Influence of Temperature on Fish Survival and Distribution in a Heated East Texas Reservoir

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Abstract: A fish die-off involving primarily threadfin shad (*Dorosoma petenense*) occurred from July through September 1985 in Lake Monticello, Texas. Heated water discharged from the Monticello Power Plant plus adverse climatic conditions elevated lake water temperatures influencing fish distribution and survival. Respiratory stressors due to crowding of fish in limited refuge areas and intensified by prolonged high water temperatures, are suspected to have caused the mortality of an estimated 756,000 fish valued at $47,000.

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Fisheries management problems associated with cooling reservoirs are unique. High water temperature, a bi-product of steam-electric power generation, and its effect on aquatic organisms poses a major challenge to fisheries managers and researchers. Coutant (1985) stated temperature was the most important environmental stimulus for fish. Siler and Clugston (1975) report temperature can influence distribution, movement, abundance, reproduction, growth and condition of fish. The amount, rate, and duration of temperature change can induce thermal stress in fish (Siler and Clugston 1975). Disease, inadequate prey and prior exposure to toxicants may intensify the impact of thermal stressors (Coutant 1985). However, specific temperature requirements vary according to species, life stage, and physiological condition (Coutant 1975, Siler and Clugston 1975). Others have noted that geographic temperature preferences may result from long term acclimation or genetic adaptation of a given species to its environment (Talmage and Opresko 1981).

A prolonged die-off of fish occurred during July, August, and September 1985 in Lake Monticello, Texas. The results and conclusions derived from an investigation of this event are provided in hopes that they will contribute to better understanding of thermally influenced fish die-offs.

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Methods

Lake Monticello is located in northeast Texas, approximately 16 km southwest of Mount Pleasant, Titus County. It was constructed on Blundell and Smith Creeks by Texas Utilities Generating Company (TUGCO) as a cooling reservoir for lignite-fired steam-electric power generation. Impoundment began in August 1972, and the reservoir reached conservation pool elevation (104 m mean sea level) in the spring of 1973. The 810-ha reservoir has a maximum depth of 14 m and mean depth of 6.6 m. This lake has received national recognition in recent years for its production of trophy largemouth bass (*Micropterus salmoides*).

A series of 11 field investigations were conducted from 24 July through 11 September 1985 as a result of a prolonged fish die-off in the portion of the reservoir below FM 127 (Fig. 1). Temperature-oxygen profiles were taken at 1 m intervals with a YSI Model 54-A meter. Water samples were collected from the surface, mid-depth, and near the bottom at Stations W-2 through W-8 (Fig. 1). Total hardness, alkalinity, pH, turbidity, conductivity, and hydrogen sulfide concentrations were measured using a Hach Model DR-EL Engineer's Laboratory. An Eagle Mach 1 graph recorder was used to record fish distribution patterns.

Threadfin shad were collected by TUGCO and Texas Parks and Wildlife Department (TPWD) personnel. All samples were submitted to NUS Corporation, Laboratory Services Division, Houston, Texas, for heavy metals and pesticides analysis.

Fish counts were conducted in accordance with procedures described in Monetary Values of Freshwater Fish and Fish-Kill Counting Guidelines (American Fisheries Society 1982). Intervals between fish die-off estimates were at least 3 days to avoid duplication of previous counts. Five permanent transects were established to obtain open-water estimates (Fig. 1). Only fish within the width of the boat (1.6 m) and 5.0 m from the shoreline were collected during open-water estimates. Lengths of open-water transects were determined from TUGCO survey maps. Shoreline count stations were established in the lower portion of the reservoir (FM 127 bridge crossing to the dam). Shoreline count stations and direction of travel were randomly selected for each investigation. Shoreline count stations were 5.0 m wide, 30.5 m long, and 609 m apart. A rangefinder (Ranging L/R 80) was used to measure the 609-m (762 m on 13 Aug 85) gap distance between counts. All dead or dying fish were collected, separated by species and 25.4 mm groups, and recorded.

