Selection of Thermal Refuges by Striped Bass in a Gulf of Mexico Coastal River

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Abstract: We located 22 potential striped bass (*Morone saxatilis*) thermal refuges created by groundwater inflows along the Flint River in southwestern Georgia. Line transect counts made by SCUBA divers June–October 1990 were used to develop striped bass abundance indices for 8 of the springs. Abundance differed among springs and was positively correlated with potassium concentration and distance upriver and negatively correlated with pH and dissolved oxygen concentration. Groundwater feeding the springs flows through conduits created by the dissolution of underlying limestone. Locations of these conduits, revealed by linear arrangements of surface depressions, can provide information for managers making decisions concerning conservation of habitats that serve as striped bass thermal refuges.

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The Flint River in southwestern Georgia contains a naturally reproducing population of striped bass. Adults in this population are highly dependent upon thermal refuges for summer habitat (Van Den Avyle and Evans 1990). Summer mortality of striped bass in reservoirs has been attributed to a temperature-oxygen "squeeze" (Coutant 1985, Lochmiller et al. 1989, Zale et al. 1990). Suitable habitat is reduced because of increased water temperature and decreased dissolved oxygen concentration near the bottom. Groundwater inflows provide a haven of cool, oxygenated water in warm southern rivers.

The springs of the Flint River arise from intersection of the river channel with solution cavities formed by groundwater dissolution of limestone in the Ocala formation (Hayes et al. 1983). Thermal refuges are created by pockets of cool water in the

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immediate area of the inflows that directly enter the river channel (termed riverine springs) or pools of cool water occurring over a broader area where inflows arise in impounded water (lacustrine springs).

Strong preference for thermal refuges indicates that degradation of spring-fed habitats could negatively affect the striped bass population in the Flint River. Van Den Avyle and Evans (1990) found, during the summer months, 96% of locations of radio-tagged adult striped bass were from 5 spring-fed areas on the Flint River, despite the presence of numerous additional spring-fed areas. Criteria for refuge selection were not evaluated by Van Den Avyle and Evans (1990), and factors controlling the distribution and abundance of striped bass in specific refuges are not known. Groundwater withdrawal could reduce the volume of cool water available, and aquifers that supply the springs may be contaminated by landfill leachates, agricultural chemicals, industrial wastes, municipal sewage, and other pollutants.

The striped bass population in the Flint River warrants special consideration because it exhibits a unique mitochondrial DNA genotype found only in populations along the Gulf of Mexico coast (Wirgin et al. 1989). This population is used as a source of brood fish for hatchery production of striped bass stocked in this and other river systems entering the Gulf of Mexico.

Decisions concerning the management of striped bass and preservation of preferred summer habitats require information on the number and location of thermal refuges, the amount of use by striped bass, and factors affecting use of specific refuges. Objectives of our study included locating potential thermal refuges in the Flint River, determining the relative importance of a sample of refuges as striped bass habitat, and evaluating the relationships between abundance of striped bass and chemical and physical characteristics of water discharged from the springs.

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Methods

Our study was conducted on the Flint River in the Dougherty Plain region of southwestern Georgia. The Flint River joins the Chattahoochee River to form the Apalachicola River approximately 0.4 km above the Jim Woodruff Lock and Dam, which impounds the lower 46 km of the Flint River. Our research was restricted to the 200-km section of the Flint River from its confluence with the Chattahoochee River upstream to the Georgia Power Dam in Albany, Georgia. This section includes the impounded waters of the Flint River arm of Lake Seminole.

We located thermal refuges using unpublished data from Georgia DNR, whose personnel identified known refuges and suggested locations of others. Local residents and others were queried about spring inflows and historic locations of striped bass. All sites were examined during summer for the presence of cool inflows (ca. 20 C) using a YSI Model 51 dissolved oxygen and temperature meter. In locations where cool water was detected, divers using SCUBA gear searched for the spring's origin and evaluated the location as a possible site for further study. United States Geological Survey maps were used to determine the latitude and longitude of each location.

