are characterized by similar fish species composition and abundance. 31

Figure 3. Plot of site scores on the two NMS axes with sites grouped by river drainage (see Table 1 for code definitions). 32

Figure 4. Plot of site scores on the two NMS axes with sites grouped by ecoregion (see Table 1 for code definitions). 32

Figure 5. A biplot of abiotic associations with the site ordination scores shows that the only significant variable is site elevation. The direction of the vector indicates that sites toward the negative end of Axis 1 are higher elevation and those toward the negative end are lower. The length of the vector indicates the strength of relationship, which in this case depicts a strong correlation between elevation and Axis 1 scores (r=-0.80). 35

Figure 6. Bivariate plot of site scores on the first ordination axis versus site elevation. 35

Table 4. Comparison of fish assemblage metrics obtained from single pass electrofishing with metrics obtained from all passes combined. 38

Figure 7. Comparison of the percentage of total species richness obtained after a single pass in upland streams (>300 ft) versus lowland streams (<300 ft). Means and 90% confidence intervals are shown. 39

Table 5. Comparison of fish assemblage metrics obtained from two-pass electrofishing with metrics obtained from all passes combined. 40

Figure 8. Comparison of the percentage of total species richness obtained after two passes in upland streams (>300 ft) versus lowland streams (<300 ft). Means and 90% confidence intervals are shown. 41

Interrelationships of land use, stream habitat quality, and fish assemblage integrity among tributaries of the Reedy River, South Carolina 43

Table 1. Location and sample site characteristics of the six Reedy River tributaries, Fall 2004. 44

Table 2. Water quality characteristics of the six Reedy River tributary sites, Fall 2004. 44

Table 3. Abundance by site for the 25 fish species present among the six Reedy River tributary sites, Fall 2004. 46

Table 4. Fish species richness, abundance, and diversity attributes by site for the six Reedy River tributaries, Fall 2004. 47

Table 5. Abundance attributes and frequency of occurrence by species for the 25 fish species present among the six Reedy River tributary sites, Fall 2004. 48

Development Of A Dynamic Water Quality Model For Lake Greenwood, SC 51

Figure 1. Conceptual diagram of watershed/water quality interactions. 52

Figure 2. Sampling stations on Lake Greenwood. 53

Table 1. Site locations and study components. 53

Figure 3. Distributions of total phosphorus and chlorophyll-a (algal biomass) in surface and bottom waters (6/23/04). 55

Figure 4. (Left Panel) Diagram of the vertical array of light and dark bottles used for evaluating plankton productivity (left panel); (Right Panel) Example of typical vertical patterns of net oxygen production (7/21/04) 56

Figure 5. Distributions of dissolved oxygen in Lake Greenwood (March-June, 2004) 58

Study Title: STATEWIDE RESEARCH

Job Title: Development of Reservoir-Specific Management Models

Period Covered January 1, 2004 – December 31, 2004

Results and Discussion

The question of whether zonal sampling was a necessary component of the largemouth bass *Micropterus salmoides* spring electrofishing sampling design was assessed with the assistance of Dr. John Grego, University of South Carolina Department of Statistics. His approach to the problem was to determine if zonal differences in largemouth bass growth could be detected using SC DNR spring electrofishing data. Likelihood ratio tests were used to compare zonal and lakewide growth curves derived from the von Bertalanffy growth model. The likelihood ratio test assumes that deviations from the growth curve model are normally distributed with constant error, irrespective of the fish's age. A normal likelihood is computed under two competing models, the ratio of which is Λ. The test statistic $-2\log\Lambda$ has a chi-squared distribution with 3(z-1) degrees of freedom, where z is the number of zones (the multiplier 3 assumes a 3-parameter von Bertalanffy growth curve model). The method must be used cautiously because the test statistic is sensitive to sample size differences. Furthermore, not all fish collected during spring electrofishing are aged; rather, a subsample is aged and age frequencies for the entire sample are assigned to length groups with an age-length key. The procedure for selecting fish for aging is not necessarily proportional with respect to length and zone, and makes an assumption about the age of small fish, all of which introduces potential bias into the estimation of age. To minimize the effect of missing data on the likelihood ratio tests, a multiple imputation technique was used to assign values of age to un-aged fish based on the relationship between age, length and weight in fish for which all three parameters were measured. Von

Bertalanffy growth curve parameters were then estimated for each dataset, providing a basis for comparing growth in different zones under the assumption of complete datasets. Unfortunately, a computer hard drive crash in September resulted in the permanent loss of programs, data, and correspondence related to the development of the likelihood ratio test. The process of finding an appropriate way to analyze zonal data was put on hold until a new computer was brought on line and essential programs and datasets were recreated. As a result, the multiple imputation approach has not yet been tested for potential applicability, and the question of whether zonal sampling provides useful information to the management biologist is still open.

Recommendations

Compile and summarize the entire dataset (1997-2003) defining best-available model parameters and providing suggested statewide and reservoir-specific management regulations within a Completion Report. Prepare a summary of biological information for outreach activities. Present findings to the Wildlife and Freshwater Fishery Advisory Board. Statistically evaluate the benefits of zonal sampling within reservoirs to develop management recommendations; publish results. Work with Information Management and Analysis to centrally archive the dataset (1997-2004) and provide web-based data entry for new information. Discontinue providing verification of otolith aging unless specifically requested by a Regional Coordinator.

Prepared By: John S. Crane Title: Fishery Biologist

Job Title: Assessing Hybridization Among Native and Introduced Black Bass Species in the Savannah River Drainage

Period Covered January 1 – December 31, 2004

Results and Discussion

The black bass are a group of congeneric species that are particularly vulnerable to hybridization (Morizot et al. 1991; Whitmore and Hellier 1988; Beaty and Childers 1980). Natural hybridization has been shown to occur with numerous species pairs. Progeny are viable and extensive backcrossing can take place, resulting in introgression (Avise et al. 1997; Turner et al. 1991; Whitmore 1983).

Four species of black bass inhabit the Savannah River drainage of South Carolina and Georgia. The largemouth bass *Micropterus salmoides* and the redeye bass *M. coosae* are native to the drainage. Spotted bass *M. punctulatus* and smallmouth bass *M. dolomieu* have been introduced (Rhode et al. 1994). Smallmouth were introduced to the upper Savannah lakes of South Carolina by the Department of Natural Resources (SCDNR). They are reproducing in Lake Jocassee. Spotted bass were introduced illegally to the upper Savannah River lakes and have rapidly expanded in that system of reservoirs. They are now present in Lakes Keowee, Jocassee, Hartwell and Russell. Spotted bass comprise a large portion of the black bass fishery on Lake Keowee (Dan Rankin, SCDNR, pers. comm.).

Concerns over hybridization among black bass species in South Carolina, and especially with regard to redeye bass, were first raised regarding Lake Keowee. In the early 1990's biologists noticed redeye bass were becoming harder to identify. Preliminary DNA analysis performed on 10 putative hybrid bass from Lake Keowee confirmed that four of the fish were hybrids (Joe Quattro, University of South Carolina, pers. comm.).

In an effort to quantitatively assess the degree of hybridization in the upper Savannah reservoirs, 1,175 redeye, largemouth, spotted, and smallmouth bass were collected from Lakes Jocassee, Keowee, Hartwell and Richard B. Russell. Fish were collected during the spring and summer of 2004 by a combination of boat electrofishing and gill netting. Total length and weight were recorded for each fish. Fin clips were taken and stored in alcohol for DNA analysis at University of South Carolina (USC). All fish were photographed. Additionally, redeye and spotted bass were scored on a series of morphological features (Table 1). Field identifications were made on 1,082 fish collected and 11% of those fish were considered potential hybrids (Table 2).

Table 1. Morphological characters scored for redeye bass, spotted bass and potential hybrids collected in 2004.

Character	Scoring
Anal Fin Pigmentation	Heavy, Sparse, Absent
Caudal Fin Margin	Prominent, Weak, Absent
Basicaudal Spot *	Prominent, Weak, Absent
Opercular Spot *	Prominent, Weak, Absent
Lateral Color Pattern	Stripe, Blotched, Vertical Bar
No. of Vertical Bars **	Count

* Reservoir Collections Only; ** Stream Collections Only

Table 2. Number of black bass collected from Savannah drainage reservoirs in 2004. Catch is listed by species as identified in the field; REB = redeye bass, SPB = spotted bass, LMB = largemouth bass, SMB = smallmouth bass, HYB = potential hybrid.

	No. Collected					
Reservoir	REB	SPB	LMB	SMB	HYB	Total
Jocassee	80	6	25	15	15	141
Keowee	62	100	83	3	47	295
Hartwell	187	10	177	0	38	412
Russell	36	26	148	0	24	234

Nine stream populations were sampled to determine the occurrence of hybridization events between redeye and spotted bass in those habitats, and to compare Savannah drainage redeye bass with other drainages within the fish's native range. Stream collections were made by back pack electrofishing and angling. Data and tissue samples were collected as described for reservoir collections on 145 fish. Redeye bass were the only black bass species collected from seven streams, while two yielded other black bass as well. Two potential hybrids were collected (Table 3).

Table 3. Number of black bass collected from Savannah drainage streams in 2004. Catch is listed by species as identified in the field; REB = redeye bass, SPB = spotted bass, LMB = largemouth bass, HYB = potential hybrid.

			Number collected		
Stream	County	Date	REB	SPB	Other species (n)
Savannah R.	Aiken	7/20/04	19	0	0
Stephens Ck.	McCormick	7/8 – 7/9/04	15	0	0
Big Generostee Ck.	Anderson	7/12/04	11	0	0
Saluda R.	Greenville	8/5/04	18	0	0
Chatooga R.	Pickens	8/19/04	19	0	0
Chauga R.	Pickens	8/17/04	28	0	0
Little R.	Oconee	8/24/04	14	10	LMB (2)
Horse Pasture	Transylvania Co., N.C.	9/3/04	5	0	0
Toxaway R.	Transylvania Co., N.C.	9/3/04	3	0	SMB (1)

DNA marker development is progressing at USC and has resulted in four nuclear and two mitochondrial markers to date (Table 4). DNA has been isolated from all reservoir samples and is stored for future sequencing at applicable markers.

Table 4. Genetic markers in development at University of South Carolina for distinguishing black bass species.

Type of Locus	Name
Mitochondrial	Cytochrome b
	Control region
Nuclear	Lactate Dehydrogenase A Intron
	S7 Intron
	Actin Intron
	MPP Intron

Recommendations

This study is currently funded through August 2006. In 2005, continue stream collections of redeye bass, with five additional sites targeted for sampling. Perform DNA sequencing of reservoir and stream samples at applicable markers.

Literature Cited

Avise, J. C., P. C. Pierce, M. J. Van Den Avyle, M. H. Smith, W. S. Nelson, and M. A. Asmussen. 1997. Cytonuclear introgressive swamping and species turnover of bass after an introduction. Journal of Heredity 88:14-20.

Beaty, P. R. and W. F. Childers. 1980. Hybridization of northern largemouth bass (*Micropterus salmoides salmoides*) and northern smallmouth bass (*Micropterus dolomieu dolomieu*). Publication of the Bass Research Foundation. Starkville, Mississippi.

Morizot, D. C., S. W. Calhoun, L. L. Clepper, M. E. Schmidt, J. H. Williamson and G. J. Carmichael. 1991. Multispecies hybridization among native and introduced centrarchid basses in central Texas. Transactions of the American Fisheries Society 120:283-289.

Turner, J. M., F. J. Bulow and C. J. O’Bara. 1991. Introgressive hybridization of redeye bass and smallmouth bass and its management implications. Proceedings of the First International Smallmouth Bass Symposium. 143-150.

Whitmore, D. H. and T. R. Hellier. 1988. Natural hybridization between largemouth bass and smallmouth bass (*Micropterus dolomieu*). Copeia 2:493-496.

Whitmore, D. H. 1983. Introgressive hybridization of smallmouth bass (*Micropterus dolomieu*) and Guadalupe bass (*M. treculi*). Copeia 672.

Prepared By: Jean K. Leitner Title: Fishery Biologist

Job Title: A Genetic Survey of Crappie Populations in South Carolina

Period Covered January 1 – December 31, 2004

Results and Discussion

Crappie were collected from five populations in order to survey the biochemical variation of black crappie *Pomoxis nigromaculatus* in South Carolina, and to determine the extent of hybridization between black and white crappie *P. annularis* where the two species co-exist. Phenotypes at 30 enzyme loci were determined using horizontal starch gel electrophoresis. Resulting data was used to identify fish to species, and to calculate measures of genetic diversity and relatedness among populations. Initial results are reported here.

Hybridization

Samples from Lakes Brown, Greenwood and Murray were 100% black crappie (Table 1). Both black and white crappie, as well as hybrids were collected from lakes Hartwell and Marion. None of the hybrids were F1, indicating little or no hybridization in the current generation. The Fx (either F2, Fn, or backcrossed) hybrids collected are likely remnants of previous hybridization events.

Table 1. Number of crappie collected by population (BLC = black crappie, WTC = white crappie, HYB = hybrid) for 2001 genetic survey.

	Population				
	L. Brown	L. Greenwood	L. Hartwell	Lake Marion	Lake Murray
BLC	30	30	13	45	35
WTC	0	0	1	70	0
HYB	0	0	1	22	0

Genetic Diversity in and among Crappie Populations

There was little genetic variation detected in the black crappie populations surveyed. The Lake Hartwell population had the highest observed number of alleles per locus and percent loci polymorphic among black crappie, however, mean heterozygosity was zero as all variant individuals were homozygotes. The Lake Brown population exhibited no biochemical genetic variation for the 30 loci surveyed (Table 2).

Table 2. Measures of genetic variability for South Carolina crappie populations as calculated from 30 loci examined. The first five populations listed represent black crappie collected. Marion (WTC) is white crappie collected from Lake Marion.

Population	Mean sample size per locus	Mean no. alleles per locus	% Loci Polymorphic	Mean Heterozygosity Direct Count	Mean Heterozygosity HdyWbg Expected
Brown	28.7 (0.4)	1.0 (0)	0	0.000 (---)	0.000 (---)
Greenwood	28.3 (0.5)	1.1 (0.1)	10.0	0.003 (0.002)	0.013 (0.010)
Hartwell	10.7 (0.3)	1.2 (0.1)	16.7	0.00 (---)	0.34 (0.015)
Marion	33.9 (2.8)	1.1 (0.1)	13.3	0.19 (0.012)	0.34 (0.022)
Murray	33.8 (0.3)	1.1 (0)	6.7	0.003 (0.002)	0.003 (0.002)
Marion (WTC)	56.6 (0.4)	1.2 (0.1)	20.0	0.037 (0.018)	0.048 (0.022)

White crappie from Lake Marion exhibited larger amounts of genetic variation in regards to number of alleles per locus, percentage of loci polymorphic and mean heterozygosity compared to the five black crappie populations (Table 2). It is not clear however what percent of this variation may be due to hybridization with black crappie.

Observed mean heterozygosities were lower than expected mean heterozygosities for all populations except Lakes Brown and Murray, where values were very near or equal to zero (Table 2). Several loci were deficient of heterozygotes. This gives the appearance that the populations were not at Hardy-Weinberg equilibrium. However, the loci that had excessive homozygotes were loci where this phenomenon is commonly observed in other species and may be due to peculiarities of protein structure of these particular enzymes (Rex Dunham, pers. comm.).

