STATEWIDE FRESHWATER FISHERIES RESEARCH

ANNUAL PROGRESS REPORT

F-63

January 1, 2008 – December 31, 2008

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Study Title: STATEWIDE FRESHWATER FISHERIES RESEARCH

Job Title: Smallmouth bass stocking assessment – Broad River, Lake Jocassee, and Lake Robinson

Period Covered January 1, 2008 – December 31, 2008

Results and Discussion

Broad River

We continued our study evaluating the SCDNR smallmouth bass stocking program. During October 2007 and 2008 smallmouth bass were collected with angling gear from the Broad River, extremely low water prevented the use of boat electrofishing gear. During 2007 three sections of river were sampled on 5 dates with a total angler effort of 114 hours, during 2008 four sections of river were sampled on 5 dates with a total angler effort of 143 hours (Table 1).

During 2007, 244 smallmouth bass were collected, measured, weighed and aged (Figure 1). Otoliths of smallmouth bass from the 2002 through 2007 year-classes were reviewed for OTC marks. Of the 73 age-0 fish collected and successfully reviewed for OTC marks only 3 were marked, each of those otoliths had a single mark indicating it was stocked in spring 2007 as a fry, the other 70 age-0 fish were presumably wild (Table 2). Otoliths from 160 age-1 fish were successfully reviewed for OTC marks, 154 of those fish were unmarked (wild), 4 were single marked (fry-stocked during spring) and 2 were double marked (fingerling-stocked during fall) (Table 2). The contribution of stocked fish to the 2006 year class was only 4%.

Table 1. 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 and 2008.

Date	River Section	No Anglers	Time Fished (h)	Total Effort (h)	SMB Collected	CPUE (no./h)
10/9/2007	Below 99-islands	4	6.0	24	105	4.38
10/16/2007	Below Neal Shoals	4	3.0	12	4	0.33
10/16/2007	Below Neal Shoals	4	1.5	6	8	1.33
10/22/2007	Below Neal Shoals	4	2.0	8	26	3.25
10/22/2007	Below Neal Shoals	4	1.5	6	12	2.00
10/22/2007	Below Neal Shoals	4	2.5	10	30	3.00
10/12/2007	Below Gaston Shoals	2	8.0	16	29	1.81
10/17/2007	Below Gaston Shoals	4	8.0	32	30	0.94
	2007 Total			**114**	**244**	**2.13**
10/8/2008	Below Neal Shoals	2	5.5	11	41	3.73
10/8/2008	Below Neal Shoals	2	7.0	14	52	3.71
10/14/2008	Below 99-islands	5	6.0	30	37	1.23
10/15/2008	Below Parr Shoals	4	6.5	26	16	0.62
10/21/2008	Below Neal Shoals	4	8.0	32	44	1.38
10/20/2008	Below 99-islands	4	6.0	24	57	2.38
10/20/2008	Below 99-islands	4	1.5	6	30	5.00
	2008 Total			**143**	**277**	**2.58**

Table 2. 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

Fish collected during the fall of 2008 have not been processed for OTC marks. Angling proved to be an excellent method for collecting age-1 fish, but probably did not collect older age classes in proportion to their true abundance (Figure 1).

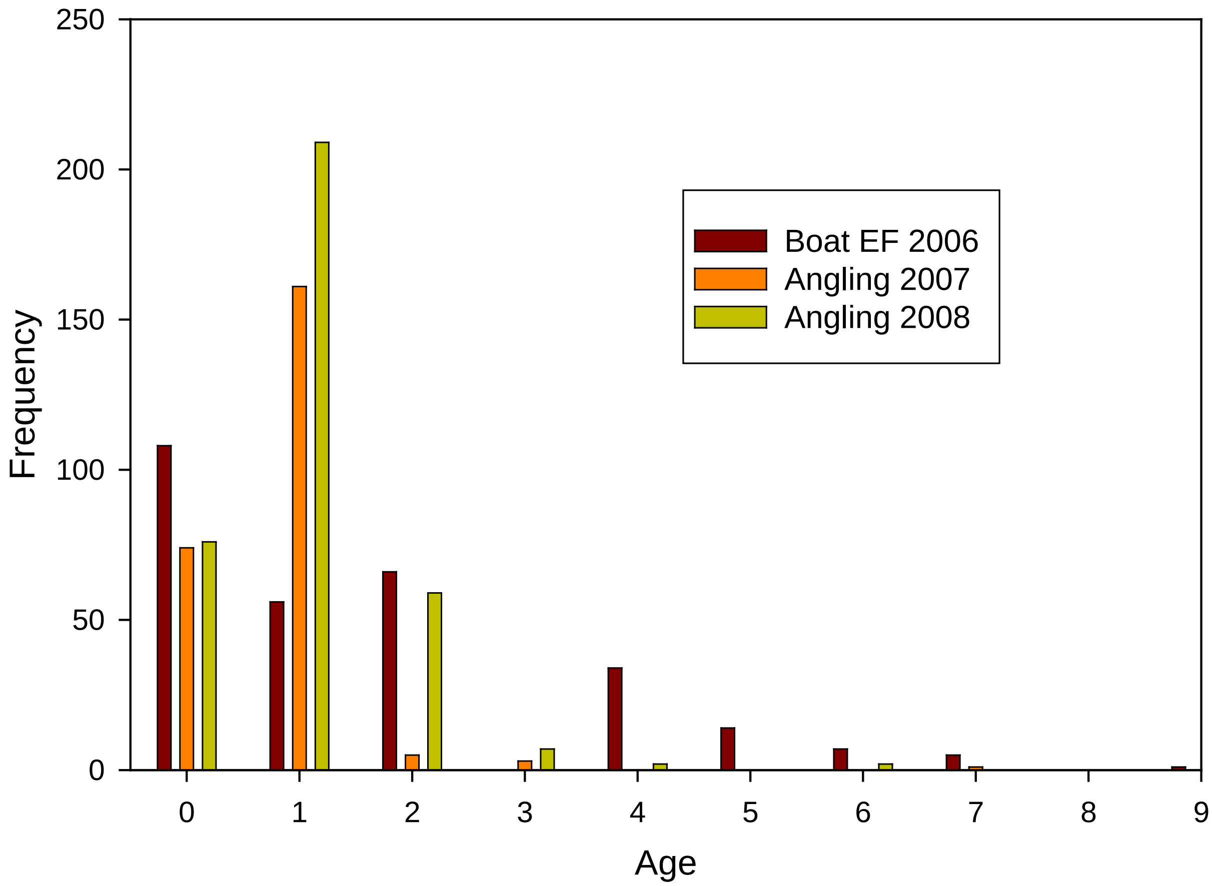

Figure 1. Number of smallmouth bass collected by age and year from the Broad River, South Carolina 2006 – 2008.

Lakes Jocassee and Lake Robinson

During spring 2007 sixty-one smallmouth bass were collected with boat electrofishing gear from Lake Jocassee. Otoliths from 54 of those fish were successfully evaluated for OTC marks. Forty-three of the 44 age-1 smallmouth bass reviewed for OTC marks contained a double mark (fingerling-stocked during fall) the other fish was a single marked spring-stocked fish (Table 3). No wild fish from the 2006 year class were collected from Lake Jocassee during 2007. Lake Robinson was not sampled during 2007.

Table 3. 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 Lake Jocassee, South Carolina.

Year	YC	Wild Fish	Spring Stocked	Fall Stocked	Number reviewed
2006					
	2003	3			3
	2004		6		6
	2005		1	93	94
2007					
	2003	1			1
	2005	1	2	6	9
	2006		1	43	44

Marking Efficacy

During 2007 an estimated 19,200 smallmouth bass fry were stocked during spring and 5,856 smallmouth bass fingerlings were stocked during fall at eight locations into the Broad River. Spring-stocked fish received a single OTC mark and most fall-stocked fish received a double OTC mark. Fish stocked into the Broad River below Parr Shoals Dam during fall received a single mark just before stocking that should be easily differentiated from single marked spring-stocked fish based on the position of the mark in relation to the otolith nucleus. All OTC immersion marking occurred at the Cheraw State Fish Hatchery. Unfortunately, smallmouth bass scheduled to be stocked during fall did not receive a second OTC mark during spring resulting in multiple fall marking events. As a result 90 smallmouth bass otoliths from 10 marking events were reviewed for OTC marks. Overall marking efficacy of spring and fall-stocked smallmouth bass was 97% with three fish missing an outer OTC mark. The lack of the outer mark was probably not due to a poor marking event, but likely related to insufficient grow-out after marking.

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 year class was only 4%. Based on the first two 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. Based on that variation no stocking recommendation can be made at this time for the Broad River and the study should be continued as planned, collecting smallmouth bass from the Broad River during fall 2009 and 2010. In Lake Jocassee, however, there has been very little natural recruitment of smallmouth bass. It appears that the fishery is largely dependent on stocked fish and that fall-stocked fingerlings are much more successful than spring-stocked fry. Region I management staff may want to consider discontinuing the stocking of fry during the spring in favor of fall-stocked fingerlings.

Prepared By: Jason Bettinger Title: Fisheries Biologist

Job Title: Sunfish growth and mortality in South Carolina's state lakes

Period Covered January 1, 2008 – December 31, 2008

Results and Discussion

During spring 2007 a statewide project was initiated to determine the growth, size structure and mortality of redear sunfish, bluegill, largemouth bass and black crappie, in South Carolina's state lakes. The information collected will be used to determine the management potential of those species in each of the lakes. Regional and Research staff collected sunfish, with boat electrofishing equipment, from 10 state lakes during the spring (primarily April) and summer (primarily June) seasons. Number of transects sampled at each reservoir during each sampling date varied from 2 to 9 and total electrofishing effort varied from 1,800 – 15,300 s (Table 1). Water quality parameters collected from each site were typical for the state. Water temperature ranged from 16 – 26º C and averaged 18º C during the spring sampling events and 25 – 31º C and averaged 28º C during the summer sampling events. Most lakes appeared to be fairly productive at the time of sampling with Secchi depths ranging from 0.4 – 1.9 m and averaging 1.0 m.

Catch per unit effort (CPUE: No/h) of sunfish species varied greatly among reservoirs and species (Table 2). Redear sunfish had the lowest catch rates among the three species, but were comparatively abundant in Cherokee, Jonesville and Sunrise. Redear sunfish CPUE was poor in several reservoirs including Ashwood, Dargans Pond, Oliphant, Mountain Lakes and Lancaster. Age structure of redear sunfish was poor in most reservoirs with several reservoirs lacking fish older than age-3. CPUE of bluegill was high in most reservoirs ranging from 40 – 368 fish per hour. Very high bluegill CPUE was observed in Cherokee, Johnson, Mountain Lakes and Sunrise. Low CPUE for bluegill was observed in Ashwood, Dargans Pond, and

Jonesville. Largemouth bass CPUE also varied among reservoirs and was highest in Oliphant, Mountain Lake and Johnson and lowest in Ashwood. Catch rates of age-2 fish were curiously low in several reservoirs (e.g., Lancaster and Jonesville) potentially indicating poor recruitment during 2005 for those reservoirs.

Table 1. State lakes sampled during spring 2007, the total number of electrofishing transects, total effort and associated water quality parameters.

Lake	Sample Date	No. Transects	Temperature (C^o)	Secchi depth (m)	Conductivity (*u*s)	Total Effort (s)
Jonesville	4/25/2007	4	21	1.2	55.3	3600
	6/5/2007	3	25	1.8	69.4	2700
Cherokee	4/26/2007	5	23	1.3	80.0	4500
	6/5/2007	4	27	1.9	75.0	3600
Johnson	4/12/2007	4	16	1.2	.	3600
	6/6/2007	4	28	1.3	68.0	3900
Ashwood	4/9/2007	4	15	0.8	50.3	3600
	6/7/2007	4	27	0.5	56.1	3600
Dargan's Pond	4/12/2007	4	17	1.2	71.1	2700
	6/14/2007	4	27	0.9	66.2	2700
Oliphant	4/19/2007	4	17	1.5	66.9	3600
	6/11/2007	4	29	0.9	77.5	3600
Wallace	March	8	17	0.4	42.2	14040
	April	9	17	0.5	48.4	15300
	May	8	22	0.5	47.6	14400
Mt. Lakes	4/16/2007	4	16	1.1	81.3	3600
	6/20/2007	4	29	1.5	87.8	3480
Sunrise	4/17/2007	2	16	1.3	59.4	1800
	6/26/2007	2	29	0.4	69.4	1800
Lancaster	4/18/2007	4	20	0.5	79.0	3600
	6/21/2007	4	31	0.4	113.0	3610
Total		93				103330

Table 2. Catch per unit effort (No/h) by age of selected sunfish collected from South Carolina State Lakes during 2007.

	Reservoir	Age 1	Age 2	Age 3	Age 4	Age 5	Total
Redear Sunfish							
	Ashwood	4.0	1.5	.	.	0.5	6.0
	Cherokee	16.9	4.0	36.0	.	2.7	60.0
	Dargans Pond	0.7	.	.	2.7	1.3	4.7
	Johnson	14.4	19.7	1.0	1.0	.	36.0
	Jonesville	2.3	45.7	2.3	.	.	50.3
	Oliphant	7.0	2.0	.	.	.	9.5
	Wallace	.	.	.	.	.	28.3
	Mtn. Lakes	8.1	.	.	.	.	8.1
	Sunrise	50.0	.	2.0	.	1.0	54.0
	Lancaster	3.0	0.5	3.5	.	0.5	8.0
Bluegill							
	Ashwood	20.5	14.5	0.5	.	.	58.0
	Cherokee	130.2	36.9	110.7	2.2	.	279.1
	Dargans Pond	28.0	4.7	0.7	.	.	40.0
	Johnson	81.1	133.9	47.5	19.2	4.8	292.3
	Jonesville	13.1	25.1	6.9	2.3	.	47.4
	Oliphant	29.5	92.5	.	.	.	126.0
	Wallace	.	.	.	.	.	24.1
	Mtn. Lakes	174.4	45.8	10.2	.	.	245.6
	Sunrise	194.0	134.0	2.0	3.0	9.0	368.0
	Lancaster	92.4	45.4	13.5	0.5	0.5	152.8
Largemouth Bass							
	Ashwood	17.0	8.5	3.0	.	0.5	29.0
	Cherokee	33.8	6.7	15.6	7.1	0.9	67.6
	Dargans Pond	7.3	14.0	2.0	6.0	4.7	40.0
	Johnson	33.1	14.9	14.9	8.6	4.8	82.1
	Jonesville	30.3	12.6	14.3	0.6	0.6	58.3
	Oliphant	41.0	35.5	10.0	6.5	7.5	101.0
	Wallace	13.8	1.0	2.1	2.7	1.4	25.0
	Mtn. Lakes 1	28.0	28.5	16.3	4.6	4.1	85.4
	Sunrise	22.0	10.0	6.0	10.0	1.0	52.0
	Lancaster	13.0	3.5	7.5	9.0	1.0	47.9

Proportional stock density (PSD) and relative stock density (RSD) varied among reservoirs and species and in general did not indicate good size structure for bluegill and redear sunfish angling (Table 3). PSD's for redear sunfish ranged from 6 – 43 and RSD-P ranged from 0 – 25, none of the reservoirs contained fishable populations of redear sunfish in the "memorable" size range. The only reservoirs that exhibited decent size structure and catch rates for redear sunfish were Sunrise and perhaps Cherokee, the other reservoirs had populations of redear sunfish with either poor catch rates or contained few individuals greater than "stock" size. Similarly bluegill populations exhibited poor size structure in South Carolina state lakes. PSD for bluegill ranged from 3 – 37, only Jonesville had RSD-P values greater than 3 and none of the reservoirs contained populations with "memorable" size fish. Jonesville was the only reservoir with PSD and RSD values indicative of a balanced bluegill population, the other reservoirs had poor bluegill size structure, with numerous small fish. Most of the state lakes had reasonable largemouth bass size structure. PSD for largemouth ranged from 20 – 90, RSD-P from 0 – 71 and RSD-M from 0 -9. Ashwood and Jonesville had very poor largemouth bass size structure with few fish greater than "stock" size and very few fish greater than "preferred" size. Several lakes had balanced largemouth populations with PSDs of 40-70, RSD-P of 10-40 and RSD-M of 0-10. Dargan's, Pond, Wallace and Lancaster contained largemouth bass populations that would be considered "big bass" populations and afford anglers the opportunity to catch "preferred" and "memorable" sized fish, though CPUE for largemouth bass was low in Lake Wallace.

Table 3. Size structure indices for redear sunfish (RES), bluegill sunfish (BLG) and largemouth bass (LMB) collected from State Lakes during 2007. Indices include Proportional Stock Density (PSD) and Relative Stock Densities for fish greater than preferred TL (RSD-P) and for fish greater than memorable TL (RSD-M).

	RES			BLG			LMB		
Reservoir	PSD	RSD-P	RSD-M	PSD	RSD-P	RSD-M	PSD	RSD-P	RSD-M
Ashwood	.	.	.	6	3	0	20	3	0
Cherokee	43	0	0	16	0	0	57	25	5
Dargan's Pond	.	.	.	13	0	0	80	42	4
Johnson	18	5	0	24	3	0	64	27	7
Jonesville	13	1	0	37	11	0	14	0	0
Oliphant	.	.	.	3	1	0	41	7	0
Wallace	6	3	0	35	1	0	97	71	4
Mtn. Lakes 1	.	.	.	9	0	0	46	15	3
Sunrise	75	25	0	7	1	0	58	14	0
Lancaster	.	.	.	29	1	0	90	66	9

Total length at age of redear sunfish varied greatly in South Carolina Sate Lakes (Figure 1). Mean length at age among reservoirs also varied, with most populations averaging approximately 110 mm TL at age-1, and fish reaching quality size (> 180 mm TL) at age-3 (Table 4). Bluegill populations showed tremendous variation in length at age (Figure 1). Bluegill growth in most reservoirs was poor (Table 5). Four reservoirs contained bluegill populations that were short-lived with no individuals older than age-3. In most reservoirs bluegills did not reach "quality" size (> 150 mm TL) until age-3. It took 4 or more years to reach "preferred" size (> 200 mm TL) in the few reservoirs where bluegill lived long enough and grew fast enough to attain larger sizes. Growth and longevity of most largemouth bass populations were typical of the region (Table 6). However, largemouth bass in Ashwood and Jonesville were short-lived with very few fish attaining ages greater than 3. Lancaster contained the oldest individuals with fish up to age-14. Growth was slowest in Ashwood and Jonesville where fish did not live long enough or grow fast enough to reach

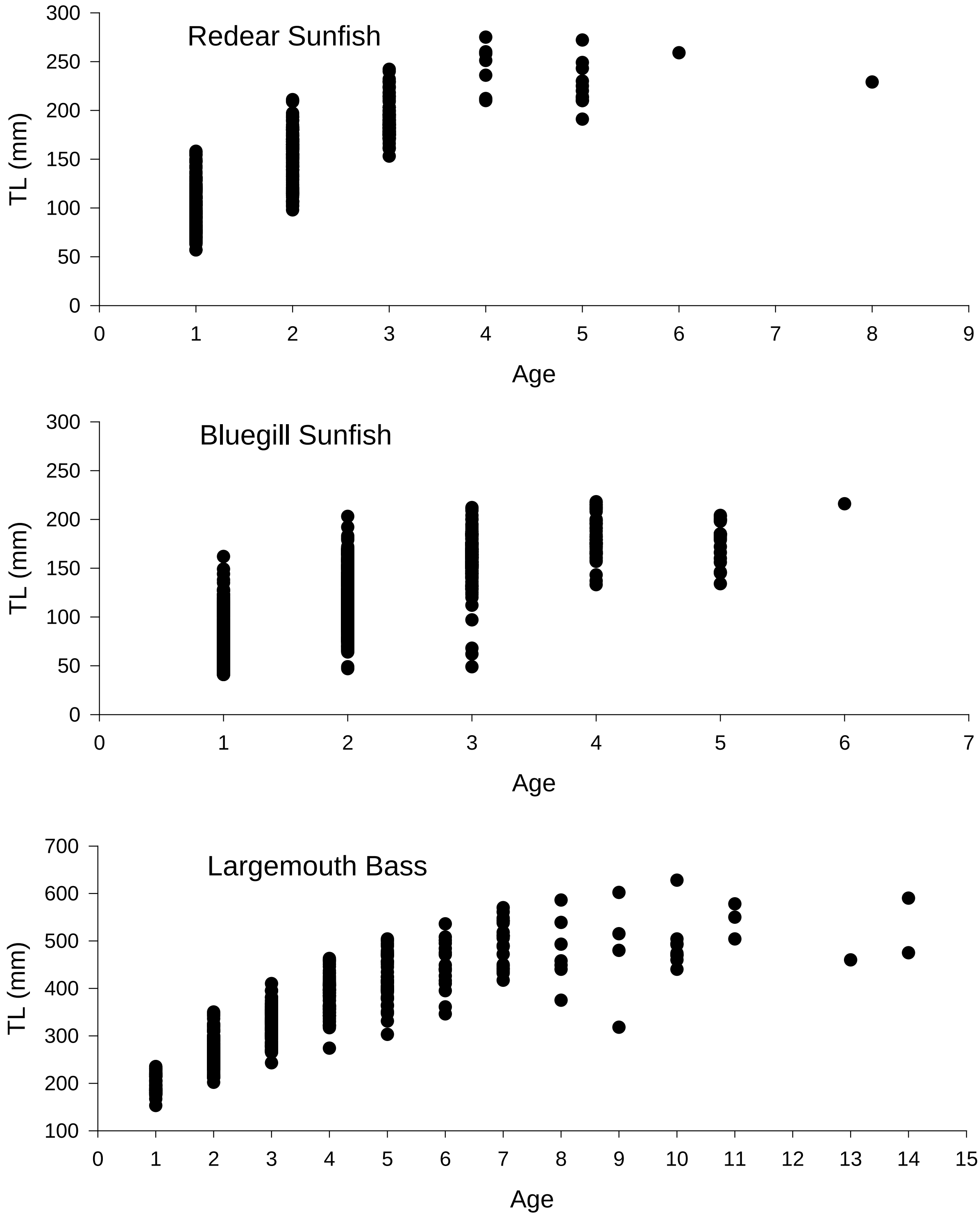

Figure 1. Total length at estimated age for redear sunfish, bluegill sunfish, and largemouth bass collected from State Lakes during 2007.

