To the Graduate Council:

I am submitting herewith a thesis written by Harold R. Waddle entitled "Summer Habitat Selection by Striped Bass, *Morone saxatilis*, in Cherokee Reservoir, Tennessee, 1977." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Wildlife and Fisheries Science.

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SUMMER HABITAT SELECTION BY STRIPED BASS, *Morone saxatilis*, IN CHEROKEE RESERVOIR, TENNESSEE, 1977

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Harold R. Waddle

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ABSTRACT

Summer habitat selection patterns of 18 adult striped bass (*Morone saxatilis*) in Cherokee Reservoir were monitored with externally attached temperature-sensing acoustic or radio transmitters from June through September 1977. Mortalities of adult striped bass in this reservoir were hypothesized to be related to high summer temperatures and low dissolved oxygen (DO). Summer home ranges of most fish corresponded to cool, oxygenated spring or tributary effluents feeding shallow, submerged channels (less than 10 m deep) located in the lower reservoir. The inhabited areas or refuges differed from noninhabited areas by maintaining temperatures less than or equal to 22 C and DO concentrations greater than 5 mg/liter. Total water hardness, pH, and water transparency were not significantly different among refuges and noninhabited areas.

Movement of fish outside refuges occurred more frequently and for longer periods during June when the summer pattern of high temperatures and low DO was less severe. Fish experienced temperatures between 15 and 27 C with mean temperatures of individuals ranging from 18.5 to 22.0 C. Several tagged fish migrated outside the refuges and selected the lowest available temperature, generally near 21 C, even though DO concentrations at these temperatures were 3 mg/liter or less. Long-term survival of tagged and nontagged fish outside refuges was undetermined because no fish were tracked outside a refuge for more than 12 days without being lost. This study indicates that temperature strongly influences the behavior of striped bass and that adults of this species may have a thermal preferendum of approximately 21 C.

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CHAPTER I

INTRODUCTION

Striped bass (*Morone saxatilis* Walbaum), once generally considered an anadromous species, are now known to successfully inhabit freshwater for their entire lives. Since this discovery in the 1950s, populations of striped bass have been established in many reservoirs throughout the southeastern United States in an effort to fill an unexploited niche in the fishery. Reservoirs stocked with juvenile striped bass in Tennessee include Cherokee, Norris, Watts Bar, Percy Priest, Barkley, and Kentucky, of which only the latter two have had a documented occurrence of natural reproduction (Hogue et al., 1977).

As a result of these stockings, much research has been initiated in an effort to add to the biological knowledge of stiped bass in freshwater. Most research has dealt with age and growth, food habits, and associated parameters.

Certain incidents in recent years in Cherokee Reservoir have prompted additional studies. The occurrence of unexplained striped bass mortalities and suggestions of summertime aggregations of adult fish in certain portions of the reservoir precipitated this study to determine the summer habitat selected by striped bass in relation to environmental factors throughout this reservoir. Based on detailed studies of striped bass temperature selection in small quarry lakes and on preliminary temperature selection studies in Cherokee, it was hypothesized that high temperatures and low dissolved oxygen (DO) were

controlling factors in habitat selection (Coutant & Carroll, submitted). The critical objectives of this study were: (1) to determine the locations and temperatures experienced by adult striped bass tagged with electronic transmitters from May through November 1977; (2) to determine temperature and DO concentrations with depth throughout the reservoir from March through November 1977; (3) to determine water quality of areas frequented by adult striped bass from May through November 1977; and (4) to develop a predictive model for determining habitat selection with changes in temperature and DO concentrations.

CHAPTER II

HISTORY OF STRIPED BASS IN THE STUDY AREA

Juvenile striped bass have been stocked in Cherokee Reservoir each year since 1964 by the Tennessee Wildlife Resources Agency (TWRA). Growth and condition of these fish were excellent until the summer of 1971 when light mortalities of fish weighing over 7 pounds occurred in heavily fished areas (Bishop, 1978). Biologists of TWRA attributed these deaths to catch and release stress. However, in July 1972, mortalities occurred in areas receiving little, if any, fishing pressure. An aggregation of large striped bass, estimated at 200 fish, was discovered in August in a previously uninhabited spring-fed cove (Bishop, 1978). Deaths in this cove and in several other areas of the reservoir continued until the fall overturn occurred in early October. At that time, water quality was suspected as the problem but had not been checked regularly during the die-off period, late July through early October. From 1973 to 1975, the pattern of striped bass mortalities was similar. However, in 1976, mortalities occurred througout the entire year, although they were less numerous than in previous years. These mortalities have involved only the striped bass weighing more than 5 pounds. Striped bass in Cherokee Reservoir do not appear to live much beyond 7 years (Bishop, 1978).

No single factor has been attributed to causing these mortalities, although many factors are suspect. The Tennessee Department of Public Health, Division of Water Quality Control (DWQC), investigated water

quality in the reservoir during several summers and found DO concentrations greater than 5 mg/liter were generally confined to the strata within 6 m of the surface and where temperatures exceeded 26 C (DWQC, 1977). They also found extremely high concentrations of ammonia in the hypolimnion. At various times since 1972, fish pathologists of Auburn University have examined both moribund and seemingly healthy striped bass but have found no pathogenic parasites or diseases which might explain the mortalities. *Epistylis* sp. and bacterial infections, causing external lesions, occurred on many of the fish examined but not on every dead or dying individual. Cadmium, mercury, and zinc concentrations are high in some tissues of some examined fish, and a possible synergistic activity of these metals may be stressing them (Coutant, 1978).

No behavioral studies on adult striped bass in Cherokee Reservoir have been conducted in the past, but information from TWRA staff provides some indications of their behavior during the year. Creel checks reveal that aggregations of adult fish are usually found in the tailwater of John Sevier Dam, located immediately upstream from Cherokee Reservoir, in the early spring. Fishermen catches decline below this dam as the summer approaches. During late spring, early summer, late fall, and early winter, catches are reported throughout the reservoir. Catches appear to be concentrated in certain locations, particularly Mossy Creek Cove, in summer and early fall. Catches of striped bass have also been reported at Mossy Creek Cove in the late winter. It is not known if these fish migrate long distances or if they move about as schools in restricted portions of the reservoir.

CHAPTER III

DESCRIPTION OF THE STUDY AREA

Cherokee Reservoir is a multipurpose storage impoundment on the Holston River in East Tennessee (Figure 1). It was formed in 1941 by the Tennessee Valley Authority (TVA) upon completion of Cherokee Dam, located at Holston River Mile (HRM) 52.3. It is operated primarily for flood control and hydroelectric power generation.

Cherokee is one of several large, deep, TVA headwater reservoirs in the Tennessee River system. The surface area at full pool elevation, 328 m above mean sea level, is 12,591 ha, and maximum depth is 46 m (TVA, 1940). The pool stage fluctuates widely, and the drawdown from normal summer pool to normal minimum pool elevation is 28 m. The mean annual flow of 4480 cfs at the dam gives an annual average retention time of 0.35 years (Ungate & Hsieh, 1976). Depending upon the pool stage elevation, the reservoir extends between 30 and 54 river miles upstream from Cherokee Dam. At full pool the reservoir extends to the detention dam near the John Sevier Steam Plan at HRM 106.3. The summer water elevations generally vary from 321 to 327 m, while winter levels vary from 211 to 318 m.

