Movements of Adult Striped Bass (*Morone saxatilis*) in the Savannah River, Georgia

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ABSTRACT

During 1973, 1974, and 1975 movements of 33 striped bass [*Morone saxatilis* (Walbaum)] in the Savannah River, Georgia were followed through the use of ultrasonic and radio transmitters. During March through May striped bass congregate and spawn in a tidally influenced, relatively shallow, small branch of the river (Little Back River) near Savannah, Georgia, about 30 km upstream from the river mouth. During the spawning season striped bass do not exhibit any specific movement pattern, but remain in this particular sector of the river. Immediately after spawning, all tracked fish moved upstream, some as far as 301 km from the spawning area. Fish remained in the upstream areas at least 4 months. We detected no fish moving downstream during this period. Our data and those from previous work strongly suggest that individuals in this population of striped bass spend the majority, if not all, of their lives in the Savannah River.

The striped bass [*Morone saxatilis* (Walbaum), family Percichthyidae] is native to the Atlantic coast of North America from the St. Lawrence River in Canada to the St. Johns River, Florida and in the Gulf of Mexico from western Florida to Lake Ponchartrain, Louisiana. Introduced to the Pacific coast in 1879, it now ranges from San Diego, California to the Columbia River, and possibly as far north as Alaska (Nichols 1966; Raney 1952).

Noted for their value to both sport and commercial fisheries, Atlantic coast striped bass populations contribute more than 9 million fish to sport fishermen (U.S. Department of the Interior 1970) and about 4,000 metric tons to commercial fishermen (Koo 1970) each year. The striped bass' habit of feeding on schools of pelagic clupeids has made it a valuable predator and popular sport fish in freshwater lakes and reservoirs as well.

Within its range on the Atlantic and Gulf coasts biologists have differentiated several races of striped bass based on clinal and other differences in meristic, morphometric, and biochemical characteristics (Raney and Woolcott 1955; Barkaloo 1967, 1970; Lewis 1957; Lund 1957; Morgan et al. 1973).

Most striped bass are anadromous, and ascend rivers to spawn in fresh or brackish water in March to June when water temperatures reach 15 C to 19 C (Raney 1952; Stevens 1964; Barkaloo 1967). After spawning, followed perhaps by a short stay in fresh waters, most adult striped bass return to marine waters. A portion of those populations from Chesapeake Bay northward participate in a general northerly migration during the early and midsummer following spawning. These fish then return to wintering areas prior to entering home streams to spawn.

Striped bass populations from southern North Carolina southward do not contribute to this northward migration (Raney 1954). A 3 year fishery survey of coastal Georgia found striped bass only in tidal creeks and rivers (Mahood et al. 1974). Smith (1970), after tagging striped bass in the Savannah River, received no tag returns from coastal waters. However, local fishermen catch adult striped bass more than 300 km upstream in the Savannah River from May to September and catch fish in the extreme downstream tidal reaches of the river during the winter. The major known spawning area for striped bass in the Savannah River is in the tidally influenced area 30 to 40 km upstream from the river mouth (Smith 1970; McBay 1968; Robert Rees, Richmond Hill Hatchery, Richmond Hill, Georgia, personal communication).

The growing sportfishery and increasing

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industrial development on the Savannah River increase our need for a better understanding of this population, which may be typical of other southern striped bass populations. Although previous work has helped delineate the spawning area in the Savannah River, these studies have not determined the extent to which this population is riverine, nor have they allowed a detailed description of the movements of these fish while in the river.

STUDY AREA

The headwaters of the Savannah River arise in the southern Appalachian Mountains of North Carolina, South Carolina, and Georgia at an elevation of about 1,600 m. They flow southeastwardly and at the confluence of the Seneca and Tugaloo rivers form the Savannah River which then flows 505 km to the Atlantic Ocean and forms the border between South Carolina and Georgia. Several dams blocking fish passage have been built on the Savannah River, but all these are more than 333 km upstream from its mouth. The New Savannah Bluff Lock and Dam, 301 km upstream, probably creates a partial barrier to fish movement. Striped bass are found above it, however, and the dam's gate type construction allows fish to pass under it. Fish probably go through the lock as well. Striped bass in this area may also originate from those stocked in upstream reservoirs. A navigation channel is maintained by the U.S. Army Corps of Engineers from the coast to Augusta (322 km).

