STRIPED BASS DISTRIBUTION AND HABITAT USE IN J. STROM THURMOND RESERVOIR, SOUTH CAROLINA - GEORGIA

STUDY COMPLETION REPORT

December 31, 2015

Jason M. Bettinger

Division of Wildlife and Freshwater Fisheries
Emily Cope, Deputy Director

EXECUTIVE SUMMARY

1. Between 16 April 2010 and 10 April 2014, 169 Striped Bass (mean Total Length [TL] = 759 mm; range 480 – 1,400 mm) were successfully implanted with acoustic transmitters and monitored with manual tracking and an array of 64 remote acoustic receivers in J. Strom Thurmond (Thurmond) Reservoir. For individual fish the mean number of days tracked was 373 and the mean number of detections at receiver stations was 48,867.

2. Between 24 February 2013 and 9 April 2014, 19 Hybrid Striped Bass (mean TL = 561 mm; range 492 – 655 mm) were successfully implanted with acoustic transmitters. The mean number of days tracked was 258 and the mean number of detections at receiver stations was 27,676.

3. As of December 2014, 17% of successfully implanted Striped Bass were known to be alive, 47% were harvested or assumed harvested, 8% died presumably of natural causes, 3% were missing and 25% had expired transmitters. Most fishing mortality (86%) occurred between April and October. Mortality most frequently occurred in the Russell Tailrace (52%) and lower reservoir (29%).

4. As of December 2014, 47% of successfully implanted and tracked Hybrid Striped Bass (N=19) were alive, 47% were harvested or assumed harvested, and one fish exited the lake through the Thurmond turbines and entered Steven's Creek Reservoir.

5. Between 2010 and 2013 the median total annual mortality (A) of Striped Bass was 48%, exploitation (u) was 40%, and natural mortality (v) was 8%. Total mortality and exploitation were highest during summer of each year.

6. Over all years the majority of Striped Bass moved into presumptive spawning tributaries by the first week of March, with the peak of residence occurring the fourth week of March, after which fish vacated the tributaries. By the second week of June all fish moved into the reservoir and tailrace. Striped Bass remained in these summer habitats until October.

7. Striped Bass exhibited site fidelity to presumptive spawning tributaries and summer habitat. All fish followed for multiple years returned to the same presumptive spawning tributary each spring. All but one fish used the same summer habitat (Lower Reservoir or Tailrace) each year.

8. The proportion of Striped Bass utilizing the oxygenated lower reservoir during summer increased each year from 25% in 2010 to 54% in 2014. Tagging location and fish length influenced summer habitat choice. Fish tagged in Broad River, GA were more likely to use the Russell Tailrace during summer and fish tagged in Little River, GA were more likely to use the lower reservoir during summer. Larger (> 815 mm) Striped Bass were more likely to use the Russell Tailrace than lower reservoir.

9. Mean annual temperature occupied by large Striped Bass (≥ 820 mm TL) was significantly cooler than that occupied by medium Striped Bass (< 820 mm TL) in each year of the study.

10. During August of 2010 and 2011 Striped Bass in the Russell Tailrace occupied significantly warmer temperatures than Striped Bass in lower reservoir, but during August of 2012, 2013, and 2014 Striped Bass in the Russell Tailrace occupied significantly cooler temperatures than Striped Bass in the lower reservoir.

11. Pumping operations at Russell Dam influenced Striped Bass temperature occupancy in the Russell Tailrace during summer. Water occupied by Striped Bass was significantly warmer during the last hour of pumping than the first hour of pumping.

12. Hypolimnetic oxygenation of lower Thurmond Reservoir was successful in creating some amount of optimal Striped Bass habitat (18 – 24°C and dissolved oxygen > 5 mg/l) on 89% of the summer dates (n = 38) reviewed during 2011 – 2014. During 2010, before oxygenation, conditions in the lower reservoir were unsuitable (> 25 °C or dissolved oxygen < 2 mg/l) for Striped Bass by early September.

13. Striped Bass (n = 105) manually located in the lower reservoir during summer occupied a mean depth of 13.4 m (range, 5.5 – 22 m), a mean dissolved oxygen concentration of 3.8 mg/l (range, 1.1 – 8.1 mg/l) and a mean temperature of 24.4 °C (range, 15.5 – 26.5).

14. Dissolved oxygen conditions and depth occupied by transmitter-implanted Striped Bass in the lower reservoir were interpolated from temperature observations of 61 fish on five dates during the summer oxygenation periods of each year (2011 – 2014). This resulted in 13,432 sets of temperature, depth, and dissolved oxygen observations for transmitter-implanted Striped Bass. Striped Bass mean dissolved oxygen and temperature were in the optimal range (18 – 24°C and dissolved oxygen > 5 mg/l), or nearly so, in every year except 2014 when Striped Bass mean dissolved oxygen was suboptimal (< 5.0 mg/l) on each of the 5 dates reviewed.

15. Striped Bass did not always occupy optimal habitat when available. Forty-one percent of Striped Bass occupied less than optimal dissolved oxygen conditions when optimal (18 – 24°C and dissolved oxygen > 5 mg/l) habitat was available. Striped Bass that used suboptimal habitat chose slightly cooler water temperatures with mean dissolved oxygen levels ≥ 2.6 mg/l.

16. While occupying the lower reservoir during the summer oxygenation period Striped Bass moved throughout the lower reservoir and were not restricted to the area directly near the oxygenation system.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PREFACE

J. Strom Thurmond (Thurmond) Reservoir supports a popular recreational Striped Bass fishery. Historically, Striped Bass production, especially trophy Striped Bass production, was largely contingent on suitable habitat provided by artificially oxygenated, hypolimnetic releases from Richard B. Russell (Russell) Dam that provide cool, well-oxygenated water in the tailrace and upper portions of Thurmond Reservoir during summer.

During 2011 the U. S. Army Corps of Engineers (USACE) commenced expanded pump-storage operations at Russell Dam which could result in warmer tailrace temperatures below the dam, possibly reducing suitable summer habitat for Striped Bass and other fishes. Given the unsuitable Striped Bass habitat throughout most of Thurmond during summer, the potential loss of summer habitat in Russell tailrace and the upper reservoir could have a negative impact on the Striped Bass fishery, especially on larger individuals that require cooler water temperatures.

To mitigate for the potential loss of Striped Bass habitat in the Russell tailrace and upper Thurmond, the USACE installed an oxygen injection system in the lower portion of the reservoir near Modoc, SC to provide additional Striped Bass habitat.

It was unknown whether the potential reduction of habitat in the Russell tailrace and upper Thurmond or the new artificially oxygenated area in the lower reservoir would affect the way Striped Bass utilize the reservoir as a whole. As considerable expense has been incurred in the development and installation of the new oxygen injection system, it was important to document the extent of Striped Bass use of the newly-created habitat.

This report presents the results of a five year study that monitored the movements of Striped Bass during 2010 – 2014 and Hybrid Striped Bass during 2013 and 2014 in Thurmond Reservoir. The report is separated into four sections: 1. The fate and mortality of transmitter-implanted

Striped Bass and Hybrid Striped Bass with description of field methods and telemetry array, 2. The seasonal distribution of Striped Bass and Hybrid Striped Bass with observations on summer habitat choice of Striped Bass before and after oxygenation, 3. Temperature occupancy of Striped Bass and Hybrid Striped Bass, and 4. Summer-time habitat conditions in Thurmond Reservoir during the study and Striped Bass distribution in the oxygenated area.

FATE AND MORTALITY

Objectives

The objectives of this section are to: 1. Describe the telemetry methods used to monitor Striped Bass and Hybrid Striped Bass Thurmond Reservoir, 2. Describe the fate of transmitter-implanted fish, and 3. Estimate seasonal and annual mortality rates of Striped Bass.

Materials and Methods

Field

During spring (February – May) of 2010- 2014, inclusive, Striped Bass were collected from four major tributaries of Thurmond Reservoir (Little River, SC; Long Cane Creek, SC; Little River, GA; and Broad River, GA, Figure 1) and surgically implanted with acoustic transmitters. Similarly, Striped Bass were collected from the Russell Tailrace during August 2010 and May of 2011 and 2012, and Hybrid Striped Bass were collected from three tributaries during spring of 2013 and 2014 for implantation with acoustic transmitters. Two sizes of individually coded temperature-sensing transmitters manufactured by Sonotronics (Tucson, AZ) were used based on fish length. A high powered long-range transmitter (Model CHP-87-L) expected to last 18 months was implanted in Striped Bass > 575 mm TL and a less powerful transmitter (Model CTT-83-3) expected to last 36 months was implanted in Striped Bass > 480 mm TL and Hybrid Striped Bass. To facilitate the return of transmitters from harvested fish, external $50 reward tags were inserted into most Striped Bass implanted during 2013 and 2014. Reward tags (Hallprint Pty Ltd., Victor Harbor, South Australia) were internal anchor tags with a 90 mm external streamer that included our phone number and the phrases “Tag inside”, “$50 reward”, and “Call SCDNR”.

All Striped Bass and Hybrid Striped Bass were collected with boat-mounted electrofishing equipment. When captured Striped Bass were immediately placed on a large v-trough measuring board, or placed in a foam-lined cooler filled with lake water, covered in wet towels, measured, and sexed, when possible. Transmitters 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). During 2013 and 2014 most Striped Bass were fitted with an internal anchor tag (Hallprint Pty Ltd., Victor Harbor, South Australia) 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, as fish were sufficiently narcotized from electrofishing for the short (3-4 minute) implantation procedure. After transmitter and tag implantation fish were immediately released near their capture location. All surgical tools and tags were disinfected with Benz-All® (Xttrium Laboratories, Chicago, IL) before surgery.

An array of remote acoustic receivers (SUR-3BT, Sonotronics Inc.) was used to collect movement data from transmitter-implanted fish (Figure 1). Up to 64 receiver locations were used each year with 73 locations among years during 2010 - 2014. Receivers were positioned throughout the mainstem reservoir with expanded arrays in the tailrace and oxygen injected area to achieve nearly continuous coverage of the Savannah River channel in those areas. A receiver was placed below Thurmond Dam on 24 June 2013 and above Russell Dam on 11 March 2014 to assess emigration from Thurmond Reservoir. Seasonal location data were collected with a hand held ultrasonic receiver (USR-08, Sonotronics Inc.) to identify other potential refuges and locate missing fish. Manual tracking was conducted during spring, summer and fall each year. Each manual track of the lake took a little over two weeks.

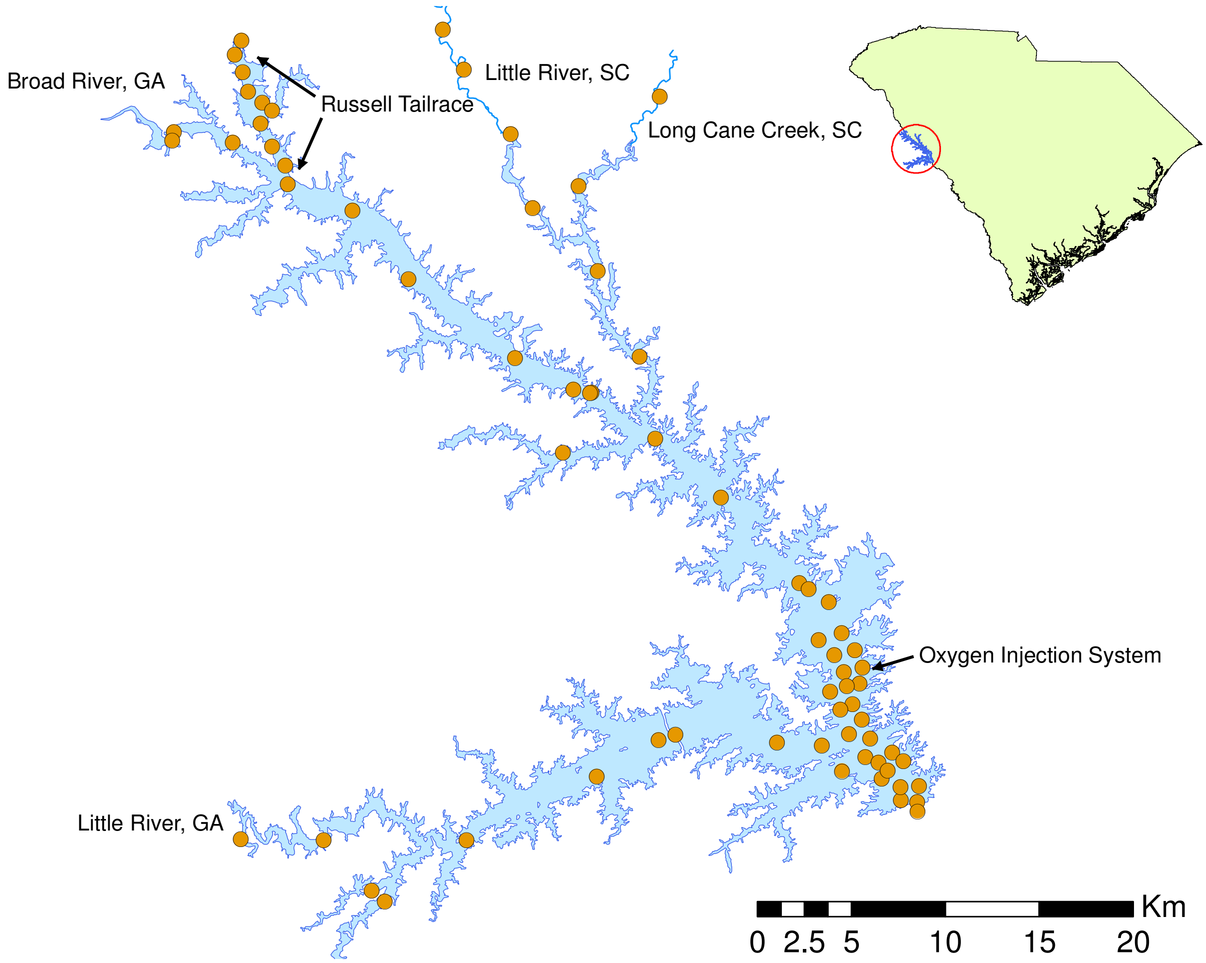


Figure 1. Acoustic receiver locations and Striped Bass collection sites in J. Strom Thurmond Reservoir, SC-GA, during 2010 - 2014.

Fate

We considered four possible fates for transmitter-implanted fish in Thurmond Reservoir. Fish could be 1) alive in the fishery until the conclusion of the study (or transmitter expiration), 2) harvested, 3) missing, or 4) dead of natural causes. During 2013 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 $50.00 reward would be given for returning transmitters from harvested fish. Fish were determined to be harvested when an angler returned a transmitter from a captured fish, or were assumed harvested when a fish went missing from an area with overlapping receiver coverage, and was not detected in subsequent manual searches. Fish lost from the fishery were either confirmed as dead by lack of movement during manual searches or simply classified as missing when they were no longer located at receiver stations or during manual searches. Due to the extensive receiver network it was unlikely that fish classified as missing were at large and simply undetected so ultimately they were lost from the fishery by harvest or natural mortality.

Striped Bass Mortality

A multistate capture-recapture model (Kery and Schaub 2012) following the methods of Hightower and Harris (2015) was used to estimate seasonal and annual mortality of transmitter-implanted Striped Bass. Seasonal manual tracking of Striped Bass allowed for total mortality (Z) to be partitioned into fishing (F) and natural mortality (M). In multistate capture-recapture models fish can occupy multiple states (e.g., alive or dead) and the model calculates the transition probability from one state to another. In this study the states were defined as detected-alive (1), detected-mortality (2) and not detected (3).

Receiver array detections, augmented with manual tracking data, were used to create seasonal capture histories for each fish (e.g., 1,1,3,1,3,1,2). Capture histories were modeled within a Bayesian framework using OpenBugs software (McCarthy 2007). An uninformative Ln-scale prior was used for estimating F and M. Fish were not entered into the model until the season after tagging, and only fish that were at large for at least three weeks were included. Fish were removed from the model the season in which their transmitter was advertised to expire.

Seasonal estimates were calculated each study year for summer (June – August), fall (September – November), winter (December – February) and spring (March – May). Due to the season of transmitter implantation, generally spring, the annual periods began during summer and concluded the following spring.

Instantaneous fishing (F), natural (M) and total (Z) mortality rates were converted to seasonal and annual interval rates with the following equations;

Total Mortality (A) = $1-e^{-z}$

Fishing Mortality (u) = FA/Z

Natural Mortality (v) = MA/Z.

Results

Field

Between 16 April 2010 and 10 April 2014, 185 Striped Bass (mean TL = 759 mm; range 480 – 1400 mm TL) were implanted with acoustic transmitters (Table 1). The mean number of fish implanted each year was 37 (range 34 – 39). During the five-year study 37 fish were implanted in Broad River, GA, 48 in the Little River system, GA, 60 in the Little River system, SC, 39 in the Russell Tailrace, and one in the upper reservoir. There was no difference in the length of fish implanted among years (ANOVA, df = 4, f = 0.31, P = 0.78); however, there was difference in length of fish among tagging locations (ANOVA, df = 3, f = 4.28, P = 0.006). Fish implanted in

Little River, GA (mean TL = 782, SE = 25) were longer than those implanted in the Russell Tailrace (mean TL = 667, SE = 23). There were no differences in mean TL among the other sites.

Between 24 February 2013 and 9 April 2014, 25 Hybrid Striped Bass (mean TL = 561 mm; range 492 – 655mm) were implanted with acoustic transmitters (Table 2). Thirteen fish were implanted in Broad River, GA, 7 in Little River, GA, and 5 in Little River, SC. There were no differences in fish length between years or among tagging locations (ANOVA, df = 3, f = 0.33, P = 0.80).

Table 1. Characteristics of Striped Bass implanted with acoustic transmitters in J. Strom Thurmond Reservoir, SC and GA. TL denotes total length in mm.

Tagging Year	Tagging Location	N	Mean TL	Min TL	Max TL
2010	Broad River, GA	8	995	722	1,400
2010	Little River, GA	3	629	565	690
2010	Little River, SC	5	704	650	820
2010	Russell Tailrace	21	647	480	1,040
2010	Thurmond	1	693	693	693
2010	**Total**	**38**	**728**	**480**	**1,400**
2011	Broad River, GA	7	680	550	780
2011	Little River, GA	9	811	620	1,300
2011	Little River, SC	12	717	600	925
2011	Russell Tailrace	8	692	574	990
2011	**Total**	**36**	**728**	**550**	**1,300**
2012	Broad River, GA	6	666	567	800
2012	Little River, GA	9	791	595	1,025
2012	Little River, SC	13	720	600	810
2012	Russell Tailrace	10	689	487	920
2012	**Total**	**38**	**720**	**487**	**1,025**
2013	Broad River, GA	12	868	685	1,050
2013	Little River, GA	12	848	690	1,155
2013	Little River, SC	15	771	627	915
2013	**Total**	**39**	**824**	**627**	**1,155**
2014	Broad River, GA	4	838	644	1,065
2014	Little River, GA	15	839	609	1,160
2014	Little River, SC	15	740	525	930
2014	**Total**	**34**	**795**	**525**	**1,160**
All Years	Total	185	759	480	1,400

Table 2. Characteristics of Hybrid Striped Bass implanted with acoustic transmitters in J. Strom Thurmond Reservoir, SC and GA. TL denotes total length in mm.

Tagging Year	Location	N	Mean TL	Min TL	Max TL
2013	Broad River, GA	8	567	525	622
2013	Little River, GA	4	573	500	615
2013	Little River, SC	2	510	508	511
2013	**Total**	**14**	**560**	**500**	**622**
2014	Broad River, GA	5	536	492	573
2014	Little River, GA	3	546	532	568
2014	Little River, SC	3	623	600	655
2014	**Total**	**11**	**562**	**492**	**655**
All years	Total	25	561	492	655

The number of manual tracking dates each year ranged from 32 to 44 and the number of person tracking days ranged from 35 to 47 (Table 3). The number of individual fish detected each year ranged from 30 to 64 and the total number of detections ranged from 81 to 191 (some fish were detected multiple times within a year).

Table 3. Results of manual tracking for transmitter-implanted Striped Bass and Hybrid Striped Bass in J. Strom Thurmond Reservoir, SC-GA, between 2010 and 2014.

Year	Individuals Detected	Total Detections	Number of Tracking Dates	Number of Person Days
2010	30	81	35	35
2011	46	89	32	40
2012	50	84	32	36
2013	58	100	37	45
2014	64	191	44	47
Total	149	545	180	203

During the study there were 8,258,512 Striped Bass detections and 525,480 Hybrid Striped Bass detections at 73 acoustic receiver locations. The mean number of detections for individual Striped Bass known to survive transmitter implantation was 48,867 (range 0 – 239,260) and the mean number of days tracked was 373 (Table 4). During manual tracking events 136 live Striped

Bass were located at least once with a total of 471 detections. The mean number of detections at receiver locations for Hybrid Striped Bass known to survive transmitter implantation was 26,292 (range 0 – 85,148). During manual tracking events 12 live Hybrid Striped Bass were located at least once with a total of 36 detections. Striped Bass and Hybrid Striped Bass with 0 receiver detections; survived transmitter-implantation, but were harvested before exiting tagging tributaries.

Table 4. Telemetry results for transmitter-implanted Striped Bass (STB) and Hybrid Striped Bass (HYB) in Thurmond Reservoir, SC-GA. Ranges for means given in parentheses.

Species	Tag Year	N	Mean Days Tracked	Mean Receiver Detections	Manual Detections
STB	2010	32	498 (28 - 1,265)	68,133 (0 - 239,260)	133
STB	2011	31	364 (4 - 1,051)	41,019 (932 - 204,467)	77
STB	2012	34	404 (3 - 985)	57,620 (162 - 210,471)	78
STB	2013	38	363 (11 - 680)	44,166 (0 - 132,880)	81
STB	2014	34	243 (51 - 280)	34,391 (706 - 79,177)	102
STB	**Total**	**169**	**373 (3 - 1,265)**	**48,867 (0 - 239,260)**	**471**
HYB	2013	9	320 (31 – 656)	27,564 (0 – 85,083)	17
HYB	2014	10	202 (12 – 289)	27,776 (864 – 85,148)	19
HYB	**Total**	**19**	**258 (12 – 656)**	**27,676 (12 – 85,148)**	**36**

Fate

Of the 185 transmitter-implanted Striped Bass, 11 were considered tagging mortalities and were removed from subsequent analysis because they did not live for at least one month post-tagging. The fate of five additional fish, tagged during 2010, was categorized as “unknown”. Fish of “unknown” fate were transmitted and released before the receiver system was deployed, and their location history could not be used to place them in another fate category. As of December 2014, 17% of successfully implanted and tracked Striped Bass (N=169) were alive, 47% were harvested or assumed harvested, 8% died presumably of natural causes, 3% were missing and 25% had expired transmitters (Figure 2).

The fate of Striped Bass implanted during 2010 – 2013, years with at least 18 months of post-implantation monitoring, were relatively consistent among years. Mean survival to advertised transmitter expiration was 36% (range, 29% - 42%) and mean mortality was 64% (range, 58% - 71%). The majority (82%) of mortality was due to reported or inferred harvest, 13% was considered natural mortality and 5% were missing fish whose mortality could not be differentiated.

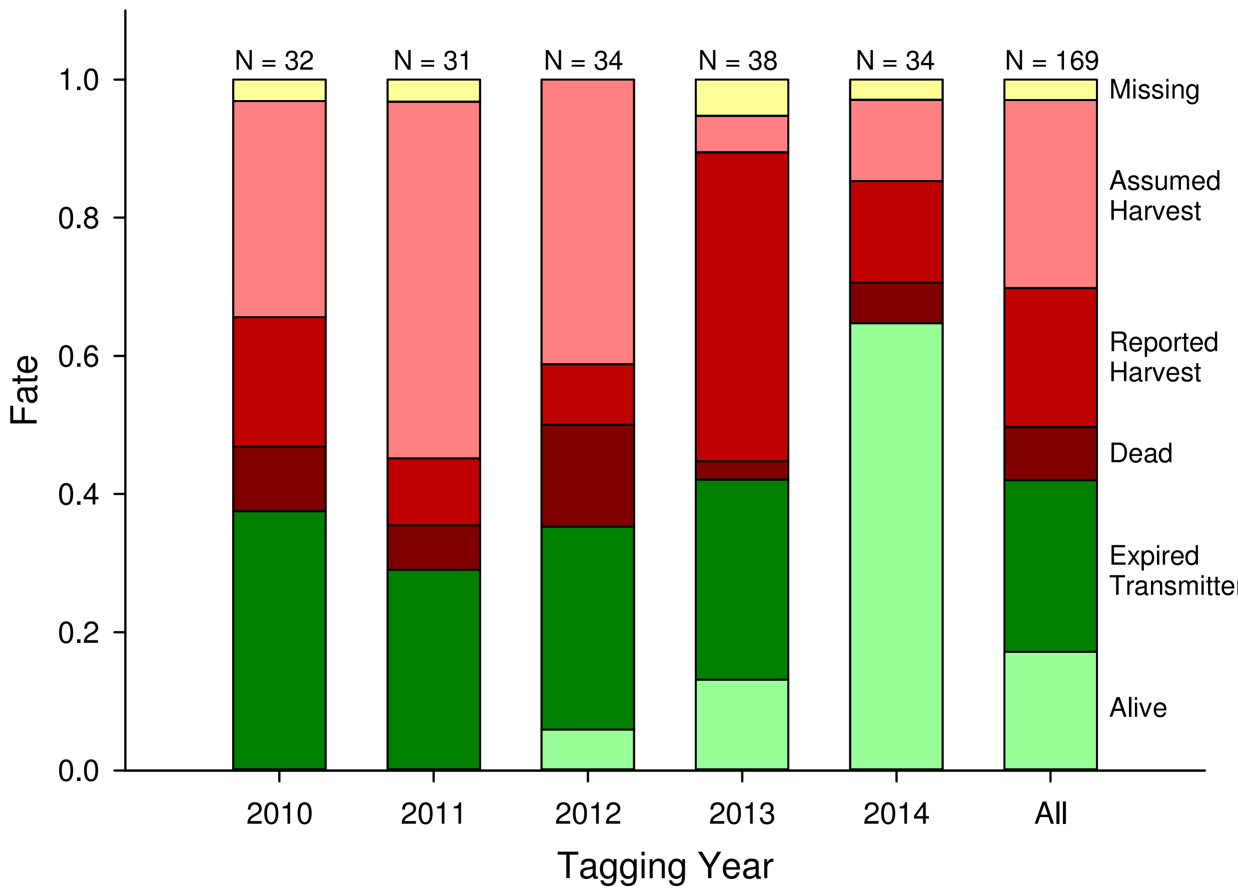


Figure 2. Fate of transmitter–implanted Striped Bass in J. Strom Thurmond Reservoir, SC – GA.

As of December 2014 ninety-two Striped Bass were categorized as mortalities. Thirteen fish were categorized as natural mortality based on lack of movement, 34 fish were reported as harvested, and 45 fish were inferred to have been harvested based on their tracking histories (Figure 3). Most mortality (86%) occurred between April and October and 48% of the mortality occurred between June and August. Most fishing mortality (86%) occurred between April and October with 47% occurring between June and August. Most natural mortality (54%) occurred during the summer (June –August); however, naturally mortality was also observed during the spring (April and May) and fall (October and December). Fishing mortality most frequently occurred in the Lower Reservoir (29%) and Russell Tailrace (52%), but was also common in tributaries (17%). Eighty-five percent of natural mortality occurred in the Russell Tailrace (38%) and Lower Reservoir (46%), one fish was found dead in each a tributary and the middle Section of the reservoir.

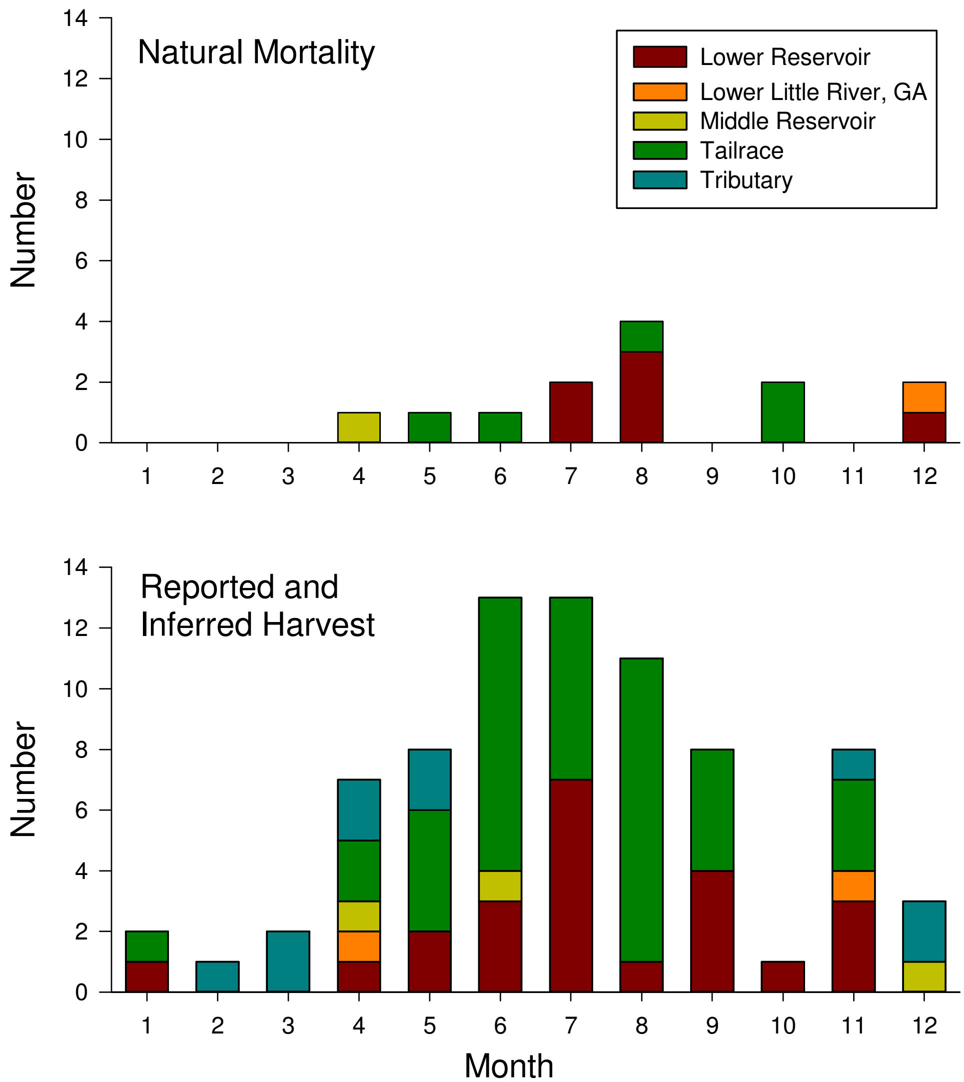


Figure 3. Number of natural, harvested, and inferred harvested mortalities by month and location for transmitter-implanted Striped Bass in J. Strom Thurmond Reservoir, SC-GA during 2010 – 2014.

