Movements and Habitat Selection of Striped Bass in the Santee-Cooper Reservoirs[1]

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Abstract: Radiotelemetry which employed temperature-sensitive transmitters was used to monitor spring movement and summer habitat selection of 19 adult striped bass (*Morone saxatilis*) in the Santee-Cooper reservoirs, South Carolina. Nine fish were followed for 63 days during the late spring and summer 1985. Of the 61 recorded locations, 9 were fish which had utilized a thermal refuge. Mean water column temperature (28.1° C) and average thermal selection (27.8° C) did not differ significantly in observations where fish did not use thermal refuges. Average water column temperature was 29.0° C when fish were observed using refuge sites. Refuge sites averaged 0.34° C cooler than the recorded bottom temperature. Ten fish were monitored during the late winter and spring 1986 and located on 74 occasions. Striped bass exhibited a spring migration out of the reservoirs and into upstream areas. Mean water temperature was 13.8° C at the time of upstream migration and 18.9° C when the fish returned to the deep water near Pinopolis Dam on Lake Moultrie. Fish averaged 0.76 km net movement per day during January, February, and March. Daily net movements averaged 2.9 km from April until mid-May and then decreased to 0.43 km from mid-May through June. Striped bass also demonstrated a preference for distribution on or adjacent to the reservoir's river channel. Striped bass in the reservoirs averaged only 0.43 km from the channel.

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The Santee River was historically a natural spawning run for coastal striped bass (*Morone saxatilis*). It became apparent that a large population of striped bass

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had become land-locked when the Santee River was impounded and the Santee-Cooper Reservoirs (i.e., Lakes Marion and Moultrie) were completed in the 1940s. Further investigations (Scruggs and Fuller 1955, Scruggs 1957) established that these land-locked fish were able to complete their life cycle in the new reservoir. Stevens (1958) gave evidence that this population was not only established, but that its numbers were steadily increasing. The success of this land-locked population led directly to the now widespread practice of introducing striped bass into freshwater impoundments (Bailey 1974). Presently, at least 34 states have established inland striped bass populations (Axon and Whitehurst 1985).

Several southeastern reservoirs where striped bass have been stocked experience summer die-off of large striped bass (Schaich and Coutant 1980, Waddle et al. 1980, Cheek et al. 1985, Matthews 1985, Moss 1985). Recent studies have found striped bass concentrated in thermal refuges during the summer (Schaich and Coutant 1980, Waddle et al. 1980, Moss 1985). These are areas having cooler water temperatures and are, reportedly, necessary for survival of large fish. It has been hypothesized that summer die-offs occur when thermal refuges do not coincide with areas of sufficient dissolved oxygen and forage (Coutant 1985).

Thermal refuges were thought to be rare in Lakes Marion and Moultrie due to their large shallow pools which do not stratify. However, distribution of striped bass through the summer, as indicated by angler catches, is widespread, and the system supports a vigorous striped bass population. Also coastal striped bass make spawning migrations traveling upstream through the estuarine and riverine systems during the spring. May and Fuller (1962) and Scruggs (1957) presented evidence that the Santee-Cooper population utilized both the Congaree and the Wateree rivers as spawning areas. Objectives of this study were to: 1) examine the role of summer thermal refuges for striped bass in Lakes Marion and Moultrie, and 2) examine the movements of striped bass before, during, and after their spawning season.

Methods

Study Area

The Santee-Cooper Reservoir system consists of Lakes Marion and Moultrie with the Congaree and Wateree rivers as the principal sources of water flow. The 2 lakes are connected by a canal which was originally constructed to divert water flow to the hydroelectric plant at Pinopolis Dam on Lake Moultrie. Lake Marion covers approximately 44,000 ha with a maximum depth of 12 m. Lake Moultrie is 25,000 ha in size and has a maximum depth of 21 m. The average depth of both lakes is approximately 5 m. The Congaree River is 85 km long. It originates at the Saluda Dam on Lake Murray and flows into the upper end of Lake Marion. The Wateree River originates at the Wateree Dam and flows 100 km before its confluence with the Congaree.