Of 22 spring-fed areas we located, 8 were chosen for determining their relative importance as striped bass habitat. Selection criteria included adequate flows to form visibly detectable cool water pockets and accessibility by striped bass and divers. Counts of striped bass were made June–October 1990, when the river temperature exceeded that of inflowing groundwater. Each spring was sampled 2–5 times during this interval.

Striped bass counts were made by 2 SCUBA divers swimming along underwater transects marked with a 0.64-cm cable. Cables were marked at 1-m intervals and extended from the origin of the spring downstream past the point where the river water and groundwater mixed. When sampling, divers located the downstream end of the cable and advanced upstream along the cable at a rate of 2 m/minute until a striped bass was observed. Subsequently, divers progressed at 1 m/minute, with 1 timing the intervals and the other counting striped bass crossing the transect line.

To standardize counts only those fish that crossed the transect line were counted. Individuals crossing the transect more than once were counted each time, making the transect count an index of abundance rather than a direct count of individuals. At the end of each minute, the time-keeper signaled the observer to record the number of fish that had crossed the transect line. This value constituted a station count. Both divers then moved 1 m to the next station and continued in this manner until reaching the end of the transect at the spring head.

The 1-m station counts for each transect were summed for each visit to a spring, and these sums were averaged for the summer to provide an index of abundance for each spring. The mean and variance of the indices were highly correlated ($N = 8$, $r^2 = 0.95$, $p = 0.0001$), so the data were log-transformed [$\log_{10}$ (X+1)]. This transformation eliminated the correlation ($N = 8$, $r^2 = 0.11$, $P = 0.77$). Analysis of variance (ANOVA) and Tukey's Honestly Significant Difference (HSD) were used with the transformed data to test for differences in striped bass abundance among springs.

Water samples were collected after fish counts were made to evaluate relationships between striped bass abundance and water quality. Samples were analyzed by the University of Georgia Cooperative Extension Service's Agricultural Services Laboratory, in Athens, Georgia. The laboratory measured concentrations of 22 purgable halocarbons, 20 pesticides, 6 phenoxy herbicides, 5 aromatic residues, and 16 minerals. Detection limits for all compounds are reported by Weeks (1996). Water temperature and dissolved oxygen concentration were measured immediately upstream of and in each spring outflow using a YSI Model 51B dissolved oxygen and temperature meter. Conductivity was measured with a YSI Model 33 SCT meter and pH measured using a Marine Enterprises pH indicator.

Correlations were evaluated between striped bass abundance indices and water quality, temperature gradient, and distance upriver. Compounds and elements present at levels below detection limits in ≥50% of the samples were deleted from correlation analyses. For all other compounds, elements, and measurements, the mean value for each spring (averaged over the summer) was calculated to evaluate correlation. When a variable was significantly correlated with striped bass abundance, Tukey's HSD was used to detect differences among springs.

Results

Twenty-two springs were identified as potential thermal refuges in the Flint River (Table 1). Five of these occurred in the impounded waters of Lake Seminole; 17 were distributed along the length of the Flint River. There was a clustering of thermal refuges in several areas along the Flint River (Fig. 1). The 8 springs chosen for further study occurred over a 186-km reach of the Flint River and included 2 lacustrine springs and 6 riverine springs.

Striped bass abundance differed among the 8 springs where fish counts were made (Table 2). Geometric mean indices ranged from 0.3 to 59.4 fish, with the highest abundance in the spring farthest upriver. The 2 lacustrine springs ranked second and fifth in abundance. Correlation analysis revealed a significant positive relationship

Table 1. Springs considered to be potential thermal refuges for striped bass, Flint River, Georgia.