The drainage area above Cherokee Dam is 8,879 sq km and is underlain by limestone, shales, and sandstones--of which limestone is dominant (Churchhill, 1970). Cover of the watershed is approximately 50% forest, 26% pasture, 12% cropland, and 12% other uses. The Holston River Basin upstream from Cherokee Reservoir is industrialized.

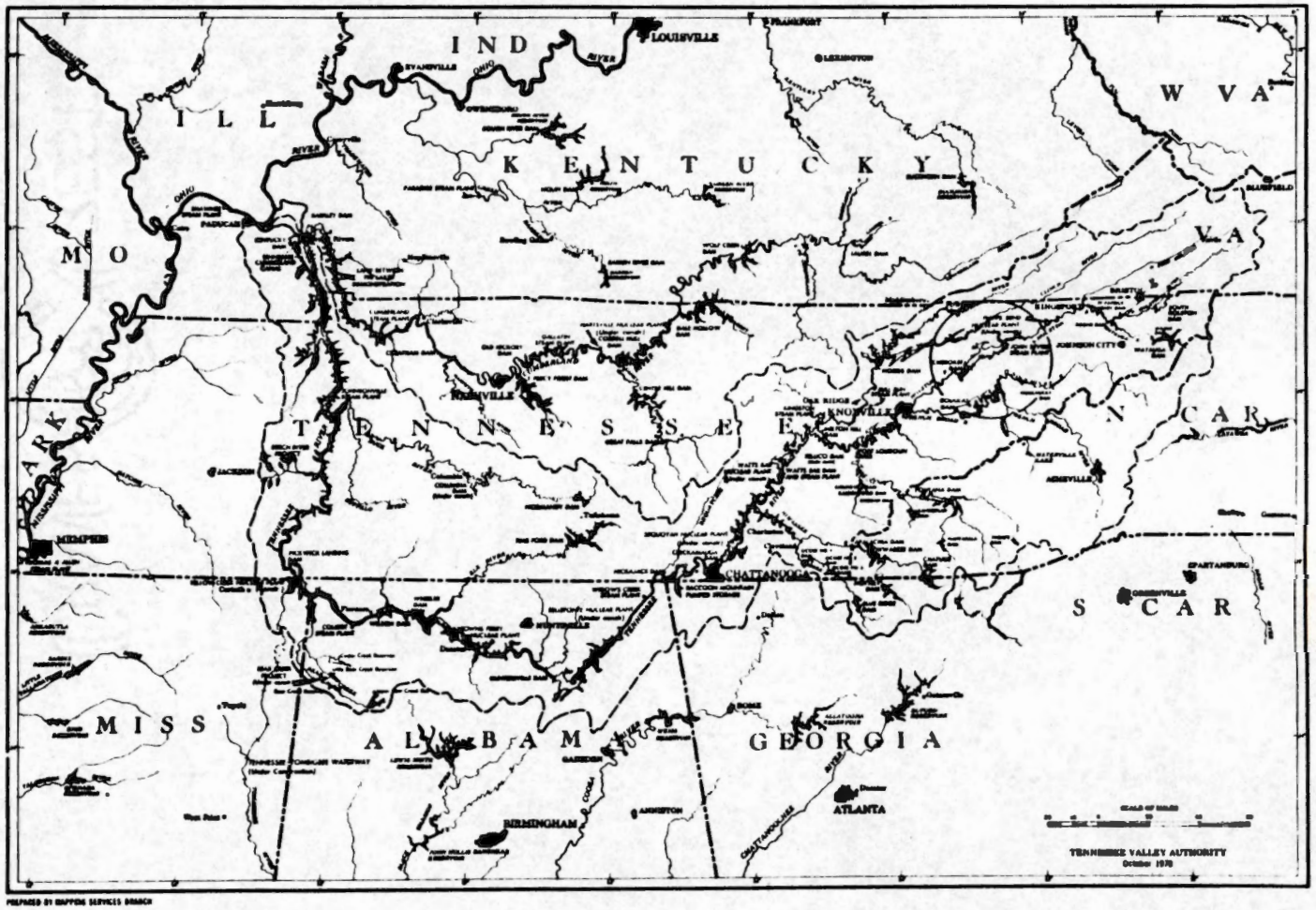

Figure 1. TVA map showing mainstream and tributary reservoirs.

Cherokee Reservoir is located in northeast Tennessee on the Holston River.

Chemical manufacturing and synthetic fiber plants comprise most of the industrial production. The Holston River upstream from Cherokee Reservoir receives large discharges of nutrient-rich domestic and industrial wastes.

Physical characteristics of the reservoir include numerous islands and large coves with shallow extremities. Ground-water springs and small tributaries are sparcely distributed in the lower reservoir.

Tributaries other than the Holston River contribute an insignificant volume of water to the reservoir compared to the Holston River inflow. Mossy Creek flows into a large cove near Cherokee Dam and is a site where striped bass mortalities occur. This creek receives tailing washings and cool seepage water from two zinc mines. The town of Jefferson City operates a secondary waste water treatment plant which empties 0.5 MGD (million gallons per day) of effluents into the outer cove of Mossy Creek. Treatments of these effluents have been described as being inadequate to protect the present water quality of the cove (DWQC, 1977).

The thermal and DO conditions in Cherokee Reservoir are known to exhibit seasonal variations (Ungate & Hsieh, 1976). During the winter months, November through February, the reservoir is practically isothermal, and dissolved oxygen concentrations remain near saturation at all depths. Temperature stratification begins in March and continues into September, when a warm horizontal surface stratum from 6 to 9 m deep is formed. Temperatures decrease at progressive depths. In late September, the water begins to cool with a large, warm surface layer

forming in the downstream portion of the reservoir. DO depletion occurs below a depth of 6 to 12 m as thermal stratification begins in the spring and continues through the summer and into the fall (Ungate & Hsieh, 1976). By October, the reservoir is only slightly stratified.

The thermal structure of Cherokee Reservoir is influenced heavily by meteorological conditions, Holston River flows, and discharge rates of the cool hypolimnion through Cherokee Dam (Ungate & Hsieh, 1976). The effect of discharges from John Sevier Steam Plant on the reservoir's thermal structure is not actually known, but results from TVA modeling studies suggest that under full plant operation, the mean monthly average outflow temperature from Cherokee Dam would increase 1.3 C in October and 2.6 C in March (Ungate & Hsieh, 1976).

CHAPTER IV

MATERIALS AND METHODS

Habitat selection of adult striped bass was determined during the late spring and summer of 1977 through the use of electronic telemetry methods. Temperature-sensing ultrasonic and radio transmitters (tags) were attached to fish taken from Cherokee Reservoir. Records were kept on fish movements and water temperatures experienced during monitoring periods. Water quality measurements, including temperature, DO concentrations, pH, total water hardness, and transparency, were taken in an attempt to relate water quality of habitat selected by fish to water quality of uninhabited areas.

