SEASONAL MOVEMENTS OF ADULT STRIPED BASS IN THE SANTEE-COOPER DRAINAGE

STUDY COMPLETION REPORT

F-63

March 1, 2006 – December 31, 2008

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<u>Summary</u>

Eighty-five striped bass *Morone saxatilis* (610-930 mm total length) were implanted with ultrasonic transmitters and tracked for up to 502 d during 2006-2008 in the Santee-Cooper system, South Carolina to determine their seasonal movement and distribution. Two broad summer occupancy patterns were observed during the study with roughly half of the fish residing in the lower Saluda River, a thermal refuge below Lake Murray, and half of the fish residing in the Santee-Cooper reservoirs during the summer. Striped bass entered the lower Saluda River post-spawn and spent between 25 d and 158 d (mean = 113 d) in the river before returning to the lakes in the late summer or fall. During winter all fish were below the tributary rivers, occupying the Santee-Cooper reservoirs. Overall exploitation of instrumented striped bass was 33% and most (73%) of the harvest occurred in the lower Saluda River during the spring and summer. Information collected during the study demonstrates the importance of the lower Saluda River as thermal refuge for adult striped bass. Seasonal segregation of the Santee-Cooper striped bass stock and disproportionate exploitation of fish that summered in the lower Saluda River indicates that multiple management strategies may be necessary to optimize stock management and allocation.

<u>Introduction</u>

The Santee-Cooper system supports a nationally known striped bass *Morone saxatilis* fishery. The fishery developed when a coastal population of striped bass residing in the Santee River was land-locked in the 1940's during the impoundment of the Santee River. The newly formed Santee-Cooper Reservoirs and its tributaries proved suitable for the natural reproduction of striped bass (Scruggs 1957) and the first freshwater self-sustaining striped bass population was born. In response to increased angling effort (Bulak et al. 1983) and declines in juvenile abundance during the mid 1970's (White and Lamprecht 1992), a stocking program was initiated in 1984 to augment natural reproduction. In the last decade hatchery augmentation and more restrictive harvest regulations have failed to maintain this once excellent fishery.

Studies have shown that portions of the Santee-Cooper striped bass population utilize various segments of the system seasonally (Braschler et al. 1988, White and Lamprecht 2002, Bales et al. 2006). Annual movement of striped bass in this system is initiated during the spring spawning season when adult striped bass move upstream out of the reservoirs to spawn in the Congaree and Wateree rivers. Striped bass utilize the lower Saluda River post-spawn during the late spring and summer months (Bales et al. 2006) where hypolimnetic discharges from Lake Murray Dam provide a thermal refuge. While studies have documented striped bass use of different regions in the Santee drainage, they do not quantify the temporal duration of seasonal habitat use or the proportion of the population utilizing those regions. Braschler et al. (1988) documented movement of striped bass up the Congaree River from Lake Moultrie during the spring spawn and back to Lake Moultrie post-spawn, however, population sampling in the Lower Saluda River has documented striped bass occurrence post-spawn (Bales et al. 2006). This suggests seasonal segregation of the striped bass population and potentially annual segregation of portions of the population between the reservoirs and the tributaries.

Segregation of the Santee-Cooper striped bass population could lead to over exploitation of striped bass, as well as regional allocation issues. Decreasing frequency of large (> 4.5 kg) striped bass and poor angler catch rates have caused dissatisfaction among anglers (Scott Lamprecht, SCDNR; personal communication). Concern exists over this decline and the susceptibility of adult striped bass in the upper tributaries of the Santee-Cooper drainage, where angling pressure is seasonally intense, to high rates of exploitation. Identification of seasonal striped bass migration patterns within the Santee-Cooper drainage could assist managers in identifying appropriate management options. The objectives of this study were to determine the seasonal movement and distribution of striped bass in the Santee Cooper system.

Materials and Methods

Study Area

The Santee-Cooper system, situated in the Coastal Plain of South Carolina, consists of two large reservoirs (Lake Marion and Lake Moultrie) formed by dams on the Santee and Cooper rivers, two canals, and tributary rivers that form the Santee River which flows into upper Lake Marion (Figure 1). Lake Marion is a partially wooded 44,000 ha impoundment on the Santee River with a maximum depth of 12 m at the dam, but overall the reservoir is shallow (1-3 m). Lake Moultrie is a 25,000 ha open water reservoir with a maximum depth of 21 m. Due to short residence times, shallow depths, and wind action neither reservoir develops strong thermal stratification during the summer (Inabinet 1985). The two reservoirs are connected by a canal that diverts water from Lake Marion (Santee drainage) to Lake Moultrie where it is discharged into the Cooper River during hydroelectric power generation at Pinopolis Dam. In 1985 a canal and the St. Stephen dam were constructed to redivert water from Lake Moultrie back into the Santee River. Pinopolis Dam is equipped with a navigation lock that allows vessels and fish to pass from Lake Moultrie into and out of the Cooper River which flows unimpeded, below Pinopolis Dam, to the Atlantic Ocean. The St.

Stephen Dam on the rediversion canal is equipped with a fish lift that allows passage of fish into and out of the Santee River, which flows directly to the Atlantic Ocean.

