Location of Thermal Refuge for Striped Bass in the Pascagoula River

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We conducted a two-year study (1997–1999) to locate cool water thermal refuge for striped bass *Morone saxatilis* in the Pascagoula River, its principal tributary streams and associated off-channel environments. Sampling with gill nets (33.2 hours soak time), hoop nets (26,160 hours soak time), electrofishing (39.9 hours pedal time), trotlines (121 lines with 10 hooks each @ 4.6 ± 1.3 hours/line) and angling (99.2 hours) resulted in the capture of only 12 striped bass. Of these, seven were large adult fish that we equipped with radio transmitters and released for telemetry. To increase sample size for the telemetry study, eight adult striped bass from the Gulf Coast Research Laboratory (Ocean Springs, Mississippi) and 15 adult striped bass from the Mammoth Springs National Fish Hatchery (Mammoth Springs, Arkansas) were equipped with radio and/or sonic transmitters and released into the system. Data for one of these Mammoth Springs National Fish Hatchery striped bass were lost, thereby resulting in a total sample size of 30 fish. Ninety-five days in 1998 and 99 days in 1999 were spent tracking striped bass by boat. Six days were spent conducting aerial radio telemetry surveys in 1998. Only the Cedar Creek effluent into the Pascagoula River (N 30° 41' 58" W 88° 37' 56") was confirmed as thermal refuge for striped bass. Although no striped bass tagged in 1998 were recorded in this thermal refuge, two of five wild fish and six of 23 hatchery fish utilized the Cedar Creek thermal refuge during 1999. In order to limit fishing mortality of large adult striped bass in this system, we recommend that the Cedar Creek thermal refuge be closed to all fishing during May-September, and that use of live bait on set lines be restricted in the river during striped bass spawning migrations (February–May).

Striped bass *Morone saxatilis* are anadromous, spawning in freshwater and then remaining in cool water thermal refuges along the stream continuum, or returning to brackish, estuarine or marine environments (Dudley et al. 1977; McLaren et al. 1981; Wooley and Crateau 1983; Moss 1985; Van Den Avyle and Maynard 1994). Intrusion of saltwater wedges into traditional spawning areas, or rapid flushing into high salinity waters, can induce high mortalities to striped bass eggs and larvae (Morgan et al. 1981; Van Den Avyle and Maynard 1994). Winger and Lasier (1994) suggested that salinities > 9.0 ppt critically impacted striped bass eggs and larvae. Subsequently, striped bass must have spawning sites sufficiently upstream in river ecosystems to ensure that eggs and larvae are buffered from salt water. In coastal streams along the northern Gulf of Mexico, striped bass spawn between February and May when water temperatures are in the 19–24°C range (Seltzer et al. 1980).

After spawning, striped bass that remain in freshwater seek cool water refuges (Cheek et al. 1985; Lamprecht and Shelton 1986). Coutant (1985) addressed this behavior and stated that in these refuges, striped bass are "squeezed" between their thermal and dissolved oxygen preferences or requirements. Moss (1985) documented lower condition for fish captured from summer thermal refuges in the Alabama River than for fish captured from the river during the spring. Coutant (1985)

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reported that crowding due to temperature preferences alone, or coupled with avoidance of low oxygen, can lead to stress-induced pathology and overfishing, both of which can contribute to population declines.

Striped bass were common to abundant in all major river systems along the Mississippi Gulf Coast until the early 1950's, but subsequently have experienced serious declines (Nicholson et al. 1986). Nicholson et al. (1986) suggested that the main reason for the declines is loss of suitable habitat, even in the Pascagoula River, which is the largest, physically-unmodified river in the lower 48 states of the continental United States (Dynesius and Nilsson 1994).

Our objective was to locate thermal refuges for striped bass in the Pascagoula River, its principal tributary streams and associated off-channel locations (Figure 1) using radio and sonic telemetry of wild-caught as well as hatchery-derived striped bass during summer and early autumn low stream flow conditions.