The tidally-influenced sector of the Savannah River is divided into three branches (Fig. 1). The Front Savannah River (the most southwestern branch) is the widest branch and is the main channel for navigation. It receives effluent from a number of industries. The Little Back River (the most northeastern branch of the river) is more narrow and shallower than the Front River, and it is bordered on both sides by marshy vegetation and cypress forest of the Savannah Wildlife Refuge. Smith (1970) and McBay (1968) found that the Little Back River upstream from the U.S. Route 17 bridge and downstream from the mouth of Union Creek, is the primary striped bass

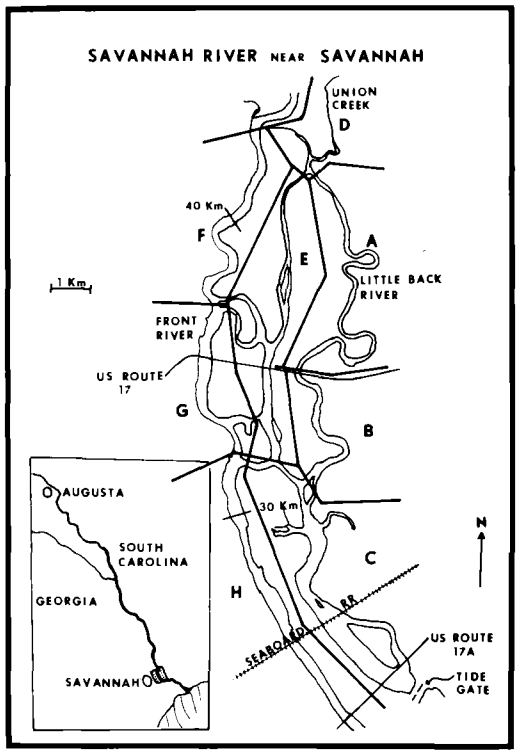

FIGURE 1.—*The Savannah River near Savannah showing the various branches of the river. Capital letters indicate the sections of the river used in the analysis of fish movements. The inset shows the relation of the enlarged portion, near Savannah, to the lower Savannah River.*

spawning area, although some spawning occurs in upstream areas (Smith 1970). The Middle River lies between the Front and Little Back rivers, and it is similar to the Little Back River in depth, width, and vegetation types. In general, salinity is less than one part per 1,000 upstream from U.S. Highway 17A and at or near zero upstream from U.S. Highway 17.

The river sector between the New Savannah Bluff Lock and Dam and the tidal area near the coast is fairly uniform and smooth flowing with a meandering pattern. In the Augusta area the Savannah River is characterized by a 25-km stretch of river above the New Savannah Bluff Lock and Dam that is similar to downstream segments. From about 5 km upstream from Augusta to 11 km upstream at the City of Augusta Dam, the river is rocky and shallow. Striped bass cannot go beyond the City of Augusta Dam.

Just upstream from Augusta four dis-

TABLE 1.—*Fish tagged and tracked during 1973 through 1975. Two other fish were tagged: one was never relocated; the other had a faulty transmitter. (Method—S = Surgical, O = Oral; Cause of termination—R = Regurgitated, L = Signal lost, P = Lack of personnel; Tag type—U = Ultrasonic, R = Radio.)*