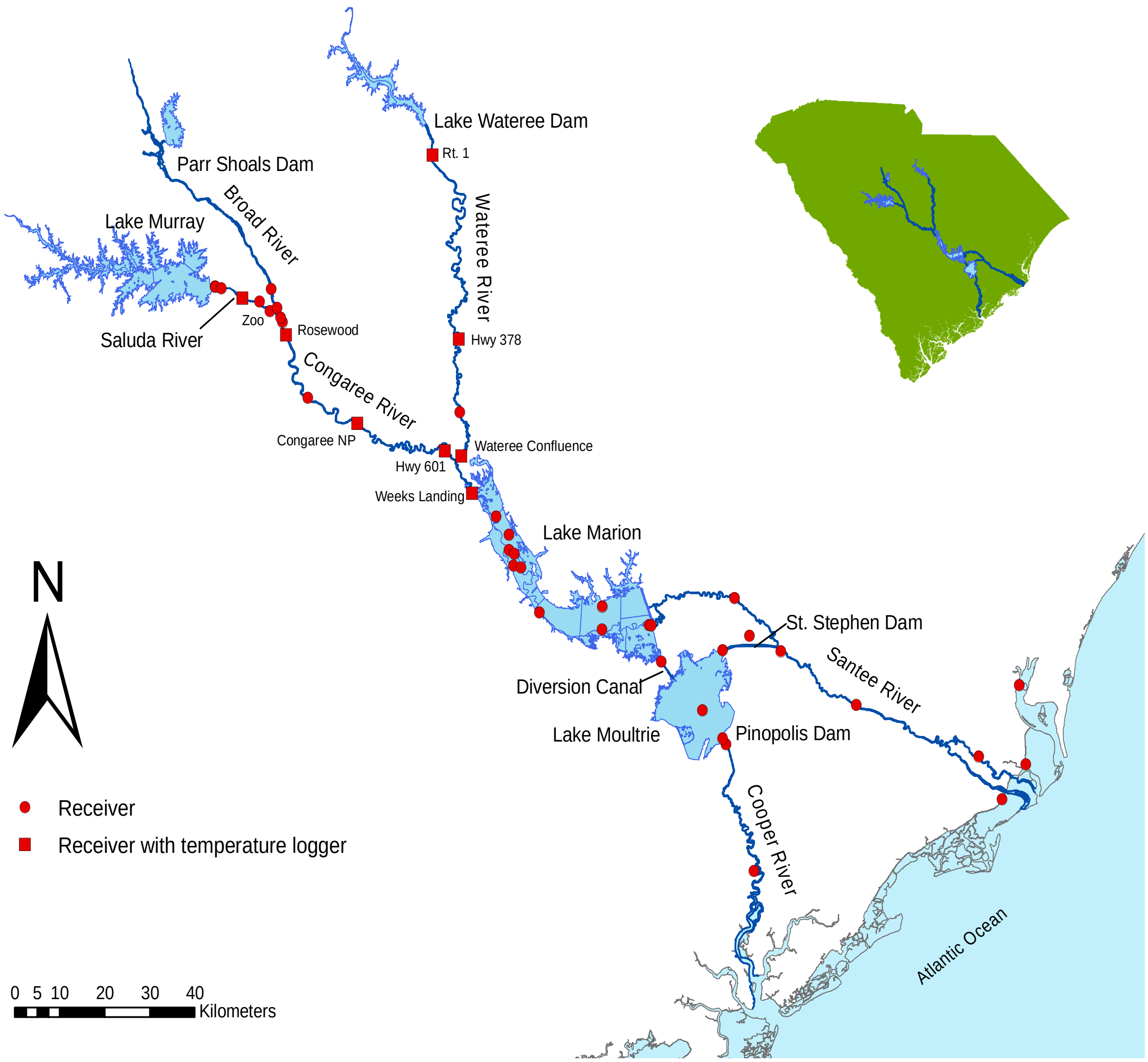

Figure 1. Ultrasonic receiver locations in the Santee-Cooper system South Carolina during 2006 – 2008.

The upstream tributaries of Lake Marion include the Congaree, Wateree and Santee Rivers. The Congaree River originates in Columbia, SC at the confluence of the Saluda and Broad Rivers, and flows 85 km until it merges with the Wateree River to form the Santee River (Figure 1). Hypolimnetic releases from the Lake Murray Dam on the Saluda River provide cool water and a summer-time thermal refuge for adult striped bass in 16 km of the lower Saluda River and in a few kilometers of the upper Congaree River. The Wateree River originates below the Wateree Dam and flows roughly 122 km before merging with the Congaree River to form the Santee River. The Santee River flows 26 km before forming the headwaters of Lake Marion. Average annual discharge of the Congaree and Wateree Rivers are 267 m^3/s and 225 m^3/s, respectively (Bennett et al. 1993).

Management of the Santee-Cooper striped bass population includes stocking roughly 2.5 million striped bass fingerlings (37 fish/ha) annually to augment natural reproduction. When this study was initiated striped bass were managed throughout the entire system with a 5 fish/d creel limit and a 533 mm TL minimum length limit. In summer 2008 new harvest restriction went into effect that limit striped bass harvest to 3 fish/d greater than 660 mm TL, except from June 1 – September 30 when no fish may be possessed. However, there is not a moratorium on angling for striped bass in any season.

Field Methods

We used ultrasonic telemetry to follow striped bass movements throughout the system. Striped bass were captured with boat-mounted electrofishing equipment from the Congaree and Saluda rivers during the spring and summer 2006, and from Lake Moultrie during the Winter 2006/2007 and implanted with ultrasonic transmitters. We attempted to limit implantation of transmitters to fish larger than 650 mm TL to ensure that most, if not all, fish were sexually mature (Bulak 1995) and to keep transmitter weight less than 2% of the fish’s body weight.

When striped bass were captured they were immediately placed on a large v-trough measuring board, covered in wet towels, measured, and sexed, when possible. Ultrasonic transmitters (VEMCO Ltd., Nova Scotia; V165H) were inserted through a 40 mm incision posterior to the right ventral fin. Incisions were closed with three interrupted absorbable sutures (2-0 Maxon; Tyco Health Care). Internal anchor tags (Hallprint Pty Ltd., Victor Harbor, South Australia) were placed in the incision before closing or inserted through a 10 mm incision anterior to the vent and to the right of the midventral line. No chemical anesthesia was used, fish were sufficiently narcotized from electrofishing for the short (3-4 minute) implantation procedure. After transmitter and tag implantation fish were immediately released. All surgical tools and tags were disinfected with Benz-All® (Xttrium Laboratories, Chicago, IL) before surgery.

Ultrasonic transmitters measured 98 mm long, 16 mm in diameter, and weighed 36 g. Each transmitter operated at 69 kHz and was uniquely identifiable based on unique pulse periods between transmissions. Transmitters had a nominal delay of 55 sec between transmissions and an expected battery life of at least 425 d. To facilitate the return of transmitters from angler harvested striped bass one side of the anchor tags external streamer was printed with "CALL SCDNR REWARD $50" and the other side of the streamer was printed with "TAG INSIDE" and the tag number.

Striped bass were located between April 2006 and January 2008 with 59 fixed receivers (VEMCO Ltd., Nova Scotia; VR2) positioned throughout the system (Figure 1). The VR2 receivers recorded the transmitter ID number, date and time whenever a fish passed within the receiver's detection range. Receiver detection range was roughly 1 km in the reservoirs, but substantially less in the tributaries. Receivers were downloaded approximately once every two months, but more frequently in areas where numerous striped bass congregated for long periods of time. Manual tracking was occasionally conducted by boat, with a VEMCO VR100 manual tracking receiver, to search for missing fish and dead fish in the tributaries. Manual searches of the lower Saluda River were conducted in June 2006, June 2007, July 2007 and September 2007. Manual searches of the Congaree River occurred in June 2006, January 2007 and February 2007.

We used the first detection at the Weeks Landing Receiver (Figure 1), which is nearly 10 km below the Congaree/Wateree confluence, to signal the start of the tributary spawning run. When fish passed the Zoo Receiver in the Saluda River heading upstream or the Weeks Landing receiver heading downstream it was assumed they had completed their spawning migration and were entering the thermal refuge of the lower Saluda River or returning to the lakes, respectively.

Water temperature was measured at nine receiver sites in the tributary rivers with submersible temperature loggers (StowAway TidBit, Onset Inc., Pokaset, Massachusetts) (Figure 1).

Analytical Methods

We considered 3 possible fates for instrumented striped bass in the Santee Cooper system. Striped bass could remain alive in the fishery until the conclusion of the study (or transmitter expiration), they could be harvested, or lost from the fishery. We posted signs at major access points, and issued press releases to inform anglers of the ongoing telemetry study. Signs and press releases advised anglers that a reward would be given for returning transmitters from harvested fish. Only after an angler returned a transmitter was a fish categorized as harvested. Fish lost from the fishery were either confirmed as dead by lack of movement during manual searches of tributary rivers or simply classified as missing when they were no longer located at automated receiver stations below tributary rivers. It was not feasible to manually search the reservoirs for missing fish to confirm mortality. However, due to the extensive receiver network it was unlikely that fish classified as missing were at large and simply undetected so ultimately they were categorized as dead, although they could have been harvested, but not reported.

Fisher's Exact test was used to determine if last known location (i.e., Saluda River, reservoir, or tributary river) or tagging location influenced overall fate or 365 day fate of striped bass. Last known location was categorized as Saluda River, spawning river (Wateree and Congaree), or reservoir (Lakes Moultrie and Marion). Chi-square analyses were used to determine if sex tagging location influenced use of the Saluda River during the summer. Analysis of variance was used to determine if TL of implanted fish differed among tagging locations; Tukey's test was used for multiple comparisons. A t-test was used to determine if fish that used the Saluda River were larger than those that did not use the Saluda River. Linear regression analysis was used to determine if entry date into spawning rivers and departure date from the Saluda River were related to fish TL. Multiple regression was used to determine if d in spawning tributaries was related to entry date into spawning tributaries or fish TL. Sex was used as a categorical covariant in regression analyses to determine if sex was a significant effect. All statistical analyses were performed with SAS. Statistical tests were considered statistically significant at $\alpha = 0.05$.