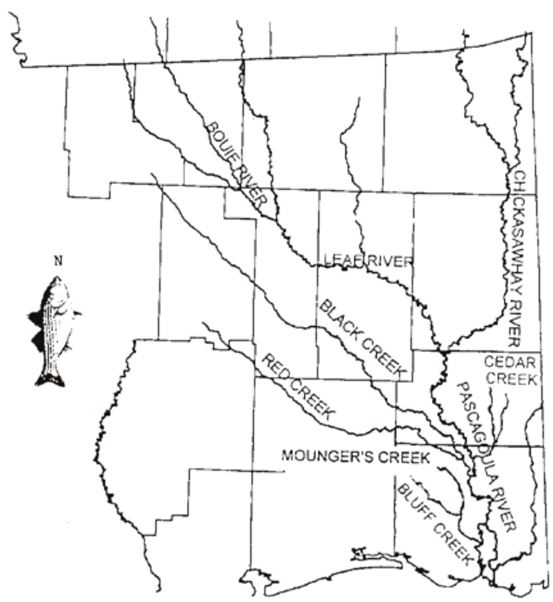

Figure 1. Pascagoula River Study Area

METHODS

Striped bass were collected from the Pascagoula River during 1998 and 1999 using hoop nets (1.5 m diameter with 7.62-cm bar mesh), experimental gill nets (3.0 m x 12.2 m, 6.35-cm and 10.16-cm bar mesh), electrofishing, and hook and line fishing (passive set lines; active angling). Hoop nets were set along streambanks, parallel with the current, with codends oriented upstream. During 1998 nets were checked every four hours during daylight, and then left overnight and checked again the following day. Due to low catch rates of striped bass in 1998, the check frequency for hoop nets in 1999 was decreased to every third day. Experimental gill nets (used only during 1998) were set parallel with the direction of the river's current and checked every 1 to 2 hours in order to minimize stress to captured fish. Fish captured by hoop nets and gill nets were processed immediately at their respective capture location and released. Trotlines were composed of a nylon main line (254 kg tensile strength) with 10 nylon dropper lines (54 kg tensile strength) equipped with 4/0 hooks baited with minnows or freshwater shrimp collected from the river. This gear and bait were the same as typically used by local fishers. Electrofishing was conducted during July and December 1998, and throughout 1999 with a boat-mounted Smith-Root unit configured to deliver three to five amperes of pulsed DC current, and 500 to 1000 volts. Electrofishing was conducted during daylight hours and at night. Fish captured by electrofishing were held temporarily in a tank onboard the vessel until they could be processed and released. Water in the tank was aerated with a sprayer system, and continually circulated and replaced with water from the river.

Captured striped bass (Table 1) were placed in a tank containing a concentration of MS-222 at a concentration of 150 mg/L. After the fish were sedated, they were weighed (kg) and total length (mm) was measured. Radio and/or sonic transmitters then were implanted completely in the abdominal cavity (no trailing antenna) of the fish. Surgical procedures were those described by Hart and Summerfelt (1975). Additionally, incisions and sutures were sealed by external application of "super glue" (cyanoacrylate**)** (Nemetz and MacMillan 1988; Petering and Johnson 1991). After surgery, fish were held until they regained equilibrium and were actively swimming, then released back into their respective capture location.

In 1998 and 1999 radio transmitters (30 MHz) were obtained from Custom Telemetry, Watkinsville, Georgia. Radio transmitters used in 1998 had a battery life of two years and a wet weight of 18 g. Radio transmitters used in 1999 had a battery life of one year and a wet weight of 8 g. Sonic transmitters

(72–76 kHz) purchased from Sonotronics, Tucson, Arizona were added to the telemetry study in 1999. Sonic transmitters had a battery life of one year and a wet weight of 8 g.

Table 1. Striped bass movements in the Pascagoula River ecosystem, Mississippi (1998–1999). The tracking period denotes number of days between release and last relocation. Fish noted by asterisk (*) were relocated in the Cedar Creek effluent.