Fish	Fork length cm	Weight kg	Sex	Start	End	Duration	Tag type	Tagging method	Cause of termination
				Spring 1973—Savannah					
SF	91.4	13.6	F	12 Apr.	20 Apr.	7.9	U	S	L
SX	83.8	10.2	M Ripe	19 Apr.	24 Apr.	4.7	U	S	L
SY	73.7	7.7	M Ripe	19 Apr.	8 May	18.9	U	S	P
SZ	52.1	2.1	M Ripe	19 Apr.	19 Apr.	0.1	U	S	L
				Spring 1974—Savannah					
SA	88.9	17.3	F	24 Mar.	1 Apr.	7.4	U	O	R
SB	71.1	6.4	F	27 Mar.	15 Apr.	18.9	U	O	R
SC	73.7	4.8	M Ripe	1 Apr.	20 Apr.	18.7	U	O	R
SD	83.8	10.2	M Ripe	4 Apr.	3 May	29.1	U	O	L
SE	83.8	8.6	M Ripe	4 Apr.	10 Apr.	5.8	U	O	R
SG	83.8	6.6	M Ripe	4 Apr.	21 Apr.	16.8	U	O	L
SH	88.9	11.4	M Ripe	4 Apr.	1 May	26.7	U	O	L
SI	99.1	13.6	F	10 Apr.	15 Apr.	4.9	U	O	R
SJ	81.3	9.1	M Ripe	17 Apr.	19 Apr.	1.9	U	O	L
SK	78.7	6.8	M Ripe	26 Apr.	7 May	10.8	U	S	L
SL	83.8	5.5	M Ripe	26 Apr.	22 May	26.1	U	S	L
SM	93.9	10.0	F Spent	28 Apr.	29 Apr.	1.1	U	O	L
SN	91.4	8.2	M Ripe	30 Apr.	2 May	1.9	U	S	L
				Fall and Winter 1974–1975—Augusta (upstream from lock and dam)					
RA	76.0	5.4		23 Oct.	22 Nov.	30	R	O	R
RB	86.5	7.5		7 Nov.	22 Feb.	107	R	O	R
RE	85.0	9.5		29 Jan.	28 May	120	R	S	L
				Fall and Winter 1974–1975—Augusta (downstream from lock and dam)					
RD	92.6	10.0		18 Dec.	29 Jan.	42	R	O	R
				Spring 1975—Savannah					
RG	84.0	10.0		4 Mar.	18 June	107	R	S	L
RI	93.7	14.1	M	12 Mar.	28 May	78	R	S	L
RJ	93.2	14.3	M	25 Mar.	31 July	129	R	S	L
RK	84.7	9.5	F	25 Mar.	28 Apr.	35	R	S	L
RL	97.5	13.6	F	1 Apr.	19 Apr.	19	R	S	L
RM	86.5	11.3	F	8 Apr.	13 June	67	R	S	L
RN	101.0	18.1	F	19 Apr.	11 June	54	R	S	L
RO	82.4	9.3	M	19 Apr.	31 July	104	R	S	L
RP	78.0	7.7	F	19 Apr.	25 Apr.	7	R	S	L
RQ	100.0	18.8	F	23 Apr.	25 Aug.	125	R	S	P
RS	76.0	7.2	M	28 Apr.	25 Aug.	120	R	S	P
RT	94.5	13.6	F	28 Apr.	29 May	32	R	S	L

charge canals enter the Savannah River from the Augusta Canal which originates at the City of Augusta Dam. These discharge canals harbored striped bass during much of the year.

Most sectors of the Savannah River suffer from some form of pollution (Georgia Water Quality Control Board 1972a, 1972b; U.S. Environmental Protection Agency 1972).

METHODS

We captured striped bass with electrofishing gear or with a pound net. After capture, we weighed and measured each fish and tagged it with an external dart tag. If the fish was large enough a radio or ultrasonic transmitter was inserted.

Initially, in 1973, we tagged fish surgically. We quieted the fish with quinaldine or by electronarcosis and made a slit about 3 cm long near the ventral midline, anterior of the anus. A transmitter was inserted and the opening closed with sutures. Since some fish died during surgery, we tagged 11 fish in early 1974 by placing transmitters into the fish's stomach via the mouth. With some fish we placed a transmitter in the stomach after attaching a short piece of monofilament line and a small trebel hook. We had hoped that the hook would prevent regurgitation of the tag, but regurgitation occurred anyway, perhaps because the hook was corroded by digestive juices. Due to this difficulty, we returned to the

surgical implantation procedure for most of the remaining fish tagged during 1974 and all fish tagged during 1975.