Results

Thirty striped bass (mean total length [TL] = 723 mm; range 663 – 860 mm TL) captured from the Congaree River were implanted with ultrasonic transmitters between 5 April and 19 April 2006 (Table 1). Thirty-seven striped bass (mean TL = 765; range 675 – 930 mm TL) captured from the Saluda River were implanted between 3 May and 13 July 2006 and eighteen fish (mean TL = 686; range 610 – 755 mm TL) were collected from Lake Moultrie, primarily in the rediversion canal, and implanted with transmitters between 19 December 2006 and 28 February 2007. Striped bass TL differed among tagging locations (ANOVA: $P < 0.05$), fish implanted in the Saluda River were larger than those implanted in the Congaree River and Lake Moultrie (Tukey's: $P < 0.05$) (Table 2).

Table 1. Summary of striped bass collected from the Santee-Cooper system during 2006 and 2007, and implanted with ultrasonic transmitters. Fate codes are: A = alive at study conclusion, D = confirmed dead, H = harvested, M = missing and S = post surgical mortality.

Date Implanted	Fish Number	Fate	365-d Fate	TL	Sex	Tagging Location	Days Tracked
4/5/2006	1	H	H	735	F	Congaree River	10
4/5/2006	2	M	M	670	M	Congaree River	77
4/5/2006	3	M	A	745	F	Congaree River	391
4/5/2006	4	M	M	710	F	Congaree River	151
4/6/2006	5	A	A	740	F	Congaree River	410
4/6/2006	6	M	D	690	F	Congaree River	98
4/10/2006	7	A	A	680	M	Congaree River	441
4/10/2006	8	M	M	734	F	Congaree River	41
4/10/2006	9	H	H	700	M	Congaree River	16
4/10/2006	10	A	A	690	M	Congaree River	488
4/10/2006	11	M	D	730	F	Congaree River	87
4/10/2006	12	A	A	680	M	Congaree River	466
4/10/2006	13	S	S	675	M	Congaree River	0
4/12/2006	14	M	D	710	F	Congaree River	146
4/12/2006	15	D	D	691	F	Congaree River	133
4/12/2006	16	S	S	700	F	Congaree River	0
4/13/2006	17	M	D	795	F	Congaree River	202
4/13/2006	18	M	D	835	F	Congaree River	285
4/13/2006	19	H	H	705	F	Congaree River	31
4/14/2006	20	S	S	705	F	Congaree River	0
4/14/2006	21	H	A	693	F	Congaree River	405
4/14/2006	22	S	S	710	F	Congaree River	5
4/14/2006	23	M	A	780	F	Congaree River	378
4/19/2006	24	M	D	807	F	Congaree River	106
4/19/2006	25	M	D	685	M	Congaree River	75
4/19/2006	26	M	D	675	M	Congaree River	312
4/19/2006	27	H	H	860	F	Congaree River	149
4/19/2006	28	A	A	663	M	Congaree River	418
4/19/2006	29	A	A	690	M	Congaree River	421
4/19/2006	30	H	A	702	M	Congaree River	362
5/3/2006	31	H	A	675	M	Saluda River	419
5/3/2006	32	H	A	865	F	Saluda River	384
5/3/2006	33	H	H	675	M	Saluda River	33
5/3/2006	34	D	D	802	F	Saluda River	94
5/3/2006	35	M	M	768	M	Saluda River	251

Table 1. Continued.

Date Implanted	Fish Number	Fate	365-d Fate	TL	Sex	Tagging Location	Days Tracked
5/3/2006	36	A	A	784	M	Saluda River	469
5/3/2006	37	M	D	713	M	Saluda River	166
5/3/2006	38	A	A	810	M	Saluda River	469
5/3/2006	39	H	H	705	M	Saluda River	111
5/3/2006	40	H	H	698	M	Saluda River	17
5/8/2006	41	A	A	725	M	Saluda River	498
5/8/2006	42	H	H	732	F	Saluda River	34
5/8/2006	43	H	A	711	M	Saluda River	388
5/8/2006	44	H	H	752	F	Saluda River	51
5/8/2006	45	H	A	793	M	Saluda River	383
5/8/2006	46	H	H	700	M	Saluda River	89
5/8/2006	47	H	H	693	M	Saluda River	49
5/8/2006	48	H	A	773	M	Saluda River	374
5/18/2006	49	A	A	760	F	Saluda River	458
5/18/2006	50	M	A	786	F	Saluda River	354
5/18/2006	51	A	A	704	M	Saluda River	465
5/18/2006	52	A	A	750	F	Saluda River	443
5/18/2006	53	A	A	885	F	Saluda River	502
5/18/2006	54	H	H	780	M	Saluda River	21
5/18/2006	55	H	A	811	M	Saluda River	414
5/18/2006	56	M	M	870	F	Saluda River	150
5/18/2006	57	H	A	930	F	Saluda River	403
5/18/2006	58	M	A	822	M	Saluda River	391
6/22/2006	59	M	D	804	M	Saluda River	101
6/22/2006	60	M	D	732	M	Saluda River	135
6/22/2006	61	A	A	782	F	Saluda River	441
7/13/2006	62	M	M	710	?	Saluda River	178
7/13/2006	63	M	D	744	?	Saluda River	73
7/13/2006	64	D	D	740	?	Saluda River	49
7/13/2006	65	H	H	740	?	Saluda River	15
7/13/2006	66	H	H	775	?	Saluda River	4
7/13/2006	67	M	D	810	?	Saluda River	111
12/19/2006	68	H	H	712	?	Lake Moultrie	201
12/19/2006	69	M	M	670	?	Lake Moultrie	162
12/20/2006	70	M	M	755	?	Lake Moultrie	270
12/20/2006	71	M	M	698	?	Lake Moultrie	95
2/9/2007	72	M	M	720	M	Lake Moultrie	39
2/15/2007	73	M	M	704	M	Lake Moultrie	114
2/15/2007	74	A	A	670	M	Lake Moultrie	412

Table 1. Continued.

Date Implanted	Fish Number	Fate	365-d Fate	TL	Sex	Tagging Location	Days Tracked
2/15/2007	75	A	A	645	M	Lake Moultrie	415
2/15/2007	76	M	M	610	M	Lake Moultrie	95
2/15/2007	77	H	H	645	M	Lake Moultrie	94
2/28/2007	78	M	M	698	F	Lake Moultrie	64
2/28/2007	79	M	M	690	M	Lake Moultrie	45
2/28/2007	80	M	M	672	F	Lake Moultrie	235
2/28/2007	81	H	H	728	F	Lake Moultrie	65
2/28/2007	82	S	S	688	F	Lake Moultrie	11
2/28/2007	83	M	M	658	F	Lake Moultrie	143
2/28/2007	84	M	M	692	F	Lake Moultrie	150
2/28/2007	85	A	A	688	F	Lake Moultrie	310

Table 2. Mean TL of striped bass and associated SE for transmitter implanted striped bass tracked in the Santee-Cooper system, South Carolina, during 2006 – 2008. Means with the same letter were not significantly different (Tukey's; $P > 0.05$).

Tagging Location	N	TL (mm)	SE
Saluda River	37	765 y	9.9
Congaree River	26	723 z	10.3
Lake Moultrie	17	686 z	8.5

Overall tagging mortality of striped bass was low (6%), only 5 of the 85 implanted fish were assumed to have expired due to tagging and handling. Four of thirty striped bass tagged during April 2006 in the Congaree River and one fish tagged during February in Lake Moultrie were assumed to have expired due to tagging and handling. The other 80 fish were successfully tracked, unless they were harvested, for at least 30 days post-implantation.

