STATEWIDE RESEARCH – FRESHWATER FISHERIES

ANNUAL PROGRESS REPORT

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January 1, 2009 – December 31, 2009

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Job Title:	Impact of point sources on phosphorus loading to Lake Greenwood
Period Covered	January 1, 2009 – December 31, 2009

Results and Discussion

Nine major domestic wastewater treatment plants in the Saluda-Reedy watershed contribute substantial loads of phosphorus to the Saluda and Reedy Rivers (Taylor, Bulak, and McKellar, 2008). We used watershed models to quantify the contributions of these facilities to the loads of phosphorus delivered to Lake Greenwood and to predict the impact of reducing the point source loads.

A watershed model provides computational mechanisms to generate nonpoint loads, to account for in-stream processing of nutrients, and to generate closer interval data, thus addressing these limitations to direct, data-based estimates of the point source contributions. These models have a history of several decades of application and refinement. The model that we used, WinHSPF (Hydrological Simulation Program in Fortran for Windows), is a widely used, exhaustively documented, and well-supported system available under the auspices of the US Environmental Protection Agency.

The limitations of watershed models lie in their complexity. They require assumptions about numerous rates and processes for which data are typically lacking. Building and calibrating models is laborious. Given the constraints of information and time, our goal for the Saluda and Reedy watersheds was to set up relatively simple models that would provide estimates of the fate of phosphorus discharged by the wastewater treatment plants.

The Saluda and Reedy watershed models were calibrated with full discharges from the nine wastewater treatment plants permitted for major domestic discharges into the Saluda-Reedy Watershed during 1999-2006. This eight-year period is the base scenario of full phosphorus discharge from the point sources (FULL scenario). It spans a wide range of weather conditions, including two extremely dry years and one very wet year. Because measurements of total phosphorus in the streams are lacking for 1999-2001 (Taylor et al., 2008), we hoped that the predictions for this period might provide insight into the conditions supporting extensive algal blooms in the Reedy Arm of Lake Greenwood in 1999-2000.

Discharges from the point sources were modeled using monthly data for water volume and total phosphorus from the discharge monitoring reports to the US EPA. During this period, total discharges of phosphorus from the major point sources were relatively constant in the Saluda watershed and decreased by about 30% in the Reedy.

In two additional scenarios, the point sources of phosphorus were reduced by half (HALF scenario) or eliminated entirely (NONE). The NONE scenario estimates the magnitude of the point source contributions. In all scenarios, the volume of water discharged from the point sources was maintained at reported levels.

The watershed models described the general patterns and ranges of values observed for stream flow. Over the eight-year simulation period, average annual discharge at the outlet of Reach S1 of the Saluda Watershed differed by about 5% from annual discharge at the USGS gage on the Saluda River at Ware Shoals (USGS 02163500). Average annual discharge at the outlet of Reach R4 differed by 3% from average annual discharge at the USGS gage on the Reedy River at Fork Shoals (USGS

02164110); records for the entire eight-year period were not available for gages further downstream on the Reedy River.

Under the scenario of full point source loads, the models reproduced the main patterns of total phosphorus concentrations observed in the streams. Total phosphorus concentrations were generally low in the reaches upstream of the point source discharges, but fluctuated with precipitation-driven input. Total phosphorus concentrations were much higher in the reaches receiving point source discharges.

Phosphorus loads in the FULL scenarios (Figure 1) varied substantially among years, with the highest loads occurring in 2003, the wettest year. Loads from the Saluda River were consistently higher than loads from the Reedy River. The phosphorus loads to the Reedy River in 1999-2000, the years of the algal bloom, were near or below the median for the eight years of simulations.

The difference between the phosphorus loads delivered to Lake Greenwood in the FULL and NONE scenarios represents the contributions of the point sources. The point sources accounted for 35-71% of the annual loads delivered to Lake Greenwood by the Saluda River and 45-73% of the annual loads delivered by the Reedy River (Figure 1). Reducing the point sources by half reduced the annual load from the Saluda River by 18-37% and from the Reedy River by 23-46%. For each watershed, about 40-60% of the phosphorus discharged by the point sources reached Lake Greenwood.

The phosphorus loads in NONE scenario represent the contribution of nonpoint sources in the simulations (Figure1). These nonpoint contributions were greater in the years of higher precipitation, particularly 2003. In the simulations, point source contributions of phosphorus to Lake Greenwood accounted for 35-71% of the annual

loads delivered to Lake Greenwood by the Saluda River and 45-73% of the annual loads delivered by the Reedy River.

Because the watershed models reproduced the main patterns of stream discharge and phosphorus concentrations in the Saluda and Reedy Rivers above Lake Greenwood under the base scenarios, we believe that they provided useful estimates of the magnitude of the contribution of point source discharges to the phosphorus loads entering Lake Greenwood over the eight-year period of the simulations (1999-2006). The models also indicate the potential impact of reducing phosphorus discharges from these point sources on both loads and concentrations of total phosphorus reaching Lake Greenwood.

During 1999, the first year of the algal blooms, the simulated concentrations of phosphorus reaching Lake Greenwood were high, especially during the winter and spring, although the annual load was moderate. We speculate that low stream flow, resulting from low rainfall, fueled development of the bloom. Low flow reduces in-stream dilution of the phosphorus discharges from point sources and increases retention times of the nutrient-enriched water in the Reedy Arm. This interpretation reinforces Anderson, Lewis, and Sargent (2006), who concluded that high concentrations of nutrients were more important than nutrient influxes to eutrophication of the Reedy Arm.

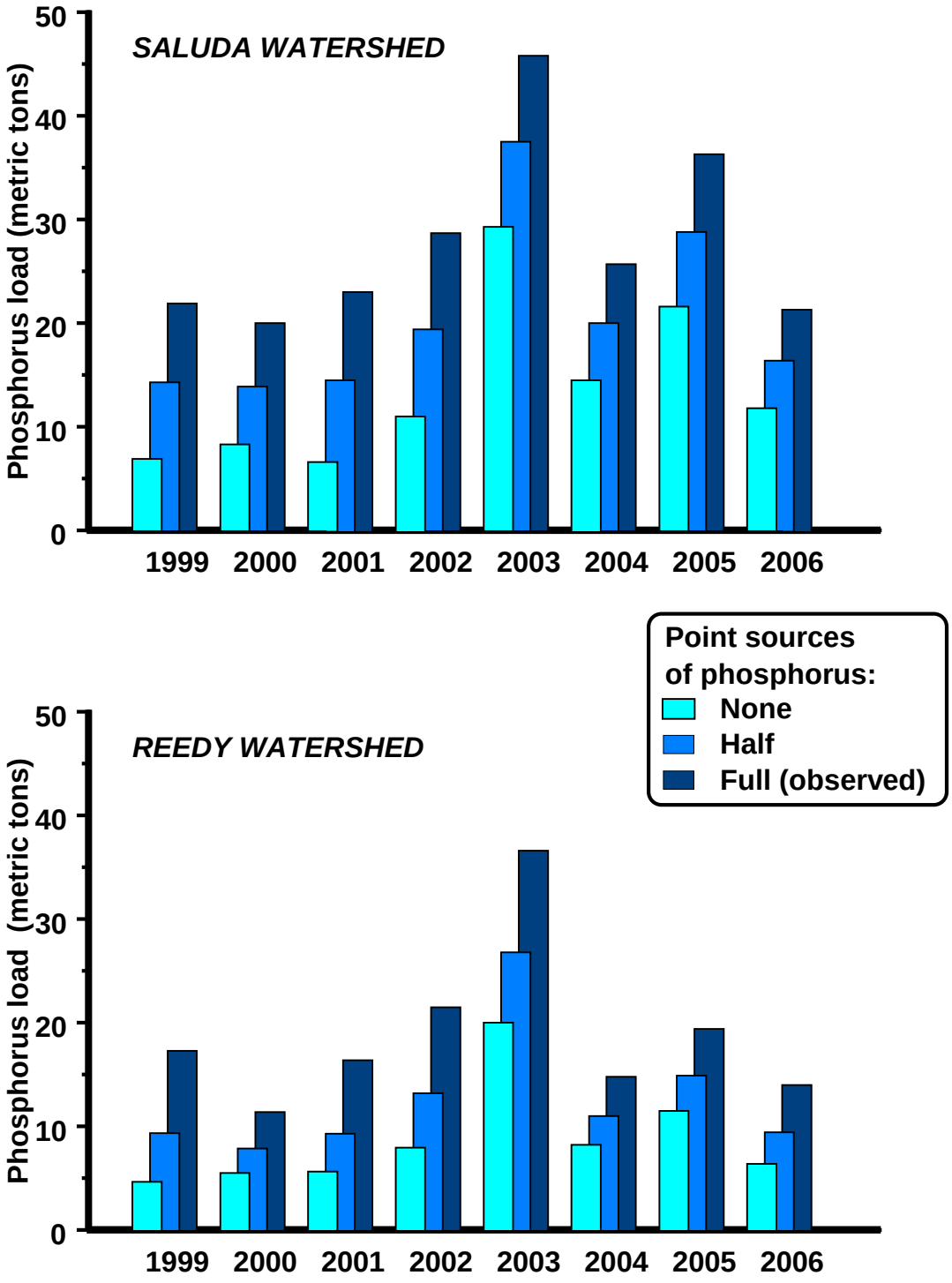

Figure 1. Simulated phosphorus loads to Lake Greenwood.

Recommendations

Use results from the Saluda-Reedy watershed models to create scenarios for the Lake Greenwood model (McKellar, Bulak, and Taylor, 2008) to examine the effects of weather and reductions in point source loads on water quality, particularly in the historically problematic Reedy Arm.

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Anderson, C. B., G. P. Lewis, and K. A. Sargent. 2006. Characterization of Wastewater Treatment Plant Effluent and the Downstream Fate of Nutrients in the Reedy River and Saluda River Watersheds. Annual Report. Saluda-Reedy Watershed Consortium.

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Prepared By: Barbara Taylor Title: Fisheries Biologist

Job Title:	Crayfishes and shrimps (*Palaemonetes* sp.) from the Statewide Stream Assessment
Period Covered	January 1, 2009 – December 31, 2009

Results and Discussion

Between May and September 2009 stream surveys were done at 64 sites in 8 ecobasins as part of the Statewide Stream Assessment. Four ecobasins in the Catawba/Wateree River drainage were surveyed, including the Atlantic Southern Loam Plains, Outer Piedmont, Sandhills, and Slate Belt, completing all sampling within the Catawba/Wateree river drainage. Additional sites were sampled in several other ecobasins to supplement sampling from previous years, in part due to sites drying up, and included the Lower Santee Carolina Flatwoods, Pee Dee Carolina Flatwoods, Pee Dee ASLP, and Savannah Carolina Flatwoods. Collections of crayfishes and shrimps from the Catawba/Wateree, Pee Dee, Savannah, and Santee river basins were made at 36 of 37 sites, 21 of 22 sites, 4 of 4 sites, and 1 of 1 site, respectively. A total of 9 to 10 species of crayfishes and 1 species of shrimp were identified from localities in the Catawba/Wateree River basin, 8 species of crayfishes and 1 species of shrimp from the Pee Dee River basin, 3 species of crayfishes and 1 species of shrimp were identified from sites in the Savannah River basin, and 2 species of crayfishes were found at the single site in the lower Santee drainage. Species richness ranged from 0–4 species of crayfishes and shrimp, with an average of 2 species per site. Abundances of species at sites were 1–81 individuals, with many collections typically including many juveniles or subdaults. Identifications of specimens from some sites cannot be made at this time as the samples consisted of juveniles or females only or involve taxonomic uncertainty. Supplemental collecting at these sites in the future would provide additional specimens that would allow for positive identifications.

Species diversity was slightly higher in the Catawba/Wateree drainage than in others sampled during the previous 3 years, but this is due in part to the presence of a primary burrowing species in one sample (see below), the Catawba/Wateree spanning 4 ecobasins, and lack of drought conditions experienced in recent years. During the 2009 surveys, *Procambarus lepidodactylus*, a species of "High" conservation concern (Kohlsaat et al., 2005), was documented at 7 of 64 sites, but none of the sites represent an extension of the known range of this species. Collections of *Procambarus chacei*, which is listed as "High" conservation concern, were made at 7 of 64 sites, but all of these collections fall within the known range of the species. *Procambarus ancylus*, a species of "High" conservation concern, was collected at 2 of 64 sites, but again within the overall known distribution for the species. *Cambarus reduncus*, a primary burrower, was collected at one site in the Catawba/Wateree drainage, within its known range; it was unusual to collect this species in a stream in the summer. The most common species were *Procambarus acutus* and *P. blandingii*, the latter being a species of "Moderate" conservation concern. During 2009, more species of conservation concern were collected, and from more sites, compared with the 3 previous years of sampling. The non-native species, *Procambarus clarkii*, was collected at three sites in the Pee Dee River drainage only.

In 2009, fewer sites lacked any invertebrates compared to the previous 2 years, during which drought conditions could have affected the behavior and distribution of crayfishes and other invertebrates, making them less available for capture during the stream surveys. However, at least a dozen or more sites scheduled for sampling in 2009 were dry and could not be sampled; they will be sampled in 2010 or 2011. Several dry sites in the Savannah River basin in 2008 were revisited in spring 2009 at which time they were found to contain good fish communities and also crayfishes, shrimps, mussels, snails, and aquatic insects. Thus, even streams that

occasionally, or even routinely, go dry can serve as habitat for diverse biological communities at times.

Mussels and snails were kept from sites where they were observed, but these collections have not been identified yet. Some sites appeared to have several species of mussels present. In 2009 mussels were recorded from 19 of 64 sites (1–19 individuals per site), snails were caught at 7 of 64 sites (1–90 individuals per site), and the non-native, *Corbicula* sp., was found at 14 of 64 sites (4–27 individuals per site but often only noted as present).

Recommendations

Collecting

Continue to collect decapods and mollusks during ecobasin surveys because in 2006–2009 useful distribution information was obtained for several rare species of conservation concern and also for non-native species, and the collections will provide data to allow better identifications of species in the future.

Literature Cited

Kohlsaat, T., L. Quattro and J. Rinehart. 2005. South Carolina Comprehensive Wildlife Conservation Strategy 2005–2010. South Carolina Department of Natural Resources. i–viii + 287 pp.

Prepared By: William Poly Title: Aquatic Biologist

Job Title: South Carolina Stream Assessment

Period Covered January 1, 2009 – December 31, 2009

Results and Discussion

Catawba/Wateree River Basin

Thirty-seven randomly selected sites were sampled in the Catawba/Wateree River basin from the Outer Piedmont (21 sites), Slate Belt (5), Sand Hills (6), and Atlantic Southern Loam Plains (5) following the South Carolina Stream Assessment (SCSA) protocol (SCDNR 2009; Table 1). This meets the target number of samples in the Catawba/Wateree basin for the first round of SCSA sampling. Fifty-nine species of freshwater fish (3 introduced) were collected in the basin, including 12 Priority species (Kohlsaat et al. 2005; Table 2; Table 3).

Several noteworthy species occurrences were documented from SCSA sampling in the Catawba/Wateree basin. A single Sandhills chub (*Semotilus lumbee*; Highest priority) was collected from the headwater site on Big Pine Tree Creek (Site 133846), the first record of this species from this stream based on Rohde et al. (2009). *S. lumbee* is otherwise known from only about three localities in the Catawba/Wateree basin and is very restricted in its overall range. The Carolina darter (*Etheostoma collis*; High priority) was collected at nine sites, including many new localities based on Rohde et al. (2009). Two blackbanded sunfish (*Enneacanthus chaetodon*; High priority) were collected from Big Pine Tree Creek (Site 156581), bringing the total number of SCSA random sites at which this species has been collected to 4—only 2.8% of the 145 coastal plain sites sampled through 2009. The black bullhead (*Ameiurus melas*), probably often mistaken for other catfishes and thus very scattered in apparent distribution (Rohde et al. 2009), was collected at Steele Creek (Site 10092). Three flathead catfish

(*Pylodictis olivaris*) were collected at Big Pine Tree Creek (Site 156581), the first occurrence of this introduced and potentially invasive species in a SCSA random sample site.

Table 1. SCSA random sample sites in the Catawba/Wateree River basin, 2009.

Ecoregion	Site Number	Date	Stream	Latitude	Longitude
Outer Piedmont	4638	12-May-2009	Beaverdam Creek	35.12667	81.16142
Outer Piedmont	8404	12-May-2009	Calabash Branch	35.07654	81.20919
Outer Piedmont	10092	13-May-2009	Steele Creek	35.08146	80.94858
Outer Piedmont	10568	12-May-2009	Big Allison Creek	35.06025	81.18056
Outer Piedmont	15086	13-May-2009	Little Allison Creek	35.03227	81.09769
Outer Piedmont	16194	13-May-2009	Little Allison Creek	35.00871	81.14401
Outer Piedmont	17447	21-May-2009	Tributary to Big Dutchman Creek	34.99867	81.07392
Outer Piedmont	21676	20-May-2009	Tributary to Tools Fork	34.97146	81.10564
Outer Piedmont	23159	20-May-2009	Manchester Creek	34.95390	80.95160
Outer Piedmont	25398	30-Jun-2009	Six Mile Creek	34.96543	80.84553
Outer Piedmont	25602	14-May-2009	Fishing Creek	34.93582	81.17455
Outer Piedmont	41820	20-May-2009	Rum Branch	34.82015	80.95905
Outer Piedmont	42905	19-May-2009	Conrad Creek	34.81048	81.14383
Outer Piedmont	45921	30-Jun-2009	South Fork Fishing Creek	34.80728	81.10925
Outer Piedmont	49488	19-May-2009	Hicklin Branch	34.78168	80.99380
Outer Piedmont	57997	19-May-2009	Hooper Creek	34.73402	81.11794
Outer Piedmont	74217	10-Jun-2009	Little Turkey Creek	34.67789	80.74379
Outer Piedmont	76972	19-May-2009	Bull Skin Creek	34.64801	81.05151
Outer Piedmont	84562	11-Jun-2009	Camp Creek	34.61444	80.83955
Outer Piedmont	86384	20-May-2009	Little Rocky Creek	34.59372	80.99616
Outer Piedmont	112131	9-Jun-2009	Beaver Creek	34.46229	80.76293
Slate Belt	51137	1-Jul-2009	Camp Creek	34.77434	80.70248
Slate Belt	58433	10-Jun-2009	Gills Creek	34.73186	80.75589
Slate Belt	60751	10-Jun-2009	Tributary to Gills Creek	34.72002	80.65618
Slate Belt	72211	9-Jun-2009	Rum Creek	34.68006	80.80038
Slate Belt	123998	9-Jun-2009	Flat Rock Creek	34.40331	80.64588
Sand Hills	133846	16-Jul-2009	Big Pine Tree Creek	34.34753	80.48655
Sand Hills	147751	29-Jul-2009	Big Pine Tree Creek	34.28194	80.52396
Sand Hills	152903	16-Jul-2009	Tributary to Wateree River	34.27827	80.64020
Sand Hills	167134	28-Jul-2009	Sandy Branch	34.18034	80.82526
Sand Hills	180390	28-Jul-2009	Spears Creek	34.12205	80.72788
Sand Hills	208930	29-Jul-2009	Colonels Creek	33.98415	80.70520
Atl. S. Loam Plains	156577	15-Jul-2009	Little Pine Tree Creek	34.24123	80.59213
Atl. S. Loam Plains	156581	15-Jul-2009	Big Pine Tree Creek	34.23512	80.59136
Atl. S. Loam Plains	184002	30-Jul-2009	Bracey Mill Creek	34.09945	80.48990
Atl. S. Loam Plains	192619	22-Jul-2009	Little Rafting Creek	34.05010	80.48054
Atl. S. Loam Plains	247762	9-Jul-2009	Shanks Creek	33.80336	80.53500

Table 2. Fish species collected from SCSA random sample sites in the Catawba/Wateree River basin, 2009. Continued on following page.