Field Methods

Temperature-sensing transmitters (48.032–48.585 MHz, Advanced Telemetry, Inc.) were used in order to determine the position of the fish in the water column and to determine if fish were using thermal refuges. Transmitters were 18 mm in diameter, 120 mm in length, and weighed 44 g. Each transmitter was equipped with a 40-cm antenna. Pulse interval-temperature (e.g., 3° to 39° C) calibration data were developed for each transmitter prior to surgical implantation. Pulse interval and temperature were related by the general equation: temperature = intercept − slope × $\log_{10}$ pulse interval. Transmitters were sensitive to temperature changes of 0.1° C. Six transmitters were recovered from recaptured fish five months after implantation. Pulse intervals were again recorded at 11.4°, 18.5°, and 24.6° C.

Striped bass were collected from the Cooper and Santee rivers during April and May 1985. Striped bass were anesthetized after capture using either 25 mg/liter quinaldine or 200 mg/liter tricaine methanesulfonate. Each fish was measured and weighed to the nearest mm total length and 10 g, respectively (range: 580–840 mm total length; 2.5–8.0 kg weight). They were then placed in an operating trough which was designed to keep the immobilized fish submersed while exposing the abdomen. Radio transmitters were surgically implanted into the body cavity using techniques described by Hart and Summerfelt (1975) and Braschler (1987). Hands, tools, and transmitters were disinfected prior to surgery.

A boat equipped with 4-element yagi antenna was employed for search on the 2 lakes and in the diversion canal. The yagi antenna was mounted on a telescoping base which increased its range. A loop antenna was mounted on a boat for use in the rivers, mounted on an airplane strut during aerial search, and used as a directional antenna in triangulation of fish locations.

Field work for the thermal selection study was conducted from June through August 1985. We were able to position the boat within 50 m of an implanted striped bass by employing several antennae (Braschler 1987). Temperature and dissolved oxygen profiles (2-m intervals) were recorded at each fish location. Each fish's relative position in the water column (i.e., 0 for surface and 1.0 for lake bottom) was computed based upon the indicated transmitter temperature and corresponding thermal profile. Striped bass were categorized as thermal refuge users if the temperature indicated by the transmitter was lower than the lowest corresponding bottom temperature and were assigned relative depths of 1.0.

Lakes Marion and Moultrie were monitored biweekly from January until mid-June 1986 in order to describe striped bass winter-spring movements. Exact locations were recorded on a map which also indicated the position of the river channel (Braschler 1987). Elapsed days and distance moved since each fish's last location were computed. Relative fish and river channel locations (i.e., 0.0 for southwest shore and 1.0 for northeast shore) were recorded along transects drawn perpendicular to the general direction of the river channel. Locations were categorized as near the reservoir center if they were within 15% of reservoir (i.e., transect) width from the transect center.

Statistical Methods

Pulse intervals at 11.9°, 18.5°, and 24.6° C of recovered transmitters were compared to pulse intervals predicted from each transmitter's calibration curve with a paired (i.e., before vs. after) t-test. Differences between surface vs. bottom and bottom vs. refuge water temperatures were also compared with a paired t-test. Distances of fish and river channel from the center of the reservoir and the differences between them were compared to zero with a t-test. Relative reservoir position of fish and river channel were linearly regressed on one another and Pearson's correlation coefficient computed. Dependency of proximity of fish to reservoir center upon proximity of river channel to reservoir center was tested with a chi-square statistic. All significance testing was done at the 0.05 error level. Standard errors ($\pm$) are provided in the text.