Of the 63 fish successfully implanted during spring/summer 2006, 26 were dead or missing 41 - 391 d post implantation (average days tracked = 174) and 23 were harvested 4 - 485 d post implantation (Figure 2), the remaining 14 fish were assumed to be alive at the time of transmitter expiration or study conclusion and were tracked for an average of 456 days. Of the 17 fish successfully implanted with transmitters during winter in Lake Moultrie, 11 were dead or missing 39-270 d post implantation (average days tracked = 124), 3 were harvested 65-201 d post implantation and three fish are were assumed to be alive at the time of transmitter expiration or study conclusion. Overall exploitation of instrumented fish was approximately 33% and most (73%) of the harvest occurred in the lower Saluda River. Nineteen fish were harvested from the lower Saluda River, three were harvested from the upper Congaree River, all above Rosewood Boat Ramp, and four were harvested from Lake Marion. Eighty-five percent of all harvest occurred in the Saluda River or upper Congaree River between April and August. Forty-six percent of fish died or went missing during the study and 21% of fish were considered to be alive at the time of transmitter expiration or study conclusion. After 365 d post-implantation 30 fish were alive (37%), 33 fish were dead or missing (42%) and 17 fish were harvested (21%) (Figure 2).

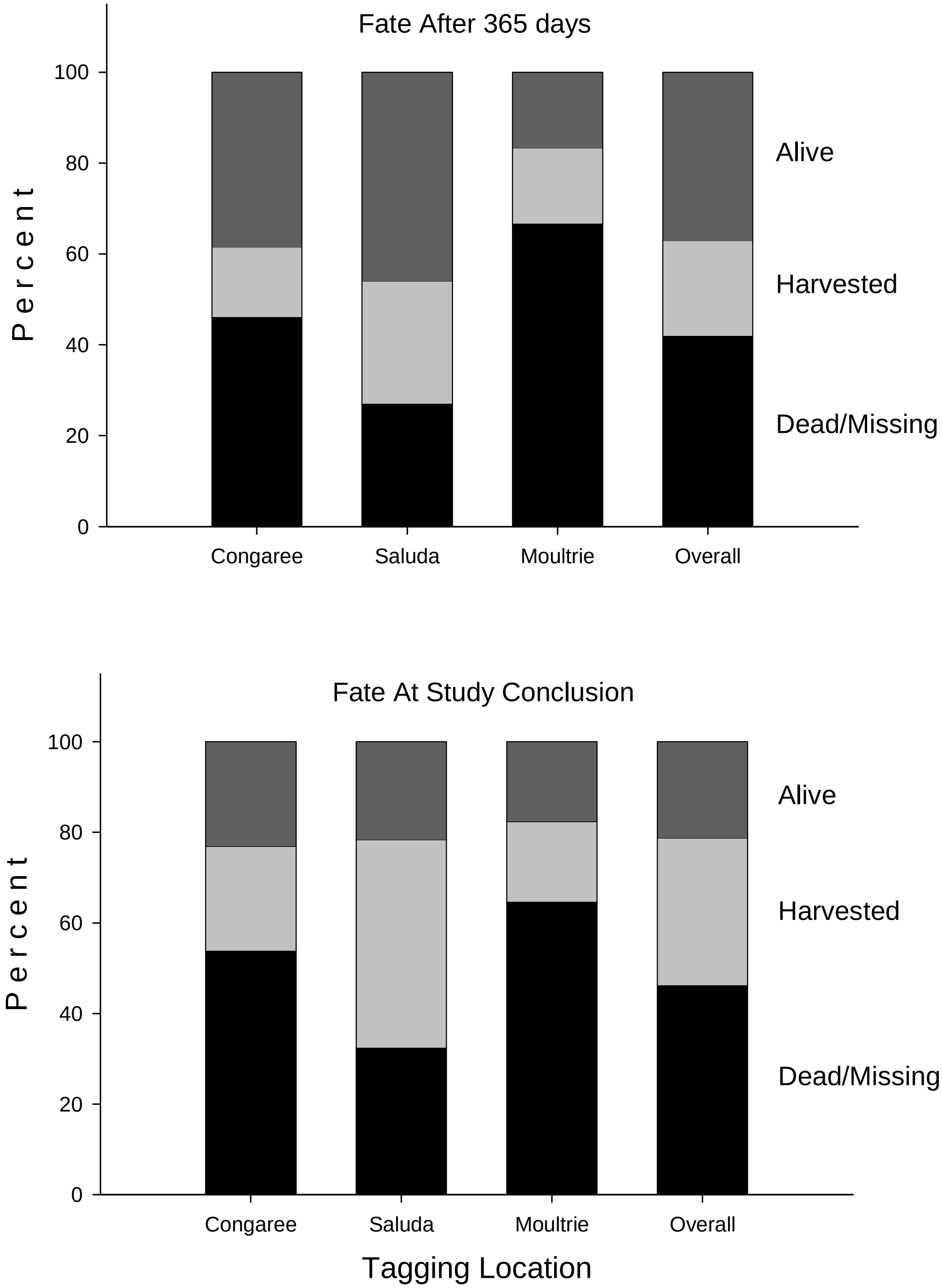

Figure 2. Fate of striped bass implanted with transmitters during 2006 and 2007 in the Santee-Cooper system. Top panel shows fate of striped bass after 365 d at large and bottom panel shows fate at the conclusion of the study.

Tagging location did not influence overall fate or 365 d fate of striped bass (Fisher's Exact; P > 0.05). However, last known location did significantly influence (Fisher's Exact: P <0.05) overall fate and 365-d fate of striped bass (Table3). Harvest rates were higher than expected in the Saluda River and lower than expected in the reservoirs and tributaries, while mortality was greater than expected in the reservoirs and tributary rivers and less than expected in the Saluda River.

Table 3. Observed frequencies and expected frequencies (in parentheses) for fate and 365-d fate of striped bass implanted in the Santee-Cooper system based on last known location. Both fate and 365-d fate were significantly influenced by last known location (Fisher's Exact Test P < 0.05).

	Fate			**Fate-365d**		
Last Location	Alive	Dead	Harvested	Alive	Dead	Harvested
Tributary River	1 (2.8)	9 (6.0)	3 (4.2)	4 (4.9)	7 (5.4)	2 (2.8)
Reservoir	7 (7.9)	26 (17.1)	4 (12.0)	10 (13.9)	24 (15.3)	3 (7.9)
Saluda River	9 (6.4)	2 (13.9)	19 (9.8)	16 (11.3)	2 (12.4)	12 (6.4)

During 2006, 14 of 26 fish successfully tagged in the Congaree River moved into the Saluda River between 21 April and 18 June (between 7 d and 73 d post implantation), the median entry data was 10 May. The fish that moved into the Saluda River on 18 June first moved down into Lake Marion and then back up the Congaree and into the Saluda River. One fish was harvested from the upper Congaree River, before it could move into the Saluda or return to the lakes and one transmitter failed (latter harvested by an angler). The other 10 fish tagged in the Congaree River moved down into the lower lakes, reaching Lake Marion between 5 and 24 d post implantation. Two of those fish moved through the lakes and Pinopolis Dam into the Cooper River within 14 and 33 d post implantation.

Striped bass tagged in the Saluda River and the Congaree-tagged striped bass that moved into the lower Saluda River during 2006 spent the spring and most of the summer in the Saluda River, then left the river and moved down to the lakes. Congaree River fish that moved into the Saluda River post implantation spent between 25 d and 158 d (mean = 113 d) in the Saluda River before heading for the lakes. Fish left the Saluda River between 13 July and 7 November; the median departure date was 25 September. Departure date from the Saluda River was not related to fish TL or sex ($P > 0.05$). After leaving the Saluda River striped bass spent between 0 d and 23 d (mean = 7.6 d) in the Congaree River before entering Lake Marion.

Table 4. The number of transmitter implanted Santee-Cooper striped bass, by tagging location, entering each tributary river during spring 2007.