Relatedness of Black Crappie Populations

Roger's genetic similarity indicates that Lake Marion is the most distinctive black crappie population, and the other four populations are closely related (Figure 1). This divergence may be due in part to the degree of hybridization detected in the Lake Marion population. Further examination of the available data is warranted here.

```
                           Similarity

.90       .92       .93       .95       .97       .98      1.00
+----+----+----+----+----+----+----+----+----+----+----+----+

                                                            * LAKE BROWN
                                                           **
                                                           ** LAKE MURRAY
                                                     *******
                                                     *     ** LAKE GREENWOOD
                                                     *     **
                                                     *      * LAKE HARTWELL
                                                     *
                                                     ******** LAKE MARION

+----+----+----+----+----+----+----+----+----+----+----+----+
.90       .92       .93       .95       .97       .98      1.00
```

Figure 1. Roger's genetic similarity dendogram for South Carolina black crappie populations surveyed in 2001.

Recommendations

Conduct further literature review and data analysis in early 2005, and produce a final report. Hybrids were determined by phenotypes at four enzyme loci, but data for additional loci may be pertinent. Repeat analysis including all loci known to be diagnostic for black and white crappie. Include historic data from Lake Wateree in calculations of relatedness among South Carolina crappie populations. Determine what proportion of variation detected in the Lake Marion black and white crappie populations is due to hybridization, and for black crappie the biological significance of the divergence of the Lake Marion population. Crappie collected from Lake Marion have been aged. Combine ageing data with individual specific genetic data to compare growth in that system for black crappie, white crappie, and hybrid individuals.

Prepared By: Jean K. Leitner Title: Fishery Biologist

Job Title: Zoogeography of Centrarchidae of the South Atlantic Slope

Period Covered January 1 – December 31, 2004

Results and Discussion

The objective of this study is to evaluate levels of within and among population diversity for six species from the family Centrarchidae; redbreast sunfish *Lepomis auritus*, redear sunfish *L. microlophus*, warmouth *L. gulosus*, dollar sunfish *L. marginatus*, spotted sunfish *L. punctatus*, and mud sunfish *Acantharchus pomotis*. Populations were sampled from the Savannah, Edisto, Santee, and Pee Dee drainages. Last year we did not see sufficient variation to assess population structure in either the dollar or mud sunfish examined. We reported that to increase confidence in the variance components we would calculate, and to determine population structure for those two species, we should increase our available data.

In 2004 additional tissues were collected from 17 mud sunfish that previously had not yielded results. Staff at Savannah River Ecology Lab also provided new samples from three sites in the Savannah drainage. Original sequences were run for these mud sunfish, and reverse sequences begun for all fish collected.

Results so far are promising. We are seeing genetic variation for all six species. It appears that dollar and mud sunfish will show two different lineages, as the other four species have with the original sequences. Approximately 40 sequences still need to be completed prior to data analysis.

Recommendations

Extend the work period for this grant, with results expected in late January. Produce a comprehensive report at that time.

Prepared By: Jean K. Leitner Title: Fishery Biologist

Job Title: Contribution of South Carolina and Georgia stocked hybrid bass in Lakes Hartwell and Thurmond

Period Covered January 1, 2004 – December 31, 2004

Results and Discussion

Relative Contribution of hybrid bass stocked by South Carolina and Georgia

To date we have been unable to repeat our assessment of the 1999 year class due to poor oxytetracycline (OTC) marks. Hybrids marked in 2004 are still being evaluated, with completion expected in January. To date marks look promising, and we expect that an assessment of relative contribution by South Carolina and Georgia to the 2004 year class will be possible. Upon completion of the mark evaluation, we will meet with hatchery staff from Bonneau to correlate this years marking success with marking protocol.

Gill Net Efficiency

In last year's report we recommended that, to increase data available for an assessment of gill net efficiency, biologists record length by mesh and age all hybrid striped bass *Morone saxatilis x M. chrysops* collected by South Carolina and Georgia. Hybrids were collected and aged from Lakes Hartwell (N = 41) and Thurmond (N = 186) during the 2003-04 sampling season and data from South Carolina and Georgia were compiled.

From Lake Thurmond relatively few age 1 fish were collected. This is consistent with low catches of age 0 fish last year, which appears to be tied to a weak 2002 year class rather than to any net selectivity against age 0's. The break out of catch by mesh is also consistent with that seen in the previous sampling season. The smallest mesh (0.75 inch) ensnared 10 percent of the total catch, and only 3 percent of the targeted age 1 fish. Seventy percent of age 1's were collected in the largest mesh (Table 1). Total catch for Hartwell was considerably lower, but followed the same pattern when broken out by mesh (Table 2.) The 0.75 inch mesh accounts for approximately 10 percent of total catch on Lake Hartwell, and 61 percent of age 1's collected.

Table 1. Hybrid striped bass gill net collections from Lake Thurmond in 2003-04, South Carolina and Georgia combined. Catch is listed by age and mesh.

	N collected		
Mesh (in.)	Age 0+	Age 1+	Age > 1+
1.75	22	21	5
1.25	108	8	4
0.75	15	1	2

Table 2. Hybrid striped bass gill net collections from Lake Hartwell in 2003-04, South Carolina and Georgia combined. Catch is listed by age and mesh.

	N collected		
Mesh (in.)	Age 0+	Age 1+	Age > 1+
1.75	8	8	3
1.25	12	2	3
0.75	1	3	1

We looked at catch for striped bass *Morone saxatilis* in the past year as well. Only South Carolina recorded catch by mesh for this species, so little data was available (Thurmond, N = 36; Hartwell, N = 17). Both lakes however showed basically the same pattern. Twelve percent of fish collected from Lake Hartwell came from the 0.75 mesh. Lake Thurmond catch is presented in Table 3.

Table 3. Striped bass gill net collections from Lake Thurmond in 2003-04. Catch is listed by age and mesh.

	N collected		
Mesh (in.)	Age 0+	Age 1+	Age > 1+
1.75	1	2	1
1.25	23	2	1
0.75	6	0	0

Current data for hybrid striped bass catches on these two lakes suggest that a reconfiguration of gill nets would maximize the return on sampling efforts. The 0.75 mesh net has added little to the total catch in the years since mesh has been evaluated. Replacing that panel with one that would better target the species and/or age class of interest should dramatically increase available data for monitoring the fishery.

This is supported by initial data from striped bass catches, however data for that species is lacking. Both South Carolina and Georgia recorded all *Morone* catch by mesh during 2004 sampling. This data will be compiled and examined as in the last two years. At that time we should be able to make a sound recommendation regarding gill net efficiency in targeting *Morone* in these lakes.

Recommendations

Continue with mark evaluation. Determine what changes in protocol resulted in successful marks, to help ensure success in the future. Compile and examine gill net catch for hybrid and striped bass. Make a recommendation regarding gill net configuration for best targeting these two species.

Prepared By: Jean K. Leitner Title: Fishery Biologist

Job Title: Evaluation of hooking mortality and recovery of striped bass held in flow-through live-release tubes

Period Covered January 1, 2004 – December 31, 2004

Results and Discussion

Mortality and physiological responses of adult striped bass *Morone saxatilis* angled from Lake Murray, South Carolina, and held in live-release tubes were evaluated during spring and summer 2003. No mortality of striped bass was observed during spring (Table 1). Overall mortality during summer was 83%. Mortality of summer caught striped bass was not related to tube residence time, fish total length, depth of capture, or surface water temperature. To characterize physiological stress we measured plasma cortisol, glucose, lactate and osmolality of 62 striped bass (mean TL = 563 mm) angled and immediately released or angled and held in live-release tubes. Plasma cortisol, glucose, lactate and osmolality were positively related to tube residence time. When the hematological characteristics were considered only in relation to tube residence time**,** responses characteristic of physiological stress continued for about 150 minutes after which they began to return to normal (Figure 1). Live-release tubes appear to be useful for keeping striped bass alive when they are angled from cool water, but they are not effective when striped bass are angled from warm water.

Table 1. Mortality (percent) for striped bass caught and released, or caught stored in live-release tubes and then released in Lake Murray, South Carolina. The number of fish (N) that were tagged and released is given in parentheses. Residence times varied and are rounded to the nearest hour.

Residence Time (h)	Spring Season	Summer Season
0	0 (1)	83 (12)
2	0 (3)	73 (11)
4	0 (3)	82 (11)

6	0 (5)	100 (7)

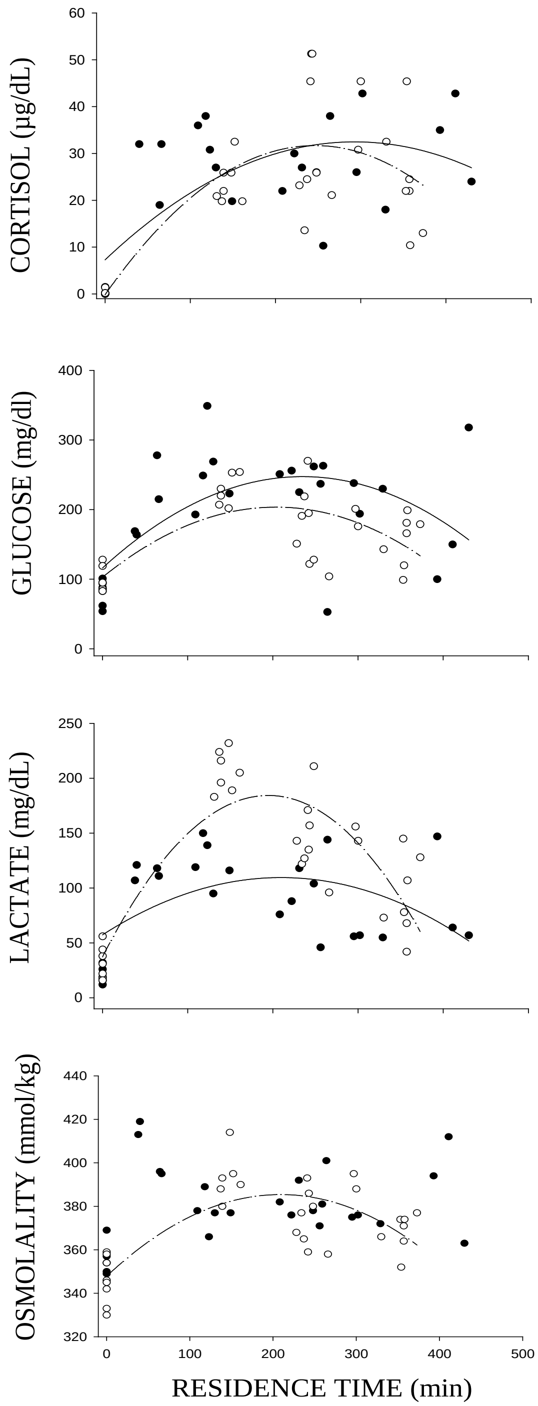


Figure 1. Relation of hematological characteristics (y) to residence time (x) for striped bass angled from Lake Murray, South Carolina. Spring-caught fish are represented by solid circles and summer-caught fish are represented by open circles. Regression equations and r^2: cortisol (spring) $y = -0.0003x^2 + 0.172x + 7.296$, $r^2 = 0.46$; cortisol (summer) $y = -0.0005x^2 + 0.259x + -0.169$, $r^2 = 0.65$; glucose (spring) $y = -0.0024x^2 + 1.118x + 116.05$, $r^2 = 0.35$; glucose (summer) $y = -0.0024x^2 = 0.989x + 102.78$, $r^2 = 0.50$; lactate (spring) $y = -0.0012x^2 + 0.498x + 57.33$, $r^2 = 0.24$; lactate (summer) $y = -0.0039x^2 + 1.511x + 37.292$, $r^2 = 0.74$; osmolality (summer) $y = -0.0009x^2 + 0.359x + 347.80$, $r^2 = 0.56$.

Recommendations

Field sampling, data analysis and report preparation for the striped bass study has been completed. A manuscript based on the study has been prepared and accepted, pending final edits, by the North American Journal of Fisheries Management. The high summer mortality of striped bass suggests a need for restrictive fishing regulations during the summer for the Lake Murray striped bass fishery.

Prepared By: Jason Bettinger Title: Fishery Biologist

Job Title: Piedmont Stream Survey – Broad River basin

Period Covered January 1, 2004 – December 31, 2004

Results and Discussion

During fall 2004, 24 streams were sampled following South Carolina Department of Natural Resources (SCDNR) protocols for sampling fish in wadeable streams (Table 1, Figure 1). Four of the sites were previously sampled during fall 2003, and were included in 2004 to provide a basis for comparing results between years. Four streams sampled by Region 1 as part of a statewide stream sampling effort are included in the total. At least one site was sampled in each of the five ecoregions present within the two study basins.

Table 1. Sites sampled within the Broad River drainage during fall 2004.

Date	Site No.	Stream	Long	Lat	Ecoregion
08/19/2004	37	South Pacolet River	-82.30856	35.15671	Blue Ridge
08/23/2004	38	Peter Hawks Creek	-81.60967	34.84633	Southern Outer Piedmont
10/07/2004	19	Gilky Creek	-81.61971	35.02004	Kings Mountain
10/07/2004	20	Cowcastle Creek	-81.75698	35.00530	Southern Outer Piedmont
10/07/2004	36	Clark Fork	-81.34174	35.11705	Kings Mountain
10/08/2004	21	Gregory Creek	-81.53058	34.69375	Southern Outer Piedmont
10/11/2004	22	Terrible Creek	-81.36711	34.38852	Southern Outer Piedmont
10/11/2004	23	McClures Creek	-81.38879	34.49984	Southern Outer Piedmont
10/15/2004	24	Wateree Creek	-81.28390	34.18986	Carolina Slate Belt
10/19/2004	25	West Fork Little River	-81.26309	34.45326	Southern Outer Piedmont
10/19/2004	9	Weir Creek	-81.26614	34.55862	Southern Outer Piedmont
10/21/2004	12	Blue Branch	-81.35592	34.85999	Southern Outer Piedmont
10/21/2004	26	Dry Fork	-81.30626	34.96095	Southern Outer Piedmont
10/22/2004	3	Harmon Creek	-81.09764	34.16433	Carolina Slate Belt
10/27/2004	27	Sandy River	-81.32191	34.65730	Southern Outer Piedmont
10/28/2004	17	Long Branch	-81.35736	35.13611	Kings Mountain
11/03/2004	29	Jumping Run Creek	-81.69684	34.86924	Southern Outer Piedmont
11/05/2004	29	Little Cedar Creek	-81.09752	34.24152	Carolina Slate Belt
11/05/2004	30	Horse Creek	-81.08697	34.21249	Carolina Slate Belt
11/05/2004	35	Green Creek	-82.26466	35.13359	Southern Interior Piedmont
11/16/2004	31	Tributary to Crims Creek	-81.42233	34.26107	Southern Outer Piedmont
11/18/2004	32	Big Creek	-81.19253	34.55195	Southern Outer Piedmont
11/18/2004	33	Susybole Creek	-81.32531	34.82079	Southern Outer Piedmont
11/30/2004	34	Kings Creek	-81.47743	35.04125	Kings Mountain