Telemetry Equipment

An ultrasonic transmitter[1] with a temperature sensing thermistor was used in this study (Rochelle & Coutant, 1973, 1974; Rochelle, 1974). The location of the thermistor, at the tip of a flexible appendage extending from the body of the tag, allowed the tag to be implanted inside the stomach or body cavity of a fish with the thermistor protruding outside the fish's body. This arrangement has been successfully used to monitor water temperatures surrounding a tagged fish (Coutant, 1975; Coutant & Carroll, submitted).

Eight ultrasonic tags used in this study were cylindrical,

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[1]Tag Q-0599, Oak Ridge National Laboratory, P. O. Box X, Oak Ridge, TN 37830.

measured approximately 18 mm in diameter and 70 mm in length, and weighed 27 g in water. Tag life was expected to be at least 6 months. These tags emitted ultrasonic waves in pulses (signals) at a specific frequency between 70 and 100 KHz. The pulse rate was proportional to the temperature of the water surrounding the thermistor. Time intervals between pulses were determined in the laboratory at eight different temperatures from 0 to 35 C at 5-degree intervals for each tag and were plotted against temperature (Figure 2). Time intervals generally varied between 300 and 1400 msec. Curves constructed for each tag were used to derive regression coefficients needed to calculate temperatures from time-interval data.

A hand-held hydrophone (Smith-Root SR-70-H), having an 8-degree conical reception beam, was immersed below the surface to collect signals emitted by ultrasonic tags. A receiver (Smith-Root TR-60) amplified signals into audible "beeps." Signals were detected by tuning the receiver to a tag's frequency and pointing the hydrophone in the direction of the loudest "beep." The receiver was modified to connect to a digital frequency counter (Hewlett-Packard 5300).

A portable electromagnetic cassette tape recorder[2] was occasionally used to store time-interval data. The recorder provided continuous, long periods of time-interval data. During late July, August, and early September, this recorder was housed in a compartment aboard an anchored boat in a location near a tagged fish. With the use of an omni-

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[2]Fish tag recorder Q-5270, Oak Ridge National Laboratory, P. O. Box X, Oak Ridge, TN 37830.

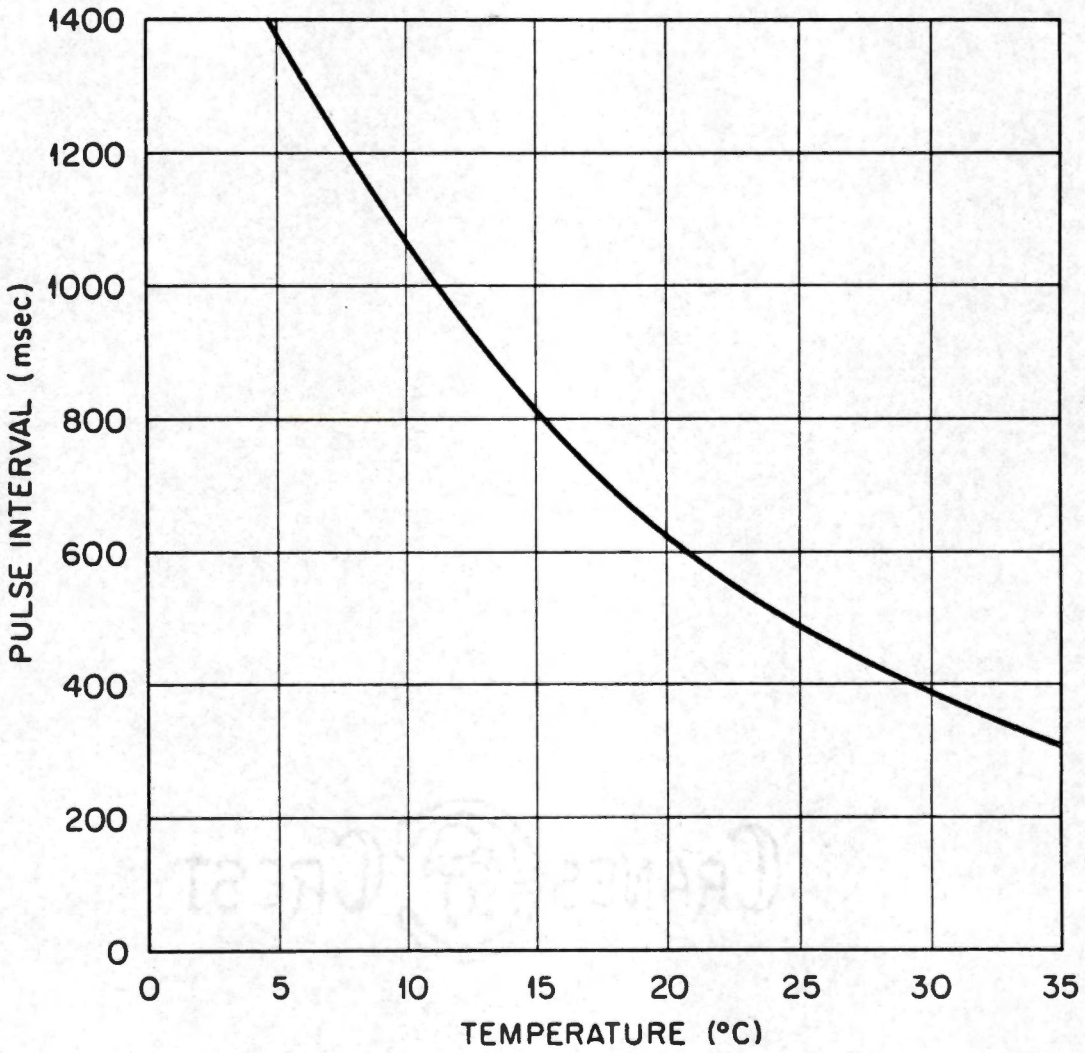

Figure 2. Pulse (time) interval-temperature relationship for ultrasonic tag number 159.

Time intervals between pulses from each tag were determined in the laboratory at 5, 10, 15, 20, 25, and 35 C. This calibration curve conformed to an exponential function, where temperature = $-a^{b}$ (time interval). The curve remained constant throughout the life of the tag and was used to convert time-interval data from the field to the appropriate temperatures.

directional hydrophone, signal reception was usually possible from any direction at distances less than approximately 100 m.

A radio-frequency telemetry system was used during September. This system worked like the ultrasonic system except that the tag transmitted its pulsed signal via a 151-152 MHz radio frequency. This frequency is received in air rather than in water. Signals were received by a hand-held yagi antenna, which relayed a tag's signals to a tuneable radio-frequency receiver (Wildlife Materials TRX-24). Seven temperature-sensing radio tags[3] were cylindrical and measured 25 mm in diameter and 80 mm in length. They weighed approximately 30 g in water.

All tags were marked at time of manufacture. This number was retained as the identification number for the tag throughout the study. When tags were reused on more than one fish (due to tagging failures, shed tags, fish being caught by fishermen, etc.), the number was followed by a letter (e.g., 152A, 152B, etc.) to provide a unique identity for individual fish.