	Tributary River		
Tagging Location	Both	Congaree	Wateree
Congaree River	4	4	1
Saluda River	6	11	
Lake Moultrie	5	6	2
Grand Total	15	21	3

During spring 2007, 39 fish made a spawning run up at least one tributary river. Twenty-one fish ascended the Congaree River, three fish ascended the Wateree River and 15 fish utilized both rivers at some point during the spring (Table 4). Spring movements into the Congaree River ranged from 1 March to 13 May, the median entry date was 2 April. Spring movements into the Wateree River ranged from 25 January to 16 May; the median entry date was 30 March. Water temperature at the Weeks Landing Receiver ranged from 8.5 ºC – 23.3 ºC and averaged 16.7 ºC when fish entered the spawning tributaries. Entry date into the spawning tributaries was not related to fish TL or sex ($P = 0.53$) (Figure 3). Fish spent an average of 34 d (range 3 – 149 d) in the Congaree River before entering the Saluda River or returning to the Lakes, while fish that primarily used the Wateree River spent an average of 54 d (range 7 – 106 d) in that location before returning to the lakes. Water temperatures at the Weeks Landing Receiver ranged from 17.5 ºC – 26.8 ºC and averaged 22.5 ºC when fish left the tributary rivers to enter the Saluda River or return to the lakes. The time striped bass spent in tributary rivers was positively related to entry date ($P < 0.05$; $r^2 = 0.70$) (Figure 3), but not related to TL or sex ($P > 0.05$).

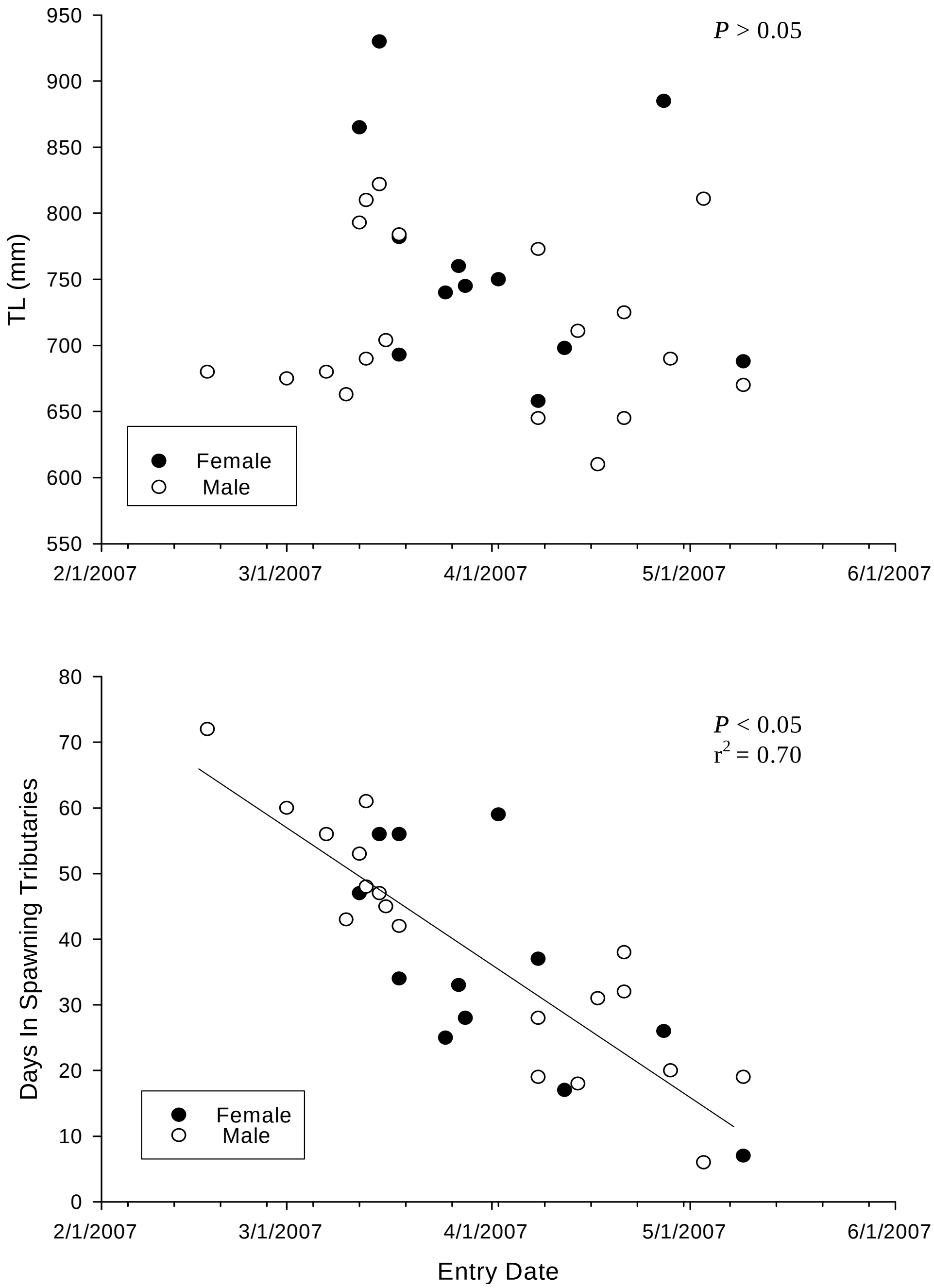

Figure 3. TL and d in spawning tributaries versus entry date into spawning tributaries for striped bass in the Santee-Cooper during spring 2007.

Twenty of the 39 fish that made a tributary spawning movement during 2007 ultimately moved into the Saluda River, movement into the Saluda River ranged from 22 April to 31 May, the median entry date was 5 May. Fish that were implanted in the Congaree River were more likely to enter the Saluda River than fish that were implanted in Lake Moultrie (Chi-square; $P < 0.05$). Sex was not a significant predictor of whether or not fish would enter the Saluda River (Chi-square; $P > 0.05$), but TL was, fish that used the Saluda River (mean = 758 mm TL) were larger than fish that did not use the Saluda River (mean = 6 83 mm TL) (T-test; $P < 0.05$). Eighteen of the fish that entered the Saluda River in 2007 also utilized the Saluda River in 2006; the other two fish that entered the lower Saluda River were tagged during the winter in Lake Moultrie. Eighteen of 19 fish from the spring/summer 2006 tagging events used the Saluda River during both 2006 and 2007; the other fish went missing just below the Saluda River on 7 May 2007.

Two basic seasonal movement patterns were observed during the study, fish either summered in the lower Saluda River or they spent the summer in the lakes. For Congaree-tagged fish, roughly 56% of the tagged fish summered in the lower Saluda and the remainder summered in the lakes, all fish were located below the tributary rivers during the winter. Seven Congaree-tagged fish that were tracked for at least one year spent the summer below the tributary rivers. Five of those fish summered in Lake Moultrie moving into Lake Marion in the fall where they spent the majority of the winter and one fish spent the entire summer and winter seasons in Lake Marion (Figure 4). The other fish spent the summer and winter in the Cooper River below Pinopolis Dam, only exiting the Cooper River to make a spawning run up the Congaree River during spring 2007 (Figure 5). Twenty-one fish (17 Saluda-tagged and 4 Congaree-tagged) that spent the summer season in the Saluda River were tracked for roughly one year. Of those 21 fish, five fish spent the entire winter in Lake Marion (Figure 5), 5 fish spent the majority of winter in Lake Marion, but made a few brief forays into Lake

Moultrie, 9 fish moved in and out of both lakes during the winter (Figure 6), one fish spent the entire winter in Lake Moultrie and one fish spent the winter in the lower Santee River (Figure 7). Few fish implanted in Lake Moultrie were tracked for multiple seasons, but those that were had similar patterns as fish implanted in the Saluda River and Congaree River. Two fish implanted in Lake Moultrie summered in the Saluda River, although an additional fish summered in the upper Congaree where water temperatures are cool due to releases from Lake Murray Dam. Four fish summered in Lake Moultrie, one fish in Lake Marion and one fish the Wateree River below Lake Wateree Dam.