Of the 25 transmitter-implanted Hybrid Striped Bass, 5 were considered tagging mortalities and were removed from subsequent analysis because they did not live for at least one month post-tagging. An additional fish tagged during 2013 was omitted because it was assumed the transmitter was faulty due to sporadic and non sensible detection locations. As of December 2014, 47% of successfully implanted and tracked Hybrid Striped Bass (N=19) were alive, 47% were harvested or assumed harvested, and one fish exited the lake through the Thurmond turbines and entered

Steven's Creek Reservoir (Figure 4). Of the fish categorized as harvest mortalities, four were harvested from lower Thurmond between the months of May and August, and five fish were harvested from tributary rivers (Broad River 4 fish and Little River, SC 1 fish) during April and May.

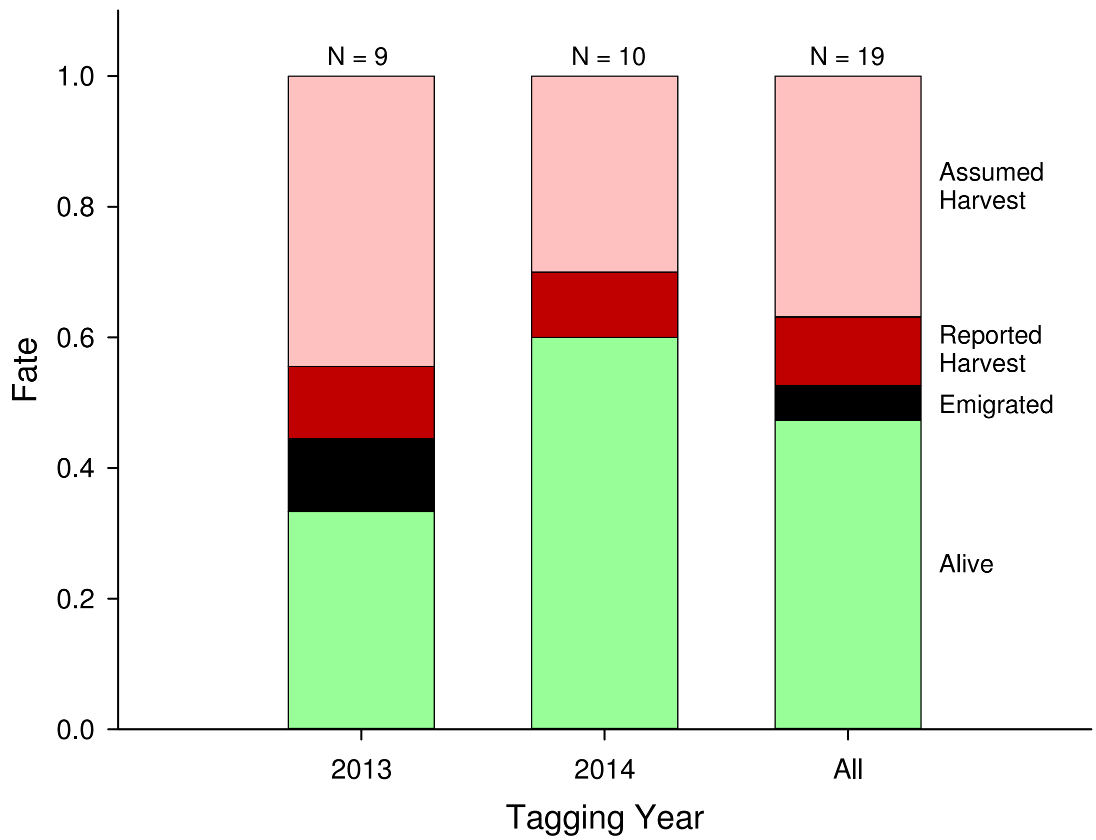


Figure 4. Fate of transmitter–implanted Hybrid Striped Bass in J. Strom Thurmond Reservoir, SC – GA.

Striped Bass Mortality

Capture histories from 153 Striped Bass were included in the multistate capture-recapture model to estimate seasonal and annual mortality during 2010 - 2013. The mean number of fish "at risk" each season was 29 (range 11 – 51). The mean detection probability for instrumented fish among seasons was 0.99 (SE = 0.004). Between 2010 and 2013 total instantaneous mortality (Z) of Striped Bass estimated from the multistate model ranged from 0.59 to 0.73 and the four year median was 0.68 (0.52 - 0.87) (Table 5). Fishing mortality (F) ranged from 0.41 to 0.63 and the four year median was 0.56 (0.41 – 0.74). Natural mortality (M) ranged from 0.06 to 0.17 and the four year median was 0.11 (0.06 – 0.19). In all years fishing mortality was the largest component of total mortality. Total annual mortality of Striped Bass ranged from 45% to 52% among years (Table 6). Total annual exploitation ranged from 31% to 45% and total annual natural mortality ranged from 6% to 13%. Seasonally mortality was highest each year during summer. In three of four years fall had the second highest mortality rates while mortality during winter and spring was generally low (Figure 5).

Table 5. Median instantaneous total (Z), fishing (F) and natural mortality (M) for transmitter-implanted Striped Bass in J. Strom Thurmond Reservoir, SC-GA. The 97.5 percent credible intervals given in parentheses.

Year	Z	F	M
2010	0.66 (0.33 - 1.20)	0.55 (0.25 - 1.07)	0.09 (0.02 - 0.30)
2011	0.73 (0.44 - 1.13)	0.63 (0.37 - 1.01)	0.08 (0.01 - 0.28)
2012	0.59 (0.34 - 0.96)	0.41 (0.20 - 0.73)	0.17 (0.06 - 0.19)
2013	0.67 (0.42 - 1.02)	0.61 (0.36 - 0.94)	0.06 (0.01 - 0.18)
Overall	0.68 (0.52 - 0.87)	0.56 (0.41 - 0.74)	0.11 (0.06 - 0.19)

Table 6. Median annual total (A), fishing (u), and natural mortality (v) for transmitter implanted Striped Bass in J. Strom Thurmond Reservoir, SC-GA during 2010 – 2013. The 97.5 percent credible intervals given in parentheses.

Year	A	u	v
2010	48% (28% - 70%)	40% (21% – 63%)	7% (1% – 20%)
2011	52% (36% - 68%)	45% (30% - 61%)	6% (1% - 18%)
2012	45% (29% - 62%)	31% (17% – 48%)	13% (5% – 27%)
2013	49% (34% - 64%)	44% (29% - 59%)	4% (1% - 13%)
Overall	48% (40% – 57%)	40% (32% – 49%)	8% (4% - 14%)

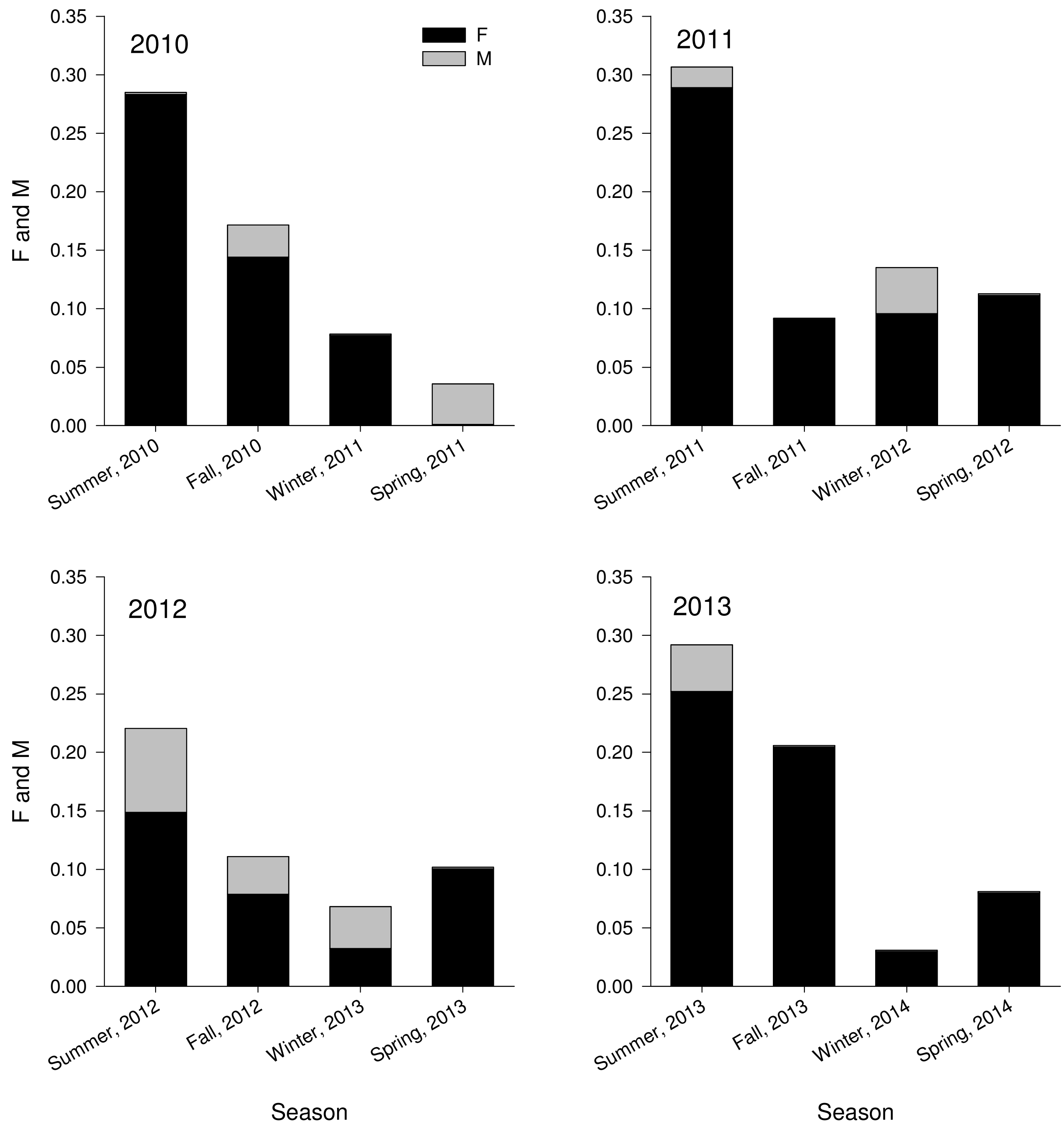


Figure 5. Median seasonal instantaneous fishing (F) and natural mortality (M) for transmitter-implanted Striped Bass in J. Strom Thurmond Reservoir, SC-GA during 2010 – 2013.

Discussion

External reward tags were effective in increasing reporting rates of harvested Striped Bass and validating assumptions about how we categorized the fate (i.e., "Alive", "Dead", or "Harvested") of Striped Bass. During 2010 – 2012 we had poor transmitter return rates; although we categorized more than 16 fish as harvested from each 2010 – 2012 implantations, the majority (>63%) of those determinations were based on either location information, indicating that the fish were removed from the lake, or the absence of detections during manual tracking searches. For the 2013 implanted fish, which had external reward tags, 17 fish were reported as harvested by anglers, and only two were classified as harvested based on location history and absence during manual searches. One of the fish categorized as harvested, but not reported, did not have an external reward tag. The proportion of fish categorized as harvested (50% during 2010 and 2012, and 61% during 2011) during years without external reward tags was qualitatively similar to the proportion of fish categorized as harvested (50%) during 2013, when most fish received an external reward tag, suggesting our methods for identifying the harvest of Striped Bass without external reward tags were effective.

Anglers were not likely to discover transmitters even in fish that possessed external reward tags that explicitly stated "Tag Inside". Sixteen fish with external reward tags from the 2013 tagging were reported as harvested; however, only 38% of those anglers discovered the transmitter while filleting the fish. It is likely that the majority of fish harvested during 2010 – 2012, years without external reward tags, were not identified by anglers as transmitter-implanted fish.

The median annual rates of total instantaneous mortality (0.59 – 0.73) in this study were relatively consistent among years and comparable to previous estimates for Thurmond Reservoir. Catch curve analysis of radio-implanted adult Striped Bass in Thurmond Reservoir resulted in annual estimates of total instantaneous mortality of 0.81 in 1999 and 0.42 in 2000 (Young and Isely 2004). In both studies fishing mortality (F) was a much larger component of total mortality than natural mortality (M). The four year median instantaneous fishing mortality (F) observed during 2010 – 2013 was 0.56, while Young and Isely (2004) observed 0.67 during 1999 and 0.37 during 2000. Natural mortality was low in both studies ($M \leq 0.14$). The low natural mortality rate (0.11) observed in this study was similar to other southeastern reservoirs where natural mortality has been estimated using telemetry assisted mark-recapture methods. Thompson et al. (2007) estimated instantaneous natural mortality of Striped Bass to be 0.10 in Badin Lake, North Carolina and Hightower et al (2001) estimated instantaneous natural mortality of Striped Bass to be 0.16 and 0.12 in a two-year study of Lake Gaston, North Carolina-Virginia. The consistency of mortality estimates in this study and previous work on Thurmond Reservoir (Young and Isely 2004) should provide managers with confidence in yield-per-recruit modeling. The high fishing mortality and low natural mortality in Thurmond Reservoir allows managers to manipulate regulations to achieve angler goals.

In each year of the study the highest fishing mortality rate was observed during summer which was consistent with prior research in Thurmond Reservoir (Young and Isely 2004) and Badin Lake, North Carolina (Thompson et al. 2007). Fifty-four percent (37 of 68) of fishing mortalities occurred during June – August. Most of that mortality occurred in the Tailrace (70%) and Lower Reservoir (27%). Similar seasonal results were found by Young and Isely (2004) during 1999 and 2000 when 48% of fishing mortalities occurred between June – August, the majority (67%) of which occurred in the Tailrace; however, only 1 fish (8%) was harvested from the Lower Reservoir during June and no fish were harvested from the Lower Reservoir during July or August. The potential increase in harvest from the Lower Reservoir during this study could be due to an increase in angling effort in the Lower Reservoir after oxygenation. Harvest from the tributaries in both Thurmond Reservoir studies largely occurred during fall and spring.

Natural mortality was low in all years. The majority (54%) of natural mortality occurred during June - August and was also observed during spring and fall. The majority of natural mortality occurred in the Lower Reservoir (46%) or Tailrace (38%). In previous work (Young and Isely 2004), natural mortality only occurred during summer in the middle section of the reservoir.

The low natural mortality rate, which would include catch-and-release mortality, suggests catch-and-release mortality was not a significant source of mortality during this study. Natural mortality cannot be distinguished from catch-and-release mortality, which frequently occurs in southeastern reservoirs during summer (Wilde et al. 2000; Bettinger and Wilde 2013), or the discard of a harvested fish which is filleted and then returned to the lake. The latter may have occurred on at least two occasions when Striped Bass transmitters were found immobile right next to boat ramps. We observed more fishing mortality in this study in the lower reservoir than that observed during 1999 and 2000 (Young and Isely 2004). This may be due to increased fishing effort in the lower reservoir during summer (personal observation) as anglers focusing their effort near the oxygenation system. Although the creel and size limits on Thurmond Reservoir are liberal (10 fish no size limit, except only 3 can be >660 mm TL) fishery managers should be aware that catch-and-release mortality in the Lower Reservoir could increase with increasing angler effort.

Literature Cited

Bettinger, J. M., and G. R. Wilde. 2013. Catch-and-release mortality of inland Striped Bass and Hybrid Striped Bass. Pages 473-499 in J. S. Bulak, C. C. Coutant, and J. A. Rice, editors. Biology and management of inland Striped Bass and Hybrid Striped Bass. American Fisheries Society, Symposium 80, Bethesda, Maryland.

Hightower, J. E., J. R. Jackson, and K. H. Pollock. 2001. Use of telemetry methods to estimate natural and fishing mortality of Striped Bass in Lake Gaston, North Carolina. Transactions of the American Fisheries Society 130:557–567.

Hightower, J. E. and J. E. Harris. 2015. Estimating fish mortality rates using telemetry and multistate models. *Submitted July 2015,* Fisheries, American Fisheries Society, Bethesda, Maryland.

Kéry, M., and M. Schaub. 2012. Bayesian population analysis using WinBUGS: a hierarchical perspective. Academic Press, Waltham, Massachusetts.

McCarthy, M. A. 2007. Bayesian methods for ecology. Cambridge University Press, New York.

Thompson, J. S., D. S. Waters, and J. A. Rice, and J. E. Hightower. 2007. Seasonal natural and fishing mortality of Striped Bass in a southeastern reservoir. North American Journal of Fisheries Management 27:681-694.

Wilde, G. R., M. I. Muoneke, P. W. Bettoli, K. L. Nelson, and B. T. Hysmith. 2000. Bait and temperature effects on Striped Bass hooking mortality in freshwater. North American Journal of Fisheries Management 20:810-815.

Young, S. P., and J. J. Isely. 2004. Temporal and spatial estimates of adult Striped Bass mortality from telemetry and transmitter return data. North American Journal of Fisheries Management 24:1112–1119.

SEASONAL DISTRIBUTION AND FIDELITY

Objectives

The objectives of this section are to: 1. Describe the seasonal distribution of Striped Bass and Hybrid Striped Bass in Thurmond Reservoir, 2. Evaluate Striped Bass use of the oxygenated area during summer, and 3. Determine if summer use of the lower reservoir changed after oxygenation.

Materials and Methods

Seasonal Distribution

Mean daily locations were calculated for each fish that was detected for at least 28 days at acoustic receiver locations and located >3 times within a day. Daily locations were calculated following the method of Simpfendorfer et al (2002), who used detection data from multiple receivers with known latitude and longitude to estimate fish position. For each date, receiver latitude and longitude coordinates for each detection of an individual fish were averaged. Daily mean locations for each fish were then averaged over each one-week period of the year to determine weekly mean position. During some weeks fish were not detected at any receivers (e.g., when fish moved far up tributaries); in these cases the weekly location was inferred based on the fish's last known location and subsequent location. For example, if a fish passed the Washington Road Receiver, Little River, GA on 1 April and was not detected again until 30 April at the Washington Road Receiver, Little River, GA it was assumed that its mean position during all weeks of April was Little River, GA. All positions within the first 21 d post-tagging were removed from analysis.

To determine the segment of reservoir occupied by each fish each week of the study, mean weekly positions were plotted in ArcGIS (Esri, Redlands, CA). The reservoir was classified into 11 sections (Figure 1), of which three sections were in the Savannah River channel (lower, middle, and upper), three sections were in the Little River, GA channel (lower, middle, and tributaries), two were in Little River, SC (Little River and tributaries), and one each were in the Richard B. Russell Tailrace, and the tributaries Soap Creek and Broad River. The tributary sections are locations where fish migrate each spring presumably in an attempt to spawn. There are other primary tributaries in Thurmond that could be used by Striped Bass during spring (e.g., Fishing Creek and Pistol Creek); however, no fish were collected from those tributaries during the study and none of those tributaries were instrumented with acoustic receivers. While the tributaries that striped bass utilize during the spring are identified herein as presumptive spawning tributaries, neither spawning nor successful natural reproduction has been observed in Thurmond.

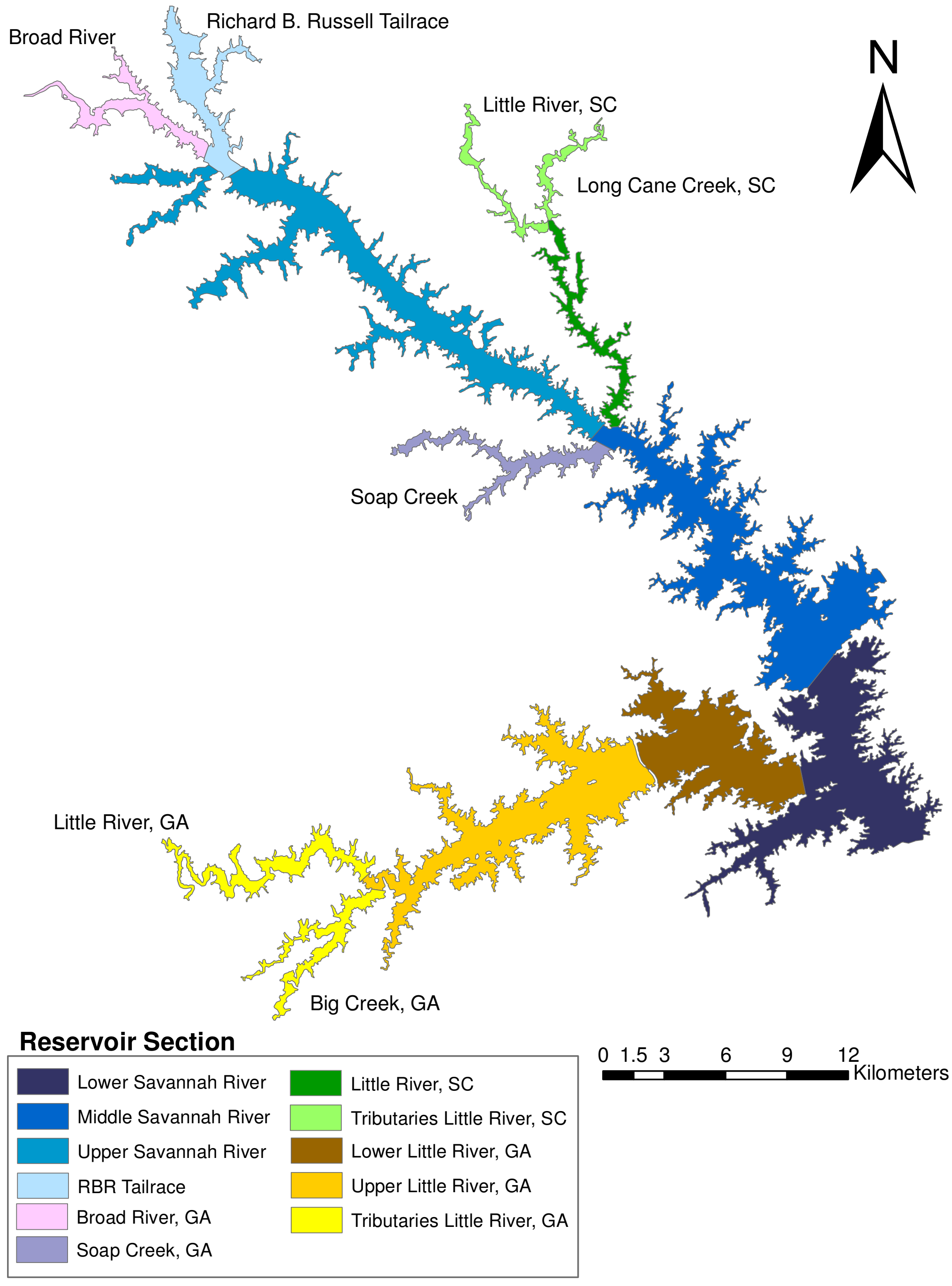


Figure 1. Reservoir sections of J. Strom Thurmond Reservoir, SC-GA, used to describe the weekly distribution of Striped Bass and Hybrid Striped Bass implanted with acoustic transmitters during 2010-2014.

Summer Habitat Fidelity

To determine summer habitat use the mean position during August for each fish was calculated by averaging all positions observed during the month of August by year. Mean August positions were plotted in ArcGIS and the fish were assigned to the reservoir section that contained their position (Figure 1). Mean August positions were calculated for 132 Striped Bass and 12 Hybrid Striped Bass. Analysis of variance (SAS, Proc GLM) was used to determine if Striped Bass total length was different between summer habitats and tagging location. A binary regression model (SAS, Proc Glimmix) was used to determine if Striped Bass summer habitat use, Lower Reservoir or Russell Tailrace, was related to year, tagging location, or TL. Because some fish were followed during multiple summers (i.e., repeatedly observed) transmitter ID was incorporated into the model as a subject random effect. Fish tagged within the Russell Tailrace were not included in any analysis of summer habitat fidelity because it was assumed they had already made their summer habitat choice at the time of tagging.

Results

Seasonal Distribution

For 159 Striped Bass 7,039 mean weekly positions between 2010 and 2014 were calculated and assigned a reservoir section. The mean number of daily position estimates used to calculate weekly position estimate was 5.25 (SE 0.02). An additional 1,142 weekly segment locations were inferred based on tracking history of Striped Bass. For 17 Hybrid Striped Bass 508 mean weekly positions between 2013 and 2014 were calculated and assigned a reservoir section. The mean number of daily position estimates used in each weekly position estimate was 5.12 (SE 0.09). An additional 63 weekly section locations were inferred based on tracking history of Hybrid Striped Bass.

When Striped Bass from all years (2010 – 2014) and all tagging locations were combined seasonal patterns in weekly reservoir section use were observed (Figure 2). By the last week of March the majority (63%) of Striped Bass were utilizing the Tributaries. Between April and June Striped Bass migrated from the Tributaries, occupying other segments of the reservoir in increasing frequency. By the first week of June the majority (60%) of Striped Bass occupied the Tailrace or the oxygenated area of the Lower Reservoir. Use of these summer habitats increased until the third week of August when 99% of the fish occupied either the Tailrace or the Lower Reservoir. During that week only two Striped Bass were found outside the Tailrace or Lower Reservoir: one fish (ID 251) used the Middle Section during 2013 and one fish (ID 2.5) used the Upper Reservoir Section during 2014. Between the third week of July and first week of August of 2013 one fish (ID 174) occupied a tributary, the lower Broad River; another fish (ID 219.5) occupied that same area during the first week of August during 2014. The majority (>65%) of fish remained in the Tailrace or Lower Reservoir segments until the second week of October, when use of other reservoir sections began to increase, particularly the Tributaries and Upper Reservoir.

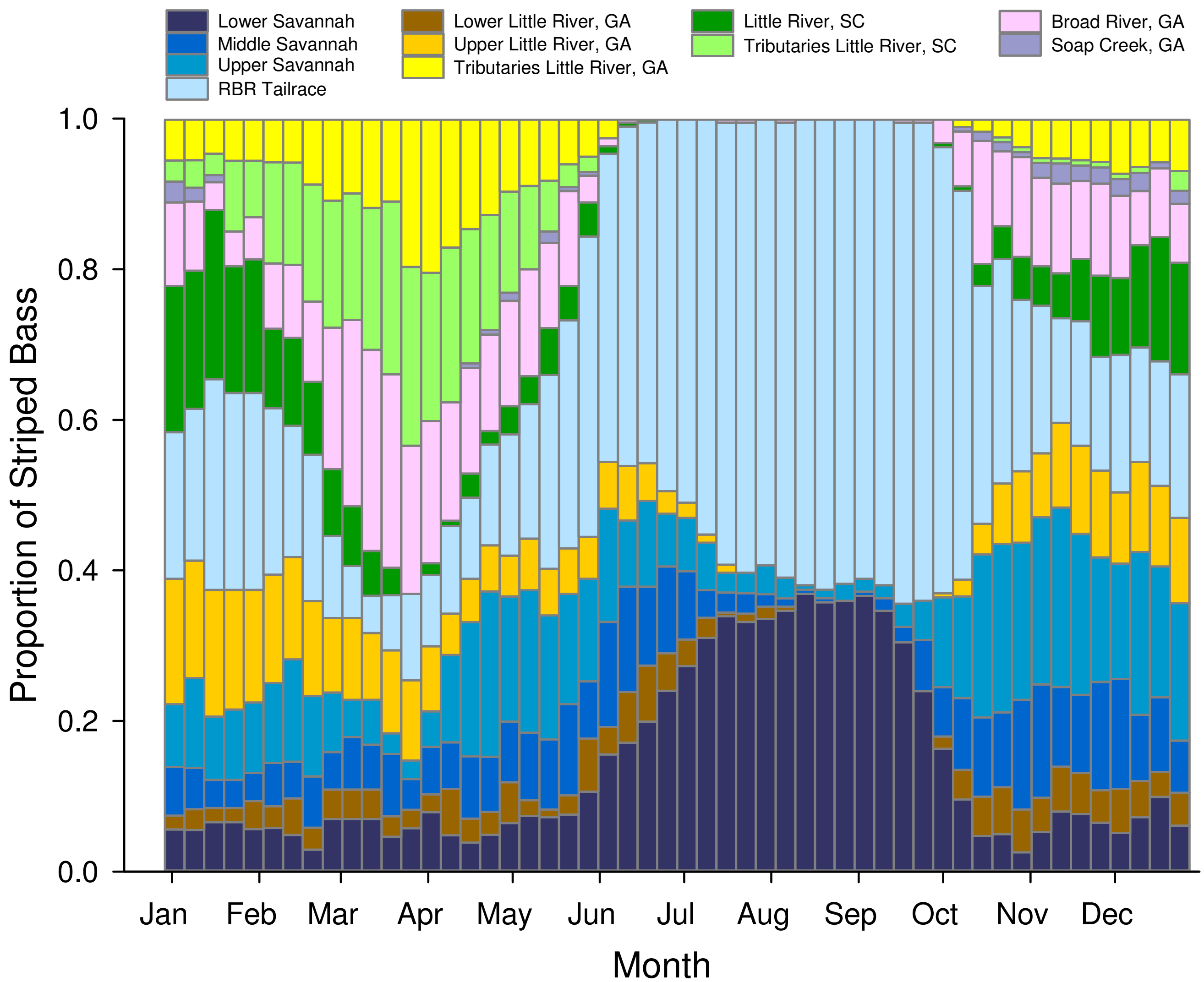


Figure 2. Proportion of Striped Bass implanted with acoustic transmitters in 11 sections of J. Strom Thurmond Reservoir, SC-GA, by week of the year, 2010 - 2014. Reservoir sections are defined in Figure 1.

Tagging location greatly influenced seasonal habitat selection (Figure 3). Fish tagged in the Little River, GA tributaries primarily resided in upper Little River, GA and its tributaries during January and February, where on average 80% of the fish were located, with increasing use of the tributaries (Little River, GA and Big Creek, GA) as the weeks progressed. By the last week of March 77% of Striped Bass tagged in Little River, GA were located in one of the Little River, GA tributaries. During April fish began moving down out of the tributaries and using other portions of the reservoir in increasing frequency; by the second week of June all Striped Bass vacated the tributaries. During the summer months Striped Bass were located in the Tailrace, Lower Reservoir, and Upper Reservoir. Between August 26 and September 15, mean weekly positions for all Striped Bass tagged in Little River, GA tributaries were in the Lower Reservoir or Tailrace with the majority (71%) of fish residing in the Lower Reservoir. During the second week of September Striped Bass began moving out of their summer habitat and as fall progressed the majority were located once again in upper Little River, GA and its tributaries. Five of the fish (ID's 5.5, 18.5, 174, 232, and 249) tagged in Little River, GA used the Broad River, GA during the spring and/or fall and one fish (ID 249) used lower Little River, SC, during fall of 2013, but never ventured up into its tributaries (upper Little River, SC and Long Cane Creek).