Table 4. Mean TL (mm) at age and standard error (SE) for selected redear sunfish collected from South Carolina state lakes during spring and summer 2007.

	Age	TL	SE	N		Age	TL	SE	N
Ashwood					**Jonesville**				
	1	71	2.3	8		1	108	14.4	4
	2	207	3.3	3		2	141	2.9	80
	3	.	.	.		3	223	6.3	4
	4	.	.	.	**Oliphant**				
	5	270	.	1		1	101	3.6	14
Cherokee						2	180	14.7	4
	1	110	2.6	38	**Sunrise**				
	2	151	6.5	9		1	81	1.3	50
	3	182	1.8	81		2		.	.
	4	.	.	.		3	205	5	2
	5	212	5.4	6		4		.	.
	6	.	.	.		5	230	.	1
	7	.	.	.	**Lancaster**				
	8	230	.	1		1	113	12.3	6
Johnson						2	160	.	1
	1	110	4.5	30		3	224	2	7
	2	165	2.3	41		4		.	.
	3	225	15	2		5	250	.	1
	4	270	10	2		6	260	.	1

Table 5. Mean TL (mm) at age and standard error (SE) for bluegill sunfish collected from South Carolina state lakes during spring and summer 2007.

	Age	TL	SE	N		Age	TL	SE	N
Ashwood					**Oliphant**				
	1	60	2.4	41		1	70	1.6	59
	2	111	2.8	29		2	109	1.5	185
	3	200	.	1	**Mt Lakes**				
Cherokee						1	80	1	343
	1	84	0.9	293		2	121	1.6	90
	2	119	1.6	83		3	167	2.7	20
	3	142	1.4	249	**Sunrise**				
	4	142	7.3	5		1	61	0.9	194
Dargan's						2	90	1.2	134
	1	67	2.1	42		3	140	10	2
	2	126	8.4	7		4	173	17.6	3
	3	180	.	1		5	163	6.7	9
Johnson					**Lancaster**				
	1	78	1.6	169		1	80	1.7	185
	2	116	1.2	279		2	148	1.6	91
	3	157	1.8	99		3	166	3.5	27
	4	179	3.3	40		4	220	.	1
	5	192	2.9	10		5	190	.	1
	6	220	.	1					
Jonesville									
	1	54	1.9	23					
	2	92	3	44					
	3	183	4.8	12					
	4	208	6.3	4					

Table 6. Mean TL (mm) at age and standard error (SE) for largemouth bass collected from South Carolina state lakes during spring and summer 2007.

	Age	TL	SE	N
Ashwood				
	1	150	8.8	28
	2	266	4.4	17
	3	308	7.7	6
	4	.	.	.
	5	462	.	1
	6	337	.	1
Cherokee				
	1	166	5.5	50
	2	277	6.8	15
	3	311	5.3	35
	4	393	11.1	16
	5	462	0	2
	6	481	15.7	4
	7	437	.	1
	8	504	33.3	3
	9	562	50	2
Dargan's				
	1	179	22.1	3
	2	305	4.9	21
	3	345	8.3	3
	4	390	12.1	9
	5	437	15.5	7
	6	427	10	5
Johnson				
	1	138	4.3	43
	2	261	3.8	31
	3	325	4.9	31
	4	361	9.8	18
	5	432	12.8	10
	6	512	25	2
	7	532	9.3	5
	8	504	44.1	3
	9	312	.	1
	10	387	50	2
Wallace				
	1	110	1.8	153
	2	316	5.2	12
	3	370	4.3	26
	4	405	3.8	33
	5	394	6	17
	6	.	.	.
	7	441	4.2	18
	8	.	.	.
	9	.	.	.
	10	484	4.5	23
Mt Lakes				
	1	170	5.5	45
	2	279	3.1	56
	3	314	4.1	32
	4	329	21.2	9
	5	396	8.1	8
	6	395	16.6	3
	7	522	12.7	5
Sunrise				
	1	189	9.8	16
	2	270	9.1	10
	3	320	10.6	6
	4	350	5.6	10
	5	512	.	1
	6	462	25	3
Jonesville				
	1	110	2.3	51
	2	237	2.9	22
	3	285	4.1	25
	4	312	.	1
	5	312	.	1

Table 6. Continued.

	Age	TL	SE	N		Age	TL	SE	N
Lancaster					**Oliphant**				
	1	141	6.8	13		1	141	5.1	57
	2	255	10.5	7		2	277	2.3	71
	3	342	5	15		3	337	5.5	20
	4	415	8.3	18		4	350	8.8	13
	5	512	0	2		5	365	6.4	15
	6	.	.	.		6	462	.	1
	7	468	10.3	13		7	.	.	.
	8	.	.	.		8	412	25	3
	9	487	0	3					
	10	.	.	.					
	11	543	18.8	4					
	12	.	.	.					
	13	.	.	4					
	14	512	25	4					

the“ preferred” size class (> 380 mm TL). Slow growth in Sunrise, Mountain Lake and Oliphant prevented the average fish from reaching the “preferred” size by age-4, but fish in the remaining reservoirs reached the “preferred” size class by age-4 which is typical growth for the state.

Mean relative weights for redear sunfish populations ranged from 0.84 – 1.04 in South Carolina state lakes (Table 7), indicating that most populations were in below average condition with regard to weight. Relative weight of bluegill populations ranged from 0.88 – 1.27. Johnson and Cherokee bluegill were in poor condition, but bluegill in some reservoirs were in relatively good condition. Largemouth bass relative weights ranged from 0.87 – 0.97, most populations were slightly below the national average, but were comparable to other South Carolina populations based on the statewide condition factor.

Table 7. Mean Relative weight (Wr) for redear sunfish, and bluegill and mean Wr and statewide (SC) condition factor for largemouth bass collected from South Carolina state lakes during 2007.

	RES	**BLG**	**LMB**	
Reservoir	Wr	Wr	Wr	SC
Ashwood	0.94	1.15	0.88	1.04
Cherokee	0.86	0.90	0.90	1.03
Dargan's	0.95	1.27	0.97	1.11
Johnson	0.84	0.88	0.87	0.99
Jonesville	0.95	0.98	0.89	1.05
Oliphant	0.95	1.02	0.88	1.02
Wallace	1.04	0.96	0.95	1.10
Mtn Lakes	0.97	0.97	0.88	1.01
Sunrise	0.85	0.95	0.87	1.00
Lancaster	0.95	0.98	0.97	1.11

Recommendations

Continue with the study as planned, fully summarizing and analyzing the data to determine the management potential of South Carolina's State Lakes. A final report will be prepared by December 2009.

Prepared By: Jason Bettinger Title: Fisheries Biologist

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

Period Covered January 1, 2008 – December 31, 2008

Results and Discussion

Previous study has shown that redeye bass *Micropterus coosae* in the Savannah drainage have been dramatically impacted by hybridization with introduced Alabama spotted bass *Micropterus punctulatus henshalli*. Surveys in 2004 indicated genetically pure redeye bass have been virtually extirpated from Lakes Keowee and Russell, while hybrid bass comprised greater than 20% of fish collected from those two lakes, as well as from Lakes Jocassee and Hartwell. Stream populations sampled in the same study were predominantly free of hybrids and of Alabama spotted bass (Leitner, 2007). In 2007 a State Wildlife Grant was awarded to further the evaluation of affected populations, and to develop new genetic assays for their continued monitoring. This work was begun in January of 2008.

In the last year work has focused largely on the development of an additional nuclear locus, calmodulin, and its application to all study individuals previously run. Calmodulin sequences were generated for N=168 black bass collected from stream sites, and for N=673 black bass collected from Lakes Jocassee, Keowee, Hartwell, and Russell. Once added to the data base with two other nuclear and one mitochondrial locus, these new sequences will increase our power to indentify hybrid individuals.

We reported in 2007 that displacement of redeye bass in favor of Alabama spotted bass in Lakes Keowee and Russell indicate that Alabama spotted bass and hybrids between the two species have selectively crossed with redeye. Further examination of mitochondrial DNA (mtDNA) data supports hybridization that is largely unidirectional. The proportion of backcrossed hybrids possessing redeye bass mtDNA, meaning their maternal lineage traces back to a redeye bass female, ranges from 60 – 94% (Table 1).

Table 1. Maternal lineage of hybrid individuals collected from four Savannah River reservoirs that possessed any combination of redeye bass (REB) and Alabama Spotted bass (ASB) alleles. Individuals possessing alleles from other black bass species are not included.

	Number Collected			
Hybrid Category	Jocassee	Keowee	Hartwell	Russell
F1				
REB mtDNA	11	1	2	4
ASB mtDNA	0	5	0	5
Backcross				
REB mtDNA	17	30	48	18
ASB mtDNA	5	16	3	12

In November of 2007 N=47 black bass were collected from Lake Keowee to supplement our original database. These fish represent collections from a geographic area previously not included in analysis due to poor DNA recovery. These fish were run and results were obtained from N=42 of the fish collected. Confirmed hybrids between Alabama spotted and redeye bass comprised 31% of the sample. No pure redeye bass were collected (Table 2). These results are consistent with those from our 2004 collections from the lake, where 25.5% of 167 individuals were hybrids, and less than 1% were pure redeye.

Samples were also analyzed from the Augusta Shoals portion of the Savannah River. Reports of angler catches of smallmouth bass *Micropterus dolomieu* in the shoals were followed up by electrofishing and angling collections there in the Fall of 2007. Twenty five bass were collected by boat electrofishing at the base of the shoals, and 13 were collected by angling within the shoals. When sampled in 2004 this population yielded only pure redeye bass. Genetic analysis of the 38 bass collected in 2007 confirmed the presence of smallmouth bass as well as hybrids in the Augusta shoals population (Table 2).

The confirmation of smallmouth bass and smallmouth bass x redeye bass hybrids in the Savannah River is unfortunate, as interspecific hybridization may impact this significant redeye population. These two species coexist in Lake Jocassee and we have found few hybrids between the two in that reservoir or its related tributaries. However, John M. Turner et al. (1991) documented introgressive hybridization between smallmouth bass and redeye bass in Roaring River Tennessee. Continued monitoring of the Augusta Shoals redeye bass population will be necessary to determine the impact of hybridization there.

Table 2. Species designations for black bass analyzed in 2008. Designations are based on results at 3 nuclear (Calmodulin, ITS2, and Actin) and 1 mitochondrial (ND2) DNA loci.

Species Designation	Lake Keowee	Savannah River at Augusta Shoals	Savannah River just below Augusta Shoals
LMB	1	1	1
REB	0	0	22
ASB	32	0	0
SMB	0	7	0
REB x ASB (REB mtDNA)	5	0	0
REB x ASB (SMB mtDNA)	8	0	0
REB x SMB (REB mtDNA)	0	1	2
REB x SMB (SMB mtDNA)	0	1	0
LMB x SMB (LMB mtDNA)	0	3	0
LMB x SMB (SMB mtDNA)	0	0	0
Total analyzed	46	13	25

During 2008 stream team sampling, n = 46 black bass collected from Savannah drainage streams, and n = 23 collected from select Santee drainage streams were fin clipped for genetic analysis. These samples were archived and will be held for processing using assays that will be developed during 2009. Additional samples were also collected from Augusta Shoals and archived for future analysis. These n= 54 black bass were collected and fin clipped by Georgia Department of Natural Resources personnel during routine shad sampling in the area.

Outreach efforts in 2008 resulted in the release of one news article with the story picked up by one upstate newspaper, and the Augusta Chronicle. A separate article was developed for BASS Times. One presentation was made to the group, Keowee Anglers association.

Work will continue over the next year. Focus will be on the inclusion of the Calmodulin data in all analysis, and on the development of rapid genetic assays for continued assessment of genetic change in these populations. Once rapid assays are developed selected populations will be sampled again. Correlations of pure and hybrid populations with habitat types will be examined.

Recommendations

Continue study. Incorporate calmodulin into final hybrid analysis. Develop and implement rapid genetic assays. Submit this and previous work for presentation at the AFS 2009 national meeting. Continue outreach effort to publicize results of this study, and dangers of the indiscriminant movement of aquatic species, through popular media and direct contact with interested groups. Recommend legislation against the unauthorized release of fish and other aquatic species into public waters of South Carolina.

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Prepared By: Jean Leitner Title: Fisheries Biologist

Job Title: An evaluation of multiple families of striped bass stocked in Lake Wateree in 2008

Period Covered January 1, 2008 – December 31, 2008

Results and Discussion

Multiple factors in the production and stocking of hatchery reared striped bass can contribute to a batch's potential for survival and eventual recruitment to a fishery. The need exist for a better understanding of how, and which, factors contribute significantly to the ultimate success of stocked fish. The development of microsatellite markers for striped bass allows the evaluation of multiple treatment batches of fish. This effort was proposed to evaluate recruitment to age 1+ of progeny from four genetic families, with measurement of size and condition of fish at stocking.

Larvae produced at Bayless Fish Hatchery were transported to Spring Stevens Hatchery for grow out. Seven ponds were stocked in April 2008 with one family (1 female x 3 males) each. In an effort to produce fingerlings of two size classes, stocking was staggered with 4 ponds receiving fish on April 24, and 3 on April 29. On May 21 all ponds were seined to determine the size structure of fingerlings in the ponds. There was considerable overlap in size of fingerlings among ponds. Mean total lengths ranged from 25.0 to 31.5 mm. The number of striped bass fingerlings collected per pond ranged from 1-58. Golden shiners were collected with striped bass from 4 ponds during seining, but were not identified in the field. Counts in the lab showed that where they were present, golden shiners made up from 6 – 85% of fish collected (Table 1).

Table 1. Striped bass (n, mean tl, sd) and golden shiners (n, % of total) collected from Spring Stevens hatchery ponds on May 29, 2008.

	Striped Bass			Golden Shiners	
Pond	n	Mean tl	sd	n	% total
1	4	27.2	.48	22	85
2	16	28.5	.55	22	56
3	40	25.8	.44	0	0
4	6	28.1	.47	0	0
5	58	31.5	.40	4	6
6	26	28.9	.61	20	43
7	1	25.0	.00	0	0

Ponds, 2, 3, 5, and 6 were chosen for harvest in anticipation that these ponds would yield the most striped bass fingerlings. Ponds were harvested on May 29 (Table 2). Dissolved oxygen (DO) was tracked in each pond kettle during harvest and readings ranged from 3.6 – 6.8 mg/l. Time to clear each kettle of fish was not more than 13 minutes, with the exception of pond 2 which took 64 minutes. There was little to no mortality observed during harvest of all four ponds. A sample of at least 300 fingerlings was retained from each pond for genetic analysis and evaluation of size at stocking.

To minimize hauling/stocking effects, fish were weighed onto one truck such that each hauling compartment carried an equal number of fish, and an equal proportion of fish from each pond. A total of 63,972 fish were transported to Lake Wateree and stocked at Beaver Creek and White Oak access points. Fish were tempered on the truck for up to 74 minutes prior to release. Mortality at stocking appeared to be near zero.

Harvest of Heath Springs ponds was well below expectations, and additional fingerlings were required to meet the stocking request for Lake Wateree. On June 13 striped bass fingerlings were harvested from two ponds at Dennis Wildlife Center. These fish represent 3 additional genetic families (Table 2). DO readings were taken in each pond in and out of the harvest basin just prior to harvest, and in the basin at the end of harvest. Pond 53 DO's ranged from 4.05 – 6.47. Pond 51 DO readings were low however, 0.94 outside and 2.78 in the basin at start of harvest. At the end of harvest DO in the basin was 0.50 mg/l. Time in the basin was not recorded in these two ponds, but personnel report that harvest of pond 51 was expedited because of the DO conditions. There was no significant mortality observed at harvest or at stocking. Fish were handled as in the previous stocking, with fingerlings from each pond spread equally across hauling units and stocking sites. A total of 195,376 striped bass fingerlings were stocked at Buck Hall and Colonel Creek access points.

We anticipated stocking Lake Wateree with approximately equal numbers of striped bass fingerlings from four genetic families and two size classes, and evaluating recruitment of each by identifying them in gillnet collections at age 1+. While we did stock fingerlings from two distinct size classes, the time between stocking dates, and different stocking locations preclude us from making meaningful comparisons between families from group A-D (stocked May 29) and group X-Z (stocked June 13; Table 2).

Table 2. Pond harvest and stocking data for genetic families of striped bass stocked in Lake Wateree in 2008.

Family	Pond	Date Stocked	Female*	Males	N stocked	% of days total	% of lake total	n/lb
A	HS 2	5/29/2008	40	13, 69, 84	38,517	60	15	694
B	HS 3	5/29/2008	41	73, 77, 87	17,108	27	7	728
C	HS 5	5/29/2008	31	12, 46, 55	1,015	2	0	580
D	HS 6	5/29/2008	32	44, 46, 64	7,332	11	3	611
X	DC 53	6/13/2008	45 (61%)	85 ,92, 93	71,312	36	27	1604
Y			53 (39%)	91, 93, 102				
Z	DC 51	6/13/2008	46	91, 95, 100	124,064	64	48	1802

*Percentages for females 45 and 53 (Pond DC 53) are percent of eggs from each female used to stock the pond. They do not confer percent of fingerlings harvested from each female.