Code	Family	Scientific Name	Common Name	Conservation Priority
SWF	Amblyopsidae	*Chologaster cornuta*	Swampfish	
PIP	Aphredoderidae	*Aphredoderus sayanus*	Pirate perch	
BSS	Atherinidae	*Labidesthes sicculus*	Brook silverside	
WHS	Catostomidae	*Catostomus commersoni*	White sucker	
CCS	Catostomidae	*Erimyzon oblongus*	Creek chubsucker	
SPS	Catostomidae	*Minytrema melanops*	Spotted sucker	
STJ	Catostomidae	*Scartomyzon rupiscartes*	Striped jumprock	
BJR	Catostomidae	*Scartomyzon sp.*	Brassy jumprock	
MDS	Centrarchidae	*Acantharchus pomotis*	Mud sunfish	Moderate
BBS	Centrarchidae	*Enneacanthus chaetodon*	Blackbanded sunfish	High
BLS	Centrarchidae	*Enneacanthus gloriosus*	Bluespotted sunfish	
RBS	Centrarchidae	*Lepomis auritus*	Redbreast sunfish	
GSF	Centrarchidae	*Lepomis cyanellus*	Green sunfish	
PPS	Centrarchidae	*Lepomis gibbosus*	Pumpkinseed	
WAR	Centrarchidae	*Lepomis gulosus*	Warmouth	
BLG	Centrarchidae	*Lepomis macrochirus*	Bluegill	
DSF	Centrarchidae	*Lepomis marginatus*	Dollar sunfish	
RES	Centrarchidae	*Lepomis microlophus*	Redear sunfish	
SOS	Centrarchidae	*Lepomis punctatus*	Spotted sunfish	
LMB	Centrarchidae	*Micropterus salmoides*	Largemouth bass	
WTC	Centrarchidae	*Pomoxis annularis*	White crappie	
RSD	Cyprinidae	*Clinostomus funduloides*	Rosyside dace	
GFS	Cyprinidae	*Cyprinella chloristia*	Greenfin shiner	Moderate
WFS	Cyprinidae	*Cyprinella nivea*	Whitefin shiner	
FBS	Cyprinidae	*Cyprinella pyrrhomelas*	Fieryblack shiner	Moderate
ESM	Cyprinidae	*Hybognathus regius*	Eastern silvery minnow	
HBC	Cyprinidae	*Hybopsis hypsinotus*	Highback chub	Moderate
BHC	Cyprinidae	*Nocomis leptocephalus*	Bluehead chub	
GLS	Cyprinidae	*Notemigonus crysoleucas*	Golden shiner	
HFS	Cyprinidae	*Notropis altipinnis*	Highfin shiner	
GHS	Cyprinidae	*Notropis chlorocephalus*	Greenhead shiner	High
DKS	Cyprinidae	*Notropis cummingsae*	Dusky shiner	
STS	Cyprinidae	*Notropis hudsonius*	Spottail shiner	
CSH	Cyprinidae	*Notropis petersoni*	Coastal shiner	
SWS	Cyprinidae	*Notropis procne*	Swallowtail shiner	
SBS	Cyprinidae	*Notropis scepticus*	Sandbar shiner	
SFS	Cyprinidae	*Pteronotropis stonei*	Lowland shiner	Moderate
CRC	Cyprinidae	*Semotilus atromaculatus*	Creek chub	
SHC	Cyprinidae	*Semotilus lumbee*	Sandhills chub	Highest
RFP	Esocidae	*Esox americanus*	Redfin pickerel	
CHP	Esocidae	*Esox niger*	Chain pickerel	
LTM	Fundulidae	*Fundulus lineolatus*	Lined topminnow	
BLB	Ictaluridae	*Ameiurus melas*	Black bullhead	
YBH	Ictaluridae	*Ameiurus natalis*	Yellow bullhead	
BBH	Ictaluridae	*Ameiurus nebulosus*	Brown bullhead	
FBH	Ictaluridae	*Ameiurus platycephalus*	Flat bullhead	Moderate
CCF	Ictaluridae	*Ictalurus punctatus*	Channel catfish	

Code	Family	Scientific Name	Common Name	Conservation Priority
TPM	Ictaluridae	*Noturus gyrinus*	Tadpole madtom	
MGM	Ictaluridae	*Noturus insignis*	Margined madtom	
FCF	Ictaluridae	*Pylodictis olivaris*	Flathead catfish	
CAD	Percidae	*Etheostoma collis*	Carolina darter	High
SWD	Percidae	*Etheostoma fusiforme*	Swamp darter	
TSD	Percidae	*Etheostoma olmstedi*	Tessellated darter	
SCD	Percidae	*Etheostoma serrifer*	Sawcheek darter	
SGD	Percidae	*Etheostoma thalassinum*	Seagreen darter	High
YLP	Percidae	*Perca flavescens*	Yellow perch	
PDD	Percidae	*Percina crassa*	Piedmont darter	High
MSQ	Poeciliidae	*Gambusia holbrooki*	Eastern mosquitofish	
EMM	Umbridae	*Umbra pygmaea*	Eastern mudminnow	

Table 3. Fish species collected from SCSA random sample sites in the Catawba/Wateree River basin, 2009 (by site). Species codes refer to Table 2. Priority species (Kohlsaat et al. 2005) appear in bold. Continued on following page.

Species Code	**4638**	**8404**	**10092**	**10568**	**15086**	**16194**	**17447**	**21676**	**23159**	**25398**	**25602**	**41820**	**42905**	**45921**	**49488**	**51137**	**57997**	**58433**	**60751**	**72211**	**74217**	**76972**	**84562**	**86384**	**112131**	**123998**	**133846**	**147751**	**152903**	**156577**	**156581**	**167134**	**180390**	**184002**	**192619**	**208930**	**247762**
SWF																															X						
PIP															X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
BSS																												X			X						
WHS			X							X																											
CCS			X	X	X	X		X		X			X	X	X	X	X	X		X	X	X	X	X	X								X	X			
SPS																										X					X		X				
STJ				X																				X													
BJR									X					X	X																						
MDS																											**X**						**X**	**X**	**X**		**X**
BBS																															**X**						
BLS																												X			X					X	
RBS	X	X	X	X		X		X	X	X	X		X	X	X		X	X	X	X	X	X	X	X	X	X		X		X	X	X	X			X	
GSF	X		X		X	X			X	X						X		X	X	X	X		X		X												
PPS									X			X	X	X	X	X	X	X	X	X					X												
WAR			X		X			X			X		X	X		X	X	X	X		X		X			X		X		X	X					X	X
BLG	X		X	X	X	X	X	X	X	X	X	X	X	X		X		X	X	X	X			X	X	X	X	X	X	X	X	X	X			X	X
DSF																		X									X	X		X	X	X		X		X	X
RES						X					X		X	X				X				X									X						
SOS																											X	X		X	X	X					
LMB		X		X	X	X			X	X	X	X		X				X										X	X	X	X						
WTC																			X																		
RSD	X	X	X				X					X			X						X	X		X														
GFS			**X**	**X**	**X**					**X**												**X**	**X**	**X**													
WFS					X																									X	X						
FBS																										**X**					**X**						
ESM																										X											
HBC		**X**			**X**								**X**	**X**								**X**															
BHC	X	X	X	X		X				X	X		X	X	X					X	X	X	X	X	X	X				X		X					
GLS			X			X		X								X	X	X	X																		
HFS			X					X		X	X		X	X	X		X					X	X			X											
GHS	**X**	**X**				**X**																				**X**											

Species Code	**4638**	**8404**	**10092**	**10568**	**15086**	**16194**	**17447**	**21676**	**23159**	**25398**	**25602**	**41820**	**42905**	**45921**	**49488**	**51137**	**57997**	**58433**	**60751**	**72211**	**74217**	**76972**	**84562**	**86384**	**112131**	**123998**	**133846**	**147751**	**152903**	**156577**	**156581**	**167134**	**180390**	**184002**	**192619**	**208930**	**247762**
DKS																												X		X	X	X	X				
STS				X	X				X		X														X	X				X	X						
CSH			X										X	X																	X						
SWS			X		X	X			X	X	X		X	X								X	X														
SBS			X						X	X	X			X											X	X											
SFS																											**X**	**X**				**X**	**X**	**X**		**X**	**X**
CRC	X	X		X		X	X											X		X	X	X		X													
SHC																											**X**										
RFP				X				X		X	X		X	X	X	X									X	X	X			X	X	X	X	X	X		X
CHP																											X	X			X	X	X			X	
LTM																															X					X	
BLB			X																																		
YBH																X		X									X	X		X		X					X
BBH					X						X																										
FBH					**X**	**X**			**X**	**X**	**X**			**X**													**X**										
CCF					X				X																												
TPM																									X		X	X		X						X	
MGM			X						X	X	X			X								X				X	X	X				X					X
FCF																															X						
CAD			**X**					**X**		**X**			**X**	**X**	**X**	**X**		**X**					**X**														
SWD																												X								X	
TSD		X	X		X	X			X	X	X		X	X	X					X		X	X	X	X	X				X	X	X					
SCD																																				X	
SGD																												**X**									
YLP				X																																	
PDD																										**X**					**X**						
MSQ			X		X					X			X	X		X		X	X									X		X	X						
EMM																																		X			X
Species Richness	**7**	**8**	**19**	**11**	**15**	**13**	**3**	**8**	**13**	**17**	**15**	**4**	**15**	**20**	**11**	**11**	**6**	**15**	**9**	**9**	**9**	**13**	**11**	**10**	**12**	**16**	**13**	**18**	**3**	**16**	**25**	**13**	**10**	**7**	**3**	**12**	**10**

Pee Dee River Basin

Twenty-three randomly selected sites were sampled in the Pee Dee River basin from the Atlantic Southern Loam Plains (7 sites) and Carolina Flatwoods (16) following SCSA protocol (SCDNR 2009; Table 4). This represents a portion of the target number of samples in the Pee Dee basin for the first round of SCSA sampling; sampling in this basin was also conducted in 2006 – 2007. Thirty-seven species of freshwater fish were collected from Pee Dee basin sites in 2009, including two Priority species (Kohlsaat et al. 2005): American eel (*Anguilla rostrata*) and mud sunfish (*Acantharchus pomotis*; Table 5; Table 6). One site, Gumtree Branch (Site 301451), produced no fish and was determined to have been dry as recently as 2 weeks prior to the sample; therefore, it is not included in Table 6.

Noteworthy collections included a single taillight shiner (*Notropis maculatus*) at Jenkins Swamp (Site 239018), the first of which to be collected at a SCSA random site despite widespread sampling across much of its range. The lack of previous collections of this species may in part reflect its preference for larger waters and swamps (Rohde et al. 2009), habitats beyond the sampling scope of the SCSA. However, its apparent rarity may warrant assessment of conservation status. Green sunfish (*Lepomis cyanellus*) were collected at three sites including a tributary to the Little Pee Dee River (Site 91717). This introduced species is established in many other river basins in South Carolina and has more recently been collected at scattered locations on the coastal plain including in the Pee Dee and Ashepoo-Combahee-Edisto (ACE) basins (K. Kubach Annual Report 2007; Rohde et al. 2009). The collection of *L. cyanellus* at Site 91717 appears to be among the first known records from the Little Pee Dee River system of

this potentially invasive species. Twelve black bullheads (*Ameiurus melas*) were collected from a tributary to Camp Branch (Site 216018).

Table 4. SCSA random sample sites in the Pee Dee River basin, 2009.

Ecoregion	**Site Number**	**Date**	**Stream**	**Latitude**	**Longitude**
Atl. S. Loam Plains	91717	23-Sep-2009	Tributary to Little Pee Dee River	34.55870	79.40499
Atl. S. Loam Plains	96007	24-Sep-2009	Tributary to Great Pee Dee River	34.54288	79.75588
Atl. S. Loam Plains	137806	24-Sep-2009	Fountain Branch	33.86595	79.64762
Atl. S. Loam Plains	138936	23-Sep-2009	Bell Swamp Branch	34.32744	79.26208
Atl. S. Loam Plains	165199	22-Sep-2009	Tributary to Jeffries Creek	34.18858	79.74920
Atl. S. Loam Plains	212546	22-Sep-2009	Mulberry Branch	33.96292	80.31386
Atl. S. Loam Plains	262461	11-Aug-2009	Big Branch	33.74852	80.25507
Carolina Flatwoods	187422	7-Jul-2009	Deep Hole Swamp	33.72458	79.03035
Carolina Flatwoods	187436	7-Jul-2009	Bay Branch	34.07864	79.97388
Carolina Flatwoods	205019	2-Jun-2009	Mill Branch	33.71562	79.44533
Carolina Flatwoods	216018	4-Jun-2009	Tributary to Camp Branch	34.08840	79.96756
Carolina Flatwoods	232055	8-Jul-2009	Juniper Bay	33.50501	79.72811
Carolina Flatwoods	233002	2-Jun-2009	Tributary to Lynches River	33.98875	79.17496
Carolina Flatwoods	239018	8-Jul-2009	Jenkins Swamp	33.86474	79.18884
Carolina Flatwoods	259298	8-Jul-2009	Tributary to Waccamaw River	33.82795	79.15150
Carolina Flatwoods	263062	3-Jun-2009	Caney Branch	33.64813	79.39651
Carolina Flatwoods	266881	3-Jun-2009	Boser Swamp Canal	33.94238	79.86211
Carolina Flatwoods	275410	3-Jun-2009	Squirrel Run	33.70087	79.34491
Carolina Flatwoods	301204	12-Aug-2009	Murray Swamp	33.32937	79.32144
Carolina Flatwoods	301451	14-Jul-2009	Gumtree Branch	33.37503	79.51358
Carolina Flatwoods	311502	12-Aug-2009	Tributary to Johnsons Swamp	33.47569	79.63219
Carolina Flatwoods	315863	11-Aug-2009	Tributary to Bond Swamp	33.42835	79.58112
Carolina Flatwoods	323298	13-Aug-2009	Tributary to Sampit River	33.86595	79.64762

Table 5. Fish species collected from SCSA random sample sites in the Pee Dee River basin, 2009.

Code	Family	Scientific Name	Common Name	Conservation Priority
BFN	Amiidae	*Amia calva*	Bowfin	
AEL	Anguillidae	*Anguilla rostrata*	American eel	Highest
PIP	Aphredoderidae	*Aphredoderus sayanus*	Pirate perch	
BSS	Atherinidae	*Labidesthes sicculus*	Brook silverside	
CCS	Catostomidae	*Erimyzon oblongus*	Creek chubsucker	
LKC	Catostomidae	*Erymyzon sucetta*	Lake chubsucker	
MDS	Centrarchidae	*Acantharchus pomotis*	Mud sunfish	Moderate
FLR	Centrarchidae	*Centrarchus macropterus*	Flier	
BLS	Centrarchidae	*Enneacanthus gloriosus*	Bluespotted sunfish	
BDS	Centrarchidae	*Enneacanthus obesus*	Banded sunfish	
RBS	Centrarchidae	*Lepomis auritus*	Redbreast sunfish	
GSF	Centrarchidae	*Lepomis cyanellus*	Green sunfish	
PPS	Centrarchidae	*Lepomis gibbosus*	Pumpkinseed	
WAR	Centrarchidae	*Lepomis gulosus*	Warmouth	
BLG	Centrarchidae	*Lepomis macrochirus*	Bluegill	
DSF	Centrarchidae	*Lepomis marginatus*	Dollar sunfish	
RES	Centrarchidae	*Lepomis microlophus*	Redear sunfish	
SOS	Centrarchidae	*Lepomis punctatus*	Spotted sunfish	
LMB	Centrarchidae	*Micropterus salmoides*	Largemouth bass	
GLS	Cyprinidae	*Notemigonus crysoleucas*	Golden shiner	
ICS	Cyprinidae	*Notropis chalybaeus*	Ironcolor shiner	
DKS	Cyprinidae	*Notropis cummingsae*	Dusky shiner	
TLS	Cyprinidae	*Notropis maculatus*	Taillight shiner	
BPS	Elassomatidae	*Elassoma zonatum*	Banded pygmy sunfish	
RFP	Esocidae	*Esox americanus*	Redfin pickerel	
CHP	Esocidae	*Esox niger*	Chain pickerel	
BLB	Ictaluridae	*Ameiurus melas*	Black bullhead	
YBH	Ictaluridae	*Ameiurus natalis*	Yellow bullhead	
BBH	Ictaluridae	*Ameiurus nebulosus*	Brown bullhead	
CCF	Ictaluridae	*Ictalurus punctatus*	Channel catfish	
TPM	Ictaluridae	*Noturus gyrinus*	Tadpole madtom	
LNG	Lepisosteidae	*Lepisosteus osseus*	Longnose gar	
SWD	Percidae	*Etheostoma fusiforme*	Swamp darter	
TSD	Percidae	*Etheostoma olmstedi*	Tessellated darter	
MSQ	Poeciliidae	*Gambusia holbrooki*	Eastern mosquitofish	
LSK	Poeciliidae	*Heterandria formosa*	Least killifish	
EMM	Umbridae	*Umbra pygmaea*	Eastern mudminnow	

Table 6. Fish species collected from SCSA random sample sites in the Pee Dee River basin, 2009 (by site). Priority species (Kohlsaat et al. 2005) appear in bold. Species codes refer to Table 5.

Species Code	**91717**	**96007**	**137806**	**138936**	**165199**	**187422**	**187436**	**205019**	**212546**	**216018**	**232055**	**233002**	**239018**	**259298**	**262461**	**263062**	**266881**	**275410**	**301204**	**311502**	**315863**	**323298**
BFN	X					X	X				X		X	X				X				
AEL		**X**			**X**			**X**		**X**	**X**		**X**			**X**	**X**				**X**	
PIP	X	X		X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	
BSS																			X			
CCS	X				X					X	X		X		X							
LKC	X			X						X									X		X	
MDS	**X**			**X**			**X**		**X**	**X**				**X**		**X**			**X**			**X**
FLR				X			X	X	X	X			X	X					X		X	
BLS	X			X			X	X	X	X	X		X			X			X	X	X	
BDS				X	X					X											X	
RBS	X			X	X					X												
GSF	X									X						X						
PPS	X				X			X	X	X	X		X		X				X			
WAR	X			X	X	X			X	X	X		X	X		X	X		X		X	
BLG	X			X			X	X	X	X			X	X					X			
DSF	X			X	X		X	X	X	X	X		X		X	X			X		X	
RES	X							X											X			
SOS	X			X				X		X	X		X		X							
LMB				X	X	X				X			X	X	X				X		X	
GLS	X			X	X	X	X	X	X	X			X		X			X	X	X	X	
ICS															X							
DKS															X							
TLS													X									
BPS	X					X	X	X	X				X					X	X	X		
RFP	X	X		X	X	X	X	X	X	X	X		X		X	X	X	X	X		X	X
CHP															X							
BLB										X												
YBH	X			X	X	X		X	X	X	X		X		X		X				X	
BBH				X																		
CCF				X																		
TPM										X												
LNG																					X	
SWD	X						X				X		X			X						
TSD															X							
MSQ	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
LSK													X									
EMM		X			X	X	X	X	X			X	X	X		X	X		X	X		
Species Richness	**19**	**5**	**1**	**18**	**14**	**10**	**13**	**15**	**14**	**22**	**13**	**2**	**21**	**9**	**14**	**11**	**7**	**6**	**17**	**6**	**14**	**3**

Savannah River Basin

Four randomly selected sites were sampled in the Savannah River basin from the Carolina Flatwoods ecoregion following SCSA protocol (SCDNR 2009; Table 7). These sites were originally scheduled for sampling in June 2008 but were dry at that time due to a combination of a severe multi-year drought and low seasonal flows. Sampling in June 2009 showed significant fish recolonization since flows resumed approximately 7 months earlier in fall 2008 (Table 8). Twenty-four species of freshwater fish were collected altogether from these sites, including two Priority species (Kohlsaat et al. 2005): American eel (*Anguilla rostrata*) and snail bullhead (*Ameiurus brunneus*; Table 8).

Table 7. SCSA random sample sites in the Savannah River basin, 2009.

Ecoregion	**Site Number**	**Date**	**Stream**	**Latitude**	**Longitude**
Carolina Flatwoods	381835	16-Jun-2009	Watch Call Branch (Gaul Branch)	32.87447	81.44602
Carolina Flatwoods	381868	16-Jun-2009	The Gaul/King Creek	32.87403	81.44184
Carolina Flatwoods	393075	17-Jun-2009	Long Branch	32.75511	81.36781
Carolina Flatwoods	399519	17-Jun-2009	Tributary to Boggy Swamp	32.68646	81.32793

Table 8. Fish species collected from SCSA random sample sites in the Savannah River basin, 2009.