Striped Bass tagged in Little River, SC had a similar pattern to those in Little River, GA except they primarily limited their spring and fall movements to Little River, SC rather than Little River, GA and during summer were more evenly divided between the Tailrace and Lower Reservoir (Figure 3). Striped Bass tagged in the Little River, SC tributaries primarily resided in Little River, SC and its tributaries between January and March, where on average 91% of the fish were located, with increasing use of the tributaries (Little River, SC and Long Cane Creek, SC) as the weeks progressed. By the last week in March 93% of Striped Bass tagged in Little River, SC were located in one of the Little River, SC tributaries. During the first week of April Striped Bass began moving down out of the tributaries and using other portions of the reservoir in increasing frequency; by the first week of June all Striped Bass vacated the tributaries. During the summer months Striped Bass were located in the Tailrace, Lower Reservoir, Middle Reservoir, and Upper Reservoir sections of the Savannah River. Between August 12th and September 1st mean weekly locations of nearly all Striped Bass were in the Lower Reservoir (47%) or Tailrace (50%). During 2013 one fish (ID 251) used the Middle Reservoir, and during 2010 and 2013 one fish used the Upper Reservoir (2010 ID 19 and 2013 ID 127). During the 3rd week of September Striped Bass began moving out of their summer habitat and as fall progressed used the Middle and Upper Reservoir sections and the Little River tributaries in increasing frequency. Eleven of the Striped Bass tagged in Little River, SC used Broad River, GA during the spring and/or fall. Four fish used upper Little River, GA during those time periods but never ventured up into its tributaries (Little River, GA and Big Creek, GA).

Mean weekly positions of Striped Bass tagged in Broad River, GA were most frequently in the Upper Reservoir and its tributaries (e.g., Tailrace, Broad River, GA, or upper Savannah). Approximately 71% of those fish resided either in the Broad River, GA or the Tailrace during January – March, with increasing use of the Broad River as the weeks progressed (Figure 3). By the third week of March mean weekly position of 88% of the fish tagged in the Broad River, GA was in the Broad River. During the first week of April fish began moving down out of the Broad River and using other portions of the reservoir, primarily the Tailrace, the Middle, and Upper Reservoir sections in increasing frequency; by the third week of June all fish vacated the Broad River. Between July 29th and August 24th all fish tagged in the Broad River were located in the Tailrace (83%) or the Lower Reservoir (17%). During September fish began moving out of their summer habitat and back into the Broad River and upper Savannah, primarily. Unlike fish tagged in Little River, SC and Little River, GA, which vacated the Tailrace Section during December – February, fish tagged in the Broad River, GA maintained a presence in the Tailrace all year, with the exception of the 2nd and 3rd weeks in March, when 87% were in Broad River and none were in the tailrace. Few Striped Bass tagged in the Broad River, GA entered other reservoir tributaries.

Three of 30 fish tagged in the Broad River, GA utilized the lower Little River, SC. Fish 4 and 214 occupied the Little River, SC during fall/winter, and fish 4 and 243 utilized the lower Little River, SC for one week each during spring, but only fish 4 entered the tributary rivers (Little River, SC and Long Cane Creek). Four Broad River, GA tagged fish also used upper Little River, GA seasonally (fall and spring), although none ventured up to the Little River, GA tributaries.

While Striped Bass tagged in Little River, GA, Little River, SC and the Broad River, GA largely restricted their spring and winter movements to the tributaries in which they were tagged, especially during the later weeks of March associated with spawning activity, Striped Bass tagged in the Tailrace used multiple tributaries during the winter and spring periods (Figure 3). During January and February 28% of the mean weekly observations were in the Tailrace, 22% in Little River, SC, 13% in Little River, GA, and 7% in Broad River, GA. During the spring spawning period a much larger proportion of the weekly observations of Striped Bass tagged in the Tailrace were outside the tributaries (71%), compared to fish tagged in Little River, GA, Broad River, GA and Little River, SC (11-28%) (Table 1). It's possible that fish tagged in the Tailrace used upper lake tributaries that were not monitored (e.g., Fishing Creek) during the spring spawning period. During summer weeks all Striped Bass tagged in the Tailrace were located in the Tailrace or the Upper Reservoir, with the exception of one fish. Fish 126 left the Tailrace on 8/10/2012, arrived at the Lower Reservoir two days later, and subsequently died around 8/16/2012. Like fish tagged in Broad River, GA, fish tagged in the Tailrace maintained a presence in the Tailrace all year.

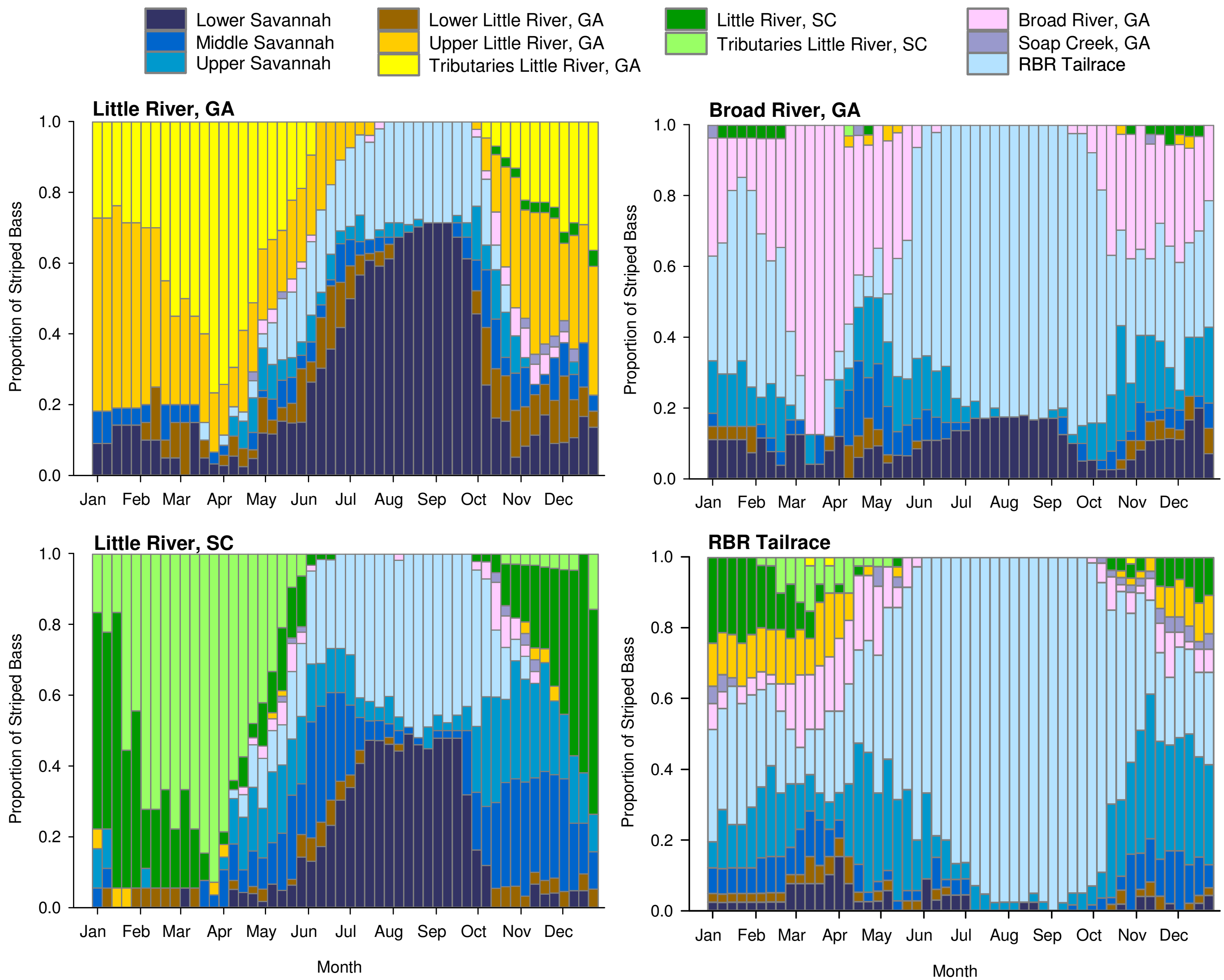


Figure 3. Proportion of Striped Bass implanted with acoustic transmitters in three tributaries of J. Strom Thurmond Reservoir, SC-GA and the Richard B. Russell tailrace using each reservoir section, by week of the year, 2010 – 2014. Reservoir sections defined in Figure 1.

Table 1. The percent of weekly observations (number of observations in parentheses) within and outside tributaries during the spawning period (weeks 12 – 14) for Striped Bass implanted with transmitters in the J. Strom Thurmond Reservoir during 2010 – 2014, by tagging location. Tributary sections were defined as tributaries to Little River, SC and Little River, GA as well as Soap Creek, GA and Broad River, GA (Figure 1).

Tagging Location	Within Tributary	Outside Tributary
Broad River, GA	74% (55)	26% (19)
Little River, GA	72% (61)	28% (24)
Little River, SC	89% (73)	11% (9)
RBR Tailrace	29% (34)	71% (83)

Based on mean weekly positions, Striped Bass in this study primarily frequented the tributaries in which they were tagged, and rarely spent significant time in other tributaries. Forty-three Striped Bass tagged in the tributaries during spring and 19 Striped Bass tagged in the tailrace during summer were followed for more than one year. Only 12 of the 43 spring-tagged fish had mean weekly positions in multiple tributaries throughout the year (Figure 4).

Striped Bass tagged in Little River, SC and the Tailrace were more likely to use multiple tributaries than those tagged in Broad River, GA or Little River, GA. Of the 15 fish tagged in Little River, SC, nine had mean weekly positions in Broad River; two of those fish also used Soap Creek. Six fish had mean weekly positions only in Little River, SC. Ten of 19 Striped Bass tagged in the Tailrace had mean weekly positions only in Broad River, GA, four used only Little River, SC, one used only Soap Creek, and four fish used multiple tributaries. Only two fish tagged in the Tailrace used Little River, GA. Of the 13 Striped Bass tagged in Little River, GA, eleven had mean weekly positions only in Little River, GA, one used Broad River, and one used both Broad River and Soap Creek. Of the 15 fish tagged in Broad River, GA, fourteen had mean weekly positions only in Broad River, GA; one fish also used Soap Creek. Some (28%) fish tagged in the tributaries moved into multiple tributaries throughout the year, but during the spring spawning period (weeks

11-15) fish always returned to the same tributary each year, exhibiting fidelity to a single tributary river.

When Hybrid Striped Bass from all years (2013 – 2014) and tagging locations were combined seasonal patterns in weekly reservoir section use were observed (Figure 5). By the last week of March the majority of fish (88%) were utilizing upper Little River, GA and upper Little River, SC (25%) or their tributaries (63%). Between April and June fish migrated from the tributaries, occupying other segments of the reservoir in increasing frequency. Hybrid Striped Bass entered summer habitats (Tailrace or Lower Reservoir) later than Striped Bass. While the majority of Striped Bass entered the summer habitats by the first week of June, the majority (76%) of Hybrid Striped Bass did not enter those habitats until the fourth week of June. Use of these summer habitats increased until the first and second week of August when all Hybrid Striped Bass occupied either the Tailrace (7%) or lower reservoir (93%). The majority of fish (92%) remained in the Tailrace or Lower Reservoir sections until the third week of September, when the use of other reservoir sections began to increase, particularly the Middle Savannah Section.

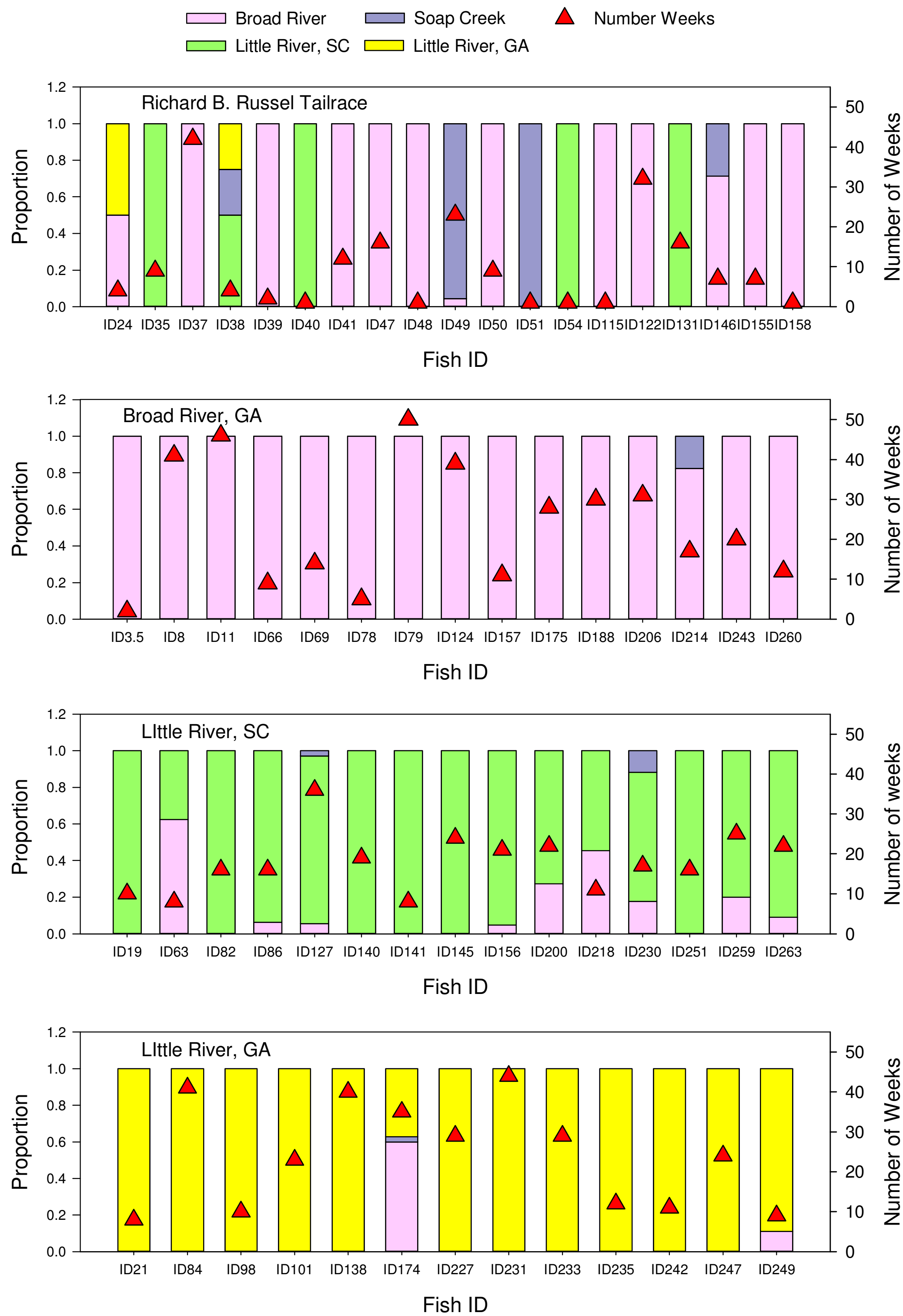
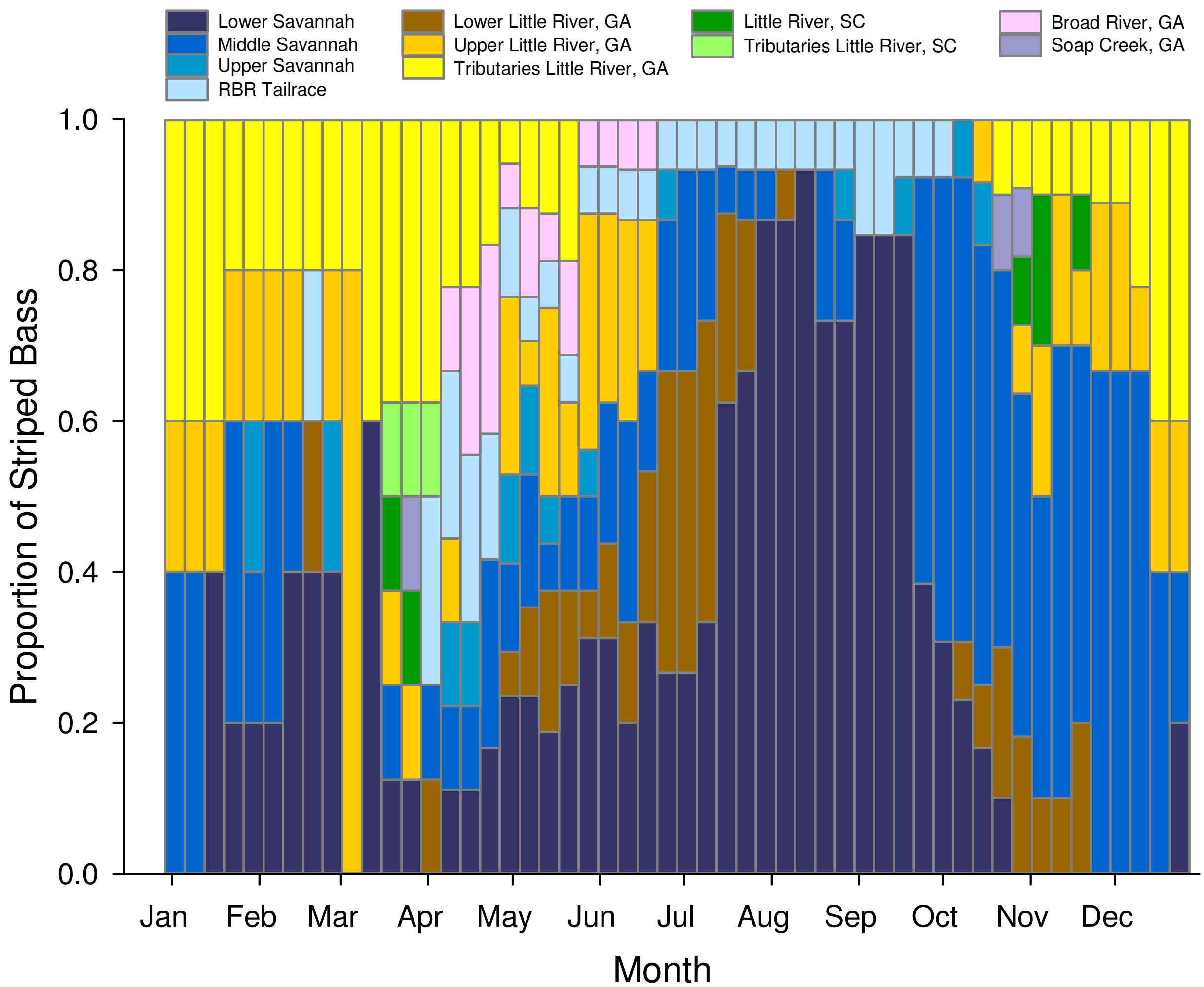


Figure 4. Proportion of weeks spent in each tributary for Striped Bass implanted with acoustic transmitters in tributaries of J. Strom Thurmond Reservoir, SC-GA and Richard B. Russell Tailrace and followed for more than one year during 2010 – 2014. Triangle denotes total number of weeks spent in tributaries.



.

Figure 5. Proportion of Hybrid Striped Bass implanted with acoustic transmitters in J. Strom Thurmond Reservoir, SC-GA using eleven reservoir sections, by week of the year, 2013 and 2014. Reservoir sections are defined in Figure 1.

Summer Habitat Fidelity

Between 2010 and 2014, only four of 132 Striped Bass had a mean August position outside the Tailrace or Lower Reservoir. During 2012 one fish (ID 126) had a mean August position in the Middle Savannah Section and one fish (ID 152) had a mean August position in the Upper Savannah. Both of these fish were ultimately residents of the Tailrace during summer 2012. Fish

126 was located in the Tailrace between 8/1/2012 and 8/10/2012 and then moved down to the Lower Reservoir on 8/12/2012 and subsequently died near W-21 around 8/16/2012. Fish 152 was located in the Middle Savannah between 8/1/2012 and 8/7/2012 and then moved to the Tailrace where it remained through the remainder of August 2012. During August 2013 one fish (ID 251) had a mean August position in the Middle Savannah. It spent the entire month of August in that area, and as such was the only fish to reside outside the Tailrace or Lower Reservoir during August of any year. During 2014 one fish (ID 2.5) had a mean August position in the Upper Savannah because it moved between S-120 (just below the Tailrace) and S-135 (Tailrace); ultimately this fish resided in the tailrace. The mean number of locations used to calculate August position among Striped Bass and year was 5,528 (SE 289, range 50 – 20,704).

Fifty-seven Striped Bass were followed for at least two summers, of which 16 were followed for three summers and three were followed for four summers. Only one fish (ID 259) changed its summer habitat during the study. All other fish used the same summer habitat (Tailrace or Lower Reservoir) each year. During August 2013, fish 259 stayed in the Lower Reservoir the entire month, but during 2014 it moved from the Lower Reservoir on 2 August and arrived at the Tailrace on 4 August where it remained through the remainder of August 2014.

The proportion of Striped Bass tagged outside the Tailrace using the Lower Reservoir during summer steadily increased each year. During 2010 only 25% (2 of 8) of Striped Bass used the Lower Reservoir and 75% (6 of 8) used the Tailrace, but during 2014 the proportion of Striped Bass using the Lower Reservoir increased to 54% (27 of 50) (Figure 6).

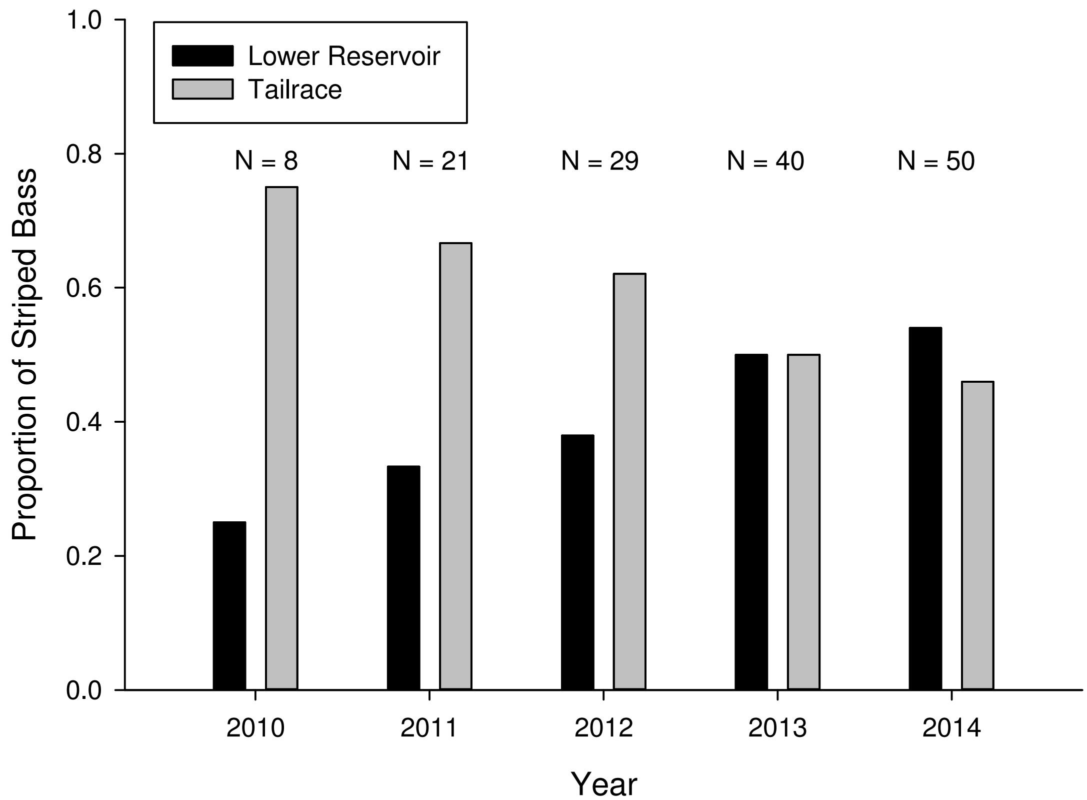


Figure 6. Proportion of Striped Bass implanted with acoustic transmitters outside the Russell Tailrace residing in the Lower Reservoir and Tailrace during August 2010 - 2014 in J. Strom Thurmond Reservoir, SC-GA.

Tagging location and Striped Bass TL had an apparent effect on summer habitat use. The majority (84%) of fish tagged in Broad River, GA used the Tailrace during summer and the majority (69%) of Striped Bass Tagged in Little River, GA used the Lower Reservoir during summer. Striped Bass tagged in Little River, SC used the Tailrace (53%) and Lower Reservoir (47%) in nearly equal proportions. Among years the proportion of fish from each tagging location utilizing the Lower Reservoir or Tailrace was variable (Figure 7). In each year at least 70% of Broad River, GA fish used the Tailrace, in 4 of five years more than 50% of Little River, GA fish used the Lower Reservoir, and in Little River, SC the proportion of fish using the Lower reservoir steadily increased from 38% in 2011 to 59% in 2014. There was a difference in TL between fish that used the Tailrace and Lower Reservoir during summer (ANOVA, df = 1, F = 10.5, $P < 0.01$), but not among tagging locations (ANOVA, df = 2, F = 2.85, P = 0.06). Striped Bass that used the Lower Reservoir were smaller (mean TL = 757 mm, 95% CI 709 – 804 mm TL) than those that used the Tailrace (mean TL = 865, 95% CI 823 – 907 mm TL) (ANOVA, df = 1, F = 66.7, $P < 0.01$). All Striped Bass greater than 930 mm TL at the time of tagging used the Tailrace during summer (Figure 8).

While proportion of tagged fish utilizing the Lower Reservoir increased each year part of that increase was due to tagging different sized fish each year and in different proportions among tagging locations. When tagging location, TL, and year were incorporated into the binary regression model only tagging location and TL were significant predictors ($P < 0.05$) of summer habitat use. Although use of the Lower Reservoir increased each year, year was not a significant predictor (P = 0.78). Striped Bass tagged in Broad River, GA were significantly (P = 0.01) more likely to use the Tailrace than Striped Bass tagged in Little River, SC or Little River, GA. Fish tagged Little River, GA appeared to select the lower reservoir in greater frequency than those tagged in Little River, SC but the difference was not significant (P = 0.05). Large (≥ 815 mm TL) Striped Bass were significantly ($P < 0.01$) more likely to use the Tailrace than Lower Reservoir during summer.

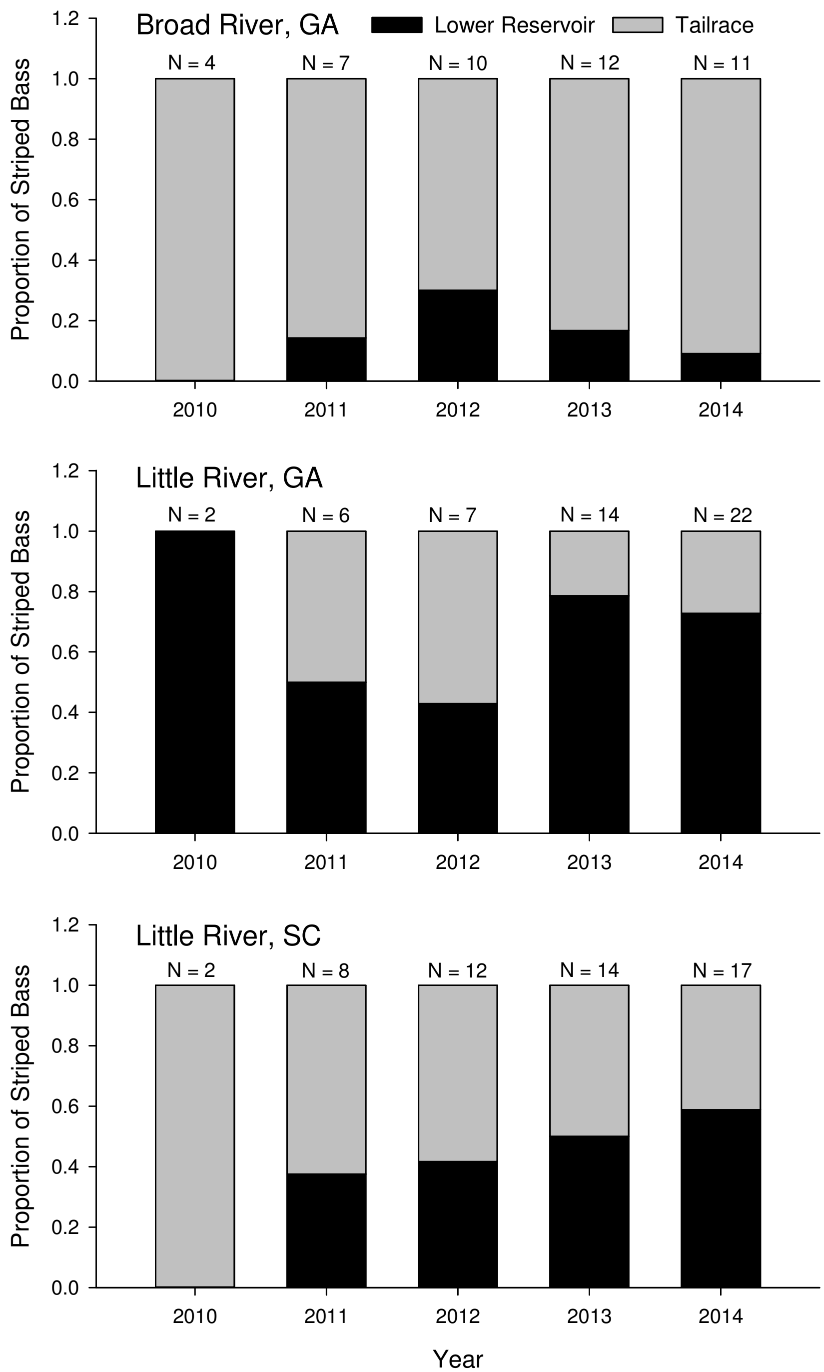


Figure 7. Proportion of Striped Bass implanted with acoustic transmitters outside the Russell Tailrace by tagging location residing in the Lower Reservoir and Tailrace during August 2010 - 2014 in J. Strom Thurmond Reservoir, SC-GA. Oxygenation of the Lower Reservoir began in 2011.