We used both ultrasonic and radio tracking equipment to study movements of striped bass in the Savannah River. The ultrasonic transmitters, type SR69A from Smith-Root Electronics (Vancouver, Washington),[3] which emit an ultrasonic signal at 74 kHz, measured 14 mm and 19 mm in diameter at the two ends and 90 mm in length. They weighed about 40 g in air, 20 g in water, and had a volume of about 20 ml. The radio transmitters, obtained from AVM Instrument Co. (Champaign, Illinois), had an irregular shape and measured 60 by 21 by 10 mm. They weighed about 20 g in air and 10 g in water, had a volume of about 10 ml, and emitted a pulsed radio signal at 50 mHz. Receiving equipment used was manufactured by the maker of the respective transmitter type. Since a 15-kg fish tagged with an ultrasonic transmitter would have to increase its air bladder volume by only 1.8% to maintain neutral buoyancy, we assumed the transmitters did not drastically alter fish behavior (Marshall 1966).

Fish tagged during 1973 and 1974 (ultrasonic transmitters) were located as often as possible, and at times virtually continuously for 24 h to study movements of these fish in the spawning areas. Fish tagged in 1975 (radio transmitters) were monitored less often, especially when they migrated upstream from the spawning areas. Attempts were made to find these fish at least once a week after they left the spawning grounds but some fish were more readily found than others. Fish tagged in the fall of 1974 (radio transmitters) in the Augusta area were located every one to two weeks. Except for the four fish tagged in the Augusta area, all fish fitted with transmitters were captured in the spawning area.

Although our primary interest was to determine the movements of striped bass in the Savannah River, we had the opportunity, especially during 1974, to attempt to correlate short term movements of the fish with environmental variables. To do this we measured surface water temperature, salinity, and dissolved oxygen in the immediate vicinity each time a fish was located. We also recorded lunar stage, tidal stage, time and date. To facilitate analysis, we divided the tidal cycle into 12 stages and divided the lunar cycle into eight stages. The location of each fish was marked on a nautical chart of the area and numbered. This number and the corresponding data was then recorded on data sheets maintained for each fish.

Minimum rates of fish movement were estimated by dividing the distance between successive locations by elapsed time. The data used for this type of analysis did not include observations separated by more than 1.5 h. We used multiple regression analysis to find what variables would best predict movement.

RESULTS

From 1973 through 1975, 33 striped bass were successfully tagged and tracked (Table 1).

Movements of Striped Bass During the Spawning Season

Striped bass electronically tagged and tracked during March and April utilized the Little Back River and its tributaries more than any other part of the lower Savannah River. By examining data from fish tracked in this part of the river for more than 4 days, we found that striped bass spent about 75% of their time in the Little Back River (Table 2, Section A and B, Fig. 1). Forty-three percent of their time was spent in the Little Back River between the Route 17 bridge and the mouth of Union Creek (Section A on Fig. 1). The proportion of time fish spent in Section A differed significantly among the 3 yr ($\chi^2 = 87.16$, df = 2). Some of the differences in use of different sections of the river among years may be due to differences in data collection. Environmental factors may have contributed to the differences between 1974 and 1975. For example, in 1974 water temperature reached a high of 21 C in late March, dropped to 14 C, and then rose again. In 1975 water temperatures did not reach 21 C until early May. The temperature regime of 1974 may have caused the fish to meander more.

[3] Mention of products in this paper does not imply endorsement of those products.