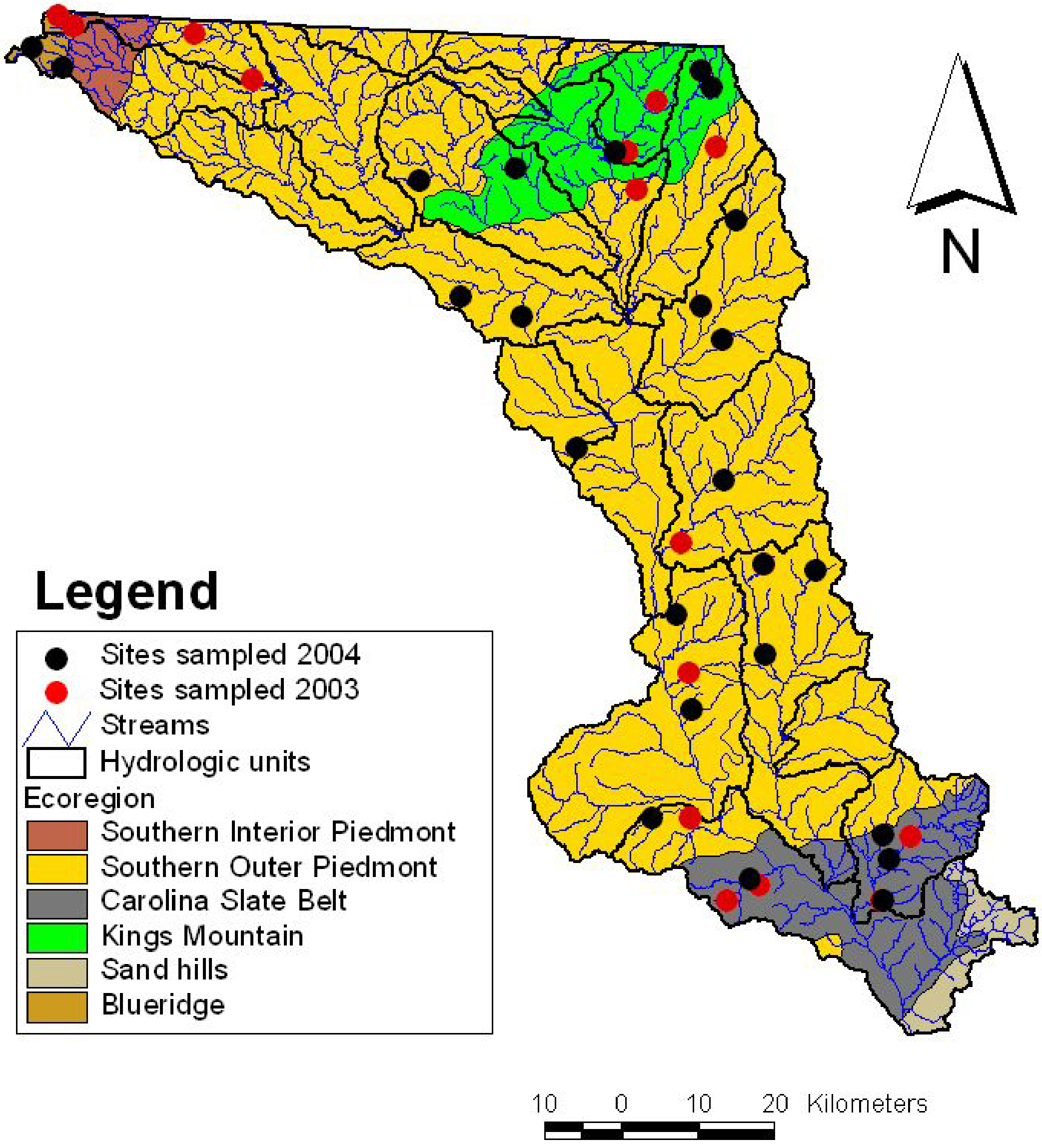


Figure 1. Sites sampled in the Broad River Drainage during fall, 2003 and 2004.

Forty-two fish species from eight families (Table 2) were collected. No federally-listed threatened or endangered species were collected. However, eight species identified as species of conservation concern in the South Carolina Comprehensive Wildlife Conservation Plan were collected. Of those species, Saluda darter *Etheostoma saludae* is listed as a species of the highest conservation concern. Four species, Santee chub *Hybopsis zanema*, fantail darter *Etheostoma flabellare*, Piedmont darter *Percina crassa*, and seagreen darter *Etheostoma thalassinum*, are identified as species of high conservation concern and three species, notchlip redhorse *Moxostoma collapsum*, greenfin shiner *Cyprinella chloristia*, and highback chub *Hybopsis hypsinotus*, are identified as species of moderate conservation concern.

Physical and chemical habitat data, including turbidity, temperature, dissolved oxygen, conductivity, and pH, were collected at each site. A visual habitat inventory was also conducted at each site. Those data have not been processed.

Recommendations

Continue study as planned, producing interim report by 15 February 2005 and final report by 15 September 2005. Inspect data to see what was gained from repetitive sampling. Evaluate the possibility of publishing study results, principally the relationship between fish community structure and environmental variables (e.g., land use and habitat variables).

Prepared By: Jason Bettinger Title: Fishery Biologist

Table 2. Fish species collected from Broad River tributaries during fall, 2004, and their conservation concern status based on the Comprehensive Wildlife Conservation Plan.

Common Name	Scientific Name	Family	Conservation Concern
Pirate perch	*Aphredoderus sayanus*	Aphredoderidae	
Redfin pickerel	*Esox americanus*	Esocidae	
Rosyside dace	*Clinostomus funduloides*	Cyprinidae	
Greenfin shiner	*Cyprinella chloristia*	Cyprinidae	Moderate
Whitefin shiner	*Cyprinella nivea*	Cyprinidae	
Eastern silvery minnow	*Hybognathus regius*	Cyprinidae	
Highback chub	*Hybopsis hypsinotus*	Cyprinidae	Moderate
Santee chub	*Hybopsis zanema*	Cyprinidae	High
Bluehead chub	*Nocomis leptocephalus*	Cyprinidae	
Golden shiner	*Notemigonus crysoleucas*	Cyprinidae	
Spottail shiner	*Notropis hudsonius*	Cyprinidae	
Yellowfin shiner	*Notropis lutipinnis*	Cyprinidae	
Coastal shiner	*Notropis petersoni*	Cyprinidae	
Swallowtail shiner	*Notropis procne*	Cyprinidae	
Sandbar shiner	*Notropis scepticus*	Cyprinidae	
Creek chub	*Semotilus atromaculatus*	Cyprinidae	
White sucker	*Catostomus commersoni*	Catostomidae	
Creek chubsucker	*Erimyzon oblongus*	Catostomidae	
Northern hogsucker	*Hypentelium nigricans*	Catostomidae	
Notchlip redhorse	*Moxostoma collapsum*	Catostomidae	Moderate
Striped jumprock	*Scartomyzon rupiscartes*	Catostomidae	
Brassy jumprock	*Scartomyzon sp.*	Catostomidae	
Snail bullhead	*Ameiurus brunneus*	Ictaluridae	
Yellow bullhead	*Ameiurus natalis*	Ictaluridae	
Flat bullhead	*Ameiurus platycephalus*	Ictaluridae	
Margined madtom	*Noturus insignis*	Ictaluridae	
Eastern mosquitofish	*Gambusia holbrooki*	Poeciliidae	
Flier	*Centrarchus macropterus*	Centrarchidae	
Redbreast sunfish	*Lepomis auritus*	Centrarchidae	
Green sunfish	*Lepomis cyanellus*	Centrarchidae	
Pumpkinseed	*Lepomis gibbosus*	Centrarchidae	
Warmouth	*Lepomis gulosus*	Centrarchidae	
Bluegill	*Lepomis macrochirus*	Centrarchidae	
Redear sunfish	*Lepomis microlophus*	Centrarchidae	
Smallmouth bass	*Micropterus dolomieu*	Centrarchidae	
Largemouth bass	*Micropterus salmoides*	Centrarchidae	
Fantail darter	*Etheostoma flabellare*	Percidae	High
Tessellated darter	*Etheostoma olmstedi*	Percidae	
Saluda darter	*Etheostoma saludae*	Percidae	Highest
Seagreen darter	*Etheostoma thalassinum*	Percidae	High
Piedmont darter	*Percina crassa*	Percidae	High

Job Title: Analysis of 2003 Stream Survey Data

Period Covered January 1, 2004 through December 31, 2004

Results and Discussion

Fish Assemblage Structure and Environmental Correlates

I summarized the predominant patterns of covariation in fish species composition and abundance among 50 sites surveyed in 2003. The 50 sites, located in three major drainages and seven ecoregions (Table 1), were selected based on the best judgment of biologists to represent best quality ("reference") streams in their respective districts. Biologists measured several stream channel dimensions and selected water quality parameters at the sites (Table 2). I analyzed these physical and chemical measures for associations with fish assemblage structure. Water temperature and dissolved oxygen were also measured in the field but were not included in this analysis. Temperature fluctuates dramatically according to time of day and seasonal fronts, so point measures are not likely to capture the mean or extreme conditions that influence fauna. Dissolved oxygen is strongly influenced by water temperature.

Table 1. Major river drainages and ecoregions sampled in the 2003 Stream Survey. Codes for each drainage and ecoregion are used in subsequent tables and figures.

Major River Drainage (DRAIN)	Code
Savannah	1
ACE	2
Santee	3
Ecoregion (ECOREG)	
Crystalline Blue Ridge	661
Inner Piedmont	451
Outer Piedmont	452
Carolina Slate Belt	453
Kings Mountain	454
Carolina Flatwoods	631
Sand Hills	651
Atlantic Southern Loam Plains	652

Table 2. Selected abiotic variables measured at 50 sites during the 2003 SC Stream Survey. Ecoregion and drainage codes are found in Table 1, ELEV is site elevation in feet, LENGTH is length of sampled stream segment in meters, WIDTH is mean channel wetted width (m), DEPTH is mean water depth (m), DEP-SD is the standard deviation of all depth measurements, CONDUC is water conductivity (S/cm), and PH is water pH. Dashes represent missing values.

SITE	ECOREG	DRAIN	ELEV	LENGTH	WIDTH	DEPTH	DEP-SD	CONDUC	PH
MCS03001	661	3	1325	158	7.92	0.406	0.2717	17.8	6.5
MCS03002	451	1	870	130	6.5	0.274	0.0608	49.8	6.5
MCS03003	452	3	650	100	4.08	0.163	0.0405	52.5	7.0
MCS03004	452	1	785	100	4.1	0.26	0.17674	51	7.0
MCS03005	452	3	455	148	7.4	0.2907	0.0829	89	8.0
MCS03006	452	3	740	106	5.6	0.336	0.1013	36	7.25
MCS03007	452	3	790	100	1.8	0.07	0.05	37	-
MCS03008	451	3	1140	106	4.55	0.1775	0.0714	36	6.7
MCS03009	661	3	1370	100	2.64	0.0947	0.0464	17	-
HB000031	651	3	260	90	4.5	0.47	0.252	61.7	5.5
HB000032	652	3	170	90	3.4	0.17	0.146	28.9	7.7
HB000033	452	3	200	90	8.4	0.27	0.181	26.1	7.0
HB000034	453	3	210	97	5.2	0.16	0.065	22.5	7.2
HB000035	453	3	220	100	4.62	0.135467	0.059697	88	7.3
HB000036	453	3	280	100	2.20	0.05588	0.046241	145	6.6
SAL03001	453	1	428	100	5.98	0.15	0.1	111.3	6.8
GWD03001	452	1	375	125	6.16	0.09	-	62	6.8
NBY03001	453	3	385	100	5.35	0.25	0.13	95	7.1
NBY03002	452	3	260	100	4.5	0.15	-	131.7	7.2
NBY03003	452	3	350	143	7.9	0.21	-	127.3	7.0
NBY03004	452	3	400	100	2.88	0.12	-	101.1	7.0
MGW0001	631	3	10	300	3.25	0.41	0.277532	120	6.95
MGW0002	631	3	32	100	1.8	0.255	0.133292	70	6.1
MGW0003	631	3	53	100	3.3	0.26	0.136168	210	7.6
MGW0004	631	3	36	100	1.97	0.268	0.055434	180	-
MGW0005	631	3	32	100	2.6	0.136	0.17466	160	7.3
MGW0006	631	3	29	100	1.9	0.15	0.057735	110	7.0
JMB403	453	3	310	100	2.44	0.046567	0.046208	82	7.3
JMB903	452	3	480	100	4.60	0.093133	0.130511	90	6.7
JMB1003	452	3	320	100	3.32	0.107696	0.088405	150	6.6
JMB1103	452	3	330	109	6.02	0.21336	0.086296	156	6.5
JMB1203	452	3	480	100	3.86	0.110067	0.081272	227	-
JMB1303	452	3	470	100	5.94	0.110067	0.070982	127	7.2
JMB1403	454	3	500	135	6.80	0.254	0.10946	87	6.8
JMB1503	454	3	590	100	4.28	0.226907	0.147003	55	-
JMB1603	453	3	280	142	7.94	0.2794	0.156576	104	-

Table 2. (cont.) Selected abiotic variables measured at 50 sites during the 2003 SC Stream Survey. Ecoregion and drainage codes are found in Table 1, ELEV is site elevation in feet, LENGTH is length of sampled stream segment in meters, WIDTH is mean channel wetted width (m), DEPTH is mean water depth (m), DEP-SD is the standard deviation of all depth measurements, CONDUC is water conductivity (S/cm), and PH is water pH. Dashes represent missing values.

SITE	ECOREG	DRAIN	ELEV	LENGTH	WIDTH	DEPTH	DEP-SD	CONDUC	PH
JMB1703	454	3	690	108	4.57	0.16764	0.078464	46	-
JMB1803	452	3	560	105.4	5.98	0.235373	0.099985	110	-
WAD03001	452	1	380	100	4.5	0.12	-	150.8	7.0
WAD03002	452	1	396	100	2.72	0.11	-	99.5	7.2
WAD03003	453	1	430	100	2.53	0.244	-	126.6	7.5
WAD03004	452	1	485	100	2.71	0.146	-	103.8	7.0
WAD03005	453	1	320	125	6.03	0.24	-	94.5	7.0
DEA001	631	2	17	100	4.9	0.3	0.06	42.5	-
DEA002	631	2	13	100	8.9	0.79	0.14	80.5	-
DEA003	631	1	25	100	3.1	0.15	0.04	67.3	-
DEA004	651	2	107	100	4.2	0.45	0.06	24.4	-
DEA005	631	2	27	100	4.4	0.29	0.1	132	-
DEA006	651	1	60	100	4.1	0.26	0.2	60.6	-
DEA007	652	2	63	100	5.5	0.33	0.12	34.3	-

Fishes were sampled following the procedures described in Thomason et al. (2002); the sum total of all electrofishing passes was used in the following analyses. Seventy-eight species of fish totaling 19,277 individuals were collected in the 2003 Survey. Total numbers of fish per site ranged from 2 individuals to 1,670 individuals (Table 3). Species richness reached a maximum of 22 species and a minimum of a single species. Shannon-Weiner diversity ranged from 0 to 2.286.