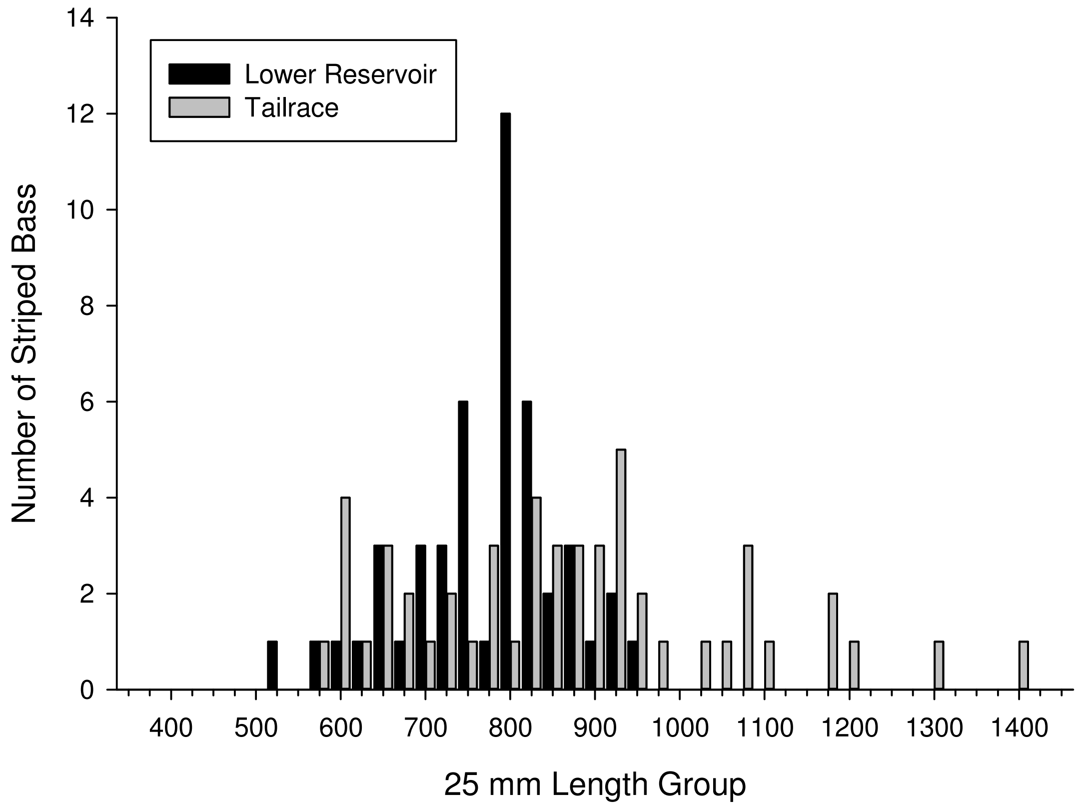


Figure 8. Size distribution of Striped Bass implanted with acoustic transmitters outside the Russell Tailrace residing in the Lower Reservoir and Tailrace during August 2010 - 2014 in J. Strom Thurmond Reservoir, SC-GA.

In 2013 and 2014, only one of 12 Hybrid Striped Bass had a mean August position outside the Tailrace or Lower Reservoir. In 2013 fish 189 was in the Lower Reservoir between 1 August and 29 August before moving to the Tailrace, resulting in a mean August position in the Middle Reservoir. During 2014 ten Hybrid Striped Bass were monitored during August; nine of these fish used the Lower Reservoir and one used the Tailrace. The mean number of locations used to calculate August position among Hybrid Striped Bass and year was 6,546 (SE 1238, range 1,990 – 19,780).

Discussion

Striped Bass in this study had consistent patterns in seasonal distribution among reservoir sections between 2011 and 2014. Over all years the majority of fish moved into presumptive spawning tributaries by the first week in March, with the peak of residence occurring the fourth week of March, after which fish began moving out of the tributaries. By the second week of June all fish had abandoned the tributaries, likely due to increasing water temperatures, and moved into the reservoir and tailrace where suitable water temperatures were available. Striped Bass remained in these summer habitats until October. Similar seasonal distribution patterns for transmitter-implanted Striped Bass in Thurmond Reservoir were observed during 1999 and 2000 (Young and Isely 2002).

During summer nearly all Striped Bass occupied the Lower Reservoir or Tailrace. During August 2010, before oxygenation, 75% of the monitored fish used the Tailrace, which was qualitatively similar to what Young and Isely (2002) found during 1999 and 2000 when "most fish" used the Tailrace during summer and "several fish" used the Lower or Middle sections of the reservoir. After oxygenation of the Lower Reservoir began in 2011 we observed a steady increase each year in Striped Bass use of the Lower Reservoir and by August of 2014 the majority (54%) of fish used the Lower Reservoir during summer. Unfortunately, a small sample size in 2010, and the significant effect of tagging location and fish size on summer habitat choice precluded a robust comparison of summer habitat use pre- and post-oxygenation.

There were size-related differences in summer habitat choice (larger fish used the tailrace); however, this did not appear to be due to larger fish selecting the Tailrace and its historically better water quality. Many fish were followed for multiple years and presumably grew in size, yet only one fish changed its summer habitat during the study. Size differences between Striped Bass utilizing the Tailrace and Lower Reservoir could be due to different rates of growth and/or mortality based on their initial summer habitat choice. Oxygenation should improve survival, and perhaps, growth of the fish utilizing the lower reservoir during summer.

Summer habitat choice was also related to tagging location. Fish tagged in the Broad River were significantly more likely to summer in the tailrace than fish tagged in Little River, GA and Little River, SC. Fish tagged in Little River, GA selected the Lower Reservoir with greater frequency than fish tagged in Little River, SC. It is unknown how tributary selection influenced summer habitat choice, but it may be related to the proximity of each tributary to the two summer habitat areas. Thirty-three percent of the fish tagged in Broad River, GA and followed for more than a year never ventured below the Middle Savannah section of the reservoir. Similarly, 47% of Little River, GA tagged fish that were followed for more than a year never ventured above the Middle Savannah section of the reservoir.

Fidelity to wintering and presumptive spawning tributaries has been documented previously in J. Strom Thurmond Reservoir (Young and Isely 2002), and in other locales (Lamprecht and Shelton 1988; Wilkerson and Fisher 1997, Jackson and Hightower 2001); however, the duration and level of surveillance in this study provided additional insights into the level of Striped Bass fidelity to these tributaries. Most (70%) fish tagged in a tributary and followed for more than a year used only one tributary during the winter and spring, and every fish returned to the same tributary during the spring spawning period, regardless of whether it utilized multiple tributaries the remainder of the year. Previous work identified this behavior for Striped Bass tagged in the Little River, SC (Young and Isely 2002), but this study shows the behavior to be consistent among each of three tributaries where tagging occurred. Further, fish that were tagged in the Tailrace, and thus their presumptive spawning tributary was unknown, were more likely to be outside the monitored tributaries during spring indicating there could be other segments of the population that exhibit fidelity to additional spawning tributaries that were not monitored in this study.

Literature Cited

Jackson, J. R., and J. E. Hightower. 2001. Reservoir Striped Bass movements and site fidelity in relation to seasonal patterns in habitat quality. North American Journal of Fisheries Management 21:34–45.

Lamprecht. S. D., and W. I. Shelton. 1988. Spatial and temporal movements of Striped Bass in the upper Alabama River. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 40(1986):266-274.

Simpfendorfer C.A., M. R. Heupel, and R. E. Hueter. 2002. Estimation of short-term centers of activity from an array of omnidirectional hydrophones and its use in studying animal movements. Canadian Journal of Fisheries and Aquatic Sciences 59:23-32.

Wilkerson, M. L., and W. L. Fisher. 1997. Striped Bass distribution, movements, and site fidelity in Robert S. Kerr Reservoir, Oklahoma. North American Journal of Fisheries Management 17:677–686.

Young, S. P., and J. J. Isely. 2002. Striped Bass annual site fidelity and habitat utilization in J, Strom Thurmond Reservoir, South Carolina-Georgia. Transactions of the American Fisheries Society 131:828-837.

TEMPERATURE OCCUPANCY

Objectives

The objectives of this section are to: 1. Describe seasonal water temperatures used by Striped Bass and Hybrid Striped Bass in Thurmond Reservoir, 2. Compare seasonal water temperatures among large Striped Bass, medium Striped Bass, and Hybrid Striped Bass, 3. Compare differences in water temperature between fish utilizing the Lower Reservoir and Russell Tailrace during the month of August, and 4. Evaluate the influence of pumpback operations on temperature of Striped Bass using the Russell Tailrace during summer.

Materials and Methods

Temperature Occupancy

Mean hourly temperature was calculated for each transmitter-implanted Striped Bass by reservoir section on each date between 8/20/2010 and 12/31/2014 for which data were available. Mean hourly temperatures were used to calculate semi-daily temperatures on each date for each fish, one for daylight hours (0700 – 1859) and one for night (1900 - 0659), by reservoir section. Therefore if a fish moved between reservoir sections during daylight or nighttime hours it could have multiple mean temperatures on a given date. To reduce the potential of a few anomalous records influencing results, all semi-daily periods with fewer than three temperature observations for an individual fish were removed from further analysis. Semi-daily mean temperatures of individual fish were then used to calculate mean monthly and annual temperatures. All subsequent analysis is based on semi-daily mean temperatures of individual fish. Minimum and maximum temperatures reported are the minimum and maximum semi-daily mean temperatures for the period of interest, and not the absolute minimum and maximum observed temperatures.

To evaluate if fish size influenced temperature occupancy, Striped Bass were placed into two size categories: large Striped Bass ≥ 820 mm TL and medium Striped Bass <820 mm TL. Because individual Striped Bass were followed for multiple years and presumably grew in length while at large, Striped Bass TL was advanced each year based on annual growth estimates from a von Bertalanffy growth model. Total length and age estimates from 285 Striped Bass collected during spring boat electrofishing in 2009, 2010, and 2012 (SCDNR, unpublished data) were modeled using an iterative nonlinear regression (SAS, PROC NLIN) to produce the von Bertalanffy growth model. Von Bertalanffy growth parameters from the nonlinear regression were L_{∞} = 1,113 mm TL (SE = 63.5), k = 0.175 (SE = 0.023), and t_0 = -0.85 (SE = 0.195).

Two way analysis of variance (SAS, PROC GLM) was used to determine if Striped Bass temperature differed among years and between size classes during 2011 - 2014. Least-squares means were used for pairwise comparisons.

To determine if there were size-related differences in temperature occupancy between the Lower Reservoir and the Tailrace during August each year, a two way analysis of variance was used (SAS, PROC GLM). Least-squares means were used to account for any significant interactions between size class and reservoir section. The receiver system was not installed until the 3rd week of August 2010; therefore the period of observation for August 2010 was 8/20/2010 – 8/31/2010.

Pumping influence on temperature

To determine if pumpback operations influenced summer-time (June 15 – September 15) Striped Bass temperature in the tailrace, the mean hourly temperature observations, pooled among fish located within 4.8 km downstream of Richard B. Russell Dam, during hours when at least 3 fish were located were calculated. Analysis of covariance (SAS, Proc GLM) was used to determine if mean Striped Bass temperature during the first hour of pumping was different than the last hour of pumping. Day of year was used as a linear covariate to account for temperature changes as each summer progressed. The analysis was conducted for temperature data collected during 2011, 2012, and 2014. During 2010 temperature data was not collected until late August and pumping operations were very limited during 2013.

Results

Temperature Occupancy

During the study there were 1,790,036 temperature observations for 166 Striped Bass. The mean number of temperature observations for each fish was 10,783 (SE = 897). For Hybrid Striped Bass there were 117,842 temperature observations for 21 fish. The mean number of temperature observations for each fish was 7,094 (SE = 1,548).

Between November and March overall mean daily Striped Bass temperatures were similar to surface temperatures recorded in the Lower Reservoir at the Plum Branch USGS gage (Figure 1 and 2). When the reservoir began to stratify, late March to mid-April, Striped Bass mean daily temperatures were considerably cooler than lake surface temperatures, and remained cooler until mid-October or November. Striped Bass maximum temperatures were most variable during summer, while Striped Bass minimum temperatures were most variable between November and April.

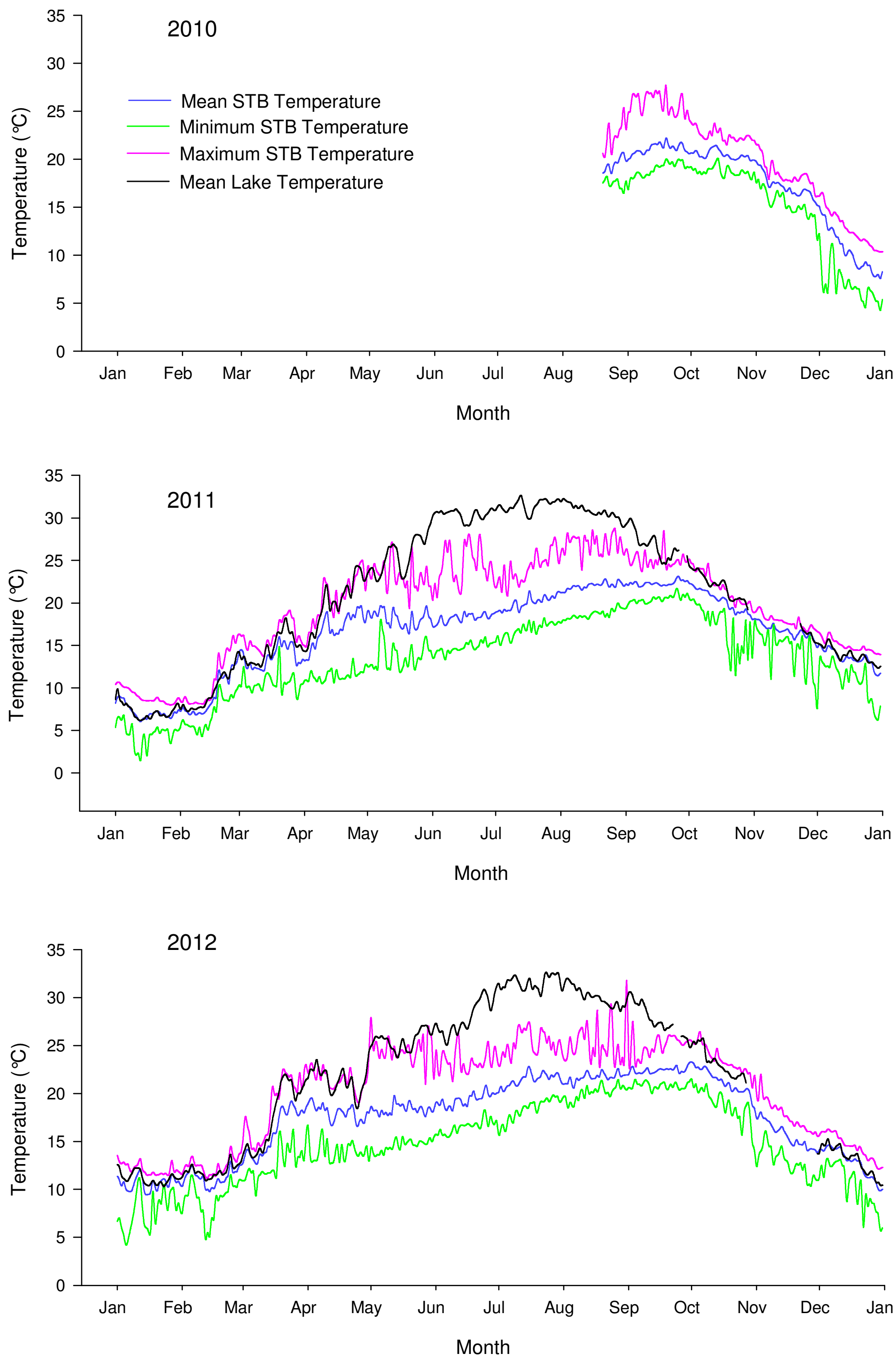


Figure 1. Mean, maximum, and minimum daily temperature for transmitter-implanted Striped Bass (STB) and mean daily surface water temperatures in lower J. Strom Thurmond Reservoir (Plum Branch USGS gage) during 2010, 2011 and 2012.

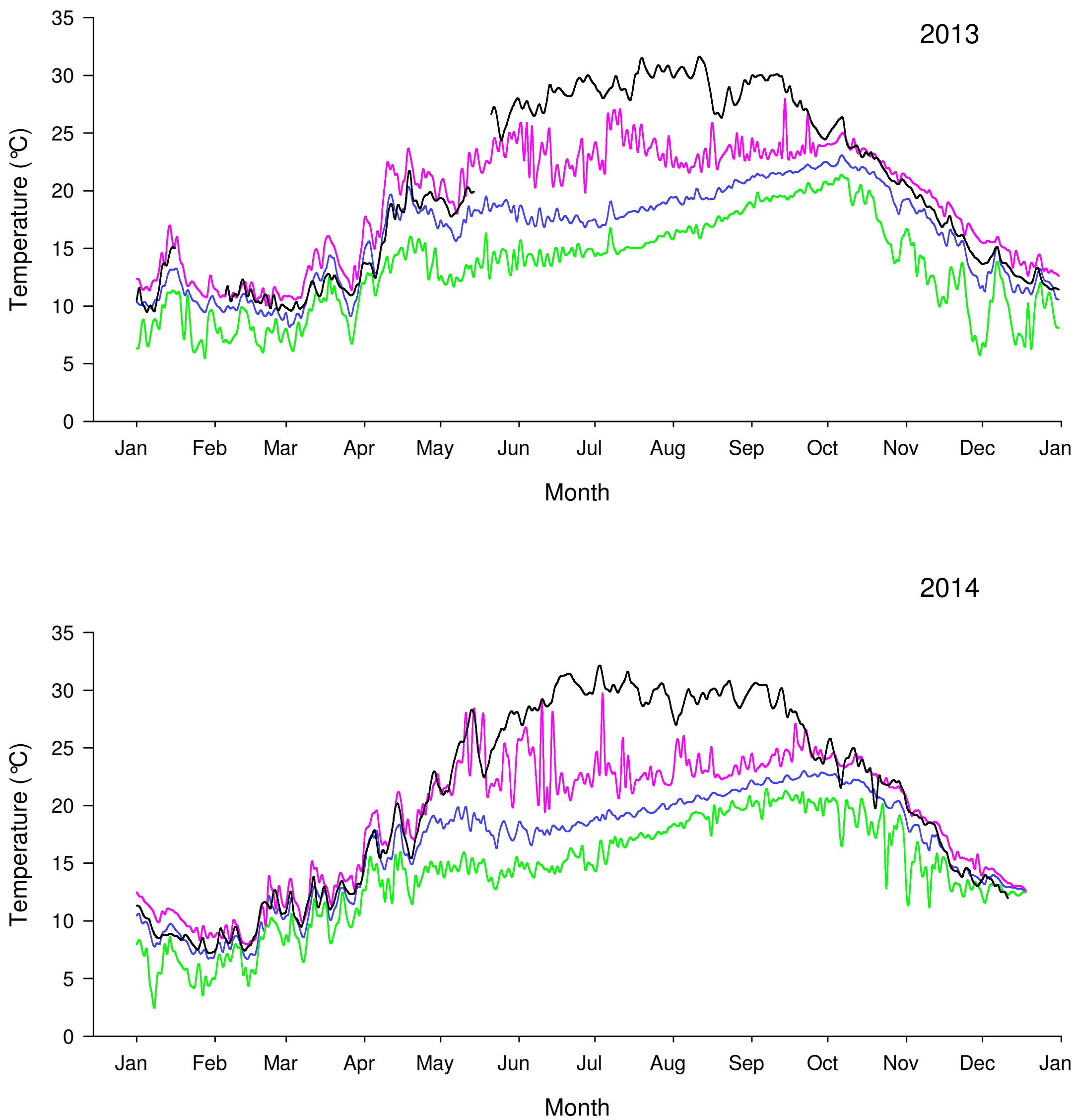


Figure 2. Mean, maximum, and minimum daily temperatures for transmitter-implanted Striped Bass (STB) and mean daily surface temperatures in lower J. Strom Thurmond Reservoir (Plum Branch USGS gage) during 2013 and 2014.

The mean annual temperature occupied by Striped Bass among years was 18.2 °C (range 18.1 – 18.7 °C). The minimum and maximum temperatures occupied among years were 1.5 °C and 31.8 °C, respectively (Table 1).

Table 1. Striped Bass annual mean temperature (°C), number of observations, standard deviation, minimum and maximum observed mean temperature for Striped Bass in J. Strom Thurmond Reservoir during 2010 – 2014.

Year	Mean	N	STD	Min	Max
2010	18.1	4,495	4.4	4.3	27.7
2011	18.1	13,014	4.6	1.5	28.6
2012	18.7	15,387	4	4.3	31.8
2013	17.6	15,899	4.1	5.5	28
2014	18.7	15,380	4.1	2.5	29.8
All	18.2	64,175	4.2	1.5	31.8

When mean monthly temperatures were pooled among years, Striped Bass temperatures were coolest during January (9.2 °C) and warmest during September (22.0 °C) (Table 2). The minimum monthly mean temperature (1.5 °C) occurred during January and the maximum mean monthly temperature (31.8°C) occurred during August. The general annual pattern for Striped Bass temperature was to increase rapidly between February (9.6 °C) and April (17.3 °C), increase slowly between May (18.2 °C) and September (22.0 °C) as fish made use of the oxygenated hypolimnion of the Lower Reservoir and Russell Tailrace, and then rapidly decrease between September (22.0 °C) and December (12.3 °C) (Figure 3).

Table 2. Striped Bass mean monthly temperature (°C), number of observations (N), standard deviation, minimum and maximum temperature each month of the year when years were pooled for Striped Bass in J. Strom Thurmond Reservoir during 2010 – 2014.

Month	Mean	N	Std	Min	Max
January	9.2	2,999	2.2	1.5	17.0
February	9.6	2,140	2.0	4.3	16.2
March	13.0	2,391	3.1	6.3	23.0
April	17.3	3,481	2.4	10.6	24.9
May	18.2	4,913	2.5	11.7	28.3
June	18.3	6,259	2.0	13.3	29.2
July	19.5	8,270	2.2	14.3	29.8
August	21.0	9,161	1.6	15.9	31.8
September	22.0	9,460	1.2	16.8	28.5
October	21.1	6,727	1.6	11.5	26.4
November	16.3	4,262	2.0	5.8	22.0
December	12.3	3,657	2.3	4.3	16.6

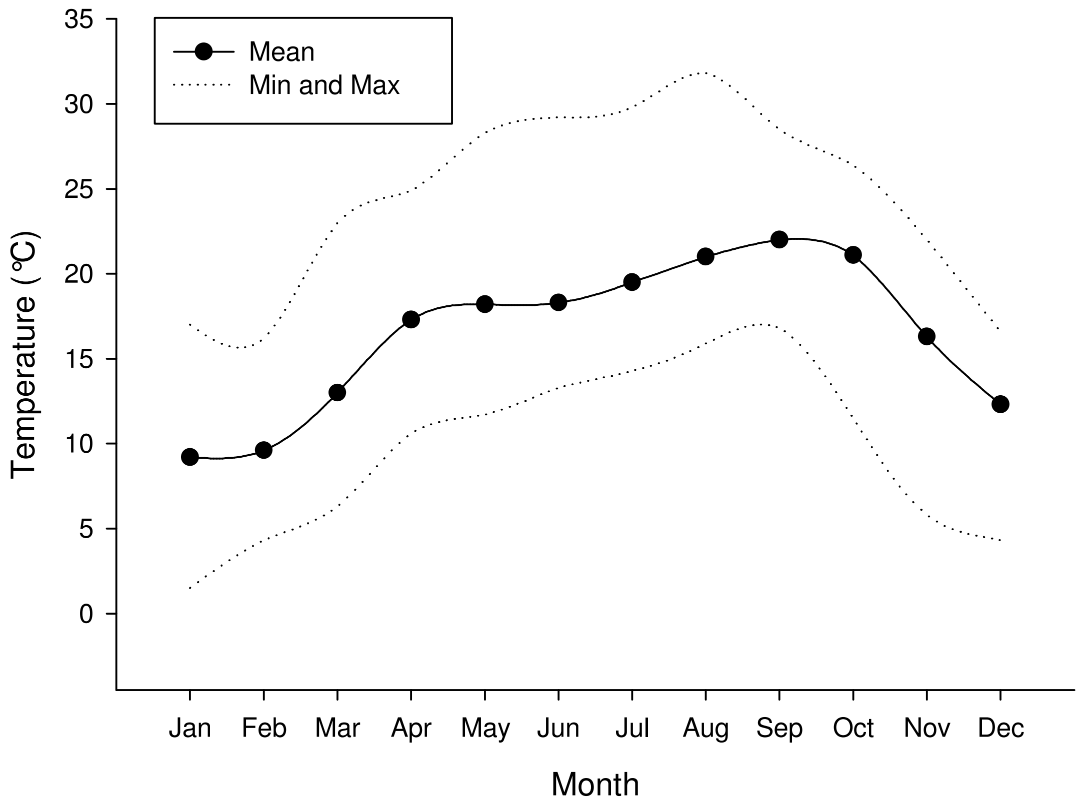


Figure 3. Mean monthly temperatures, pooled among years, for transmitter-implanted Striped Bass in J. Strom Thurmond Reservoir during 2010 – 2014.

There were significant differences in mean daily Striped Bass temperatures among years and between size classes (ANOVA, df = 7, F = 301, P < 0.001). Striped Bass mean daily temperatures were cooler during 2011 (mean = 17.52°C, 95% CI 17.44 – 17.61°C) and 2013 (mean = 17.64°C, 95% CI 17.57 -17.70°C) than 2012 (mean = 18.46°C, 95% CI 18.39 - 18.53°C) and warmest during 2014 (mean = 18.84°C, 95% CI 18.77 – 18.91°C). In each year of the study large (> 820 mm TL) Striped Bass occupied significantly cooler water than medium Striped Bass (Figure 4). In all year's large Striped Bass mean daily annual temperature was at least 0.74 °C cooler than medium Striped Bass.

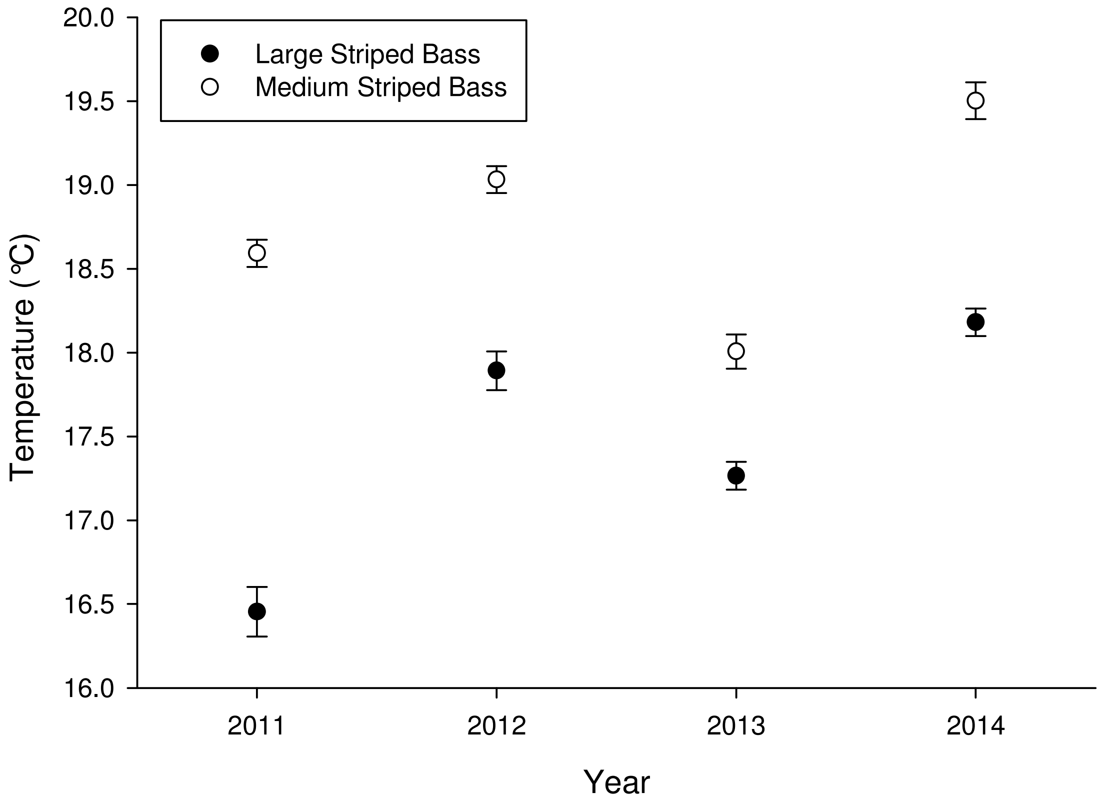


Figure 4. Mean annual temperatures and 95% confidence limits for large (> 820 mm TL) and medium (< 820 mm TL) Striped Bass in J. Strom Thurmond Reservoir during 2010 – 2014.

Overall annual mean temperatures were lower for large Striped Bass, but within years monthly trends in mean temperature were variable, particularly during winter and spring (Figure 5 and 6). Qualitatively, large Striped Bass temperatures were cooler than medium Striped Bass temperatures in nearly every month of each year. During January through June of 2011 large Striped Bass occupied cooler temperatures than medium Striped Bass; temperatures were significantly cooler during January, February, May, June, and December. For the remainder 2011 large and medium-sized Striped Bass occupied similar temperatures. During 2012 large Striped Bass temperature was significantly cooler only during May and June. During 2013 large Striped Bass temperature was significantly cooler during February, June, July, August, September, October and December, and during 2014 large Striped Bass temperature was significantly cooler in January, May, August, September and October.

Hybrid Striped Bass were monitored during 2013 and 2014. During 2013 Hybrid Striped Bass occupied significantly warmer temperatures then either Striped Bass size class between the months of May and October. However, during 2014 Hybrid Striped Bass occupied similar temperatures as Striped Bass most of the year only during September and October did they occupy significantly warmer temperatures than both size classes of Striped Bass and during May and June occupied warmer temperatures than large Striped Bass. While the differences in mean temperatures between the species within months of 2014 were significant those differences were often small, ranging from 0.33°C to 1.73°C. Hybrid Striped Bass occupied significantly warmer temperatures during 2013 (Mean = 17.4°C, 95% CL 17.3 – 17.5°C) than during 2014 (Mean = 16.5°C, 95% CL 16.4 – 16.6°C). The cooler temperatures during 2014 were largely due to their occupying significantly cooler temperatures each month April – August of 2014.