Capture of Fish

Electrofishing with a boom shocking boat (Smith-Root Electrofisher IV), delivering 840 volts in pulsed direct current from a 4,000 watt generator, proved to be the only method successful for capturing adult striped bass in good condition. The boat with 6 m long electrodes was slowly motored into areas of coves where striped bass were suspected.

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[3]Manufactured by Cedar Creek Bio-Electronics Laboratory, University of Minnesota, St. Paul, MN 55101.

When a fish was stunned, it was immediately dipnetted and placed in a livewell with surface water cooled to approximately 21 C with ice.

The initial problem of capturing fish by this method was in locating them at depths less than approximately 5 m (the effective depth of the electroshocker). It was intended to obtain fish in the shallow tailwater of John Sevier Dam in the spring run, but initial electrofishing efforts there in mid-May produced only one fish. Later in May, striped bass were readily caught by fishermen at depths of 5 to 8 m over submerged islands or bars in the lower reservoir. However, electrofishing in areas where striped bass were known to concentrate in the summer produced no fish. Angling was attempted, and even though several fish were quickly pulled to the boat and tagged, the angling stress proved to be too great for them to endure. Survival time of tagged and released fish captured by angling did not exceed 6 hr. The capture of fish with gill or trammel nets was considered but not attempted. Survival of Cherokee fish caught by nets, even when immediately removed, was poor during the late spring and summer months (Bishop, 1978).

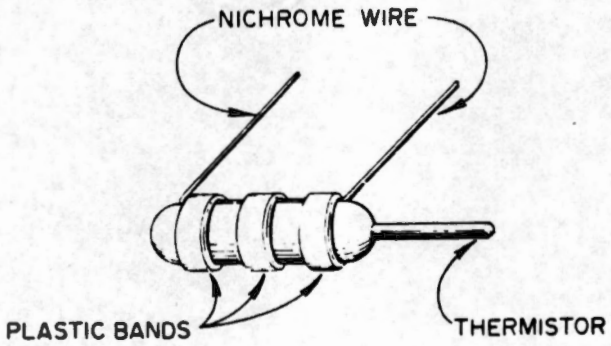
Tagging Procedure

Previous investigators have tagged striped bass by inserting transmitters into the stomach via alimentary canal (Koo & Wilson, 1972) or coelomic cavity by surgical methods (Summerfelt & Mosier, 1976; Coutant & Carroll, submitted; Dudley et al., 1977; Stooksbury, 1977). Coutant and Carroll (submitted) also found that 2-to-3-year-old fish would retain stomach tags with a flexible thermistor appendage extending

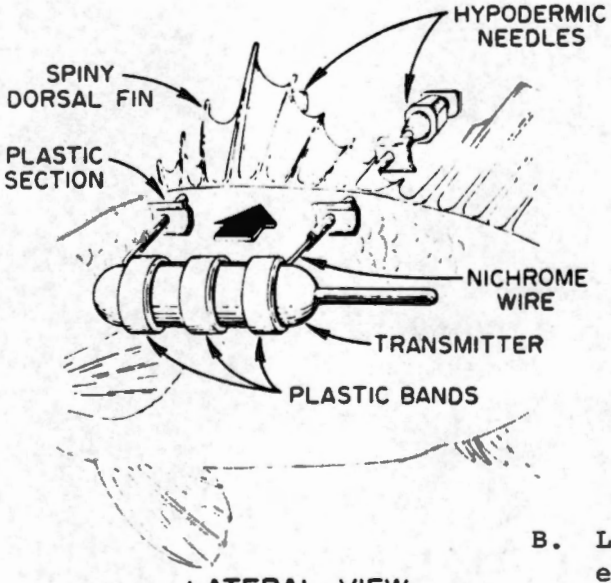
into the opercular cavity. However, they found that premature tag failure was much greater in the stomach tagging method than the surgical implantation method. The surgical method was attempted for this study but abandoned when striped bass died during the surgery. It was felt that a procedure was needed to rapidly attach the tag to a fish's body with a minimum of stress.

A method was developed that allowed a tag to be attached externally to a fish within 5 minutes. This method required rigging the tag with attachment wire and using surgical needles for penetrating the dorsal skin and connective tissue where the tag was attached. Low-carbon nichrome wire of 1 mm diameter, surgical grade plastic tubing, and two #16 gauge hypodermic needles with syringes were used. A length of wire about 15 cm in length was placed lengthwise on a tag, and narrow bands, cut approximately 1 cm wide from the tubing, were slipped over the ends of the tag-wire assembly. Three bands secured the wire to the tag. Ends of the wire were then bent at right angles to the lengthwise tag (Figure 3A).

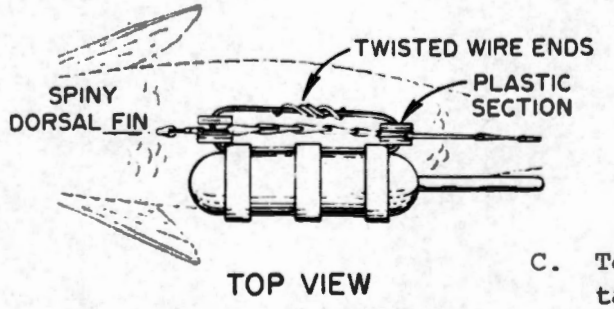
Immediately after captured fish were placed in the livewell, one hypodermic needle, piercing a small section of plastic cut from the tubing, was pushed through tissue just ventral to the anterior base of the spiny dorsal fin (Figure 3B). The second needle with a section of plastic was pushed through the back in the same direction as the first needle but located 5 to 7 cm posterior to the first needle. Insertion was made much easier by positioning the needle point under a scale before the needle was pushed through the back. Upon removal of the



A. Tag readied for attachment on fish



B. Lateral view of wire ends inserted through hypodermic needles



C. Top view of completed tagging procedure

Figure 3. Sequence of events in the attachment of a transmitter (tag) to a fish.

Fish and tag are not drawn to scale (tag size is exaggerated to show details).

syringe bodies, the ends of the wire on the tag assembly were pushed through the two needles, with the tag positioned on the fish's side with the protruding needle points. After wire ends were grasped on the opposite side of the fish, both needles were removed. Each tag was pulled tight against the fish's back, and the wire ends were secured by twisting them together (Figure 3C). Excess wire was clipped and removed. The four sections of plastic were provided to prevent the wire from cutting the fish at the wire penetration sites.

The entire tagging procedure could be performed in less than 5 min. Anesthetics, antibiotics, or other treatments were not used on any fish. Most fish were still in a state of electronarcosis during the tagging procedure. One person was required to perform the tagging procedure while another held the fish.

Because of the need to minimize handling to assure survival, accurate length and weight data could not be obtained for tagged fish. Visual estimates, based on nontagged fish which were examined, were made and noted.

Monitoring Tagged Fish

Attempts to locate tagged fish were made daily; however, bad weather, equipment failure, or inability to locate or detect tag signals precluded daily monitoring of most fish. Tagged fish were sought by cruising the reservoir and stopping at short intervals to listen for signals. A boat was motored to within effective signal range distance, usually less than 50 m, from tagged fish. However, both ultrasonic and radio tags could be detected at distances up to 300 m under ideal

conditions. Fish with ultrasonic tags located in submerged channels or areas with obstructions had to be approached within 20 m for signal reception. Radio tag signals from fish at depths greater than approximately 8 m could not be readily detected.