The small proportion of stocked fingerlings that some families comprised impacts our ability to assess change in those proportions at age 1+. Specifically, within families A-D, none comprised more than 15% of the year class at stocking. Further work is needed to determine if comparisons within group X-Z are worth pursuing. Within that group, family Z comprised 48% of stocked fingerlings. Families X and Y comprised 27% collectively, but because they were grown out in the same pond assigning individual contributions to them will require genetic evaluation of a subsample of fingerlings stocked.

There are questions of interest that may still be addressed through study of within family differences. In our striped bass hatchery protocol, three males are sequentially added to the eggs from each female. The use of 3 males per female is in part to maximize genetic diversity, and the effective population size in year classes stocked. However, studies have shown that sperm competition inherent to similar protocols leads to loss of genetic variation (Wedekind et al. 2006, Martinez et al. 2007). We have never quantified the contribution of individual males to families produced in our hatchery. This could be done for multiple families with the samples retained from pond harvests.

Growth of striped bass progeny of each male contributing to a family could also be compared. Genetic effects on growth, and on other aspects of performance, are important to consider when evaluating effects such time as or location of stocking. Ideally study designs will allow for a homogenized gene pool across treatments. This is not possible however when treatment groups are identified by their genetic mark. Wang et al. 2006 found that dam and sire effects on juvenile growth and growth rate were significant in hybrid striped bass (*M. chrysops* female x *M. saxatilis* male). Results for measurement at two time intervals also suggested that selection for growth rate at an early life stage could affect growth rate at a later life stage.

Because all the fish within our families were grown out in a common environment, evaluation of growth by sire would be a step toward better understanding the genetic effect on early growth in our hatchery produced striped bass.

Currently the broodfish used to stock Lake Wateree are in genetic analysis. Those results will be used to determine the cost of identifying striped bass juveniles to family within the lake, and to sire within families. Benefits of moving forward with a new initiative, or with a portion of our original objective will be assessed at that time.

Recommendations

Following genotyping of broodfish, determine costs and benefits associated with further analysis of 2008 year class of striped bass in Lake Wateree. Submit proposals as needed.

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Prepared By: <u>Jean Leitner</u> Title: <u>Fisheries Biologist</u>

Job Title: Evaluation of ultrasonic transmitter retention in blue catfish.

Period Covered January 1, 2008 – December 31, 2008

Results and Discussion

Blue catfish came to Santee Cooper in 1964 and 1965 when a total of 825 fish weighing about a pound each were obtained from Arkansas in exchange for striped bass fry. In 2007 new laws were passed limiting harvest of blue catfish to one 36 inch fish per person per day. These regulations apply to only the waters of Lake Marion, the Diversion Canal, the Rediversion Canal above St. Stephen Dam and Lake Moultrie.

Blue catfish age and growth (White,M.G. III 1980) and fishing mortality of large catfish in Lakes Marion and Moultrie (White and Lamprecht 1990) have been studied, but little is known about the movement of blue catfish within the Santee Cooper system. Movement between the two lakes, their tributaries, and outfall rivers is of long term management interest. Ultrasonic transmitters and receivers have been used in the system to assess movement of other species. This acquired expertise and equipment could be used to track blue catfish. However, no published data exists on the retention of such transmitters in blue catfish. Catfish are known to expel internally placed tags (Summerfelt and Mosier 1984). This study will evaluate methods for surgical transmitter implantation in blue catfish, including one that has been shown to be effective in channel catfish (Siegwarth and Pitlo 1999).

In July 2008, 40 blue catfish (TL>600mm) were collected below Santee Dam, Lake Marion, and held at the Dennis Wildlife Center for transmitter implantation. All 40 blue catfish were placed in a 6,000 gal. holding tank (20' in diameter), which was supplied with well water. On July 30th, 15 blue catfish were implanted with acoustic transmitters. These transmitters were surgically implanted directly into the body cavity. On July 31st, 15 blue catfish were implanted with dummy acoustic transmitters that were tied off to the pectoral girdle. The 10 remaining blue catfish were not implanted.

All 40 fish were returned to the holding tank and all appeared to be feeding 10 days after surgery. Fish were checked and fed approximately daily. Of the 30 implanted fish, no mortality was observed. One of the 10 non-implanted fish was found dead on September 29th, presumably due to lack of feeding.

Nine of 15 fish from the abdominal insertion without tying to pelvic girdle group expelled their transmitters (Table 1). Tags from this group of fish began showing up in the tank 23 days post surgery, and every 10 to 12 days afterwards. Of the 15 fish with tags tied off to the pectoral girdle, four transmitters were expelled (Table 1). Notably, these are 4 of the 6 largest fish that underwent this procedure.

Preliminary data indicates that transmitters implanted directly into the body cavity of blue catfish are more likely to be expelled than those anchored to the pectoral girdle. However, some transmitters tied off to the pectoral girdle were still adsorbed by the intestine, suggesting that intestinal blockage and resultant aberrant behavior may occur. Perhaps, implanting the transmitters more anteriorly, away from the intestines, should be evaluated. We plan to hold these fish for 8 months, after which retention following the two surgical procedures will be compared.

Table 1. Surgical data for blue catfish implanted with sonic transmitters July 30-31, 2008. Transmitters were either inserted directly into the abdominal cavity ('cavity implant') or inserted into the abdominal cavity and tied off to the pectoral girdle ('tied off'). Entries within each procedure are sorted by total length(TL).

Fish ID #	**TL (mm)**	**Weight (g)**	**Surg. Procedure**	**Time to complete Surg.**	**Days post surgery expelled**
8653	600	2651	Cavity Implant	3:36	23
8211	604	2440	Cavity Implant	3:07	
1035439	617	2540	Cavity Implant	3:07	
1062	619	2500	Cavity Implant	2:47	
7317	651	3309	Cavity Implant	3:10	83
8620	653	2856	Cavity Implant	2:40	
7314	686	4396	Cavity Implant	3:43	23
1035440	697	3747	Cavity Implant	5:23	
8615	709	4299	Cavity Implant	2:35	29
8609	710	4014	Cavity Implant	3:04	53
8629	717	4385	Cavity Implant	3:41	23
8643	776	5479	Cavity Implant	4:38	81
7312	815	6558	Cavity Implant	3:14	39
8666	832	6775	Cavity Implant	3:10	39
1035438	887	10216	Cavity Implant	4:00	
9	605	2548	Tied off	7:08	
10	642	2324	Tied off	5:40	
14	655	3225	Tied off	5:58	
1	672	3611	Tied off	6:03	
2	694	3503	Tied off	4:59	
12	707	3109	Tied off	6:37	
15	708	3843	Tied off	6:37	
13	715	3545	Tied off	7:44	
3	729	4052	Tied off	6:20	
8	739	5328	Tied off	4:57	100
6	752	4070	Tied off	7:02	47
5	771	5021	Tied off	5:58	71
11	790	5565	Tied off	5:50	
4	822	7559	Tied off	6:45	
7	1100	19348	Tied off	8:05	62

Recommendations

Continue study. Retain fish for at least 8 months post surgery. Necropsy fish at end of holding period for internal examination of surgical site, examination of reaction to the internal tag, and evidence of impending trans-intestinal expulsion. Report results to section, and submit as publication to a peer reviewed journal.

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Prepared By: Treye Byars Title: Fisheries Tech III

Job Title: Initial assessment of water quality and productivity of select public fishing lakes

Period Covered January 1, 2008 – December 31, 2008

Summary

Temperature, conductivity, secchi disk transparency, and chlorophyll were measured in 13 public fishing lakes during 2007. There were substantial differences among the lakes and, within a particular lake, small to large variability in productivity during the growing season. This initial effort identified general trends in and the condition of 13 public fishing lakes and offers recommendations for future efforts that could benefit the long-term management of these facilities.

Introduction

South Carolina's public fishing lakes, i.e. State Lakes, provide fishing opportunities throughout the state. The quality of the fishing in these lakes is partly dependent on the quality and the fertility of the water. To better understand these factors, a water quality survey was performed in 2007. The goal of this survey was to increase understanding of water quality and fertility of these lakes.

Methods

When they were working in the area, State Lake's personnel measured temperature at one meter, secchi disk visibility, and conductivity at a mid-lake station. Temperature and conductivity were measured with a YSI Model 30 meter. During these visits, water samples were collected in amber bottles for subsequent laboratory measurement of chlorophyll a, an index of the primary productivity of a lake. On a sampling day, three water samples were collected from each lake. They were collected from the upstream, middle, and downstream end of the lake to account for spatial variability. Water samples were placed in a cooler with ice and were delivered either that day or the next to the DNR water quality lab in West Columbia. State Lake personnel also noted the days upon which the lakes were fertilized.

Water samples were agitated and a 100 mL aliquot was measured by graduated cylinder and filtered on a vacuum filter apparatus using a 47 mm glass fiber filter with a pore size of 0.7 μm. The filter was removed, folded, placed into aluminum foil, and placed into a laboratory freezer maintained at -80 C. Filters were removed from the freezer and extracted with 90:10 (acetone: deionized water) using a powered tissue grinder. The extract was centrifuged and analyzed using fluorescence detection on a Turner TD-700 Fluorometer. Chlorophyll results were calculated using an external standard curve, measured at the same time as the samples, with five standards ranging from 11.4 to 157 μg/L chlorophyll. If dilutions were needed, the dilution was made so that fluorescence was within the range of the standard curve. The fluorometer was checked prior and immediately after each run to verify consistency and accuracy using a red standard.

Results

Thirteen lakes were sampled three to five times each during the summer months (Table 1). Water temperature varied seasonally, ranging from 20 to 31.6°C (Figure 1).

Average conductivity ranged from 70 to 100 µS in 9 of the 13 lakes. Lakes Paul Wallace (58 µS) and Ashwood (61 µS) had relatively low conductivity while Star Fort (116 µS) and Lancaster (112 µS) had relatively high conductivities.

Average secchi disk transparency varied from 15 to 49 inches and exhibited greater variability at certain sites (Table 2). Star Fort, Lancaster, Edgar Brown, and Wallace had average transparencies below 20”, which is indicative of a reasonable plankton bloom. Transparency was relatively high and exhibited relatively high variation at Edwin Johnson, Oliphant, John D. Long, and Jonesville, perhaps indicative of lakes possessing short-term plankton blooms due to fertilization efforts.

Table 1. South Carolina public fishing lakes sampled in 2007.

Lake	**Dates sampled**	**County**	**Acres**
Ashwood	Aug 6, 29, Sep 27	Lee	75
Edgar Brown	Jun 6, Aug 9, Sep 6, 27	Barnwell	100
Cherokee	Jul 12, Aug 6, Sep 10, 26	Cherokee	50
Dargans Pond	Aug 6, 29, Sep 27	Darlington	50
Edwin Johnson	Jun 5, Jul 9, Aug 6, Sep 10, 26	Spartanburg	40
Jonesville	Jun 5, Jul 9, Aug 6, Sep 10, 26	Union	35
Lancaster	Jun 14, 21, Aug 8, Sep 5, 26	Lancaster	62
John D. Long	May 9, Jul 12, Aug 6, Sep 10, 26	Union	80
Mountain Lake 1	May 9, Jul 12, Aug 2, Sep 10, 26	Chester	42
Oliphant	May 9, Aug 2, Sep 10, 26	Chester	40
Star Fort	Jun 6, Aug 9, Sep 13, 28	Greenwood	27
Sunrise	Jun 14, Aug 2, Sep 5, 26	Lancaster	25
Paul Wallace	Aug 6, 29, Sep 27	Marlboro	280

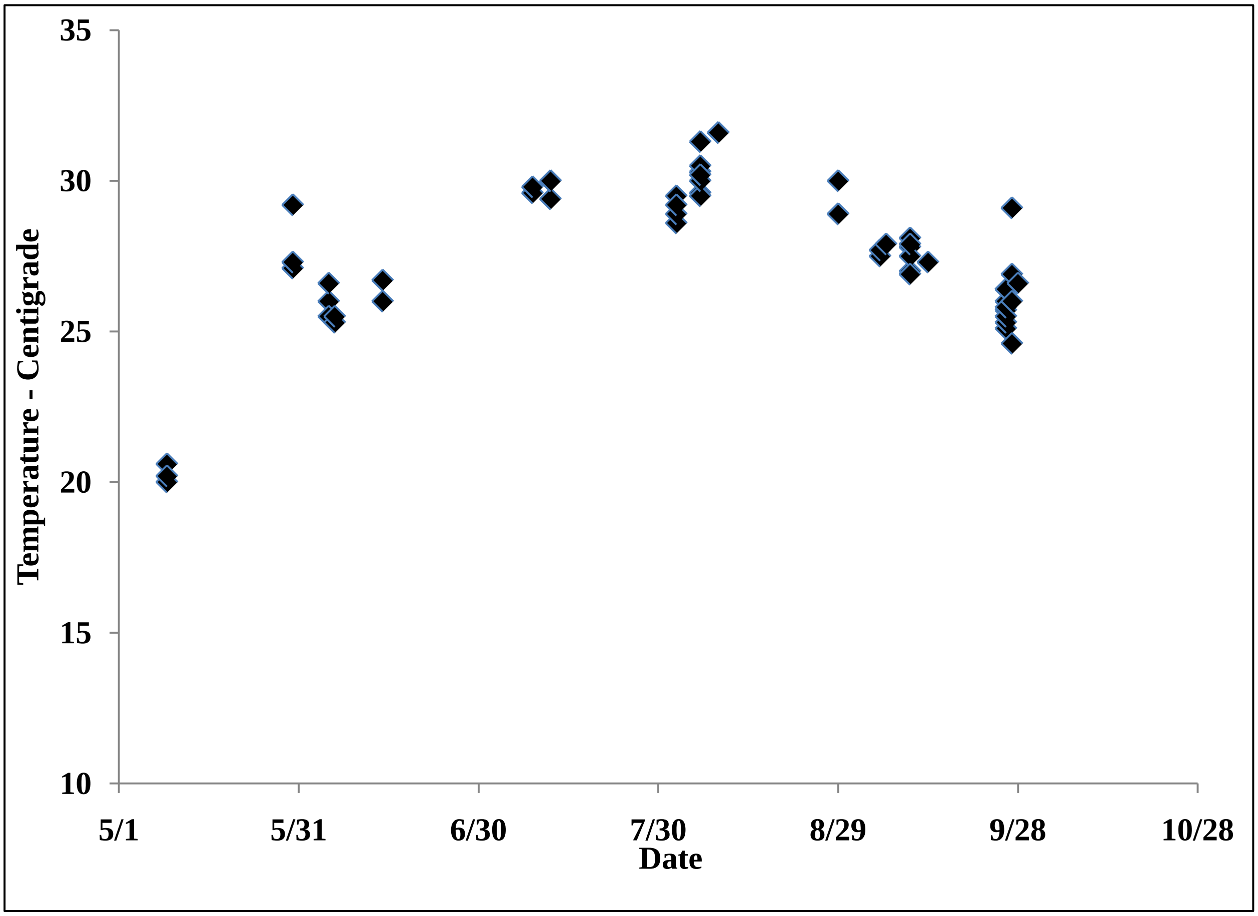

Figure 1. Daylight water temperature at one meter at 13 public fishing lakes in 2007.

Table 2. Average secchi disk transparency of 13 public fishing lakes in 2007. RSE denotes relative standard error (RSE = 100 * (standard error/estimate)).

Lake	**Average Transparency - inches**	**N**	**RSE**
Star Fort	15	4	24
Lancaster	15	3	9
Edgar Brown	16	4	14
Paul Wallace	19	4	10
Sunrise	23	4	15
Dargans Pond	29	4	10
Mountain Lakes 1	30	5	16
Oliphant	30	4	24
Ashwood	30	4	9
Edwin Johnson	32	5	27
John D. Long	33	5	22
Jonesvillle	35	5	19
Cherokee	49	5	14

Average chlorophyll a concentration ranged from 16 to 127 µg/L, nearly an order of magnitude difference among lakes (Table 3). Dargans Pond and Ashwood had the lowest average chlorophyll concentrations. As also shown by secchi disk data, Star Fort, Lancaster, Wallace, and Brown had the highest average chlorophyll concentrations. Similar to secchi disk results, Cherokee, Oliphant, Jonesville, and Edwin Johnson had the highest variation in chlorophyll values, perhaps indicative of short-term plankton blooms as a result of fertilization. Seasonal patterns of chlorophyll abundance are shown in Figures 2-7. The trends in these figures suggest that spring fertilizations were not as successful as those performed during the summer.

There was a significant negative correlation, $r = -0.79$, between average chlorophyll and average secchi disk transparency. While not significant ($P = 0.0576$), there was a trend for a positive relationship between average chlorophyll and conductivity.

Table 3. Average chlorophyll a concentration in 13 public fishing lakes in 2007. RSE denotes relative standard error (RSE = 100 * (standard error/estimate)).

Lake	Average Chlorophyll a - µg/L	N	RSE
Star Fort	127	3	38
Lancaster	100	4	24
Edgar Brown	97	3	30
Paul Wallace	97	5	23
Sunrise	83	5	27
Edwin Johnson	60	4	40
Jonesville	57	5	39
Oliphant	54	5	56
Mountain Lakes 1	51	4	24
John D. Long	50	4	34
Dargans	45	3	9
Cherokee	40	5	75
Ashwood	16	4	11

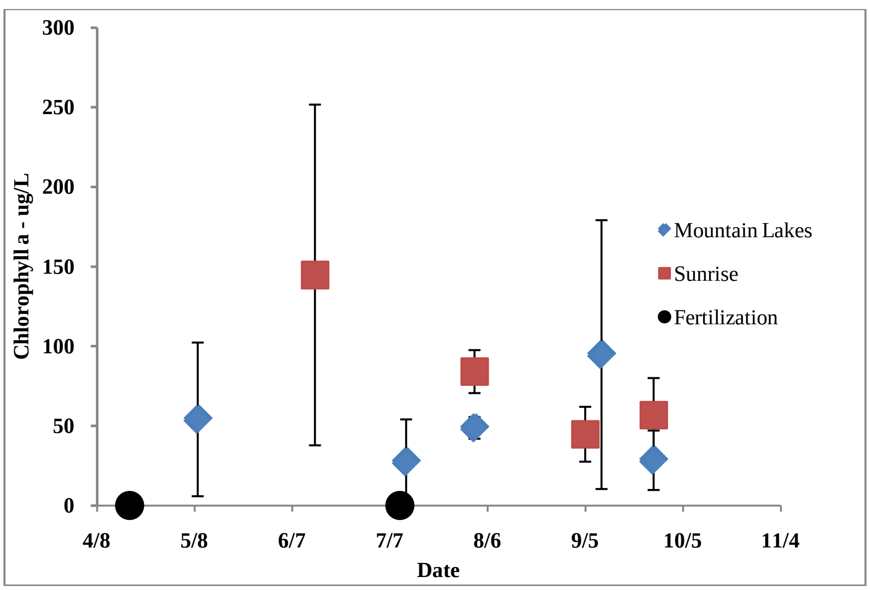

Figure 2. Chlorophyll a levels in Mountain Lake I and Sunrise Lake during 2007. Three water samples were collected each sampling day from the upstream, middle, and lower ends of each lake. Error bars denote the 90% confidence interval. Dates of fertilizer applications are noted.