Scientific Name	Common Name	Conservation Priority	381835	381868	393075	399519
Amia calva	Bowfin		X	X	X	X
Anguilla rostrata	American eel	Highest	X	X	X	
Aphredoderus sayanus	Pirate perch		X	X	X	X
Erimyzon oblongus	Creek chubsucker			X		
Erymyzon sucetta	Lake chubsucker				X	
Centrarchus macropterus	Flier		X	X	X	X
Lepomis auritus	Redbreast sunfish		X	X		
Lepomis gulosus	Warmouth			X	X	
Lepomis macrochirus	Bluegill			X	X	
Lepomis marginatus	Dollar sunfish					X
Lepomis punctatus	Spotted sunfish		X	X		
Micropterus salmoides	Largemouth bass		X		X	
Notemigonus crysoleucas	Golden shiner		X	X	X	X
Notropis chalybaeus	Ironcolor shiner			X		
Esox americanus	Redfin pickerel		X	X	X	X
Esox niger	Chain pickerel				X	
Ameiurus brunneus	Snail bullhead	Moderate	X			
Ameiurus natalis	Yellow bullhead				X	
Noturus leptacanthus	Speckled madtom		X			
Etheostoma fusiforme	Swamp darter				X	
Etheostoma olmstedi	Tessellated darter		X	X		
Gambusia holbrooki	Eastern mosquitofish		X	X	X	X
Heterandria formosa	Least killifish				X	
Umbra pygmaea	Eastern mudminnow					X
Species Richness			**13**	**14**	**15**	**8**

Lower Santee Basin

One randomly selected site, Mount Hope Swamp (Site 279527; N33.61447; W80.07353), was sampled in the Lower Santee Basin from the Carolina Flatwoods. This site was sampled in continuation towards the target number of samples in this basin; sampling was also conducted in this basin in 2006 – 2007. Seven fish species were collected at Mount Hope Swamp: American eel (Highest priority), mud sunfish (Moderate priority), eastern mosquitofish, redfin pickerel, pirate perch, warmouth, and eastern mudminnow.

Recommendations

This report summarizes SCSA sampling of randomly selected sites in 2009. Further analyses will focus on standardized estimation of stream resources (completion reports by river basin), including development of conservation criteria for South Carolina stream fishes based on standardized abundance estimates and other measures. These criteria will assist biologists and resource managers in assigning conservation status in future efforts such as revisions of the Comprehensive Wildlife Conservation Strategy.

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Prepared By: Kevin Kubach Title: Fisheries Biologist

Job Title: Trophic resources for larval fish in Lake Marion

Period Covered January 1, 2009 – December 31, 2009

Results and Discussion

In 2008, the South Carolina Department of Natural Resources (SCDNR) re-convened the Santee-Cooper Comprehensive Study Group to provide an update and overview of current conditions in the system and to guide and promote development of a scientific basis for management decisions about aquatic resources within the Santee-Cooper basin. The most critical short-term goal identified by the Study Group was to evaluate whether zooplankton abundance may limit the recruitment of key fish species, including striped bass, American shad, blueback herring, threadfin shad, and white perch.

These key species have overlapping spawning seasons (April to June), shared nursery areas in Upper Lake Marion, and similar preferences for zooplankton during early life stages. In the last five years, blueback herring and striped bass recruitment is at historically low levels (Lamprecht, S., SCDNR, personal communication). The causes for these declines, and the implications for success of the Santee-Cooper anadromous fish passage and restoration efforts, are presently unknown. To date, striped bass has received more attention than the other key species in Lake Marion. However, because all of the key species share habitat and resources during early development, reduced recruitment of striped bass probably indicates changing conditions for the other species.

Investigations of factors influencing successful striped bass recruitment were conducted in Santee-Cooper in the 1980s and early 1990s. Successful recruitment depends on the abundance and timing of zooplankton production. Striped bass appeared to require zooplankton densities on the order of 100 animals/liter or more (Bulak et al., 1997).

For Lake Marion, the most important controls on zooplankton abundance in spring are probably intensity of predation, adequacy of phytoplankton, and advective loss. Spring temperatures are fairly consistent between years, so are unlikely to produce great differences in zooplankton abundances. Feeding by the larval fish could suppress zooplankton abundances, and larval fish may compete for this resource (for example, the hypothesized interaction between anadromous American shad and salmon in the Columbia River; Fresh, 1996).

The benthos may also affect the plankton in Lake Marion. *Corbicula fluminea*, the invasive Asiatic clam, appears to be abundant, although its populations have not been quantified. *Corbicula* can be highly productive (Sousa et al., 2008). *Corbicula* spp. have greatly suppressed phytoplankton and zooplankton in other shallow systems (for example, Hwang et al., 2004; Lopez et al., 2006), causing major changes in trophic structure.

We began investigations to determine whether zooplankton abundance in Upper Lake Marion is sufficient to support good survival and growth of ichthyoplankton during the spring. We also conducted an initial survey of the benthos in collaboration with Santee-Cooper.

Plankton

We sampled plankton from mid-April to early June on a bi-weekly basis (five sampling dates) at six stations in Upper Lake Marion. Water samples were collected with a 2.2-liter Van Dorn bottle. Samples from 0, 1, 2, 3, and 4 m at each station were pooled. A small subsample of the pooled sample was taken for analysis of chlorophyll a. The remainder was filtered through an 80-micron mesh net to collect zooplankton.

Chlorophyll a was very low (<5 micrograms/liter) in all samples in April and in most samples in May. These values indicate a poor base of resources to support zooplankton production. By early June, chlorophyll a was higher (5-21 micrograms/liter).

The zooplankton samples have not yet been counted. After processing the zooplankton samples, we will estimate the magnitude of zooplankton production using abundances, birth rates derived from egg ratios, and mass estimates. We will also estimate advective loss using retention times based on flow rates in the Congaree and Wateree Rivers and the Lake Marion hydrologic model (Tufford and McKellar, 1999).

Benthos

In collaboration with Santee Cooper, we sampled the benthos of Upper Lake Marion at 50 stations on 10 transects. Samples were collected with a Petite Ponar grab sampler, then gently rinsed on a 0.5 mm stainless steel screen. Material retained on the screen was preserved in 70% alcohol. Additional material was collected at each station for analysis of sediment texture and organic carbon content.

We completed sorting and counting the benthic invertebrates. One unexpected discovery was the snail *Valvata bicarinata*, a new record for the state of South Carolina. It is native to the region, but its distribution and ecology are poorly known.

We made preliminary estimates of biomass, based on published regressions. The benthos was dominated by the Asiatic clam *Corbicula fluminea* (46 g dry mass/m^2) and the olive mystery snail *Viviparus subpurpureus* (17 g dry mass/m^2). Both are invasive species. Biomass of the mayfly *Hexagenia limbata* (3 g dry mass/m^2) may have been near an annual minimum due to emergence. Other invertebrates, including other molluscs and dipterans, were present in much smaller quantities. Native unionid clams (*Elliptio* spp. and *Lampsilis splendida/radiata*) were very sparse.

Corbicula and, possibly, *Viviparus* may feed either on the plankton or on benthic deposits We will use published estimates of filtering rates for *Corbicula* to estimate its potential impact on the plankton.

Recommendations

Develop a process-oriented, modeling framework to allow continued refinement of a system-based ecological model, as more data are obtained and lake processes continue to change. Specific management applications resulting from this effort may include predicting optimal levels and times for striped bass stocking.

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Job Title: A Watershed Planning Guide for the Reedy River, South Carolina

Period Covered January 1, 2009 through December 31, 2009

Abstract

The Reedy River represents a case study in urban watershed development and its associated ramifications on the biological condition of tributary fish communities. We conducted a threat analysis on Reedy River subwatersheds to identify areas where the condition of fish assemblages are most threatened by future predicted land development and to prioritize specific areas for conservation/restoration actions. Threat levels were determined by bivariate plots of baseline development (year 2000) versus predicted development for the years 2010, 2020, and 2030. The bivariate plots were split into 4 quadrants, defined by reference lines at each 20% axis, the determined development threshold over which declines in biotic condition are observed. Threats were defined as low to high, and specific conservation actions were prescribed for each. Subwatersheds representing low threats were prescribed passive conservation, high threat sites were prescribed active conservation, and sites which had previously exceeded the 20% development threshold were prescribed restoration and public development activities. Alternative threshold analyses indicated similar general trends among three different threat scenarios, and may be beneficial when communicating results to interested stakeholders.

Introduction

The Reedy River watershed represents a case study in watershed development and its associated ramifications on the biological condition of fish communities. The Reedy watershed harbors land use activities ranging from intensive urban/suburban development and associated population growth near the River's headwaters in the Greenville metropolitan area to extensive agricultural and relatively undisturbed forested areas in the lower portion of the watershed. Such

heterogeneity provides a spatial framework for characterizing a gradient of urban disturbance and the associated effects on fish assemblage condition.

A recent South Carolina Department of Natural Resources (SCDNR) study examined the biological (fish) status of 15 Reedy tributaries by 'ranking' sites based on their relative biological condition, and examined the spatial distribution of site ranks across a gradient of urban land use intensities (Marion 2008). A threshold in land use level/type where fish community condition exhibited significant decline in rank (i.e. biological condition) was identified at > 20% urban watershed land use. Tributaries within watersheds that had exceeded a 20% urban threshold were characterized by fish assemblages with simplified taxonomic and functional composition, and reductions/eliminations of sensitive species.

Of greatest concern for Reedy River watershed fish communities is the potential threat of predicted future urban expansion in upstate South Carolina. Clemson University's Strom Thurmond Institute recently estimated that from 1990-2000 the amount of developed land in upstate SC grew from approximately 223,000 to 576,000 acres. Under a predicted 5:1 growth ratio (5 developed acres to each 1 additional person), the amount of developed land is anticipated to grow to over 1,500,000 acres by the year 2030 (Campbell 2007). It is highly likely that as the Reedy watershed develops, many if not all Reedy tributaries will surpass a threshold where biological condition declines irrevocably. Future observed changes may mimic what the SCDNR observed in the lower ranked upper Reedy watershed tributaries; losses of sensitive species and community simplification. Therefore, it is vital, at this juncture, to identify Reedy sub-watersheds most and least at risk for future urban expansion, and to select and prioritize areas suitable for conservation and/or restoration efforts.

We conducted a threat analysis on Reedy River subwatersheds using information regarding the identified 20% urban land use threshold (SCDNR), current conservation lands (The Nature Conservancy), and predicted future development (Upstate Growth Model, STI), we predict areas within the Reedy River watershed that are most (and least) vulnerable to future declines in biological condition, and prioritize subwatersheds for conservation/restoration efforts based on those predictions. This type of proactive conservation approach will greatly enhance our ability to communicate predicted trends in aquatic resources and to recommend resource conservation strategies to land managers, local governments, private citizens, special interest groups, and other stakeholders. Our primary objectives were to: 1) perform a threat assessment to identify Reedy River subwatersheds most and least at-risk for future declines in biological condition, 2) prioritize subwatershed areas for conservation/restoration efforts, and 3) explore alternative biological threshold values and assess their potential impacts on conservation/restoration scenarios.

Methods

Study Area

The Reedy River drains a watershed of approximately 700 km^2 within the Southern Inner and Outer Piedmont ecoregions (Griffith et al. 2002) of the upper Santee River basin in northwestern South Carolina (Fig. 1). The watershed is situated in one of the most vigorously developing areas of South Carolina; developed land an eight-county region of Upstate South Carolina is projected to increase by almost 40% by the year 2030 (Campbell 2007). The upper portion of the watershed includes a rapidly growing urban area centered around the city of Greenville and Interstates I-85 and I-385 corridors, while lower parts of the watershed are moderately forested or in various forms of agrarian use. The Reedy watershed is relatively narrow, draining 15 major tributaries and numerous smaller tributary streams. The tributaries of

the Reedy River are characterized primarily by sandy runs interspersed with bedrock and cobble/gravel riffles.

Biological Data

A recent SCDNR study examined the status of fifteen Reedy River tributaries by 'ranking' sites based on their relative biological condition, and examined the spatial distribution of site ranks across a gradient of urban land use intensities (Marion 2008). A threshold in land use level/type where fish community condition exhibited significant decline in rank (i.e. biological condition) was identified at approximately > 20% urban/developed watershed land use. Fish communities in watersheds that had surpassed a 20% threshold in developed land cover were characterized by reductions/eliminations in sensitive taxa, and general simplification of the structural (taxonomic) and functional composition of assemblages. For the purpose of this project, we used the 20% watershed development level as a benchmark, or threshold, upon which to judge our threat levels among three years of predicted development. We considered subwatersheds with current or predicted development levels of greater than the 20% threshold to reflect a landscape environment conducive to biological decline.

Growth Model

Clemson University's Strom Thurmond Institute (STI) modeled future predicted growth in developed land for an 8-county region of upstate South Carolina that makes up the Saluda River – Reedy River watershed (Campbell 2007). A geographic information system-based model was developed which combined a binomial logistic regression approach with expert information provided by informed participants throughout the region. The STI model predicted the amount of developed land for every 5 years, beginning in 2005. Twenty-one parameters affecting growth were included as predictive variables in the model. The growth of developed

land was modeled based on several potential growth ratios, each indicating differing intensities of development. For the purpose of our project, we chose to use spatial data for the years 2010, 2020, and 2030, based on the assumption of a 5:1 growth ratio, indicating a 5:1 ratio of developed area growth to population growth. This ratio is considered conservative, and is recommended by the STI for use in practical applications of the STI growth model.

Protected Lands

Protected land spatial layers were obtained from the South Carolina Chapter of The Nature Conservancy. Layers included federal, state, and private protected lands updated for 2009. The Reedy River watershed contained only private and state protected lands, both in negligible quantities. There was a total of 2.26 km^2 of private protected lands, and a total of 0.26 km^2 of state protected lands within the Reedy watershed. The STI growth model accounted for 2006 Nature Conservancy documented protected lands, therefore we simply updated the STI growth model with the 2009 state and private protected lands records. Protected lands were accounted in our threat analysis by treating individual protected areas (individual 30 m^2 raster cells) as unable to develop over time.

Watershed Framework

The digital elevation model (DEM) used for watershed delineation was obtained from the U.S. Geological Survey National Map Seamless Server (http://seamless.usgs.gov). This layer was imported into ArcGIS 9.3 and projected into an appropriate coordinate system and cell size with 'raster projection' under Data Management Tools in the Arc Toolbox. ArcHydro was used for further layer manipulation to 'fill sinks' in the DEM, create "flow direction', 'flow accumulation', and 'stream definition' layers. The Reedy watershed was created using existing coordinates obtained from a field GPS unit and saved as a .csv file extension. A personal

geodatabase was created in Arc Catalog and the .csv file was imported as a single table. Once the personal geodatabase table was added into Arc Map, the point was displayed by selecting 'display XY data'. Arc Hydro's 'catchment grid delineation' tool was used to define the Reedy watershed. The Reedy watershed layer was further used to define all subwatersheds using 'catchment grid delineation' with a stream link area definition threshold of 1 km^2. There were over 300 subwatersheds created for the Reedy River watershed, of average size 1.7 km^2.

Threat Assessment

Threat assessment methodology was modified from the recommendations of Margules and Pressey (2000), who proposed a strategy for conservation prioritization based on a bivariate scatter plot of irreplaceability versus vulnerability. Site irreplaceability is defined as the extent to which the loss of the area will compromise regional conservation targets, and vulnerability as the risk of landscape transformation. Areas of both high irreplaceability and high vulnerability should receive priority conservation action, because they are most likely to be lost and their loss will have the most serious impact on the achievement of conservation targets.

For our analysis, 'vulnerability' as defined by the latter example is analogous with the future predicted level of percent developed land within subwatersheds. Using the STI growth model, the predicted level (%) of developed land in all individual subwatersheds was projected for three separate time periods – 2010, 2020, and 2030. We did not have information directly equivalent to Margules and Pressey's (2000) irreplaceability variate, however for the purpose of this analysis, we defined a given subwatershed as irreplaceable if it contained less than 20% developed land cover at year 2000. The Reedy River tributary ranking analysis conducted by the SCDNR concluded that sites with watershed development levels of less than 20% were in better

biological condition than watersheds with development levels of greater than 20%, the latter of which displayed losses of sensitive taxa and increased assemblage simplification (Marion 2008).

Figure 2 shows a generalized example of the threat analysis strategy. Subwatershed percentage levels of developed land at year 2000 (irreplaceability value) are plotted on the Y-axis, and predicted percentage levels of developed land for three separate time periods, 2010, 2020, and 2030, are plotted on the X- axis (vulnerability value). Threat classification quadrants were established by drawing both X- and Y- reference lines set at 20%, our established developed land threshold. Quadrant I represents subwatersheds that have low current development (<20%), and that are not predicted to exceed 20% development at time X_n. These subwatersheds were deemed to contain low threat, since they were not expected to surpass the 20% threshold over time. Quadrant II represents subwatersheds that have low current development (<20%), but are predicted to exceed 20% development at time X_n. Quadrant II subwatersheds contain high threat levels, and are of most concern because they are most likely to foster environments conducive to biological decline. Quadrant III represents subwatersheds that have high current development (>20%), and are predicted to decrease in development to less than 20% at time X_n – an improbable circumstance. Our analysis contained no quadrant III sites for any time period X_n. Quadrant IV represents subwatersheds that have high current development (>20%), and are predicted to remain above and/or exceed beyond the 20% developed land level over time. Quadrant IV subwatersheds have exceeded the 20% development threshold at some point in time prior to our base year 2000, so we assume that these sites are already degraded and therefore are considered to contain the lowest threat. This assumption is reinforced by the fact that sites with >20% watershed developed land at year 2000 ranked low in biological condition (Marion 2008).

Alternative Threshold Analysis

Previous research has indicated that landscape urbanization can affect stream habitats and biota at even relatively low levels (≤ 10%) of watershed development (Wheeler et al. 2005, Wang et al. 2001). Other studies indicate urban land cover ranging from 7-20% to impair biological communities, and above 20% to cause irreparable damage (Paul and Meyer 2001, Morgan and Cushman 2005). Although our data indicate that the watershed landscape development threshold is approximately 20%, we deemed it prudent to explore both more conservative and liberal scenarios. In order to account for potential alternative watershed development threshold values, we introduced alternative threshold scenarios of 10% and 30% development for model comparison. Differing trends over time were evaluated, as well as potential impacts to conservation scenarios.

Results

Threat Assessment

Three unique threat assessments were produced for the years 2010, 2020, and 2030. Figure 3 shows plots of the sequential shifts in threat categories through time. Of greatest concern is the mass of subwatershed sites that are predicted to shift into quadrant II over time. Quadrant II represents subwatersheds of highest threat - they are predicted to shift from less than 20% watershed development to greater than 20% watershed development, a known threshold associated with local biological decline. The sequential increase of plots in both breadth of scatter and left to right movement over time is indicative of an overall trend of increasing levels of development within the entire Reedy watershed. Maps depicting shifts in threat categorization from base year 2000 (48.2 % developed) to years 2010, 2020, and 2030, respectively are

displayed in figure 4. At year 2010, there is predicted to be a 5.2 % increase in high threat (quadrant II) sites. At year 2020, there is predicted to be a 15.3% increase in high threat sites. By the year 2030, there is predicted to be a 25.9% increase in high threat sites. In other terms, the percent of the Reedy watershed as a whole that contains subwatersheds greater than 20% developed is 53.2 % in 2010, 63.5% in 2020, and 74.1% in 2030. The general trend of development shows a southern progression over time, with largest aggregated areas of development occurring along the I-385 corridor, and along the outskirts of the cities of Laurens and Honea Path.

Conservation Prioritization

Three conservation prioritization categories were defined for each of the three threat assessments, however we used the analysis for year 2030 in the following interpretation. For each time period, Quadrant I sites (low threat – level I) are targeted for passive conservation efforts, quadrant II sites (high threat – level II) are targeted for active conservation efforts, and quadrant IV sites (exceeded 20% development threshold prior to 2000 – level IV) are targeted for stream/landscape restoration projects (Fig. 5a). Potential approaches to conservation prioritization may include a subwatershed approach, or an aggregate watershed approach (Fig. 5a,b). A subwatershed approach treats individual subwatershed units separately, and while greatly informative when viewed at an entire Reedy watershed scale, may not be pertinent individually (i.e. development in one subwatershed may negate the benefits of non-development another subwatershed within the same dendritic stream network). An aggregate watershed approach treats subwatersheds as part of a greater stream network, and may provide a more intuitive and logical way to prioritize conservation efforts. Figure 5c shows 15 major tributaries to the Reedy river and depicts areas of ‘good’ and ‘poor’ biological condition (Marion 2008).