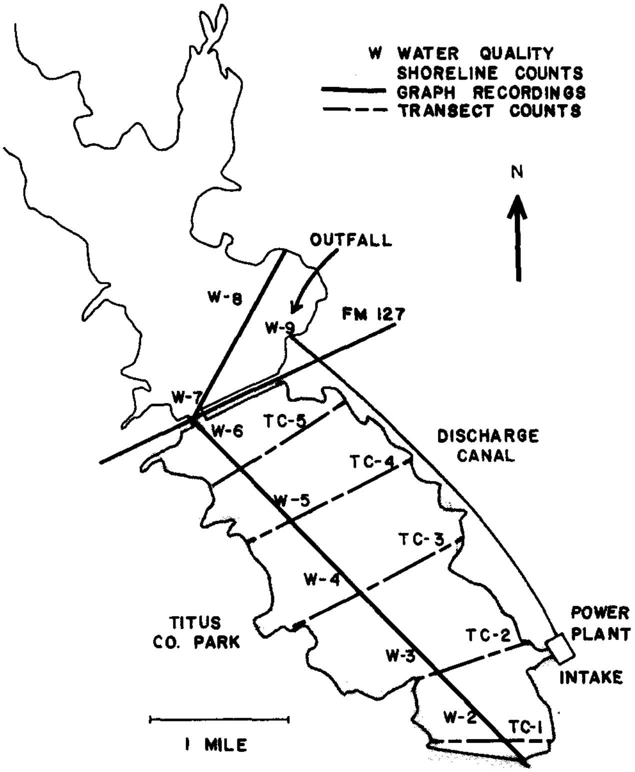

Figure 1. Fish distribution transects, water quality sampling stations, fish kill counting transects, and shoreline counting areas, in Lake Monticello, Texas, August and September 1985.

Results and Discussion

An estimated 756,000 fish were killed (Table 1). Threadfin shad comprised 99.5% of the numbers of fish killed. Other species affected were gizzard shad, minnows (*Notropis* spp.), largemouth bass, sunfish (*Lepomis* spp.), catfish, (*Ictalurus* spp. and *Noturus* spp.), and logperch (*Percina caproides*). Also, Asiatic clams and crayfish (*Procambarus* sp.) were killed.

Surface water temperature up to 45° C was recorded at the cooling water discharge (Station W-9). However, TUGCO was not in violation of their State or Federal discharge permits. Oxygen-temperature profiles at Station W-8, near the power station discharge, approached isothermal conditions, near 40° C. Profiles in the lower portion of the reservoir indicated little change in temperature from surface to 8 m (Fig. 2 and Table 2), but the water was approximately 4° C cooler than at

Table 1. Fish kill estimates and monetary values from Lake Monticello, Texas, 24 July–12 September 1985.

Species	Size range (mm)	Number killed	Monetary value
Gizzard shad	101.6–431.8	427	$ 104.51
Threadfin shad	25.4–127.0	752,139	45,128.34
Miscellaneous minnows	25.4	21	1.26
Black bullhead	76.2	39	5.07
Channel catfish	50.8–381.0	54	5.66
Madtom sp.	25.4–50.8	971	322.60
Green sunfish	10.16	18	10.62
Orangespotted sunfish	76.2–101.6	42	22.26
Bluegill	76.2–152.4	293	174.80
Longear sunfish	101.6	1	0.59
Redear sunfish	101.6–152.4	37	24.04
Largemouth bass	25.4–457.2	1,457	1,402.37
Logperch	25.4–127.0	570	34.20
TOTAL		756,069	$47,236.32

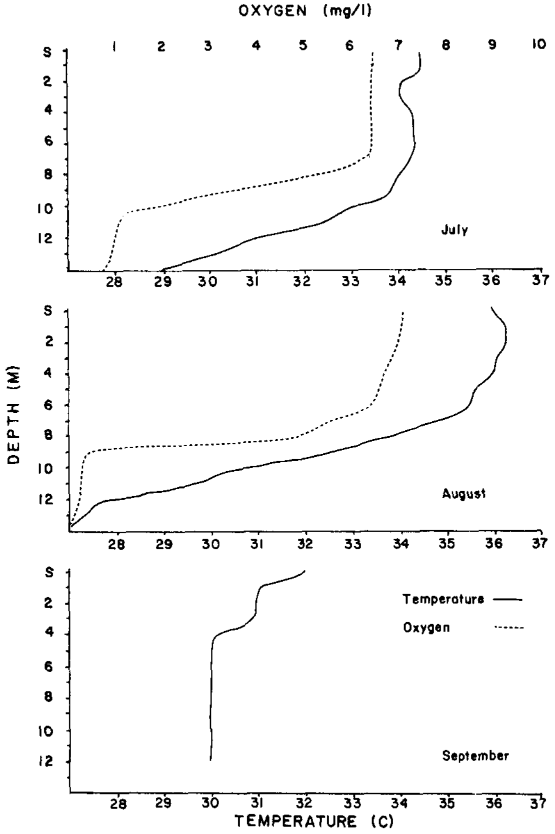

Figure 2. Temperature-oxygen profiles from W-3 at Lake Monticello, Texas, July, August, and September 1985.

Table 2. Water quality data from Lake Monticello, Texas, May, July, August, and September 1985.