Spring name	River km[a]	Latitude	Longitude	Type[b]
Sealy's Spring	8.0	30°46′31″	84°50′34″	Lacustrine
Mud Spring	9.3	30°46′46″	84°49′50″	Lacustrine
Wingate's Spring	18.3	30°46′49″	84°44′26″	Lacustrine
Dead Cypress	39.4	30°52′10″	84°36′57″	Lacustrine
State Dock Spring	41.3	30°53′43″	84°36′27″	Lacustrine
The Cove	95.8	31°02′28″	84°30′45″	Riverine
The Hog Parlour	103.5	31°03′41″	84°30′47″	Riverine
Cowpasture Spring	106.3	31°06′08″	84°30′29″	Riverine
Double Spring	154.0	31°20′17″	84°14′56″	Riverine
Culpepper Spring	157.0	31°20′46″	84°13′45″	Riverine
Walton Spring	161.5	31°21′14″	84°12′00″	Riverine
The Vine	173.0	31°24′47″	84°10′12″	Riverine
Riverbend #3	176.8	31°25′45″	84°08′42″	Riverine
Riverbend #2	177.5	31°25′24″	84°08′36″	Riverine
Riverbend #1	178.5	31°26′28″	84°08′24″	Riverine
Blue Hole	179.0	31°26′53″	84°08′13″	Riverine
Wilson's Blue Hole	181.2	31°27′14″	84°09′25″	Riverine
Radium Spring	190.8	31°31′13″	84°08′24″	Riverine
Duckman Spring	191.6	31°32′05″	84°08′17″	Riverine
The Blow Hole	193.0	31°32′47″	84°08′37″	Riverine
The Boat	193.3	31°32′50″	84°08′40″	Riverine
The Cave	193.6	31°33′05″	84°08′51″	Riverine

[a]Distance upriver from confluence with the Chattahoochee River.

[b]Lacustrine springs are in impounded waters; riverine springs enter in the river channel.

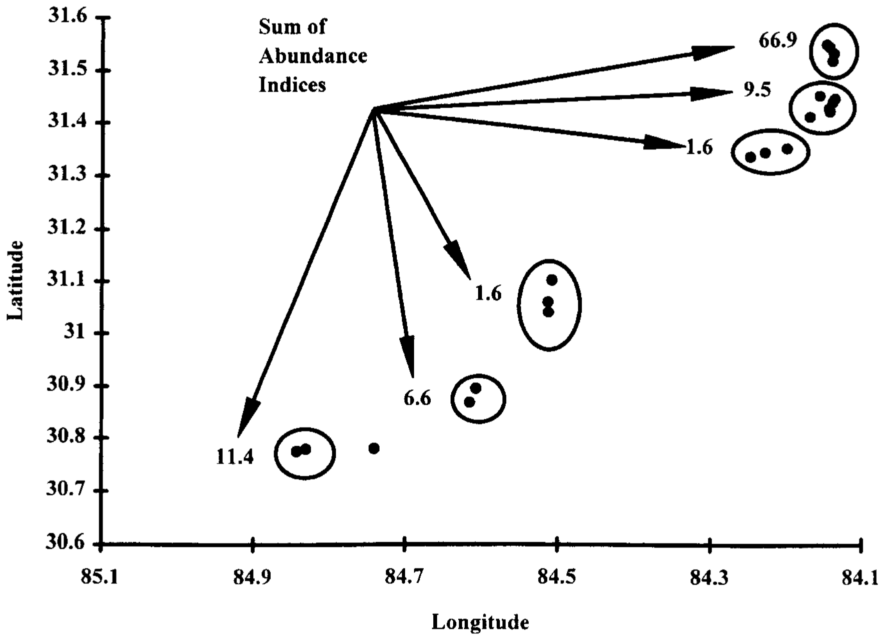

Figure 1. Clusters of springs along the Flint River, Georgia, in relation to latitude and longitude. Totals of striped bass abundance indices for spring areas in each cluster are included.

($r^2 = 0.69$, $P = 0.04$) between the abundance index of striped bass in the 6 riverine springs and the distance upriver from the confluence of the Flint and Chattahoochee rivers (Fig. 2). The relationship was not significant ($P > 0.05$) when the 2 lacustrine springs were included.