Fish	Source	Release Date	Release Site	Relocations[c]	Tracking Period	Last Location
1	Wild	19 Feb 98	W Pascagoula R.	2	181	Chickasawhay R. (Dead)
2	Hatchery	24 Apr 98[a]	Red Creek	1	13	Confl. Red & Black Creeks
3	Hatchery	24 Apr 98[b]	Red Creek	3	169	W Pascagoula R (Dead)
4	Hatchery	24 Apr 98[b]	Black Creek	1	19	Bluff Creek
5	Hatchery	24 Apr 98[b]	Black Creek	None	-	Release Site
6	Hatchery	27 Apr 98[b]	Bluff Creek	None	-	Release Site
7	Hatchery	27 Apr 98[b]	Chickasawhay R.	1	75	Chickasawhay R.
8	Hatchery	27 Apr 98[b]	Chickasawhay R.	1	46	E Pascagoula R. (Dead)
9	Hatchery	27 Apr 98[b]	Leaf River	1	75	Leaf River (Dead)
10	Hatchery	27 Apr 98[b]	Leaf River	None	-	Release Site
11	Wild	29 Apr 98	Pascagoula R.	None	-	Release Site
12*	Wild	15 Feb 99	Pascagoula R.	9 (8)	211	Cedar Creek Effluent
13	Wild	19 Feb 99	Pascagoula R.	2	145	Bouie River
14*	Wild	03 Mar 99	Pascagoula R.	2 (2)	61	Cedar Creek Effluent
15	Wild	04 Mar 99	Pascagoula R.	None	-	Release Site
16	Hatchery	08 Mar 99[a]	Bluff Creek	1	53	Conf. Bluff and Little Bluff Creeks
17	Hatchery	08 Mar 99[a]	Bluff Creek	None	-	Release Site
18	Hatchery	08 Mar 99[a]	Bluff Creek	2	92	Bluff Creek
19	Hatchery	08 Mar 99[a]	Bluff Creek	1	71	Bluff Creek
20	Hatchery	08 Mar 99[a]	Bluff Creek	None	-	Release Site
21*	Hatchery	08 Mar 99[a]	Pascagoula R.	6 (5)	143	Escatawpa River
22*	Hatchery	08 Mar 99[a]	Pascagoula R.	4 (1)	117	Pascagoula River (Dead)
23*	Hatchery	08 Mar 99[a]	Pascagoula R.	4(2)	72	Cedar Creek Effluent
24*	Hatchery	08 Mar 99[a]	Pascagoula R.	6(3)	76	Cedar Creek Effluent
25*	Hatchery	08 Mar 99[a]	Pascagoula R.	3(2)	67	Cedar Creek Effluent
26	Hatchery	08 Mar 99[a]	Pascagoula R.	>10	213	Conf. Black Creek and Pascagoula R. (Dead)
27*	Hatchery	08 Mar 99[a]	Pascagoula R.	2(2)	67	Cedar Creek Effluent
28	Hatchery	08 Mar 99[a]	Pascagoula R.	4	123	Pascagoula R. below Interstate-10 (Dead)
29	Hatchery	08 Mar 99[a]	Pascagoula R.	3	43	Pascagoula River
30	Wild	12 Mar 99	Pascagoula R.	None	-	Release Site

[a]Fish donated by the Mammoth Springs National Fish Hatchery, Arkansas
[b]Fish donated by the Gulf Coast Research Laboratory, Mississippi
[c]Numbers in parentheses are relocations in Cedar Creek effluent

The Gulf Coast Research Laboratory (GCRL), Ocean Springs, Mississippi donated eight broodstock striped bass to the project in 1998. These fish were implanted with radio transmitters on 21 and 22 April 1998 and released into the Pascagoula River system on 24 and 27 April 1998. The fish weighed an average of 3.3 kg and were fed pelleted feed prior to their release. Fifteen additional striped bass were donated to the program in 1998 by the Mammoth Springs National Fish Hatchery, Arkansas. However, only one of these 15 fish survived after the trip from Arkansas to Mississippi. This fish was implanted with a radio transmitter on 22 April 1998 and released into the Pascagoula River system on 27 April 1998.