An aggregate watershed map for projected development in 2030 shows that the majority of sites deemed to be in ‘good’ current biological condition (Fig. 5c) are largely predicted to fall into categories of high threat (Fig.5b). Potential expected biological declines in high threat areas may include the loss/elimination of sensitive taxa and a simplification of the taxonomic and functional structure of fish assemblages.

Alternative Threshold Analysis

In order to account for potential alternative watershed development threshold values, we introduced alternative threshold scenarios of 10% and 30% development for model comparison (Table 1). Each shows a general trend of development moving in a southern progression over time, similar to the trend for our threat analysis using a 20% threshold. The total percentage of Reedy subwatersheds containing greater than 20% developed for the year 2030 ranges from 65.2% at the 30% threshold level to 84.8 % at the 10% threshold level. This analysis acts as a confidence interval for the potential biological threats and related consequences of watershed development, for exact thresholds are difficult to define definitively with a single, hard number. It is expected that the ‘real’ threat to biological condition will fall somewhere between predictions for 10% and 30%.

The Reedy River represents a case study in watershed development and its associated ramifications on the biological integrity of fish communities. The Reedy watershed harbors land use activities ranging from intensive urban-/suburban development and associated population growth in the Greenville metropolitan area to extensive agricultural and relatively undisturbed forested areas. Although certain stressors are locally dominant and relatively contiguous where so (e.g., urban/suburban development near the city of Greenville), at the scale of the entire watershed system, a wide range of land cover/uses and intensities (i.e., degrees of disturbance)

exists among and within sub-watersheds as well as longitudinally along individual streams, including areas of little or no disturbance. Such heterogeneity provides a spatial framework for characterizing the gradient of disturbance and the associated effects on fish assemblage integrity.

The primary focus of this study was to 'rank' fifteen Reedy River tributary sites based on their relative 'biological integrity', and examine potential relationships among land use and fish community integrity (rank) across an environmental gradient of urban and forest land cover intensities within the Reedy River watershed. Secondly, the analysis was intended to identify rough thresholds in land use level/type at which fish community integrity exhibits significant decline. Third, the ranking scheme should provide initial input/identification of sites and watersheds which may represent 'best candidates' for conservation and restoration efforts. Likewise, such analysis should also identify those sites and components on the other end of the spectrum of conservation potential, or those which are functionally (ecologically) irreparable or otherwise not expected to yield efficient return.

Recommendations

Conservation prioritization and regulated development within the Reedy River watershed are essential for the maintenance and continuance of its biological viability. The Reedy river has suffered thorough at least 200 hundred years of anthropogenic impacts; historically deriving from point-source pollutants from local industry, to a modern onslaught of landscape-derived non-point source pollutants and anthropogenically induced habitat / hydraulic alterations (O'Neil 2005, Allen et al. 2007). Despite this ragged history of degradation, the Reedy River is also a testament to the inherent resiliency of natural systems. Current research has shown that tributary sites in the lower portion of the Reedy watershed remain in 'good' biological condition (Marion 2008). Unfortunately, our threat analysis shows that it is precisely these subwatersheds that are

at most risk of future development over the next 20 years. In order to mitigate the potential deleterious effects of predicted future development, we suggest the following conservation actions. We suggest acknowledging the general development trends portrayed in all three threat maps (2010, 2020, 2030), but to plan conservation strategies based on threats portrayed by the 2030 threat analysis map (Fig. 4). We recommend passive conservation efforts be applied to low threat sites. We define passive conservation as concentrating more on damage prevention than on active physical intervention. Conservation recommendations for low threat sites may include: routine biological monitoring, development regulation (e.g. zoning regulation), strict adherence to and monitoring of best management practices for all construction efforts, landowner environmental education programs, and the creation of a watershed development 'master plan' advocating development by choice, rather than chance. We recommend active conservation be applied to high threat sites. We define active conservation as a concentration of effort focusing on ecologically defensive actions to mitigate the effects of landscape development. Recommendations for high threat sites include all recommendations cited for low threat sites as well as aggressively advocating conservation easements and other landowner conservation agreements, active purchases of land tracks by private and government institutions, and active riparian protection and enhancement zones. We recommend restoration efforts be applied to our subwatershed sites that have already exceeded the 20% threshold (threat level IV). Because these are mostly established urban sites, we feel that a focus on restoration of stream channels to mitigate flood events and to enhance aesthetic qualities is appropriate. These areas are also appropriate for the construction of publicly accessible parks, walkways, and other public gathering sites that may generate and increase public interest in the natural world and the ecological system in which they reside.

The Reedy River watershed is only one of many watersheds residing in upstate South Carolina. Of greatest concern is future predicted urban expansion in the entirety of Upstate South Carolina. Future research should be expanded to focus on evaluating the threat of predicted development on the aquatic biotic community of upstate South Carolina as a whole.

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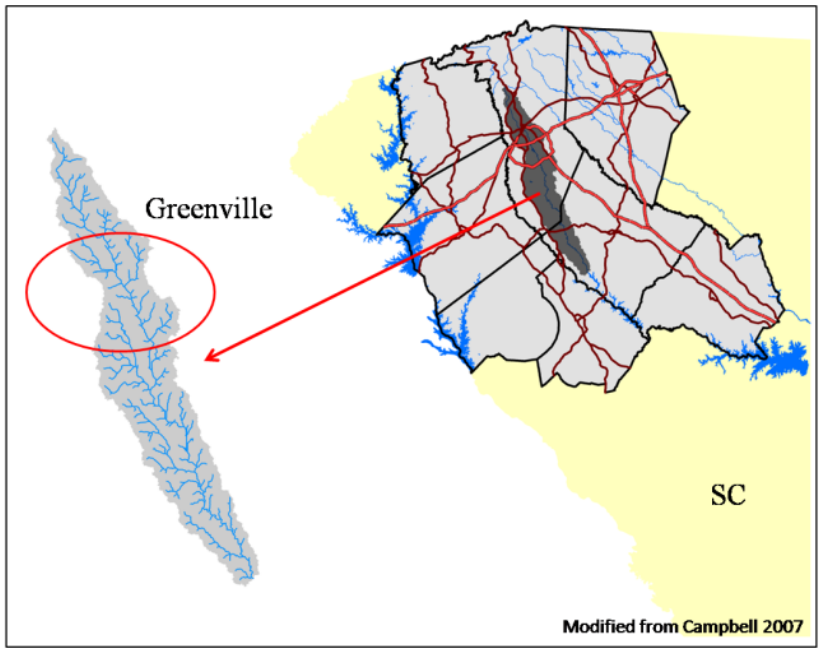

Figure 1. Map of study watershed and location in the upstate of South Carolina with major roads, county boundaries, rivers, and reservoirs.

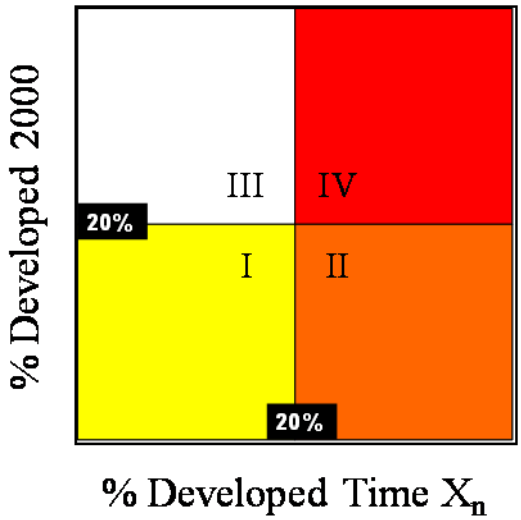

Figure 2. General example of threat analysis strategy with threshold values of 20% urban development. Quadrants I-IV represents threat levels relating current conditions to projected urban development. Quadrant I = low threat, Quadrant II = high threat, Quadrant IV = previously exceeded 20% threshold – low threat.

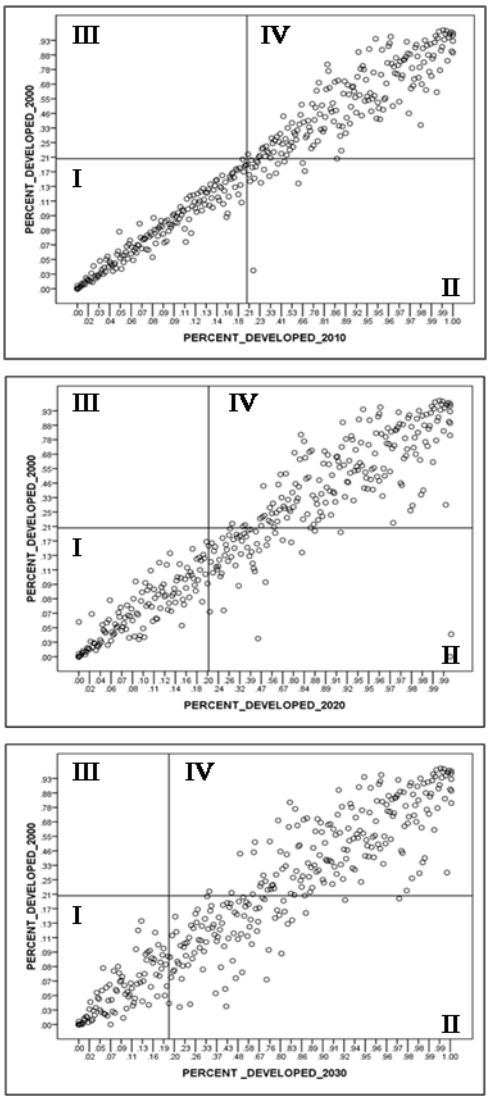

Figure 3. Threat assessment scatter plots for the years 2010, 2020, and 2030. Reference lines indicate 20% development threshold values, resulting quadrants reflect threat levels I-IV.

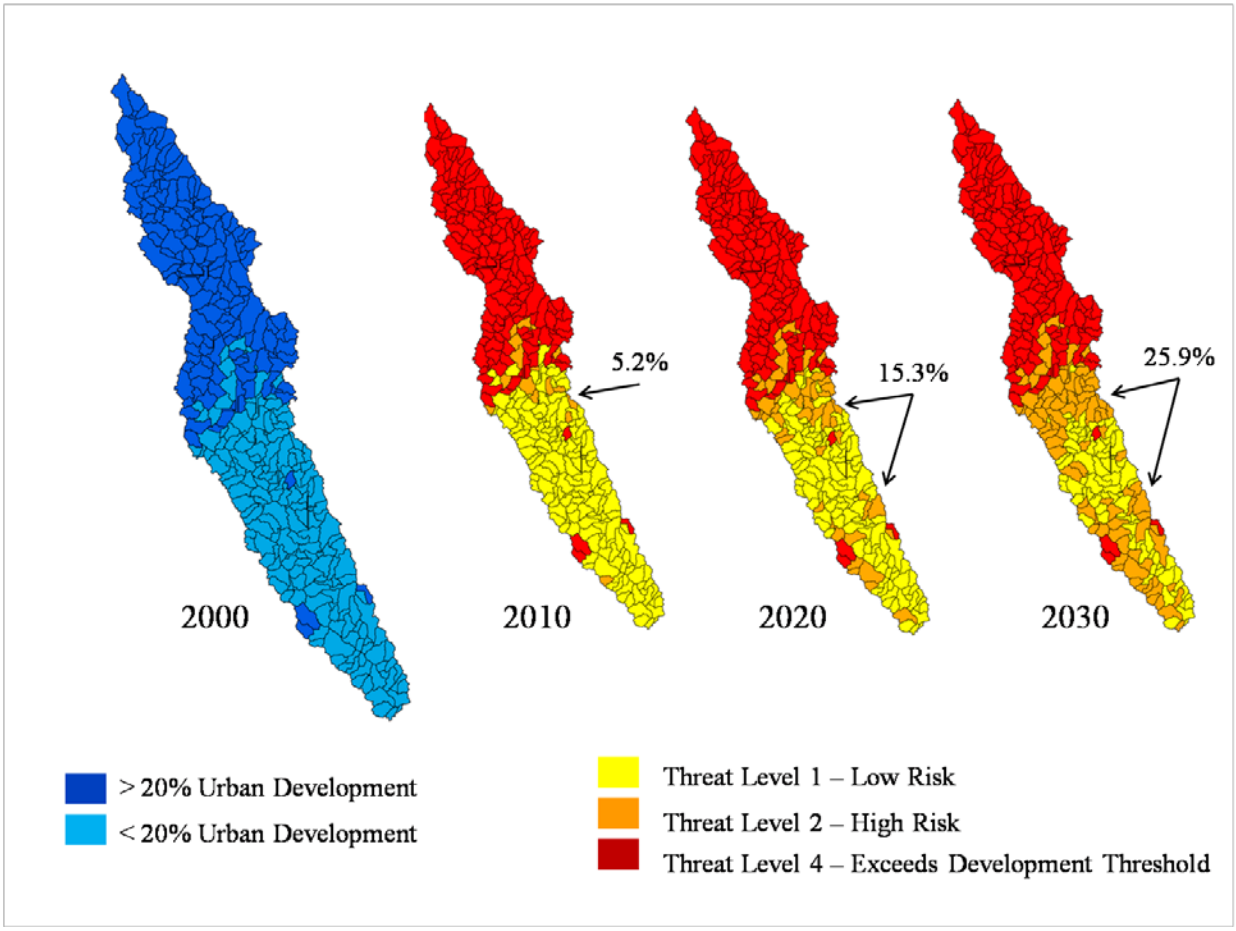

Figure 4. Threat analysis maps for 2010, 2020, and 2030 using base year 2000 for the Reedy watershed. Map for base year 2000 indicates areas above and below development threshold values of 20%. The watershed was 48.2% developed for the year 2000. Threat analysis maps for 2010, 2020, and 2030 show low threat subwatersheds in yellow, high threat subwatersheds in orange, and subwatersheds already exceeding the 20% threshold by 2000 in red. In 2010, there is predicted to be a 5.2% increase in high threat subwatersheds, a 15.3% increase by 2020, and by 2030 there is predicted to be a 25.9% increase.

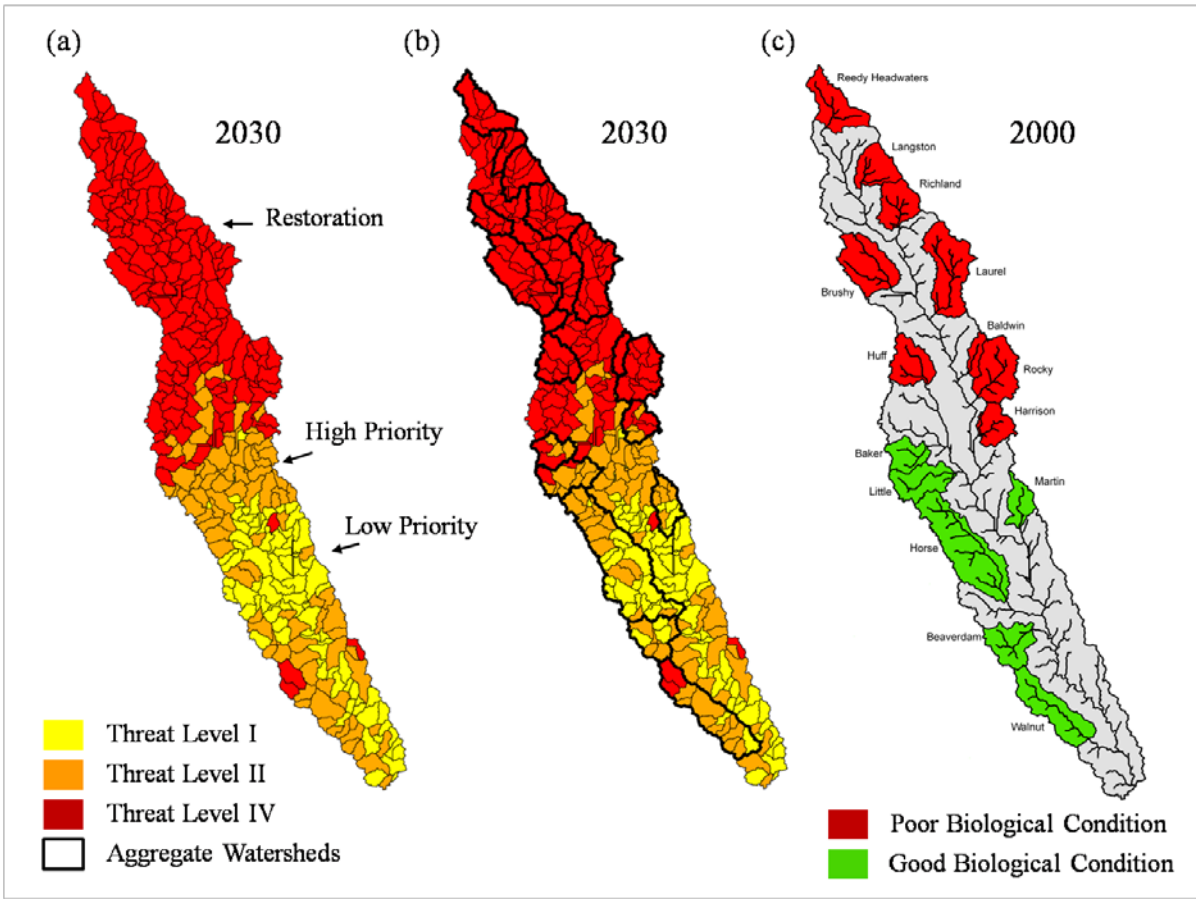

Figure 5. Conservation prioritization maps for the Reedy watershed. 5a represents conservation prioritization map for 2030. 5b represents aggregated conservation prioritization map for 2030. 5c shows South Carolina Department of Natural Resources results 'good' vs 'poor' biological condition sites for 2000. Conservation prioritization for 5b shows that most 'good' condition sites are predicted to fall into a high threat category by 2030.

Table 1. Alternative threshold analysis of 10% and 30% for model comparison to original urban development threshold value of 20% for each threat level and year.

	10% urban development threshold			20% urban development threshold			30% urban development threshold		
	2010	2020	2030	2010	2020	2030	2010	2020	2030
Threat Level	Percent developed	Percent developed	Percent developed	Percent developed	Percent developed	Percent developed	Percent developed	Percent developed	Percent developed
1	29.4	19.3	15.3	46.6	36.5	25.9	51.8	43.9	34.3
2	1.9	12.0	16.1	5.2	15.3	25.9	9.5	17.4	27.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	68.4	68.4	68.7	48.2	48.2	48.2	38.7	38.7	38.7

Prepared By: Cathy Marion Title: Fisheries Biologist

Job Title:	Influence of Land Use on In-Stream Substrate and Single-Metric Fish Indicators in South Carolina Coastal Plain Streams
Period Covered	January 1, 2009 through December 31, 2009

Results and Discussion

We evaluated four metrics of SC Coastal Plain fish assemblage composition (richness, Shannon diversity, guild breadth, and endemic abundance) and quantified their relationships with in-stream substrate and catchment land use. Data were drawn from 79 wadeable streams across three South Carolina coastal plain ecobasins, including the ACE Carolina Flatwoods, the Pee Dee Carolina Flatwoods, and the Pee Dee Atlantic Southern Loam Plains.

Fish Metrics

Species richness and Shannon diversity were calculated using PC ORD version 4 software. Descriptive statistics for richness and Shannon diversity are reported in table 1. Guild breadth was generated by placing fishes in trophic, reproductive, and habitat guilds based on life history characteristics, and for each site, dividing the number of guilds present by the total number of possible guilds for a particular ecobasin. The guild breadth calculation is intended to represent the variation in trophic, reproductive, and habitat preferences among fish in a given assemblage. Descriptive statistics for guild breadth are reported in table 1. Coastal plain endemic fishes were identified by complete restriction to the level III ecoregions Middle Atlantic Coastal Plain, Southern Coastal Plain, and Southern Florida Coastal Plain. If a fish's distribution range fell completely within these designated level III ecobasins, then the species was determined to be coastal plain endemics (range restricted). Fishes considered to be catadromous or anadromous were excluded from this metric. There were a total of 9 fishes considered to be endemic to the coastal plain: banded sunfish (Enneacanthus obesus), dusky shiner (Notropis

cummingsae), eastern mudminnow (Umbra pygmaea), lined topminnow (Fundulus lineolatus), mud sunfish (Acantharchus pomotis), sailfin shiner (Pteronotropis hypselopterus), savannah darter (Etheostoma fricksium), sawcheek darter (Etheostoma serriferum), and swampfish (Chologaster cornuta). Endemic abundance was calculated as a percent (# Endemic fishes / Total # fishes). Descriptive statistics for endemic abundance are reported in table 1.