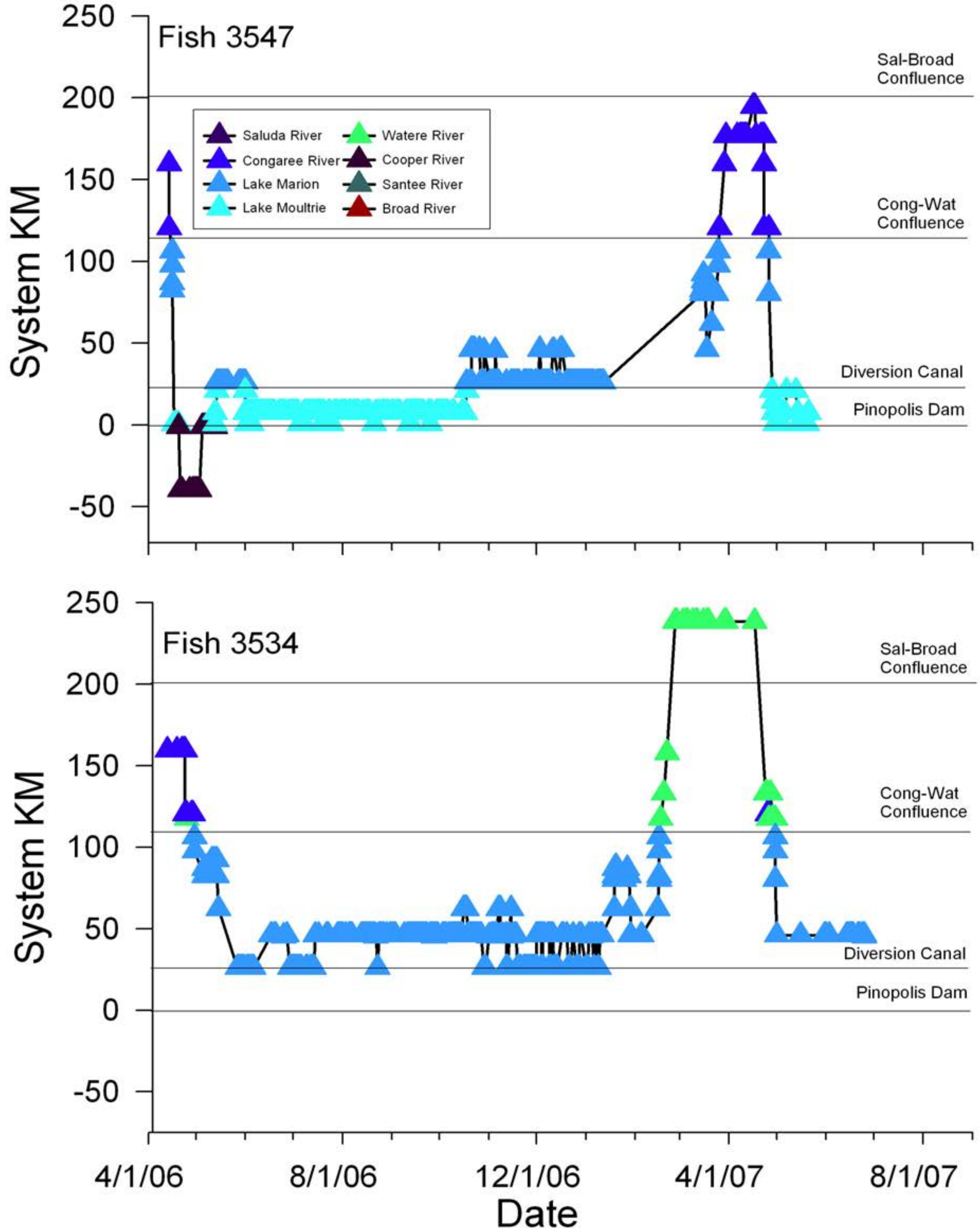

Figure 4. Locations of striped bass 3547 and 3534 in the Santee-Cooper system during 2006 and 2007. Fish 3547 displays a common seasonal pattern, occupying Lake Moultrie during summer, Lake Marion during winter and making a spring spawning migration up the Congaree River, while 3534 utilizes Lake Marion during both summer and winter and ascends the Wateree River.

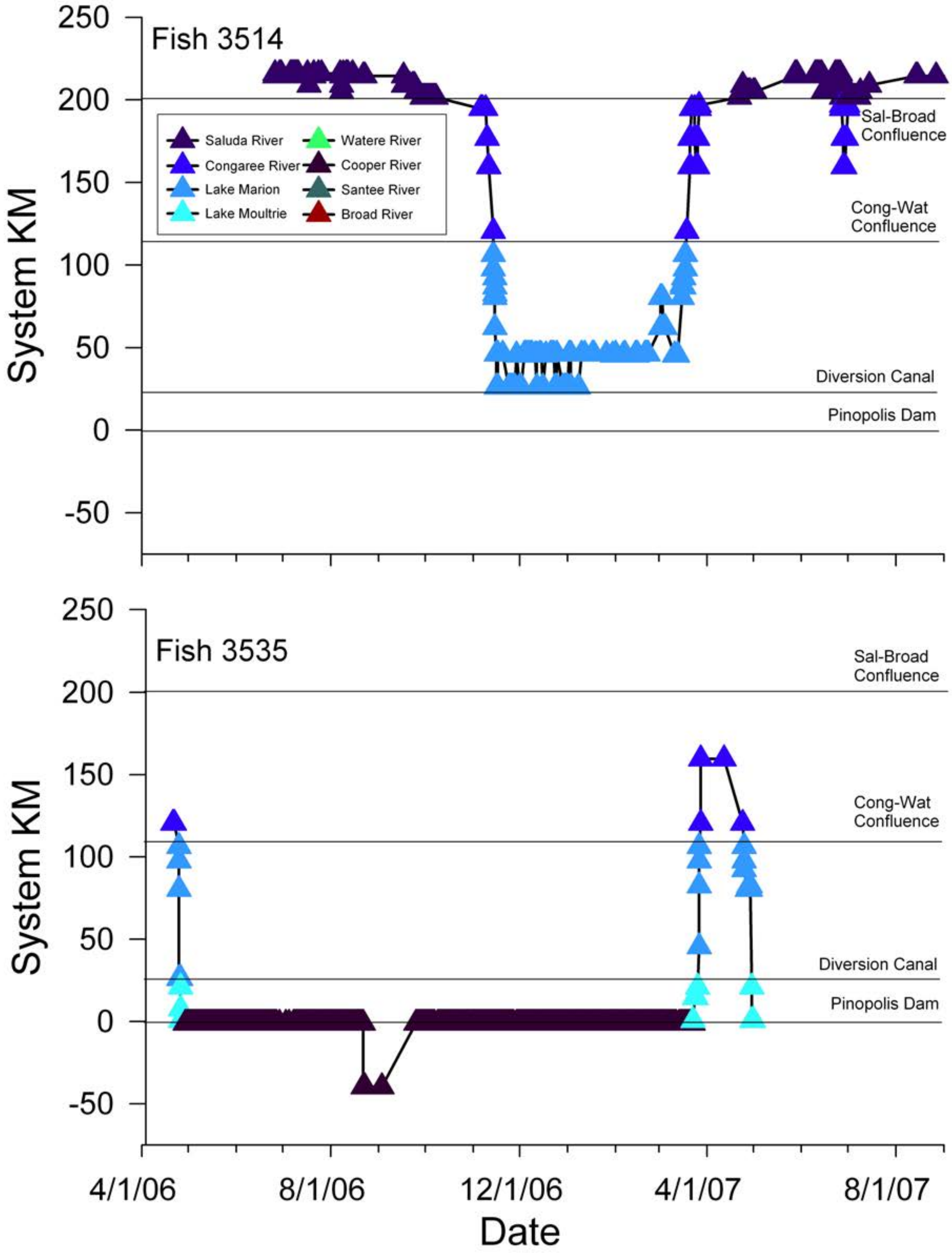

Figure 5. Locations of striped bass 3514 and 3535 in the Santee-Cooper system during 2006 and 2007. Fish 3514 displays a common seasonal pattern, occupying the lower Saluda during the summer and spending the winter in Lake Marion, fish 3535 spends nearly the entire year in the Cooper River.