Predominant patterns in species composition and abundance among collections were extracted by an indirect-gradient ordination method, non-metric multidimensional scaling (NMS), implemented with PCOrd software (McCune and Mefford 1997). NMS requires no assumptions about distributions or forms of relationships in biological data (Minchin 1987). Only the rank order of dissimilarities (ecological distance) among samples is used, thus NMS estimates nonlinear monotonic relationships in the data. The data were trimmed prior to ordination by removing five sites that were either known to be impacted by human activities or in which fewer than four species were present. Abundances of species at the remaining 45 sites were fourth-root transformed prior to analysis to reduce the influence of very abundant species (Clarke 1993). Bray-Curtis dissimilarity values were calculated for each pair of collections as a measure of ecological distance (Faith et al. 1987). Two dimensions accounted for over 88% of the variance in Bray-Curtis values among sites (final stress=13.44), significantly greater than would be expected in random data (Monte Carlo test, $p<0.02$). The first dimension accounted for the most variance ($R2=0.74$).

Table 3. Summary statistics for 50 sites sampled for fish in 2003 SC Stream Survey (all passes combined). Sum is total number of fish collected, Sp. Rich is species richness, Even is assemblage evenness, and H Divers is Shannon-Weiner diversity.

		Total_Collections			
Site	Sum	Sp. Rich	Even	H Divers	Collector
MCS03001	525	15	0.668	1.81	Rankin/Scott
MCS03002	487	12	0.81	2.013	Rankin/Scott
MCS03003	284	12	0.648	1.61	Rankin/Scott
MCS03004	352	13	0.563	1.445	Rankin/Scott
MCS03005	1670	22	0.705	2.181	Rankin/Scott
MCS03006	502	22	0.792	2.45	Rankin/Scott
MCS03007	125	3	0.852	0.936	Rankin/Scott
MCS03008	369	7	0.794	1.545	Rankin/Scott
MCS03009	2	1	0	0	Rankin/Scott
HB000031	20	5	0.811	1.305	Beard
HB000032	53	2	0.657	0.456	Beard
HB000033	208	10	0.535	1.231	Beard
HB000034	183	12	0.851	2.114	Beard
HB000035	246	17	0.774	2.192	Beard
HB000036	81	10	0.757	1.743	Beard

SAL03001	541	15	0.785	2.126	Hayes
GWD03001	301	14	0.618	1.631	Hayes
NBY03001	321	11	0.646	1.549	Hayes
NBY03002	415	20	0.637	1.91	Hayes

Table 3.(cont.) Summary statistics for 50 sites sampled for fish in 2003 SC Stream Survey (all passes combined). Sum is total number of fish collected, Sp. Rich is species richness, Even is assemblage evenness, and H Divers is Shannon-Weiner diversity.

		Total Collections			
Site	Sum	Sp. Rich	Even	H Divers	Collector
NBY03003	249	14	0.853	2.25	Hayes
NBY03004	384	10	0.742	1.709	Hayes
MGW0001	105	18	0.773	2.234	White
MGW0002	174	14	0.74	1.953	White
MGW0003	321	10	0.667	1.537	White
MGW0004	436	20	0.858	2.57	White
MGW0005	276	17	0.707	2.004	White
MGW0006	716	24	0.631	2.006	White
JMB403	11	3	0.906	0.995	Bettinger
JMB903	278	16	0.825	2.286	Bettinger
JMB1003	643	10	0.759	1.748	Bettinger
JMB1103	1397	17	0.704	1.994	Bettinger
JMB1203	233	13	0.831	2.131	Bettinger
JMB1303	667	15	0.707	1.914	Bettinger
JMB1403	999	17	0.754	2.137	Bettinger
JMB1503	226	15	0.596	1.615	Bettinger
JMB1603	427	20	0.755	2.262	Bettinger
JMB1703	632	9	0.743	1.632	Bettinger
JMB1803	238	13	0.777	1.993	Bettinger
WAD03001	697	12	0.683	1.698	Bales
WAD03002	247	10	0.492	1.132	Bales
WAD03003	258	11	0.751	1.801	Bales
WAD03004	174	12	0.802	1.994	Bales
WAD03005	354	17	0.793	2.247	Bales
DEA001	432	15	0.704	1.907	Allen
DEA002	473	13	0.473	1.213	Allen
DEA003	270	17	0.755	2.139	Allen
DEA004	161	16	0.595	1.65	Allen
DEA005	323	18	0.631	1.824	Allen
DEA006	380	17	0.64	1.813	Allen
DEA007	411	20	0.714	2.138	Allen
sum total	19277				

A plot of fish species scores on the two NMS dimensions (axes) illustrates the major species associations across the state (Figure 1). Similar species scores on the two axes indicate that those taxa tend to occur (and not occur) at the same sites. Associations apparent from these scores include:

rainbow trout, brown trout, and central stoneroller; seagreen darter, greenfin shiner, spottail shiner, sandbar shiner, and margined madtom; creek chubsucker, redbreast sunfish, tessellated darter, and bluegill; speckled madtom, Savannah darter, and sailfin shiner; tadpole madtom, bluespotted sunfish, sawcheek darter, and flier.

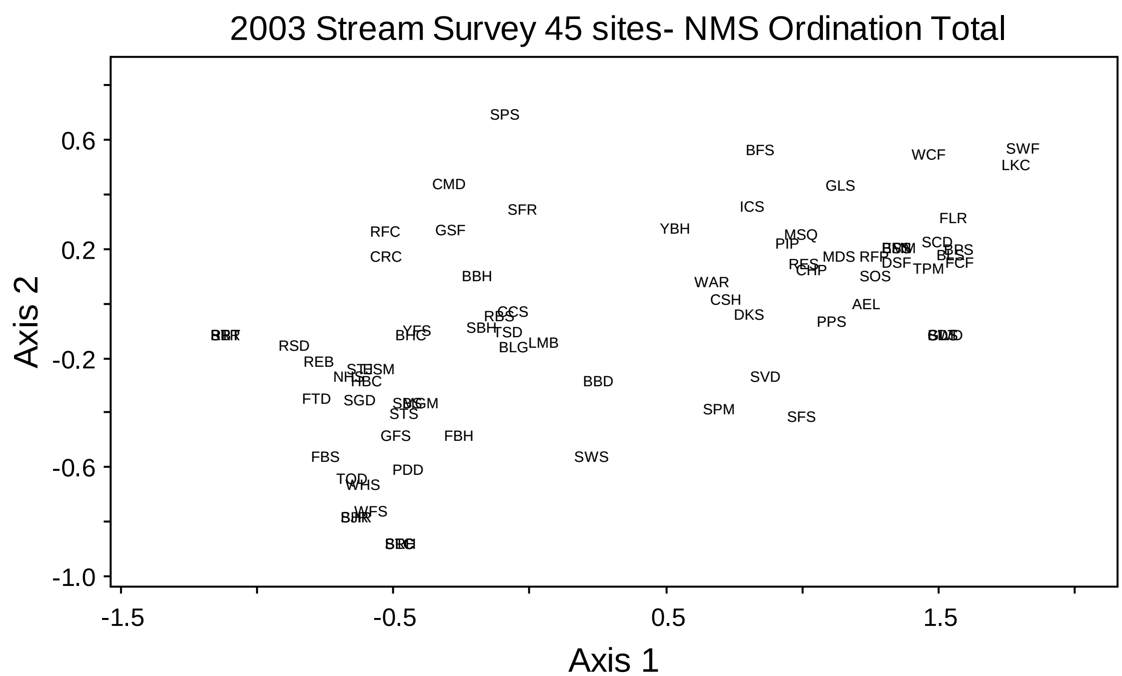


Figure 1. Plot of species scores on two ordination axes produced by nonmetric multidimensional scaling illustrates a gradient in species composition. Species with similar scores co-occur. For example, associations of greenfin shiner, spottail shiner, and seagreen darter through blackbanded darter, dusky shiner, and warmouth to sawcheek darter, tadpole madtom and flier are apparent.

A plot of site scores on the same NMS axes illustrates faunal similarity among sites (Figure 2). Sites located near each other in the two-dimensional space have similar fish assemblages. The location of sites in ordination space (Figure 2) can be compared to the species locations (Figure 1) to visualize which species characterize particular sites. When sites were coded according to river drainage, there was little separation of sites by respective basins (Figure 3). Although Savannah drainage sites tended toward the upper left of the two-dimensional space and ACE basin sites tended toward the lower right, the interspersion of sites suggests that fish assemblages among the three drainages are not highly distinct from each other. Sites coded by ecoregion produced a clear faunal gradient (Figure 4). Coastal Plain sites separated toward the upper end of Axis 1 from Piedmont sites arranged toward the lower end. A single Blue Ridge site scored lowest on the first axis (Figure 4).

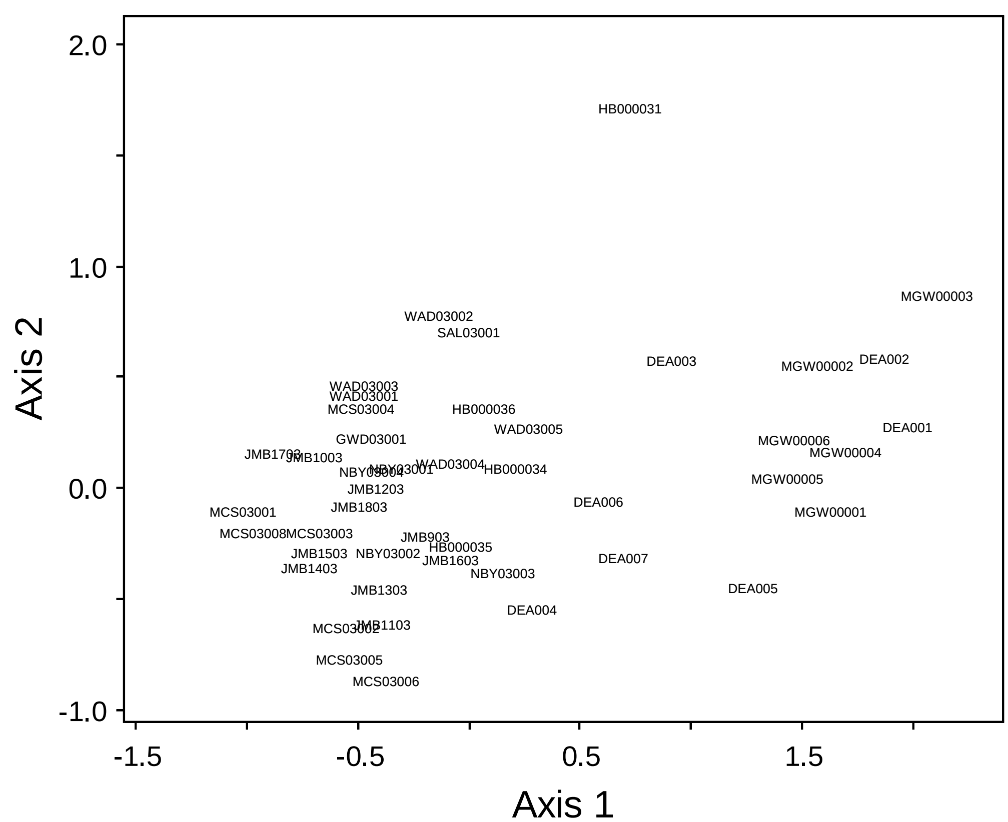


Figure 2. Plot of site scores on the two NMS axes illustrates site similarities in terms of fish fauna. The two dimensional space is defined by the fish species scores depicted in Figure 1, so sites located in a similar region of the graph are characterized by similar fish species composition and abundance.

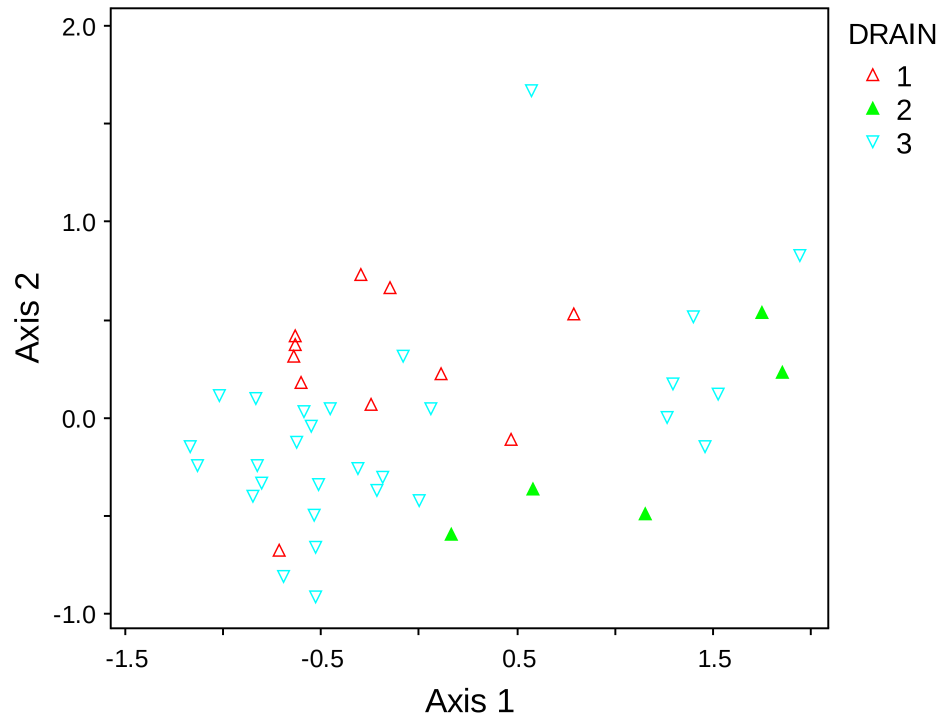


Figure 3. Plot of site scores on the two NMS axes with sites grouped by river drainage (see Table 1 for code definitions).

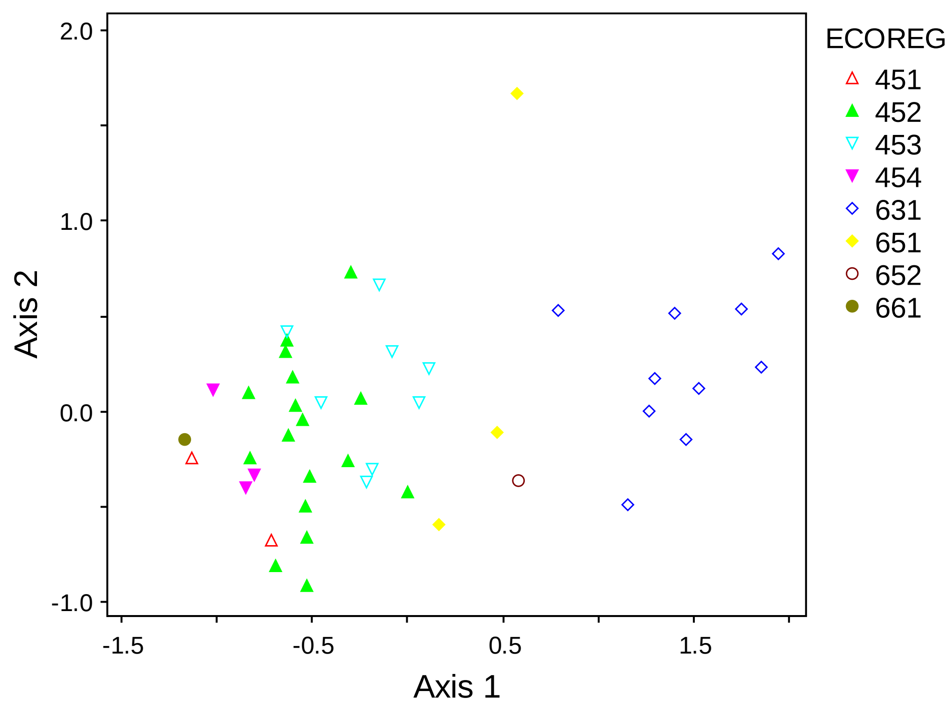


Figure 4. Plot of site scores on the two NMS axes with sites grouped by ecoregion (see Table 1 for code definitions).