Station	Depth (m)	Temp (°C)	D.O. (ppm)	pH	Total alk. (ppm)	Specific conductance (umhos/cm)	Turbidity (FTU)	Total hardness (ppm)
				May				
W-3	Surface	29.0	7.3	6.5		50	*	40
	1	29.0	7.0					
	2	29.0	6.8					
	3	29.0	6.8					
	4	29.0	6.8	6.5		60		40
	5	29.0	6.8					
	6	29.0	6.8					
	7	29.0	6.5					
	8	28.0	5.4					
	9	28.0	5.0	6.8	30	60		40
				July				
W-3	Surface	34.5	6.4	7.0	30	450	5	65
	1	34.5	6.4					
	2	34.0	6.3					
	3	34.0	6.3					
	4	34.3	6.3					
	5	34.3	6.4					
	6	34.4	6.4	7.3	40	450	20	60
	7	34.2	6.3					
	8	34.0	5.2					
	9	33.9	3.6					
	10	33.0	1.8					
	11	32.4	0.9					
	12	31.0	1.1	7.0	81	450	60	85
	13	30.1	1.0					
	14	28.9	0.7					
				August				
W-3	Surface	36.0	7.1					
	1	36.2	7.1					
	2	36.2	7.0					
	3	36.0	6.9					
	4	36.0	6.7					
	5	35.5	6.6					
	6	35.5	6.5					
	7	34.8	5.5					
	8	33.8	5.0					
	9	32.5	0.4					
	10	30.5	0.2					
	11	29.8	0.2					
	12	27.8	0.2					
	13	27.0	0.1					
				September				
W-3	Surface	32.0	*	*	45	*	*	65
	1	31.0						
	2	31.0						
	3	31.0						
	4	30.0						
	5	30.0						
	6	30.0			60			80
	7	30.0						
	8	30.0						
	9	30.0						
	10	30.0						
	11	30.0						
	12	30.0			45			65

Stations W-7, W-8, or W-9. Upper lethal tolerances for threadfin shad, gizzard shad, channel catfish and largemouth bass have been reported to range between 32° and 38° C, 28.5° and 36° C, 33.5° and 35.5° C, and 35.6° and 36.0° C, respectively (McKee and Wolf 1971, Talmage and Opresko 1981). Water temperatures in the epilimnion during the summer at Lake Monticello approaches or exceeds these upper lethal tolerances. An appreciable drop in temperature occurred below the thermocline but oxygen concentrations were too low to sustain fish life (Table 2). Boyd (1979) reported prolonged exposure of fish to dissolved oxygen concentrations ≤ 1 ppm would cause mortalities.

Fish distribution recordings indicated that most fish were distributed between FM 127 and the dam. Because water from the upper portion of the reservoir can only flow into the lower portion through a relatively narrow opening at the FM 127 bridge, heated water is concentrated in the upper portion of the reservoir, circulation flow is restricted, and current is intensified under the bridge (Geo-Marine 1984). Current may also be intensified as warmer water is pushed to the surface due to differences in the density of cooler water in the lower reservoir. Threadfin shad are likely attracted to the area near the bridge because of the current (Burns 1966) and lower water temperatures.

Fish occurred at all depths in the lower portion of the reservoir; however, the greatest concentrations were found between 3 and 6 m. Temperature-oxygen profiles at Stations W-5 and W-6 indicate this was also the area of coolest oxygenated water. The combination of high water temperature ($\geq$ 36 C) and low dissolved oxygen concentration ($\leq$ 1 mg/liter) restrict suitable habitat for fish to a relatively narrow zone in the lower portion of the reservoir (Fig. 3). Temperature-oxygen profiles taken at W-3 suggests this refuge zone was further reduced from July to August, corresponding with the height of the die-off (Table 2, Fig. 2). This reduction may be due to the combination of continued heating of the water column, a decrease of the epilimnion by evaporation and an increase in the hypolimnion by the addition of cool deoxygenated water pumped from Bob Sandlin Reservoir to maintain pool level. In addition, crowding may have degraded the quality of this refuge area inducing respiratory stressors.