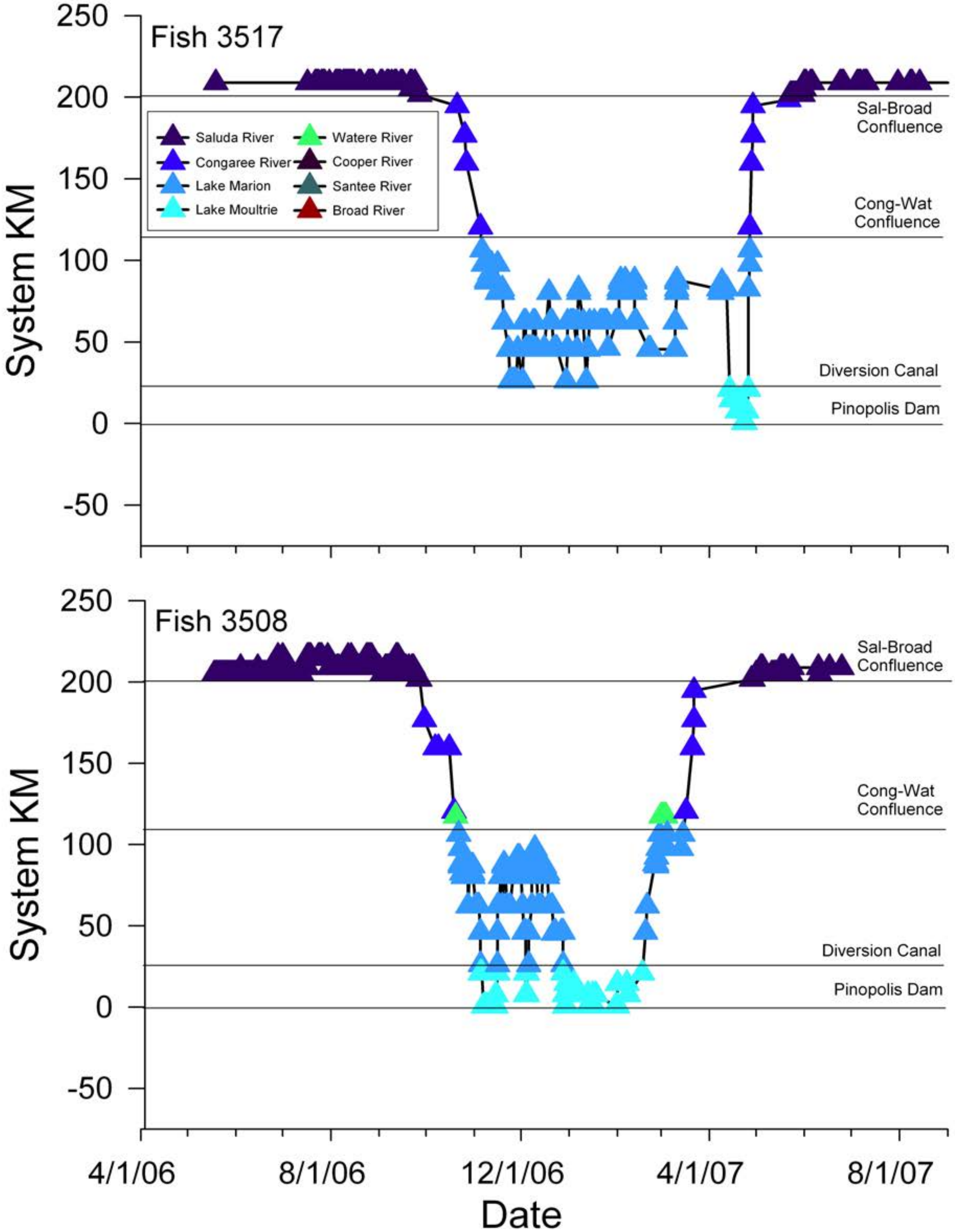

Figure 6. Locations of striped bass 3517 and 3508 in the Santee-Cooper system during 2006 and 2007. Fish 3517 spends the majority of the winter in Lake Marion, fish 3508 moves frequently between the lakes.

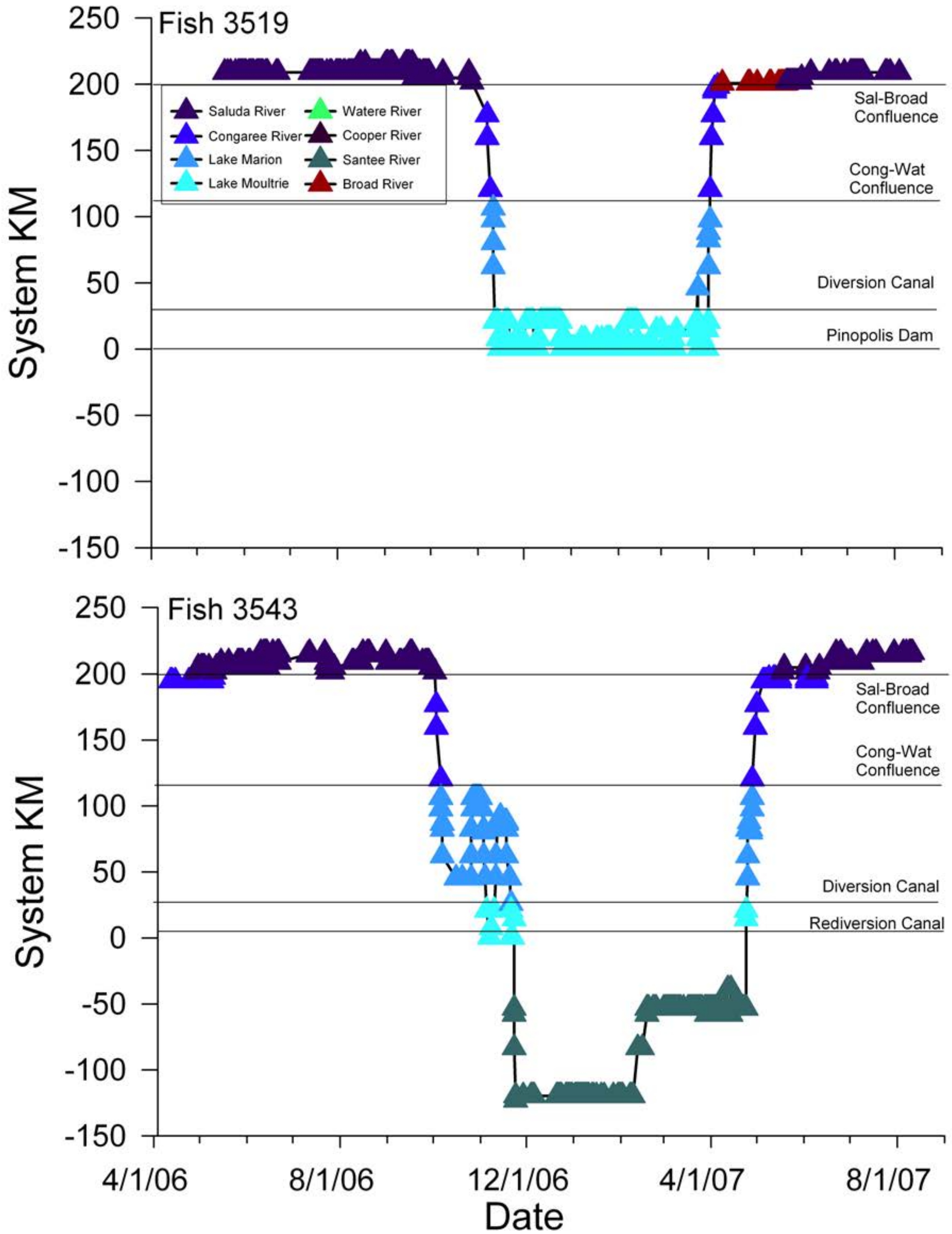

Figure 7. Locations of striped bass 3519 and 3543 in the Santee-Cooper system during 2006 and 2007. Each fish represents an anomalous seasonal pattern with 3519 spending the winter in Lake Moultrie and 3543 passing through St. Stephen fish ladder and spending the winter in the lower Santee River.