Land Use Variables

Urban, Forest, and Agrarian catchment influences (land use 'x' (km^2) / total watershed area (km^2)) were calculated at the watershed scale, which included the entire drainage area upstream of sample sites. Land use data was obtained from the U.S. Geological Survey (USGS) national map seamless server (http://seamless.usgs.gov). Two land use variables were derived related to each of the three land use variables: 1) 2001 watershed land use, and 2) watershed land use change over time (% watershed land use change over time = 2001 watershed land use categories – 1992 watershed land use categories). Land use categories were defined according to Fry et al. 2009.

Inorganic and Organic In-stream Substrate Variables

Benthic substrate composition was quantified using the 'zig-zag' method of habitat sampling (Bevenger and King 1995). A total of 50 individual measurements were taken along the sample reach that measured (if inorganic) or classified (if organic) the substrate. Inorganic substrate particles were measured at the intermediate axis in millimeters, and the median particle size D_{50} was calculated for each sample site. Organic substrate was classified into one of five categories – Fine Particulate Organic Matter (%FPOM), Coarse Particulate Organic Matter (%CPOM), Fine Woody Debris (%FWD), Large Woody Debris (%LWD), and Aquatic Vegetation (%AV) (SCDNR 2009). In addition, suspended inorganic sediments were accounted

for by measuring the turbidity at each site with a portable turbidimeter. Descriptive statistics for D_{50}, turbidity, and organic substrate measures are recorded in table 1.

Statistical Analysis

Two approaches were used to evaluate relationships among land use, in-stream substrate, and fish assemblage metrics. The first was an information-theoretic approach to multiple regression. Akaike's Information Criterion, adjusted for small sample size (AICc) was used to assess the relative fit of candidate models. Lower AICc values indicate a better supported model for predicting the dependant variable, relative to other models (Burnham and Anderson 2002). This method is useful for selecting among competing models and reduces the reliance on statistical significance tests, an advantageous attribute when dealing with data that violates the assumption of a normal distribution (as exemplified by several of our substrate and fish metric variables). Several variables were transformed using the Box-Cox power transformation, which tended to improve the normality and error structure (Sokal and Rolf 1995). However, even after transformed, several variables remained non-normal.

The second approach to analyzing relationships among landscape, substrate, and fish metrics was conducted by path analysis (Shipley 1997) with AMOS (SPSS v.17, AMOS v. 17). Path analysis is a form of structural equation modeling that measures both direct and indirect causal relationships among variables. Causality was established by pre-defining one-way mechanisms (e.g. a —> b, but b $\not\Rightarrow$ a) among the hierarchical levels in the design phase. In addition, causal mechanisms were based on theoretical direct relationships of land use —> fish metrics, land use —> in-stream substrate, in-stream substrate —> fish metrics, and indirect relationships of land use —> fish metrics via an in-stream substrate mediator variable. Path analysis was chosen because the structure of our data was spatially hierarchical in nature,

ranging from landscape to in-stream features to fish assemblage measures. The nature of our data structure suggested that landscape level variables may be having both a direct (implicit relationship between land use and fish metric) and/or indirect (the impact of land use on fish metrics is mediated by an influence on the physical habitat (i.e. substrate) within coastal plain streams) effect on fish metrics. The goal of the path analysis was to develop a multilevel model that assessed both the direct and indirect relationships of land use on coastal plain fish assemblage metrics.

Results

AICc results indicated that measures of inorganic substrate (D50, turbidity) do not significantly influence the structure of coastal plain fish assemblages. In contrast, organic debris, particularly large woody debris, plays a very influential role in structuring coastal plain fish communities (table 2). Results indicated that large woody debris were positively related to increased forested catchment, and negatively related to landscape level watershed disturbances, particularly forest loss, current agriculture practices, and increased urban land cover. In addition, large woody debris was positively related to increased loss of agricultural land, which by examining the raw land cover data can be interpreted as a reversion to grassland or pasture, an arguably less intensive land practice.

In addition to large woody debris, AICc analysis indicated that fish metrics were positively related to increased forested catchment and increased conversion from agriculture to grassland over time, and negatively related to landscape level watershed disturbances, particularly forest loss, increased agriculture, and urban land cover.

To summarize, we found that reduced richness, reduced Shannon diversity, reduced functional diversity (i.e. reduced number of life-history and resource use guilds present), and

reduced taxonomic diversity (loss of Atlantic coastal plain endemic species) were related to both landscape-level disturbances and reductions in large woody debris. The primary findings of this research indicate that as natural forested coastal plain landscapes are lost and replaced by human dominated landscapes, declines are seen in the occurrence of large organics, and cumulatively these terrestrial and habitat disturbances result in the decreased integrity of coastal plain fish assemblages.

The results of the path analysis are summarized in table 3, which reports the direct and indirect causal relationships among land use, in-stream substrate and fish metrics. Figures 1-4 graphically display the direct and indirect relationships, and may be more intuitive to the reader. Path analyses for richness and Shannon diversity show that each metric is directly related to large woody debris (positive relationship), and indirectly related to land use. More implicitly, large woody debris acts as a mediator variable between land use and the fish metrics. The results can be interpreted as increased current forest, minimal forest loss, and minimal current urbanization are related to increased large woody debris, which is in turn related to increased Richness and Shannon diversity. Guild breadth reveals identical relationships, but additionally shows a direct relationship with increased loss of agrarian land over time. As stated before, this can be interpreted as a reversion from agrarian land to grassland or pasture, an arguably less intensive land practice. In contrast, endemic abundance shows no relationship with large woody debris, however it is directly related to several land use variables, specifically we see increased endemic abundance in areas with greater forested catchments, minimal forest loss over time, and increased reversion from agrarian land to grassland.

To summarize, we see an indirect relationship between both richness and Shannon diversity and landcover, where in disturbed landscapes (decreased forest, increased urbanization)

we see a loss in large woody debris, and therefore a decline in assemblage integrity. We also see this pattern in guild breadth. Additionally, guild breadth is increased in watersheds that have reverted away from intensive agriculture to a less intensive grassland land cover. Endemic abundance is not related to large woody debris, however increased endemic abundance is directly related to minimally disturbed landscapes (forested, non-agrarian). These findings may indicate that both guild breadth and endemic abundance are more sensitive metrics to detecting long-term environmental phenomenal related to landscape disturbances (i.e. the assemblages ability to disperse through a disturbed landscape, or the long-term stability of stream chemical and habitat conditions).

Recommendations

- Further explore functional and taxonomic characteristics of coastal plain fish assemblages and their relationships with landscape / habitat disturbance. Identify specific functional traits that characterize the loss of breadth in functional diversity. Identify specific species lost with increased disturbance scenarios. Identify potential 'signals' reflecting where we loose functional and taxonomic diversity within the progression of a coastal plain landscape disturbance regime.
- Incorporate data from SCSA reference sites.
- Expand GIS database to include additional variables related to land cover, soils, climate, and various anthropogenic influences.

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Table 1. Landscape variables, in-stream substrate variables, and fish metrics measured for 79 coastal plain streams.

Variable	Variable Name	Units	Range	Mean	SD
Catchment Land Use / Land Cover Variables					
Watershed Area	WS_AREA	km²	1.15 - 126.09	30.062	28.969
Catchment Forest Cover (2001)	FOR_WS_01	km²	0.072 - 0.601	0.290	0.142
Catchment Urban Cover (2001)	URB_WS_01	km²	0.000 - 0.613	0.075	0.094
Catchment Agriculture Cover (2001)	AG_WS_01	km²	0.001 - 0.620	0.251	0.169
Change in Catchment Forest Cover Over Time (1990-2001)	FOR_WS_D	km²	-0.423 - 0.111	-0.162	0.117
Change in Catchment Urban Cover Over Time (1990-2001)	URB_WS_D	km²	0.000 - 0.124	0.045	0.024
Change in Catchment Agriculture Cover Over Time (1990-2001)	AG_WS_D	km²	-0.214 - 0.032	-0.074	0.055
In-Stream Substrate/ Habitat Variables					
Median Inorganic Particle Size D50	D50	mm	0.5 - 7.0	0.72	0.96
Turbidity	TURBIDITY	NTU	1.03 - 59.29	11.39	12.19
Fine Organic Debris	FINE_ORG	%	0.0 - 0.70	0.16	0.17
Coarse Organic Debris	COARSE_ORG	%	0.0 - 0.62	0.21	0.15
Large Woody Debris	LWD	%	0.0 - 0.40	0.08	0.10
Fish Metrics					
Richness	RICHNESS		2 - 25	11	5.4
Shannon Diversity	SHANNON DIVERSITY		0.099 - 2.479	1.248	0.648
Guild Breadth	GUILD BREADTH	%	0.375 - 1.0	0.787	0.157
Endemic Abundance	ENDEMIC ABUNDANCE	%	0 - 0.46	0.052	0.089

Table 2. Linear models of four fish metrics (Richness, Shannon Diversity, Guild Breadth, Endemic Abundance) as a function of landscape and in-stream substrate predictor variables. Models are ranked by their AICc performance statistic. The models labeled 'current' include only catchment land use variables for 2001. The models labeled 'Δ / time' include only catchment land use variables representative of land use change over time (1990-2001).

Dependant Variable	Model Rank	AICc	Model Predictors	Standardized Estimates	Adj. R^2
Large Woody Debris	1	39.704	FOR_WS_01	0.265	0.058
current	2	40.352	URB_WS_01	-0.148	0.065
			FOR_WS_01	0.207	
	3	40.421	FOR_WS_01	0.418	0.064
			AG_WS_01	0.202	
• / time	1	35.831	FOR_WS_D	0.339	0.103
	2	37.43	URB_WS_D	-0.083	0.099
			FOR_WS_D	0.335	
	3	37.831	FOR_WS_D	0.352	0.094
			AG_WS_D	0.051	
Richness	1	453.996	LWD	0.326	0.095
current	2	454.028	FOR_WS_01	-0.164	0.108
			LWD	0.371	
	3	455.111	URB_WS_01	0.115	0.096
			LWD	0.353	
• / time	1	453.805	FOR_WS_D	-0.174	0.111
			LWD	0.383	
	2	453.996	LWD	0.326	0.095
	3	455.189	FOR_WS_D	-0.171	0.109
			URB_WS_D	0.100	
			LWD	0.393	
Shannon Diversity	1	149.451	LWD	0.369	0.125
current	2	150.08	FOR_WS_01	0.136	0.131
			LWD	0.333	
	3	150.578	AG_WS_01	-0.11	0.126
			LWD	0.357	
• / time	1	149.451	LWD	0.369	0.125
	2	150.01	FOR_WS_D	-0.084	0.154
			LWD	0.417	
	3	151.252	URB_WS_D	0.068	0.118
			LWD	0.376	

Table 2. Continued

Dependant Variable	Model Rank	AICc	Model Predictors	Standardized Estimates	Adj. R^2
Guild Breadth	1	-78.176	AG_WS_01	0.195	0.059
current			LWD	0.241	
	2	-77.766	URB_WS_01	-0.152	0.069
			AG_WS_01	0.209	
			LWD	0.208	
	3	-77.279	LWD	0.216	0.034
• / time	1	-79.618	AG_WS_D	-0.233	0.077
			LWD	0.213	
	2	-79.335	URB_WS_D	-0.165	0.088
			AG_WS_D	-0.296	
			LWD	0.195	
	3	-79.068	URB_WS_D	-0.187	0.100
			FOR_WS_D	-0.167	
			AG_WS_D	-0.343	
			LWD	0.246	
Endemic Abundance	1	30.946	AG_WS_01	0.272	0.069
current			LWD	0.162	
	2	30.967	AG_WS_01	0.055	0.055
	3	31.218	FOR_WS_01	0.231	0.066
			AG_WS_01	0.433	
• / time	1	19.826	FOR_WS_D	0.305	0.191
			AG_WS_D	-0.275	
	2	22.036	FOR_WS_D	0.298	0.181
			AG_WS_D	-0.273	
			LWD	0.028	
	3	22.107	URB_WS_D	0.000	0.181
			FOR_WS_D	0.305	
			AG_WS_D	-0.275	

Table 3. Summary results for path analysis showing significant model predictors, as well as the standardized strengths of both the direct and indirect effects of land use on in-stream substrate and fish metrics. Reduced models included only 2001 catchment land use variables, and full models included both 2001 catchment land use and land use change over time (1990-2001).

Criterion Variable	Model Predictors	Correlation	Direct Effect	Indirect Effect	Total Effects	Non-Causal Effects
Guild Breadth	WS_AREA	0.347	0.322	*	0.322	0.025
• ² = 179.469	FOR_WS_01	-0.023	*	0.059	0.059	-0.082
reduced	URB_WS_01	-0.215	*	*	*	*
	LWD	0.261	0.222	*	0.222	0.039
• ² = 316.768	WS_AREA	0.347	0.296	*	0.296	0.051
full	FOR_WS_01	-0.023	*	*	*	*
	URB_WS_01	-0.215	*	-0.053	-0.053	-0.162
	FOR_WS_D	0.032	*	0.076	0.076	-0.044
	AG_WS_D	-0.283	-0.247	*	-0.247	-0.036
	LWD	0.261	0.219	*	0.219	0.042
Shannon Diversity	FOR_WS_01	0.225	*	0.131	0.131	0.094
• ² = 177.430	URB_WS_01	-0.142	*	*	*	*
reduced	COARSE_ORG	0.381	0.255	*	0.255	0.126
	LWD	0.369	0.224	*	0.224	0.145
• ² = 320.173	FOR_WS_01	0.225	*	0.072	0.072	0.153
full	URB_WS_01	-0.142	*	-0.055	-0.055	-0.087
	FOR_WS_D	0	*	0.078	0.078	-0.078
	COARSE_ORG	0.381	0.256	*	0.256	0.125
	LWD	0.369	0.226	*	0.226	0.143
Richness	WS_AREA	0.525	0.496	*	0.496	0.029
• ² = 176.271	FOR_WS_01	0.017	*	0.079	0.079	-0.062
reduced	URB_WS_01	-0.049	*	*	*	*
	LWD	0.356	0.298	*	0.298	0.058
• ² = 314.429	WS_AREA	0.525	0.496	*	0.496	0.029
full	FOR_WS_01	0.017	*	0.103	*	*
	URB_WS_01	-0.049	*	-0.072	-0.072	0.023
	FOR_WS_D	-0.014	*	*	0.103	-0.117
	LWD	0.356	0.299	*	0.299	0.057
Endemic Abundance	FOR_WS_01	-0.096	0.215	*	0.215	-0.311
• ² = 218.335	URB_WS_01	0.019	*	*	*	*
reduced	AG_WS_01	0.259	0.404	*	0.404	-0.145
• ² = 353.941	FOR_WS_01	-0.096	*	*	*	*
full	URB_WS_01	0.019	*	*	*	*
	FOR_WS_D	0.377	0.312	*	0.312	0.065
	AG_WS_D	-0.354	-0.281	*	-0.281	-0.073

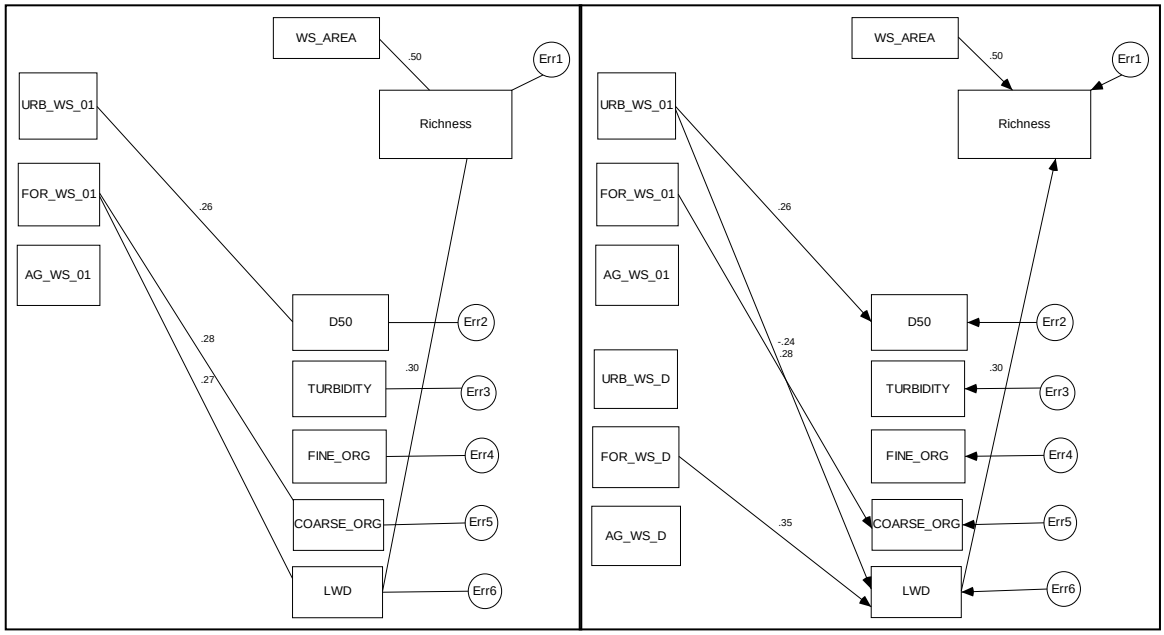

Figure 1. Reduced and full path analysis models for Richness. Significant relationships ($p \leq 0.5$) indicated by solid lines between variables. Standardized strength and direction of relationships indicated.

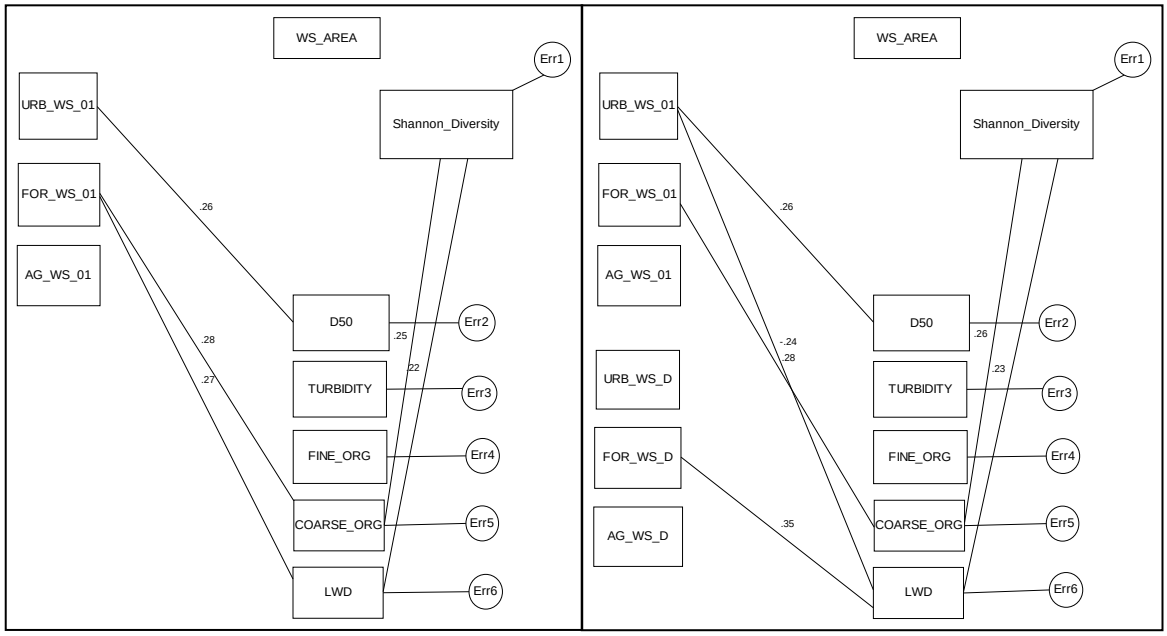

Figure 2. Reduced and full path analysis models for Shannon diversity. Significant relationships ($p \leq 0.5$) indicated by solid lines between variables. Standardized strength and direction of relationships indicated.