The ecoregional pattern of faunal change from uplands to lowlands was reinforced when the continuous physicochemical measures presented in Table 2 were related to the site ordination scores. A biplot of these variables on the ordination axes indicated a strong association between elevation and Axis 1 (Figure 5). A bivariate plot of Axis 1 scores on elevation illustrates the strength of the relationship (Figure 6), as well as the logarithmic form (y=3.3721-0.6317Ln[elevation]). The equation explains nearly 88% of variation among sites in Axis 1 scores, suggesting that fish assemblage structure is highly predictable with respect to elevation. Elevation is a primary influence on temperature, an important factor controlling key biological functions (Scott et al. 2002). No other variables reflecting stream size, channel morphology, or water chemistry were significantly related to assemblage structure. However, an outlying site at the top of Axis 2 (HB000031; Figure 2) suggests there may be another important environmental influence. This site in the Inner Piedmont is also an outlier in terms of pH (5.5; Table 2). This important measure of stream chemistry can indicate naturally acidic streams such as "blackwater" or human inputs of pollutants. The large number of missing values for pH precludes statistical conclusions, but the available evidence suggests that pH and related measures such as acid neutralizing capacity and dissolved organic carbon may be important influences on assemblage structure in South Carolina.

Ecoregion was clearly a prominent influence on fish assemblages. Ecoregion boundaries are delineated based on ecological factors such as physiography, geology, and land cover. As such, the factor(s) responsible for the observed differences in fish faunas among ecoregions are unclear at present. Elevation may be a suitable variable for use in predicting fish assemblage composition and abundance based on the strength of relationship presented here and its known influence on temperature, and important factor controlling biological functions. Nonetheless, many other environmental factors were not measured and therefore their utility as predictors remains unknown. For example, channel gradient and nutrient concentrations are two other important factors that may covary to some degree with elevation. Slope generally becomes more gentle from upstate to coast, controlling features of hydrology and channel morphology such as flow rates and prevalence of riffles. Nutrients such as nitrogen may play a larger role in ecosystem productivity, particularly coupled with higher temperatures in lowlands. The effects of these environmental factors fish assemblages in South Carolina are currently unknown, but warrant additional observation and analysis.

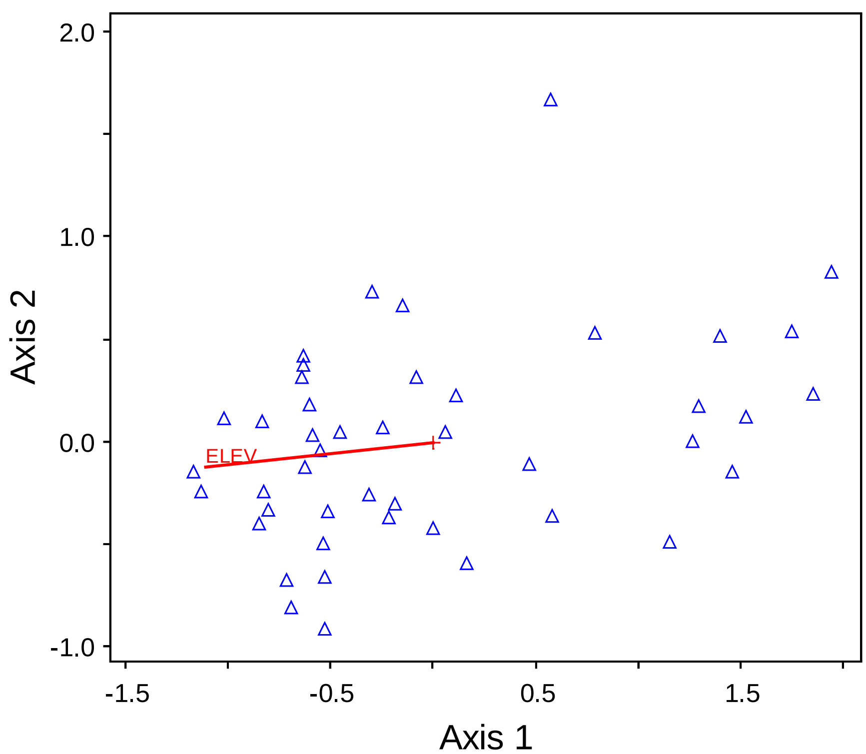


Figure 5. A biplot of abiotic associations with the site ordination scores shows that the only significant variable is site elevation. The direction of the vector indicates that sites toward the negative end of Axis 1 are higher elevation and those toward the negative end are lower. The length of the vector indicates the strength of relationship, which in this case depicts a strong correlation between elevation and Axis 1 scores (*r*=-0.80).

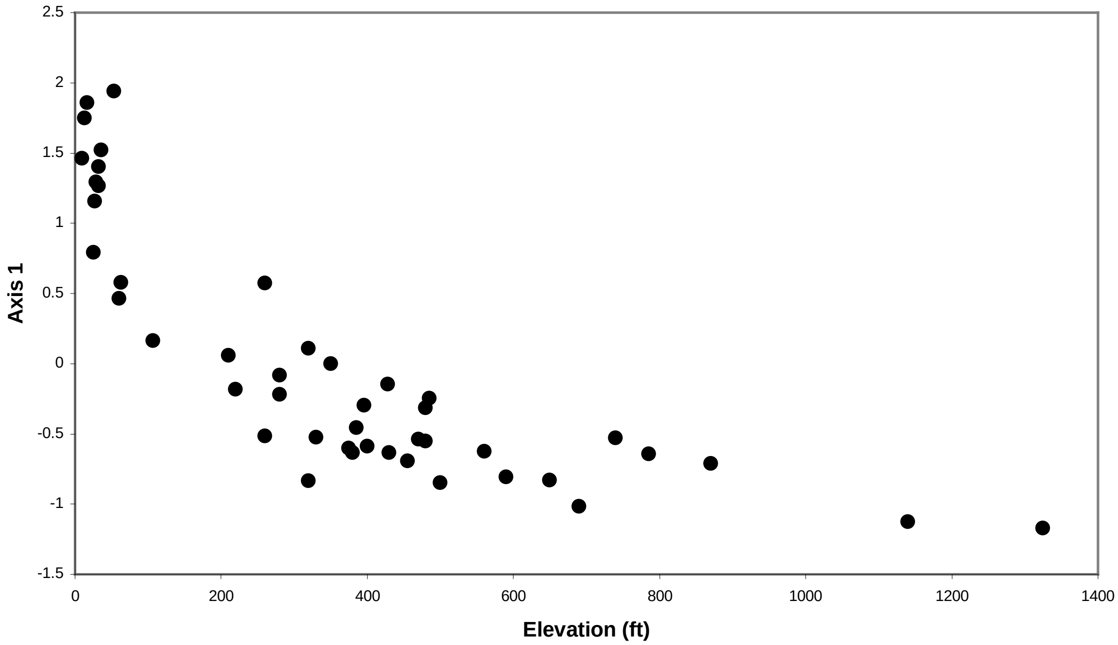


Figure 6. Bivariate plot of site scores on the first ordination axis versus site elevation.

Electrofishing Effort Comparison

I examined the effects of electrofishing effort on key metrics of fish assemblage composition and abundance using the 2003 Stream Survey data. The total collection including all electrofishing passes (three or more) was the benchmark to which single pass and two-pass collections were compared. Comparisons involved fish species richness, total fish collected, community diversity, and patterns in assemblage structure as determined by ordination.

Single pass electrofishing compared to total electrofishing effort resulted in 1.82 fewer species on average (Table 4). On a percentage basis the difference was 13.4%. Total number of fish was 11,177 from single pass collections versus 19,277 from the total effort, a difference of 42%. Although at 17 sites all species collected were captured in the first pass, at the remaining 33 sites additional species were collected in subsequent passes. Number of additional species collected reached a maximum of 8, and as high as 80% of the total species richness was collected on subsequent passes (Table 4). There appeared to be a physiographic component to the results. I separated the sites into two groups based on elevation: a lowland group of sites less than 300 feet in elevation and an upland group greater than 300 feet. Lowland effort on average collected only about 79% of species in the first pass compared to almost 92% in the uplands (Figure 7). An ordination using identical methods to those described in the previous section was conducted using the single pass data. Faunal patterns were quite similar to those observed with the full-effort data. The Axis 1 site score correlation was 0.94, and that for Axis 2 was 0.72. Similar ecoregional patterns were apparent as well, suggesting that fundamental differences and similarities in faunal structure among sites can be discerned with results from a single electrofishing pass.

Predictably, the situation substantially improved when the first two passes were compared to the total effort. The number of fish collected was about 84% of the total, and on average 0.5 species were missed, or 3.64% (Table 5). At thirty-five sites total richness was obtained by the second pass. Nonetheless, only two-thirds of total richness was obtained by the second pass at one site. The difference observed between uplands and lowlands in percent richness obtained after second pass was much less than that observed after a single pass. In the lowlands the second pass effort averaged 95% and in uplands it averaged 97.3% of total richness (Figure 8). Correlations of two-pass and full-effort ordination axes were 0.94 and 0.76, respectively for Axis 1 and Axis 2.

The rationale for multi-pass electrofishing is to derive population estimates for species of interest using depletion curves. In community assessments the objective shifts from population

Table 4. Comparison of fish assemblage metrics obtained from single pass electrofishing with metrics obtained from all passes combined.

	Total Collections			Pass 1 Only				
Site	Sum	S	H	Sum	S	H	S Diff.	% Missed
MCS03001	525	15	1.81	99	11	2.091	4	26.7
MCS03002	487	12	2.013	238	12	1.964	0	0
MCS03003	284	12	1.61	170	10	1.55	2	16.7
MCS03004	352	13	1.445	263	9	1.233	4	30.8
MCS03005	1670	22	2.181	1126	22	2.131	0	0
MCS03006	502	22	2.45	327	19	2.42	3	13.6
MCS03007	125	3	0.936	103	3	0.967	0	0
MCS03008	369	7	1.545	266	7	1.523	0	0
MCS03009	2	1	0	2	1	0	0	0
HB000031	20	5	1.305	4	1	0	4	**80**
HB000032	53	2	0.456	27	2	0.419	0	0
HB000033	208	10	1.231	89	7	1.195	3	30
HB000034	183	12	2.114	90	7	1.823	5	41.7
HB000035	246	17	2.192	162	12	1.82	5	29.4
HB000036	81	10	1.743	51	9	1.488	1	10
SAL03001	541	15	2.126	243	15	2.079	0	0
GWD03001	301	14	1.631	178	10	1.477	4	28.6
NBY03001	321	11	1.549	53	11	1.831	0	0
NBY03002	415	20	1.91	308	20	1.961	0	0
NBY03003	249	14	2.25	107	14	2.231	0	0
NBY03004	384	10	1.709	103	10	1.757	0	0
MGW0001	105	18	2.234	37	10	1.93	**8**	44.4
MGW0002	174	14	1.953	101	12	1.908	2	14.3
MGW0003	321	10	1.537	140	9	1.809	1	10
MGW0004	436	20	2.57	214	19	2.535	1	5
MGW0005	276	17	2.004	170	11	1.882	6	35.3
MGW0006	716	24	2.006	429	22	1.979	2	8.3
JMB403	11	3	0.995	10	3	0.898	0	0
JMB903	278	16	2.286	192	16	2.263	0	0
JMB1003	643	10	1.748	399	10	1.768	0	0
JMB1103	1397	17	1.994	1072	15	1.934	2	11.8
JMB1203	233	13	2.131	177	12	2.071	1	7.7
JMB1303	667	15	1.914	372	15	1.846	0	0
JMB1403	999	17	2.137	654	16	2.103	1	5.9
JMB1503	226	15	1.615	148	13	1.658	2	13.3
JMB1603	427	20	2.262	270	19	2.156	1	5
JMB1703	632	9	1.632	455	9	1.628	0	0
JMB1803	238	13	1.993	153	12	1.904	1	7.7
WAD03001	697	12	1.698	279	10	1.685	2	16.7
WAD03002	247	10	1.132	129	9	1.076	1	10
WAD03003	258	11	1.801	153	10	1.741	1	9.1
WAD03004	174	12	1.994	89	8	1.38	4	33.3
WAD03005	354	17	2.247	126	16	2.28	1	5.9
DEA001	432	15	1.907	323	15	1.934	0	0
DEA002	473	13	1.213	245	9	1.121	4	30.8
DEA003	270	17	2.139	190	15	2.154	2	11.8
DEA004	161	16	1.65	42	9	1.597	7	43.8
DEA005	323	18	1.824	195	16	1.83	2	11.1
DEA006	380	17	1.813	261	15	1.76	2	11.8
DEA007	411	20	2.138	143	18	2.121	2	10
sum total	19277			11177		mean	1.82	13.40

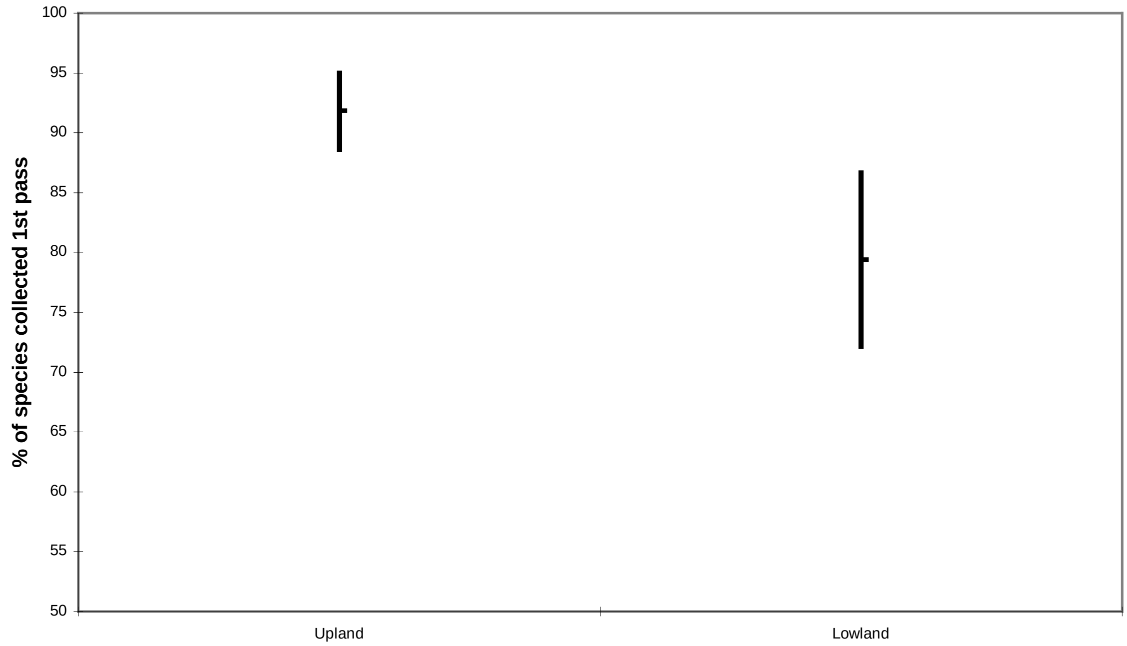


Figure 7. Comparison of the percentage of total species richness obtained after a single pass in upland streams (>300 ft) versus lowland streams (<300 ft). Means and 90% confidence intervals are shown.

estimation to accurate reporting of species composition and relative abundance. The results of the effort comparison suggest that a single pass may miss a substantial fraction of the species present at a site, particularly in coastal plain streams, but that general patterns of assemblage structure are discernable with data from a single pass. Effort through the second pass generally produced within 95% of species present in the total sample, and similar patterns of faunal structure across sites. If the objective of the stream survey is to accurately report fish assemblage composition and relative abundance in streams of the state, rather than estimate population sizes, then running three or more passes may not be an efficient use of resources. Utilizing the most efficient sampling protocol would likely mean additional sites could be sampled over the course of the season, thereby increasing sample size and thus the power to determine cause-effect relationships in the data.