Discussion

Annual mortality, based on the fate of striped bass 365 d post implantation, was 63% which was comparable to catch curve derived estimates of 60% (Bulak et al. 1995) and 70% (White and Bulak 2008) for the Santee-Cooper striped bass population. However, in this study only 21% of striped bass were known to be harvested while a previous study, using tag returns from harvested fish, estimated an annual exploitation rate of 39% (White and Bulak 2008). The disparity in exploitation estimates could be due to unreported harvest in the current study and/or a recent decrease in fishing effort. Thirty-three fish were confirmed dead or went missing within in 365 days of transmitter implantation, it is possible that some of those missing fish were harvested, but not reported. Unreported harvest would increase the estimate of natural mortality in the current study. Fishing effort has decreased dramatically in recent years and could account for a decrease in exploitation rates. The White and Bulak (2008) study was conducted during the late 1990’s when fishing effort and angler success were considerably higher than during the current study.

Based on this study and previous efforts (Bulak 1995, White and Bulak 2008) it appears that the Santee-Cooper striped bass population experiences higher natural mortality rates than populations in other southeastern reservoirs. Recent telemetry derived estimates of instantaneous natural mortality for striped bass in North Carolina (Hightower et al. 2001, Thompson et al. 2007) and South Carolina (Young and Isely 2004) reservoirs have ranged from 0.09 -0.16 and in some years those populations experienced very high (> 65%) exploitation rates. Higher natural mortality rates in the Santee-Cooper lakes could be due to marginal habitat for striped bass during summer. Short water retention times, shallow depths and other physical factors in the Santee-Cooper reservoirs result in weak or even nonexistent thermal stratification during summer (Inabinet 1985) and summer-time water temperatures can exceed 28ºC throughout the water column. Although striped bass can survive temperatures in excess of 27ºC when oxygen exceeds 2 mg/L (Farquhar and Gutreuter 1989, Zale et al. 1990, Haeseker et al. 1996) exposure to high temperatures for prolonged periods may result in poor condition (McDaniel et al. 1991) and ultimately death (Zale et al. 1990).

Seasonal and temporal patterns of exploitation and mortality were apparent in this study. Eighty-five percent of the harvest occurred in the lower Saluda River or upper Congaree River and most (92%) harvest occurred between the months of April and August. Months which represent the spring spawning movement up the tributaries and the summer-time use of the thermal refuge in the lower Saluda River. Only four fish were harvested from Lake Marion, 2 from the upper reaches of the reservoir during the spring spawning run and two from the lower embayment during the fall. No fish were harvested from other segments of the system. Similarly, in J. Strom Thurmond Reservoir, South Carolina most striped bass were caught from a thermal refuge located in the tailrace of Richard B. Russell Dam during May-October (Young and Isely 2004). Wilkerson and Fisher (1997) determined striped bass in Robert S. Kerr Reservoir, Oklahoma were susceptible to overfishing when fish congregated in the Illinois River and exhibited strong site fidelity. Although most angling mortality occurred in the lower Saluda River very little, if any, natural mortality occurred in that segment of the system. Only two fish went missing from the Saluda River and both of those fish were likely unreported harvest, or their transmitters failed prematurely, because subsequent manual tracking efforts failed to detect their transmitters within in the Saluda River and they were not detected at any of the receivers below the Saluda River

Timing of spawning migrations was similar to what was known previously for striped bass in the Santee Cooper system. Braschler (1987) found that striped bass moved from the lakes into the spawning tributaries in April and returned to the lakes during mid-May. Similarly, during egg production studies Bulak (1997) found the peak spawning activity of striped bass typically occurred during late April. In this study striped bass sex did not influence entry date into the spawning tributaries or duration in spawning tributaries. Data from a previous study showed that males entered the spawning grounds before females and remained on the spawning grounds longer than females (Bulak 1990), however, most (81%) of the males in that study were less than 650 mm TL and male striped bass in the current study averaged 721 mm TL. It may be that young, but mature male striped bass enter the spawning grounds earlier than females and larger older males. Males in anadromous striped bass populations in the Roanoke River (Carmichael et al. 1998) and Hudson River (McLaren et al. 1981) have been shown to enter the spawning grounds earlier than females.

Wilkerson and Fisher (1997) identified two broad patterns of seasonal striped bass movement in inland reservoirs. In the first pattern striped bass move into reservoir tributaries during the spring to spawn and then return to the reservoir following spawning where they disperse until high summer-time water temperatures force them into spatially restricted habitats generally in the most downstream portions of the reservoir (Combs and Peltz 1982, Farquhar and Gutreuter 1989). In the other movement pattern striped bass utilize thermal refuges in lotic environments following spawning and do not disperse throughout the reservoir (Cheek et al. 1985, Lamprecht and Shelton 1988, Wilkerson and Fisher 1997) until water temperature fall below a critical level during autumn. The Santee-Cooper striped bass population displayed both general patterns of movement with a portion of the population summering in the lower Saluda River before returning to the lakes and a portion forgoing the thermal refuge in the Saluda River and returning to the reservoirs, primarily Lake Moultrie post-spawn. A similar pattern of seasonal movement was observed in Lake Murray, South Carolina where striped bass used both the lower embayment of the reservoir and a tailrace below an upstream dam for thermal refuge (Schaffler et al. 2002).

We did not observe annual segregation of the striped bass population or evidence of multiple stocks. However, there is seasonal segregation of adult striped bass with a portion of the population utilizing the lower Saluda River as a thermal refuge during the summer and another portion of the population inhabiting the lakes, primarily Lake Moultrie. The exact percentage of the population utilizing the various segments during the summer is unknown. Roughly 56% of the adult fish tagged in the Congaree River used the lower Saluda during the summer, but only 2 of 11 fish tagged during winter in Lake Moultrie used the lower Saluda River, although one other fish spent the summer near the confluence of the Broad and Saluda rivers before returning to the lakes. The striped bass tagged in Lake Moultrie were significantly smaller than fish that utilized the Saluda River, perhaps larger adults were more likely to use the Saluda River as a thermal refuge. Data collected during the study demonstrates the importance of the lower Saluda River as a thermal refuge for adult striped bass. While occupying the lower Saluda River striped bass are vulnerable to intense angling pressure and high rates of exploitation.

Recommendations

Seasonal segregation of the Santee-Cooper striped bass stock warrants, may even necessitate, the use of multiple management strategies (e.g., seasonal closures, length and creel restrictions) to optimize stock management and allocation. For example, during the summer different management strategies could be employed in the lower Saluda River and Lake Moultrie, the two primary summer-time habitats for Santee-Cooper striped bass. In the Saluda River large numbers of adult striped bass are subjected to intense angling pressure and high rates of exploitation, but the cool water temperatures should allow for a successful catch and release fishery. Multiple studies have documented that striped bass can be angled and released successfully when water temperatures are cool, but when water temperatures are warm catch and release mortality can be as high as 83% (Bettoli and Osborne 1998, Wilde et al. 2000, Bettinger et al. 2005). In the current study at least two fish were angled and successfully released by an angler who reported the tag numbers and released the fish, one of those fish was caught and harvested by a different one year later. In the lower Saluda River angling mortality could be reduced by implementing more conservative size and or creel limits. Conversely, in Lake Moultrie catch and release mortality due to warm summer water temperatures could negate the effectiveness of any creel or length restrictions enacted to reduce angling mortality. Reducing angling mortality in Lake Moultrie may require seasonal closures as opposed to creel and length restrictions.

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