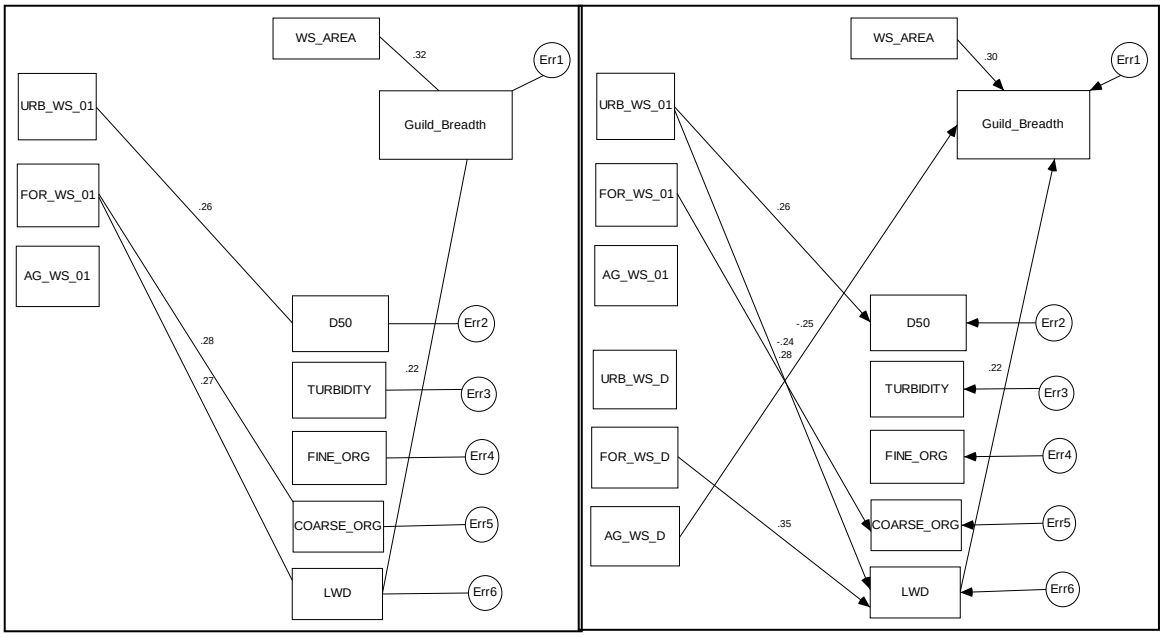

Figure 3. Reduced and full path analysis models for Guild Breadth. Significant relationships ($p \leq 0.5$) indicated by solid lines between variables. Standardized strength and direction of relationships indicated.

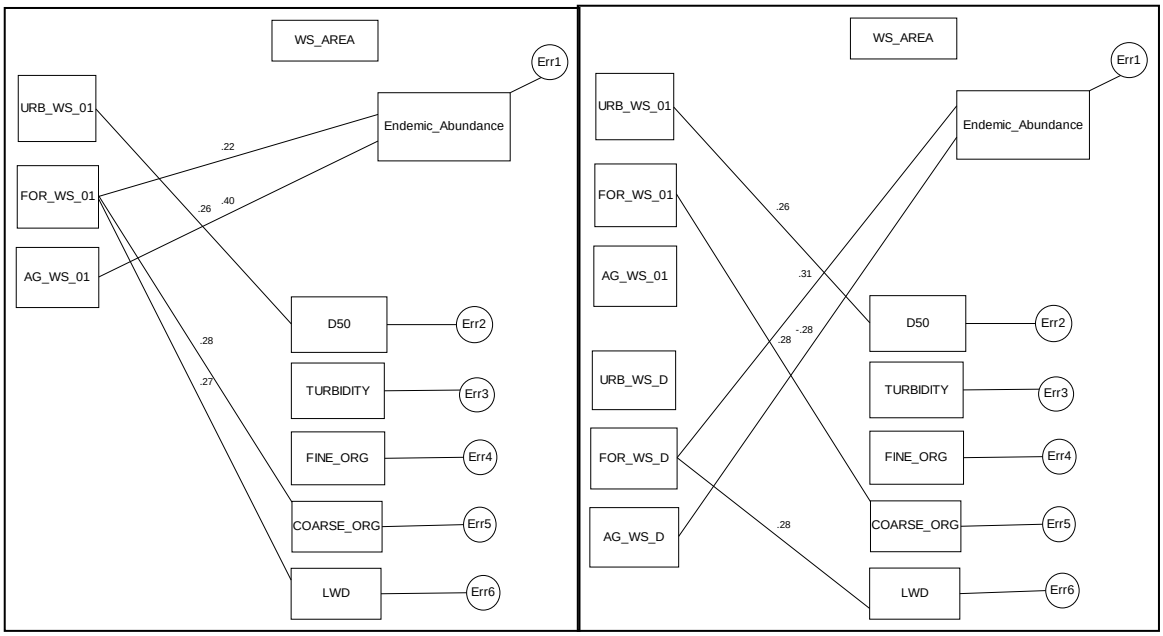

Figure 4. Reduced and full path analysis models for Endemic Abundance. Significant relationships ($p \leq 0.5$) indicated by solid lines between variables. Standardized strength and direction of relationships indicated.

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Job Title: Twelvmile Creek Dam Removal Monitoring

Period Covered January 1, 2009 through December 31, 2009

Introduction

Few studies on the ecological effects of dam removal have been conducted in North America due to the lack of opportunity, particularly in the Southeast. An opportunity has been presented with the removal of two dams on 12-Mile Creek, Pickens County, as part of the Schlumberger settlement. The project should provide information on a series of questions:

1) How do environmental factors and biological communities in the impounded (i.e., "lake-like") reaches differ from those found in free-flowing sections of 12Mile Creek?

2) What are the effects of dam removal on downstream channel dimensions, biological communities, and water quality?

3) How long does it take for the geomorphology, water quality, and biological community in the impounded reaches to recover to a typical stream ecosystem?

The objective of this investigation is to document changes in the 12-Mile Creek aquatic ecosystem before and after removal of the Woodside I and II dams. This report will detail fish collections and water quality parameters measured at the time of fish collections (temperature, dissolved oxygen, pH, conductivity, and turbidity) in 2006 and 2009, two samples that were taken prior to work commencing on removing the dams.

Methods

Eight sampling stations were established for geomorphic, water quality, and biological community monitoring. Six stations are located on Twelve-Mile Creek, distributed as follows: 1) the alluvial stream section downstream of Woodside II dam (near Maw Bridge), 2) the bedrock-constrained stream section downstream of Woodside II dam (at Lay Bridge), 3) the impounded area above Woodside II dam, 4) the flowing stream section downstream of Woodside I dam, 5) the impoundment above Woodside I dam, and 6) a reference station in the flowing section upstream of the Easley-Central Water District Reservoir (at Robinson Bridge). Two stations are located in nearby Three and Twenty Creek, a stream system that is similar in physiography and drainage area but without major mainstem dams. The two Three and Twenty Creek reference stations are located a similar distance apart as the extreme downstream and upstream Twelve-Mile stations and will be monitored concurrently with the Twelve-Mile Creek stations to document variation in aquatic variables longitudinally and over time in a system not undergoing dam removal. Sampling commenced prior to dam removal, will be repeated three times per year for the first three years after dam removal, and repeated once each year thereafter for two more years, for a total of 96 sampling events (eight stations x twelve sample periods). The impoundment above Woodside II dam was not sampled in 2006 due to access problems. Sampling focuses on measurements in four categories of aquatic ecosystem variables: channel geomorphology, water quality, aquatic invertebrates, and fishes.

Fishes were collected within 300m segments at each station with a standardized effort using electrofishing gear and seines. Backpack electrofishers and seines were used in wadeable stream segments to sample a standard area of 15 m^2. A boat-mounted electrofishing rig was used

in deeper impounded segments. All fishes encountered were collected, field identified to species level, photo-vouchered, and released.

Results and Discussion

Results of water quality measurements taken at the time of fish sampling in 2006 and 2009 are found in Tables 2 and 3, respectively. Dissolved oxygen levels predictably were higher in 2006 than in 2009, as sampling took place during October through December and water temperatures ranged from 4.4 – 11.8°C. In contrast, 2009 water temperatures ranged from 19.8 – 25.9°C during the August – September sampling. Nonetheless, dissolved oxygen levels were near 8 mg/L at the Twelvemile Creek (12MI) stations and slightly less at the Three and Twenty Creek (3&20) stations. Conductivities were between 35 and 52 µs/cm in 2006, and most stations were slightly elevated in 2009. Hydrologically, 2006 was a drought year while rainfall in 2009 was above normal, which may have had some effect on differences between years. Range for pH from both years was 6 – 7.6, and tended to be lower in 2009. Turbidities were higher at most stations in 2009, but overall ranged from 3.5 NTU in 2006 to 27.7 NTU in 2009.

Habitat variables measured at the time of fish sampling in 2006 and 2009 are found in Tables 4 and 5, respectively. Average depth at the stations remained within a fairly tight range (0.35 – 0.56 m) between years (habitat measures were not taken at impounded stations in 2006). Average flow velocities at most stations were slightly lower in 2009 compared to 2006, particularly 3&20 sites, ranging from 0.19 – 0.48 m^3/s. Interestingly, average wetted width tended to decrease at 12MI stations from 2006 to 2009 whereas width increased at 3&20 sites.

Fish sampling in 2006 resulted in collection of 962 individuals representing 21 species (Table 6). The catch was numerically dominated by a conservation priority species, turquoise darter, and was followed in abundance by another priority species, rosyface chub. Overall,

conservation priority species comprised 35% of the total fish collection, nearly all of them found at 12MI sites. One non-native species, green sunfish, was collected in 2006 at 12MI and 3&20 stations. Collections in 2009 resulted in 1,337 individuals from 27 species (Table 7). This year the catch shifted to predominantly spottail shiners followed by bluehead chubs, with far fewer turquoise darters and rosyface chubs encountered. Conservation species comprised only 8% of total collections in 2009. Two non-native species were collected, green sunfish and flathead catfish, the latter at the lower 12MI station closest to Lake Hartwell.

The sampling events from 2006 and 2009 will serve as benchmarks for comparison as dam removal activities commence and ramp up in 2010 and beyond. Although some variation exists due to interannual variation in climate and precipitation patterns, as well as watershed differences between 12MI and 3&20 stations, the variation in the pre-dam removal data will allow us to assess the magnitude of impact due to project activities. After dam removal is completed, further sampling is intended to document the duration of impacts and time to recovery in the system.

Table 1. The eight stations sampled in 2006 and 2009 prior to dam removal activities.

SITE	Sample Date 2006	Sample Date 2009	Latitude	Longitude
ROBINSON BR	25-Oct-2006	18-Aug	34.78079	-82.75465
WOODSIDE1 ABOVE	11-Dec-2006	19-Aug	34.77456	-82.77877
WOODSIDE1 BELOW	30-Oct-2006	20-Aug	34.7717	-82.77998
WOODSIDE2 ABOVE	na	2-Sep	82.79163	-82.76583
WOODSIDE2 BELOW	31-Oct-2006	19-Aug	34.76262	-82.79202
LOWER RIVER	11-Dec-2006	19-Aug	34.75367	-82.79219
3&20 LAFRANCE	7-Dec-2006	18-Aug	34.60878	-82.76286
3&20_BURNS_BR	7-Dec-2006	18-Aug	34.58987	-82.78222

Table 2. Water quality measured at sample stations in 2006.

SITE	Temperature (°C)	D.O. (mg/L)	Conductivity (µs/cm)	pH	Turbidity (NTU)
12MI_ROBINSON_BR	10.7	10.58	37	6.61	6.87
12MI_WOODSIDE1_ABOVE	4.44	13.3	41	7.61	4.86
12MI_WOODSIDE1_BELOW	11.7	11.03	35	6.9	9.33
12MI_WOODSIDE2_ABOVE	-	-	-	-	-
12MI_WOODSIDE2_BELOW	11.82	10.87	37	7.1	7.84
12MI_LOWER	5.5	13.38	45	7.56	3.54
3&20_LAFRANCE	8.25	11.53	52	7.22	9.64
3&20_BURNS_BR	7.19	11.47	44	6.66	12.91

Table 3. Water quality measured at sample stations in 2009.

SITE	Temperature (°C)	D.O. (mg/L)	Conductivity (µs/cm)	pH	Turbidity (NTU)
12MI_ROBINSON_BR	23.66	7.90	43	6	27.66
12MI_WOODSIDE1_ABOVE	25.89	8.50	54	6.83	10.69
12MI_WOODSIDE1_BELOW	24.31	8.80	53	6.7	9.22
12MI_WOODSIDE2_ABOVE	19.85	8.26	50	7.56	9.37
12MI_WOODSIDE2_BELOW	24.43	8.51	52	6.87	10.58
12MI_LOWER	23.72	8.37	51	6.5	10.92
3&20_LAFRANCE	24.36	6.84	65	6.4	15.74
3&20_BURNS_BR	24.06	7.15	92	6.5	16.81

Table 4. Habitat variables measured at each station in 2006.

SITE	Avg. Depth (m)	SD Depth	Avg. Velocity (m^3/s)	SD Velocity	Avg. Width
12MI_ROBINSON_BR	0.54	0.17	0.41	0.29	20.6
12MI_WOODSIDE1_ABOVE	-	-	-	-	-
12MI_WOODSIDE1_BELOW	0.56	0.22	0.47	0.46	25.58
12MI_WOODSIDE2_ABOVE	-	-	-	-	-
12MI_WOODSIDE2_BELOW	0.54	0.26	0.38	0.31	24.28
12MI_LOWER	0.44	0.22	0.34	0.16	-
3&20_LAFRANCE	0.39	0.16	0.43	0.26	11.38
3&20_BURNS_BR	0.43	0.21	0.31	0.18	18.88

Table 5. Habitat variables measured at each station in 2009.

SITE	Avg. Depth (m)	SD Depth	Avg. Velocity (m^3/s)	SD Velocity	Avg. Width
12MI_ROBINSON_BR	0.47	0.15	0.36	0.13	18.60
12MI_WOODSIDE1_ABOVE	0.52	0.29	0.07	0.05	13.10
12MI_WOODSIDE1_BELOW	0.47	0.18	0.41	0.29	19.30
12MI_WOODSIDE2_ABOVE	0.40	0.26	0.10	0.09	45.00
12MI_WOODSIDE2_BELOW	0.42	0.16	0.48	0.29	18.40
12MI_LOWER	0.47	0.18	0.30	0.09	24.13
3&20_LAFRANCE	0.35	0.17	0.21	0.20	19.70
3&20_BURNS_BR	0.41	0.17	0.19	0.16	33.50

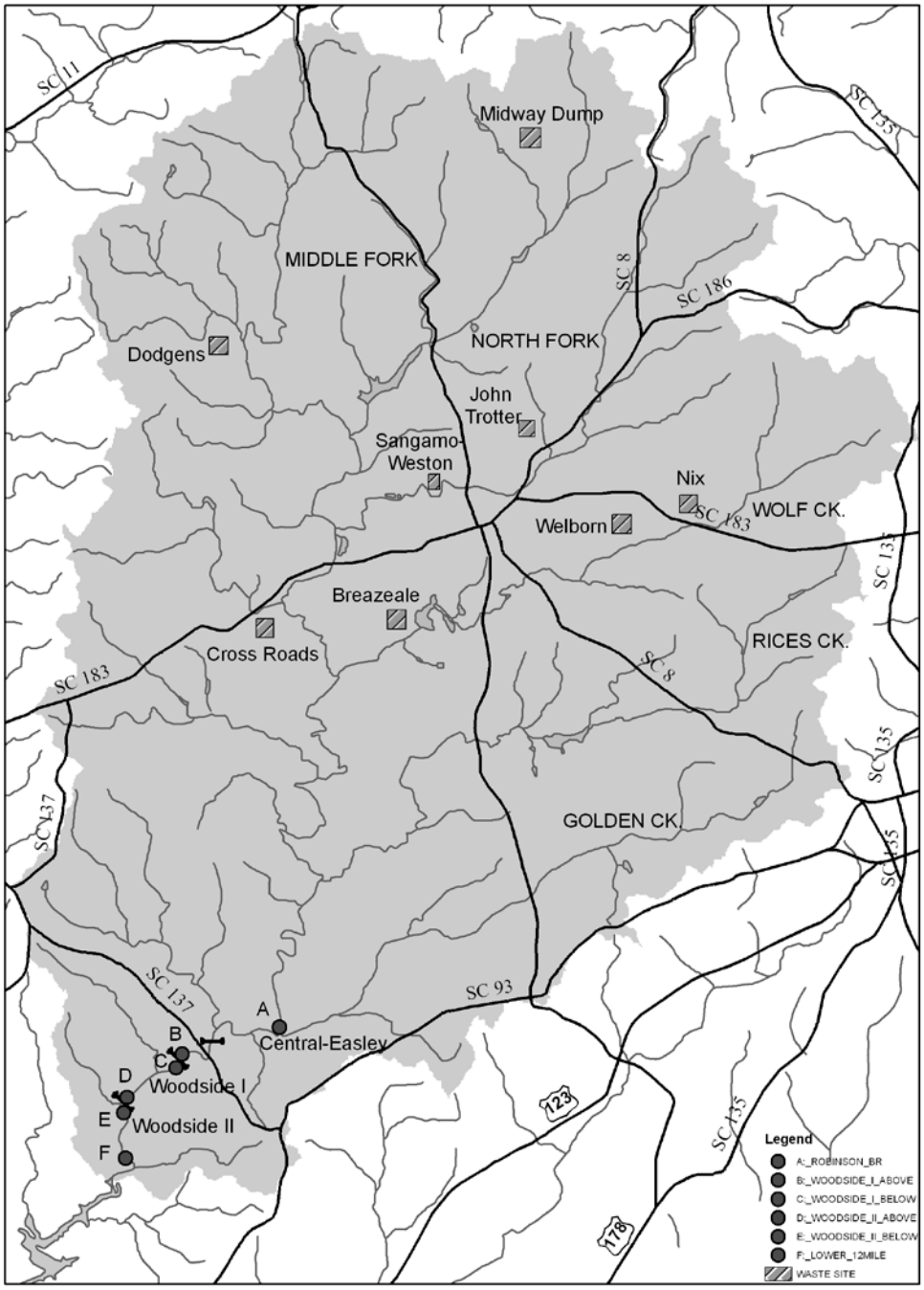
Table 6. Fish species and number collected at each station in 2006.

Species	Site	Robinson Bridge	Woodside1 Above	Woodside1 Below	Woodside2 Below	12MI Lower	3&20 LaFrance	3&20 Burns Bridge	Total
BBD		18	1	36	40	25	6	1	127
BHC		14	0	17	14	20	9	26	100
BLG		3	3	1	4	11	8	8	38
CHP		0	0	0	0	0	1	0	1
FBH		0	0	1	1	0	0	1	3
GSF		4	0	2	0	4	0	1	11
LMB		0	2	0	0	3	0	0	5
MGM		10	0	6	4	0	2	10	32
NHS		13	6	48	10	30	3	5	115
NLR		0	1	1	4	0	0	0	6
RBS		0	1	3	1	4	1	1	11
REB		0	0	1	0	1	0	0	2
RES		0	0	0	0	1	0	0	1
RFC		5	7	47	0	76	0	2	137
SBH		3	0	5	1	0	3	2	14
SPM		0	0	0	0	0	2	0	2
STJ		0	0	0	0	0	1	1	2
STS		0	0	0	14	0	1	0	15
TQD		50	0	82	39	8	0	0	179
WFS		6	4	10	13	46	0	1	80
YFS		3	5	39	17	10	3	4	81
Total collected		129	30	299	162	239	40	63	962
Richness		11	9	15	13	13	12	13	21

Table 7. Fish species and number collected at each station in 2009.