Table 5. Comparison of fish assemblage metrics obtained from two-pass electrofishing with metrics obtained from all passes combined.

	Total Collections			Pass 2 Collections				
Site	Sum	Sp. Rich	H Divers	Sum	Sp. Rich	H Divers	Sp Diff.	% Missed
MCS03001	525	15	1.81	415	14	1.797	1	7
MCS03002	487	12	2.013	402	12	2.009	0	0
MCS03003	284	12	1.61	246	11	1.63	1	8
MCS03004	352	13	1.445	326	12	1.37	1	8
MCS03005	1670	22	2.181	1504	22	2.168	0	0
MCS03006	502	22	2.45	423	20	2.416	2	9
MCS03007	125	3	0.936	125	3	0.936	0	0
MCS03008	369	7	1.545	336	7	1.532	0	0
MCS03009	2	1	0	2	1	0	0	0
HB000031	20	5	1.305	11	4	1.121	1	20
HB000032	53	2	0.456	47	2	0.421	0	0
HB000033	208	10	1.231	162	10	1.277	0	0
HB000034	183	12	2.114	117	8	1.874	**4**	**33**
HB000035	246	17	2.192	226	15	2.066	2	12
HB000036	81	10	1.743	71	10	1.641	0	0
SAL03001	541	15	2.126	409	15	2.053	0	0
GWD03001	301	14	1.631	241	12	1.553	2	14
NBY03001	321	11	1.549	128	11	1.593	0	0
NBY03002	415	20	1.91	382	20	1.954	0	0
NBY03003	249	14	2.25	178	14	2.225	0	0
NBY03004	384	10	1.709	204	10	1.748	0	0
MGW0001	105	18	2.234	63	15	2.285	3	17
MGW0002	174	14	1.953	148	14	1.953	0	0
MGW0003	321	10	1.537	204	10	1.758	0	0
MGW0004	436	20	2.57	354	20	2.573	0	0
MGW0005	276	17	2.004	243	17	2.019	0	0
MGW0006	716	24	2.006	625	24	2.022	0	0
JMB403	11	3	0.995	11	3	0.995	0	0
JMB903	278	16	2.286	259	16	2.281	0	0
JMB1003	643	10	1.748	549	10	1.758	0	0
JMB1103	1397	17	1.994	1397	17	1.994	0	0
JMB1203	233	13	2.131	220	13	2.106	0	0
JMB1303	667	15	1.914	556	15	1.879	0	0
JMB1403	999	17	2.137	857	17	2.119	0	0
JMB1503	226	15	1.615	206	14	1.657	1	7
JMB1603	427	20	2.262	379	20	2.225	0	0
JMB1703	632	9	1.632	573	9	1.622	0	0
JMB1803	238	13	1.993	190	12	1.939	1	8
WAD03001	697	12	1.698	512	10	1.661	2	17
WAD03002	247	10	1.132	211	10	1.181	0	0
WAD03003	258	11	1.801	224	11	1.809	0	0
WAD03004	174	12	1.994	148	12	1.959	0	0
WAD03005	354	17	2.247	254	17	2.19	0	0
DEA001	432	15	1.907	411	15	1.908	0	0
DEA002	473	13	1.213	407	13	1.172	0	0
DEA003	270	17	2.139	229	17	2.192	0	0
DEA004	161	16	1.65	93	14	1.658	2	13
DEA005	323	18	1.824	282	18	1.892	0	0
DEA006	380	17	1.813	344	16	1.788	1	6
DEA007	411	20	2.138	288	19	2.132	1	5

Sum total	19277	16192	mean	0.5	4

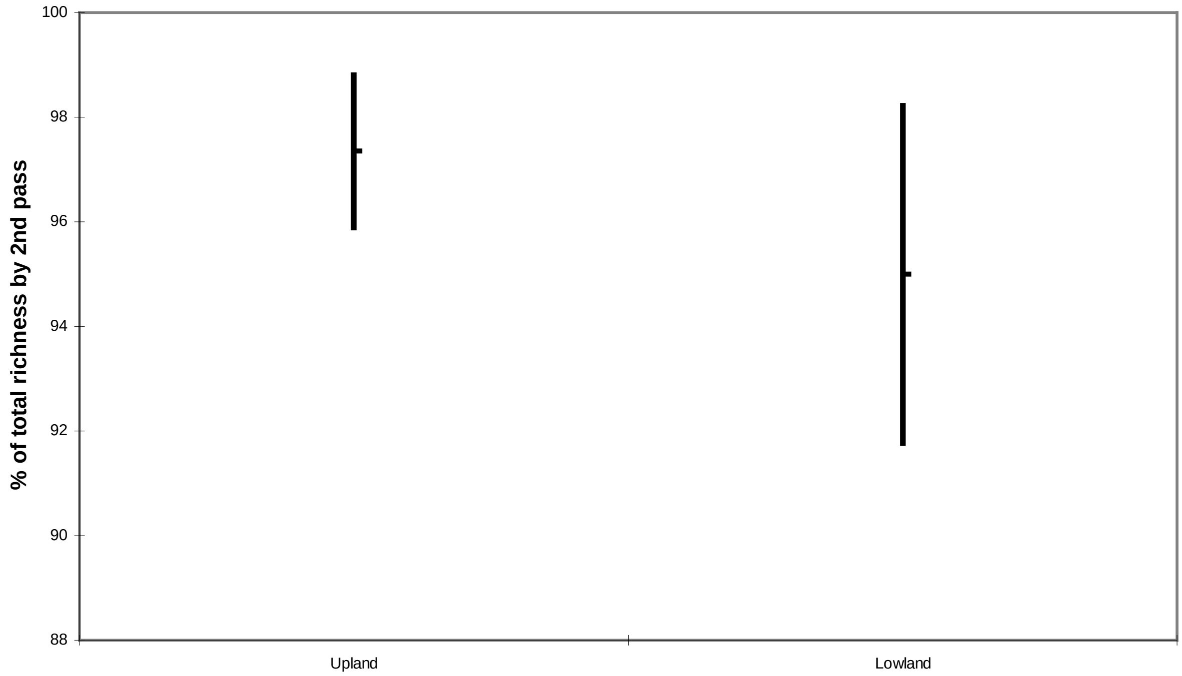


Figure 8. Comparison of the percentage of total species richness obtained after two passes in upland streams (>300 ft) versus lowland streams (<300 ft). Means and 90% confidence intervals are shown.

Recommendations

Fish Assemblages and Environmental Correlates

An understanding of the principal environmental influences, both man-made and natural, on aquatic communities is necessary for effective management of freshwater resources. In order to achieve understanding, DNR needs to implement a comprehensive monitoring and assessment program. Such a program should strive to place the biological component within a hierarchical context of physicochemical conditions within the stream, catchment characteristics including land use/land cover, and physiographic variation across landscapes in the state. I recommend charging the

Stream Survey Committee within Freshwater Fisheries with the task of detailing the scope and protocols of the effort in the winter of 2004-2005.

Electrofishing Effort Determination

The Freshwater Fisheries Section may be using a sampling protocol that is inappropriate for the study objective. I recommend charging the Stream Survey Committee with the task of reviewing sampling protocols appropriate for community sampling in the winter of 2004-2005. They should detail the options for further research into sampling efficiency, if needed. The committee should construct a timetable for making final recommendations to Section biologists concerning an appropriate sampling protocol for wadeable streams in South Carolina.

Literature Cited

Clarke, K.R. 1993. Non-parametric multivariate analyses of changes in community structure. Austral. J. Ecol. 18:117-143.

Faith, D.P., P.R. Minchin, and L. Belbin. 1987. Compositional dissimilarity as a robust measure of ecological distance. Vegetatio 69:57-68.

McCune, B., and M.J. Mefford. 1997. PC-ORD. Multivariate analysis of ecological data, Ver. 3.0. MjM Software Design, Gleneden Beach, Oregon.

Minchin, P.R. 1987. An evaluation of the relative robustness of techniques for ecological ordination. Vegetatio 69:89-107.

Scott, M.C., G.S. Helfman, M.E. McTammany, E.F. Benfield, and P.V. Bolstad. 2002. Multiscale influences on physical and chemical stream conditions across Blue Ridge landscapes. Journal of the American Water Resources Association 38:1379-1392.

Thomason, C, J Bettinger, D Rankin, D Crochet, L Rose and H Beard. 2002. The South Carolina Standard Operating Procedures for Sampling Fish in Wadeable Streams. South Carolina Department of Natural Resources, Freshwater Fisheries Section, Columbia, SC.

Prepared By: Mark Scott Title: Research Fisheries Biologist

Job Title: Interrelationships of land use, stream habitat quality, and fish assemblage integrity among tributaries of the Reedy River, South Carolina

Period Covered January 1, 2004 – December 31, 2004

Results and Discussion

Within the scope of the comprehensive monitoring of the aquatic community of the Reedy River watershed (South Carolina Department of Natural Resources [SCDNR] Project 2360000203), Greenville-Laurens Counties, South Carolina, is the characterization of the interrelationships of land use, stream habitat quality, and fish assemblage integrity among tributaries of this system. Preliminary fish and water quality sampling was conducted at six tributary sites (Table 1) in Fall 2004. Sites were selected under a comparative monitoring framework in collaboration with the South Carolina Department of Health and Environmental Control (SCDHEC) from pre-established water quality and macroinvertebrate sampling localities. Fish sampling followed the SCDNR standard operating procedures (Thomason et al. 2002). Descriptive ecological statistics (abundance and diversity attributes) were generated using PC-ORD (McCune and Mefford 1999) from the species-abundance data of each site. The sampling conducted over the current reporting period served primarily to provide a preliminary perspective of the range of site and fish assemblage conditions present within the study system, from which the interrelationships among land use, stream habitat quality, and fish assemblage integrity will be further examined.

In upstream to downstream order of confluence with the Reedy River main stem, the tributaries sampled were Brushy Creek, Baldwin Creek, Rocky Creek, Huff Creek, Horse Creek, and Walnut Creek. Mean wetted width among the six sites averaged 5.42 m, ranging from 2.93 m (Baldwin Creek) to 7.36 m (Brushy Creek), which corresponded to a sample reach length range of

100 m to 147 m, respectively (Table 1). Water quality over the sample period was characterized by a temperature range of 12.84 (Brushy Creek) to 18.77 °C (Walnut Creek), dissolved oxygen levels from 8.17 (Walnut Creek) to 10.34 mg/L (Brushy Creek), pH values ranging from 6.60 (Horse and Baldwin Creeks) to 7.04 (Walnut Creek), conductivities of 39.0 (Huff Creek) to 76.0 µS/cm (Walnut Creek), and turbidity levels ranging from 5.70 (Baldwin Creek) to 7.40 NTU (Walnut Creek) Table 2).

Table 1. Location and sample site characteristics of the six Reedy River tributaries, Fall 2004.

Site Number	Stream/Locality	Sample Date (2004)	Latitude/ Longitude	Elevation	Mean Wetted Width (m)	Sample Length (m)*
S-091	Rocky Creek at S.S.R. 453	22 October	34° 42’ 10.1” N 82° 17’ 55.1” W	216 m (710 ft)	5.70	114
S-861	Walnut Creek at S.S.R. 64	25 October	34° 23’ 31.6” N 82° 08’ 56.0” W	134 m (440 ft)	4.60	100
S-862	Horse Creek at S.S.R. 69	27 October	34° 31’ 24.9” N 82° 15’ 48.3” W	182 m (597 ft)	5.20	104
BC-3	Baldwin Creek at N. Moore Rd.	27 October	34° 43’ 26.9” N 82° 18’ 31.2” W	207 m (678 ft)	2.93	100
S-863	Huff Creek at S.S.R. 459	08 November	34° 39’ 17.8” N 82° 19’ 33.4” W	212 m (697 ft)	6.71	134
S-030	Brushy Creek at S.S.R. 30	15 November	34° 47’ 56.5” N 82° 23’ 30.2” W	284 m (932 ft)	7.36	147

*Sample length = 100 m if mean wetted width ≤ 5.0 m; = 20X mean wetted width if > 5.0 m (SCDNR Standard Operating Procedures)

Table 2. Water quality characteristics of the six Reedy River tributary sites, Fall 2004.

Site	Sample Date (2004)	Water Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Conductivity (µS/cm)	Turbidity (NTU)
Rocky	22 October	17.24	9.28	6.80	59.0	6.49
Walnut	25 October	18.77	8.17	7.04	76.0	7.40
Horse	27 October	15.92	8.91	6.60	42.0	7.09
Baldwin	27 October	17.00	8.96	6.60	41.0	5.70
Huff	08 November	14.39	9.72	6.83	39.0	6.18
Brushy	15 November	12.84	10.34	6.62	73.0	6.78
Mean		16.03	9.23	6.75	55.0	6.61

Twenty-five fish species were collectively present among the six Reedy River tributary sites (Table 3). The distribution of these species by site was characterized by a mean species richness of 14.3, from a low of 10 (Brushy Creek) to a high of 18 (Huff and Walnut Creeks) (Table 4). An average of 14.89 individuals occurred per species present at any given site, with specific site mean abundance per species present ranging from 4.44 (Horse Creek) to 28.88 (Huff Creek) (Table 4). Site total fish abundance averaged 372, from 111 (Horse Creek) to 722 (Huff Creek), and the most abundant species present numbered 165.5 on average, with site maxima ranging from 62 bluehead chubs *Nocomis leptocephalus* at Horse Creek to 339 yellowfin shiners *Notropis lutipinnis* at Huff Creek (Table 4). Furthermore, either the bluehead chub or yellowfin shiner was always the most abundant species (Table 4).

Table 3. Abundance by site for the 25 fish species present among the six Reedy River tributary sites, Fall 2004.