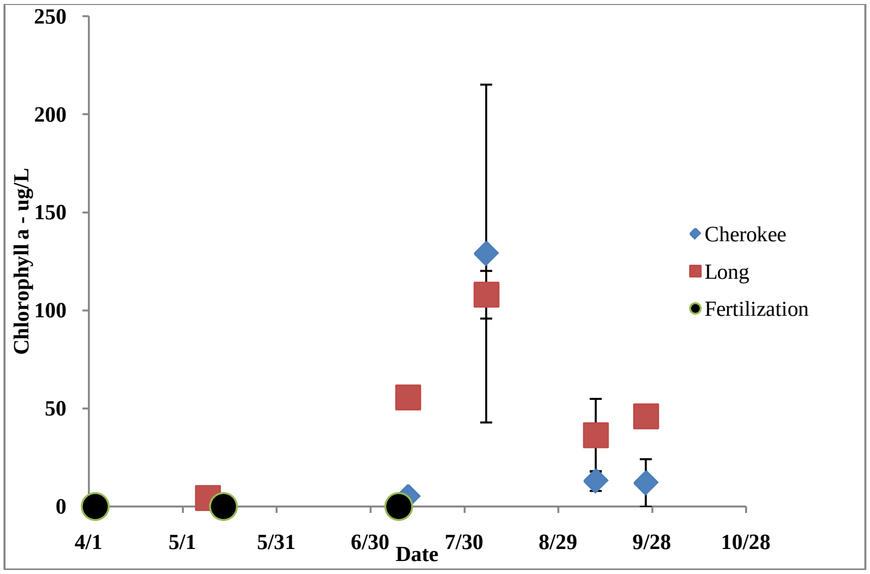

Figure 3. Chlorophyll a levels in lakes Cherokee and John D. Long during 2007. Three water samples were collected each sampling day from the upstream, middle, and lower ends of each lake. Error bars denote the 90% confidence interval. Dates of fertilizer applications are noted.

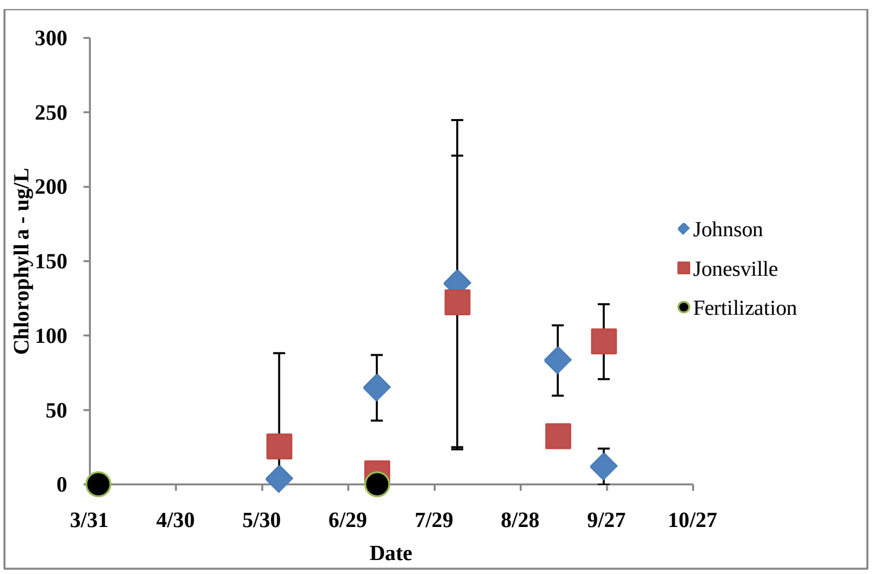

Figure 4. Chlorophyll a levels in lakes Edwin Johnson and Jonesville during 2007. Three water samples were collected each sampling day from the upstream, middle, and lower ends of each lake. Error bars denote the 90% confidence interval. Dates of fertilizer applications are noted.

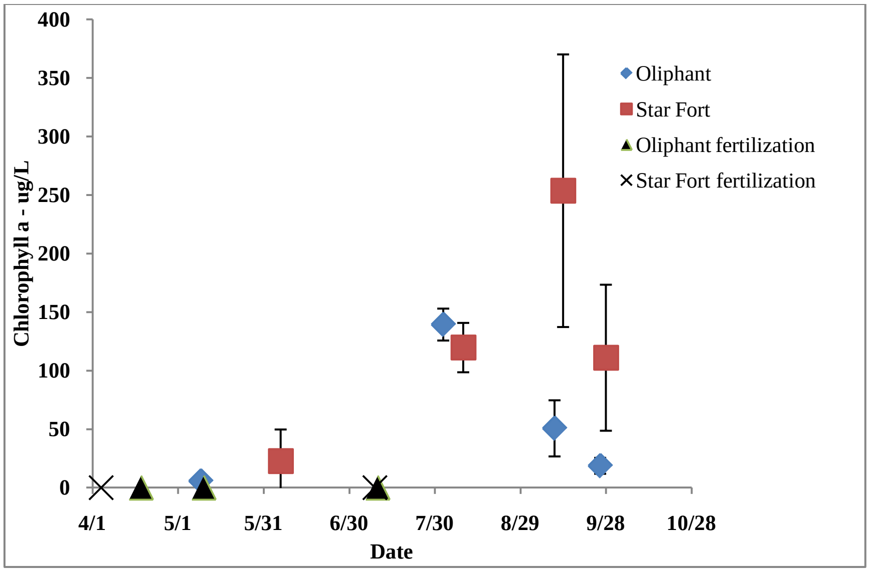

Figure 5. Chlorophyll a levels in lakes Oliphant and Star Fort during 2007. Three water samples were collected each sampling day from the upstream, middle, and lower ends of each lake. Error bars denote the 90% confidence interval. Dates of fertilizer applications are noted.

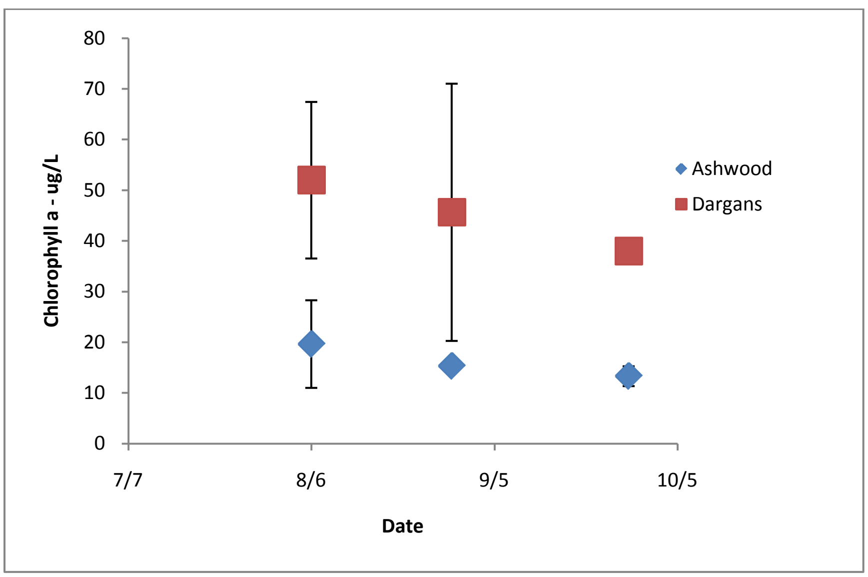

Figure 6. Chlorophyll a levels in Lake Ashwood and Dargans Pond during 2007. Three water samples were collected each sampling day from the upstream, middle, and lower ends of each lake. Error bars denote the 90% confidence interval.

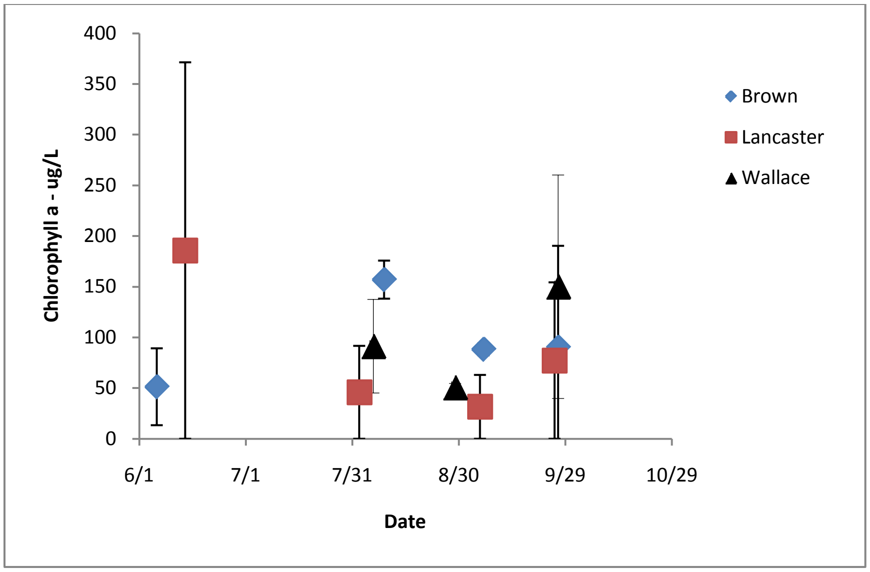

Figure 7. Chlorophyll a levels in lakes Edgar Brown, Lancaster, and Paul Wallace during 2007. Three water samples were collected each sampling day from the upstream, middle, and lower ends of each lake. Error bars denote the 90% confidence interval.

Discussion

This was a first look at the basic water chemistry and fertility of 13 public fishing lakes in South Carolina. The analysis assumes these lakes were randomly sampled, though this is probably not true as State Lake personnel revisited lakes at a regular interval. Nevertheless, the information suggests some important trends. These are:

- Ashwood and Dargans Pond have a consistently low fertility and are not fertilized. The Dargans Pond fishery is limited entry, which would hold down fishing pressure. Lake Ashwood is continually open, providing a local recreational opportunity. Due to the low fertility, innovative management is needed on these lakes.
- Lancaster, Edgar Brown, and Paul Wallace are not fertilized but maintain relatively high fertility throughout the growing season. In the absence of hypereutrophic conditions, these lakes should support 'good' fisheries.

- Of the fertilized lakes, only Star Fort maintained relatively high fertility throughout the growing season, though there was substantial variation.
- Cherokee, Edwin Johnson, Jonesville, John D. Long and Oliphant, are primary examples of fertilized lakes that responded to fertilization but the plankton bloom was relatively short-lived. On lakes such as this, a more in-depth investigation is needed to determine whether more aggressive management (i.e. increased liming and fertilization) to maintain fertility is cost effective. These studies should quantify the average retention time of these lakes.
- In fertilized lakes, chlorophyll peaks were higher in mid-summer than in spring.

Recommendations

- Discuss these results with regional and state lakes staff. Develop a basic, water quality monitoring strategy for state lakes in 2009. On those lakes which seem to only have a short-term ability to maintain production after fertilization, include an assessment of retention time and natural nutrient inflow and outflow.
- Consider a more intensive sampling selected fertilized lakes to follow bloom dynamics.
- This study did not distinguish between fluorescence due to green algae as opposed to that due to blue-green algae, which are not as beneficial to fisheries. Future studies should partition the sources of chlorophyll as this may explain higher chlorophyll peaks in late summer, as opposed to spring.

Prepared By: Jim Bulak Title: Research Coordinator

Job Title: Application of a cohort-structured, bioenergetics-based population model to assess factors affecting condition of brown trout in Lake Jocassee

Period Covered January 1, 2008 – December, 2008

Results and Discussion

Overview

Lake Jocassee supports a highly valued sport fishery for brown trout (*Salmo trutta*) and rainbow trout (*Onchorhynchus mykiss*), but numbers and size of trout (primarily brown trout) in the creel and gill-net catches have declined since the 1980s. Observations of thin trout have heightened recent concern about the trout fishery. Factors potentially influencing abundance, growth, and condition of the trout include abundance and composition of forage fishes, available summer habitat, trout stocking rates and schedules, and intensity of harvest by fishermen. Environmental conditions mediating effects of these factors include winter severity, rainfall, and pumped storage hydropower generation at the Jocassee and Bad Creek stations.

The two main hypotheses about the decline in quality of the brown trout fishery implicate reductions in the forage base, due either to overstocking of trout or to entrainment of forage fishes at the Bad Creek and Jocassee stations.

The main objectives of this project are: 1) to construct a cohort-structured, bioenergetics-based population model for brown trout in Lake Jocassee; and 2) to apply this model to evaluate factors potentially affecting condition of brown trout in Lake Jocassee. The first objective has been accomplished. Work toward the second objective is well underway.

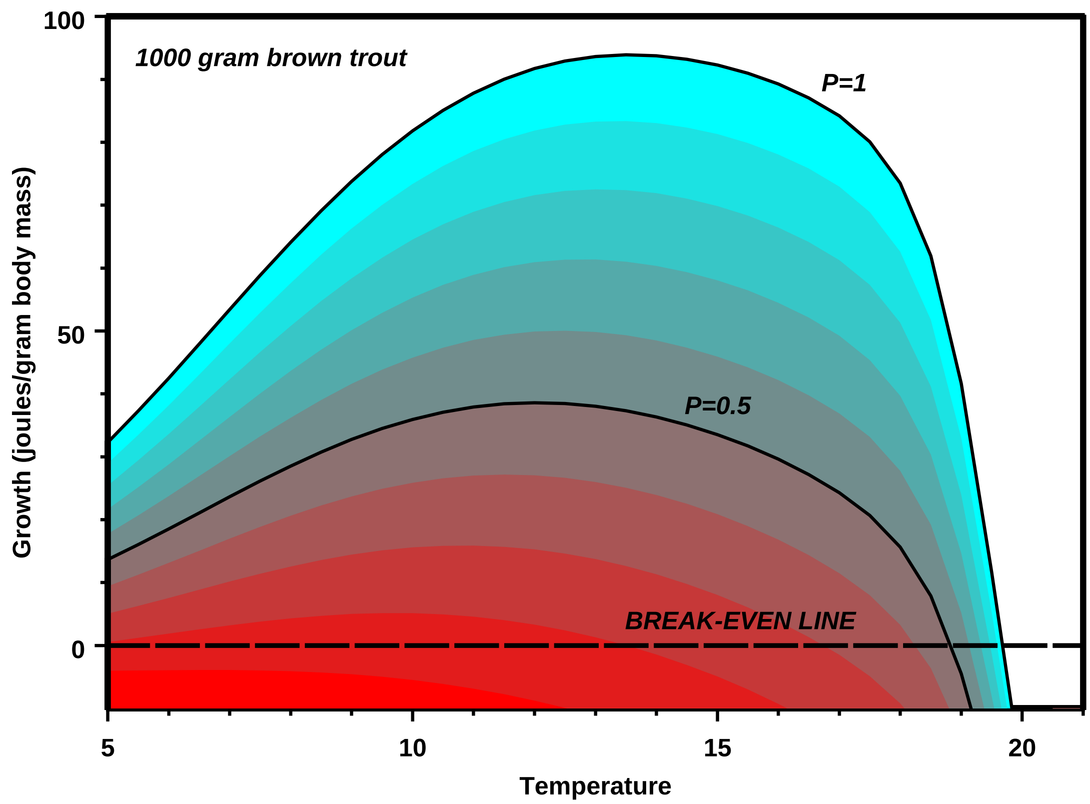

Figure 1. Growth per gram body mass as a function of temperature over a range of feeding rates. Proportions of maximum feeding rate P are shown in increments of 0.1; rates were computed with prey energy density = 4000 joules/gram.

Bioenergetics of brown trout in Lake Jocassee

Bioenergetic models for brown trout have been developed for a variety of applications (Elliott and Hurley, 1999; Hayes, Stark, and Shearer, 2000; Brown, 2004). For our analysis, we chose the model of Dieterman, Thorn, and Andersen (2004) in Fish Bioenergetics 3.0 (Hanson et al., 1997). Negus et al. (2004) subsequently applied this model to brown trout in Lake Superior to assess adequacy of the forage base for predatory fish. Bioenergetic processes explicitly considered in the model are energy gains due to consumption and energy losses due respiration and waste. These processes depend on water temperature and body weight of the fish.

We programmed functions from the Fish Bioenergetics 3.0 model to run in S-Plus (Insightful Corporation, Seattle, WA). S-Plus provides a convenient, powerful platform for implementation of the model, as well as for analysis of model output and supporting data.

Temperature dependency of these bioenergetic processes is illustrated for 1000 g fish (Figure 1). At the maximum feeding rate P=1, the maximum growth rate occurs at 13.5 ºC, and the growth rate remains within 80% of this value over the temperatures ranging from 9-18 ºC. The feeding rate P is defined as the proportion of the maximum possible feeding rate. The break-even point, where consumption just meets maintenance requirements, occurs at just under 20 ºC when P=1. Reducing P slows growth and shifts the break-even point to lower temperatures. Sensitivity to temperature increases with decreasing ingestion rate. At P=0.5, growth remains within 80% of the maximum over the range 8.5-16 ºC, and growth at 18 ºC is just 40% of the maximum. Growth rate per unit body mass decreases with increasing body size, but the effects of temperature are similar.

Currently, the designation for suitable habitat at Jocassee extends up to 20 ºC. The model suggests that temperatures of 18-20 ºC are only marginally suitable for brown trout, depending on availability of forage.

Growth of brown trout in Lake Jocassee

We constructed and tested several temperature regimes based on seasonal variation in temperature profiles in the lake (data from Bill Foris, Duke Power), telemetry studies of temperature selection (Barwick, Foltz, and Rankin, 2004), and other information. To calibrate feeding rates, we compared modeled growth of brown trout with field data from gill netting. Dan Rankin (SC DNR) provided length and weight measurements of brown trout from the cohort stocked in 2006 at age 2. The stocked fish were identified by an adipose fin clip. For growth under the 10-18 ºC temperature regime (Figure 2), brown trout from Lake Jocassee fall generally within the range of sizes predicted using feeding rates set at about half of the maximum.

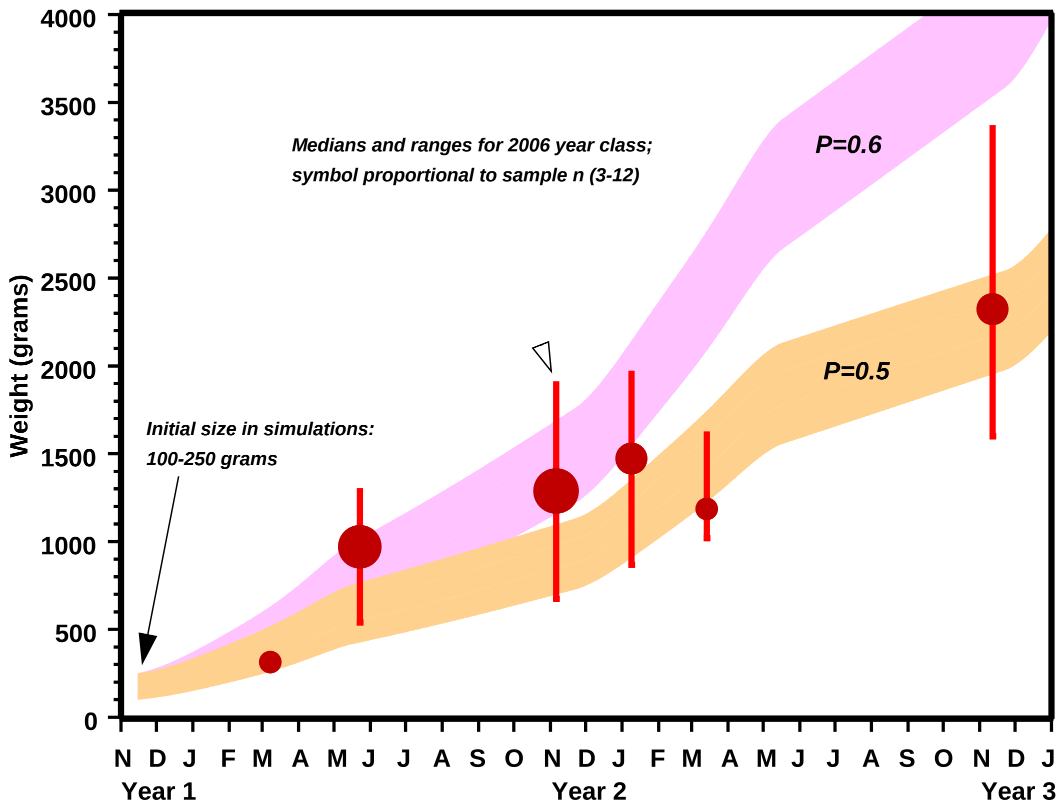

Figure 2. Comparison of simulated growth of brown trout with growth of brown trout from Lake Jocassee. The bands shown results from simulations for feeding rates of P=0.5 and P=0.6 for a cohort experiencing an annual cycle of temperatures from 10 to 18 ºC. Range of initial sizes in simulations was 100 grams (200 mm or 8 inches) to 250 grams (280 mm or 11 inches). Prey energy density was set at 4000 joules/gram. Average size of stocked fish in 2006 in Lake Jocassee was 236 mm (9.3 inches). 'P' is defined as the proportion of the maximum possible feeding rate.