The Mammoth Springs National Fish Hatchery donated another 15 broodstock striped bass in 1999. These fish were implanted with radio and/or sonic transmitters on 26 February1999 at the GCRL and released into the Pascagoula River system on 8 March 1999. Six of these striped bass were implanted with radio transmitters, three were implanted with sonic transmitters, and six received both radio and sonic transmitters. The average weight of these striped bass was 2.0 kg at the time of transmitter implantation. They were fed twice prior to release with live prey obtained from the Pascagoula River.

Ninety-five days were spent tracking transmitter-equipped striped bass by boat during 1998 (April through November) and 99 days were spent tracking during 1999 (March through October). Searches included the main channels of the Pascagoula River and its principal tributaries and off channel backwaters. Data for one of the 1999 Mammoth Springs National Fish Hatchery striped bass were lost, thereby resulting in a total sample size of 30 fish for the study.

In 1998 six days were dedicated to aerial radio telemetry surveys that covered Red and Black creeks and the Pascagoula, Chickasawhay, Escatawpa and Leaf rivers. Black Creek was surveyed twice by aerial radio telemetry, and the Pascagoula River was surveyed on each flight date in route to the above-mentioned tributary streams. Aerial surveys used a loop antenna mounted to the right wing strut of the aircraft.

We recognized that telemetry might not be sufficient for locating potential cool water thermal refuges for striped bass in this system. Therefore, we conducted environmental surveys April through September of both years along the entire main channel of the Pascagoula River, as well as in off-channel locations (i.e., oxbow lakes, bayous, and tributary streams) throughout the lower Pascagoula River system (Figure 1). The environmental surveys initially encompassed the Pascagoula River north of Interstate 10 (both east and west forks of the river), upstream to the river's confluence with the Chickasawhay and Leaf rivers. The survey area was expanded during the second year of the project to include the Chickasawhay River up to its confluence with Buckatunna Creek, the Leaf River up to Hattiesburg, Mississippi, and the lowermost reaches of the Bouie River at Hattiesburg (to the Glendale Bridge). Additionally, Black, Red, Cedar, and Bluff creeks were included in the survey area. Black, Red, and Cedar creeks were surveyed as far upstream as was possible using small boats and canoes. Bluff Creek was surveyed up to its confluence with Mounger's Creek.

Environmental variables measured during habitat surveys were water temperature (°C), dissolved oxygen (mg/L), and salinity (ppt). These variables were measured with a YSI Model 85 meter. Additionally, these environmental variables were measured at each site where transmitter-tagged striped bass were located.

Thermal refuge was defined as locations in two manners: (1) potential—locations meeting physiological temperature preferences of striped bass as stated in the literature; (2) actualized—locations meeting physiological temperature preferences of striped bass as stated in the literature, and that yielded multiple relocation records of transmitter-tagged striped bass. By using these definitions, we avoided inclusion of locations of transmitter-tagged striped bass that may have been used by the fish for other purposes (e.g., foraging, transitory movements).

RESULTS

Gillnets (33.2 hours soak time), hoopnets (26,160 hours soak time), electrofishing (39.9 hours pedal time), trotlines (121 lines with 10 hooks each @ 4.6 + 1.3 hour/line; baited with live bait) and angling (99.2 hours) resulted in the capture of 12 striped bass (one with gillnet; four with hoopnet; four with electrofishing; two with trotlines). One striped bass was donated to the project by an angler. Three additional striped bass were observed during electrofishing but evaded capture. Of the 12 striped bass captured from the wild, seven were adult fish having total lengths greater than 500 mm. These seven fish were equipped with radio and/or sonic transmitters and released for telemetry (Table 1). Three of these seven fish had tags when captured indicating that they had been stocked by the Gulf Coast Research Laboratory.