TABLE 2.—*Utilization of various sections of the lower Savannah River by striped bass during the spawning season. Each number represents the number of days on which each fish was found in a particular section. If a fish was observed more than once per day in a given section this was counted as one observation. If this fish was found in more than one section on a given day this was counted as one observation in each section. Only fish observed on more than 4 days on the spawning grounds are presented here. See Fig. 1 for location of river sections.*

Year	Fish	River section A	B	C	D	E	F	G	H	Total
1973	SF	5	2	1						
	SY	2	2							
	Total days	7	4	1						12
	% of total	58%	33%	8%						
1974	SB	5	3	8					1	
	SC	6	5	5	3	1				
	SD	2	1	1	6	3	1			
	SE	5			2					
	SG	8	4		5	1				
	SH	14	13							
	SI	3	3		2					
	Total days	43	29	14	18	5	1		1	111
	% of total	39%	26%	13%	16%	5%	1%		1%	
1975	RG	2	1		1					
	RI	6	17	2	2					
	RJ	6	3							
	RK	10		1	2					
	RL	5	7	1						
	RM	5	5		1					
	RO	6	1							
	Total days	40	34	4	6					84
	% of total	48%	40%	5%	7%					
1973–1975	Total days	90	67	19	24	5	1		1	207
	% of total	43%	32%	9%	12%	2%	0.5%		0.5%	

Striped bass tended to move more when the water was cooler (Fig. 2) but we obtained very little continuous data at water temperatures below 14 C. However, regression tests indicated that movement was significantly ($P < 0.1$) higher at lower temperatures.

Although movement patterns of individual striped bass differed greatly, as a group they tended to move primarily during the afternoon and early evening (Fig. 2) while in the spawning area. The few fish which were tracked continuously to about 32 km upstream in 1974 tended to move at night while in upstream areas, but there are too few data to draw any definite conclusions.

Fish tended to move less at flood tide than at any other tide and seemed to move more when the tide was dropping than when it was rising (Fig. 2). Due to the large confidence intervals no statistical significance can be attached to the data although cyclic (cubic and fourth power) regressions were tested.

Fish tended to move least during the period surrounding the new moon (Fig. 2). A cyclic relationship seems to be present in the data (Fig. 2) but again large variances prevent the assigning of statistically significant cyclic (cubic or fourth power) relationships.

Using multiple regression we found significant relationships between movement on the spawning grounds and the following combinations of variables: (1) water temperature and change in water temperature ($R^2 = 0.07$); (2) lunar stage and tidal stage ($R^2 = 0.05$); and (3) lunar stage, tidal stage, and season ($R^2 = 0.07$). Since none of these combinations accounted for more than 7% of the variability in the movement data and were significant only at the $P \leq 0.1$ level, the regressions have no predictive value.