Cohort-structured population model

To estimate demand on the forage base, we need to model the composition and abundance of brown trout in the lake, as well as the bioenergetics of the individual fish. Some important quantities describing the brown trout population are not easily measured in Lake Jocassee using technologies presently available. However, the number of fish stocked annually is known fairly precisely, the annual harvest is known at least approximately, and the natural mortality of fish of harvestable size is assumed to be small in relation to harvest mortality. Natural reproduction is negligible. If stocking levels remain consistent over time, the model shows that we can use this information to estimate the age or size composition and numbers of fish of harvestable size, with a minimum estimate of the number of fish smaller than harvestable size.

Results from the population model demonstrate that the number of harvestable fish that is dying annually is equal to the number of fish reaching harvestable size, if rates remain constant in time. Therefore, if natural mortality is negligible, the annual harvest estimates the annual recruitment to the fishery. The fish not recruited to the fishery have not necessarily died, they simply haven't attained the minimum harvestable size.

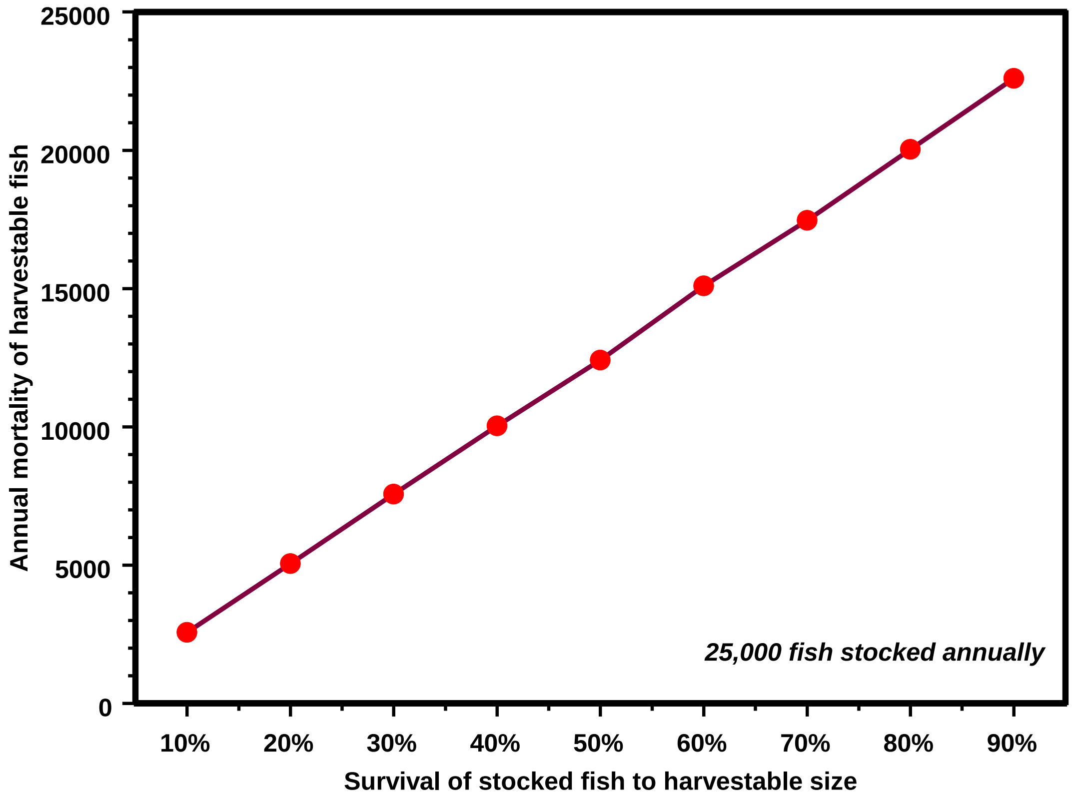

Figure 3. Relation between annual mortality of harvestable fish and survival of stocked fish to harvestable size. Results from simulations with 10-18 ºC annual temperature range, P = 0.6, minimum harvestable size = 685 g. ‘P’ is defined as the proportion of the maximum possible feeding rate.

Under the current stocking program at Lake Jocassee, 25,000 brown trout are stocked annually in November. This program was started in 2005. In preceding years, 47,000 fish were stocked annually. The creel census for 2006 reported only about 500 fish. If the creel census were an accurate and complete measure of mortality, the result would imply that about 2% of the stocked fish were recruited to the harvestable population. If the creel census is assumed to account for only a tenth of the actual mortality, the estimate of recruitment rises only to 20%.

Similar estimates based on the earlier data and higher stocking rates also suggest that a small proportion of the stocked fish eventually enter the fishery.

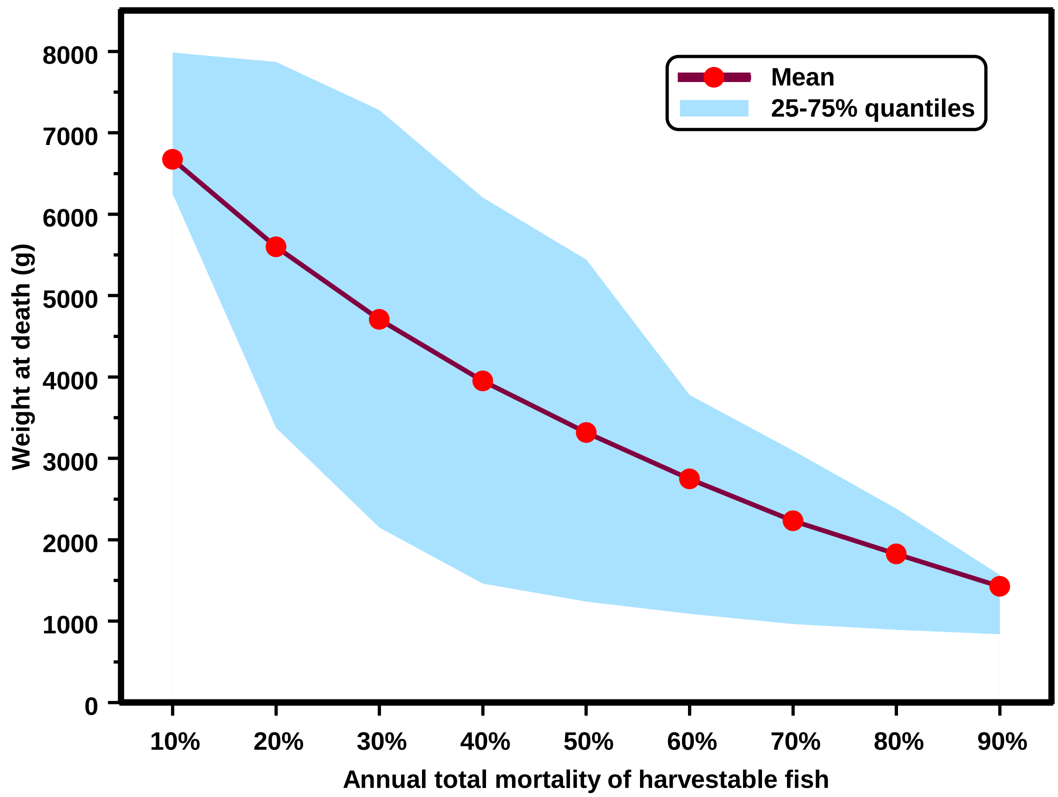

Figure 4. Relation between annual mortality of harvestable fish and weight of fish at death (or harvest). Results from simulations with 10-18 ºC annual temperature range, P = 0.6, minimum harvestable size = 685 g. 'P' is defined as the proportion of the maximum possible feeding rate.

The population of harvestable fish in the lake depends on the survival of stocked fish to harvestable size and on the annual mortality of harvestable fish. Higher annual mortality rates (Figure 4) greatly diminish size of harvested fish.

Estimates of forage requirements

The forage requirement for the brown trout population is extremely sensitive to the population dynamics (Figure 5). The annual forage requirement for a population based on annual stocking of 25,000 fish varies by more than an order of magnitude for the rates illustrated in Figure 5.

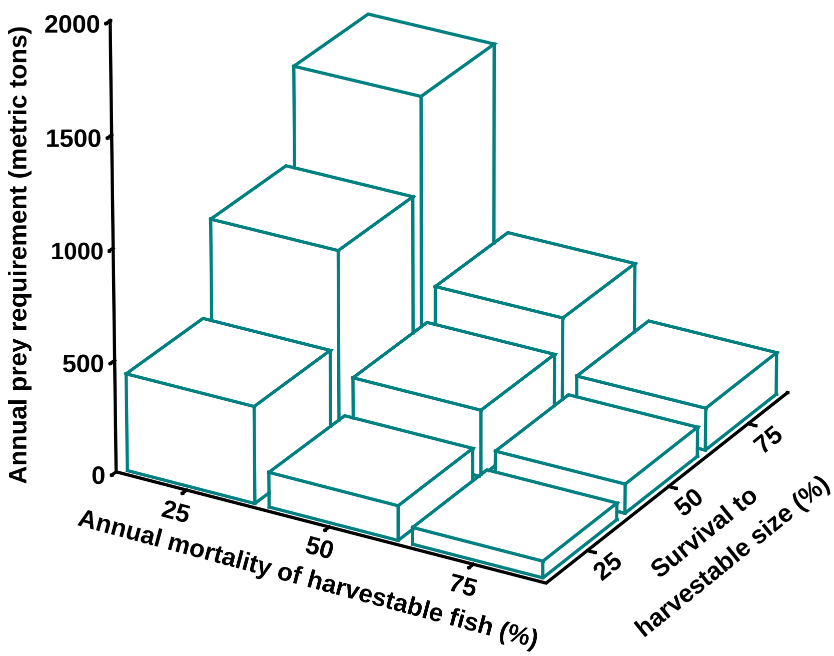

Figure 5. Impact of survival to harvestable size and annual mortality of harvestable fish on annual forage requirement of the brown trout population. Results from simulations with 10-18 ºC annual temperature range, P = 0.5, minimum harvestable size = 685 g, stocked population of 25,000 fish at 150 grams weight. 'P' is defined as the proportion of the maximum possible feeding rate.

Recommendations

Because the project is still in progress, we will defer making any recommendation about managing the trout population.

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Prepared By: Barbara Taylor   Title: Wildlife Biologist III

Job Title: South Carolina Stream Assessment

Period Covered January 1, 2008 – December 31, 2008

Results and Discussion

Savannah River Basin

Fifty-three randomly selected sites were sampled in the Savannah River basin following South Carolina Stream Assessment (SCSA) Standard Operating Procedures (SCDNR 2006). Samples were conducted in the following ecoregions: Blue Ridge (3 samples), Inner Piedmont (9), Outer Piedmont (26), Slate Belt (5), Sand Hills (4), Atlantic Southern Loam Plains (5), and Carolina Flatwoods (1). Nine sites went dry prior to the time of attempted sampling due to prevailing drought conditions, including all six of the original Carolina Flatwoods sites. These sites will be sampled as hydrologic conditions recover and fish recolonization is expected. A subset of the data is currently being entered into the centralized Stream Assessment database in order to test the database's data entry and retrieval applications. Further analysis will be conducted once the database is fully implemented, allowing analysis of the entire SCSA dataset.

Fifteen Priority fish species as identified in the South Carolina Comprehensive Wildlife Conservation Strategy (CWCS; SCDNR 2005) were collected at randomly selected sample sites in the Savannah River basin in 2008 (Table 1). The occurrence and/or relative abundance of species at randomly selected sample sites may represent useful quantitative criteria for re-assessing Priority status in the upcoming revision of the CWCS and will be explored in this role.

Table 1. Priority fish species (SCDNR 2005) collected from randomly selected sample sites in the Savannah River basin in 2008.

Common Name	Scientific Name	SCDNR Conservation Priority
American eel	*Anguilla rostrata*	Highest
Savannah darter	*Etheostoma fricksium*	Highest
Christmas darter	*Etheostoma hopkinsi*	Highest
Redeye bass	*Micropterus coosae*	Highest
Smoky sculpin	*Cottus bairdi*	High
Blackbanded sunfish	*Enneacanthus chaetodon*	High
Turquoise darter	*Etheostoma inscriptum*	High
Mud sunfish	*Acantharchus pomotis*	Moderate
Snail bullhead	*Ameiurus brunneus*	Moderate
Flat bullhead	*Ameiurus platycephalus*	Moderate
Central stoneroller	*Campostoma anomalum*	Moderate
Rosyface chub	*Hybopsis rubrifrons*	Moderate
Warpaint shiner	*Luxilus coccogenis*	Moderate
Notchlip redhorse	*Moxostoma collapsum*	Moderate
Lowland shiner	*Pteronotropis stonei*	Moderate

Saluda River Basin

Thirty-four randomly selected sites in the Saluda River basin were sampled from the following ecoregions: Blue Ridge (2 samples), Inner Piedmont (4), Outer Piedmont (21), and Slate Belt (7). Drought-affected sites that went dry (n=5) will be re-visited as described for the Savannah basin above. Seventeen Priority fish species were collected altogether from random sample sites in the Saluda River basin (Table 2).

Table 2. Priority fish species collected from randomly selected sample sites in the Saluda River basin in 2008.

Common Name	**Scientific Name**	**SCDNR Conservation Priority**
American eel	*Anguilla rostrata*	Highest
Saluda darter	*Etheostoma saludae*	Highest
Redeye bass	*Micropterus coosae*	Highest
Santee chub	*Cyprinella zanema*	High
Carolina fantail darter	*Etheostoma flabellare*	High
Seagreen darter	*Etheostoma thalassinum*	High
Piedmont darter	*Percina crassa*	High
Snail bullhead	*Ameiurus brunneus*	Moderate
Flat bullhead	*Ameiurus platycephalus*	Moderate
Central stoneroller	*Campostoma anomalum*	Moderate
Greenfin shiner	*Cyprinella chloristia*	Moderate
Thicklip chub	*Cyprinella labrosa*	Moderate
Fieryblack shiner	*Cyprinella pyrrhomelas*	Moderate
Highback chub	*Hybopsis hypsinotus*	Moderate
Rosyface chub	*Hybopsis rubrifrons*	Moderate
Notchlip redhorse	*Moxostoma collapsum*	Moderate
V-lip redhorse	*Moxostoma pappillosum*	Moderate

Estimation of Stream Resource Parameters

A primary objective of the South Carolina Stream Assessment (SCSA) is the development of statewide estimates of stream resource parameters (Scott 2008). This is accomplished through a simple random sampling design employing river basin and ecoregion (Griffith et al. 2002) strata, or "ecobasins" (Table 3), with stream reach as the sampling unit. Data are collected on a wide array of physical, chemical, and biological variables characterizing the wadeable streams of South Carolina. Quantitative measurements for at least 12 physical/geomorphological, 21 chemical/toxicological, and 12 biological variables are typically obtained from each sample reach (Scott 2008). Many additional measures are computed from these variables, reflecting the multitude of parameters for which statewide estimates of mean and variance may be obtained. Statistical estimates of resource parameters serve as baseline measures of the average and variability in stream conditions across the state, providing a look at overarching spatial patterns. Further, these estimates represent standards to which individual stream reaches—and watersheds—can be compared, providing a means of ranking watersheds for conservation prioritization. For this report, estimates of mean and variance for selected physical, chemical, and biological variables are computed for three large coastal plain ecobasins as a preliminary assessment of resource conditions.

The population of wadeable streams as defined by the SCSA encompasses all 100-m freshwater stream reaches draining watersheds of 4 km^2 to 150 km^2. As an inherent property of stream networks, smaller streams comprise a greater proportion of total stream length on the landscape than larger streams. That is, the number of reaches draining smaller watersheds is greater than that draining larger watersheds. To reflect the actual distribution of watersheds, stream reaches were further categorized by watershed area into three mutually exclusive classes: Class 1: 4-24.99 km^2; Class 2: 25-74.99 km^2; Class 3: 75-150 km^2. By identifying the populations of each of these classes (i.e., number of 100-m reaches) at the scale of interest (e.g., ecobasin or statewide), parameter estimates can be weighted according to these values. This produces estimates of the average and variance in resource conditions that are representative of the total wadeable stream population. Formulae for the computation of these estimates in the SCSA experimental design were developed by Dr. Mark Scott (SCDNR) in collaboration with Dr. John Grego (University of South Carolina).

Table 3. Ecobasins of South Carolina as defined in the SCSA.

River Basin	**Ecoregion**	**Ecobasin Code**
Ashepoo-Combahee-Edisto (ACE)	Atlantic Southern Loam Plains	ACEASLP
	Carolina Flatwoods	ACEFLATW
	Sand Hills	ACESAND
Broad	Blue Ridge	BRBLUER
	Inner Piedmont	BRIPIED
	Outer Piedmont	BROPIED
	Slate Belt	BRSLATE
Catawba-Wateree	Atlantic Southern Loam Plains	CWASLP
	Outer Piedmont	CWOPIED
	Sand Hills	CWSAND
	Slate Belt	CWSLATE
Lower Santee	Atlantic Southern Loam Plains	LSASLP
	Carolina Flatwoods	LSFLATW
	Sand Hills	LSSAND
Pee Dee	Atlantic Southern Loam Plains	PDASLP
	Carolina Flatwoods	PDFLATW
	Sand Hills	PDSAND
	Slate Belt	PDSLATE
Saluda	Blue Ridge	SALBLUER
	Inner Piedmont	SALIPIED
	Outer Piedmont	SALOPIED
	Sand Hills	SALSAND
	Slate Belt	SALSLATE
Savannah	Atlantic Southern Loam Plains	SAVASLP
	Blue Ridge	SAVBLUER
	Carolina Flatwoods	SAVFLATW
	Inner Piedmont	SAVIPIED
	Outer Piedmont	SAVOPIED
	Sand Hills	SAVSAND
	Slate Belt	SAVSLATE

The estimated mean response is defined by the formula:

;

estimated variance is computed as:

.

Terms and definitions are presented in Table 4 (J. Grego, University of South Carolina).

Table 4. Terms and definitions for computing estimated mean and variance of statewide stream resource parameters.

Term	Definition
	Stratum index (h = 1,..., L)
	Number of 100-m reaches in stratum h
	Total number of 100-m stream reaches in SC
	Number of sampled 100-m reaches in stratum h
	Total number of sampled 100-m stream reaches
y_{hi}	Response for reach i in stratum h
	Mean response for stratum h
	Estimated mean response
	Sample variance for stratum h

Population sizes (i.e., the total number of 100-m stream reaches) for each ecobasin and watershed area class were obtained from the master database containing all 100-m stream reaches in South Carolina as derived by a digital elevation model (DEM)-based Geographic Information Systems (GIS) delineation program. Each point (row) in the database represents a 100-m stream reach and is assigned a unique site identification number. The database was filtered by ecobasin and then watershed area to obtain populations (N_h) by watershed area class for each of the 30 ecobasins (Table5).