Cedar Creek and its effluent into the Pascagoula River (N 30° 41' 58" W 88° 37' 56"), was identified and confirmed as a thermal refuge utilized by striped bass. Water temperature in Cedar Creek and its effluent never exceeded 24.6°C. Two wild and six hatchery striped bass equipped with transmitters were located in the Cedar Creek effluent. An additional five striped bass were observed while electrofishing in the Cedar Creek effluent. Aside from the Cedar Creek effluent, coolwater refuges were not located in the main channel (including east and west forks) of the Pascagoula River from the I-10 Bridge upstream to the confluence of the Chickasawhay and Leaf Rivers. Environmental surveys of principal tributaries and off-channel backwaters associated with the Pascagoula River ecosystem also did not have characteristics favorable as thermal refuges for striped bass (Jackson et al., 2000).

Although Bluff Creek at its confluence with Mounger's Creek (N 30° 31' 36" W 88° 40' 54") tended to have characteristics favorable as thermal refuge for striped bass, these conditions were not as consistent as those of the Cedar Creek effluent. We recorded only one striped bass (total length ca. 75 cm) while electrofishing in Bluff Creek, and none of our transmitter-equipped fish were ever re-located in the Bluff Creek-Mounger's Creek confluence. Favorable thermal refuge characteristics were never recorded downstream from the junction of Bluff Creek with Little Bluff Creek (N 30° 29' 32" W 88° 41' 06").

The Cedar Creek effluent was approximately 15-m wide and 14-m long. In September 1999 it was reduced to a small 2-m deep thermal refuge where water spilled over a shallow sand bar at the creek's mouth. Water temperature in Cedar Creek ranged from 20.3°C to 24.6°C during June-September 1999 (corresponding with severe regional drought conditions). Dissolved oxygen concentration ranged from 4.1 mg/L to 7.1 mg/L.

The Bluff Creek refuge was a somewhat larger area with a width of approximately 20 m and a length that varied seasonally up to 200 m. During September 1997 we found water temperatures that ranged from 26°C at the surface to 23°C at a depth of 3 m. Corresponding dissolved oxygen concentrations were 5.2 mg/L at the surface and 6.0 mg/L at a depth of 3 m. Similar conditions were found again in May 1998 (surface readings 24.1°C and 6.3 mg/L). On 17 July 1998 water temperature at the Bluff Creek refuge was 27.0°C at the surface and 25.9°C at a depth of 3 m. On 22 July 1998, we were able to electroshock a large adult striped bass in this location. Favorable thermal conditions also were recorded in the Bluff Creek refuge from May through September 1999. However, continuation of regional drought conditions during 1999 resulted in saltwater encroachment. This led to warmer, more saline water with reduced dissolved oxygen concentrations at greater depths. For example, on 22 September 1999, even though water temperature was 24.7°C at the surface, it was 27.2°C at a depth of 2 m. Corresponding dissolved oxygen concentrations were 4.1 mg/L at the surface but only 0.2 mg/L at a depth of 2 m. Salinity was 0.1 ppt at the surface but 9.8 ppt at a depth of 2 m. It is unlikely that striped bass would long remain in an area where favorable temperature and oxygen conditions were associated only with water near the surface.

DISCUSSION

Our study suggests that the number of adult striped bass in the Pascagoula River is very small. From our sampling, upstream migration of striped bass apparently began in the second week of February during both 1998 and 1999. Spawning of striped bass is induced by a rapid rise in water temperature (Setzler et al. 1980). In the Pascagoula River, a rapid rise in temperature occurred around the first week of April during both years of our study (Figure 2). Most of the fish we captured were female, a situation that may be problematic because spawning stocks of striped bass typically are dominated by males (Worth 1903; Merriman 1941; Trent and Hassler 1968).