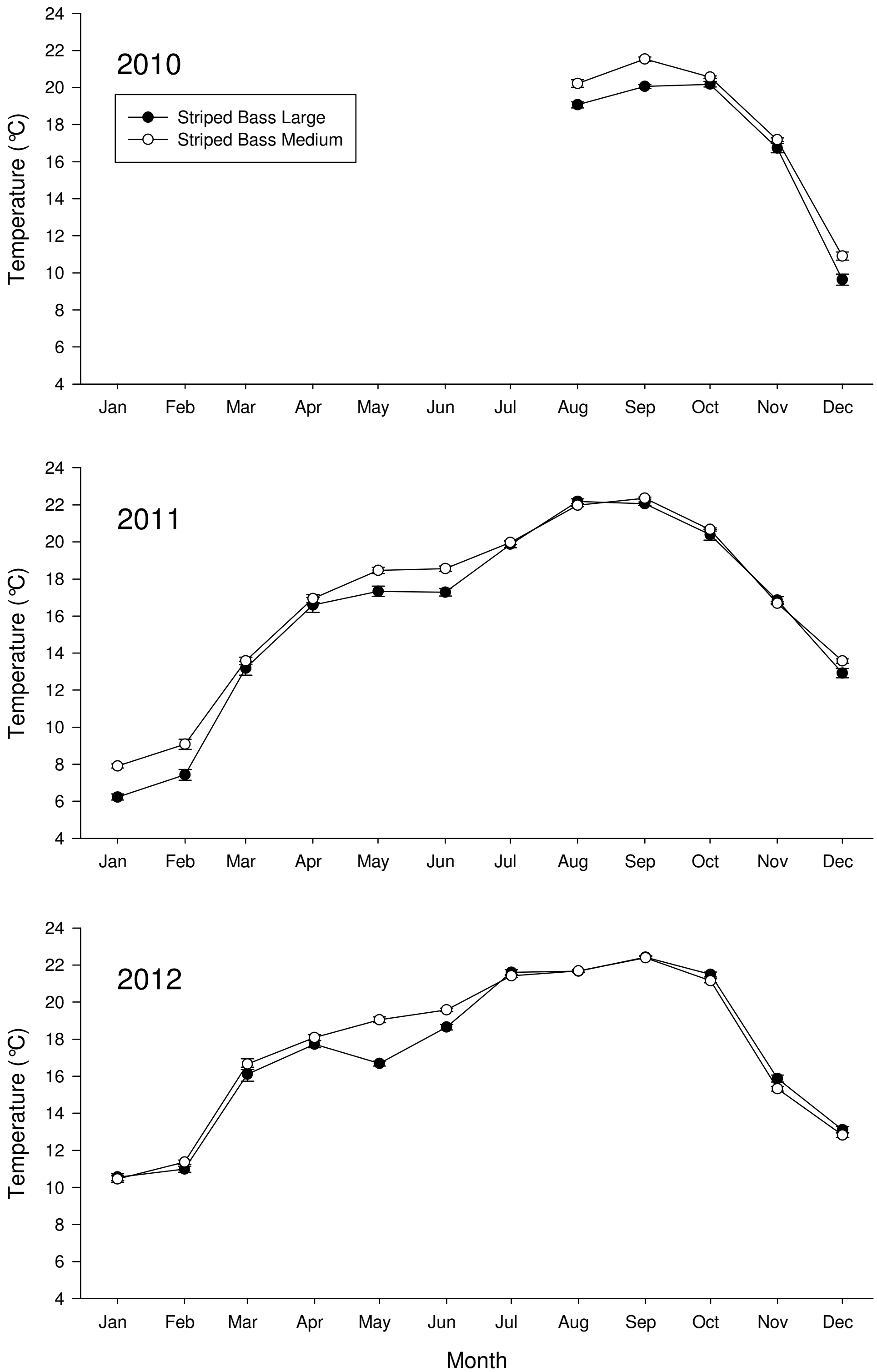
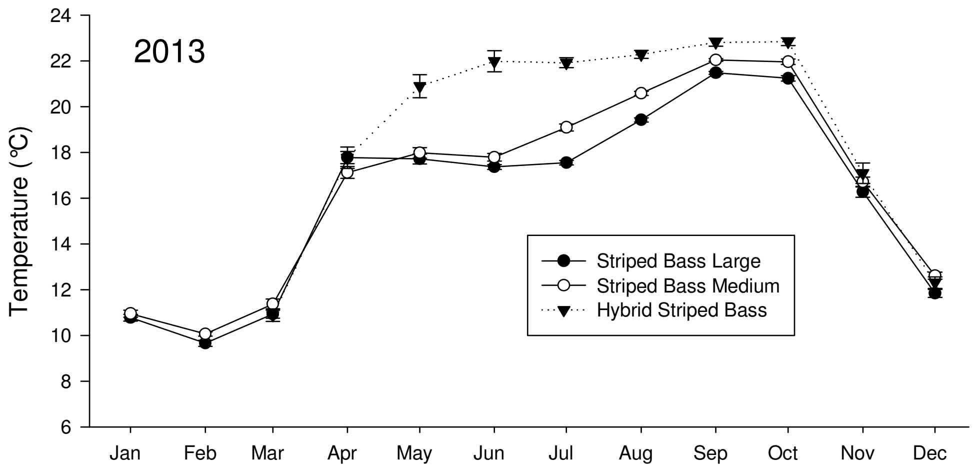


Figure 5. Mean monthly temperature and 95% confidence limits for large (> 820 mm TL) and medium (<820 mm TL) Striped Bass in J. Strom Thurmond Reservoir each year during 2010 – 2012.



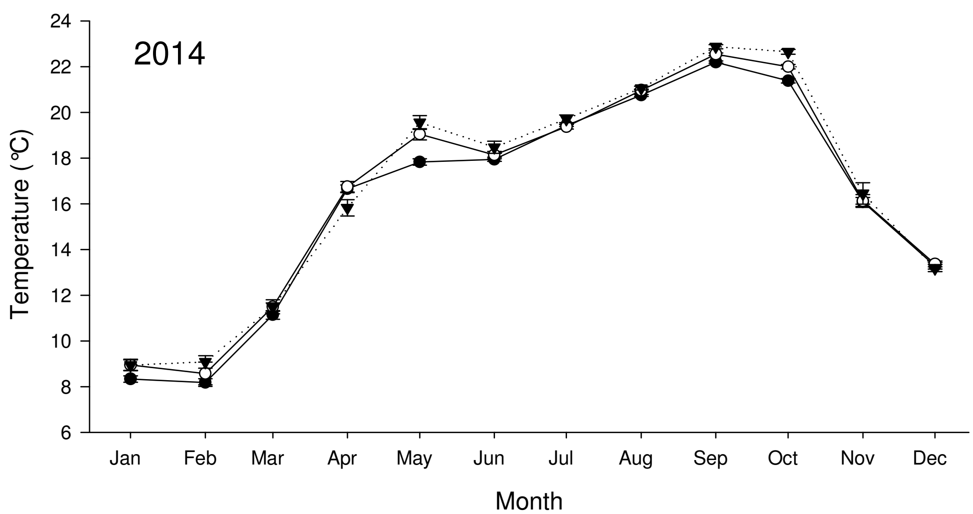


Figure 6. Mean monthly temperature and 95% confidence limits for large Striped Bass (> 820 mm TL), medium Striped Bass (<820 mm TL), and Hybrid Striped Bass in J. Strom Thurmond Reservoir each year during 2013 and 2014.

Mean August temperatures within years differed among summer habitat and size class. In general, Striped Bass occupied warmer temperatures in the Tailrace than the Lower Reservoir during 2010 and 2011 and occupied cooler temperatures in the Tailrace than the Lower Reservoir during 2012, 2013 and 2014. Within the Tailrace large Striped Bass occupied cooler temperatures than medium Striped Bass, but in the Lower Reservoir large Striped Bass occupied warmer water than medium Striped Bass during two of the three years both size groups were monitored in the Lower Reservoir (Figure 7).

During August 2010 there were significant differences in Striped Bass mean temperature between size groups (ANOVA, df = 1, F = 47.8, P < 0.001) and sections (ANOVA, df = 1, F = 16.5, P < 0.001); however, no large Striped Bass occupied the Lower Reservoir. Large Striped Bass (19.1°C) occupied cooler temperatures than medium Striped Bass (20.1 °C) in the Tailrace, but the two medium fish that occupied the Lower Reservoir used the coolest temperatures (18.6 °C) during August (Table 3).

During August 2011 there were significant differences in Striped Bass mean temperature between size groups (ANOVA, df = 1, F = 7.85, P = 0.005) and sections (ANOVA, df = 1, F = 559, P < 0.001); however, no large Striped Bass occupied the Lower Reservoir. Large Striped Bass occupied cooler temperatures (22.0°C) than medium Striped Bass (22.3°C) in the Tailrace, but the two medium fish that occupied the Lower Reservoir used the coolest temperatures during August (20.5°C).

During August 2012 there were significant differences in Striped Bass mean temperature between sections (ANOVA, df = 1, F = 66.7, P < 0.0001), size class (ANOVA, df = 1, F = 14.26, P < 0.0001) and an interaction between size-class and section (ANOVA, df = 1, F = 12.93, P < 0.001). Medium and large Striped Bass within the Tailrace occupied similar water temperatures

(21.5°C); however, large Striped Bass in the Lower Reservoir occupied water temperatures slightly warmer (22.3°C) than medium fish (21.8°C) and both size classes in the Tailrace.

During August 2013 there were no differences between size classes (ANOVA, df = 1, F = 2.22, P = 0.14), but there were differences between sections (ANOVA, df = 1, F = 3018, P < 0.0001) and the interaction between section and size class (ANOVA, df = 1, F = 67.11, P < 0.0001). Large Striped Bass in the Lower Reservoir occupied warmer water (21.5°C) than medium Striped Bass there (21.2°C); and medium fish in the Tailrace occupied warmer water (18.9°C) than large fish (18.4°C). Both size classes of fish in the Tailrace occupied cooler water than both size classes in the Lower Reservoir.

During 2014 there were differences among size classes (ANOVA, df = 1, F = 15.45, P < 0.0001) and sections (ANOVA, df = 1, F = 371, P < 0.0001), but the interaction was not significant (ANOVA, df = 1, F = 3.44, P = 0.6). Both size classes occupied warmer water in the Lower Reservoir (large 21.0°C, medium 21.1°C) than the Tailrace (large 20.3°C, medium 20.5°C).

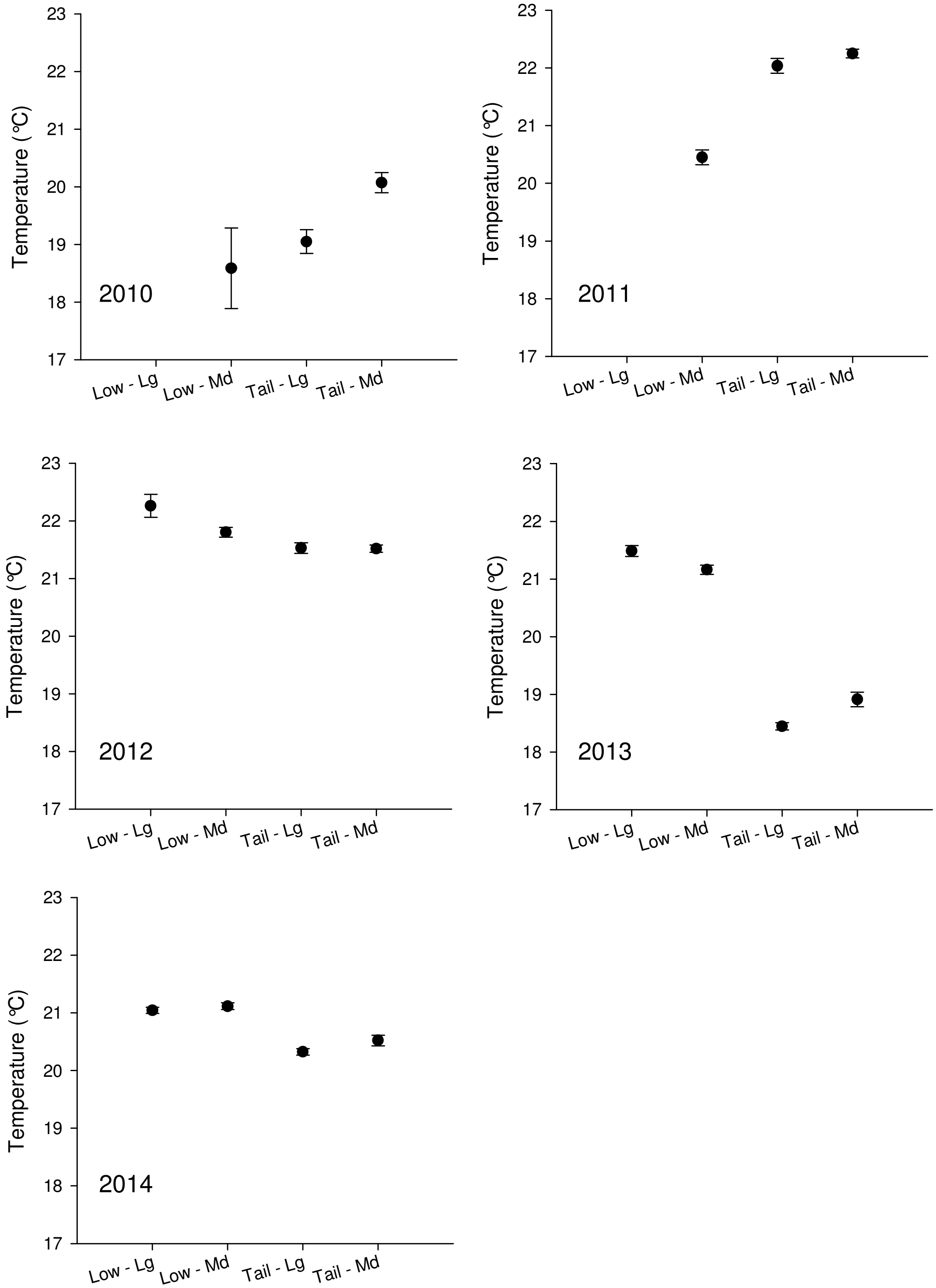


Figure 7. Mean August temperatures and 95% confidence intervals for two size classes (large [Lg] and medium [Md]) of Striped Bass occupying the Lower (Low) and Tailrace (Tail) summer refuges in J. Strom Thurmond Reservoir during 2010 – 2014.

Table 3. Mean daily temperatures (°C), upper and lower confidence intervals, number of individual fish, number of mean daily estimates, minimum and maximum daily temperatures by year, size class, and section during August for Striped Bass tracked in J. Strom Thurmond Reservoir, 2010-2014.

Year	Size	Section	Mean	Upper CI	Lower CI	N_fish	N	Min	Max
2010	Medium	Lower	18.59	17.89	19.29	2	12	16.50	23.66
2010	Large	Tailrace	19.05	18.84	19.26	8	137	17.29	22.14
2010	Medium	Tailrace	20.07	19.9	20.25	18	194	17.66	23.83
2011	Medium	Lower	20.45	20.32	20.58	7	359	17.63	28.20
2011	Large	Tailrace	22.04	21.91	22.17	9	358	19.24	27.22
2011	Medium	Tailrace	22.25	22.17	22.33	23	1034	19.03	27.62
2012	Large	Lower	22.26	22.06	22.46	2	88	21.10	23.83
2012	Medium	Lower	21.80	21.72	21.89	10	475	18.50	31.80
2012	Large	Tailrace	21.53	21.44	21.62	13	411	18.75	24.46
2012	Medium	Tailrace	21.52	21.46	21.58	22	893	18.70	25.67
2013	Large	Lower	21.49	21.39	21.58	9	373	20.05	24.70
2013	Medium	Lower	21.16	21.08	21.24	11	551	18.20	23.25
2013	Large	Tailrace	18.44	18.38	18.51	23	868	16.43	25.62
2013	Medium	Tailrace	18.91	18.79	19.04	4	219	15.88	22.83
2014	Large	Lower	21.04	20.99	21.10	16	810	17.43	23.04
2014	Medium	Lower	21.11	21.06	21.17	12	719	18.22	26.06
2014	Large	Tailrace	20.32	20.27	20.38	18	818	18.28	23.86
2014	Medium	Tailrace	20.52	20.43	20.61	6	283	18.82	23.13

Pumping influence on temperature

The temperature of Striped Bass residing in the Tailrace during summer differed among years (ANOVA, df = 2, F = 61.8, P < 0.001), during the first and last hour of pumping operations (ANOVA, df = 1, F = 69.0, P < 0.001), and was positively related to day of the year (ANOVA, df = 1, F = 447.7, P < 0.001). Overall Striped Bass hourly mean temperatures during the first and last hour of pumping were significantly warmer in 2011 (mean = 21.1°C 95% CL 20.93 – 21.28°C) and 2012 (mean = 21.09°C 95% CL = 20.94 – 21.25°C) than during 2014 (mean = 20.01°C 95%

CL 19.85 – 20.16°C). In each year Striped Bass temperatures were significantly warmer during the last hour of pumping than during the first hour of pumping. The annual differences in mean temperature during the first and last hour of pumping were small, ranging from 0.64 to 0.98°C, and mean summer temperatures were less than 24°C (Figure 8). However, on some dates the difference in temperatures during the first and last hour of pumping were substantial (> 2.5°C) and occasionally temperatures during the last hour of pumping exceeded 24°C during August and September of 2011 (Figure 9).

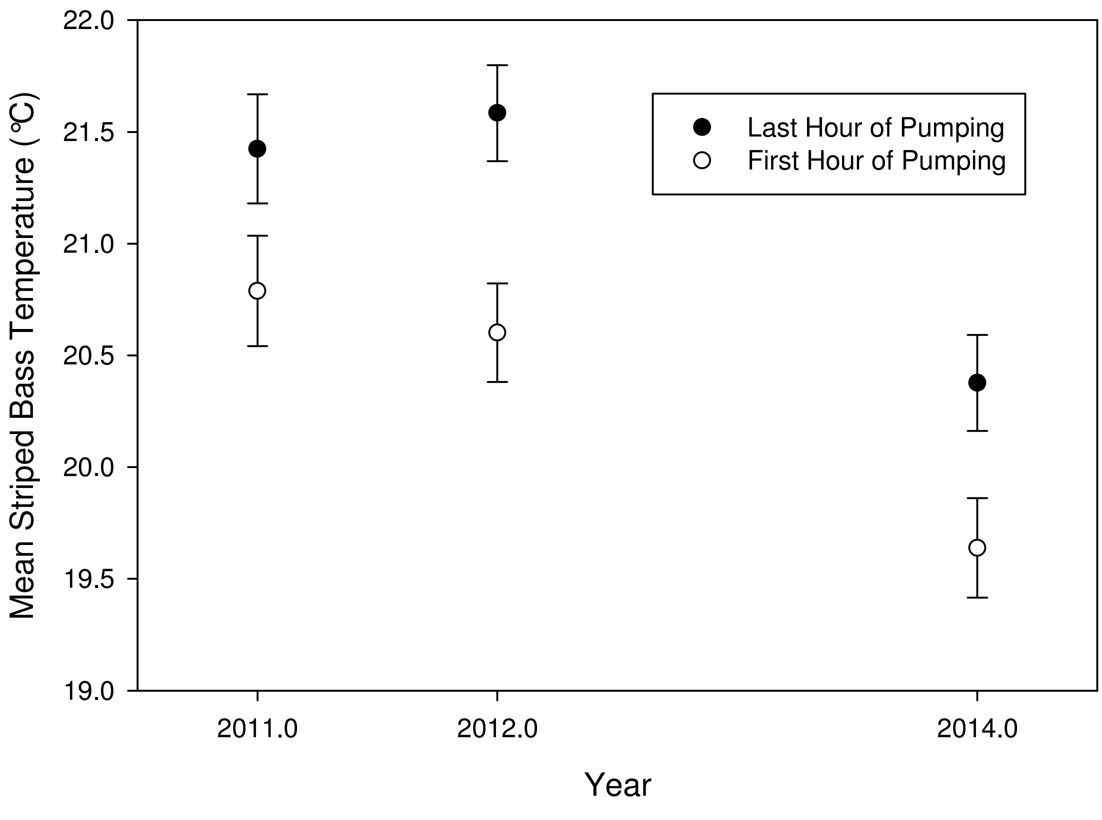


Figure 8. Mean summer temperature, and 95% confidence intervals, the first and last hour of pumpback operations for Striped Bass occupying the Richard B. Russell Tailrace during 2011, 2012, and 2014.

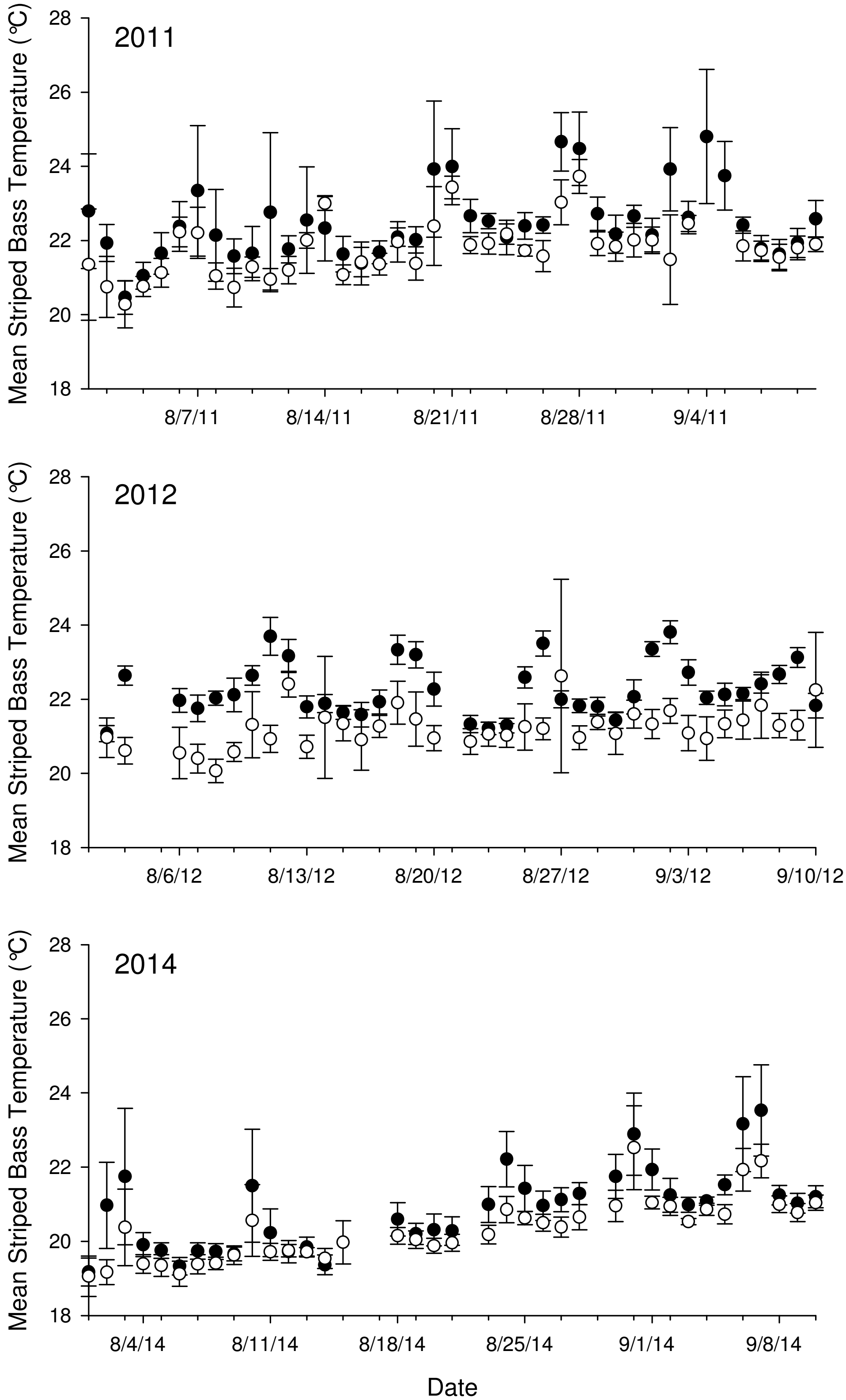


Figure 9. Mean daily temperatures, and 95% confidence intervals, the first (white circles) and last hour (black circles) of pumpback operations for Striped Bass occupying the Richard B. Russell Tailrace during 2011, 2012, and 2014.

Discussion

Mean daily Striped Bass temperatures were similar to surface water temperatures in the lower reservoir between November and March each year. When the reservoir began to stratify Striped Bass moved into the thermal refuge of the Russell tailrace or occupied deeper depths of the lower reservoir seeking cooler water temperatures. During summer there was large variation in maximum temperatures, which was largely attributed to some of the Striped Bass occupying the lower reservoir periodically making vertical migrations to shallower depths and warmer water temperatures. Vertical migrations of Striped Bass in the lower reservoir occurred most frequently at night. Between November and February there was large variation in Striped Bass minimum temperatures. Much of that variation occurred when fish moved from Tailrace and main reservoir sections into cooler tributaries. During winter Striped Bass often vacated the more stable and warmer temperatures of the Tailrace and moved into the cooler and highly variable temperatures of the Broad River. Striped Bass temperatures in the Broad River were on average 2°C cooler than the Tailrace during winter; however, on some dates Striped Bass occupied water as much as 7°C cooler in the Broad River (7°C) than Tailrace (14°C).

Striped Bass are often restricted to temperatures outside their preferred range during summer in southern reservoirs without thermal refuges due to thermal stratification that results in hypoxic or anoxic conditions at depths where temperatures are suitable. During the four years (2011 – 2014) of post-oxygenation monitoring overall Striped Bass mean summer (July – August) temperature in the lower reservoir ranged from 20.3°C to 21.6°C annually and rarely (2.8% of 9,224 observations) did mean temperature of individual Striped Bass exceed 24°C. During 1999 and 2000, before oxygenation, most Striped Bass vacated lower Thurmond Reservoir to avoid hypoxic conditions for the thermal refuge of the Russell Tailrace by August when temperatures reached 23°C to 25°C, and those that remained in the lower reservoir all summer inhabited 23.7°C to 25°C temperatures in the lowest strata of the thermocline, or the cooler deeper hypolimnetic water where dissolved oxygen rapidly became hypoxic (Young and Isely 2002). After oxygenation Striped Bass in Thurmond Reservoir mostly occupied temperatures within the optimal range.

In each year of the study large (≥ 820 mm TL) Striped Bass had lower mean annual temperatures than medium (< 820 mm TL) Striped Bass. However, during August large Striped Bass occupied significantly warmer water temperatures in the lower reservoir during 2 of 3 years, although the differences were small (< 0.5°C). In the Tailrace where dissolved oxygen conditions were likely similar among depths large Striped Bass occupied significantly cooler temperatures during August in 2 of 3 years. It is unknown why large Striped Bass in the lower reservoir chose warmer water temperatures during August, but it may have been related to dissolved oxygen levels, perhaps large fish selected warmer temperatures with higher dissolved oxygen concentrations.

Hybrid Striped Bass in this study occupied cooler summer (July – September) water temperatures (mean = 22.1°C during 2013 and mean = 21.1°C during 2014) than that previously reported for Hybrid Striped Bass in Thurmond Reservoir and other reservoirs. A telemetry study, before oxygenation, of Hybrid Striped Bass in Thurmond Reservoir found that fish occupied the top of the thermocline during summer where mean water temperature was 26.3°C (Windham 1986). Average summer temperatures of Hybrid Striped Bass in a Virginia reservoir were 23.8°C to 25.5 °C and Hybrid Striped Bass occupied warmer water than Striped Bass during early summer before temperature selection was constrained by hypoxia (Kilpatrick and Ney 2013).

There is a perception that adult Hybrid Striped Bass prefer warmer water temperatures and tolerate a wider range of temperatures than Striped Bass which have a temperature preference centered around 22°C (Coutant and Carroll 1980, Coutant 2013). The literature to support that perception is based on the thermal ecology of juvenile fish (Woiwode and Adelman 1991) and a few field studies that monitored Hybrid Striped Bass summer temperatures in thermally stratified reservoirs with hypoxic conditions (Windham 1986, Douglas and Jahn 1987, Kilpatrick and Ney 2013). We observed that Hybrid Striped Bass occupied warmer temperatures than Striped Bass during summer of 2013, but Hybrid Striped Bass and Striped Bass occupied similar temperatures during summer 2014. During 2013 the oxygen injection system provided greater dissolved oxygen concentrations, and suitable dissolved oxygen values over a greater range of depths (and temperatures) than during 2014 (Habitat Section). In the suboptimal dissolved oxygen conditions present during 2014 Hybrid Striped Bass choose to occupy cooler temperatures, rather than occupy shallower depths with water temperatures > 24°C where dissolved oxygen was > 4.0 mg/l, indicating that Hybrid Striped Bass preferred temperature may be less than 24°C in Thurmond Reservoir and closer to the preferred temperature (22°C) of Striped Bass reported by Coutant and Carroll (1980).

Literature Cited

Coutant, C. C. 2013. When is habitat limiting for striped bass? Three decades of testing the temperature-oxygen squeeze hypothesis. Pages 65-91 *in* J. S. Bulak, C. C. Coutant, and J. A. Rice, editors. Biology and management of inland Striped Bass and Hybrid Striped Bass. American Fisheries Society, Symposium 80, Bethesda, Maryland.

Coutant, C. C., and D. S. Carroll. 1980. Temperatures occupied by ten ultrasonic-tagged striped bass in freshwater lakes. Transactions of the American Fisheries Society 109:195-202.

Douglas, D. R., and L, A. Jahn. 1987. Radio tracking hybrid striped bass in Spring Lake, Illinois, to determine temperature and oxygen preferences. North American Journal of Fisheries Management 7:531-534.

Kilpatrick, J. M., and J. J. Ney. 2013. Temperature and dissolved oxygen habitat use by striped bass and hybrid striped bass in Claytor Lake, Virginia. Pages 147-159 *in* J. S. Bulak, C. C. Coutant, and J. A. Rice, editors. Biology and management of inland Striped Bass and Hybrid Striped Bass. American Fisheries Society, Symposium 80, Bethesda, Maryland.

Windham, W. T., Jr. 1986. Summer temperature selection of striped bass x white bass hybrids in a southeastern reservoir. Master's thesis. University of Georgia, Athens.

Woiwode, J. G., and I. R. Adelman. 1991. Effects of temperature, photoperiod, and ration size on growth of hybrid striped bass x white bass. Transactions of the American Fisheries Society 120:217-229.

Young, S. P., and J. J. Isely. 2002. Striped Bass annual site fidelity and habitat utilization in J. Strom Thurmond Reservoir, South Carolina–Georgia. Transactions of the American Fisheries Society 131:828–837.

HABITAT CONDITIONS, STRIPED BASS HABITAT USE AND DISTRIBUTION IN THE OXYGENATED AREA

Objectives

Historically thermal stratification of lower J. Strom Thurmond Reservoir during summer has resulted in unsuitable and suboptimal Striped Bass habitat due to hypoxic conditions at depths where water temperatures were suitable. In summer 2011 an oxygen injection system was installed into the lower reservoir to provide optimal habitat for Striped Bass during summer. The objectives of this section were to; 1. Qualitatively assess the habitat conditions in lower Thurmond Reservoir during summer, 2. Describe Striped Bass distribution in the lower reservoir during summer, and 3. Estimate summer dissolved oxygen and temperature conditions occupied by Striped Bass.

Materials and Methods

Water Quality data

Between January 2010 and October 2014 the United States Army Corp of Engineers (USACE) collected temperature (°C) and dissolved oxygen (mg/l) profiles at 2-m depth intervals monthly from 12 fixed stations to describe seasonal and spatial trends in water quality (Figure 1). In addition to monthly collections, the USACE made weekly collections at the four lowermost stations (sites 20, 21, 23, and 25) in the Savannah River channel during summer, typically June through September of each year to monitor the oxygenated area.