Water quality measurements were below the limits of detectability in >50% of the samples for all purgable halocarbons, pesticides, and phenoxy herbicides. However, 8 minerals were found at detectable levels in 6 springs (Table 3). Of these, striped bass abundance was positively correlated with potassium ($P = 0.013$, $r^2 = 0.82$, Fig. 2). The spring with the highest mean abundance also had the highest concentration of potassium, which was significantly different from those in all other springs sampled (Table 3).

Striped bass abundance was negatively correlated with pH ($P = 0.03$, $r^2 = 0.56$, Fig. 2) and dissolved oxygen concentration ($P = 0.03$, $r^2 = 0.57$, Fig. 2). The spring with the lowest mean pH and lowest dissolved oxygen concentration also had the highest abundance index. Average pH ranged from 6.9 to 7.3 among springs, and dissolved oxygen concentration was 2.6–6.6 mg/liter (Table 4). We detected no significant relationship between fish abundance and conductivity, ambient pH, ambient

Table 2. Index of striped bass abundance determined by divers in 8 springs, Flint River, Georgia, 1990.

		N striped bass							
Spring name[a]	River km[b]	25–27 Jun	11–12 Jul	21–30 Jul	27 Aug–18 Sep	29 Sep–6 Oct	20–21 Oct	Abundance index[c]	Mean index[d]
Sealy's Spring (L)	8.0		16	57	0	23		1.0935	11.4AB
State Dock Spring (L)	41.3		0	2	21	49		0.8796	6.6AB
The Cove (R)	95.8			11	0	0		0.3597	1.3AB
Cowpasture Spring (R)	106.3		3	0	0	0		0.1204	0.3B
Double Spring (R)	154.0	0		53	1		0	0.4067	1.6AB
The Vine (R)	173.0	71			2	18	2	1.0226	9.5AB
Duckman Spring (R)	191.6	8		7				0.9287	7.5AB
The Cave (R)	193.6	145		42	41	108	27	1.7811	59.4A

[a]R = riverine, L = lacustrine.

[b]Distance upriver from confluence with the Chattahoochee River.

[c]Abundance index is equal to the mean of $\log_{10}(x + 1)$, where x = number of striped bass observed crossing the sampling transect at each spring.

[d]Geometric mean, calculated as antilog_{10} of abundance index minus 1.0. Values followed by the same letter were not significantly different (Tukey's HSD; $P = 0.05$).