Common Name	Scientific Name	Species Code	Site						Total
			Rocky	Walnut	Horse	Baldwin	Huff	Brushy	
Bluegill	*Lepomis macrochirus*	BLG	4	27	1	20	28	43	123
Bluehead chub	*Nocomis leptocephalus*	BHC	181	138	62	145	123	76	725
Brown bullhead	*Ameiurus nebulosus*	BBH	1	0	0	0	1	0	2
Creek chub	*Semotilus atromaculatus*	CRC	11	4	9	34	0	3	61
Flat bullhead	*Ameiurus platycephalus*	FBH	4	1	2	0	3	0	10
Green sunfish	*Lepomis cyanellus*	GSF	13	24	1	2	2	13	55
Greenfin shiner	*Cyprinella chloristia*	GFS	0	14	0	0	26	0	40
Largemouth bass	*Micropterus salmoides*	LMB	0	0	0	2	5	5	12
Marginted madtom	*Noturus insignis*	MGM	0	1	0	0	9	0	10
Mosquitofish	*Gambusia affinis*	MSQ	0	1	1	0	3	2	7
Northern hogsucker	*Hypentelium nigricans*	NHS	59	17	1	31	73	0	181
Pumpkinseed	*Lepomis gibbosus*	PPS	0	1	0	1	0	0	2
Redbreast sunfish	*Lepomis auritus*	RBS	1	9	4	3	27	0	44
Redear sunfish	*Lepomis microlophus*	RES	0	2	1	0	0	0	3
Redfin pickerel	*Esox americanus*	RFP	0	0	1	0	0	0	1
Rosyside dace	*Clinostomus funduloides*	RSD	1	0	0	21	0	0	22
Seagreen darter	*Etheostoma thalassinum*	SGD	1	0	0	1	4	0	6
Spottail shiner	*Notropis hudsonius*	STS	15	22	0	1	74	0	112
Striped jumprock	*Moxostoma rupiscartes*	STJ	0	24	0	2	1	0	27
Tessellated darter	*Etheostoma olmstedi*	TSD	0	4	0	0	0	0	4
Warmouth	*Lepomis gulosus*	WAR	0	2	0	1	2	1	6
White sucker	*Catostomus commersoni*	WHS	0	0	0	1	1	4	6
Whitefin shiner	*Cyprinella nivea*	WFS	0	3	0	0	0	0	3
Yellow bullhead	*Ameiurus natalis*	YBH	10	0	0	1	1	22	34
Yellowfin shiner	*Notropis lutipinnis*	YFS	120	190	28	48	339	13	738

Total	421	484	111	314	722	182

Table 4. Fish species richness, abundance, and diversity attributes by site for the six Reedy River tributaries, Fall 2004.

Site	Species Richness	Mean (Std. Dev.)	Total	Maximum	Evenness	Shannon Diversity	Simpson Diversity
Huff	18	28.88 (71.40)	722	339 (YFS)	0.596	1.723	0.725
Walnut	18	19.36 (45.07)	484	190 (YFS)	0.632	1.826	0.752
Baldwin	16	12.56 (30.53)	314	145 (BHC)	0.621	1.720	0.733
Rocky	13	16.84 (42.92)	421	181 (BHC)	0.605	1.552	0.711
Horse	11	4.44 (13.30)	111	62 (BHC)	0.552	1.323	0.616
Brushy	10	7.28 (17.29)	182	76 (BHC)	0.724	1.666	0.743
Mean	14.3	14.89 (36.75)	372	165.5	0.621	1.635	0.713

From a diversity standpoint, the sites were collectively described by an evenness of 0.621, Shannon diversity index value of 1.635, and Simpson diversity index value of 0.713 (Table 4). Sites ranged from 0.552 (Horse Creek) to 0.724 (Brushy Creek) in evenness, 1.323 (Horse Creek) to 1.826 (Walnut Creek) in Shannon diversity, and 0.616 (Horse Creek) to 0.752 (Walnut Creek) in Simpson diversity (Table 4). A near complete agreement in site rank by the three diversity measures existed at the range extremes, with Horse Creek ranking the lowest in evenness, Shannon diversity, and Simpson diversity, while Walnut Creek was the most diverse according to both Shannon and Simpson indices (Table 4). However, as these indices principally reflect relative abundance characteristics and do not incorporate components of assemblage integrity, the interpretation of such values is inherently limited to a snapshot of community structure rather than true ecological condition in the context of change or degradation.

By species, absolute abundance ranged from one individual (redfin pickerel *Esox americanus*) to 738 (yellowfin shiner) (Table 5). Consequently, these two species produced the low and high extremes of 0.17 and 123 in mean abundance, respectively (Table 5). Along with the highest absolute abundance, the yellowfin shiner exhibited the greatest range in abundance (13-339, standard deviation 124.83) among the six sites (Table 5). Although almost as numerous (725), the bluehead chub displayed less variability in abundance (range 62-181, SD 44.67; Table 5) than the yellowfin shiner, explaining its rank as the most abundant species at four of the six sites (Table 4).

Table 5. Abundance attributes and frequency of occurrence by species for the 25 fish species present among the six Reedy River tributary sites, Fall 2004.

Species	Mean	Standard Deviation	Total	Minimum	Maximum	Frequency of Occurrence (Sites)*
BLG	20.50	15.86	123	1	43	6 (All)
BHC	120.83	44.67	725	62	181	6 (All)
BBH	0.33	0.52	2	0	1	2 (Hf, R)
CRC	10.17	12.35	61	0	34	5 (Ba, Br, Hr, R, W)
FBH	1.67	1.63	10	0	4	4 (Hf, Hr, R, W)
GSF	9.17	9.15	55	1	24	6 (All)
GFS	6.67	11.00	40	0	26	2 (Hf, W)
LMB	2.00	2.45	12	0	5	3 (Ba, Br, Hf)
MGM	1.67	3.62	10	0	9	2 (Hf, W)
MSQ	1.17	1.17	7	0	3	4 (Br, Hf, Hr, W)
NHS	30.17	30.33	181	0	73	5 (Ba, Hf, Hr, R, W)
PPS	0.33	0.52	2	0	1	2 (Ba, W)
RBS	7.33	10.13	44	0	27	5 (Ba, Hf, Hr, R, W)
RES	0.50	0.84	3	0	2	2 (Hr, W)
RFP	0.17	0.41	1	0	1	1 (Hr)
RSD	3.67	8.50	22	0	21	2 (Ba, R)
SGD	1.00	1.55	6	0	4	3 (Ba, Hf, R)
STS	18.67	28.62	112	0	74	4 (Ba, Hf, R, W)
STJ	4.50	9.59	27	0	24	3 (Ba, Hf, W)
TSD	0.67	1.63	4	0	4	1 (W)
WAR	1.00	0.89	6	0	2	4 (Ba, Br, Hf, W)
WHS	1.00	1.55	6	0	4	3 (Ba, Br, Hf)
WFS	0.50	1.23	3	0	3	1 (W)
YBH	5.67	8.87	34	0	22	4 (Ba, Br, Hf, R)
YFS	123.00	124.83	738	13	339	6 (All)
Mean	14.89	13.28	89.36	3.08	37.24	3.4

*Frequency of Occurrence = number of sites (6 maximum) at which species was present, independent of abundance; Sites: Ba = Baldwin; Br = Brushy; Hf = Huff; Hr = Horse; R = Rocky; W = Walnut

In the context of all 25 species, a wide range of absolute abundances and frequencies of occurrence (by presence, independent of abundance) was exhibited. Relatively rare and/or infrequently occurring species in addition to redfin pickerel included brown bullhead *Ameiurus nebulosus* (two individuals total between two sites), pumpkinseed *Lepomis gibbosus* (two individuals total between two sites), redear sunfish *Lepomis microlophus* (three individuals total between two sites), tessellated darter *Etheostoma olmstedi* (four individuals total from one site), and whitefin shiner *Cyprinella nivea* (three individuals total from one site) (Table 5). Conversely, four species—bluegill *Lepomis macrochirus,* bluehead chub, green sunfish *Lepomis cyanellus,* and yellowfin shiner—occurred at all six sites (Table 5). Aside from bluehead chub (725 individuals total) and yellowfin shiner (738) and with the exceptions of bluegill (123), northern hogsucker *Hypentelium nigricans* (181), and spottail shiner *Notropis hudsonius* (112), all other species numbered 61 or fewer each from all sites combined (Table 5). As occurrence and abundance are dependent on habitat type as a function of position along a stream gradient, the above findings cannot be considered representative of the entire respective tributaries nor the Reedy River system as a whole; more extensive site coverage is necessary and planned for the present study to achieve representativeness.

Recommendations

The above findings represent a pilot characterization of the fish assemblage conditions of tributaries to the Reedy River, among which more thorough investigations into the relationships of land use, stream habitat condition, and fish assemblage integrity are planned. This analysis therefore provides a limited yet useful base for directing further efforts.

As noted, the diversity measures employed herein are inherently limited from an assemblage integrity assessment standpoint, as they incorporate abundance attributes only and do not account for the biological and ecological components of integrity (e.g., species distributions, native versus introduced/invasive status, degree of ecological specialization/generalization, pollution/habitat degradation tolerance). Integration of such components is among the primary objectives over the remaining study duration. Also, factors including proximity to the Reedy River main stem or other streams, and position in relation to reservoirs, barriers, and other potential sources of bias or disproportionate species composition were not yet applicable to the present assessment.

However, the current findings altogether reflect fish communities indicative of ecological degradation among the Reedy River tributaries. This general biological impairment was apparent in the relatively low abundance and inconsistent presence of native intolerant and/or specialist species such as seagreen darter *Etheostoma thalassinum* and margined madtom *Noturus insignis* in contrast to the dominance or consistent presence of more tolerant, generalist, and/or opportunistic native (e.g., bluegill, bluehead chub) and introduced (e.g., green sunfish) or invasive species (Table 5). Many such native intolerant and/or specialist species were absent or uncommon at sites for which habitat would be expected to be suitable and abundances relatively high under little or no disturbance, suggesting degradation rather than natural variability alone as the explanation. More intensive sampling is necessary to fully characterize the degree, spatial pattern, and source(s) of this apparent loss in fish assemblage integrity and will comprise the bulk of 2005 efforts for the present study.

Literature Cited

McCune, B., and M. J. Mefford. 1999. PC-ORD. Multivariate Analysis of Ecological Data, Version 4. MjM Software Design, Gleneden Beach, Oregon, USA.

Thomason, C., J. Bettinger, D. Rankin, D. Crochet, L. Rose, and H. Beard. 2002. The South Carolina Standard Operating Procedures for Sampling Fish in Wadeable Streams. South Carolina Department of Natural Resources, Freshwater Fisheries Section, Columbia, SC.

Job Title: Development Of A Dynamic Water Quality Model For Lake Greenwood, SC

Period Covered January 1, 2004-December 31, 2004

Results and Discussion

Model Development

The primary goal of this two-year study is to develop a dynamic simulation model of water quality in Lake Greenwood (one of South Carolina's most eutrophic lakes). The model will help quantify interactions among lake hydrology, nutrient loading and water quality in the lake. Furthermore, the model will help predict implications of alternate management plans for water quality and water level and will help formulate long-term plans for water quality enhancement and aquatic habitat protection. Once developed for Lake Greenwood, this model could be expanded to examine related issues of water and habitat quality for the series of river/reservoir segments along the Saluda River and other drainage basins.

The basic conceptual scope of this modeling effort (Figure. 1) is to link information on inputs from the larger watershed (point-source dischargers and nonpoint source runoff) to ecological/water quality patterns and interactions within the lake. We are using a state-of-the-art, reservoir-modeling platform (CE-QUALl-W2) to simulate in-lake processes as they respond to input hydrology and nutrient loading. The primary objective of Yr-1 of the study (2004) has been to develop a detailed, comprehensive data set on key parameters needed for model development and calibration (nutrient loading and distributions, algal productivity and biomass, and rates of oxygen depletion).

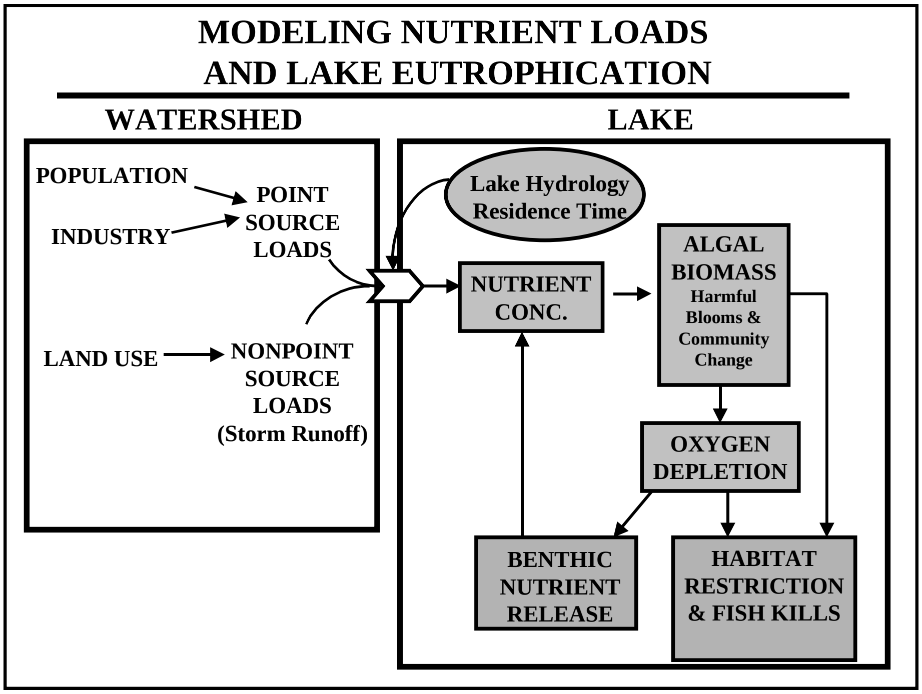


Figure 1. Conceptual diagram of watershed/water quality interactions.

Field Sampling

Figure 2 shows the location of 11 sampling sites that we established this year to quantify the spatial detail in the reservoir from the input tributaries (Saluda and Reedy River Arms) to the downstream forebay. Table 1 indicates the study components conducted at each of the stations. Additional information will be available from the current monitoring program conducted by SCDHEC (sites S-308, S-024, RL-04387, and S-303) as well as ongoing analyses by the Saluda-Reedy Watershed Consortium to quantify trends in water quality and nutrient loading in the major catchments flowing into Lake Greenwood.