To obtain semi-monthly water quality information during summer from areas outside the oxygenated area South Carolina Department of Natural Resources (SCDNR) collected monthly temperature and dissolved oxygen profiles at the USACE collection sites during June – October of each year approximately 2 weeks after the USACE monthly collections. SCDNR added an additional site (site 33) in Little River, GA to evaluate water quality further up the Little River, GA channel. Temperature and dissolved oxygen profiles were also collected at manually located fish locations during summer. SCDNR temperature and dissolved oxygen profiles were collected at 1-m depth intervals with a YSI Professional Plus multi-parameter meter (YSI Inc., Yellow Springs, Ohio).

We classified the summer habit within each reservoir section based on the proportion of water quality observations at each station that were: 1. Unsuitable (> 25 °C or dissolved oxygen < 2 mg/l), 2. Suboptimal (< 18 or 24 – 25°C or dissolved oxygen 2 – 5 mg/l), 3. Optimal (18 – 24°C and dissolved oxygen > 5 mg/l). Water quality stations 20, 21, and 23 were used to evaluate water quality in the lower reservoir, stations 25 and 28 for the middle reservoir, stations 30, 35 and 38 for the upper reservoir, stations 40 and 45 for the tailrace, station 15 for lower Little River, GA, and station 33 for middle Little River, GA (Figure 1).

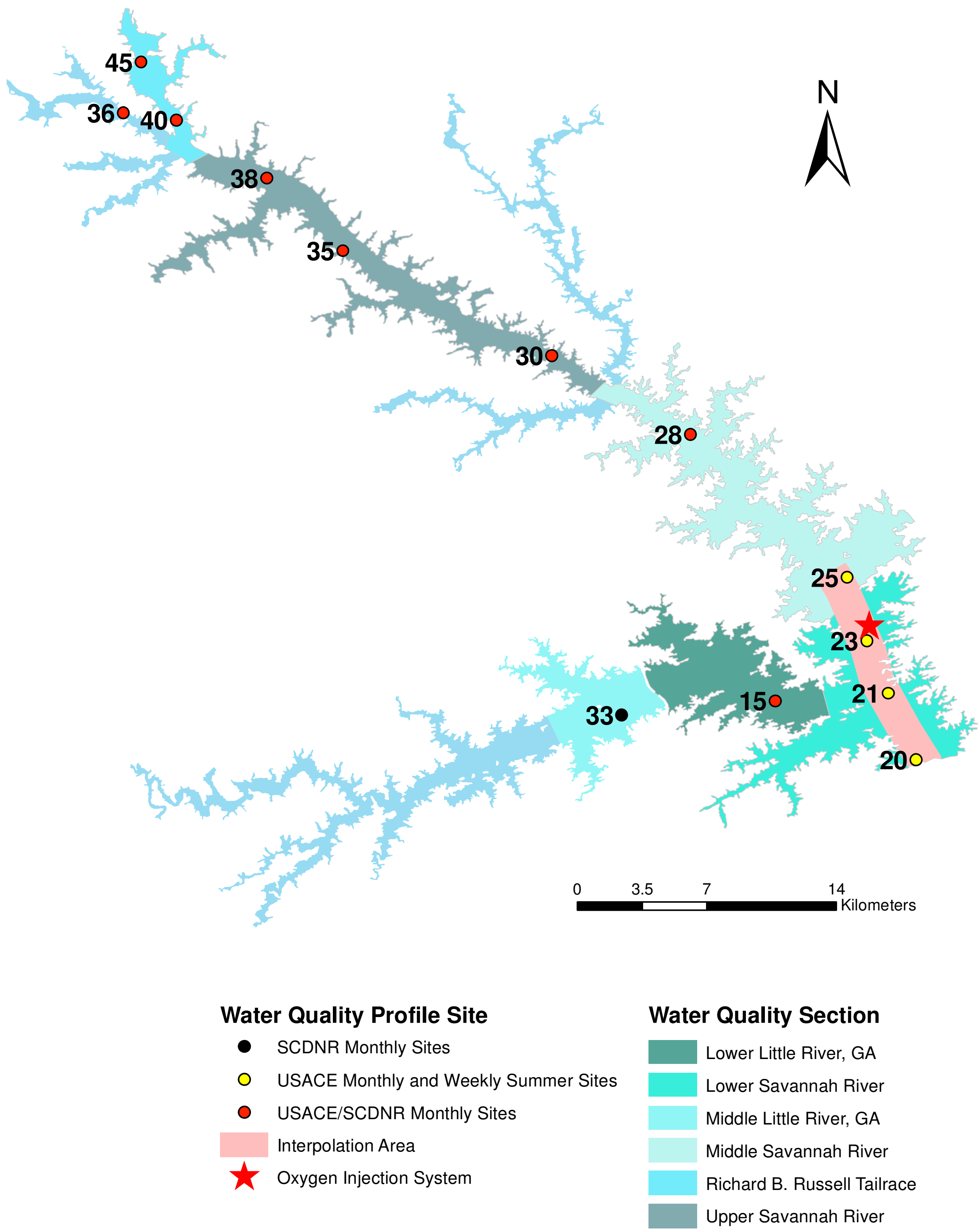


Figure 1. Water quality collection sites, reservoir sections, oxygenation system location, and area of water quality interpolations in J. Strom Thurmond Reservoir, SC-GA. Striped Bass dissolved oxygen and depth interpolations were restricted to fish located within the interpolation area.

Interpolation of Water Quality Data

USACE temperature dissolved oxygen profiles were used to create a surface of dissolved oxygen and temperature for five summer dates (13 June – 15 September) during each year, 2010 through 2014. Dissolved oxygen and temperature values collected at each station were interpolated using kriging with a linear interpolation of temperature and dissolved oxygen, by distance from Thurmond Dam (reservoir km) and depth (m) using Surfer®12 Software (Golden Software, LLC, Golden, CO). The resulting temperature and dissolved oxygen surfaces for each date were plotted and visually reviewed to qualitatively compare habitat conditions among dates and years.

Striped Bass location records recorded at acoustic receiver stations in the lower reservoir below km 11 were used to determine the habitat conditions for each fish on each date that water quality data were collected and interpolated (Figure 1). Only locations recorded at acoustic receiver stations within 800 m of the main Savannah River Channel and collected on the day of water quality collections were used to assess Striped Bass habitat conditions. Depth for each Striped Bass location record was interpolated from transmitted temperature using the previously described methods. Striped Bass locations (reservoir km and depth) were plotted on the interpolated dissolved oxygen surface and dissolved oxygen was extracted from the surface for each fish location. Striped Bass with less than 3 dissolved oxygen observations on a single date were removed from further analysis. The habitat plots with fish locations presented in the results section show the range of observed fish locations, but not the frequency with which fish used each location (i.e., each fish location symbol could represent 1 or multiple values).

Analysis of covariance was used to determine if Striped Bass mean dissolved oxygen, temperature, and depth varied among years during the period of oxygenation (July – 15 September of 2011 – 2014). The model included Year and fish ID as classification variables and day of the year of each observation as a linear covariate. Analysis of variance was used to determine if Striped Bass mean dissolved oxygen, temperature, and depth differed among dates and among individual fish within dates. The model included Fish ID and Date as classification variables as well as the interaction between Fish ID and date. Least-squares means were used for comparing significant differences of all estimates. All statistical analysis was performed using SAS® 9.3 (SAS Institute Inc., Cary, North Carolina).

Results

Water Quality Data

Temporal and spatial trends in Striped Bass habitat suitability were evident during June – October in Thurmond reservoir as habitat conditions deteriorated between June and September in the lower and middle reservoir (Figure 2). During 2010, before oxygenation, the lower reservoir lacked optimal habitat throughout most of the summer; by early September conditions were unsuitable for Striped Bass. During the summers of 2011 – 2014 there was some (1% - 12%) optimal habitat available on 34 of the 38 summer dates reviewed and suboptimal habitat comprised 8% to 81% of available habitat. The middle section of the reservoir contained mostly (>78% on 8 of 9 dates) unsuitable habitat during summer 2011 and 2012 and no optimal habitat. Conditions in the middle reservoir were better during 2013 and 2014 when optimal and suboptimal conditions comprised at least 30% of habitat on 8 of 12 dates.

Habitat conditions in the upper reservoir were better than those observed in the middle reservoir and comparable to those observed in the lower reservoir, while habitat conditions in the Richard B. Russell (RBR) tailrace were optimal on most dates (Figure 3). In the upper reservoir optimal and suboptimal conditions comprised 43% – 73% of habit on all 28 summer dates that were reviewed. Optimal conditions were present on 21 dates, comprising 3% - 53% of the habitat. In the RBR Tailrace optimal and suboptimal conditions comprised 40% – 100% of habit on all 29 summer dates that were reviewed. Optimal conditions were present on each date, comprising 8% - 88% of the habitat.

Habitat conditions in the Little River, GA portion of the lake were mostly unsuitable for Striped Bass during summer (Figure 4). Between July and September in the lower Little River, GA there was no optimal habitat. The proportion of unsuitable habitat during summer ranged from 18 – 100%; on 22 of 27 dates > 70% of habitat was unsuitable. Conditions were worse in upper Little River, GA where on the 14 summer dates reviewed at least 64% of the habitat was unsuitable with nine of those dates having more than 93% unsuitable habitat.

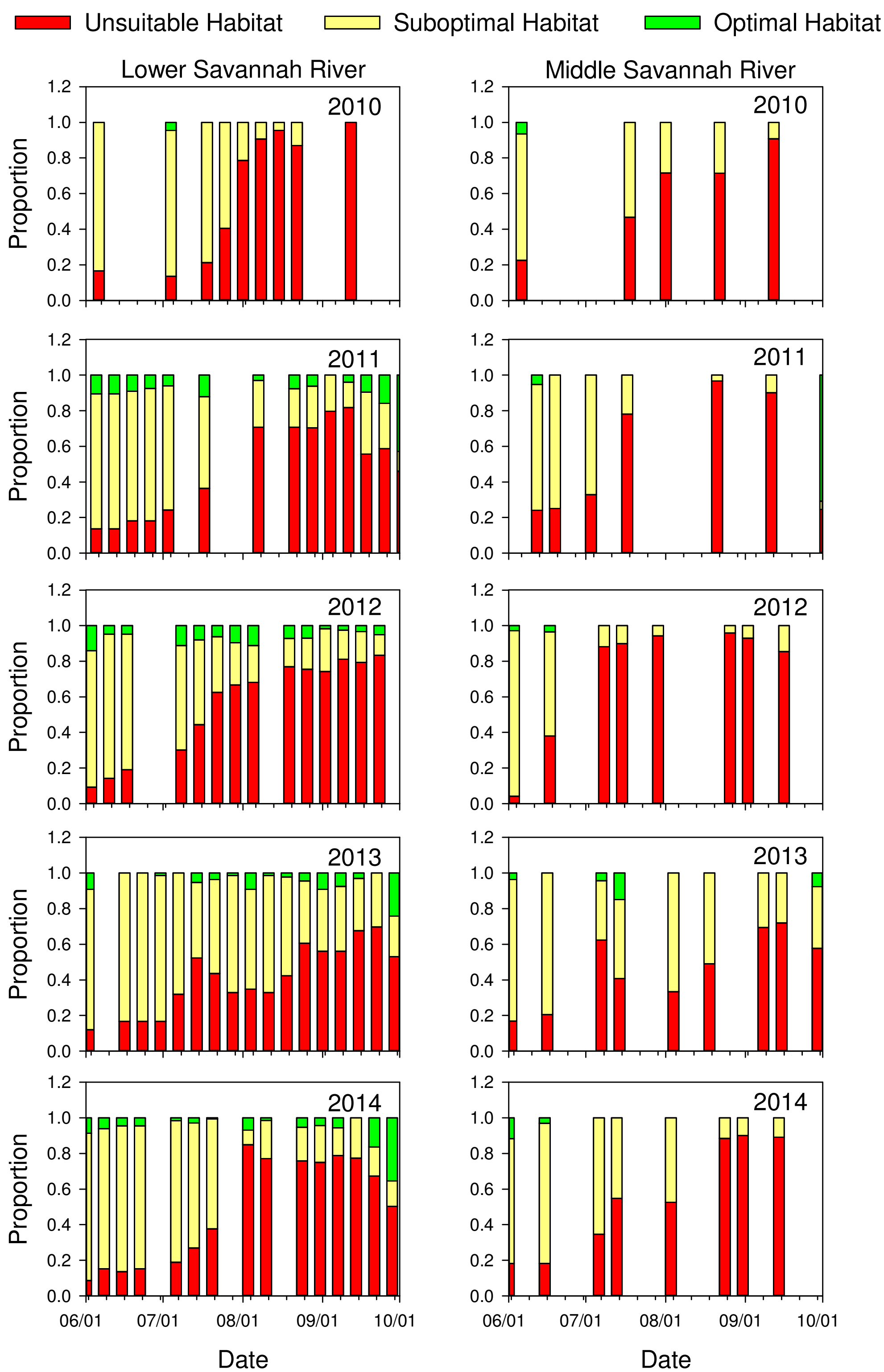


Figure 2. Proportion of optimal, suboptimal, and unsuitable Striped Bass habitat in lower and middle Savannah River channel in J. Strom Thurmond Reservoir during summer 2010 – 2014.

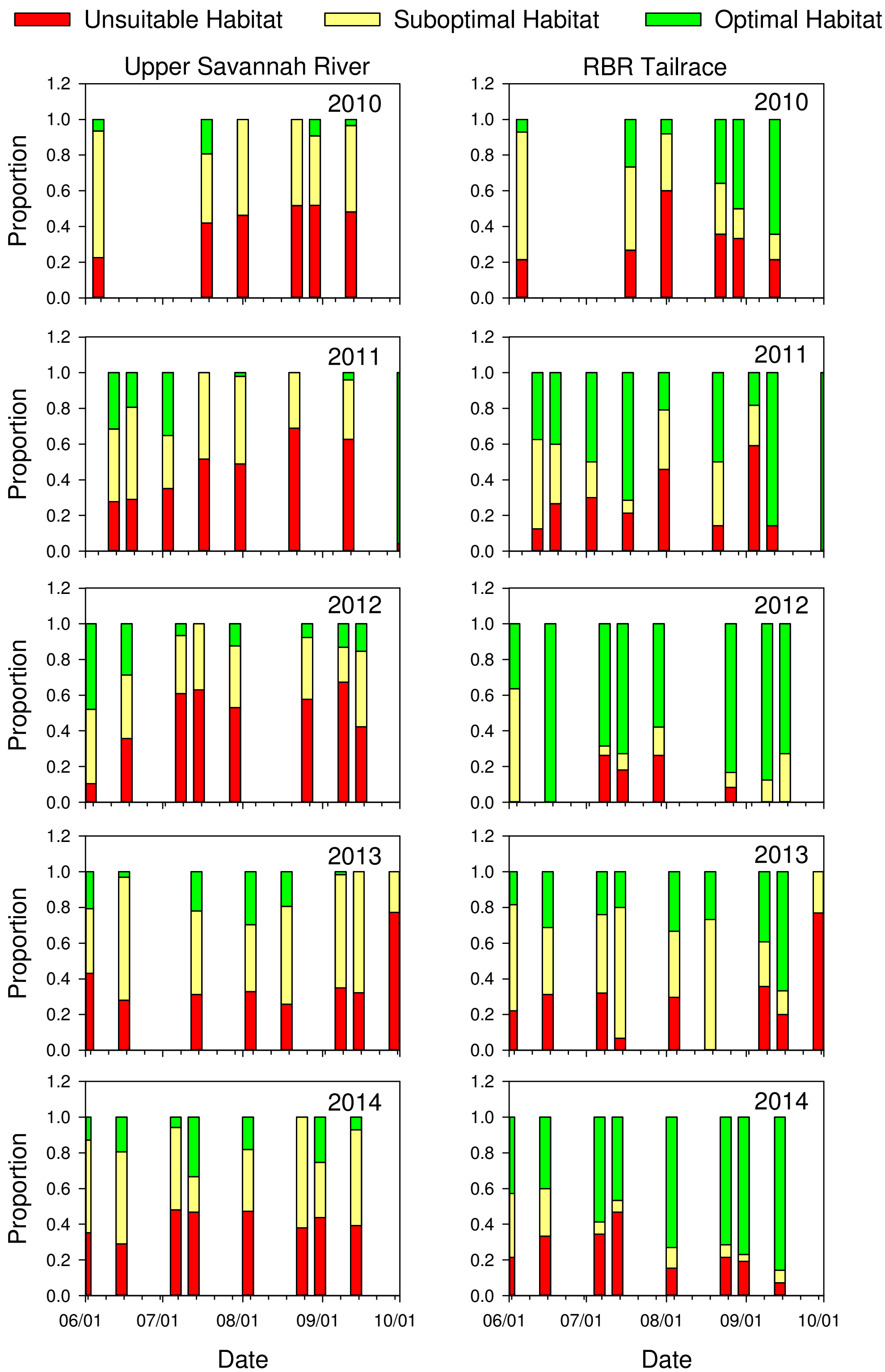


Figure 3. Proportion of optimal, suboptimal, and unsuitable Striped Bass habitat in upper Savannah River channel and Richard B. Russell Tailrace in J. Strom Thurmond Reservoir during summer 2010 – 2014.

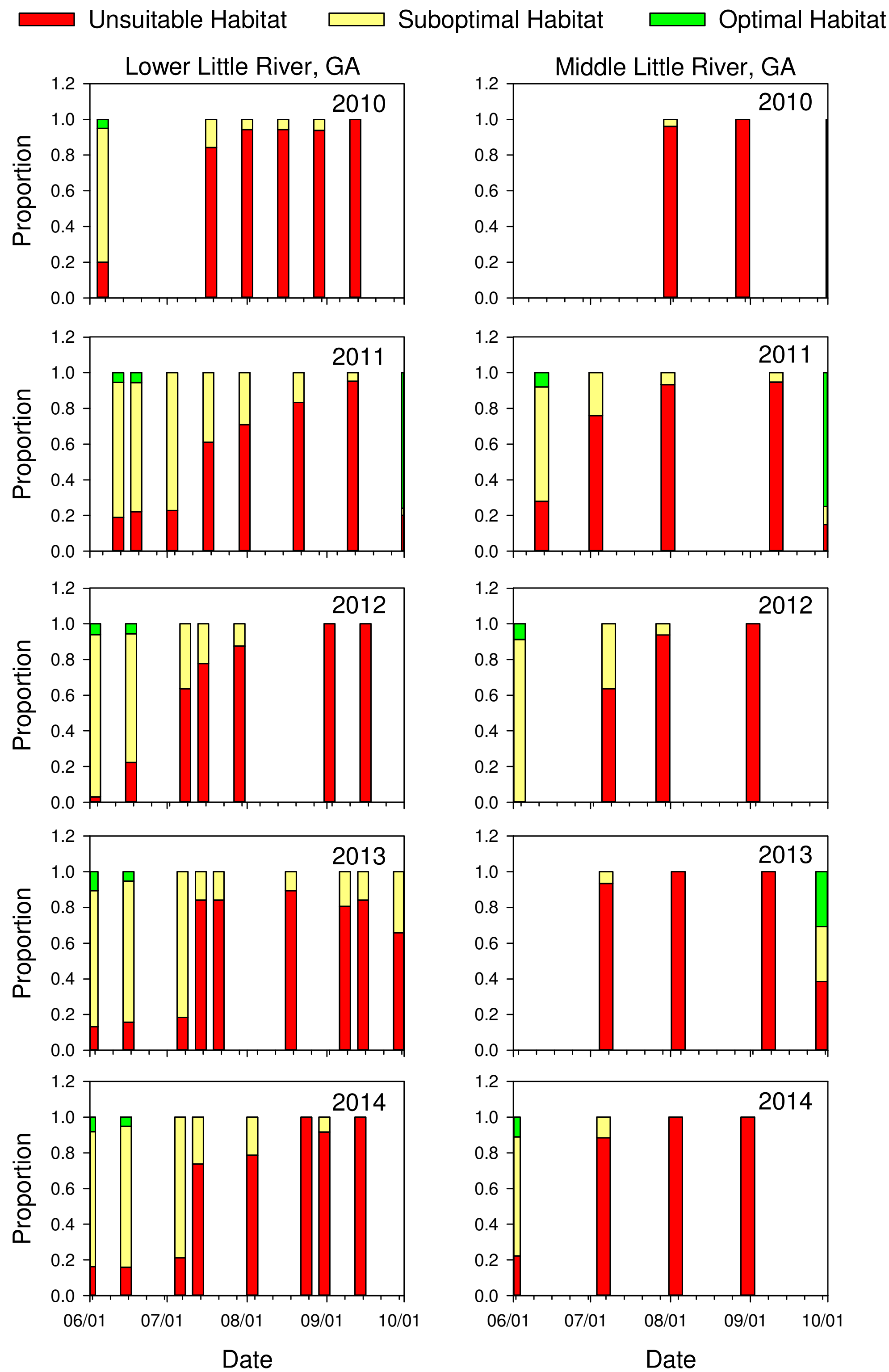


Figure 4. Proportion of optimal, suboptimal, and unsuitable Striped Bass habitat in lower and middle Little River, GA channel in J. Strom Thurmond Reservoir during summer 2010 – 2014.

During July, August, and September of 2010, 2011, 2013, and 2014 a total of 129 temperature and dissolved oxygen profiles were collected at manually detected fish locations. Summer manual tracking was conducted during June of 2012 and water quality profiles were collected, but are not reported here. Water quality profiles were collected from manually tracked fish in the Tailrace during the summers of 2010, 2011 and 2013. Striped Bass manually detected in the lower reservoir during summer occupied a mean depth of 13.4 m (range, 5.5 – 22 m), a mean dissolved oxygen concentration of 3.8 mg/l (range, 1.1 – 8.1 mg/l) and a mean temperature of 24.4 °C (range, 15.5 – 26.5°C) (Table 1). Striped Bass manually detected in the RBR Tailrace during summer occupied a mean depth of 9.1 m (range, 4.8 – 16.0 m), a mean dissolved oxygen concentration of 5.3 mg/l (range, 3.5 – 6.6 mg/l) and a mean temperature of 20.7 °C (range, 16.0 – 23.5°C) (Table 1).

Table 1. Mean dissolved oxygen, temperature, and depth of manually located transmitter-implanted Striped Bass in the Savannah River channel of J. Strom Thurmond Reservoir, during July – September of 2010, 2011, 2013, and 2014. The range of values is presented in parantheses.

Section	Year	Detections	Dissolved Oxygen (mg/l)	Temperature (°C)	Depth (m)
Lower	2010	4	2.6 (1.9 - 3.1)	19.8 (15.5 - 24.5)	15.3 (9.6 - 22.0)
Lower	2011	5	3.3 (2.0 - 4.4)	18.5 (17.0 - 19.5)	13.8 (11.2 - 15.3)
Lower	2013	13	3.5 (1.1 - 5.3)	22.4 (20.0 - 26.5)	13.1 (5.5 - 19.8)
Lower	2014	83	3.9 (1.3 - 8.1)	21.5 (18.5 - 24.0)	13.3 (9.5 - 18)
Middle	2011	1	2.2 (2.2 - 2.2)	20.0 (20.0 - 20.0)	12.0 (12.0 - 12.0)
Middle	2013	1	2.2 (2.2 - 2.2)	26.0 (26.0 - 26.0)	7.0 (7.0 - 7.0)
Middle	2014	3	3.7 (2.7 - 4.3)	20.3 (20.0 - 20.5)	10.8 (10.3 - 11.0)
Tailrace	2010	5	5.7 (5.1 - 6.2)	18.8 (16.0 - 22.0)	8.3 (4.8 - 11.0)
Tailrace	2011	10	5.3 (3.5 - 6.6)	21.6 (18.5 - 23.5)	9.5 (6.8 - 16.0)
Tailrace	2013	1	4.3 (4.3 - 4.3)	20.5 (20.5 - 20.5)	8.8 (8.8 - 8.8)
Upper	2011	1	4.3 (4.3 - 4.3)	22.0 (22.0 - 22.0)	8.5 (8.5 - 8.5)
Upper	2013	1	3.4 (3.4 - 3.4)	19.5 (19.5 - 19.5)	18.0 (18.0 - 18.0)
Upper	2014	1	4.4 (4.4 - 4.4)	20.0 (20.0 - 20.0)	11.5 (11.5 - 11.5)

Striped Bass occupied a range of temperature and dissolved oxygen conditions during the summers of 2010-2011 and 2013-2014 (Figure 5). Generally, Striped Bass occupied temperatures from 18 to 24°C with dissolved oxygen > 2.0 mg/l. During summer 2010, before oxygenation, 3 of 4 Striped Bass detections in the lower reservoir were in suboptimal habitat with dissolved oxygen ≤ 3.1 mg/l, one detection occurred in unsuitable habitat where dissolved oxygen was 1.9 mg/l (Figure 5). Three of 5 detections in the RBR Tailrace were in optimal habitat; two detections occurred in suboptimal habitat due to cool (< 18°C) water temperatures. During summer 2011 all five detections in the lower reservoir were in suboptimal habitat due to dissolved oxygen ≤ 4.4 mg/l, seven of 10 detections in the RBR Tailrace were in optimal habitat; three detections occurred in suboptimal habitat due to low (< 4.6 mg/l) dissolved oxygen. During summer 2013, 10 of 13 detections in the lower reservoir were in suboptimal habitat due to suboptimal dissolved oxygen concentrations (≤ 4.8 mg/l) and three detections were in unsuitable habitat due to unsuitable dissolved oxygen (≤ 1.5 mg/l) (two detections) or supraoptimal water temperature(26.5°C) (one detection). During summer 2014, 25% of detections (N=83) in the lower reservoir were in optimal habitat, 70% were in suboptimal habitat due to dissolved oxygen values < 4.6 mg/l, and 5% of detections were in unsuitable habitat due to dissolved oxygen concentrations < 2.0 mg/l.

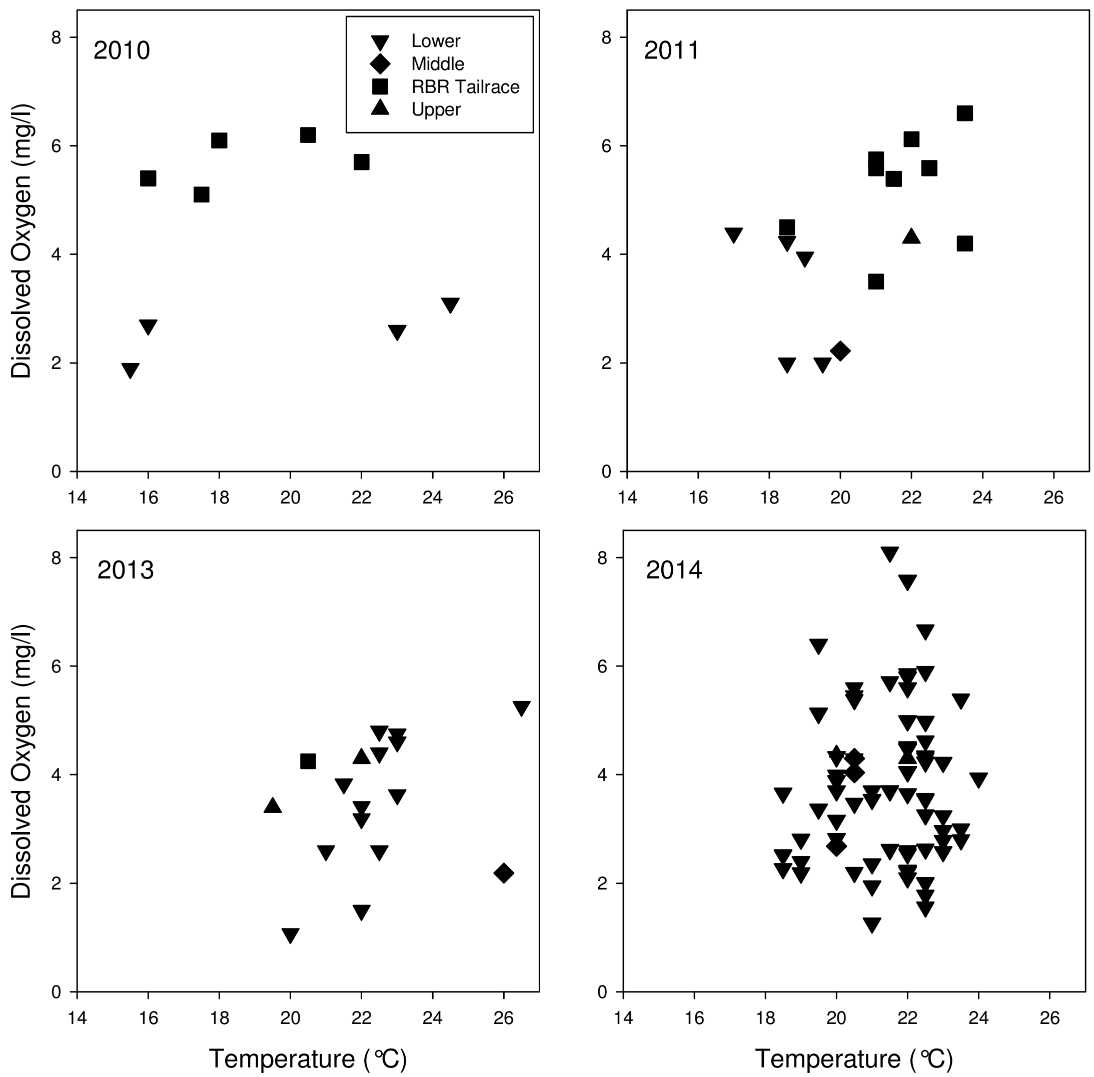


Figure 5. Temperature and dissolved oxygen observations for transmitter-implanted Striped Bass manually located during July – September of 2010, 2011, 2013, and 2014 in three sections of the Savannah River channel and the Richard B. Russell Tailrace of J. Strom Thurmond Reservoir.

Interpolation of Water Quality Data

Dissolved oxygen and depth of transmitter-implanted Striped Bass were interpolated from temperature observations of 61 fish over 20 dates during the summer oxygenation period. This resulted in 13,432 sets of temperature, depth, and dissolved oxygen observations for transmitter-implanted Striped Bass.

During summer 2010, before oxygenation of the lower reservoir, optimal habitat existed in only a very thin layer of water through 21 July, at depths between 6 and 7 m (Figure 6). During August only suboptimal habitat was available due to supraoptimal temperatures in the epilimnion and suboptimal dissolved oxygen at depths where temperatures were optimal. During September suboptimal habitat was available in a thin depth layer between 8.5 and 9.0 m, deeper areas of the reservoir contained unsuitable habitat due to low (< 2.0 mg/L) dissolved oxygen. Unfortunately, receivers were not deployed in the lower reservoir until 23 August and temperature/dissolved oxygen profiles were not collected between 19 August and 13 September, limiting Striped Bass depth and dissolved oxygen interpolations to one date (14 September) during summer 2010. On 14 September Striped Bass were restricted to water temperatures > 24°C as deeper depths with cooler temperatures were hypoxic. Temperature observations for three fish using the lower reservoir indicated that two of them utilized the hypoxic (< 2.0 mg/l dissolved oxygen) hypolimion during late August before moving to epilimnion in early September, where water temperatures and dissolved oxygen levels were higher (Figure 7).