Table 5. Number of 100-m stream reaches by watershed area class for the 30 ecobasins of the SCSA.

		Number of 100-meter reaches (N_h)			
		Class 1	**Class 2**	**Class 3**	
Ecobasin	**Area (km^2)**	**4-24.99 km^2**	**25-74.99 km^2**	**75-150 km^2**	**Total**
ACEFLATW	10637.40	22197	5687	2000	29884
PDFLATW	8804.66	17016	5302	2052	24370
BROPIED	8608.54	15601	5094	1828	22523
PDASLP	7131.14	13464	4288	1996	19748
SAVOPIED	4588.57	8272	2596	1182	12050
ACEASLP	3685.31	6888	2717	538	10143
SALOPIED	3955.55	6640	2200	969	9809
CWOPIED	3354.84	5368	2201	970	8539
PDSAND	3078.98	5687	1701	538	7926
LSASLP	2138.73	3184	1234	542	4960
ACESAND	2000.89	3452	884	595	4931
SAVSAND	1802.77	3235	930	495	4660
LSFLATW	1588.63	2903	1170	244	4317
SAVIPIED	1483.74	2456	822	161	3439
SAVSLATE	1373.43	1982	986	242	3210
SALSLATE	1463.32	2120	635	404	3159
SAVFLATW	848.71	2155	661	168	2984
LSSAND	1193.32	1691	684	177	2552
CWSLATE	813.02	1327	705	385	2417
CWASLP	819.10	1623	452	317	2392
CWSAND	998.08	1737	407	241	2385
PDSLATE	710.58	1333	580	366	2279
SAVASLP	752.18	1605	565	68	2238
BRSLATE	566.48	1229	376	183	1788
SAVBLUER	734.07	1119	343	226	1688
BRIPIED	474.08	1192	284	146	1622
SALIPIED	487.09	1093	247	175	1515
SALBLUER	397.44	799	171	289	1259
SALSAND	177.46	203	75	24	302
BRBLUER	57.93	73	0	0	73
Totals	**74726.03**	**137644**	**43997**	**17521**	**199162**

A total of 199,162 stream reaches (19,916 km) comprises the population of freshwater streams draining watersheds of 4 km^2 to 150 km^2 in South Carolina (Table 5). Ecobasin populations range from 73 reaches (BRBLUER) to 29,884 reaches (ACEFLATW). The mean wadeable stream density in South Carolina is 0.27 km/km^2, ranging from 0.13 (BRBLUER) to 0.35 (SAVFLATW).

Estimates of selected physical, chemical, and biological variables were computed for three large coastal plain ecobasins sampled between 2006-2007: PDASLP, PDFLATW, and ACEFLATW. These samples reflect prevailing drought conditions in which many sample reaches exhibited overall reductions in wetted habitat and associated biological measures (e.g., decreased fish species richness and abundance). In some cases, sample reaches became partially or entirely dewatered. While partially dewatered reaches in which biological sampling was conducted were included in this analysis, completely dry reaches were excluded from the dataset. Exclusion of dry sites and other circumstances have precluded the attainment of target sample sizes for certain ecobasins; the following computations represent preliminary estimates based on lower sample sizes. Final estimates will be reported once the target sample size—proportional to ecobasin area—is met for such ecobasins.

Marion (2008) found certain measures of organic substrate composition to be closely related to characteristics of fish assemblage structure in South Carolina coastal plain streams. These organic substrate measures included the proportion of large woody debris (LWD) and proportion of coarse organic debris (= LWD + fine woody debris [FWD]) occurring in sample reaches. Methods are described in detail in Marion (2008). Ecobasin estimates of these organic substrate measures would therefore be useful in examining potential determinants of fish assemblage structure across the coastal plain and potentially statewide. Ecobasin estimates of mean and variance in proportion of LWD, proportion of coarse organic debris, fish species richness, relative abundance of Priority fishes (SCDNR 2005), and pH were calculated for the aforementioned three ecobasins (Table 6).

Table 6. Ecobasin estimates of mean and variance (bold font) of proportion of large woody debris (%LWD), proportion of coarse organic debris (%COD), fish species richness, relative abundance of Priority fishes, and pH for three South Carolina coastal plain ecobasins. Values for %LWD, %COD, and relative abundance of Priority fishes are presented as proportions.

				%LWD		%COD		Fish Species Richness		Relative Abundance of Priority Fishes		pH	
Ecobasin	**Class**	**N**	**n**	**Mean**	**Variance**	**Mean**	**Variance**	**Mean**	**Variance**	**Mean**	**Variance**	**Mean**	**Variance**
PDASLP	1	13464	13	0.01	0.00020	0.12	0.00705	8.38	29.42308	0.01	0.00074	6.16	0.20632
	2	4288	6	0.05	0.00040	0.22	0.01541	16.00	20.80000	0.02	0.00010	6.32	0.01670
	3	1996	3	0.09	0.00172	0.28	0.00303	19.33	37.33333	0.01	0.00001	6.53	0.28603
	Total	19748	22	**0.03**	**0.00002**	**0.16**	**0.00038**	**11.14**	**1.34122**	**0.01**	**0.00003**	**6.23**	**0.00847**
PDFLATW	1	17016	11	0.04	0.00411	0.16	0.01273	8.55	12.67273	0.01	0.00020	7.28	0.17006
	2	5302	10	0.06	0.00417	0.16	0.01969	13.30	24.23333	0.01	0.00031	7.01	0.68989
	3	2052	2	0.12	0.02880	0.33	0.16619	20.00	2.00000	0.01	0.00001	7.40	0.12005
	Total	24370	23	**0.05**	**0.00030**	**0.18**	**0.00125**	**10.54**	**0.68288**	**0.01**	**0.00001**	**7.23**	**0.01122**
ACEFLATW	1	22197	15	0.07	0.00602	0.18	0.01414	6.53	24.83810	0.01	0.00056	6.84	0.26744
	2	5687	19	0.09	0.01029	0.25	0.02262	9.79	22.06433	0.04	0.00395	6.64	0.64450
	3	2000	6	0.23	0.02635	0.39	0.05356	16.83	9.36667	0.04	0.00233	6.76	0.65338
	Total	29884	40	**0.09**	**0.00026**	**0.21**	**0.00060**	**7.84**	**0.96183**	**0.02**	**0.00003**	**6.80**	**0.01154**

General spatial patterns in parameter estimates are apparent among the three ecobasins. On average, the ACEFLATW exhibited a greater proportion of LWD and coarse organic debris than the PDASLP and PDFLATW (Table 6). Interestingly, the ACEFLATW ranked lowest in fish species richness. This may reflect seasonal and long-term hydrology, as the ACEFLATW was sampled later in the summer of 2007 than the PDFLATW, when stream flows and resulting habitat availability for fishes were decreasing as a result of seasonal patterns and an extended drought. While fish species richness was low in the ACEFLATW, this ecobasin displayed the greatest relative abundance of Priority fishes. Further analysis is needed to determine if this is a product of habitat quality or rather a greater inherent occurrence of Priority species in the ACEFLATW relative to the PDASLP and PDFLATW.

Recommendations

The variables for which ecobasin estimates of mean and variance are presented in this report represent only a handful of the data being collected in the SCSA. Estimates will ultimately be computed for all variables and ecobasins of the state, producing a framework of baseline physical, chemical, and biological stream resource information from which spatial patterns in stream conditions can be assessed. The spatial estimates generated from sampling of randomly selected sites complement the estimates of temporal variability obtained from annual sampling of fixed reference sites.

Potential applications of the data in a conservation context include the development of rarity indices for aquatic species (M. Scott, SCDNR, pers. comm.). For example, species occurrence and/or relative abundance estimates obtained from a known subsample of stream reaches could be expanded to produce ecobasin- and statewide estimates based on the known populations (i.e., total length) of stream reaches at these larger spatial scales (Table 5).

Essentially, a “probability of occurrence” could be computed for each species, providing a means of ranking species in terms of their rarity at spatial scales of interest.

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Prepared By: Kevin Kubach Title: Fisheries Biologist

Job Title: Crayfishes and shrimps from the Statewide Stream Assessment

Period Covered January 1, 2008 – December 31, 2008

Results and Discussion

Collections of crayfishes and shrimps from the Saluda and Savannah river basins were made at 27 of 34 sites and 47 of 53 sites, respectively, between April and October 2008 as part of the Statewide Stream Assessment. A total of 6 to 7 species of crayfishes and 1 species of shrimp were identified from localities in the Saluda River basin, and 7 to 8 species of crayfishes and 1 species of shrimp were identified from sites in the Savannah River basin. Species richness ranged from 0–4 species, and was usually one or two species per site. Identifications of specimens from some sites cannot be made at this time as the samples consisted of juveniles or females only. Supplemental collecting at these sites in the future would provide additional specimens that would allow for positive identifications.

During the Savannah River basin surveys, collections of one crayfish, *Procambarus chacei*, which is listed as "High" conservation concern (Kohlsaat et al., 2005), were made at four sites, but all of these collections fall within the known range of the species. The most common species was *Cambarus latimanus*, which is a widely-distributed species across several states. The non-native species, *Procambarus clarkii*, was collected at two locations in the Saluda River drainage.

Sites at which no crayfishes or shrimps were collected might have some individuals present at times, but sampling in late summer and fall could have contributed to lower numbers of crayfishes being collected for some species. Drought conditions in 2008 (as in 2007) also could have contributed to changes in crayfish abundance at some sites.

In 2007 a State Wildlife Grants project was initiated to study life history and taxonomy of *Procambarus echinatus* from October 2007 to September 2008. All historic localities were georeferenced, and many new collections were made during 2007 and 2008, including several semi-quantitative and one quantitative sample. Egg data were gathered from seven females in 2008 and commensal organisms were collected as well (ostracods and branchiobdellids). The results of the study will be completed by February/March 2009.

Mussels and snails were kept from sites within the Saluda and Savannah river basins as well, but most of these collections have not been identified yet. Mussels were recorded from 1 site in the Saluda River basin, whereas mussels and snails were found at 7 and 2 sites, respectively, in the Savannah River basin. The non-native, *Corbicula* sp., was found at 11 sites in the Savannah River basin and 5 sites in the Saluda River basin.

Recommendations

Continue to collect decapods and mollusks during ecobasin surveys because in 2006-2008 new 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.

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Prepared By: William Poly Title: Aquatic Biologist

Job Title: Recovery of the Main Stem Reedy River Fish Community from a Major Oil Spill.

Period Covered January 1, 2008 – December 31, 2008

Results and Discussion

In response to the June 26, 1996 diesel oil pipeline spill of 22,800 barrels (957,600 gallons) that killed an estimated 35,000 fish along 37 km of the Reedy River south of Greenville, South Carolina (Rankin et al. 1996), a longitudinal sampling framework was implemented to monitor the recovery of the affected river section. Five fixed sites—an undisturbed reference site approximately 5 km upstream of the oil spill origin, and four sites within the disturbed section ranging from 2-30 km downstream—were each sampled once in August 1996 (1.5 months post-disturbance), October 1996 (4 months post-disturbance), October 1997 (16 months post-disturbance), October 1998 (28 months post-disturbance), October 2000 (52 months post-disturbance), September-October 2005 (112 months post-disturbance), and September-October 2008 (148 months post-disturbance) (Table 1). Site A was not sampled in August 1996; therefore, a total of 34 samples have been conducted to date.

Table 1. Reedy River recovery monitoring study sites relative to the oil spill origin.

Site	Type	Position Relative to Spill Site (river km)
833-REF	Reference	5.4 km upstream
845-A	Disturbed	1.8 km downstream
835-B	Disturbed	14.2 km downstream
778-C	Disturbed	20.6 km downstream
070-D	Disturbed	29.5 km downstream

Kubach et al. (2006) found that fish assemblages within disturbed Reedy mainstem sites showed initial signs of recovery in 1997, species re-colonization in 1998, and that overall recovery was largely achieved by 2000 (4.3 years post-disturbance). Analysis of 2005 data was statistically similar to 2000 data, reiterating that recovery from the oil-spill was mostly complete.

Sampling of all 5 Reedy mainstem sites was conducted again in 2008, and the preliminary results and characterization of that sampling effort will be the focus of this report. Site locations and 2008 sample dates are listed in Table 2.

Table 2. Reedy mainstem sample locations and 2008 sample dates.

Stream Name	Sample Date	Latitude (°N)	Longitude (°W)
Reedy 833-REF	9/29/2008	34.8052	82.30559
Reedy 845-A	9/30/2008	34.64606	82.29235
Reedy 835-B	10/6/2008	34.58015	82.27396
Reedy 778-C	10/6/2008	34.55256	82.24178
Reedy 070-D	10/7/2008	34.50508	82.2223

Fish sampling consisted of three-pass depletion electrofishing by 12-15-person crews. In previous Reedy sampling efforts, a combination of tandem backpack and barge-mounted electrofishing gear were used. However, due to extremely low flows of 2008 (avg. 40-50 cfs), only tandem backpack gear were used in sites 833-REF, 845-A, 835-B, and 778-C. A combination of tandem backpack and barge electrofishing gear were used in site 070-D, which was characterized by greater depths than the upstream sites. The entire wetted channel was sampled over a reach length of 150 m, with the same reach sampled year to year for each site. All fish were collected and identified after each pass. Questionable specimens were preserved on site and identified at a later time.

In addition to fish collection, a habitat assessment of all 5 Reedy mainstem sites was conducted in 2008. Habitat was quantified using the ‘zig-zag’ method of habitat sampling (Bevenger and King 1995). This method requires traversing a random zig-zag longitudinal transect in a downstream to upstream direction along the sample reach. A total of 50 individual measurements are taken along the transect, recording depth(m), velocity (m/sec, at 60% depth), and substrate size (if inorganic) or type (if organic).

A total of 3,017 fish representing 22 species were collected among all sites in 2008 (Table 3). Seven metrics of fish assemblage composition were generated to generally compare the 2008 sampling effort to identical metrics calculated for all previous years sampling efforts. Descriptive ecological statistics, species richness and Shannon diversity were generated using PC-ORD v.5 (McCune and Mefford 2006). Other metrics generated included relative abundance of South Carolina species of concern (SCDNR 2005), shiner/sucker/darter richness, relative abundance of benthic specialists, relative abundance of fluvial specialists, and relative abundance of sunfish. A summary of all metrics for all sample periods is cited in Table 4.

Table 3. Species collected in Reedy mainstem sites in 2008.

Species \ Site		833-REF	845-A	835-B	778-C	070-D	Total
Bluehead chub		1	1	1	1	1	5
Bluegill		1	0	1	1	1	4
Channel catfish		0	0	1	1	1	3
Flat bullhead		0	0	0	2	5	7
Flier		0	0	0	0	2	2
Greenfin shiner		6	2	55	60	45	168
Greenfin shiner		0	1	0	0	1	2
Gizzard shad		0	0	0	0	6	6
Largemouth bass		7	4	5	2	12	30
Mosquito fish		96	129	241	24	172	662
Northern hogsucker		228	47	55	66	58	454
Pumpkinseed		0	0	0	0	108	108
Redbreast sunfish		258	50	105	57	109	579
Redfin pickeral		0	0	0	0	2	2
Snail bullhead		0	0	0	1	6	7
Sandbar shiner		0	0	1	1	1	3
Seagreen darter		1	0	1	1	0	3
Striped jumprock		0	0	1	0	0	1
Spottail shiner		1	1	1	1	1	5
Warmouth		0	0	0	0	8	8
White catfish		0	0	0	0	2	2
Yellowfin shiner		564	316	46	14	16	956
Total		1163	551	514	232	557	

Table 4. Summary table for seven metrics of community composition across all sample dates.

Sample Period	Months Post-Disturbance	Site	Raw Abundance	Spp. Richness	Shannon Diversity	% Spp. Of Concern	shiner/sucker/darter richness	% Benthic	% Fluvial	% Sunfish
8/1/1996	1.5	833-Ref	268	15	1.93	0	1	31.72	1.87	38.06
		835-B	14	4	1.12	0	0	0	0	57.14
		778-C	31	9	1.58	0	0	9.68	0	80.65
		070-D	118	10	0.73	0	1	1.69	0.85	92.37
10/1/1996	4	833-Ref	266	12	2.06	0	1	28.95	9.02	30.45
		845-A	126	15	2.10	0	0	26.19	0	34.92
		835-B	35	9	1.50	0	0	0	0	68.57
		778-C	49	10	1.70	0	1	2.04	2.04	83.67
		070-D	125	15	1.42	0	3	9.60	2.40	74.40
10/1/1997	16	833-Ref	485	14	1.88	0	1	30.72	0.21	24.54
		845-A	431	13	1.20	0	1	14.85	0.70	9.74
		835-B	576	21	1.50	0	0	6.25	0	30.56
		778-C	153	15	2.00	0	0	20.26	0	42.48
		070-D	309	16	1.99	0	2	13.92	0.32	40.78
10/1/1998	28	833-Ref	616	14	1.76	0	1	44.16	0	22.24
		845-A	211	13	2.01	0	1	31.75	1.90	25.59
		835-B	192	19	2.02	0	3	12.50	7.29	64.06
		778-C	113	17	2.09	0	1	15.04	0.88	64.60
		070-D	211	14	1.63	0	0	23.22	0	71.09
10/1/2000	52	833-Ref	276	12	1.69	0	1	17.75	0	50.72
		845-A	205	10	1.80	0	1	21.46	1.95	40.49
		835-B	232	19	2.29	0	2	18.97	5.60	56.03
		778-C	163	15	2.20	0	3	31.29	6.13	47.85
		070-D	439	22	2.41	0	3	15.72	4.10	57.63
10/1/2005	112	833-Ref	768	15	2.19	0	2	5.86	22.92	30.47
		845-A	600	17	1.99	0	2	10.83	7.83	22.83
		835-B	494	20	2.19	0.20	4	15.79	1.82	37.04
		778-C	391	21	2.53	0	3	21.23	3.07	42.20
		070-D	561	22	2.39	0.36	4	13.37	2.14	40.46
10/1/2008	148	833-Ref	1561	10	1.72	0.64	3	0.64	9.61	17.23
		845-A	748	9	1.59	0	2	0	8.16	7.22
		835-B	872	13	2.10	1.61	5	2.18	27.98	15.37
		778-C	453	14	2.19	1.77	4	5.08	30.68	14.13
		070-D	881	20	2.02	0	3	2.72	0.45	60.16

Several coarse measurements of habitat were derived for each site from the ‘zig-zag’ habitat assessment. Means and standard deviations were calculated for depth and velocity. In addition, the median particle size was extracted, as well as the percent of observations as organic substrate. Results of an ANOVA suggested that site 070-D had a significantly greater mean depth, and significantly slower mean velocity than all of the upstream sites. These ANOVA results indicated that site 070-D was better characterized as a pool habitat than its upstream counter parts, which were more riffle or glide habitats. Summarized measurements from the habitat assessment are listed in Table 5.

Table 5. Summary table for ‘zig-zag’ habitat assessments conducted at individual sites.