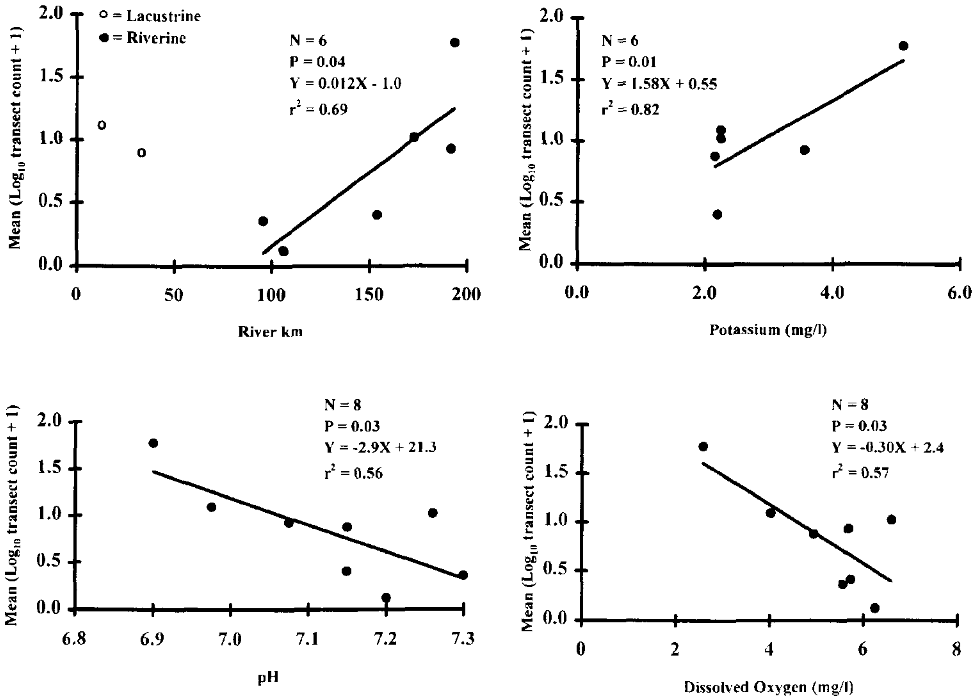

Figure 2. Relationship between the abundance index of striped bass in spring areas and the distance upriver (river km from the confluence of the Flint and Chattahoochee rivers, Georgia), potassium concentration, pH, and dissolved oxygen concentration. Only riverine springs (solid circles) were included in the regression analysis for distance upriver. Lacustrine springs are shown as open circles.

dissolved oxygen, spring temperature, ambient river temperature, or temperature gradient (difference between ambient temperature and spring temperature).

Discussion

Twenty-two areas of groundwater inflow were discovered on the Flint River, and data collected on 8 indicated not all were used equally by striped bass as thermal refuges. The spring farthest upriver and closest to the city of Albany, Georgia, had the highest index of abundance, the lowest pH and dissolved oxygen concentrations, and the highest potassium concentration. This spring was unique because it entered the river channel from the mouth of an underwater cave. If data from this spring were ignored, index of fish abundance would not have been significantly related to any of the measured environmental variables. However, we are not aware of any factors that would justify removal of this spring from the analysis.

Variation of fish abundance among springs did not appear to be related to the

Table 3. Average element concentration (mg/liter) in 6 springs entering the Flint River, Georgia, 1990. Only potassium (K) differed among springs (ANOVA, $P < 0.001$); values followed by the same letter were not significantly different.

Spring name	River km[a]	Mg	Al	Cu	Pb	Na	B	Mb	K
Sealy's Spring	8.0	1.6	0.014	0.015	0.010	2.2	0.025	0.010	0.21B
State Dock Spring	41.3	1.9	0.014	0.006	0.005	2.2	0.015	0.015	0.12B
Double Spring	154.0	1.0	0.008	0.006	0.010	2.2	0.008	0.002	0.12B
The Vine	173.0	1.0	0.017	0.012	0.008	2.2	0.009	0.004	0.29B
Duckman Spring	191.6	1.4	0.025	0.009	0.010	3.6	0.012	0.004	0.24B
The Cave	193.6	1.0	0.017	0.011	0.009	5.1	0.020	0.013	0.80A

[a]Distance upstream from confluence with the Chattahoochee River.

Table 4. Mean pH, conductivity, temperature, and dissolved oxygen (DO) concentration for springs sampled on the Flint River, Georgia, 1990. Only DO varied significantly among springs; values followed by the same letter were not significantly different.

Spring name	River km[a]	pH	Conductivity (µmhos/cm)	Temperature (C)	DO (mg/liter)
Sealy's Spring	8.0	7.0	192.5	20.5	4.0BC
State Dock Spring	41.3	7.2	229.6	20.1	4.9AB
The Cove	95.8	7.3	203.2	20.8	5.6AB
Cowpasture Spring	106.3	7.2	246.8	20.3	6.2A
Double Spring	154.0	7.2	259.8	20.0	5.7AB
The Vine	173.0	7.2	221.2	19.9	6.6A
Duckman Spring	191.6	7.1	256.2	20.2	5.7AB
The Cave	193.6	6.9	340.3	20.0	2.6C

[a]Distance upriver from confluence with the Chattahoochee River.

temperature of the ambient waters surrounding the springs. We detected no significant correlations between the index of striped bass abundance and ambient temperature or the difference between ambient and spring temperature. Van Den Avyle and Evans (1990) reported that ambient water temperature was relatively constant among sites within a given month.