During summer 2011 oxygenation provided optimal habitat conditions on each of the five dates reviewed (Figure 8). Striped Bass utilized the entire area monitored from the Thurmond Dam (km 0) to the area just above (km 10) the oxygen injection system. During summer 2011 individual Striped Bass ranged in depth from 2 to 33 m, with 97% of the observations between 8 and 23 m. At Striped Bass locations dissolved oxygen ranged from 0.94 to 8.10 mg/L, with 90% of the observations ≥ 2.5 mg/L, and temperature ranged from 15 to 30.5°C, with 96% of the observations between 18.0 and 24.0°C.

During summer 2012 optimal habitat conditions were available on each of the 5 dates reviewed (Figure 9). Striped Bass largely restricted their movements to the area near the oxygen injection system with 89% of the observations occurring between rkm 5 and rkm 8. Individual Striped Bass ranged in depth from 8 to 30 m, with 92% of the observations between 13 and 21 m. At Striped Bass locations dissolved oxygen ranged from 0.8 to 9.8 mg/L, with 97% of the observations ≥ 2.5 mg/L and temperature ranged from16.5 to 27.0°C, with 98% of the observations between 18.0 and 24.0°C.

During summer 2013 optimal conditions were available on four dates (Figure 10). On 8 July dissolved oxygen levels were suboptimal at depths where temperature was optimal throughout the monitored area. Striped Bass utilized most of the area monitored from the Thurmond Dam to rkm 9. During summer 2013 individual Striped Bass ranged in depth from 1 to 39 m, with 91% of the observations between 9 and 19 m. At Striped Bass locations dissolved oxygen ranged from 1.1 to 8.8 mg/L, with 99% of the observations ≥ 2.5 mg/L and temperature ranged from 14.5 to 28.5°C, with 90% of the observations between 18.0 and 24.0°C.

During summer 2014 optimal conditions were available only on 7 July in a thin layer (between 6.5 and 7 m deep) from Thurmond Dam to approximately rkm 6. On all other dates during 2014 only suboptimal habitat was available due to dissolved oxygen values < 5.0 mg/l at depths where temperature was optimal (Figure 11). Striped Bass utilized most of the area monitored from Thurmond Dam to rkm 9. Individual Striped Bass ranged in depth from 6 to 35 m, with 98% of the observations between 7 and 18 m. At Striped Bass locations dissolved oxygen ranged from 0.6 to 6.5 mg/L, with 95% of the observations ≥ 2.5 mg/L and temperature ranged from 14 to 26°C, with 96% of the observations between 18 and 24°C.

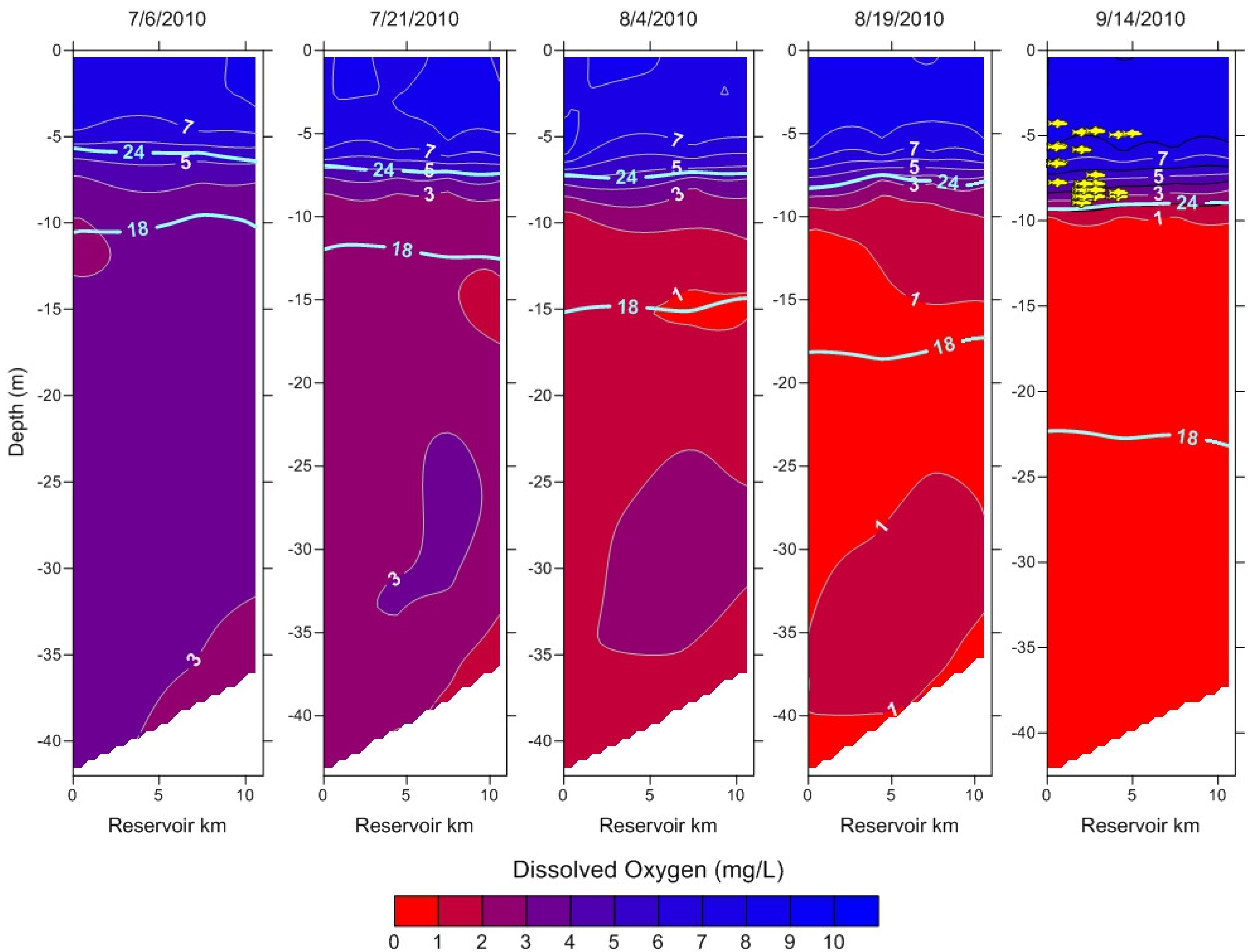


Figure 6. Dissolved oxygen conditions, 24 and 18°C temperature contours, and range of locations for transmitter-implanted Striped Bass, as depicted by fish symbols, in lower J. Strom Thurmond Reservoir during summer 2010, before hypolimnetic oxygenation.

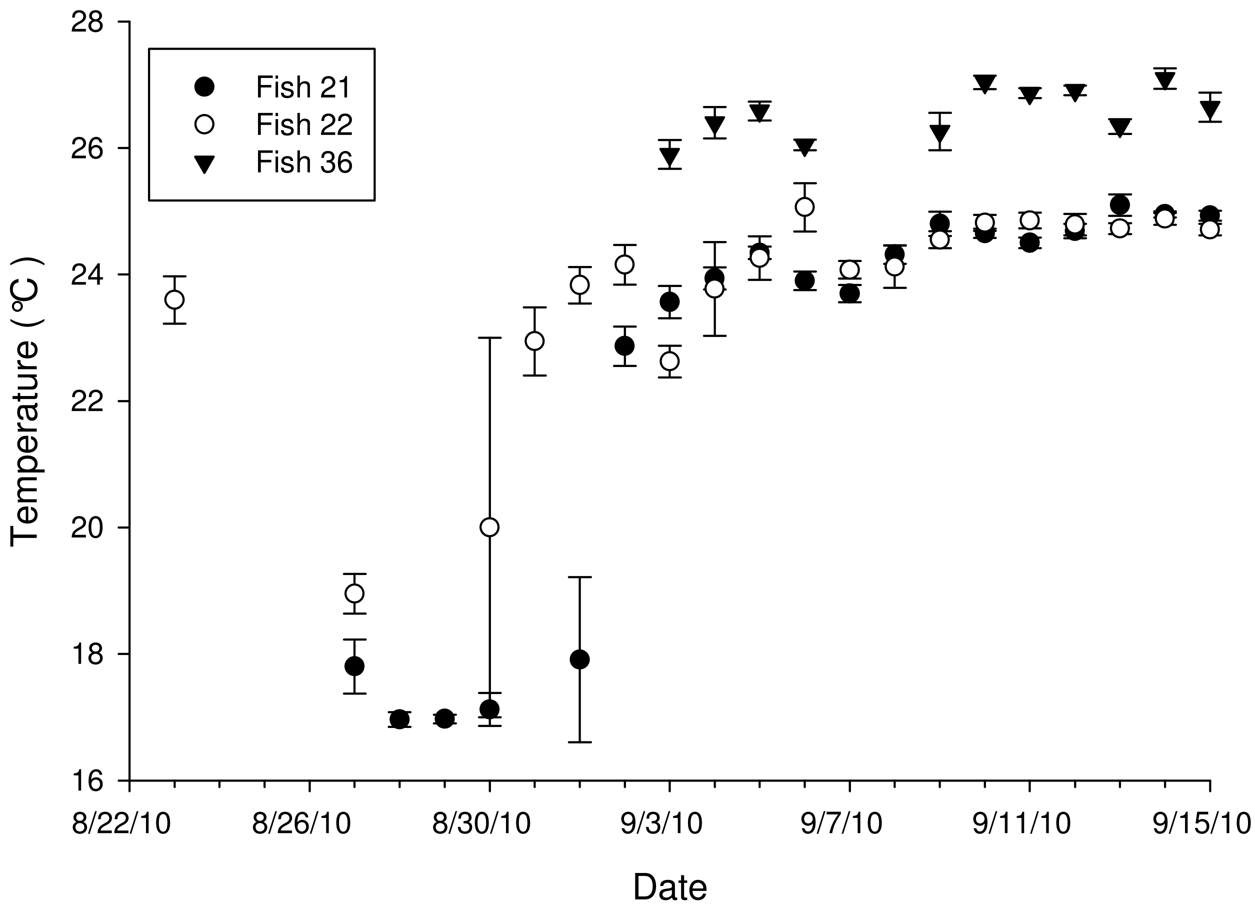


Figure 7. Mean daily temperature and 95% confidence intervals of three transmitter-implanted Striped Bass monitored in lower J. Strom Thurmond Reservoir during August and September of 2010.

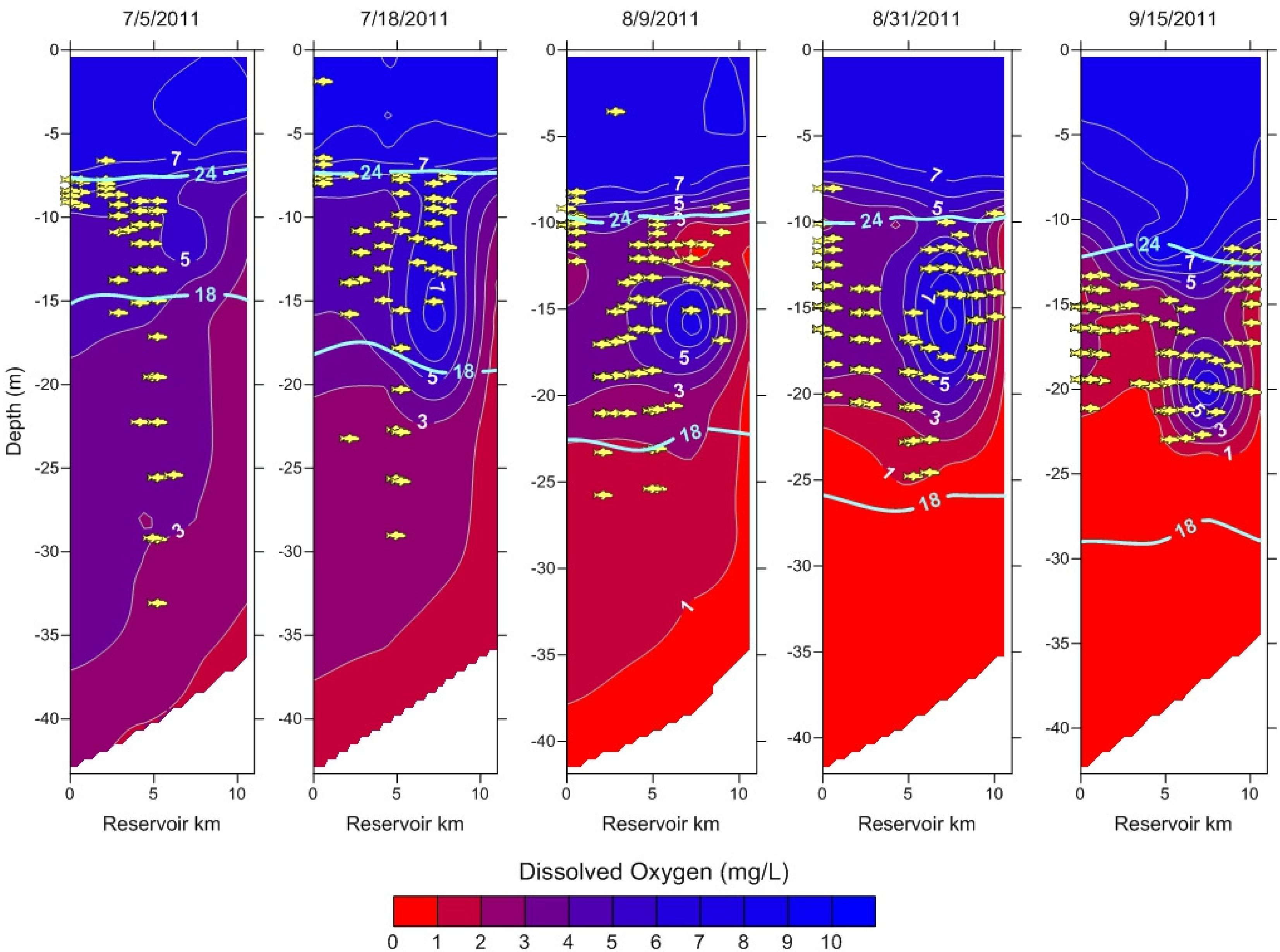


Figure 8. Dissolved oxygen conditions, 24 and 18°C temperature contours, and the range of locations for transmitter-implanted Striped Bass, as depicted by fish symbols, in lower J. Strom Thurmond Reservoir during summer 2011.

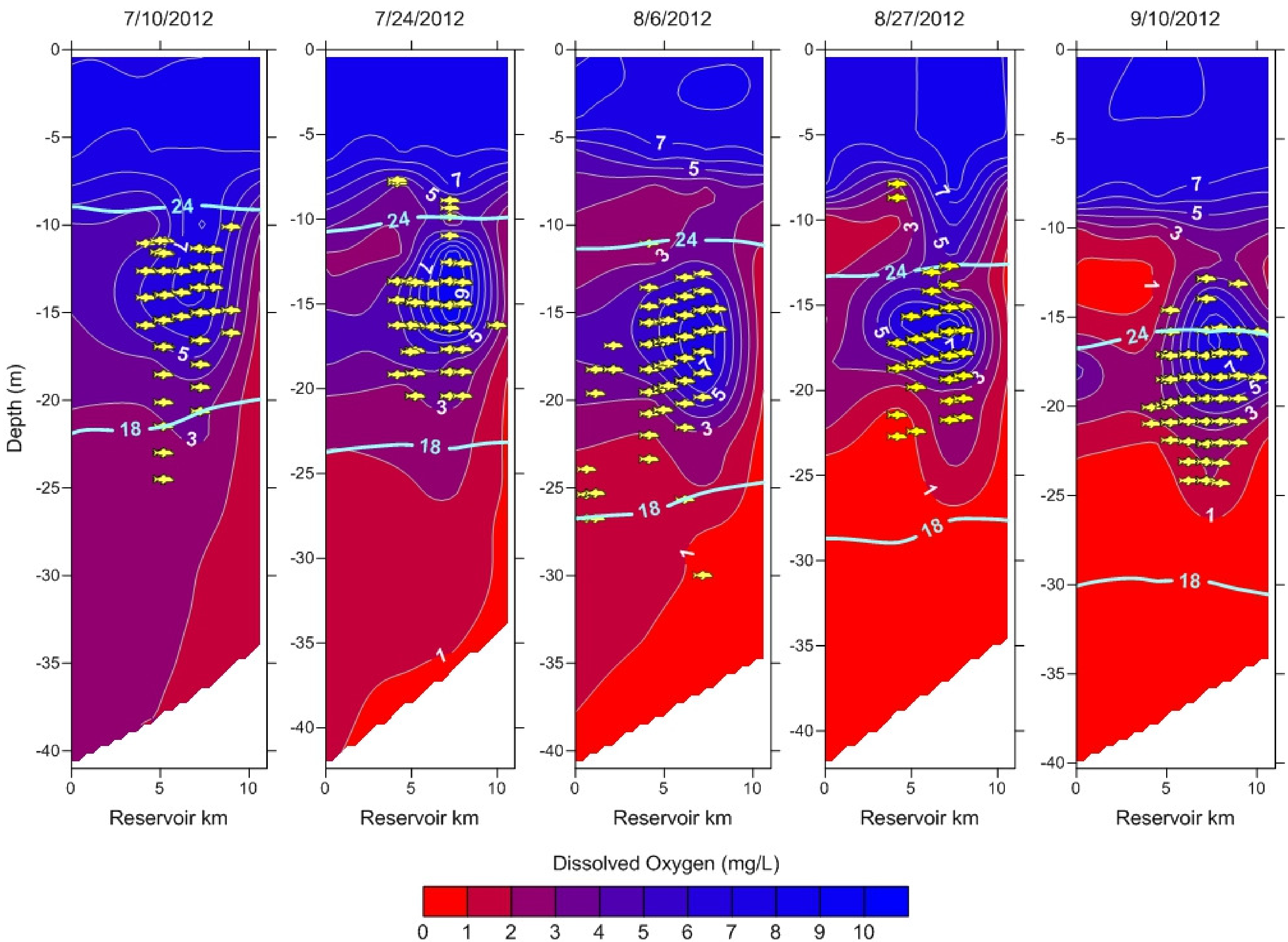


Figure 9. Dissolved oxygen conditions, 24 and 18°C temperature contours, and the range of locations for transmitter-implanted Striped Bass, as depicted by fish symbols, in lower J. Strom Thurmond Reservoir during summer 2012.

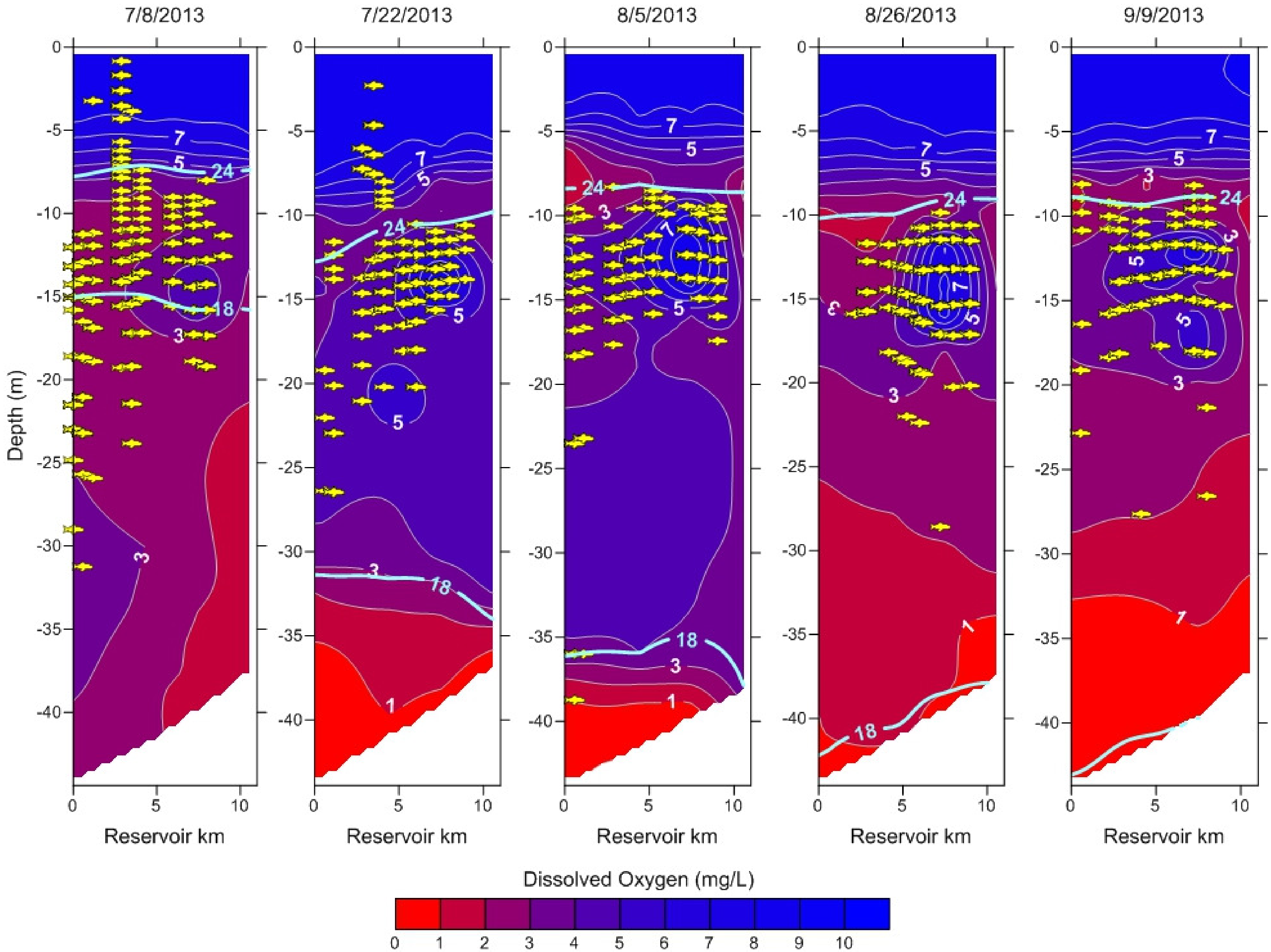


Figure 10. Dissolved oxygen conditions, 24 and 18 °C temperature contours, and the range of locations for transmitter-implanted Striped Bass, as depicted by fish symbols, in lower J. Strom Thurmond Reservoir during summer 2013.

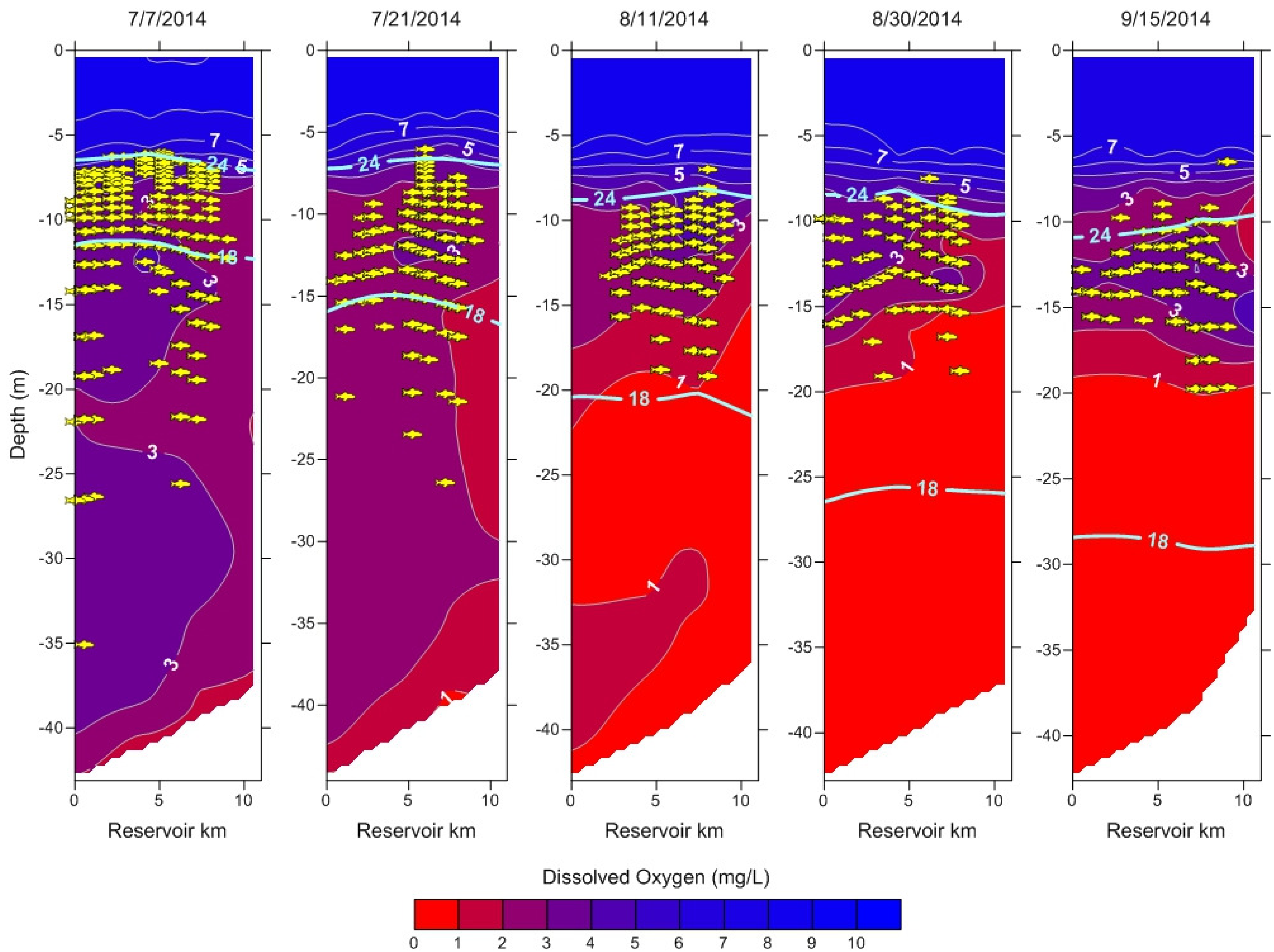


Figure 11. Dissolved oxygen conditions, 24 and 18 °C temperature contours, and the range of locations for transmitter-implanted Striped Bass, as depicted by fish symbols, in lower J. Strom Thurmond Reservoir during summer 2014.

Mean dissolved oxygen concentrations, temperatures, and depths of Striped Bass were significantly different among years (ANCOVA, $P < 0.05$). The linear covariate day of the year was a significant factor for depth and temperature, but not for dissolved oxygen. Striped Bass depth and temperature were positively related to day of the year, as summer progressed Striped Bass temperature and depth increased. Striped Bass mean dissolved oxygen and temperature were in the optimal range, or nearly so, in every year except 2014 when dissolved oxygen was suboptimal (Table 2). Mean depth varied by year with Striped Bass occupying the deepest depths during 2012 and the shallowest depths during 2014.

Table 2. Mean dissolved oxygen, temperature, and depth of transmitter-implanted Striped Bass in J. Strom Thurmond Reservoir, during the oxygenation period (July – September) of 2011 - 2014. Ninety-five percent confidence limits in parantheses.

Year	Dissolved oxygen (mg/l)	Temperature (°C)	Depth (m)
2011	4.8 (4.6 - 5.0)	21.1 (20.9 - 21.3)	14.2 (13.9 - 14.6)
2012	5.5 (5.4 - 5.6)	21.8 (21.7 - 21.9)	16.7 (16.5 – 17.0)
2013	4.9 (4.9 - 5.0)	21.6 (21.6 - 21.7)	13.4 (13.3 - 13.5)
2014	3.1 (3.0 - 3.2)	21.1 (21.1 - 21.2)	12.1 (11.9 - 12.2)

Mean dissolved oxygen concentrations, temperatures, and depths of Striped Bass were significantly different among dates (ANOVA, $P < 0.05$) and among individual fish within dates (ANOVA, $P < 0.05$). Striped Bass mean temperature on each observation date were within the optimal range, as each summer progressed mean temperature tended to increase with the greatest increase in temperatures observed during 2013 and 2014 (Figure 12). Striped Bass mean dissolved oxygen was variable among dates. Suboptimal dissolved oxygen conditions were observed on ten of the 20 dates reviewed and on every date during 2014 (Figure 12).

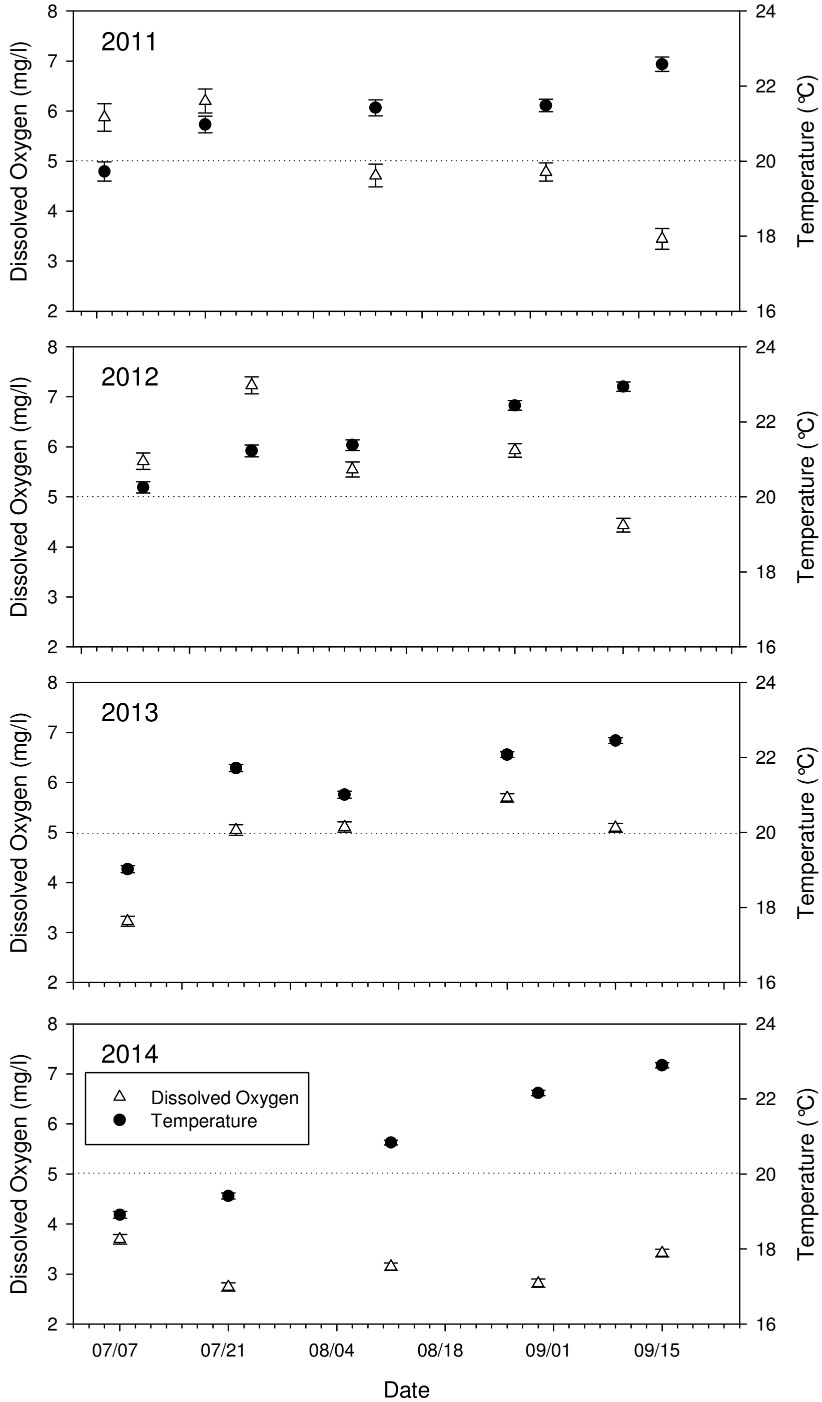


Figure 12. Mean daily dissolved oxygen (mg/l) and temperature (°C), with associated 95% confidence limits, for transmitter-implanted Striped Bass in J. Strom Thurmond Reservoir during July – September 2011 - 2014.