Movement of Striped Bass after the Spawning Season

The movement patterns of striped bass changed markedly at the end of the spawn-

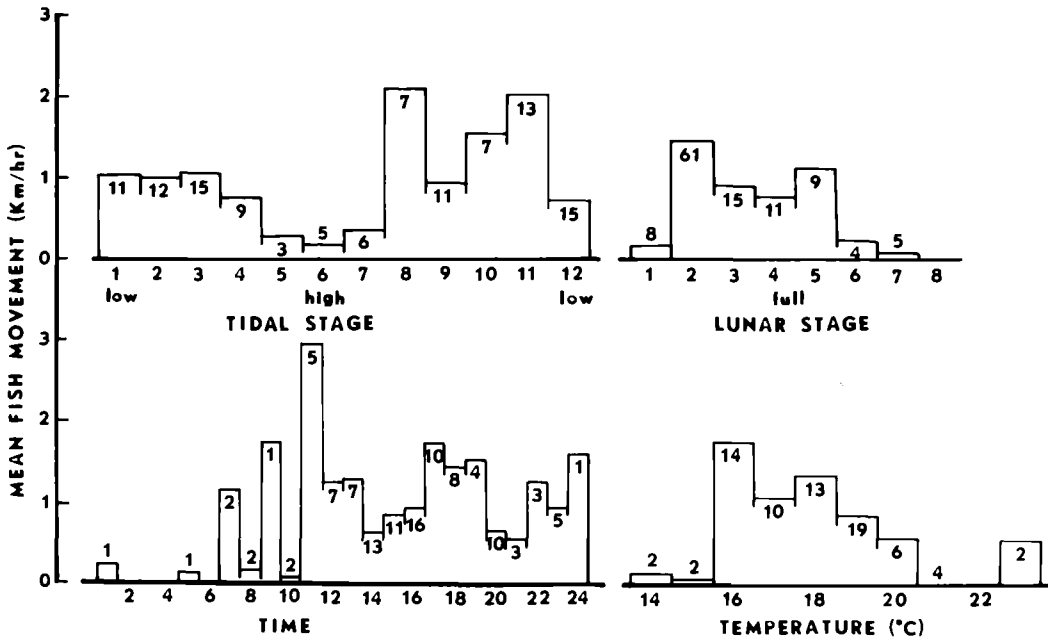

FIGURE 2.—*Relationship between some variables and movement of striped bass on the spawning grounds in the spring of 1974. In most cases small sample sizes within each category and large variances precluded the assignment of statistically significant relationships. Numbers of observations are given at the tops of columns.*

ing season. After remaining in a relatively confined area of the Little Back River all fish left this area. Of 20 fish which contained working tags when they left the spawning grounds, 14 were subsequently found upstream; six were never found. Only three of 12 radio-tagged fish were not found after spawning.

Most fish observed left the spawning area between 16 April and 1 May. Fish RG may have left the spawning area quite a bit earlier (18 March) than the other fish, but this fish was not relocated for almost 2 months. Excluding fish RG the mean date of last observation on the spawning grounds was April 25 (± about 5 days). Male fish did not leave on a significantly different date from females. Fish tagged in 1974 did not leave the spawning area earlier in spite of the warmer water temperatures which occurred that year. Fish which were not later located did not leave at a different date than those which were located.

Striped bass tagged with ultrasonic transmitters provided little information on post-spawning movement. Striped bass tagged with radio tags were easier to locate in upstream areas than ultrasonic tagged fish and were found for several months. Some striped bass moved upstream quite rapidly after spawning. Two radio-tagged fish (RI and RN) moved 240 km upstream from the spawning grounds in less than 3 weeks. Another (RJ) remained 136 km upstream for several weeks before moving further. Eight of the nine radio-tagged fish found after spawning moved at least 160 km upstream from the spawning grounds. The other fish (RT) was last located at the mouth of a tributary impassable to our boat. Most fish remained in a relatively short section of the river after the post-spawning migration (Table 3). We detected no significant downstream movement. The fish remained in upstream portions at least until we lost the transmitter signal.

Movement of Striped Bass in the Augusta Area

We tagged and tracked four striped bass captured near Augusta in the autumn and winter of 1974–75 (Table 1). None of these fish moved great distances and none exhibited movement patterns related to any obvi-

TABLE 3.—*Distances from the mouth of the Savannah River where individual striped bass remained for more than 5 days. Data are from fish tagged with radio transmitters in 1975. Of nine fish tagged and subsequently found upstream, these seven remained in specific areas more than 5 days. (Fish RI and RT moved steadily upstream until the signal was lost.) The last date shown is the last date on which a signal was found for that fish.*

Fish	Location (km from river mouth)	First found at this location	Last found at this location
RG	195	14 May	30 May
RJ	127–137	29 May	17 June
	257–280	15 July	31 July
RM	225–228	14 May	13 June
RN	283–291	10 May	11 June
RO	253–272	5 June	31 July
RQ	232–238	15 May	11 June
	249–252	19 June	25 Aug.
RS	293–301	19 June	25 Aug.

ous influence. Three fish (RA, RB, RE) tagged in or near the discharge canals were most often found either in the canals or within a few kilometers of them. They were never found more than 10 km from the tagging site. A fish (RD) tagged a few hundred meters downstream from the New Savannah Bluff Lock and Dam remained within 7 km of the dam.

Other Tagging Methods and Collections

Of 126 striped bass marked with external anchor tags only two were recaptured. One fish tagged at Augusta just downstream from the lock and dam in early November was found at the Savannah spawning grounds in March. One fish tagged (7 November 1974) in the Augusta area in canal 2 was captured by a fisherman about a month later in the rapids upstream from Augusta.