Site	Mean Depth (m)	SD Depth	Mean Velocity (m/sec)	SD Velocity	Median Inorganic Particle Size (mm)	% of Observations as Organic Substrate
833-Ref	0.34	0.20	0.30	0.21	1	28.00
845-A	0.46	0.24	0.28	0.15	0.5	38.00
835-B	0.42	0.23	0.29	0.15	1	40.00
778-C	0.31	0.16	0.28	0.15	1	42.00
070-D	0.60	0.27	0.19	0.13	1	34.00

2008 Summary

Sampling conditions for 2008 were generally characterized by low water conditions due to a prolonged period of drought. Flow conditions at the time of the 2008 sample were approximately 40-50 cfs, and historic average flows since the time of the oil spill have normally ranged from 130-300 cfs (USGS historical flow data – Reedy River above Fork Shoals). These low flow conditions prompted the use of a different sampling methodology (primarily backpack electroshocking), as well as presumably altered ‘normal’ habitat conditions and fish distributions. Several changes in species presence/absence were observed in 2008. The following species were absent or displayed greatly reduced abundances in 2008 compared to previous sampling dates: Black crappie (Pomoxis nigromaculatus), Green sunfish (Lepomis cyanellus), Margined madtom (Noturus insignis), White catfish (Amerius catus), Yellow bullhead (Amerius natalis), and Flat bullhead (Amerius platycephalus). In addition, the following species were generally found in greater abundances than in previous sampling events: Yellowfin shiner (Notropis lutipinnis), Spottail shiner (Notropis hudsonius), Sandbar shiner (Notropis scepticus), Greenfin shiner (Cyprinella chloristia), and Seagreen darter (Etheostoma thalassinum). In general, there were observed decreases in Ictalurid species, and general increases in Cyprinid species (specifically shiner spp.). Presumably the differences in community observed in 2008 may reflect changes in habitat conditions due to low sustained flows. However, these findings may warrant further investigation.

Looking at Table 4, which compares 7 metrics of community composition across all years of sampling, we can see general trends that have emerged since 1996. Of particular interest is that the abundance of SC species of concern (primarily represented by SGD: Etheostoma thalassinum) has increased, beginning in 2005 and continuing through 2008. Interestingly, there were no SC species of concern in any of the sites (including the reference site) prior to 2005. This may indicate a more 'general', long-term recovery of the Reedy River over time – not necessarily related to the recovery from the oil spill. In addition, the richness of shiner/sucker/darter species has increased over time in all sites, including the reference site. This finding may also indicate that the Reedy is experiencing a long-term recovery unrelated to the oil spill. The abundance of benthic specialists has generally increased over time since the spill, but that increase was not reflected in the 2008 sample, where benthic specialists (primarily ictalurids) greatly decreased relative to previous years. Again, this change may be due to the low water conditions of 2008 and resultant changes in habitat and fish distributions. The abundance of fluvial specialists has also generally increased over time. Interestingly, 2008 marks the year where the highest abundances of fluvial specialists were observed, in some cases representing 25-30% of all species captured at a given site. The abundances of sunfish among sites were relatively low for 2008 (compared to other years) in all sites except site 070-D, which again, significantly deviated in habitat conditions from the other sites (i.e. displayed a significantly greater average depth). Greater average depths at site 070-D may have provided more suitable habitat for sunfish species – more resembling a pool environment than the other upstream sites.

Recommendations

The Reedy River oil spill represents a valuable empirical context from which to address disturbance in aquatic community ecology. Ensuing efforts will be aimed at further analyzing and interpreting the data and producing a completion report as well as manuscript for publication in an applicable scientific journal. An additional sample is scheduled for 2012, and funding may be sought for future sampling to analyze the more general recovery/decline of the Reedy River within the context of an urbanizing landscape.

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Prepared By: Cathy Marion   Title: Fisheries Biologist

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

Period Covered January 1, 2008 – December 31, 2008

Results and Discussion

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.

Fish sampling was conducted during the summers of 2005 and 2006. Fifteen Reedy River tributary sites were selected under a criterion framework based on catchments at least 1km upstream of the Reedy mainstem, catchment size of at least 5 km^2, and absence of dams between the sample site and the mainstem. Fish sampling followed the SCDNR standard operating procedures (SCDNR 2003). Sample sites, sample dates, watershed area, and site locations are cited in Table 1. Thirty-three species were collectively present (2005 and 2006) among the fifteen Reedy River tributary sites (Table 2). Nine metrics of fish assemblage composition were generated to rank observed 'biological integrity' by site (Table 3). Descriptive ecological statistics, species richness and Shannon diversity, were generated using PC-ORD (McCune and Mefford 2006). Other metrics generated included shiner/sucker/darter richness, relative abundance of SC species of concern (SCDNR 2005), relative abundance of benthic specialists, relative abundance of fluvial specialists, relative abundance of sunfish, relative abundance of invasive/non-native species, and relative abundance of each sites dominant species.

Table 1. Reedy tributary sample sites, watershed area, coordinate location, and sample dates.

Reedy River Tributary Stream	Watershed Area (km2)	Latitude (°N)	Longitude (°W)	2005 Sample Date	2006 Sample Date
Baker Creek	10.2195	34.66114	82.34817	6/22/2005	6/29/2006
Baldwin Creek	5.0211	34.72433	82.30769	7/14/2005	6/6/2006
Beaverdam Creek	15.687	34.49901	82.23488	10/11/2005	6/17/2006
Brushy Creek	23.3181	34.79914	82.3919	10/18/2005	6/5/2006
Harrison Creek	11.1042	34.66914	82.29473	6/15/2005	6/7/2006
Horse Creek	41.3109	34.52373	82.26418	10/19/2005	6/7/2006
Huff Creek	15.3675	34.71488	82.35223	9/21/2005	6/5/2006
Langston Creek	13.3785	34.88538	82.42379	9/21/2005	6/5/2006
Laurel Creek	28.5498	34.77899	82.34481	10/13/2005	6/6/2006
Little Creek	16.002	34.62658	82.31021	6/16/2005	6/8/2006
Martin Creek	9.3339	34.58704	82.24868	6/23/2005	6/7/2006
Reedy River Headwater	18.1269	34.94153	82.46429	7/20/2005	6/5/2006
Richland Creek	14.4774	34.85457	82.38395	7/19/2005	6/5/2006
Rocky Creek	21.51	34.70389	82.29763	7/18/2005	6/6/2006
Walnut Creek	23.6241	34.40212	82.1735	10/11/2005	6/7/2006

Table 2. Raw abundances of species collectively present in 2005 and 2006 among the 15 Reedy tributary sites.

Species	Site	Baker	Baldwin	Beaverdam	Brushy	Harrison	Horse	Huff	Langston	Laurel	Little	Martin	Reedy HW	Richland	Rocky	Walnut	Total
Brown bullhead		0	0	1	0	0	3	0	0	0	0	0	0	0	0	0	4
Bluehead chub		80	172	124	174	92	105	474	40	78	95	111	49	193	265	349	2401
Black crappy		0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	2
Bluegill		46	11	81	45	9	10	255	66	11	78	41	52	19	22	15	761
Channel catfish		0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Creek chubsucker		0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Creek Chub		0	36	42	37	2	22	26	4	9	1	26	2	171	15	25	418
Eastern Silvery		0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3
Flat bullhead		9	3	2	1	6	3	26	2	1	2	0	7	2	2	5	71
Flathead minnow		0	0	0	17	0	0	0	0	0	0	0	0	0	0	0	17
Flier		0	0	0	0	0	0	0	0	0	0	13	0	0	0	0	13
Golden shiner		0	0	0	3	0	0	0	0	0	0	1	4	0	0	0	8
Green sunfish		2	1	5	3	2	7	0	3	12	18	6	104	14	8	3	188
Largemouth bass		9	3	3	20	1	1	17	25	7	6	0	10	17	7	2	128
Margined madtom		11	0	4	0	0	2	0	0	0	9	0	0	0	0	9	35
Mosquitofish		0	0	0	109	0	9	1	2	1	0	4	4	0	0	5	135
Northern hogsucker		34	18	32	1	10	22	121	0	15	52	22	0	0	75	58	460
Pumpkinseed		0	0	4	0	1	1	0	0	0	1	1	4	0	0	0	12
Redbreast sunfish		49	24	112	23	1	6	108	24	1	29	5	4	17	18	29	450
Redear sunfish		0	0	0	0	0	0	0	2	0	0	3	0	0	0	0	5
Redfin pickeral		0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	4
Rosyside dace		0	8	1	0	0	0	0	0	0	0	0	0	0	0	0	9
Sandbar shiner		0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	2
Seagreen darter		5	0	0	0	0	0	0	0	0	10	10	0	0	0	1	26
Striped jumprock		0	0	0	0	1	10	0	0	0	1	2	0	0	3	27	44
Spottail shiner		0	11	91	0	0	0	0	0	32	53	3	0	0	82	130	402
Swamp darter		0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
Tessellated darter		0	0	0	0	2	0	0	0	0	1	0	0	0	0	7	10
Warmouth		3	1	4	3	0	0	13	22	1	10	6	22	0	0	0	85
White sucker		2	1	0	12	3	1	2	0	11	5	2	0	36	6	0	81
Yellow bullhead		4	2	8	42	5	0	0	3	4	0	1	15	12	13	1	110
Yellowfin shiner		114	53	132	8	15	65	0	106	124	168	138	99	183	129	341	1675
Yellow perch		0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	12
Total		368	344	646	498	150	268	1055	300	307	539	399	378	664	645	1013	

Table 3. Nine metrics of fish assemblage integrity that were utilized in the ranking scheme.

SITE	Species Richness	Shannon Diversity	shiner/sucker/darter richness	% Spp. Of Concern	% **B**enthic	% Fluvial	% Sunfish	% Invasive	% Dominance	
Baker	13	1.933	2	0.014	0.166	0.000	0.291	0.005	0.310	(YFS)
Baldwin	14	1.682	3	0.000	0.064	0.055	0.113	0.003	0.500	(BHC)
Beaverdam	16	2.057	2	0.000	0.060	0.142	0.316	0.008	0.204	(YFS)
Brushy	15	1.979	1	0.000	0.028	0.000	0.183	0.040	0.349	(BHC)
Harrison	14	1.506	3	0.000	0.147	0.000	0.080	0.013	0.613	(BHC)
Horse	16	1.881	3	0.000	0.153	0.004	0.067	0.026	0.392	(BHC)
Huff	11	1.557	1	0.000	0.141	0.000	0.373	0.000	0.449	(BHC)
Langston	13	1.839	0	0.000	0.010	0.000	0.463	0.010	0.353	(YFS)
Laurel	14	1.784	2	0.000	0.088	0.104	0.065	0.039	0.404	(YFS)
Little	17	2.051	5	0.019	0.148	0.098	0.230	0.033	0.312	(YFS)
Martin	19	1.944	4	0.025	0.090	0.008	0.140	0.015	0.346	(YFS)
Reedy HW	15	1.959	1	0.000	0.021	0.000	0.246	0.275	0.275	(GSF)
Richland	10	1.682	1	0.000	0.057	0.000	0.080	0.021	0.291	(BHC)
Rocky	13	1.771	3	0.000	0.133	0.127	0.073	0.012	0.411	(BHC)
Walnut	20	1.723	6	0.001	0.106	0.132	0.046	0.003	0.345	(BHC)

Land use variables were derived from data generated by Clemson University's Strom Thurmond Institute of Government and Public Affairs (STI). Two data sets were utilized. Forest land use was derived for the years 1990 and 2000, and were generated by STI's Arvind Pasula. Urban land use was also derived for the years 1990 and 2000, and was generated by STI's Craig Campbell (Campbell 2007). Campbell (2007) used a GIS-based 'filtering' method to refine Pasula's urban land cover layer, creating a more accurate urban data layer.

USGS seamless digital elevation models and STI land cover data were utilized in ESRI's ArcGIS v.9.2 to a) delineated watersheds based on entire drainage area upstream of sample locations, b) categorize forest and urban watershed land use for 2000, and c) categorize forest and urban watershed land use for 1990. In addition, a variable indicating watershed land cover change over time was generated by subtracting 1990 forest and urban land use categories from 2000 land use categories (% land use change = % 2000 land use - % 1990 land use). For the analysis, only the 2000 land use variables and the percent land use change over time variables were used. All map layers were projected in the Universal Transverse Mercator (UTM) projection system (zone 17 N), using the North American 1983 datum.

Fish metric data (Table 3) were compared to urban land use data using Pearson correlation analysis (Microsoft Excel). Metrics that were negatively correlated with urban land use were species richness, Shannon diversity, shiner/sucker/darter richness, relative abundance of SC species of concern, relative abundance of benthic specialists, and relative abundance of fluvial specialists. Metrics that were positively correlated with urban land use were relative abundance of sunfish species, relative abundance of invasive/non-native species, and species dominance. For the means of the ranking scheme, fish metrics that were negatively correlated with urban land use were considered to be ‘positive’ variables, and fish metrics that were positively correlated with urban land use variables were considered to be ‘negative’ variables. The equation used for ranking is as follows Rank Sum: = (sum positive variables) – (sum negative variables).

Ranking Scheme

Two coarse groups were defined from the ranking scheme, reflecting ‘high’ rank sums (increased biological integrity), and ‘low’ rank sums (decreased biological integrity). A geographic separation was observed, indicating that tributary sites located lower in the Reedy watershed generally displayed better biological conditions (higher rank sum), and sites located higher in the Reedy watershed (closer to Greenville) generally displayed poorer biological condition (lower rank sum) (Figure 1, Table 4).

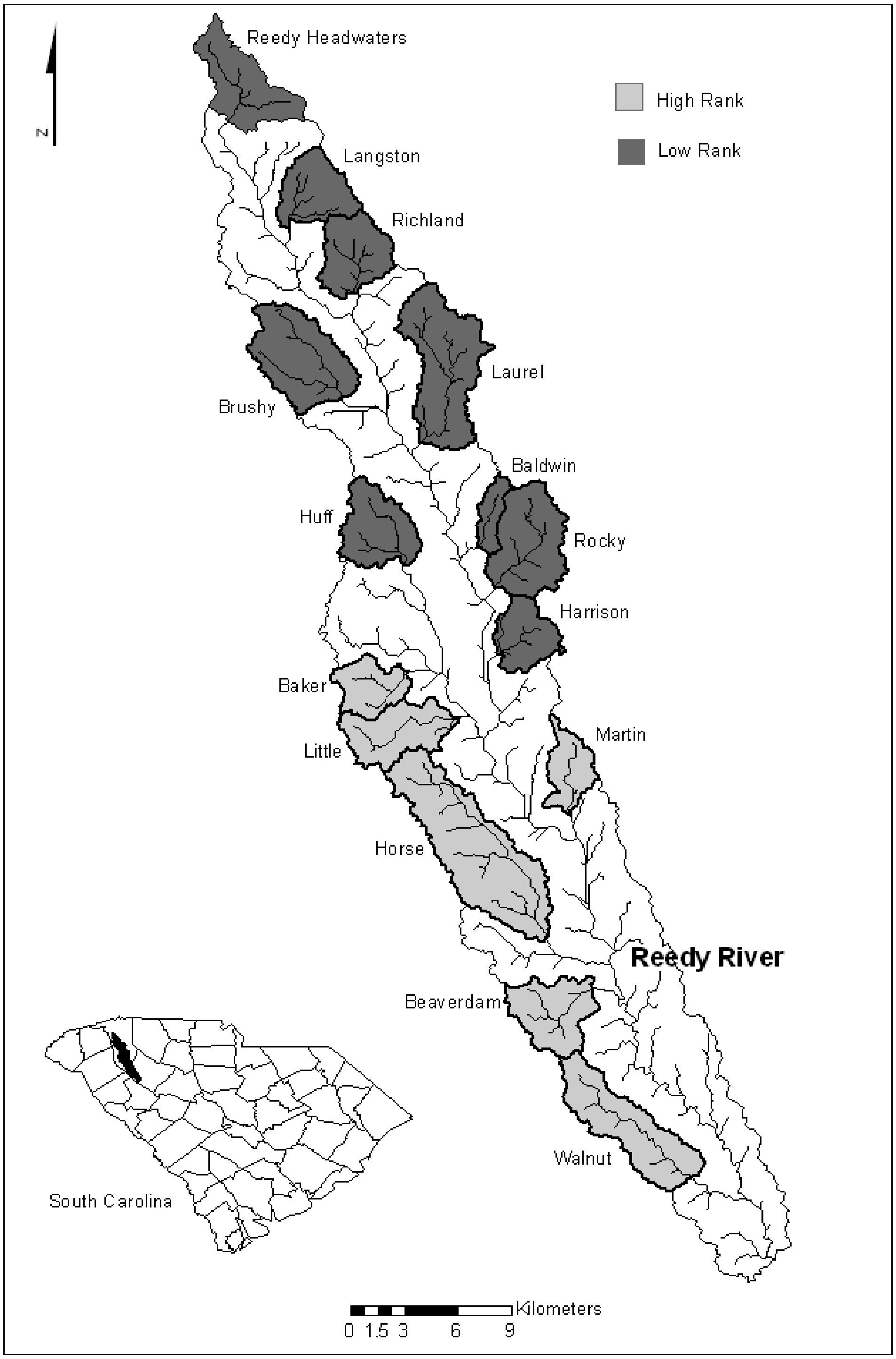

Figure 1. Map of Reedy River watershed and 15 sampled tributaries. Tributaries shaded dark were ranked ‘low’ in biological integrity, and tributaries shaded light ranked ‘high’ in biological integrity.

Table 4. Reedy tributaries in order of rank. The category 'rank sum'equates to the total score derived from the equation Rank Sum = (sum positive variables) – (sum negative variables). Associated land use levels are listed. Sites shaded lightly ranked 'high' in biological integrity, and sites shaded dark ranked 'low' in biological integrity.

Site	Rank Sum	%Urban 2000	% Urban Increase (1990-2000)	% Forest 2000	% Forest Decrease (1990-2000)
Walnut	60	14.488	8.701	65.481	-0.587
Little	52	14.966	7.238	64.432	-1.192
Martin	46	13.711	8.784	75.981	-4.378
Beaverdam	34	8.721	5.737	70.568	-2.146
Horse	28	10.795	6.279	74.820	-1.087
Baker	28	20.978	8.613	47.794	-0.511
Rocky	19	63.494	38.276	31.707	-25.473
Laurel	13	59.858	30.402	37.680	-19.312
Baldwin	12	57.573	43.592	36.942	-31.654
Harrison	1	20.214	11.193	63.122	-5.852
Reedy HW	-1	34.035	25.828	53.845	-23.688
Brushy	-2	89.780	40.573	9.707	-31.997
Richland	-5	83.626	45.711	16.592	-37.878
Huff	-9	64.627	31.075	26.823	-7.286
Langston	-15	50.420	36.495	40.626	-32.856

This geographic separation poignantly indicated a relationship between biological integrity and watershed land cover (Table 4, Figures 2;3;4;5). Land use among sites ranked 'high' in biological integrity were characterized by decreased urban and increased forest land cover, specifically: a) ≤ 20% urban 2000 land cover, b) ≤ 9% urban land cover increase over time (1990-2000), c) > approximately 50% forest 2000 land cover, and d) < 5% forest loss over time (1990-2000). Conversely, sites which ranked 'low' in biological integrity were characterized by increased urban and decreased forest land cover, specifically: a) > 20% urban 2000 land cover, b) > 10% urban land cover increase over time between 1990-2000, c) < approximately 50% forest 2000 land cover, d) > 5% forest loss over time (1990-2000).