Individual Striped Bass occupied habitats with significantly different temperature, dissolved oxygen, and depths within dates (ANOVA, $P < 0.05$). Mean temperature ranged from 14.7 to 27.1°C, mean dissolved oxygen ranged from1.98 to 8.63 mg/l, and mean depth ranged from 4.3 to 24.8 m among fish within the summer dates reviewed. The general pattern was greater variation in temperature and dissolved oxygen within and among fish early in the summer when more suitable habitat was available (Figures 13 – 16). As the summer progressed and optimal habitat decreased, within fish variation typically decreased; however, variation among fish often remained high, indicating that individual fish selected a specific combination of habitat conditions, or perhaps location with suitable habitat conditions. Limited variation among individual fish in both temperature and dissolved oxygen was observed during late August and September of 2014 when habitat conditions throughout the water column were suboptimal (Figure 16). Over all years the majority (88%) of Striped Bass occupied depths between 12 and 18 m (Figure 17). Mean depths during most years increased, and variation among individual fish decreased as the summer progressed.

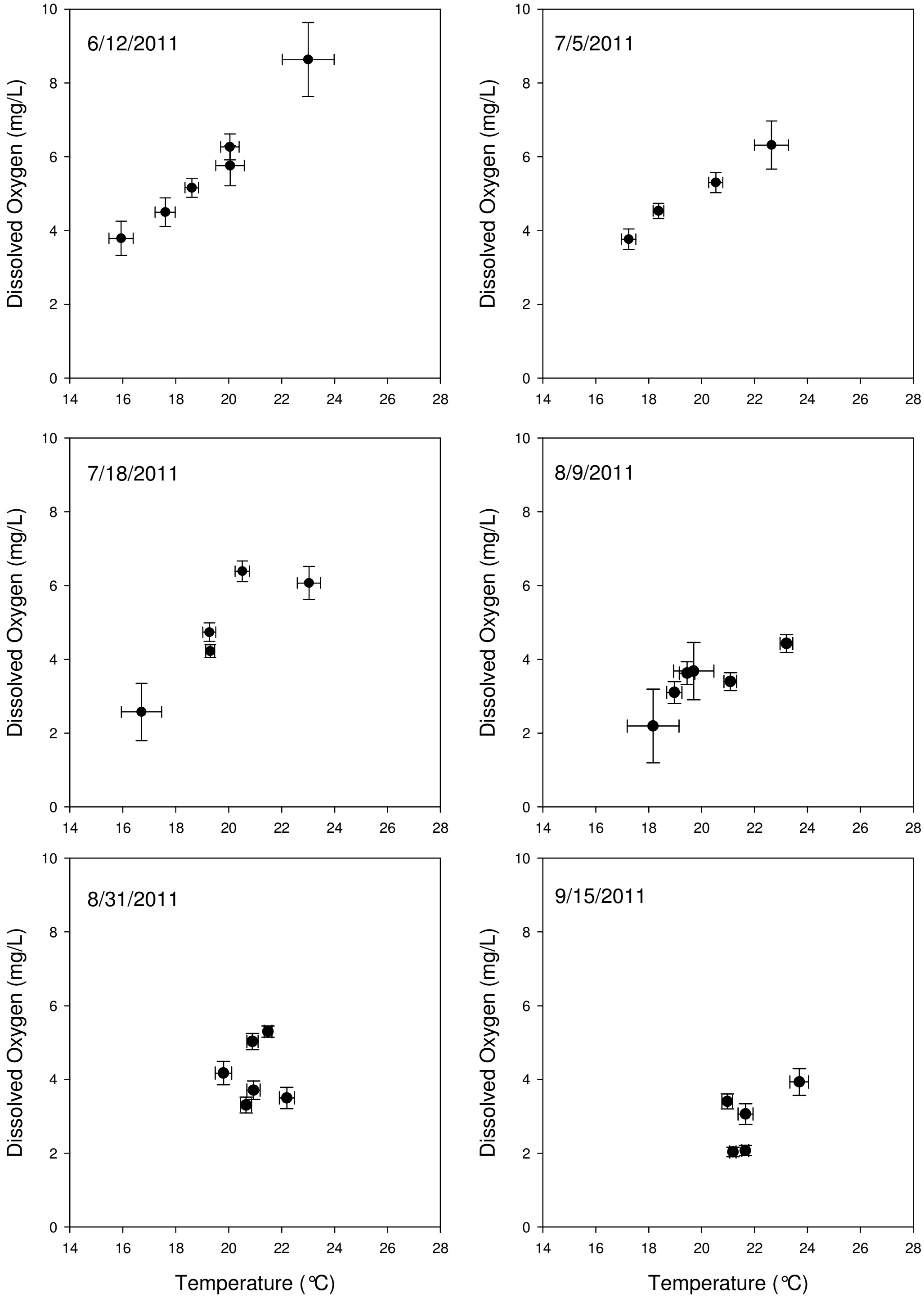


Figure 13. Mean dissolved oxygen (mg/l) and temperature (°C), with associated 95% confidence limits, for transmitter-implanted Striped Bass in lower J. Strom Thurmond Reservoir during 2011.

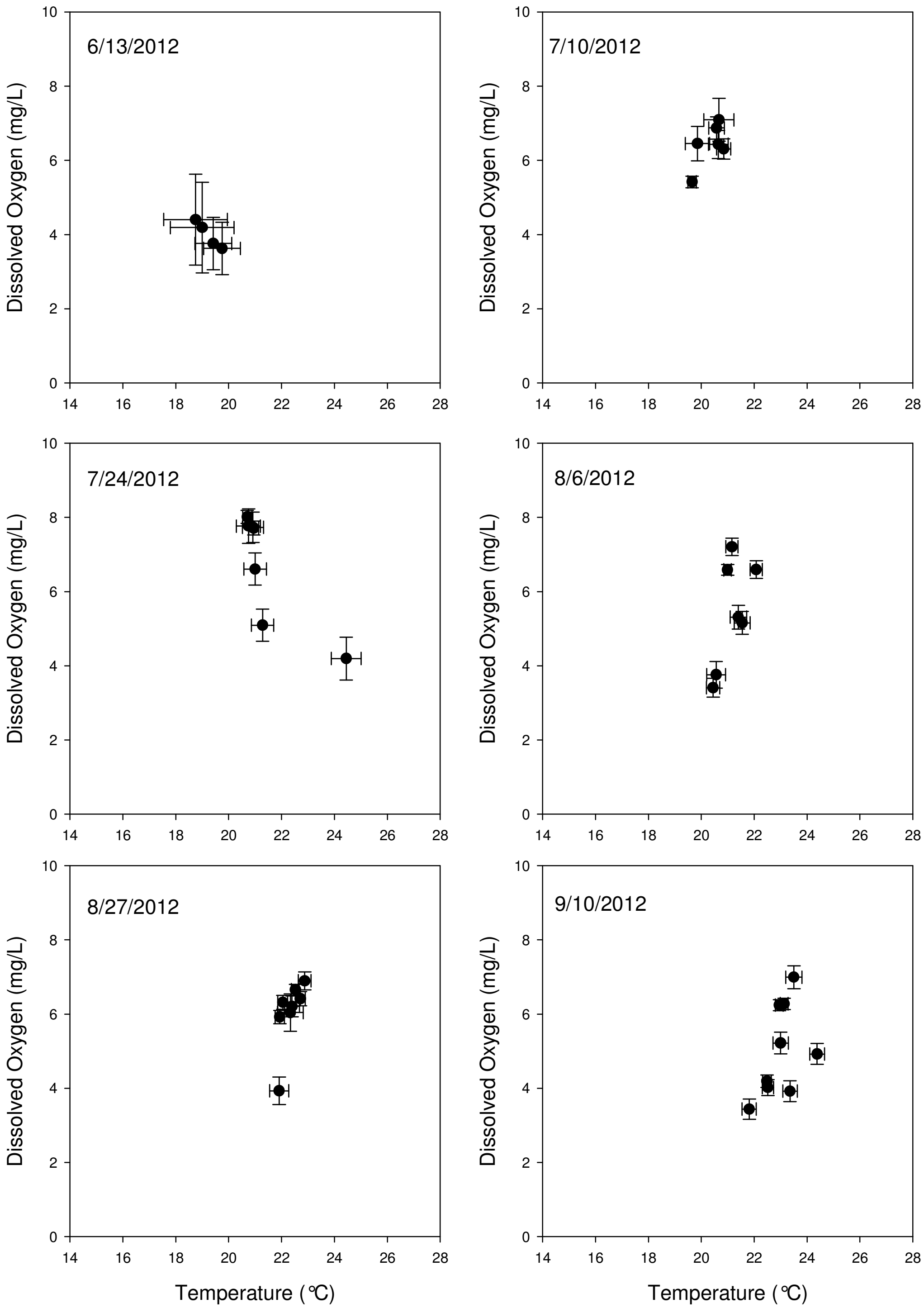


Figure 14. Mean dissolved oxygen (mg/l) and temperature (°C), with associated 95% confidence limits, for transmitter-implanted Striped Bass in lower J. Strom Thurmond Reservoir during 2012.

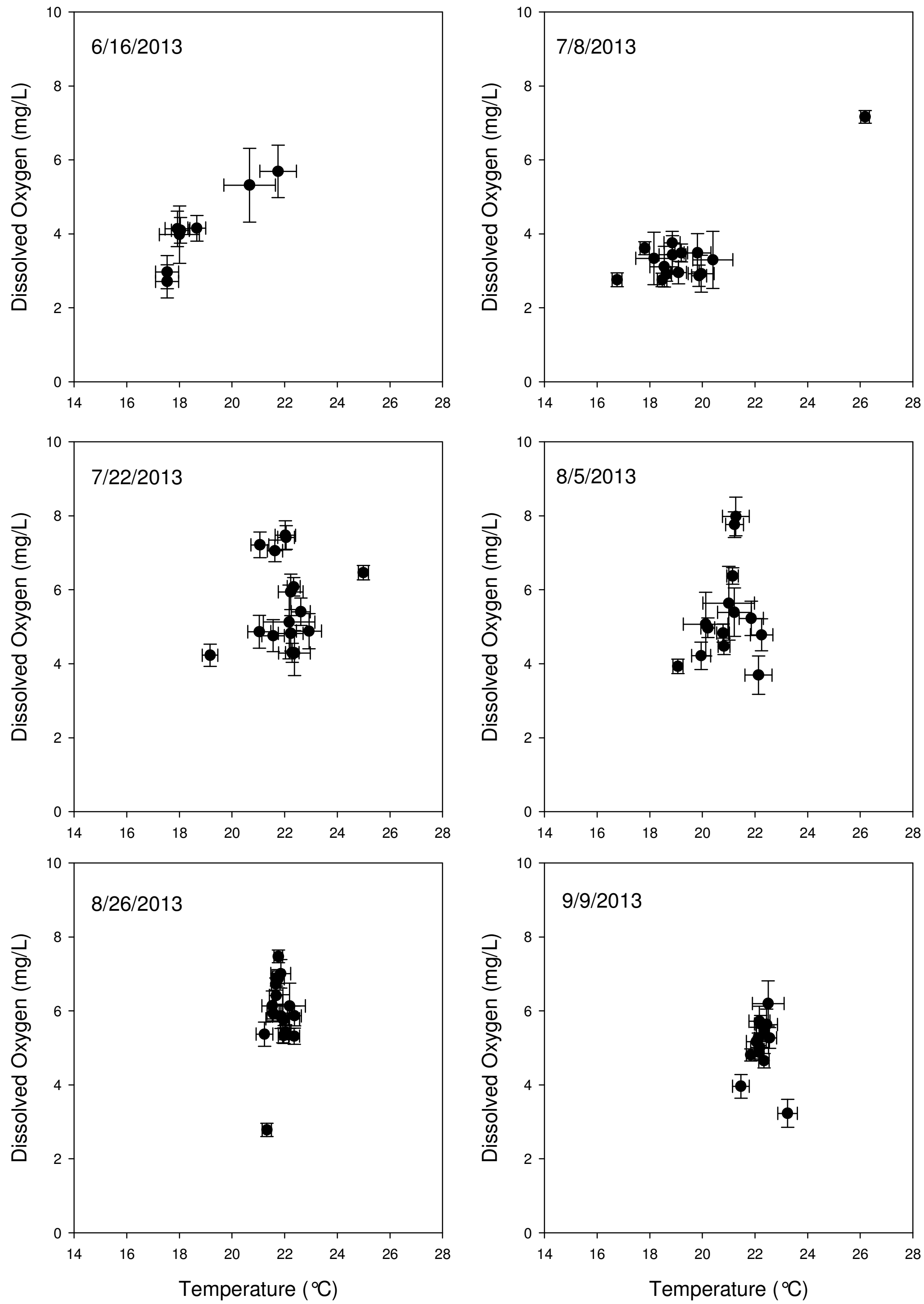


Figure 15. Mean dissolved oxygen (mg/l) and temperature (°C), with associated 95% confidence limits, for transmitter-implanted Striped Bass in lower J. Strom Thurmond Reservoir during 2013.

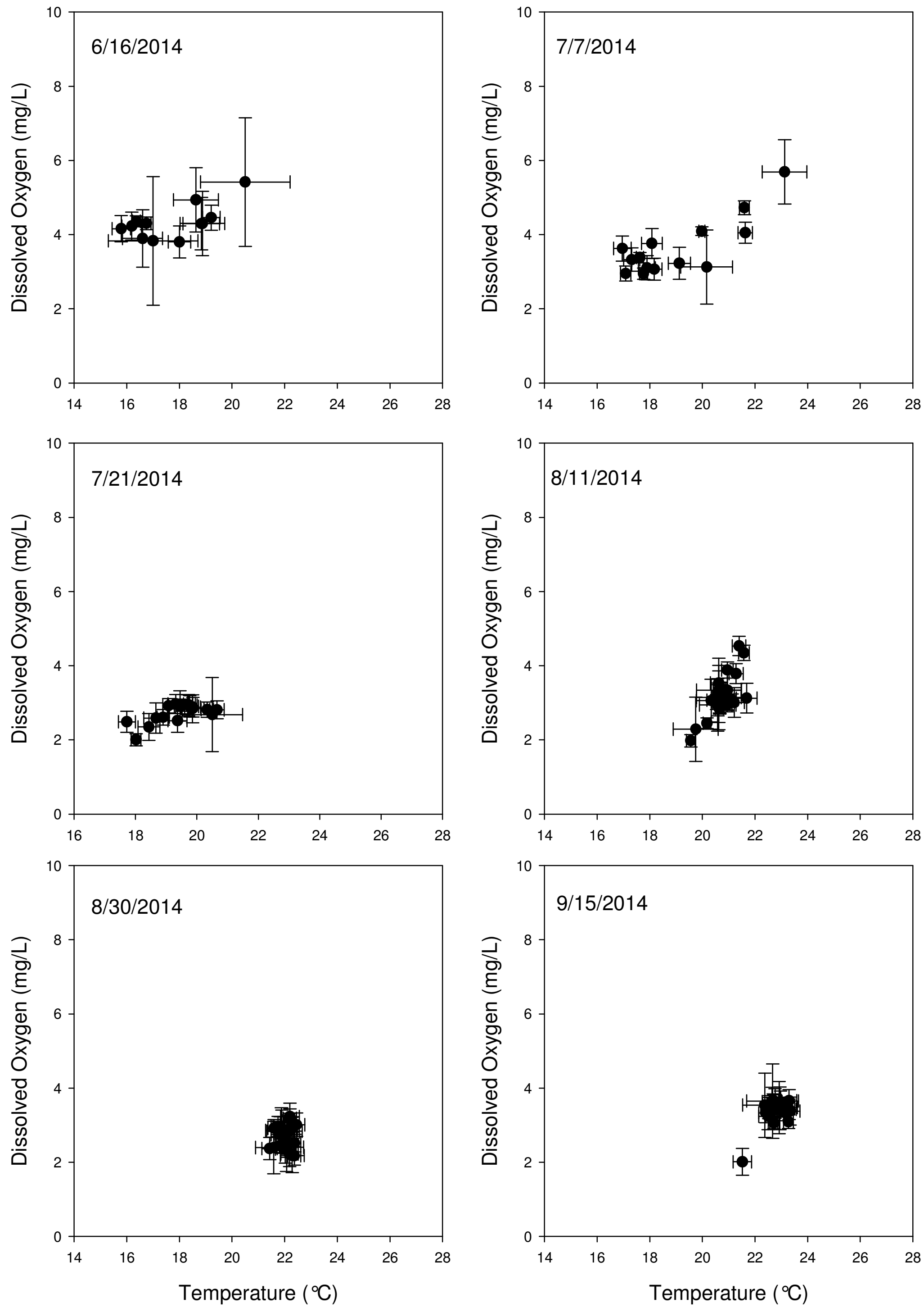


Figure 16. Mean dissolved oxygen (mg/l) and temperature (°C), with associated 95% confidence limits, for transmitter-implanted Striped Bass in lower J. Strom Thurmond Reservoir during 2014.

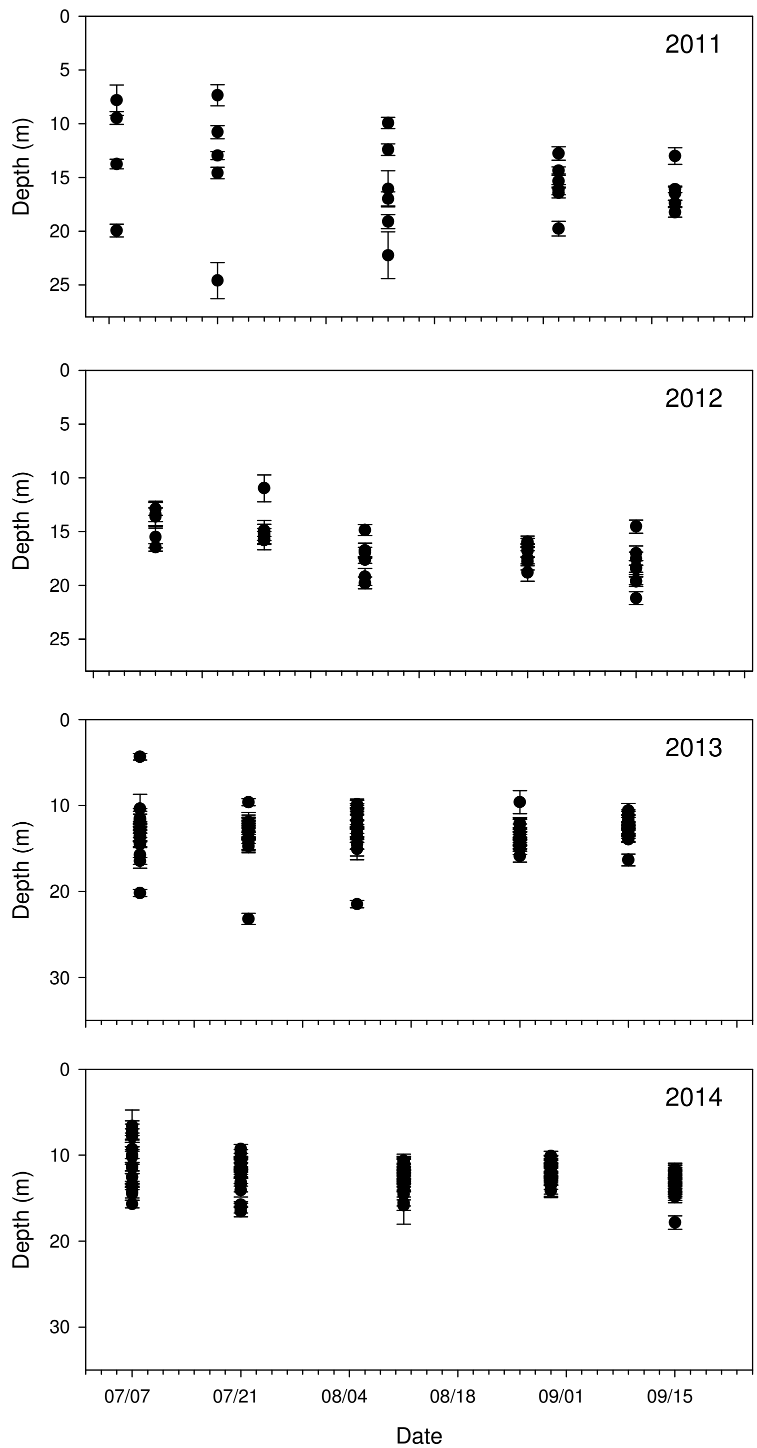


Figure 17. Mean depth (m), with associated 95% confidence limits, for transmitter-implanted Striped Bass in lower J. Strom Thurmond Reservoir during oxygenation 2011 - 2014.

On 13 of the 20 dates reviewed during the summer oxygenation period individual Striped Bass occupied optimal dissolved oxygen and temperature conditions, indicating that optimal habitat was available in some quantity on those dates. However, not all fish occupied optimal habitat when available. On average 41% of fish occupied less than optimal dissolved oxygen conditions. Striped Bass that used suboptimal habitat chose slightly cooler water temperatures with mean dissolved oxygen levels ≥ 2.6 mg/l.

Table 3. Date, number of Striped Bass, mean dissolved oxygen (mg/l), and mean temperature (°C) for Striped Bass that occupied suboptimal and optimal habitat on dates during the summer oxygenation period when optimal habitat (dissolved oxygen ≥ 5.0 mg/l and temperature 18 – 24°C) was available in J. Strom Thurmond Reservoir, SC-GA. Range of means given in parentheses.

	Suboptimal			Optimal		
Date	N	Dissolved Oxygen (mg/l)	Temperature (°C)	N	Dissolved Oxygen (mg/l)	Temperature (°C)
7/5/2011	2	4.2 (3.8 - 4.5)	17.8 (17.2 - 18.4)	2	5.8 (5.3 - 6.3)	21.6 (20.5 - 22.6)
7/18/2011	3	3.8 (2.6 - 4.7)	18.4 (16.7 - 19.3)	2	6.2 (6.1 - 6.4)	21.8 (20.5 – 23)
8/31/2011	4	3.7 (3.3 - 4.2)	20.9 (19.8 - 22.2)	2	5.2 (5.0 - 5.3)	21.2 (20.9 - 21.5)
7/10/2012	0			6	6.4 (5.4 - 7.1)	20.4 (19.7 - 20.9)
7/24/2012	1	4.2 (4.2 - 4.2)	24.4 (24.4 - 24.4)	6	7.2 (5.1 – 8.0)	20.9 (20.7 - 21.3)
8/6/2012	2	3.6 (3.4 - 3.8)	20.5 (20.4 - 20.6)	5	6.2 (5.2 - 7.2)	21.4 (21.0 - 22.1)
8/27/2012	1	3.9 (3.9 - 3.9)	21.9 (21.9 - 21.9)	7	6.3 (5.9 - 6.9)	22.4 (21.9 - 22.9)
9/10/2012	5	4.1 (3.4 - 4.9)	22.9 (21.8 - 24.4)	4	6.2 (5.2 – 7.0)	23.1 (23.0 - 23.5)
7/22/2013	8	4.8 (4.2 - 6.5)	22.1 (19.2 – 25)	8	6.5 (5.1 - 7.5)	22.0 (21.1 - 22.6)
8/5/2013	7	4.4 (3.7 – 4.9)	20.7 (19.1 - 22.3)	7	6.2 (5.1 – 8.0)	21.1 (20.1 - 21.9)
8/26/2013	1	2.8 (2.8 - 2.8)	21.3 (21.3 - 21.3)	17	6.1 (5.3 - 7.5)	21.8 (21.2 - 22.4)
9/9/2013	5	4.3 (3.2 - 4.9)	22.2 (21.5 - 23.2)	9	5.5 (5.0 - 6.2)	22.3 (22.1 - 22.6)
7/7/2014	13	3.5 (2.9 - 4.7)	18.7 (17.0 - 21.6)	1	5.7 (5.7 - 5.7)	23.1 (23.1 - 23.1)

Discussion

Oxygenation of lower J. Strom Thurmond Reservoir was successful in creating optimal and suboptimal habitat for Striped Bass during 2011 - 2014. Oxygenation during the summers of 2011 – 2013 provided optimal Striped Bass habitat on all but one of the dates reviewed. Although oxygenation was not successful creating optimal habitat conditions during summer 2014 there was some habitat with > 3 mg/l of dissolved oxygen at depths with optimal temperatures throughout the summer. During 2010, before oxygenation, the majority of lower reservoir habitat with optimal temperatures had unsuitable dissolved oxygen levels by mid August, and fish were forced to use hypoxic areas with optimal temperatures or move to shallower depths where temperatures exceeded 24°C. In a previous study, Young and Isely (2002) found similar water quality conditions in lower Thurmond reservoir during the summers of 1999 and 2000. Most of the Striped Bass in that study vacated the lower reservoir in August when water quality deteriorated and moved to more favorable conditions in the upper reservoir and Richard B. Russell tailrace. Similar to the fish followed during 2010 in this study Striped Bass that remained in the lower reservoir throughout the summers of 1999 and 2000 occupied the lower thermocline or deeper hypolimnetic waters (Young and Isely 2002).

In most years Striped Bass did not restrict their movements to locations near the oxygenation system, but utilized the entire lower reservoir, from the dam to 3 km above the oxygenation system. The oxygenation system also provided optimal and suboptimal habitat conditions over a wide range of depths allowing fish to move vertically through the water column. In southeastern reservoirs without oxygenation systems Striped Bass are often “squeezed” into a narrow depth range between warm epilimnetic water and the cool hypoxic or anoxic hypolimnion (Coutant 1985, Matthews et al. 1985, Sammons and Glover 2013).

In this study we present a qualitative review of the habitat conditions present in lower Thurmond reservoir and describe the habit conditions occupied by Striped Bass after oxygenation. Our habitat classifications were guided by the widely accepted habitat classifications of Crance (1984). However, Striped Bass in Thurmond reservoir frequently occupied suboptimal dissolved oxygen conditions even when optimal (dissolved oxygen and temperature) conditions were available. Fish that used suboptimal dissolved oxygen selected slightly cooler water temperatures with individual fish having mean dissolved oxygen values as low as 2.6 mg/l. Recent work in other systems has shown that Striped Bass will select cooler water temperatures when dissolved oxygen is greater than 2.0 mg/l, but below that level will select for warmer water (Thompson et al. 2010, Sammons and Glover 2013). Future work should use the data obtained in this study to quantify available habitat so that Striped Bass habitat preference in Thurmond reservoir can be more fully evaluated. Understanding Striped Bass preferred habitat in Thurmond reservoir would allow managers to make the best use of available resources when oxygenating the lower reservoir.

Literature Cited

Coutant, C. C. 1985. Striped Bass, temperature, and dissolved oxygen: a speculative hypothesis for environmental risk. Transactions of the American Fisheries Society 114:31–61.

Crance, J. H. 1984. Habitat suitability index models and instream flow suitability curves: inland stocks of Striped Bass. U.S. Fish and Wildlife Service, FWS/OBS-82/10.85, Washington, D.C.

Matthews, W. J., L. G. Hill, and S. M. Schellhaass. 1985. Depth distribution of Striped Bass and other fish in Lake Texoma (Oklahoma–Texas) during summer stratification. Transactions of the American Fisheries Society 114:84–91.

Sammons, S. M. and D. C. Glover. 2013. Summer habitat use of large adult Striped Bass and habitat availability in Lake Martin, Alabama. North American Journal of Fisheries Management. 33:762-772.

Thompson, J. S., J. A. Rice, and D.S., Waters. 2010. Striped Bass habitat selection rules in reservoirs without suitable summer habitat offer insight into consequences for growth. Transactions of the American Fisheries Society 139:1450-1464.

Young, S. P., and J. J. Isely. 2002. Striped Bass annual site fidelity and habitat utilization in J. Strom Thurmond Reservoir, South Carolina–Georgia. Transactions of the American Fisheries Society 131:828–837.

ACKNOWLEDGEMENTS

Funding for the study was provided by the United States Army Corp of Engineers (USACE). We thank the Midlands (Columbia, SC), Clark Hill (Augusta, GA) and Striper Kings (Greenville, SC) striper fishing clubs for donating acoustic transmitters that were used to evaluate Hybrid Striped Bass movements and temperature use.

Fieldwork could not have been completed without the assistance and coordination of multiple agencies. Georgia Department of Natural Resources (GADNR), USACE, and South Carolina Department of Natural Resources (SCDNR) personnel were critical for accomplishing our objectives. Ed Bettross (GADNR), Jamie Sykes (USACE), Edwin Ott (SCDNR), Seth Mycko (SCDNR), Treye Byars (SCDNR), Charlie Poeta (SCDNR), Terry Bryant (SCDNR) and Mike Wilson (SCDNR) assisted with capturing and implanting the fish monitored in this study. Edwin Ott (SCDNR) and Seth Mycko (SCDNR) maintained the acoustic receiver array, manually tracked fish, and collected temperature and dissolved oxygen profiles. William Jabour (USACE) provided USACE collected temperature and dissolved oxygen profile data.

General statistical design and interpretation assistance was provided by John Grego (University of South Carolina). Joseph Hightower (North Carolina State University) assisted in the development of the multistate mark-recapture model for estimating Striped Bass mortality. The study and report benefitted from the constructive comments of John Crane (SCDNR) and Jim Bulak (SCDNR).