Tracking striped bass using radio signals from transmitters implanted completely within the abdominal cavity of the fish often required the radio receiver to be within 10 meters of a transmitter-equipped fish. To have greater signal range, sonic transmitters were added to the program in 1999. This substantially enhanced our ability to relocate fish in the system, including also fish with internal radio transmitters. When sonic transmitter-tagged fish were located, radio transmitter-tagged striped bass frequently were associated with them.

Broodstock fish implanted with radio transmitters in 1998 had just 12 to 15 days after being released into the Pascagoula River before water temperature in the river exceeded 26ºC. None of these fish were ever relocated in thermal refuge areas. Some were never relocated at all following their release, and there were several cases of confirmed post-release mortalities.

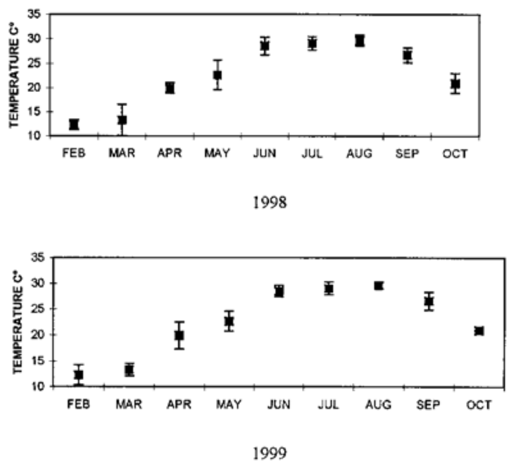

Figure 2. Mean monthly water temperatures in the main channel of the Pascagoula River during 1998–1999.

In contrast to 1998, radio and sonic transmitter-equipped broodstock hatchery fish released into the Pascagoula River in 1999 had 67 days in the river before water temperature in the river exceeded 26□C. This gave the 1999 broodstock hatchery fish an opportunity to explore the riverine environment prior to the onset of adverse thermal conditions, and subsequently an opportunity to find thermal refuge. These 1999 broodstock hatchery fish found the thermal refuge of the Cedar Creek effluent and, in contrast to tagged wild caught striped bass utilizing the refuge, the tagged broodstock fish remained in the refuge for a period of 11 days after water temperatures decreased below 25□C.

Cedar Creek and its effluent into the Pascagoula River provided thermal refuge for striped bass in this riverine ecosystem. However, it was a very small refuge and subsequently may induce crowding of striped bass in a very localized area. It also was readily accessible to anglers. Such crowding of striped bass has been shown to lead to overfishing, and can contribute to population declines (Coutant 1985).

This may be the case for the Cedar Creek effluent thermal refuge. The Cedar Creek effluent was the last relocation for five of the eight transmitter-equipped striped bass that we recorded in this thermal refuge. Striped bass using the thermal refuge at Cedar Creek possibly were targeted by local anglers. The Pascagoula River channel near the Cedar Creek effluent is heavily fished with trotlines. Additionally, one illegal hoopnet was located in Cedar Creek, approximately 500 meters upstream from the creek's confluence with the Pascagoula River.

One angler we interviewed reported that in 1985 Hurricane Elena changed the location of the Cedar Creek confluence with the Pascagoula River. He indicated that the original confluence was about one kilometer downstream from the present confluence location, and that this shift in the creek channel may have isolated important coolwater springs. This coincides with historical accounts that the last significant catches of the larger striped bass from the area were more than 10 years ago, and suggests that basin-wide natural disturbances (e.g., hurricanes) may be responsible for declining populations of striped bass in the Pascagoula River ecosystem.

Bluff Creek also served as a thermal refuge for striped bass during our study. It was also a small refuge but notably larger than the Cedar Creek effluent refuge. In addition to our observation of a large striped bass while electrofishing in Buff Creek during July 1998, angler reports during our creel surveys indicated numerous catches of smaller striped bass in the creek.