Species	Site	Robinson Bridge	Woodside1 Above	Woodside1 Below	Woodside2 Above	Woodside2 Below	12MI Lower	3&20 LaFrance	3&20 Burns Bridge	Total
BBD		32	0	44	0	23	5	19	49	172
BHC		21	5	33	4	20	3	38	106	230
BLC		0	0	0	0	1	0	0	0	1
BLG		5	6	1	16	13	13	15	11	80
CCF		0	0	0	0	0	9	0	0	9
FBH		3	1	2	1	0	0	3	0	10
FCF		0	0	0	0	0	1	0	0	1
GSF		0	0	0	0	7	4	0	1	12
LMB		0	6	0	5	21	7	4	11	54
MGM		0	0	6	0	2	0	4	10	22
MSQ		0	1	0	0	0	0	0	0	1
NHS		7	0	16	0	7	5	12	28	75
NLR		0	0	0	2	0	1	0	0	3
RBS		1	40	3	35	2	8	37	18	144
REB		2	0	1	0	7	4	0	4	18
RES		0	0	0	4	0	1	0	1	6
RFC		6	0	0	0	0	0	7	0	13
SBH		3	0	14	4	0	1	0	6	28
SPM		0	0	0	0	0	0	2	0	2
STJ		0	0	2	0	0	1	4	0	7
STS		0	0	3	0	384	52	55	76	570
TQD		0	0	38	0	15	0	0	0	53
WAR		0	0	0	0	1	0	0	0	1
WFS		5	0	6	8	39	38	0	3	99
WHS		0	0	0	0	0	0	0	1	1
YFS		5	0	59	0	19	0	82	60	225
YLP		0	0	0	0	0	0	1	1	2
Total collected		90	59	228	79	561	153	283	386	1337
Richness		7	3	10	6	11	12	10	13	27

Figure 1 Map of Twelvemile Creek drainage (shaded) showing the existing dams and locations of sampling stations.



Recommendations

- Continue standardized sampling according to schedule at Twelvemile Creek and Three and Twenty Creek to provide a multi-year record of aquatic resource conditions during and after removal of Woodside I and Woodside II dams on Twelvemile Creek.

Literature Cited

SCDNR. 2005. South Carolina's Comprehensive Wildlife Conservation Strategy. URL as of 1/31/09 http://www.dnr.sc.gov/cwcs/index.html

Prepared By: Mark Scott and Cathy Marion

Title: Fisheries Biologists

Job Title:	Preliminary population estimates for blackbanded sunfish in South Carolina
Period Covered	January 1, 2009 through December 31, 2009

Results and Discussion

How Rare is "Rare"?: A Conservation Ranking System for South Carolina Stream Fishes

One of the objectives of the South Carolina Stream Assessment (SCSA) is the development of standardized estimates of stream resource parameters, including physical, chemical, and biological variables measured at SCSA sampling sites (Scott 2008). Methods for the computation of standardized resource estimates are provided in K. Kubach Annual Report (2008), along with a preliminary analysis of selected variables for three large Coastal Plain ecobasins.

Information on the distribution and abundance of fish and wildlife species is a required element of the South Carolina Comprehensive Wildlife Conservation Strategy (CWCS; SCDNR 2005) and a fundamental component of natural resource conservation at any scale. Currently, the CWCS employs a categorical conservation ranking system in which Priority species are assigned to one of three Priority levels: Highest, High, or Moderate. For freshwater fishes, this Conservation Priority status is based primarily on the expertise of biologists and other taxonomic authorities in conjunction with quantitative data from existing surveys and studies. For the majority of non-game species in particular, existing information is usually limited in geographic scope, focusing on a particular river system or even a politically defined region of the state. Furthermore, sampling methods and reporting formats may vary widely from study to study, precluding accurate comparisons of species abundance across regions. The quantitative and standardized estimation of species rarity provided by the SCSA—in terms of both frequency of

occurrence and relative abundance—will enhance our ability to objectively assess conservation status and appropriately manage ecosystems and habitats.

The blackbanded sunfish (*Enneacanthus chaetodon*) is a small centrarchid distributed primarily on the Atlantic Coastal Plain from New Jersey to Florida and in portions of the Gulf slope in Florida and Georgia (Rohde et al. 2009). While the range of historical collection localities for *E. chaetodon* spans most of the inner Coastal Plain of South Carolina (Rohde et al. 2009), relatively few recent specimens have been collected despite widespread stream sampling across its range in South Carolina (Scott, Kubach, and Poly unpubl. data). Where collected, it is usually low in abundance (W. Poly unpubl. data). *E. chaetodon* populations have recently declined or become highly restricted geographically in other parts of its range, such as in Maryland (Kilian et al. 2009). In South Carolina it is currently considered a species of High priority in the CWCS (SCDNR 2005). The current uncertainty regarding the distribution and abundance of this species makes *E. chaetodon* an ideal candidate for an analysis of standardized abundance estimates in order to assess conservation status.

Standardized abundance estimates for *E. chaetodon* were generated using data from 145 SCSA sites in 10 coastal plain ecobasins sampled between 2006 – 2009 (Table 1). *E. chaetodon* was rarely encountered, occurring in only 4 of 145 sites (2.8%). Among sampled ecobasins, the proportion of sites at which *E. chaetodon* was collected ranged from 0% (7 ecobasins) to 25% (Savannah basin/Sand Hills ecoregion). Mean abundance of *E. chaetodon* across the coastal plain was 0.6 per km (95% CI = 0 – 1.2). The Savannah basin/Atlantic S. Loam Plains ecoregion produced the highest mean abundance at 8.8 per km (0 – 26.5), although this reflects a single site at which the species was present.

By generating similar statistics for all SC fishes, we will have an objective means of evaluating rarity in wadeable streams across the state. Note that for species with preferred habitats outside of wadeable streams, such as wetlands or rivers, these estimates will be biased. A sampling regime focusing on these habitats is warranted if we are to develop a comprehensive assessment of fish species rarity.

Table 1. Abundance and occupancy estimates for *Enneacanthus chaetodon* (blackbanded sunfish) from SCSA coastal plain sites, 2006 – 2009.

Scale	**Number of Sites Sampled**	**Number of Sites Occupied**	**Proportion of Sites Occupied**	**Mean Abundance (per km)**	**95% CI Lower**	**95% CI Upper**
Ecobasin						
SAVASLP	5	1	20.0%	**8.8**	0	26.5
SAVSAND	8	2	25.0%	**4.3**	0	12.3
CWASLP	5	1	20.0%	**2.7**	N/A	N/A
SAVFLATW	5	0	0.0%	**0.0**		
CWSAND	6	0	0.0%	**0.0**		
ACEFLATW	40	0	0.0%	**0.0**		
LSFLATW	6	0	0.0%	**0.0**		
PDASLP	29	0	0.0%	**0.0**		
PDFLATW	38	0	0.0%	**0.0**		
SALSAND	3	0	0.0%	**0.0**		
River Basin						
Savannah	18	3	16.7%	**3.7**	0	8.4
Catawba/Wateree	11	1	9.1%	**0.8**	0	2.3
Saluda	3	0	0.0%	**0.0**		
ACE	40	0	0.0%	**0.0**		
Lower Santee	6	0	0.0%	**0.0**		
Pee Dee	67	0	0.0%	**0.0**		
Coastal Plain	**145**	**4**	**2.8%**	**0.6**	**-0.1**	**1.2**

Recommendations

Continue generating population estimates for fish species in wadeable streams from South Carolina Stream Assessment data to develop a conservation ranking system based on frequency occurrence and abundance.

Literature Cited

Kilian, J. V., S. A. Stranko, R. L. Raesly, A. J. Becker, and P. Ciccotto. 2009. *Enneacanthus chaetodon* (Blackbanded Sunfish): an imperiled element of Maryland's coastal plain ichthyofauna. Southeastern Naturalist 8: 267-276.

Rohde, F. C., R. G. Arndt, J. W. Foltz, and J. M. Quattro. 2009. Freshwater Fishes of South Carolina. The University of South Carolina Press, Columbia. 430 pp.

Scott, M. C. 2008. A probabilistic stream assessment to support freshwater conservation: preliminary results from the coastal plain. Proceedings of the 2008 South Carolina Water Resources Conference.

Prepared By: Kevin Kubach and Mark Scott

Title: Fisheries Biologists

Job Title: Assessing introgressive hybridization within and habitat requirements of native South Carolina redeye bass

Period Covered January 1, 2009 – December 31, 2009

Results and Discussion

In the last year calmodulin sequences previously generated for 152 black bass collected from stream sites, and for 635 black bass collected from lakes Jocassee, Keowee, Hartwell, and Russell, were added to our data base. This provided three nuclear and one mitochondrial locus, which were used to identify all collected fish to species or to hybrid status (Table 1). The addition of calmodulin to the database increases our ability to identify backcrossed individuals. As a result, the number of hybrids identified from each reservoir population increased by 15-65% from those reported in 2008.

Two additional hybrids were identified from stream samples. Both were collected from the upper site on Little River near where it flows into Lake Keowee. This site is above a natural barrier. Previous analysis had indicated that while 93% of fish collected below that barrier were hybrids, only pure redeye bass were collected above. All other stream collection results from 2004-2005 remain unchanged (Table 2).

New reservoir and stream black bass collections were made in the last year (Table 3), primarily for the purpose of comparing species composition with results from the 2004 survey. For all fish collected, total length and weight was recorded, photographs were taken, and fin clips were taken and stored in ethanol. On June 24 and 25, 2009, 142 black bass were collected from Lake Russell. However, these fish were collected considerably later in the year than those in 2004, which were taken beginning in March and ending in May. Because of the potential for a seasonal effect on species composition, Lake Russell samples were set aside and it was decided

to wait until Spring 2010 to sample all four lakes. Collections were made in the last year at 9 stream sites in the Savannah and Santee drainages. One fish from the Oolenoy River was collected during routine Stream Team sampling, and was taken to confirm species identification, as redeye bass were not expected this high in the Santee drainage. One fish from Savannah River at Augusta Shoals was collected by an angler and turned in for species identification. All other collections are from sites that were also sampled in 2004. All stream samples are stored pending genetic analysis.

Table 1. Proportion of black bass collected by species and hybrid categories, for 4 reservoir populations. Maternal lineage is included for hybrids only. REB = redeye bass, ASB = Alabama bass, SMB = smallmouth bass, LMB = largemouth bass.

		Reservoir			
Species	Maternal Lineage	Jocassee N=127	Keowee N=164	Hartwell N=201	Russell N=143
REB		.38	-	.22	.02
LMB		.20	.32	.37	.44
SMB		.11	-	-	-
ASB		.01	.15	-	.13
F1 ASBxREB	ASB	-	.01	-	.05
F1 ASBx REB	REB	.04	-	-	.01
Bx ASBxREB	ASB	.04	.21	.01	.14
Bx ASBxREB	REB	.20	.16	.30	.14
Bx ASBxLMB	ASB	-	.02	.01	.01
Bx ASBxLMB	LMB	-	.06	.06	-
Bx REBxSMB	SMB	.02	-	-	-
Bx REBxSMB	REB	-	-	-	-
Bx REBxLMB	LMB	-	-	.01	-
Bx REBxLMB	REB	-	-	.005	.01
Bx ASBxLMBxREB	ASB	-	.01	-	.01
Bx ASBxLMBxREB	LMB	-	.01	.005	-
Bx ASBxLMBxREB	REB	-	.05	-	.03

Table 2. Redeye bass and hybrid collections from stream populations in 2004-2005, as identified by genetic analysis; REB = redeye bass, ASB = Alabama bass, SMB = smallmouth bass.

		N		
Site	Drainage	REB	REBxASB	REBxSMB
Chatooga	Savannah	19	0	0
Chauga-Upper	Savannah	15	0	0
Chauga-Lower	Savannah	13	0	0
Eastatoee	Savannah	12	0	0
Horse Pasture	Savannah	6	0	0
Toxaway	Savannah	2	0	2
Little River-Upper	Savannah	10	2	0
Little River-Lower	Savannah	1	13	0
Big Generostee	Savannah	11	0	0
Little Coldwater Creek	Savannah	12	0	0
Steven's Creek	Savannah	19	0	0
Savannah River-Augusta Shoals	Savannah	15	0	0
Saluda River-Pelzer	Santee	18	0	0

Table 3. Black bass collected in 2009. Number collected (N) by species is based on field identification; REB = redeye bass, ASB = Alabama bass, LMB = largemouth bass, SMB = smallmouth bass.

			N				
Site	Drainage	Col. Date(s)	REB	ASB	LMB	SMB	Hybrid
Lake Russell	Savannah	June 24, 25	0	26	72	0	44
Steven's Creek	Savannah	July 29	15	0	6	0	0
Big Generostee Creek	Savannah	July 30	16	0	0	0	0
Saluda River at Pelzer	Santee	Sept. 9	17	0	9	0	0
Chauga River (lower)	Savannah	Sep. 14, 29	14	0	6	0	0
Chauga River (upper)	Savannah	Sep. 29	15	0	0	0	0
Chatooga River	Savannah	Sep. 29	2	0	0	0	0
Little River (upper)	Savannah	Sep. 30	4	1	0	0	2
Oolenoy River	Santee	Jul. 23	1	0	0	0	0
Savannah River	Savannah	Jan. 4	0	0	0	1	0

Work in the laboratory has focused on the development of new genetic assays. New assays for each of the four loci studied will be used to determine specific and hybrid status in all

collections made after 2005. These assays will be markedly faster and less expensive than the direct sequencing we have used to date. Assays for the mtDNA locus ND2 were successfully developed, using the program Web-based Allele-Specific Primers (WASP) by Pongsakorn et al. (2007). Primers were designed for haplotypes specific for the five species of black bass present or having genetic influence in South Carolina; largemouth bass, Florida bass, Alabama bass, redeye bass, and smallmouth bass (Figure 1).

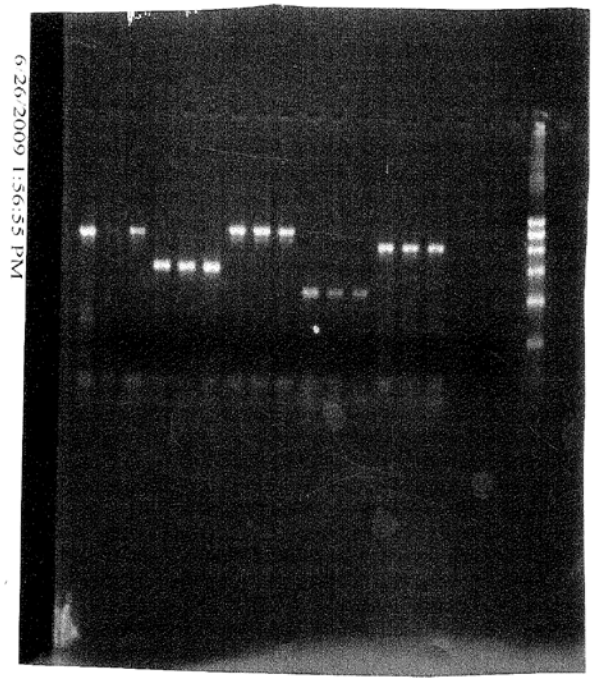


Figure 1. Agarose gel run to confirm diagnostic differences in fragment lengths, in base pairs (bps), for ND2 assays for five black bass species. In lanes 1-3 beginning on the left are Alabama bass (744 bps), 4-6 are smallmouth bass (432 bps), 7-9 are largemouth bass (800 bps), 10-12 are Florida bass (284 bps), and 13-15 are redeye bass (647 bps). A ladder of fragments of known bps is in the last lane.

Assay development will be completed for nuclear DNA loci in the coming year. New collections for reservoir and stream populations will be completed. All collected fish will be

identified to species or hybrid status using new assays, or a combination of new assays and sequencing. Results from 2009 – 2010 will be compared to results from the initial survey, and any expansion or new incidence of Alabama bass or hybrids will be documented. A GIS database will be developed that incorporates all genetic data. Site specific abiotic parameters contributing to presence of Alabama bass or hybrids will be examined.

Work from this and related efforts was invited for presentation at the Southeastern Endemic Black Bass symposium held at the 2009 annual meeting of the American Fisheries Society in Nashville, Tennessee. Three presentations were made. Stemming from participation in this symposium, our investigators were invited to assist in development of a new funding initiative proposal for National Fish and Wildlife Foundation (NFWF), targeting native black bass. During proposal development, redeye bass of the Savannah drainage were chosen as a keystone species for the initiative. A final draft of this initiative will be prepared for presentation to the NFWF board in March 2010.

Recommendations

Continue study. Complete assay development, field collections and genetic analyses as described. Develop GIS data base. Submit study efforts for publication.

Literature Cited

Wangkumhang, Pongsakorn, Kridsakorn Chaichoompu, Chumpol Ngamphiw, Uttapong Ruangrit, Juntima Chanprasert, Anunchai Assawamakin and Sissades Tongsima. 2007. WASP: a Web-based Allele-Specific PCR assay designing tool for detecting SNPs and mutations. BMC Genomics. 8:275.

Prepared By: Jean Leitner Title: Fishery Biologist

Job Title: Assessment of condition, growth, contribution to fish community, and diet of striped bass, white perch, and American shad young-of-the-year in the Santee-Cooper lakes, South Carolina

Period Covered January 1, 2009 – December 30, 2009

Results and Discussion

Juvenile morones and clupeids were collected at night from three Lake Marion sites with boat electrofishing during June – November 2009. The two upper lake sites, "State Park" and "Big Water", were located near I-95 on the Orangeburg and Clarendon County sides, respectively. The third site, "Indian Mound", was located midway down the reservoir on the Orangeburg County side. At least two transects were sampled at one or more sites on 8 different dates. Each site received approximately 0.5 h of electrofishing effort on each sample date. During 2009 forty transects were sampled with a total electrofishing effort of 7.33 h (Table 1). Due to the limited effort subsequent results will not be reported for the State Park site.

Table 1. Number of transects sampled on each date and electrofishing effort (h) during nighttime electrofishing at three sites on Lake Marion, SC.

	Big Water		Indian Mound		State Park		Total	
Date	Transects	Effort (h)	Transects	Effort (h)	Transects	Effort (h)	Transects	Effort (h)
6/10/2009	--	--	--	--	2	0.33	2	0.33
6/24/2009	--	--	4	0.91	--	--	4	0.91
6/30/2009	4	0.83	--	--	--	--	4	0.83
7/7/2009	3	0.45	3	0.43	--	--	6	0.88
7/21/2009	3	0.50	3	0.50	--	--	6	1.00
8/18/2009	3	0.50	3	0.50	--	--	6	1.00
9/15/2009	3	0.50	3	0.72	--	--	6	1.22
11/3/2009	3	0.65	3	0.50	--	--	6	1.15
Total	19	3.44	19	3.56	2	0.33	40	7.33

Overall white perch were the most abundant species representing 37% of all fish collected. American shad, striped bass and threadfin shad were common each accounting for roughly 20% of the fish collected and blueback herring were rare accounting for < 1% of all fish collected. Relative abundance of the target species varied by site and date. American shad and threadfin shad were a larger component of the sample at the Big Water site, where they accounted for more than 60% of all fish collected, than the Indian Mound site where those species represented only18% of all fish collected (Table 2). However, the majority of the threadfin shad collected at Big Water were collected on a single date. Overall, striped bass and white perch relative abundance was greater at the Indian Mound site than the Big Water site. However, striped bass relative abundance at the Indian Mound site was highest during the June sample and steadily declined throughout the summer. Striped bass relative abundance at the Big Water site was more consistent.

Table 2. Percent relative abundance of young of year fish species collected from two Lake Marion sites with night-time electrofishing during 2009. Young of the year fish species collected included American shad (AMS), blueback herring (BBH), striped bass (STB), threadfin shad (TFS) and white perch (WTP).

	Big Water					Indian Mound				
Date	AMS	BBH	STB	TFS	WTP	AMS	BBH	STB	TFS	WTP
6/24/2009	--	--	--	--	--	16.7	0.0	64.6	6.3	12.5
6/30/2009	23.5	0.6	2.8	70.3	2.8	--	--	--	--	--
7/7/2009	28.7	0.0	25.2	0.5	45.5	10.2	0.0	47.0	11.2	31.6
7/21/2009	37.7	0.0	36.7	0.0	25.6	0.0	0.0	41.3	0.0	58.7
8/18/2009	17.7	0.7	15.6	0.0	66.0	2.8	0.0	8.8	3.1	85.3
9/16/2009	62.5	0.0	16.5	0.0	20.9	12.8	0.0	6.1	19.5	61.6
11/3/2009	7.8	0.0	15.5	1.0	75.7	33.3	2.1	3.1	0.0	61.5
Grand Total	32.5	0.3	14.5	28.0	24.7	10.1	0.2	26.3	7.5	55.9

Catch per unit effort (CPUE) appeared to vary among species and dates, but high variation within sites precluded meaningful statistical comparisons. American shad CPUE

(No/h) ranged from 0 to 424 and appeared to be highest at Big Water (Table 3). Striped bass and white perch CPUE ranged from 0 to 359 and 0 to 544, respectively, and were similar between sites.