Striped bass were found (with electrofishing equipment) in the Augusta area both upstream and downstream from the lock and dam during the summer, fall and winter months. Fish were most likely to be found in the discharge canals, in the vicinity of a power plant downstream from Augusta and in a 1 km section of river downstream from the lock and dam. No fish were found in the spring when these sections were sampled on 16 April 1975. However, the water levels on this date were too high for efficient shocking.

DISCUSSION

In general the striped bass is an anadromous fish, but in the Savannah River the degree of anadromy is greatly reduced. This tendency in southern populations has been reported by previous workers (Barkaloo 1967; Raney 1952; Raney and Woolcott 1955).

Although our study strongly supports earlier studies (Smith 1970; McBay 1968) in establishing the Little Back River as the major spawning area, we did not discover what environmental characteristics attract striped bass to this area.

Our data indicate that most Savannah River striped bass migrate upstream after spawning and remain in the river. These fish must then return to the spawning grounds the following spring, although little direct evidence for downstream migration is provided by this study. This theory is supported by virtually all our data although some factors still remain unclear.

Although Mahood et al. (1974) found very few striped bass in a coastal survey of Georgia marine waters, fishermen do catch striped bass in the lower estuaries especially from 15 November through January 31. On the other hand we captured an adult striped bass (fish RD) just downstream from the lock and dam in December of 1974, and in January of 1974 we saw numerous striped bass in the rapids upstream from Augusta. The meaning of this latter observation is clouded by the existence of the lock and dam which may hinder free movement of fishes. Striped bass may remain in all parts of the river in winter, and then perhaps move toward the spawning area in February or early March. Striped bass were not captured in the Augusta area during the spawning season which might indicate that they did move downstream to spawn, but water conditions in Augusta hampered sampling during that period.

A possible reason as to why riverine populations of striped bass developed may be their temperature preferences. Excessively warm coastal waters may limit seaward migration of striped bass. Merriman (1941) felt that the maximum water temperatures at which striped bass would be found were 25 to 27 C. Maximum temperatures found in

the downstream (warmest) part of the Savannah River were 26 C in July through September 1971 (Georgia Water Quality Control Board 1972b). Maximum temperatures of marine waters along the coast of Georgia in 1974 (Mahood et al. 1974) reached 27 to 30 C.

In years of warm ocean temperatures (up to 18.5 C) on the Pacific coast, seaward migrations of striped bass occurred, while during cooler years bass remained in inland reaches of the San Francisco Bay-Sacramento River system (Radovich 1963). Temperature preference could also be the constraint on the riverine population of striped bass in the St. Lawrence River (Magnin and Beaulieu 1967; Beaulieu 1962). In general the larger rivers of the South are probably cooler than adjacent coastal waters and upstream portions are cooler than downstream waters. The construction of large reservoirs (e.g., Clark Hill and Hartwell on the Savannah River) lower the water temperatures of rivers further. Thus striped bass would be more likely to find acceptable temperatures by moving upstream after spawning.

ACKNOWLEDGMENTS

We are indebted to Messrs. R. Michaels, D. Stoeppelwerth, and F. Rosen for their many months of help in the field. We also thank Dr. M. Rawson, and Messrs. R. Boyer, D. Thompson and graduate students in fisheries at the School of Forest Resources, University of Georgia, who assisted us with the fieldwork. Drs. J. Clugston and A. Fox of the Georgia Cooperative Fishery Unit provided valuable support and suggestions.

Our thanks also go to Messrs. R. Rees, C. Hall, R. Harrington, X. Bunch and other State of Georgia personnel who cooperated fully in this project, especially Mr. L. Kirkland, Chief of Fisheries for the State of Georgia, and Mr. D. Holder, Anadromous Fish Coordinator. We also thank Mr. L. Villanova and other workers at the Fish and Wildlife Service, Division of Federal Aid in Atlanta.

This project was initiated by Dr. M. Huish.

This project was financed by the people of the United States via the Anadromous Fish Conservation Act administered by the U.S. Fish and Wildlife Service and by the citizens of the State of Georgia via the School of Forest Resources, University of Georgia.

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