Coutant (1985) theorized that a temperature-oxygen squeeze occurs when thermal loading and deoxygenation during summer reduces the volume of water having

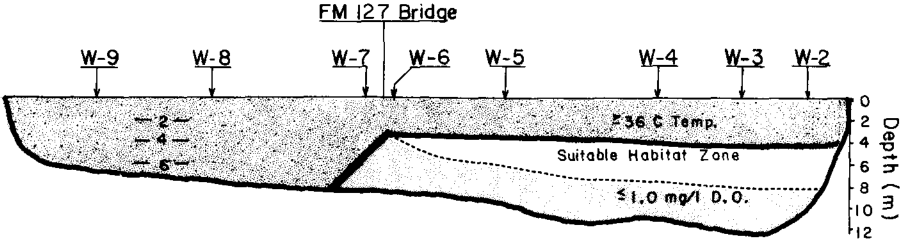

Figure 3. Suitable habitat zone in Lake Monticello, Texas, August 1985.

preferred temperatures. He stated that when the volume of suitable habitat is reduced during a temperature-oxygen squeeze, fish must either live in marginal habitat or move to refuges which maintain adequately cool and oxygenated water. When these refuges are not available or are too small to contain the numbers of fish present, population-limiting mechanisms come into play. In Lake Monticello, such refuges apparently were not sufficient in size or quality to sustain the threadfin shad population.

The extent of a die-off or adverse effects during a temperature-oxygen squeeze are dependent on: 1) severity of warming and deoxygenation, 2) duration of spatial limitations, and 3) the availability of thermal refuges in relation to numbers of fish during critical periods (Coutant 1985). As noted earlier, both temperature and oxygen concentration in Lake Monticello were critical. The data also indicate that the duration of spatial limitations lasted approximately 45 days (Fig. 2, Table 2). Finally, there was extremely limited thermal refuge in the lake (Fig. 3). Although Blundell and Smith creeks may provide a refuge in the riverine reach of the lake,

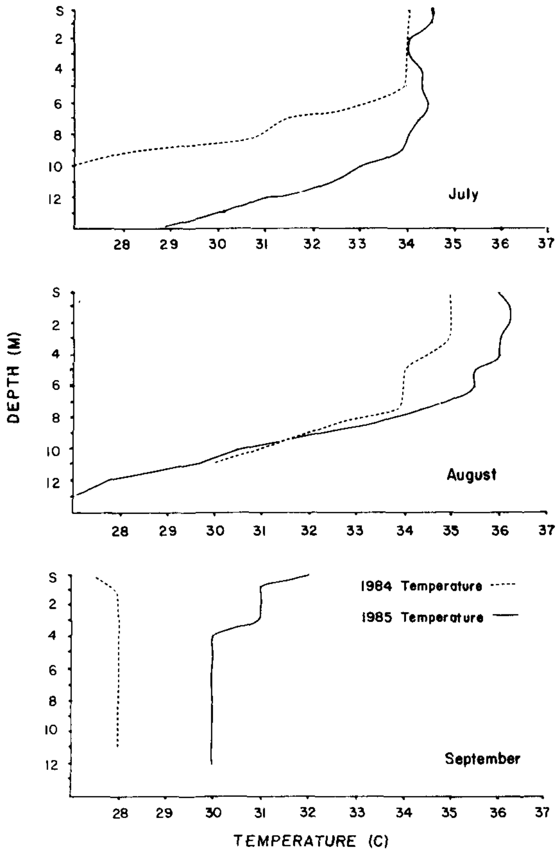

Figure 4. Comparisons of temperature profiles from Station W-3 at Lake Monticello, Texas, July, August, and September 1984 and 1985.

Table 3. Comparison of power production in megawatts/acre (MW/A) and megawatts/acre-foot (MW/A-ft) of several cooling reservoirs in Northeast Texas, 1986.

Reservoir	Utility co.	Max. power production (MW)	Reservoir size (A)	Storage capacity (A/ft)	MW/A	MW/A-ft
Alcoa	TUGCO	890	880	14,750	1.01	0.060
Arlington	TUGCO	1375	2275	45,170	0.60	0.030
Brandy Branch	SWEPCO[b]	720	1242	29,513	0.58	0.024
Fairfield	TUGCO	1150	2350	50,600	0.49	0.023
Fayette County	LCRA[c]	600	2400	72,000	0.25	0.008
Lake Creek	TUGCO	317	500	8,400	0.63	0.038
Martin Creek	TUGCO	2250	5020	77,620	0.44	0.029
Monticello	TUGCO	1900	2000	43,360	0.95	0.043
Mountain Creek	TUGCO	893	2710	22,840	0.33	0.039
North Lake	TUGCO	650	800	17,000	0.81	0.038
Rivercrest	TUGCO	110	550	7,000	0.20	0.016
Savoy (Valley)	TUGCO	1100	1080	15,400	1.02	0.067
Striker	TUGCO	675	2400	26,960	0.28	0.025
Tradinghouse	TUGCO	1340	2010	37,800	0.67	0.035
Welsh[a]	SWEPCO	1530	1365	23,205	1.12	0.066
Wilkes[a]	SWEPCO	879	650	10,000	1.35	0.088

[a] Equipped with cooling tower
[b] Southwestern Electric Power Co.
[c] Lower Colorado River Authority

most of the upper region of Lake Monticello above FM 127 was essentially uninhabitable due to high water temperature. Because of the reservoir design, this upper region presented a thermal barrier to fish migrating from the lower portion of the reservoir to the riverine reach. In addition, there was insufficient refuge area for threadfin shad in the lower portion due to the temperature-oxygen squeeze. The combination of the factors culminated in a prolonged die-off.