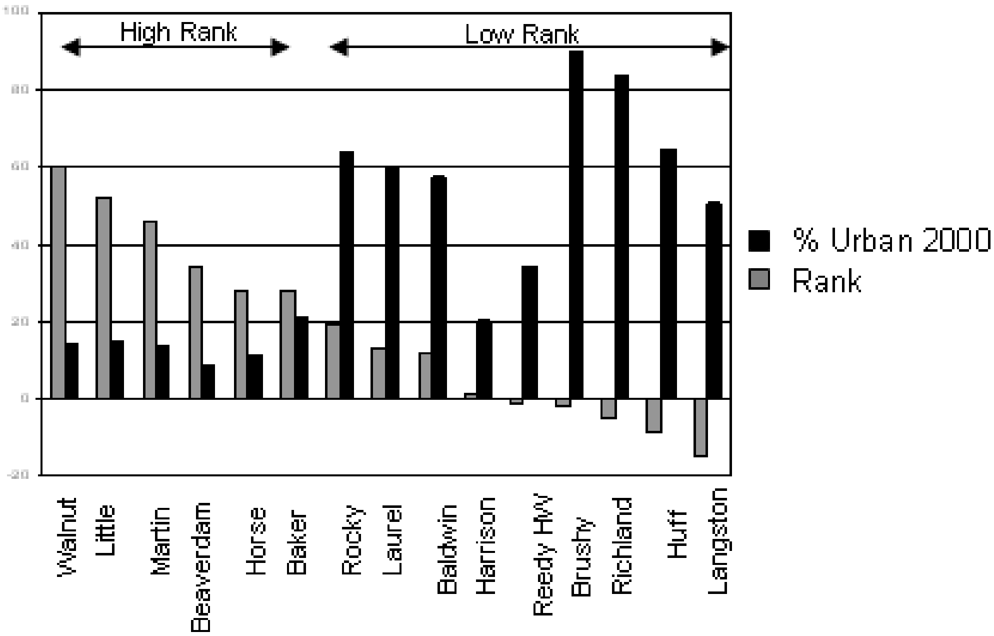

Figure 2. Tributary sites in ascending order of rank sum, overlain with % urban 2000 land use.

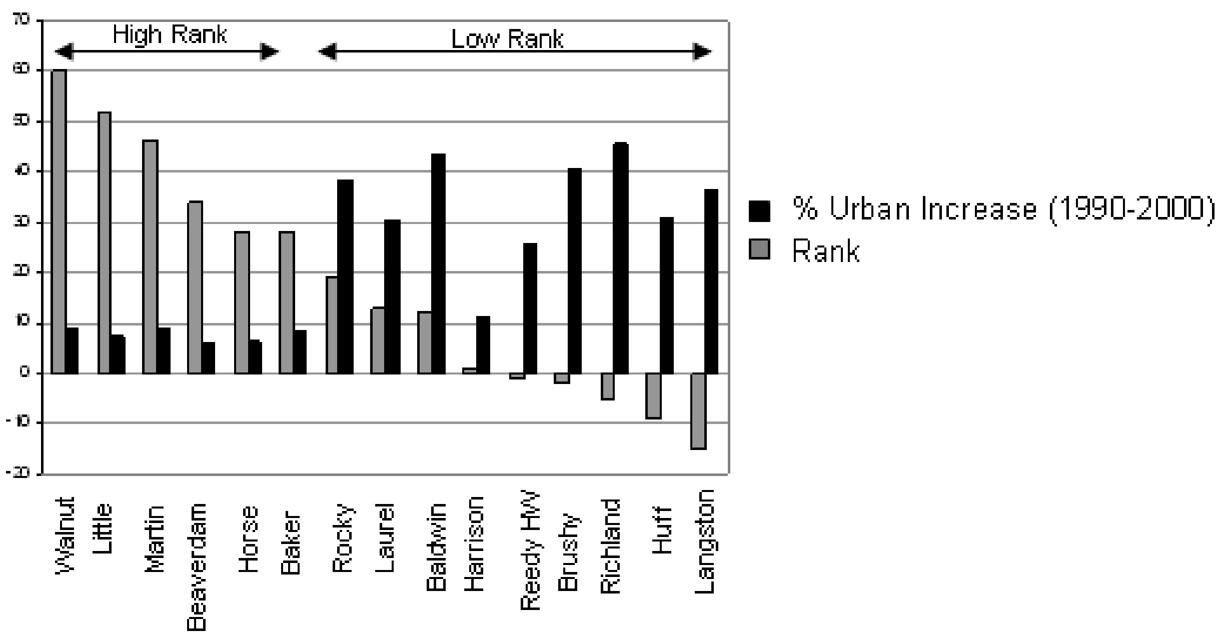

Figure 3. Tributary sites in ascending order of rank sum, overlain with % urban land use over time (1990-2000).

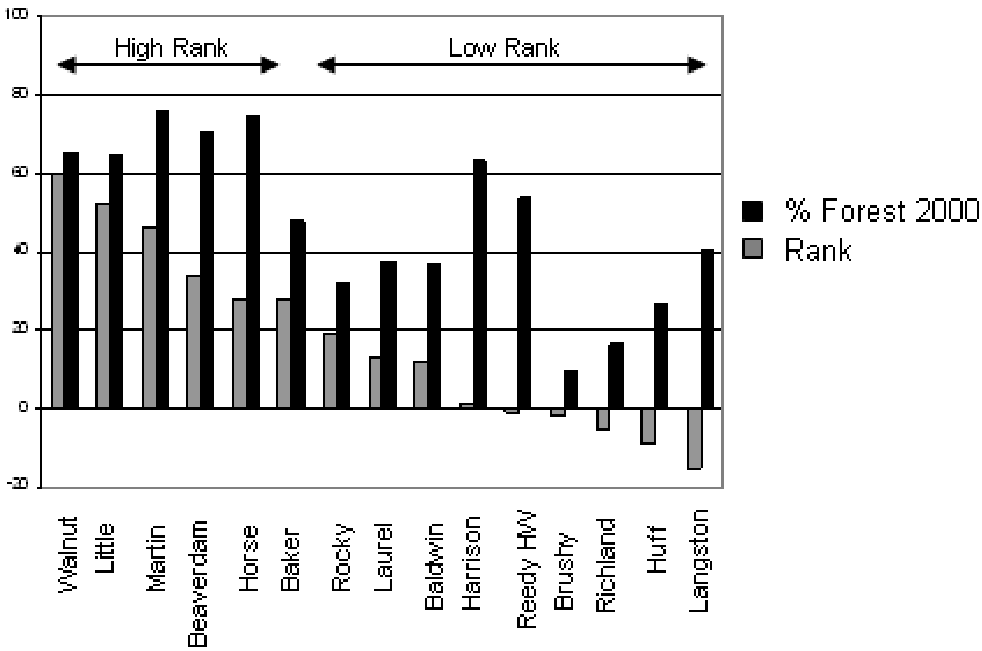

Figure 4. Tributary sites in ascending order of rank sum, overlain with % forest 2000 land cover.

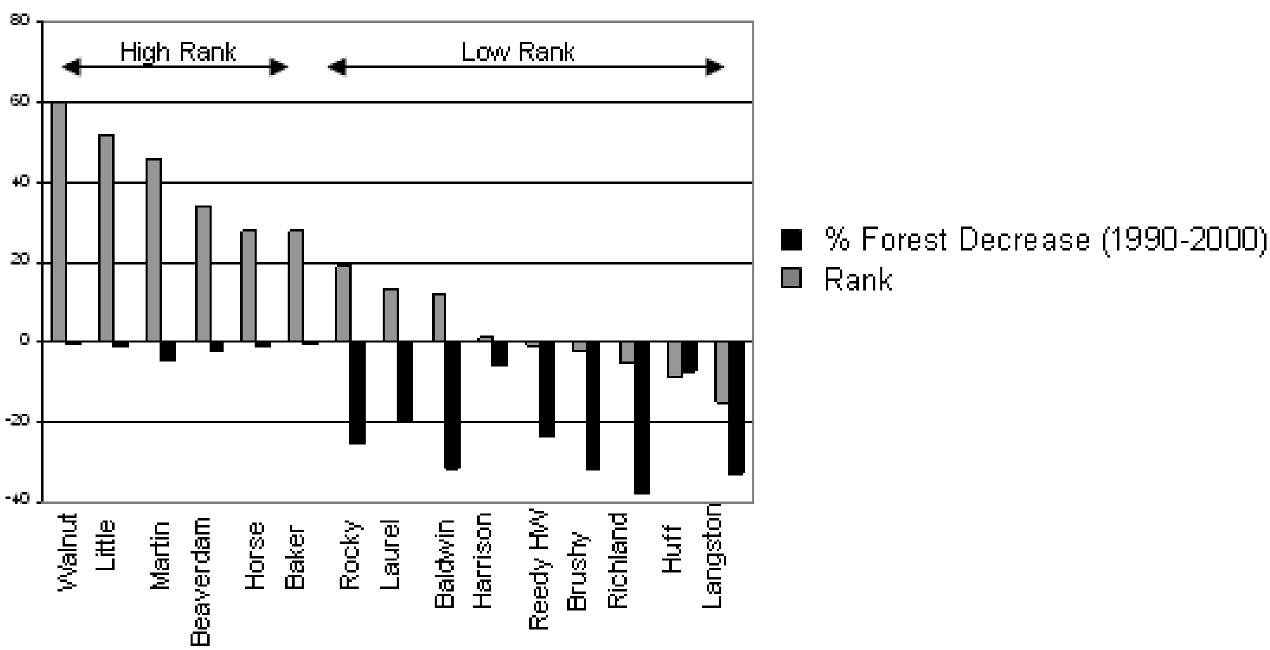

Figure 5. Tributary sites in ascending order of rank sum, overlain with % forest loss overlain with % forest loss over time (1990-2000).

Biological characterization of sites ranked 'high' (lower Reedy watershed, decreased urbanization, increased forest) generally displayed increased species richness, Shannon diversity, and shiner/sucker darter richness. Sites ranked 'high' were the only sites that contained SC species of concern, however only one species was represented, the seagreen darter (*Etheostoma thalassinum*). A point of interest was that these sites were typified by approximately 30% or less abundance of a single dominant species relative abundance, primarily represented by yellowfin shiner (*Notropis lutipinnus*). In addition, these sites generally contained higher percentages of both fluvial and benthic specialists, and decreased percentages of sunfish and invasive species.

Conversely, biological characterization of sites ranked "low" (upper Reedy watershed, increased urbanization, decreased forest) generally displayed decreased species richness, Shannon diversity, and shiner/sucker/darter richness. None of the low ranked sites contained SC species of concern. Additionally, low ranked sites displayed increased sunfish abundances, as well as increased abundances of invasive species. In general, the relative abundances of a single dominant species was greater than 30%. The most pervasive dominant species in low ranked sites was blue head chub (Nocomis leptocephalus), rather than yellowfin shiner (*Notropis lutipinnus*) as observed in the higher ranked sites. The reedy headwaters was the only site not dominated by either yellowfin shiner (*Notropis lutipinnus*) or bluehead chub (*Nocomis leptocephalus*), but was dominated by green sunfish (*Lepomis cyanellus*) – an invasive species. These low ranking sites also contained few or no fluvial specialists, including notable reductions/exclusions of eastern silvery minnow (*Hybognathus regius*), rosyside dace (*Clinostomus funduloides*), sandbar shiner (*Notropis scepticus*), and spottail shiner (*Notropis hudsonius*). In addition, they were typified by a general decrease in benthic specialist species,particularly striped jumprock (*Moxostoma rupiscartes*), margined madtom (*Noturus insignis*), and seagreen darter (*Etheostoma thalassinum*).

It is important to note that this ranking scheme is not absolute; obviously aquatic systems and assemblages are complex and fluctuate with stochastic events, natural influences/gradients, and both chronic and acute anthropogenic impacts. This ranking structure is meant to generally identify assemblage responses to a land use gradient. Two coarse response groups were identified by this study, indicating that increased urbanization and forest loss negatively influences biological integrity (rank). However, care should be taken when interpreting ranks as 'exact' in their order.

Thresholds

There is evidence that suggests that the Reedy watershed as a whole is relatively degraded system. Previous work conducted by Clemson University researchers demonstrated the difficulty of implementing a 'traditional' IBI within this watershed system, primarily due to the relative lack of 'reference condition' sites, upon which the cornerstone of any traditional IBI based evaluation is constructed (Wilson and English 2007). Associated work has reported urban land cover ranging from 7-20% to impair biological communities, and above 20% to cause irreparable damage (Karr and Chu 2000, Paul and Meyer 2001, Snyder et al. 2004, Morgan and Cushman 2000), thresholds which are surpassed by all of the Reedy tributary sites. It is additionally dissuading that the Reedy tributaries contained only one SC species of concern (Seagreen darter: *Etheostoma thallassinum*), where additional species should be present as evidenced by their documentation in the Reedy river's sister watershed, the Saluda. Species of concern documented in the Saluda that should be present in the Reedy may include: Piedmont darter (*Percina crassa)*; Fieryblack shiner, (*Cyprinella pyrrhomelas)* and Rosyface chub

(*Hybopsis rubrifrons*) (Foltz,J. *pers.comm*.). An argument could be constructed which proposes that the Reedy watershed has already surpassed graduated thresholds of degradation, after years of both "chronic" cumulative stressors (e.g., non-point source pollution, runoff, sedimentation, nutrients) as well as significant discrete sources (e.g., point sources) and acute events (e.g., direct 957,600-gallon diesel oil spill), particularly in higher order tributaries near the Greenville centroid.

Although arguably degraded, it is also clear that a spectrum of biological integrity also exists, where as observed, some tributaries display increased biological integrity over other tributaries. Urban land use appears to represent a better indicator of biological decline than loss of forest land cover, although the two are related. Looking at natural cut-offs in urban land use and biological integrity rank values, it can be inferred that a relative threshold where biological integrity poignantly decreases may exist at:

- > 20% urban 2000 land cover (10-15% more realistic), and
- > 10% urban increase over time (1990-2000)

All sites which ranked 'high' fell below this threshold criteria, and all sites ranked 'low' surpassed this threshold. Of greatest concern is future predicted urban expansion in upstate SC. From 1990-2000 the amount of developed land in upstate SC (8-county area) grew from approximately 223,000 to approximately 576,000 acres. Under a predicted 5:1 growth ration (5 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). The Reedy watershed, with its headwaters originating within upstate SC's largest city Greenville, is at great risk of future development. It is highly likely that as the Reedy watershed develops, many if not all Reedy tributary sites will surpass a threshold where biological integrity declines irrevocably. Future observed changes may mimic what we already observed in the lower ranked upper Reedy tributaries; losses of benthic and fluvial specialists, loss of SC species of concern, increases in non-native abundances, sunfish, or increased abundances of a single dominant species.

Candidates for Conservation

The results of this study indicate a negative relationship between urban watershed land cover and biological integrity, a probable result of long-term cumulative impacts associated with urban landscapes. Current urban land cover among Reedy tributary sites ranges between 8.7%-89.8%. Urban land cover change over time of all sites was positive, indicating that all 15 reedy tributary sites have experienced some degree of urban/suburban expansion/development. One potential criteria for selecting sites as candidates for conservation or restoration may include those that a) display minimal current urban land cover, and b) have experienced minimal increases in urban land cover over time (1990-2000). Another landscape-based approach would be to use predictive urban land cover layers to identify tributaries most and least at risk for future urban expansion. This predictive data is available through Clemson University's Strom Thurmond Institute, and is available for 2010, 2020, and 2030.

An alternative approach would be to focus on tributaries of specific biological interest. For example, sites containing SC species of concern (Seagreen darter: *Etheostoma thalassinum*) may be targeted (Baker, Laurel, Little, Walnut), or those containing increased abundances of fluvial (Walnut, Beaverdam, Rocky) or benthic specialists (Baker, Harrison, Horse, Huff, Little), or a combination variable shiner/sucker/darter richness (Walnut, Martin, Little). It may prove prudent to expect that with increased urban expansion, we may ultimately observe intensive reductions or loss of sensitive species, as already observed in most of the low ranked, highly urbanized tributaries near the Greenville centroid. Conservation efforts should focus on these systems containing under-represented species in order to maintain a spectrum of biological diversity in the Reedy watershed, additionally they may represent potential areas of refuge and sources for re-colonization of the Reedy mainstem.

Recommendations

- Continue standardized sampling at Reedy tributary stream sites to provide a multi-year data set of aquatic resource conditions.
- Analyze tributary streams for relationships between biological variables, habitat conditions, and community metrics.
- Although predetermined sampling methodologies (SCDNR) were followed for consistency and comparative purposes in the currently outlined base projects of the Reedy River Comprehensive Monitoring Study, further methodological prioritization and optimization will be necessary to meet the objectives of our associated study incorporating land use/watershed condition, stream habitat quality, and assemblage integrity.
- Utilize predicted urban expansion land cover layers to identify areas predicted to be most and least susceptible to urban expansion
- Include habitat data such as physical habitat data (substrate size distribution, depth, depth fluctuation over time, velocity, presence of woody debris), water quality parameters (temperature fluctuation over time, dissolved oxygen, conductivity, pH, hardness, alkalinity, and turbidity).

- Analyze effect of natural gradients (e.g., watershed area, elevation, gradient, etc.), and measure effects of/identify any differences in population structure across natural gradients
- Potentially utilize additional land/watershed use/condition variables, such as impervious cover, riparian zone land cover, point source discharge density/intensity, road density.
- Refine metrics of fish assemblage integrity, considering additional diversity variables (e.g. functional diversity, B-diversity), as well as additional variables not inherently accounting for assemblage integrity (i.e. native versus introduced status, distribution, tolerant versus intolerant species, specialist versus generalist species).

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Job Title: Fish Ladder and Mussel Research

Period Covered January 1, 2008 – December 31, 2008

Results and Discussion

State Wildlife Grant number T-24-R-1 was used to evaluate the benefit of the Columbia dam fish ladder on the Broad River to freshwater mussels. The fish ladder was first operational in 2007 and the planned to remain open from March 1 (or earlier depending on the movement patterns of American Shad and Blueback Herring downstream) until late May. Since the larvae of native freshwater mussels must attach to the gills or fins of fish in order to complete transformation to the adult stage, the fish ladder is also expected to aid in the dispersal of freshwater mussels. The species diversity of mussels is greater below the dam (10 species) than it is above the dam (4 species). Since there is no baseline data, it is impossible to determine if the 6 species found only below the dam were once present above it. Because the decline in freshwater mussels over the last 150 years has been documented as more rapid than any other North American faunal group, the historic range is suspected to be larger than the current range for most species and regions lacking in data. The 22 mile stretch of the Broad River between the Columbia dam and the Parr Reservoir dam appears to be excellent habitat for freshwater mussels and supports a high density of the species found there. If the Columbia dam facilitates the transport of freshwater mussels above the dam, it will open up additional habitat for the six additional species found only below the dam, most of which have a smaller global distribution and are of higher conservation concern than the species found above the dam. Transport of individuals above and below the dam will also allow for gene flow between populations which helps protect populations from the potentially harmful effects of inbreeding, low effective population size, and susceptibility to population extirpation.

This project assessed the seasonality of reproduction in mussels below the dam to determine if the season during which the fish ladder is open will allow the greatest opportunity to facilitate the movement of mussels. As part of the project, we also tested the species of mussels found only below the dam to determine which fish species served as appropriate hosts for those species and determine if those fish species were also using the ladder. One of the mussel species, *Elliptio roanokensis*, used primarily anadromous and migratory fish species, making it especially likely that the restriction of fish passage could be responsible for the absence of this mussel above the dam. In the lower Broad River, a large fraction of the mussels present were observed to be reproducing. In the upper Congaree River, very few of the mussels found were reproducing, and mortality was high. Mussels were found to be releasing their larvae between March and July. Although many mussels were releasing their glochidia in April and May, several species, including *Ligumia nasuta*, and *Lampsilis cariosa* were most likely to release during June, and *Lampsilis splendida* did not begin releasing glochidia until June. Following their release from the mother, glochidia must attach to a fish, which could be instantaneous or take up to two weeks, and complete development into free-living adults. Our laboratory tests showed that these mussels completed development in anywhere from 10 to 30 days. Therefore, glochidia may still be transported on the host fish a month or more after their release. Based upon the data we provided, SCE&G has agreed to leave the fish ladder open until the end of August in years when the flow is sufficient to facilitate it. The potential range expansion of mussels allowed by the extended fish ladder schedule is particularly important given the poor condition of the population of mussels assessed in the upper Congaree River. The cause of the low reproductive rates and high mortality is unknown at this time, but several potential explanations are currently being investigated, and possible solutions explored.

Prepared By: Jennifer Price Title: Fishery Biologist