Table 3. Mean catch per unit effort (no/h), standard error in parentheses, for young of year American shad, striped bass, and white perch at each of two Lake Marion sites sampled with boat electrofishing during 2009.

	American shad		Striped bass		White perch	
Date	Big Water	Indian Mound	Big Water	Indian Mound	Big Water	Indian Mound
6/10/2009	--	--	--	--	--	--
6/24/2009	--	21 (13)	--	68 (22)	--	12 (9)
6/30/2009	227 (203)	--	14 (14)	--	14 (14)	--
7/7/2009	124 (33)	62 (21)	118 (33)	359 (165)	204 (99)	219 (83)
7/21/2009	150 (60)	0 (0)	146 (80)	86 (4)	102 (51)	122 (88)
8/18/2009	50 (33)	18 (0)	44 (2)	56 (19)	186 (40)	544 (186)
9/15/2009	424 (317)	29 (3)	112 (51)	10 (7)	142 (16)	134 (28)
11/3/2009	13 (7)	64 (37)	29 (22)	6 (6)	122 (11)	118 (54)
Mean	168 (65)	32 (8)	74 (19)	96 (36)	122 (23)	182 (50)

In late June American shad mean total length (TL) was 62.4 mm (SE = 1.20), American shad grew rapidly during July, but growth slowed during mid-summer (Figure 1). American shad reached a mean TL of 89.2 mm (SE = 1.07) by early November. In late June threadfin shad mean TL was 57.7 mm (SE = 0.94), threadfin shad grew steadily throughout the summer and reached 82.1 mm TL (SE = 0.50) by mid September (Figure 1). Growth of the two clupeid species did not appear to differ between sites.

In late June white perch mean total length was 51.5 mm (SE = 0.79), white perch grew steadily throughout the summer and attained mean total lengths of 85.4 mm (SE = 0.45) by early November (Figure 2). White perch appeared to have a growth advantage at the Indian Mound site where they were often a few mm larger than those captured at the Big Water site on the same date. Striped bass mean total length in late June was 82.7 mm (SE = 1.40) (Figure 2). Striped

bass did not appear to grow much during July, but grew steadily thereafter reaching a mean total length of 151.8 mm (SE = 6.14) by November. Unlike white perch, striped bass appeared to have a growth advantage at the Big Water site. Striped bass growth was significantly slower in 2009 than 2008 (Figure 3). Mean TL of striped bass collected in August 2008 was greater than 140 mm while those collected during August 2009 were less than 100 mm. Striped bass collected during 2009 did not attain August 2008 lengths until late October.

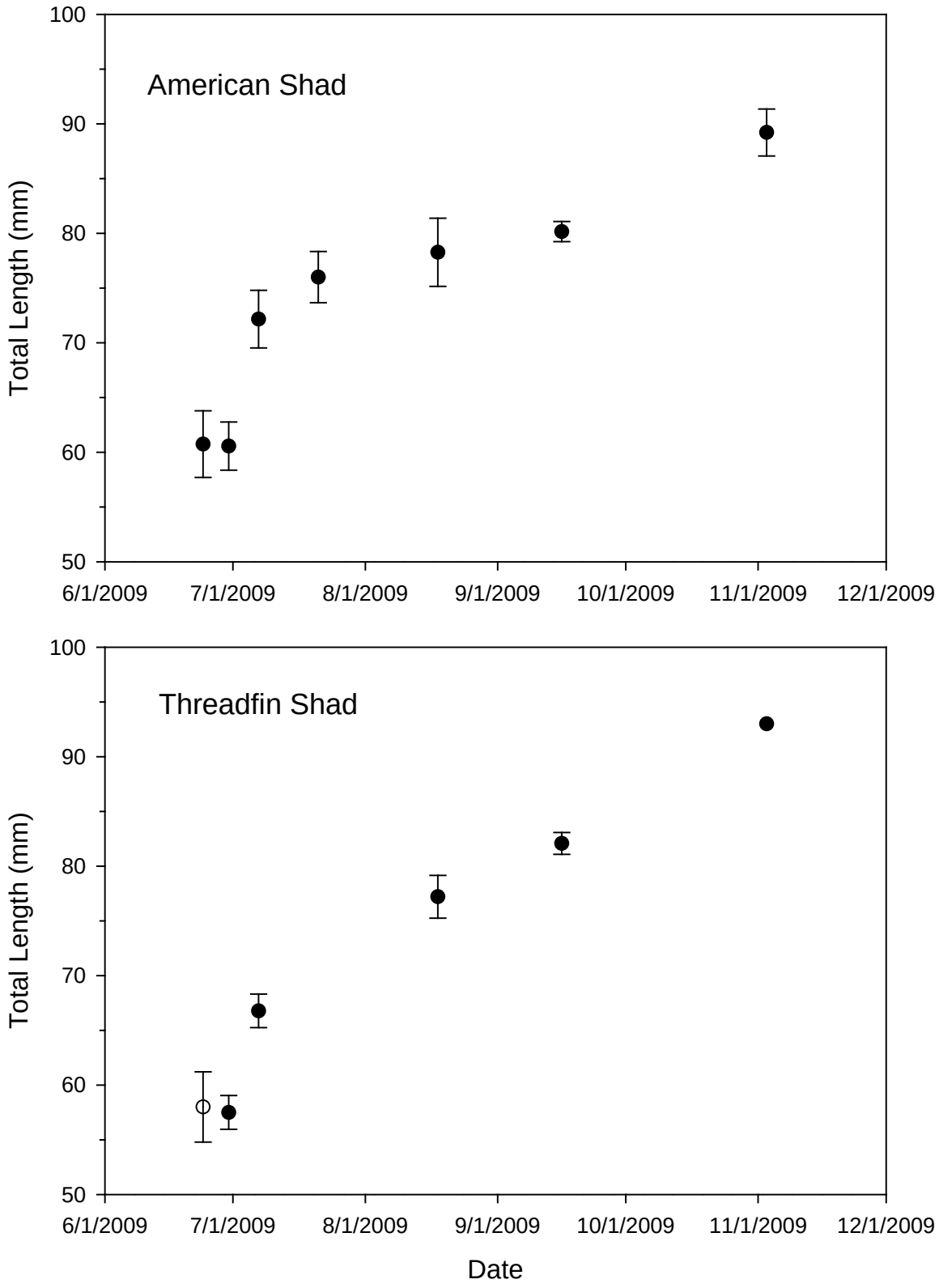


Figure 1. Mean total length (± 2 SE) of American shad and threadfin shad collected from Lake Marion, South Carolina during 2009.

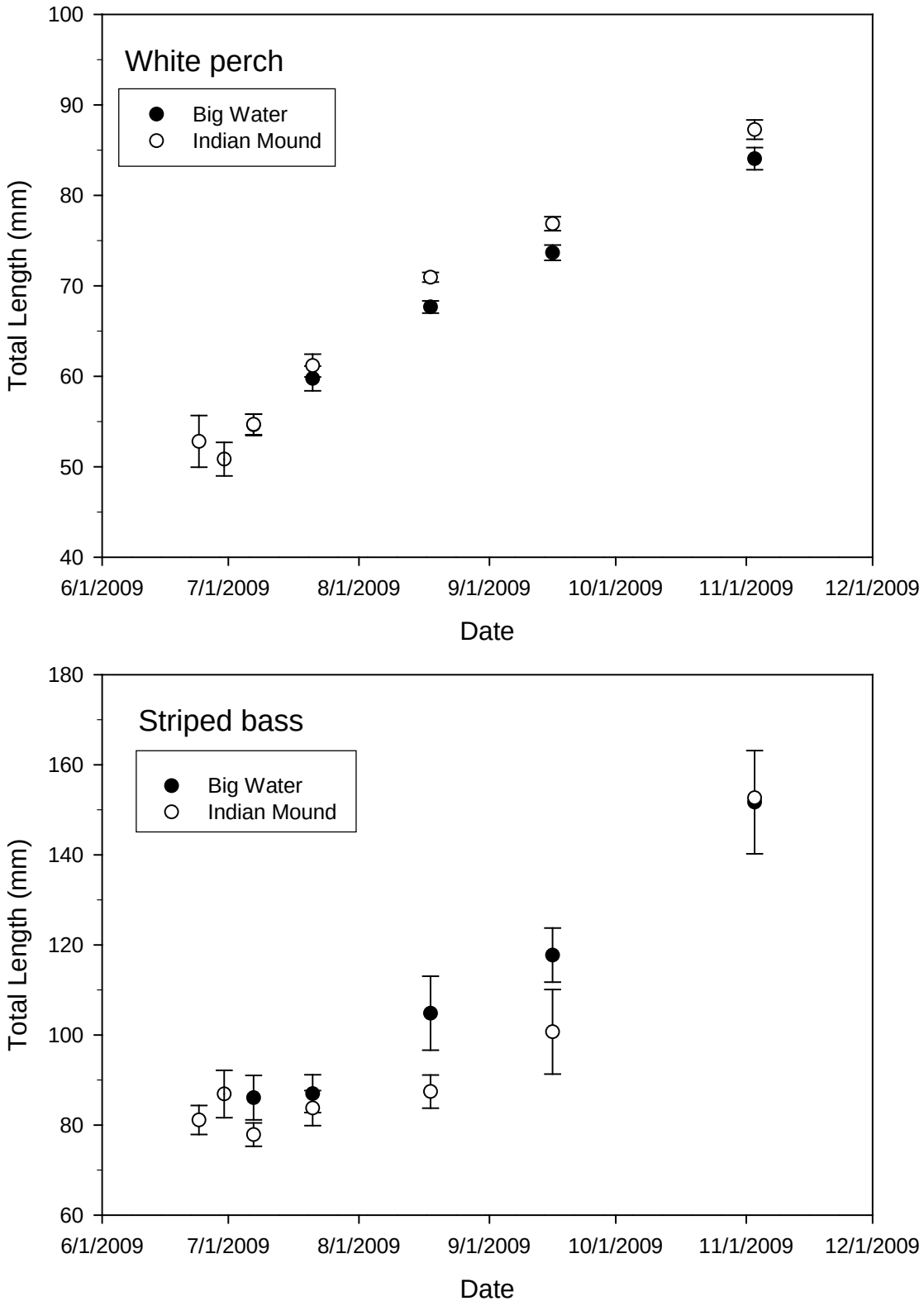


Figure 2. Mean total length (± 2 SE) of white perch and striped bass collected from Lake Marion, South Carolina during 2009.

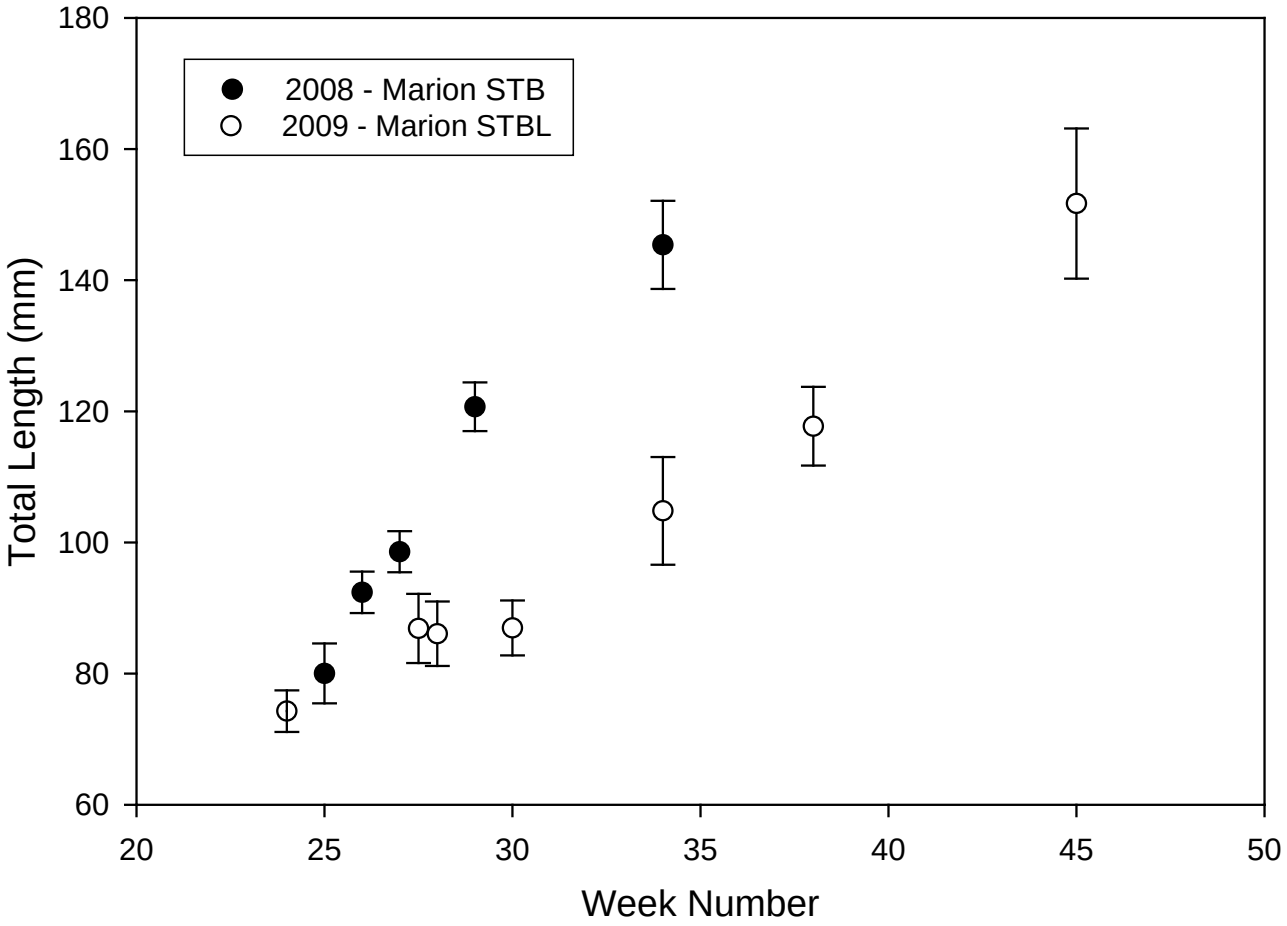


Figure 3. Mean total length (± 2 SE) of striped bass collected from the "Big Water" site on Lake Marion during summer 2008 and 2009.

Recommendations

Continue study as planned. Dry weights will be collected from a sample of each target fish species collected during 2009 to determine average energetic content as function of total length and to determine condition. Condition of striped bass collected during 2009 will be compared to similar data collected during a 2008 "pilot" study. Stomach contents of juvenile white perch, striped bass and American shad will be inspected to describe the diet of each species.

Prepared By: Jason Bettinger Title: Fisheries Biologist

Job Title:	Smallmouth bass stocking assessment – broad river lake jocassee, and lake robinson
Period Covered	January 1, 2009 – December 30, 2009

Results and Discussion

Broad River

We continued our study evaluating the SCDNR smallmouth bass stocking program. Otoliths from 354 smallmouth bass collected from the Broad River during 2008 were successfully reviewed for OTC marks to determine whether they were wild fish or hatchery stocked fish. Of the 76 age-0 fish collected and successfully reviewed for OTC marks only 5 were marked, each of those otoliths had a single mark indicating it was stocked in spring 2008 as a fry, the other 71 age-0 fish were presumably wild (Table 1). Otoliths from 206 age-1 fish were successfully reviewed for OTC marks, 188 of those fish were unmarked (wild), 12 were single marked (fry-stocked during spring) and 6 were double marked (fingerling-stocked during fall) (Table 1). The contribution of stocked fish to the 2007 year class one year post-stocking was less than 9%.

During October 2009 smallmouth bass were collected with angling gear from three river sections on 4 sampling days (Table 2). An unusually wet fall limited the number of "good" angling days, as a result smallmouth bass collections were augmented with 3 days of electrofishing on two river sections (Table 3). In all, 202 smallmouth bass were collected during 2009 and their otoliths were read whole to estimate their age (Table 4).

Table 1. Collection year, year class (YC) and the number of wild spawned, spring-stocked and fall-stocked smallmouth bass, based on differential OTC marks, collected from the Broad River, South Carolina.

Year	YC	Wild Fish	Spring Stocked	Fall Stocked	Number Reviewed
2006					
	2002	34			34
	2004	64			64
	2005	29	2	24	55
	2006	92	3		95
2007					
	2004	3			3
	2005	5			5
	2006	154	4	2	160
	2007	70	3		73
2008					
	2002	2			2
	2004	3			3
	2005	5			5
	2006	57	2	1	60
	2007	188	12	6	206
	2008	71	5		76

Table 2. River section sampled number of anglers, effort and CPUE (No/h) of smallmouth bass (SMB) collected from the Broad River with angling gear during October 2007 - 2009.

Date	River Section	No Anglers	Time Fished (h)	Total Effort (h)	SMB Collected	CPUE (no./h)
10/27/2009	Below Neal Shoals	4	6.5	26	56	2.15
10/28/2009	Below 99-islands	4	NA	NA	4	NA
10/2009	Below Gaston Shoals	NA	NA	NA	44	NA
11/9/2009	Below 99-islands	4	6.5	26	25	0.96
	2009 Total				**129**	**NA**

Table 3. River section sampled, electrofishing effort, number of smallmouth bass collected and catch per unit effort (CPUE) of smallmouth bass collected from the Broad River during Fall 2009.

Date	River section	Effort (h)	Catch	CPUE (no./h)
10/8/2009	Below Neal Shoals	2.07	28	13.5
10/28/2009	Below 99-islands	0.56	10	17.9
11/19/2009	Below Neal shoals	2.77	35	12.6
Total			73	13.5

Table 4. Age, number of smallmouth collected, mean total length (TL) mm, and standard error (SE) of smallmouth bass collected during fall 2009.

Age	Number	Mean TL	SE
0	9	140	4.4
1	98	222	2.9
2	71	263	4.8
3	22	325	10.7
4	1	408	

Lakes Jocassee and Lake Robinson

During 2008 eighteen smallmouth bass were collected from Lake Jocassee with boat electrofishing and 11smallmouth bass were collected with gillnetting. Nine smallmouth bass were collected from Lake Jocassee during 2009 with gillnetting and no fish were collected with boat electrofishing. Otoliths collected from Lake Jocassee smallmouth bass have not been processed. Lake Robinson was not sampled during 2009.

Marking Efficacy

During 2008 an estimated 8,500 smallmouth bass fry (mean TL = 46 mm) were stocked during spring at four locations and 5,000 smallmouth bass fingerlings (mean TL = 150 mm) were

stocked during fall at seven locations into the Broad River. All fish received a single OTC mark, during a single marking event, and fall-stocked fish received a second OTC mark before stocking into grow-out ponds. All OTC immersion marking occurred at the Cheraw State Fish Hatchery. Overall marking efficacy of spring and fall-stocked smallmouth bass was 100% with all 30 otoliths reviewed having each the spring and fall mark, although 3 otoliths had poor mark quality.

During spring 2009 an estimated 10,000 smallmouth bass fry (mean TL = 47 mm) and 3,500 smallmouth bass fingerlings (mean TL = 154 mm) were stocked at five locations into the Broad River. All spring stocked fry received a single OTC mark in one immersion event and fall stocked fingerlings received their first OTC mark in a second immersion marking event. Each fall stocked fingerling received a second OTC mark during one of three separate marking events.

Recommendations

In the Broad River the contribution stocked fish to the 2005 year class was 46%, but the contribution of stocked fish to the 2006 and 2007 year classes was only 4% and 9%, respectively. Based on the first three years of data collection it appears that there could be large annual variation in the recruitment of wild and stocked fish to age-1 in the Broad River. Due to that variation no stocking recommendation can be made at this time for the Broad River and the study should be continued as planned, reviewing otoliths collected during fall 2009 for OTC marks. After reviewing the 2009 data a decision will be made on whether or not to continue field collections in 2010.

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