The negative relationship between striped bass abundance and dissolved oxygen concentration was not expected based on published reports of striped bass oxygen requirements (Chittenden 1971). Fish movement in and out of this refuge may serve to balance the demands of thermal regulation and oxygen. A striped bass may remain in the refuge until its oxygen resources are reduced, and then move to the higher dissolved oxygen concentration of the warmer water in the river channel. After ambient water increases body temperature, the fish may then return to the cooler waters of the refuge. This activity could have affected indices of abundance at this spring because fish may have been more active or may have spent more time outside the spring-influenced area.

Variation in prey abundance could have affected variation of striped bass abundance among springs. We did not quantify prey abundance but rarely observed prey fishes in thermal refuges. Thus, any influence of prey availability would more likely have been related to forage availability outside the refuge.

The clustering of thermal refuges may reflect the flow dynamics of groundwater in this region. Groundwater transport is primarily through conduits of solution cavities which develop along faults and joints known as fracture traces (Brook and Sun 1982). Lineaments are manifestations of fracture zones 1.5 km or longer, and they can be detected from remotely sensed images as groups of surface depressions in a linear arrangement (Brook and Sun 1982). Lineaments or fracture traces with spring clusters along their axes may signify an intersection of the riverbed with a fracture zone. In such areas, land use and groundwater withdrawal have greater probabilities of affecting the quality and quantity of water in refuges used by striped bass.

It may not be possible to readily detect lineaments and fracture traces near the springs with the greatest abundance of striped bass, such as those near the city of Albany, Georgia (the cluster with the greatest abundance indices, Fig. 1). Aerial photos dating back to 1937 do not reveal lineaments because of land development. Brook and Sun (1982) used aerial photos from 1947 to predict specific well capacities because the photos were taken when there was standing water in the surface depressions. An alternative to using lineaments and fracture traces for identifying potential impact zones in heavily developed areas may be well yields, the assumption being more productive wells penetrate a fracture zone.

Size and shape of the refuges and their effects on fish distribution and behavior presented challenges for quantitative sampling in this study. The size and shape of each spring area depended on hydrostatic pressure, river stage, current velocity, and position of the spring entry in the riverbed. There was noticeable reduction in the size of refuges during high river stages. The refuge at river kilometer 173 completely receded on 22 July 1990, when river stage readings were higher than on any other sample date. The spring nearest the Georgia Power Dam in Albany, Georgia, at river kilometer 193.6 issued from a completely submersed vertical opening near the edge of the river channel. On 24 July 1990, while we were attempting to measure current velocity, the upper edge of the clear groundwater was lowered approximately 0.6 m in <45 minutes, presumably because of increased river stage and rate of flow caused by water releases from the upstream dam. This variability made estimation of refuge size beyond the scope of this research and prohibited the possibility of estimating fish abundance using subsample densities expanded for a known area or volume.

Quantification may have been affected by the reaction of striped bass to the presence of divers. Recordings made with video equipment suggested fish were aware of and reacted to the divers. Fish typically swam into view obliquely from upstream, crossed the transect line in front of the divers and moved away upstream. Fish rarely came within 2 m of divers. Remote video recordings showed fish oriented into the current near the mouth of a spring, but divers never observed this behavior.

The quantity and quality of groundwater that supplies springs used as thermal refuges in the Flint River should be conserved. Heavy groundwater withdrawal may not only reduce flow to the springs, but may also increase the rate of collapse of solution cavities and the probability of surface contamination of groundwater through breeches of the confining layer. Strategies for protection of groundwater resources might include avoiding the placement of wells on or near lineaments that include springs on the Flint River and closely monitoring wells already placed on lineaments.

In addition to protecting spring habitats, management of the striped bass population in this system requires protection of reproducing individuals and consideration of the amount of habitat available when prescribing numbers of fish to be stocked. Some measures have already been taken to protect the existing brood stock. Starting in spring 1991, the Georgia DNR restricted fishing from 1 May to 31 October in several thermal refuges. This restriction applied to 5 springs in Lake Seminole, the Flint River and the Chattahoochee River, including their tributaries upstream from Lake Seminole to the first dam and the entire length of Spring Creek and its tributaries.

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