Results and Discussion

Thermal Habitat Selection

The monitoring of 9 of 21 striped bass implanted with radio transmitters in 1985 was successful. These fish were monitored for temperature selection during June, July, and August 1985, with 61 individual locations made over a period of 63 days. Study fish were concentrated largely in the deep waters at the lower end of Lake Moultrie during the period of rising water temperatures. Fish did not exhibit any substantial horizontal movements during the summer months of 1985. Mean water column temperature (28.1° C ± 0.2) and average fish temperature (27.8° C ± 0.2) did not differ significantly ($P > 0.05$) when fish did not use thermal refuges. There was a slight but significant unstratified linear thermal gradient from surface to bottom. Average surface to bottom temperature difference was −2.4° C (t-statistic for a difference of $0 = 16.87$, $P < 0.001$), while the mean difference between fish and surface temperature was −2.0° C. Average position of striped bass within the water column was 0.77 (±0.10) of maximum depth. Thermal refuges (i.e., areas where water temperatures were cooler than surrounding bottom temperatures) were utilized on 9 of the 61 occasions when fish were located during 1985. Eight of the 9 instances occurred when average water column temperature exceeded 28° C. Average water column temperature was 29.0° C (±0.3) when fish were observed using refuge sites. Fish in refuge sites averaged 0.34° C (±0.1) ($t = 3.01$, $P < 0.02$) cooler than the recorded bottom temperature and 1.0° C (±0.1) ($t = 8.00$, $P < 0.0001$) cooler than average column temperature. Structure maps showed that refuge areas had high occurrences of springs, wells, sink holes, and old creek beds. Pulse intervals for recovered transmitters did not differ before and after an average of 5 months' implantation ($t = 1.49$, $P = 0.1548$).

Winter-Spring Movements

Transmitters were implanted in 13 striped bass, of which 10 implantations were successful. These 10 fish were monitored and 74 observations recorded from late

January until mid-June of 1986. Striped bass were distributed primarily in the areas surrounding the 2 dams and the open waters of Lake Moultrie during the months of January, February, and March (Fig. 1). Horizontal movements at this time of the year were low, averaging 0.76 (±0.29) km/day. In April, striped bass migrated into the area at the upper end of Lake Marion and up the Congaree River (Fig. 1). Water temperatures at this time ranged between 13° and 15° C. Tagged fish continued to use this area until mid-May, and then returned to the deep waters near Pinopolis Dam (Fig. 1). Mean water temperature recorded during the period in which study fish utilized the river and headwater areas of Lake Marion was 16.6° C. Average temperature at time of their downstream departure was 18.9° C. Movement per day values from April until mid-May were high, averaging 2.90 (±0.55) km/day. Fish concentrated primarily around Pinopolis Dam from mid-May through early June (Fig. 1). Movement per day values at this time were considerably lower, averaging 0.43 (±0.15) km/day.

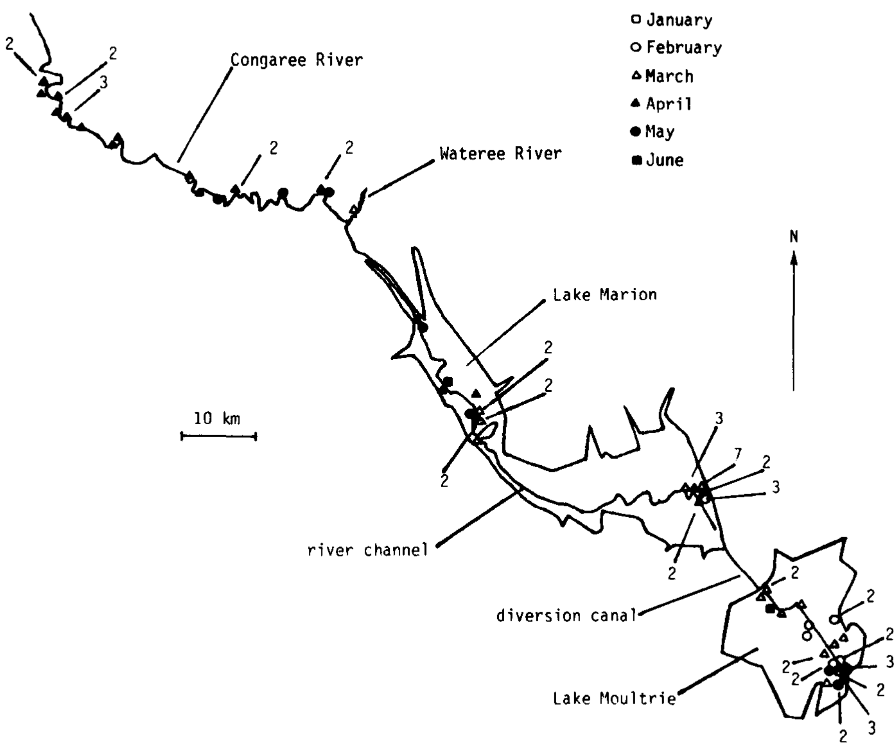

Figure 1. Striped bass distribution, late January until mid-June 1986, in Lakes Marion and Moultrie (Santee-Cooper) in relation to the river channel. Cumulative number of radio-transmitter implanted fish was: January, 2; February, 6; March-June, 10. Numbers indicate multiple (but not necessarily simultaneous) observations at approximately the same graphic location.