Thermal loading at Lake Monticello appears high compared to other cooling reservoirs in Texas (Table 3). Excluding Lakes Wilkes and Welsh (reservoirs having cooling towers), Lake Monticello ranks third behind Lakes Savoy and Aloca in power production per surface acre (MW/A) and power production per volume (MW/A-foot). During periods of peak power production, a greater demand for cooling water results in higher water temperature in the reservoir. Geo-Marine (1984) reports that consistently high power generation with prolonged hot atmospheric conditions may produce worst case conditions at Lake Monticello.

Concentrations of heavy metals and pesticides (Table 4) were either below detectable limits or were not considered high enough to induce moralities. All values were less than those reported as lethal by McKee and Wolf (1971).

Conclusion

Prolonged high water temperatures (at upper tolerance levels) caused a reduction of suitable habitat for fish, particularly clupeids. The effects of high water temperature alone may have caused some moralities. However, thermal effects were

Table 4. Concentration of heavy metals (mg/kg) and pesticides (μg/kg) found in *threadfin shad tissue (whole fish composite) from fish kill investigations conducted on* Lake Monticello, Texas, 24 July through 11 September 1985.[a]

	Station				
Parameter	1	2	3	4	5
Heavy Metals					
Se	<0.3	<0.3	<0.3	<0.3	<0.3
Ba	15	<7.4	<7.4	<7.4	15
Cd	<0.20	<0.17	<0.17	<0.17	<0.20
Cr	<1.0	<1.0	<1.0	<1.0	<1.0
Cu	0.7	0.7	0.7	0.7	0.7
Pb	<1.7	1.7	<1.7	<1.7	<1.7
Mn	55	63	37	52	52
Hg	0.7	0.2	0.4	0.3	<0.2
Ni	2.0	<0.67	<0.67	<0.67	<0.67
Ag	<0.7	<0.7	<0.7	<0.7	<0.7
Zn	32	27	24	33	20
Pesticides (NPDES Solids)					
Aldrin	<3	<3	<12	<19	<5
Alpha BHC	<2	<2	<5	<15	<4
Beta BHC	<2	<3	<6	<19	<3
Delta BHC	<2	<3	<6	<19	<5
Gamma BHC (indane)	<2	<2	<5	<17	<2
Chlordane	<4	<5	<12	<37	<5
4-4'DDD	<3	<3	<6	<19	<5
4-4'DDE	<3	<3	<6	<19	<3
4-4'DDT	<3	<3	<6	<19	<3
Dieldrin	<5	<3	<12	<19	<5
Endosulfan I	<2	<3	<6	<18	<5
Endosulfan II	<5	<5	<56	<19	<22
Endosulfan sulfate	<4	<5	<55	<18	<22
Endrin	<3	<3	<6	<19	<3
Endrin aldehyde	<5	<5	<6	<36	<7
Heptachlor	<2	<3	<6	<17	<4
Heptachlor epoxide	<3	<3	<6	<19	<3
Toxaphene	<21	<23	<55	<180	<22
Chlorinated Herbicides–solids					
2,4-D-Solids	<210	<200	<1700	<76	<400
2,4,5-T (Silvex)	<210	<200	<1700	<38	<200
Methoxychlor	<40	<44	<110	<360	<430

[a] Data supplied by TUGCO.

probably intensified by respiratory stressors resulting from concentrated numbers of fish in limited suitable habitat. Although thermal discharge limits were not violated, reservoir design and increased thermal loading may have exacerbated conditions leading to the die-off (Fig. 4).

Based on the findings in this study, the design of cooling reservoirs and appropriate measures to alleviate critically high thermal loading at future power plant sites should be a major concern of fisheries managers. As the demand for electricity increases, expanding the generating capacity of present power plant facilities may increase thermal loading in existing cooling reservoirs and prolonged die-offs caused by conditions similar to those observed at Lake Monticello may become more frequent. To maintain the outstanding sport fisheries many cooling reservoirs provide throughout the Southeast, further understanding of thermal effects on fish and the development of strategies to reduce the impact of such effects may be necessary to prevent major fisheries die-offs.

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