After a tagged fish was within monitoring distance, time-interval observations were recorded during a 30 min period. Time intervals were displayed on the counter every 10 sec. On many occasions time-intervals were recorded for periods less than a 30 min period. These data were referred to as "spot checks" and were not included in the thermal history statistics. Location, fish movement, time, and weather conditions were noted at each monitoring period. Triangulation was used to determine a fish's horizontal location which was marked on a 1:24,000-scale aerial photograph map. Vertical locations of monitored fish were determined from time-interval statistics and temperature-depth profiles.

Calculation of Temperatures from Time-Interval Data

Descriptive statistics were determined for each data set of manually and automatically recorded time intervals by computer. Time intervals and corresponding temperatures were best described by the logarithmic function, $y = a + b (\ln x)$, where x = temperature in degrees Celsius and y = time intervals in msec. The a and b coefficients were determined for each tag's calibration curve by using the temperature range tagged fish would most probably experience during the summer (14 to 30 C) in a logarithmic curve-fit program. Time intervals of those temperatures within the 14 to 30 C range not checked during tag calibration were determined by inspection from the calibration curve. The

coefficient of determination was also computed to show the goodness of fit. Temperatures at the extremes of some calibration curves were deleted in computations to obtain coefficients best fitting that portion of the curve between 18 and 25 C.

Time intervals (observations) recorded on cassette tapes were transferred to a DEC System 10 computer memory disk. Because electronic static or interfering noises from passing boats caused occasional erroneous observations, a series of programs (Watts, 1978) were used to delete some of the erroneous data. All observations outside a range of time intervals, corresponding to the minimum and maximum temperatures available in the area where a fish was monitored (usually between 15 and 30 C), were determined erroneous and deleted. Occasional erratic observations (i.e., those outside the narrow, well-defined range of most of the data but within the range of available temperatures) could not be verified as accurate but were not deleted. The figures in Appendix A show possible erroneous observations (i.e., those occurring at temperatures outside the narrow band of obviously accurate observations). Because manual data sets showed occasional observations outside a definite, more frequent range of observations and these observations were known to be valid, the erratic observations in automatic data sets could have been valid. Mean, standard deviation (SD), skewness, kurtosis, and frequency distributions were calculated by an IBM 360 computer for each hour and by each cumulative period of data using a SAS 76 program (Barr et al., 1976). Only the statistics for the consistent automatic data were included in the results. These statistics are presented in Appendix A.

Manually recorded time intervals were punched on computer cards. Descriptive statistics for these 30 min data sets were determined for individual sets and for the cumulative data on each fish.

Time-interval data could be easily converted to temperatures and average temperatures and standard deviations calculated in the field using a programmable pocket calculator (Hewlett-Packard HP-65) with a program described by Coutant (1977b). These preliminary data analyses allowed rapid recognition of trends in temperature selection by the fish.

Collection of Water Quality Data

Measurements of temperature, DO, pH, total water hardness, and transparency were taken at least twice a month from March through October at eight stations in the reservoir channel (Figure 4). Stations upstream from HRM 98 were not surveyed after June because shoals made them inaccessible by boat. Areas inhabited by tagged fish were surveyed as were the main stations. Temperatures were measured with an electronic thermometer (YSI 46 TUC) to tenths of a degree Celsius. Data were taken at 1 m intervals in the top 10 m of the water column, then at 5 m intervals from there to the bottom. Concentrations of DO were determined by a portable electronic meter in the field at the same depths as the temperature measurements. The DO meter was checked for accuracy during a sampling run with a portable chemical kit. Transparency was measured with a Secchi disk. Total hardness and pH were determined in the field with a portable chemical kit (Hach DR-EL). Water samples for the latter two parameters were taken at the surface and at a depth of 8 m or bottom.

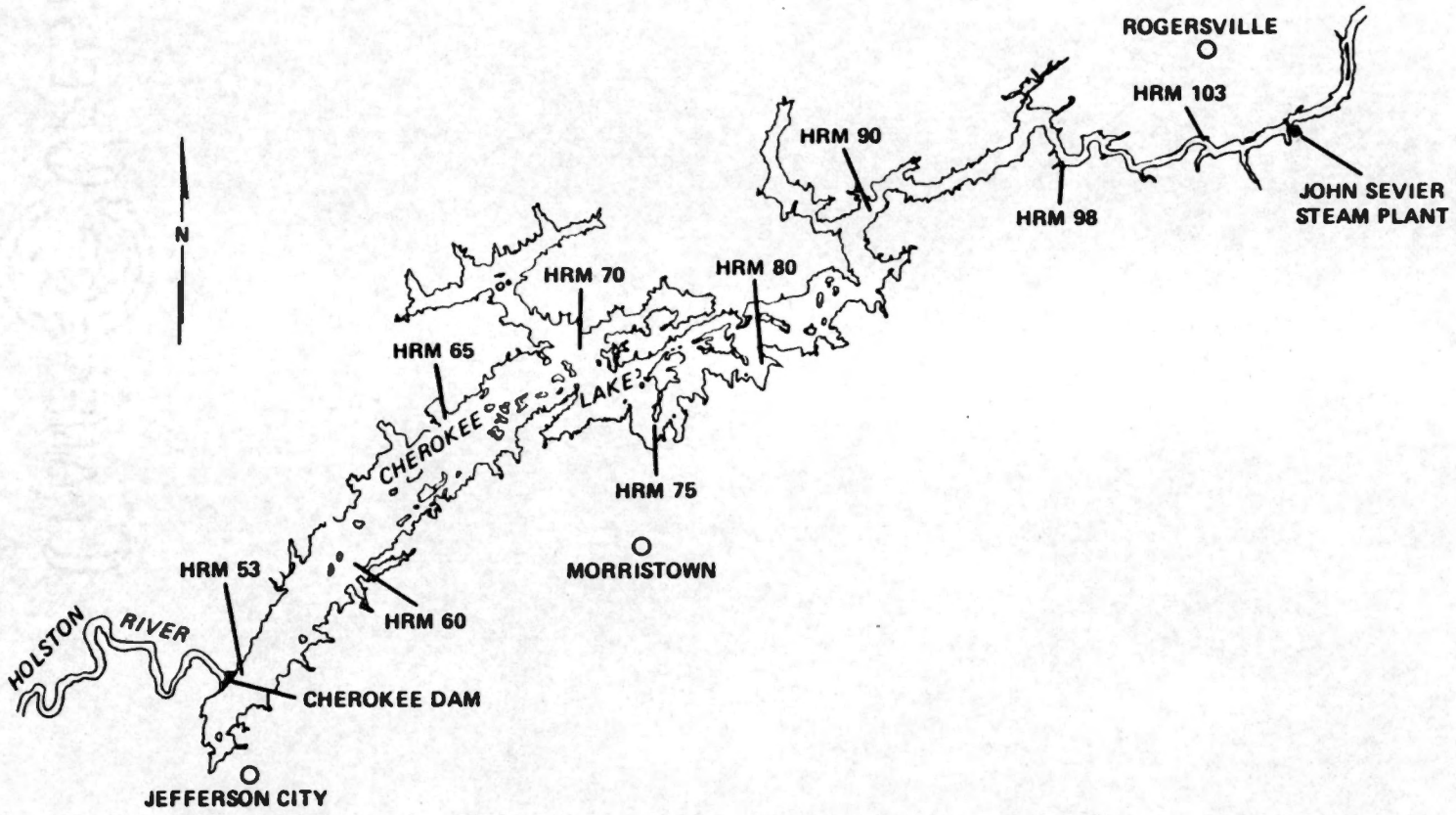


Figure 4. Locations of nine water-quality sampling stations in Cherokee Reservoir (designated by the Holston River Miles (HRM) shown).