Interviews with fishers encountered throughout the Pascagoula River system revealed that they typically did not target striped bass, but will harvest them given the opportunity. This was especially so for larger fish. The river was exploited for catfishes, primarily with trotlines and limblines, and for flathead catfish *Pylodictis olivaris*, a highly predatory catfish (Jackson 1999), the trotlines and limblines were baited with live bait. Larger striped bass in the river seem to be vulnerable to this gear when it is baited with live bait, and especially so from February through May when these fish are engaged in upstream movements to spawn and/or to locate thermal refuge.

In consideration of the limited availability of thermal refuge for striped bass in the Pascagoula River ecosystem, and the system's apparently small number of large, potentially spawning adult fish, we propose that Bluff Creek and Cedar Creek thermal refuges be protected from fishing during the period May through September. This would help protect striped bass using these areas. Additionally, and because live baits have been associated with high hooking mortalities for striped bass (Harrell 1987; Hysmith et al. 1992), we also recommend that use of live bait on trotlines and other set lines be regulated during the period February through May in order to minimize bycatch harvesting and hooking mortality of striped bass, and particularly with respect to adult fish that may be moving in the system for spawning purposes.

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Use of Pulsed-light to Treat Raw Channel Catfish Fillets

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Fish shelf-life is determined mainly by microbiological spoilage. Shelf-life of raw, refrigerated channel catfish (*Ictalurus punctatus*) fillets ranges from 4–14 days. A new processing technology uses very brief intense pulses of broad-spectrum white light to reduce microbial loads of products. Catfish fillets were subjected to 0.25 and 0.50 J/cm^2 and 2–4 flashes, for a total of 0.5, 1, and 2.0 J/cm^2. Psychrotrophic plate counts were reduced ($p \le 0.05$) by 1.5 log CFU/g after treatment. Increased Hunter 'L' and 'b' values were observed after 4 and 2 days, respectively, on treated fillets. Thiobarbituric acid oxidation values (TBARs) increased for all treated fish after 2 days storage. Gapping was not affected by treatment and storage time. Decreased water holding capacity and moisture were observed for all catfish fillets during storage time.

Annual (live weight) catfish sales have grown from 87 million kg to more than 270 million kg in 2000. The U.S. per capita consumption has more than doubled to 0.51 kg in 2000 (USDA, 2001) in the past 10 years. Most of the catfish produced is in the form of fillets (Silva and Dean, 2001). Fresh shelf-life is limited by initial microbial load, temperature, handling, and other factors. Due to increased distribution channels and further distances to markets, it is necessary to search for methods and procedures to increase product's shelf-life. Conventional methods of extending shelf-life of channel catfish such as ice and refrigeration may not be sufficient to reach further markets from the center of the source, the Mississippi Delta. Investigations on the use of modified atmospheres (Ashie et al., 1996; Silva and White, 1994), sanitizers and antimicrobials (Handumrongkul and Silva, 1994; Efiuvwevwere and Ajiboye, 1996), and super chilling(Ashie et al., 1996) have shown the possibility of extending shelf-life by 2X to 5X. However, some of these technologies pose safety concerns, use unapproved additives, or may not be economically feasible. Non-thermal processes (Barbosa-Canovas et al., 1998) are being explored to treat products for increased shelf-life, increased keeping quality, and safety. Amongst these is pulsed light. The Pure Bright® process (Barbosa-Canovas et al., 1998) utilizes flashes of intense broad-spectrum pulse light to sterilize or decrease microbial load in pharmaceuticals, medical devices, packaging, and water. This process utilizes flashes of very short duration (<1 ms) of light contained in the visible, UV, and IR spectrum.

The system delivers a spectrum of light much more intense than sunlight or UV alone on the earth's surface. Since it is short in duration, the product suffers little, if any, temperature increases, thus maintaining its "freshness."

The system offers other advantages such as being able to act on the surface of prepackaged products and avoiding post-process contamination. The process has proven to be effective against spore and non-spore formers and achieving many log reductions in "transparent" materials (Barbosa-Canovas et al., 1998; Stier, 2000). The objectives of this study were to evaluate initial and periodic quality and

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