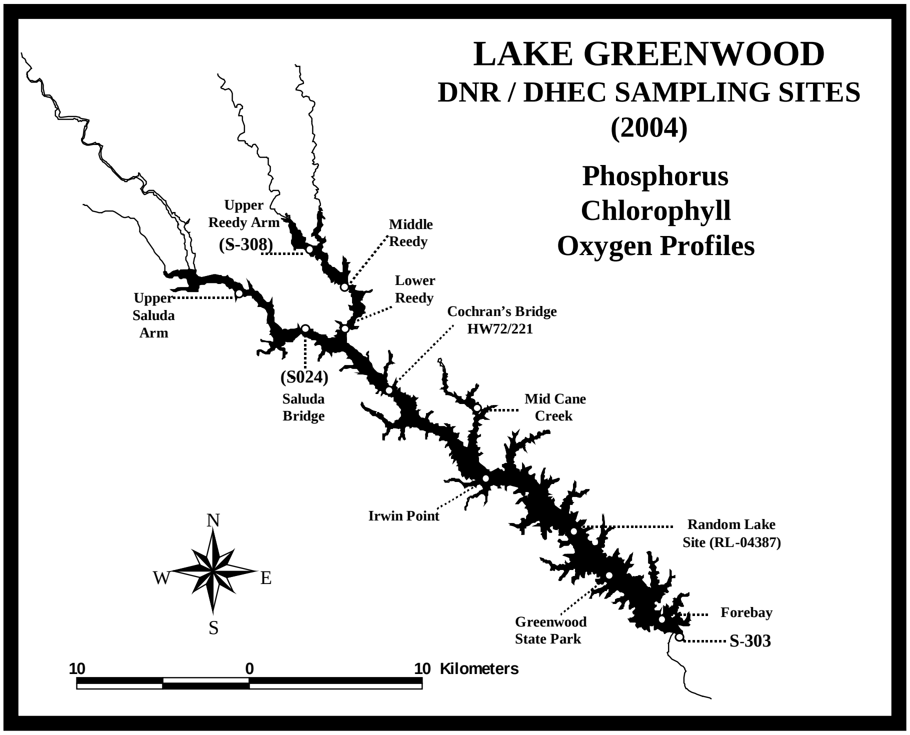


Figure 2. Sampling stations on Lake Greenwood.

Table 1. Site locations and study components.

Site Locations	Temperature/ Oxygen Profiles	Phosphorus/ Chlorophyll Concentrations	Plankton Productivity
	*	*	
Upper Saluda Arm	*	*	
Saluda Bridge	*	*	
Upper Reedy Arm	*		*
Middle Reedy Arm	*		
Lower Reedy Arm	*		
Highway 72 Bridge	*	*	*
Irvin's Point	*		
Hidden Lake Embayment	*	*	
Random Lake Station	*	*	*
Forebay	*	*	*
Forebay Channel (S-303)	*	*	

Sampling Schedule and Analysis

The original sampling protocol included monthly sampling for all study components (Table 1) throughout the annual cycle of 2004. While this sampling protocol was adequate to capture broad-scale seasonal patterns, it was not effective in quantifying key, short-term events such as short-lived algal blooms and storm events. With additional support from the Saluda-Reedy Watershed Consortium (SRWC), we increased sampling frequency to twice monthly through the active growing season (May-Oct) with additional sampling during major storm events. This additional support also provided funds for quantifying algal community structure (pigment analyses and microscopic examinations) to complement our own studies of algal biomass and production. During 2004, we sampled the lake for distributions of oxygen, phosphorus, algae distributions and productivity on 35 days, including 9 days of sampling during and following 2 major storm events (tropical storm Bonnie and hurricane Frances).

To insure a high level of quality control in data collection and analysis, we are using State-Certified laboratories to conduct all major field measurements and laboratory analyses. Our own laboratory (DNR Freshwater Fisheries Research Lab) became certified for field measures of temperature and oxygen profiles (ID 40570, 21 May 2004) while samples for phosphorus and chlorophyll are contracted to Shealy Environmental Services and SEAUS Inc, respectively.

While most of this data set is still being analyzed, the following charts provide preliminary examples of the kinds of information gained thus far and potential interpretations regarding water quality dynamics in Lake Greenwood.

Phosphorus and Chlorophyll Distributions

Phosphorus concentrations in the upper reaches of the lake (both the Saluda and Reedy River Arms, > 30 km upstream from the dam) were typically elevated above the SC water quality standard of 0.06 mg/L (Figure 3). This observation was consistent with SCDHEC placement of Lake Greenwood on the State list of impaired waters due to high nutrient concentrations. Surface water concentrations typically declined quickly due to algal uptake and sedimentation as water moved toward downstream locations in the lake. However, bottom concentrations of phosphorous were often much higher than in the surface waters, due to settling of phosphorus into deeper layers as well as the potential release of phosphorus from anoxic benthic sediments. These data will help quantify the importance of external loading (largely from the Saluda and Reedy River inputs) and internal loading from legacy phosphorus in the bottom sediments of Lake Greenwood.

NUTRIENT DISTRIBUTIONS

ALGAL BIOMASS

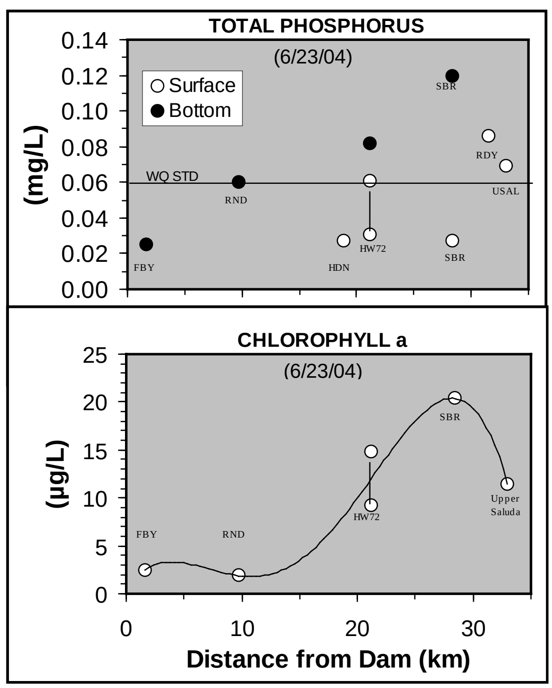
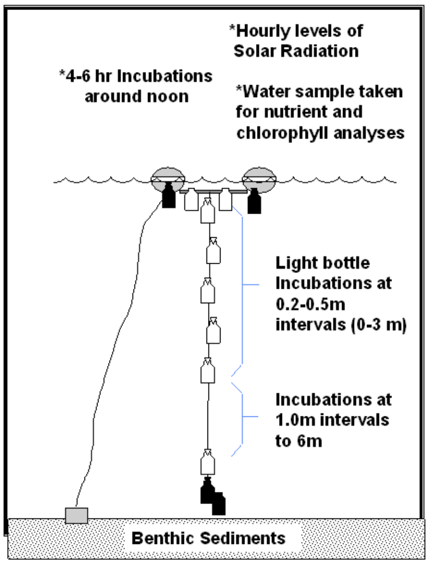


Figure 3. Distributions of total phosphorus and chlorophyll-a (algal biomass) in surface and bottom waters (6/23/04)

Algal biomass (chlorophyll) also exhibited higher concentrations in the upper reaches of the lake (Figure 3), extending downstream to the middle sections (20 km upstream) and into tributary embayments (Cane Creek). While algal concentration during mid-summer (Figure 3) reached moderate levels (10-20 µg/L) in the upper reaches, concentrations occasionally exceeded state standards (40 µg/L) at several locations in the spring and fall, further documenting the eutrophic state of Lake Greenwood.

Algal Productivity

Algal productivity is being evaluated monthly as the rates of oxygen change in vertical arrays of light and dark bottles (Figure 4, left panel). Results for July 2004 (Figure 4, right panel) illustrated some typical differences between the upper, nutrient-rich, and turbid parts of the lake (Reedy Arm, RDY) and the nutrient poorer, less turbid stations downstream (HW72).



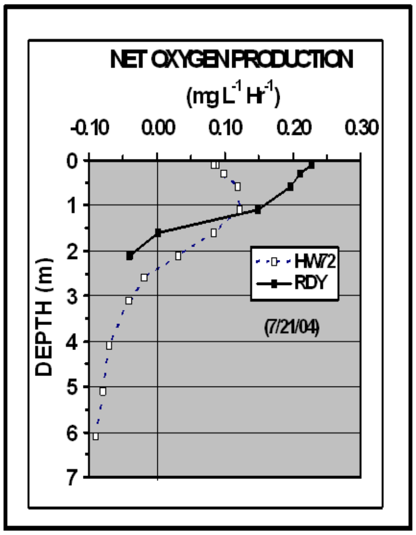


Figure 4. (Left Panel) Diagram of the vertical array of light and dark bottles used for evaluating plankton productivity (left panel); (Right Panel) Example of typical vertical patterns of net oxygen production (7/21/04)

The Reedy Arm exhibited higher rates of production in the surface waters (> 0.2 mg L^{-1} Hr^{-1}), which attenuated rapidly with depth due to turbid conditions. In contrast, the station at HW72 displayed lower production in the surface (< 0.1 mg L^{-1} Hr^{-1}) but sustained higher levels of net production in deeper levels of the water column. These observed vertical patterns will be correlated with ambient conditions of temperature, phosphorus concentration, algal biomass, and solar radiation to calibrate production coefficients for the simulation model.

Oxygen Depletion

Lake Greenwood has a history of oxygen depletion in the bottom waters during the summer and fall stratification. During the current sampling season (2004), the distribution of dissolved oxygen in Lake Greenwood exhibited a rapid depletion in the bottom waters from well-mixed conditions in March to highly stratified conditions in spring and early summer (Figure 5). Zones of hypoxia (<2.0 mg/L) extended throughout most of the lake below the thermocline (5-15 m) from mid-May through the fall. Although oxygen decline in the hypolimnion is a natural process, the intensity and extent of hypoxic conditions in Lake Greenwood are related in part to the phosphorus loading and eutrophication exhibited in the upper regions of the lake. Since the pattern of oxygen distribution represents a key component of water quality (which responds directly to levels of nutrient loading and algal production), a major goal of the model will be to predict spatial and temporal distributions of oxygen as functions of hydrology and management alternatives.

Timeline for Completion

The database collected during 2004 represents a good foundation for model development and calibration. According to the current study plan, we will devote the 1st quarter of 2005 to a complete data analysis and preliminary application of the data to model development. The remaining 12 months of study will be devoted to full model development, calibration, and testing model responses to different management scenarios. With funding currently committed, the final report will be completed during the spring 2006.

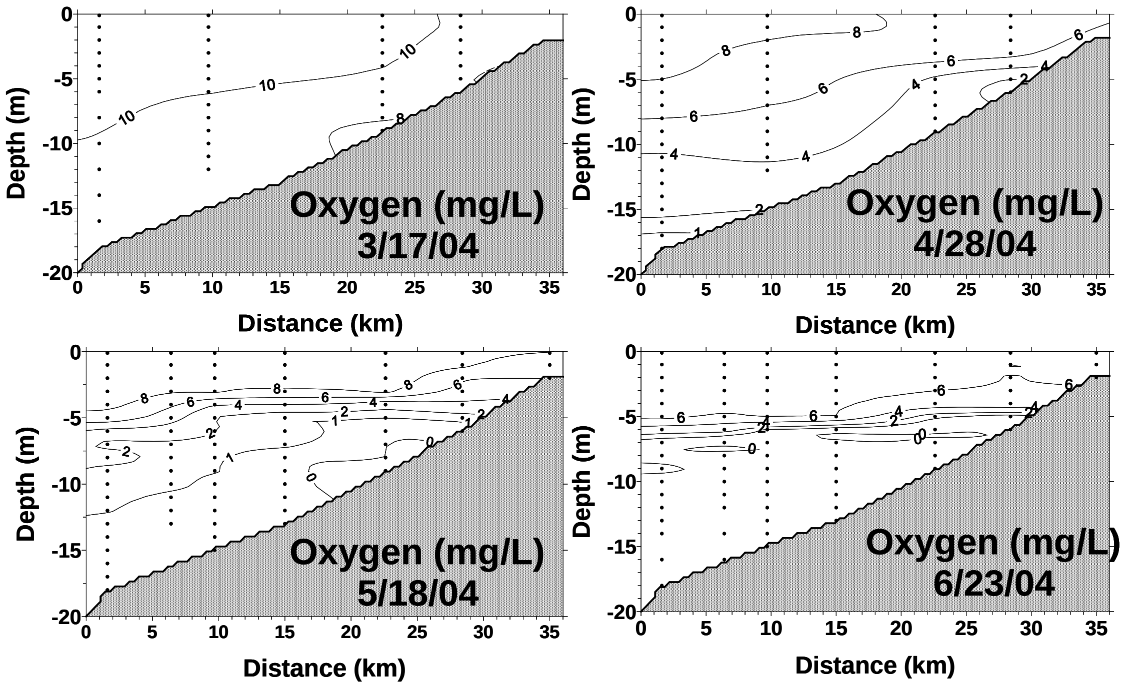


Figure 5. Distributions of dissolved oxygen in Lake Greenwood (March-June, 2004)

<u>Recommendations</u>

1. Enhance sampling protocol and extend sampling through a second growing season.

While, the database collected during 2004 represents a good foundation for model development and calibration, we recognize three limitations in the data that should be addressed for optimum model development and application.

(a) While Year 1 data collection was initiated in Jan-Feb 2004, a standard, effective methodology for the contracted work on phosphorus and chlorophyll analyses was not finalized until April-May 2004. Preliminary analysis of the data indicates that the April-June period in Lake Greenwood was a very dynamic time, with intense algal blooms (chlorophyll > 40 µg/L) followed by rapid oxygen depletion in the hypolimnion (Figure 5). Since the ecological interactions that culminate from the spring bloom dynamics may play a key role in subsequent water quality conditions, we recommend continued sampling at least through the spring bloom conditions of the coming season. The cost of continued sampling through the spring 2005 could be covered under current funding (Buzzard's Roost Mitigation Funds, and Saluda-Reedy Watershed Consortium).

(b) While we conducted detailed vertical profiles of oxygen and temperature in Lake Greenwood during 2004, our phosphorus/chlorophyll sampling included samples only at the surface and bottom waters. This sampling clearly identified the potential effects of phosphorus release from benthic sediments into the bottom waters (see Figure 3). However, to accurately quantify the effect of benthic phosphorus releases, we need information from more detailed vertical profiles of phosphorus through the water column. We recommend the extension of such profile sampling through the growing season of 2005, especially during the summer/fall periods of widespread stratification and oxygen depletion. The sampling would require additional funds, which are being sought in a pending proposal through the Saluda-Reedy Watershed Consortium (SRWC) to the V.K. Rasmussen Foundation (VKRF).

(c) While Year 1 data collection included nutrient analyses for 3 forms of phosphorus (total, dissolved, and ortho-phosphorus), other issues of water quality and algal nutrient limitation involve information on related forms of nitrogen. We recommend an enhanced analysis of water samples for 3 forms of nitrogen (total, nitrate, ammonia) for the 2005 growing season. As for the previous recommendation, this addition to the current sampling protocol would require additional funds included in the SRWC/VKRF proposal.

2. Expand model development to include lake/watershed interactions throughout the Saluda Basin.

    a. The model being developed according to the current study plan will result in a dynamic simulation of in-lake interactions and water quality patterns in Lake Greenwood in response to the total nutrient loading from the contributing watersheds. While this model will represent a powerful tool in developing management plans for Lake Greenwood, long-term management plans for aquatic resources in the entire basin will require more comprehensive modeling of lake/watershed interactions. A modeling effort of this scope would seek to integrate information on land-use changes and resultant nonpoint sources of runoff, with additional information on projected population growth and related changes in wastewater processing and point source discharges. This scope of modeling would address issues of water quality and aquatic resources throughout the entire Saluda River Basin, facilitating coordinated basin management from the Upper Saluda-Reedy watershed and Lake Greenwood, through the Middle Saluda River and Lake Murray.

       Funding for this scope of model development would require additional funds, which could be met, at least in part, by the pending SRWC/VKRF proposal

Prepared By: Hank McKellar Title: Fishery Biologist