All of the study fish exhibited movement patterns, with 7 fish migrating to the Congaree River, 1 to the Wateree River, and 2 to the headwater area of Lake Marion. The mean distance moved per day during the study was 2.4 km ($\pm$0.5). Striped bass in this study migrated much like anadromous stocks from which they originated. Similar findings were reported by Combs and Peltz (1982) in their study of striped bass in Keystone Reservoir in Oklahoma.

Striped bass in Lakes Marion and Moultrie demonstrated preference for the river channel during the 1986 study (Fig. 1). Mean reservoir width along transects drawn perpendicular to the river channel through fish locations was 7.35 km (SE = 0.54), yet striped bass utilized only a narrow corridor of the reservoir. Mean distance of striped bass from the river channel was 0.43 km (SE = 0.06). Relative reservoir positions of fish and river channel were correlated (Pearson's $r = 0.76$, $P = 0.0001$). Furthermore, proximity of fish to the reservoir center (i.e., "near" = $\pm$15% reservoir width from center) was dependent upon proximity of the river channel to the reservoir center ($X^2 = 11.502$, $P = 0.0001$). Average depth where fish were located was 9.5 m compared to a mean overall depth of 5 m.

Stratification does not occur in the Santee-Cooper reservoirs due to the physiographic characters of the lakes. Surface to bottom temperatures may not vary by more than 3° C during the summer months. Recorded summer water temperatures in the lakes were warmer than what has been determined as ideal to support striped bass (Coutant and Carroll 1980, Coutant 1985). Coutant (1985) suggested that dissolved oxygen levels less than 2 to 3 mg/liter can be limiting in maintaining striped bass populations. In this study, striped bass occupied the coolest water available in the vertical gradient and were more likely (e.g., 8 of 9 instances) to utilize a thermal refuge when average water column temperature exceeded 28° C. However, thermal refuges do not appear necessary if adequate dissolved oxygen concentrations exist. Dissolved oxygen concentrations greater than 3.4 mg/liter were recorded throughout this study. Forty observations were made when mean water temperature exceeded 28° C, but only 8 cases were refuged fish. In this study, refuges were probably provided by springs, wells, sink holes, and creek beds. Preferred distribution near or in the river channel also substantiates the importance of the deep and/or flowing waters in the ability of the relatively shallow Santee-Cooper system to support striped bass.

Striped bass monitored in this study demonstrated a spring migration out of the reservoirs and into upstream areas. Previous studies which sampled planktonic eggs indicated that these areas were utilized in striped bass reproduction (Scruggs 1957, May and Fuller 1962), but tagged or monitored fish had never been followed. More significantly, the striped bass exhibited a much higher utilization (e.g., 94% of river observations) of the Congaree River, presumably as a spawning ground. This selection was probably made on the basis of the greater amount of water flow of the Congaree River relative to the Wateree (61 year averages were 266 m^3/sec and 183 m^3/sec for the Congaree and the Wateree rivers, respectively). Striped bass concentrated in the area surrounding Pinopolis dam from mid-May through June. This could be attributed to instinctive downstream movement after spawning, utilization of deeper and cooler waters as the temperatures warmed, or high concentrations of blueback herring (*Alosa aestivalis*) at Pinopolis Dam during this time.

This study documents 3 behavioral patterns of the radio-tagged striped bass: 1) that utilization of thermal refuge sites occurred only when water temperature exceeds 28° C; 2) striped bass can tolerate water temperatures in excess of 28° C if adequate dissolved oxygen is present; 3) that spring migrations out of the reservoirs and into the upstream areas occur when water temperatures reach 13° C; and 4) that fish occur in or around the lake's river channel. Longer duration telemetry data on individual fish are needed in order to ascertain whether or not individual striped bass move in and out of thermal refuges over 24-hour periods. Knowledge of the existence of springtime concentrations of striped bass could be useful in management, especially when considering the amount of sport fishing pressure these locations experience during the spring.

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