A computer program (DeAngelis, 1978) was used to draw isopleths of temperatures and DO concentrations on a longitudinal section of Cherokee Reservoir. Field data were transferred to computer cards for mechanical graphing.

CHAPTER V

RESULTS

A total of 34 striped bass adults were tagged during the study, but 16 of these taggings were not successful, and the data (if any) were not included in the habitat selection statistics. Fates of the unsuccessfully monitored fish were as follows: one died after surgical implantation of a tag; eight died within 24 hr after release (four of these were captured by angling); and seven were not found after release (two of these were displaced to sites other than where captured).

Eighteen fish provided valuable habitat selection results during a period from June 6 to September 30, excluding 2 days in September when no tags were on fish. A summary of these results is presented in Table 1. Sixteen of these fish were monitored over a period of at least 1 week before their termination, except Fishes 152C and 156C. Both fish were caught by fishermen several days after their releases and were included in the 18 successfully monitored fish due to their apparent good condition and typical temperature selection behavior. The elapsed period of time from release to termination of a fish ranged from 2 to 37 days and averaged 17 days.

Six of the 18 fish (33%) were caught by fishermen, but only one fish (155B) was known to be released after being captured by a fisherman. Questions answered by four fishermen who returned tags from captured fish revealed that (1) three fish were hooked in the mouth, and one was snagged in the body; (2) each fish was located on or near

Table 1. Summary of Biotelemetry Data from 18 Adult Striped Bass in Cherokee Reservoir During the Summer of 1977

Fish number	Date released	Date terminated	Elapsed tag or fish life	Reason terminated[a]	Refuge inhabited[b]	Cumulative distance moved[c]	Monitored temperature results						
							Number of observations[d]	Mean	Modal class	SD	Min	Max	Skewness	Kurtosis
			----Days---			----km----		-----°C----			°C	°C		
Sonic tags														
152A	June 6	July 1	25	Shed	MC	7.9	910	19.1	18[e]	2.6	14.8	25.9	.12	-.90
155A	June 7	June 22	15	Shed	MC	7.5	901	20.8	21	1.1	16.6	23.9	-.89	-.20
160A	June 21	July 9	18	Shed	MC	1.4	1099	18.5	17	1.2	17.1	23.6	1.14	.69
156C	June 29	July 22	23	Caught	MC	NMD	154*	18.0	16	1.9	17.1	23.6	-.07	-1.13
152B	July 12	July 23	11	Died	MC	6.6	943*	22.2	22	2.4	17.6	27.9	.21	-.83
155B	July 12	July 20	8	Shed	MC	2.3	1089	20.4	20	1.4	17.6	26.5	.39	-.23
158	July 12	Aug 18	37	Died	CH	4.2	7041*	20.9	21	2.2	15.0	31.4	.11	.29
159A	July 12	Aug 1	20	Caught	CH	2.1	5004*	22.0	20	2.1	15.5	29.4	1.24	2.14
152C	Aug 1	Aug 3	2	Caught	MC	NMD	361	21.2	19	1.3	19.1	24.1	-.38	-1.39
									22+					
156D	Aug 1	Aug 18	17	Caught	BS-MC	2.2	1933	20.9	19	1.4	17.8	26.6	.69	.46
160B	Aug 1	Aug 15	14	Caught	MC	0.9	1375	21.9	21	1.9	16.7	25.2	-.66	-.51
									23+					
159B	Aug 1	Aug 26	25	Shed	BS	10.8	2478	21.9	21	1.9	18.1	27.1	.73	.17
155C	Aug 4	Aug 30	26	Lost	CH	4.3	2345	21.1	20	3.5	16.1	27.3	.48	-1.34
152D	Aug 16	Sept 5	20	Caught	BS	2.2	1949*	20.2	20	4.2	14.1	29.8	.28	.51
Radio tags														
338	Sept 1	Sept 12	11	Shed	CH	NMD	1193	21.8	21	1.8	17.9	27.9	.01	-.15
268	Sept 1	Sept 20	19	Lost	CH	NMD	1755	19.3	18	1.9	15.3	25.9	.64	.45
211	Sept 8	Sept 20	12	Lost	CH	NMD	1049	19.2	19	1.8	15.6	22.7	.78	-.65
196	Sept 23	Sept 30	7	Lost	MC	NMD	884	19.3	20	1.2	16.6	26.1	.08	1.05

[a] Caught--Fish was captured by a fisherman.
Died--Death of the fish was verified.
Lost--No signal was received from the tag.
Shed--Tag became detached from fish's body.

[b] BS = Byrd Spring; CH = Cedar Hill; MC = Mossy Creek

[c] NMD = Little or no movement detected

[d] The * monitored temperature results presented for this fish are from pooled manual and automatic data sets.

[e] Histograms showing distributions with modal classes are presented in Appendix C. + = bimodal distributions

the bottom when caught; and (3) all fish seemed in good condition. No angler-captured fish was examined by the author.

Several decomposing carcasses with tags were examined for evidence of tagging effects. Each carcass possessed external trauma areas as large as 1.0 cm in diameter surrounding the wire penetration sites.

The loss of six fish due to shed tags ranked second in total number of tags returned for reuse (Table 1). All shed tags recovered, except one (No. 338), a radio tag, had the harness assembly intact and attached to the tag body. The presence of aquatic vegetation on one tag and external scratches on another tag recovered near a rocky, creviced bottom may indicate tags were snagged and pulled loose from the fish's body. It is not unlikely, with the high percentage of tagged fish being caught, that some "shed tags" were actually discarded by fishermen who caught tagged fish.

Inhabited Sites and Fish Activity

During the period from June through September, 17 of the 18 successfully monitored striped bass inhabited one or at most two of three relatively small areas, compared to the remainder of the reservoir, for the majority of their tracking lives (Figure 5). Only one fish (155A) spent more than 75% of its tracking life outside one of these areas (Table 2). These areas were generally confined to or in the near vicinity of the submerged channels located in Mossy Creek, Byrd Spring, and Cedar Hill coves. Specific locations inhabited by individual fish with a description of each fish's thermal history and movements are presented in Appendix B.

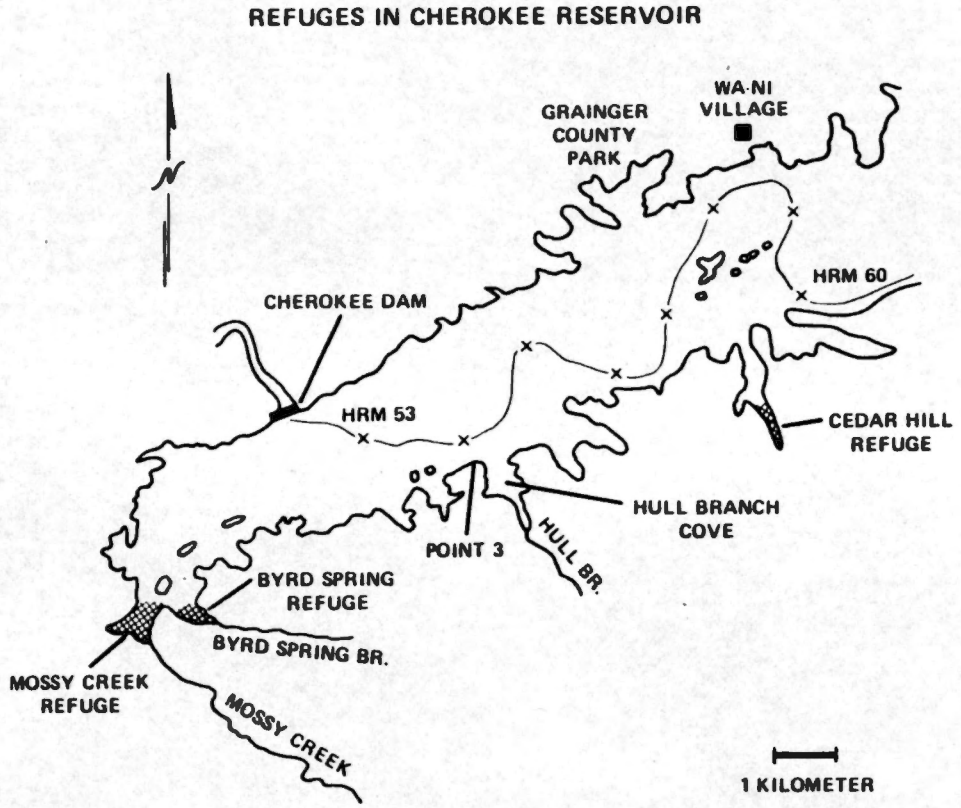


Figure 5. Zones of habitation by 18 tagged striped bass in Cherokee Reservoir as indicated by the shaded areas.

Fish inhabited only one zone, but three moved from Byrd Spring to the Mossy Creek zone during their tracking lives.

Table 2. Amount of Time Spent by 18 Tagged Fish in Refuge Areas During Tracking Intervals[a]

Month(s) tracked	Fish number	Time in refuges (days)	Time outside refuges (days)	Percentage of tracking life in refuge
June	152A[b]	19	5	79
June	155A[b]	3	12	20
June-July	160A	18	0	100
July	152B	9	2	82
July	155B	7	1	88
July	156C[c]	3	--	--
July	159A	20	0	100
July-August	158	37	1	97
August	152C	2	0	100
August	152D	20	0	100
August	155C	21	5	81
August	156D	16	0	100
August	159B	25	1	96
August	160B	14	0	100
September	338[d]	11	0	100
September	268[d]	19	--	--
September	196B[d]	7	--	--
September	211[d]	12	--	--

[a]The majority of tagged striped bass preferred refuges during their tracking lives.

[b]Tracking life of fish was terminated outside a refuge.

[c]Fish's movements were indeterminate.

[d]Fish was believed to have moved from a refuge.

Coves frequented by the fish were in a dynamic state during the study because their areas, depths, and water column temperatures were constantly changing. The reservoir surface level rose from 311 m above sea level on March 1 to a high of 323 m in early May. By May 31, it had receded by 5 m, and it continued to drop between 2 and 3 m during June, July, and August to a low of 315 m in early September. By mid-August the surface dropped below the springs in Byrd Spring and Cedar Hill coves, and tagged fish were then found in the spring-reservoir confluence area downstream from the groundwater sources.

For the majority of monitoring periods, tagged fish in refuges were located adjacent to the bottom within the channels originating from the flowing creek or spring effluents. Fish in Byrd Spring and Cedar Hill coves were often located directly over the springs when depths there were not less than approximately 2 m.

Fifteen of the 18 tagged fish inhabited the cove where they had been captured, tagged, and released. The other three fish (152D, 156D, and 159B) migrated to Mossy Creek cove after being released near Byrd Spring. Fish 159B moved from Byrd Spring immediately after release, whereas the other two fish inhabited Byrd Spring cove for the majority of their tracking lives. These two zones of habitation were separated by a direct water distance of approximately 2 km.

Unlike most other tagged fish, four fish (152A, 152B, 155A, and 155C) frequented areas other than those we came to recognize as refuges for a considerable portion of their tracking lives (Table 2). Each fish, except 152B, moved from its respective refuge within several

days after its release. Fish 152B was found alive outside Mossy Creek refuge for only two brief periods during its tracking life. Fish 152A, 155A, and 155C returned to their respective refuges within 5 days after their movements outside them. No long-term tracking data were obtained from these four fish when outside refuges because they either returned to a refuge, shed their tags, died, or were lost.

Three fish with radio tags may have moved from refuges in late September when reservoir temperatures began dropping. These fish were not found subsequent to their loss, although extensive searches were made in the lower reservoir. Recovery of one radio tag (No. 196) on the shore near HRM 68 over 1 year later suggests that these fish moved beyond the lower reservoir study area.

Most fish moved occasionally during monitoring periods. These distances were usually less than 200 m away from the stationary tracking boat. Out of 189 monitoring periods for sonic-tagged fish when the fish's activity was determinable, 116 (61%) showed movement. Automatically recorded time-interval data also revealed occasional movements of fish, as changes in a fish's location resulted in bad time-interval observations from poor signal reception.

Only three fish were monitored while moving outside a refuge, and they moved considerably further than 200 m. Fish 155A and 159B moved 2.6 and 3.2 km, respectively, before stopping, with their rates of movement being 0.7 and 1.1 km/hour, respectively. Fish 155C moved about 1.1 km during a 30 min period at a rate of 2.2 km/hour. Each of these fish exhibited a stop and rest behavior during monitoring periods.

Fish outside refuges were never found at depths greater than approximately 15 m (Figures 6-10). Depths frequented during monitoring

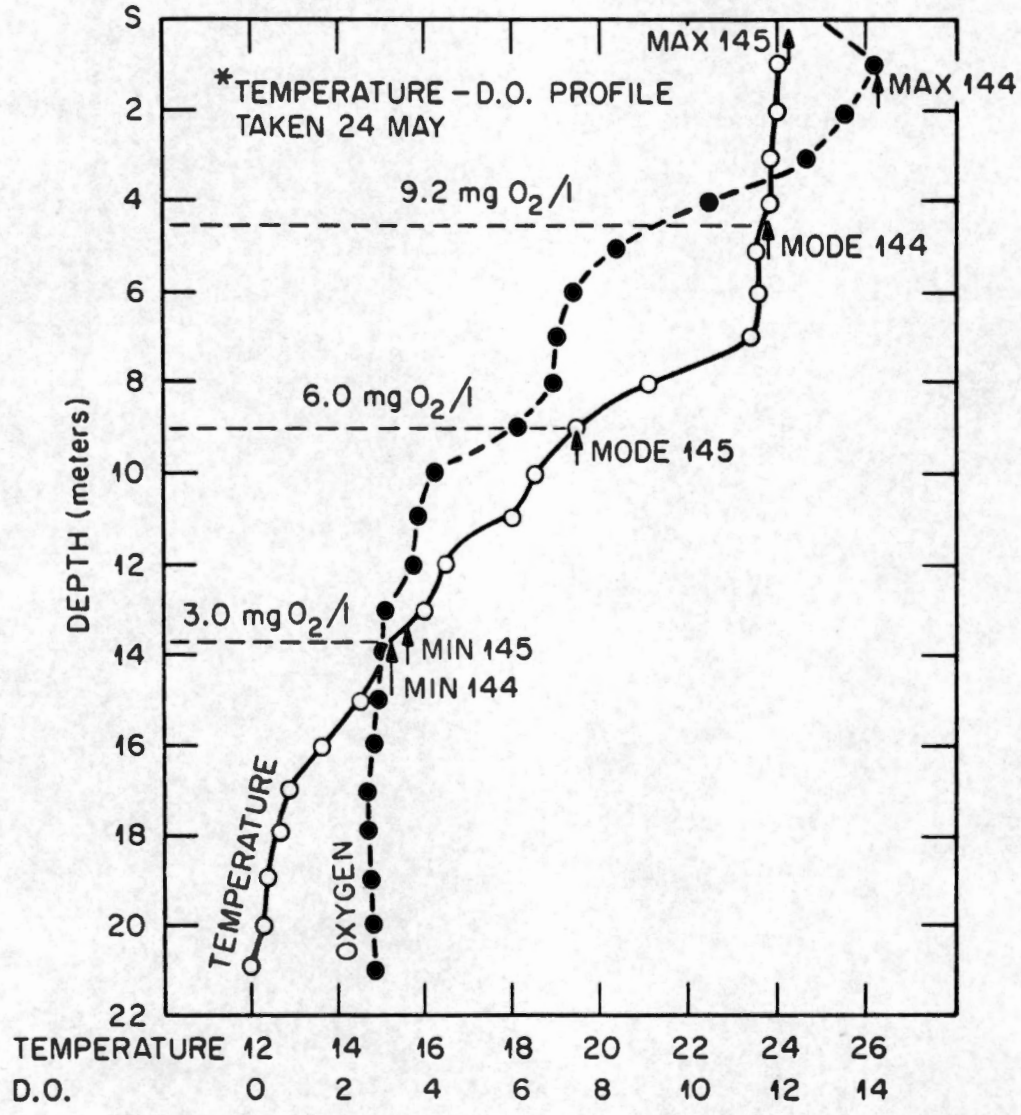


Figure 6. Temperature-dissolved oxygen profile with an analysis of temperatures experienced by two unsuccessfully tagged fish (144 and 145) after their release in water outside refuges on May 23 and 24, 1977.

Both fish were believed to have died within 6 hr of release.

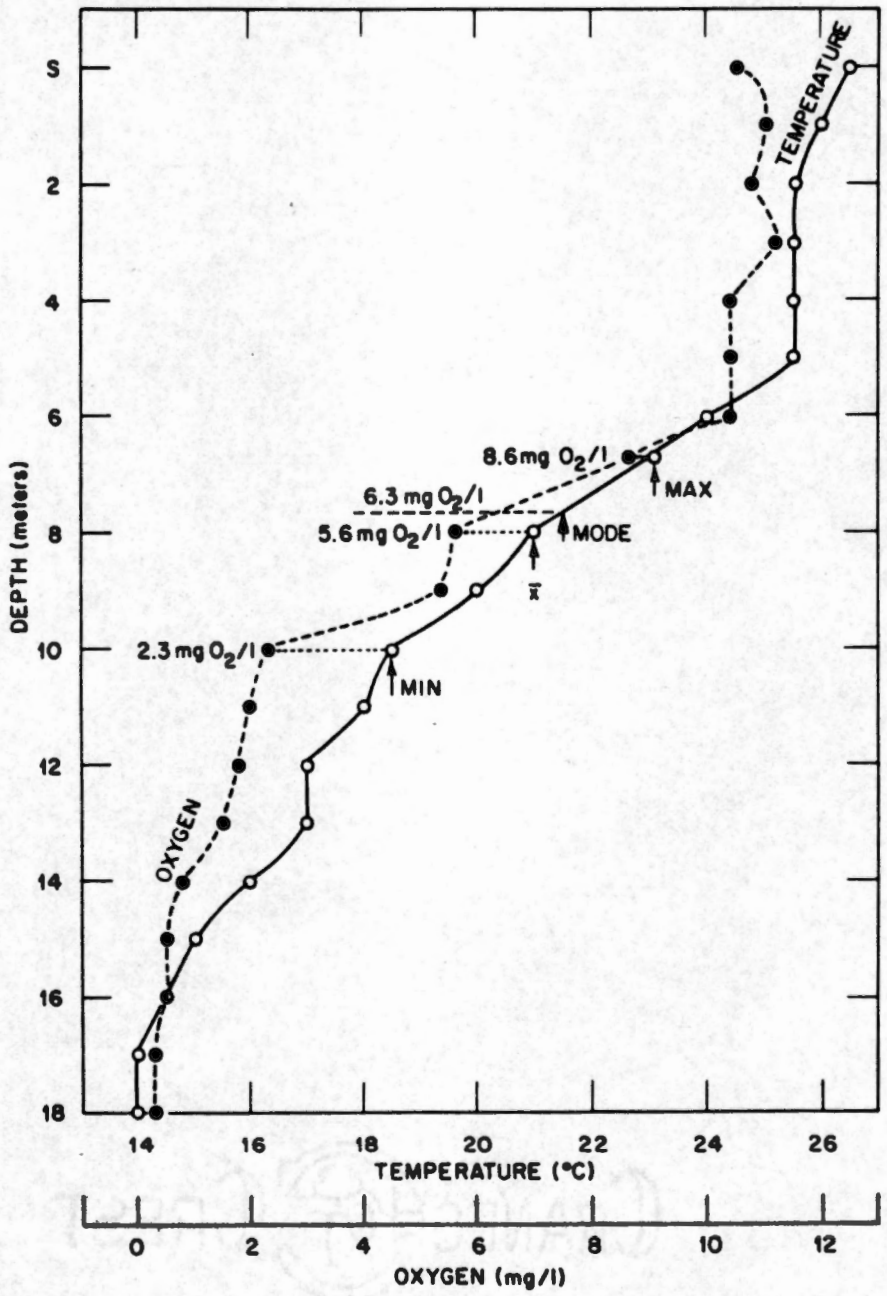


Figure 7. Temperature-dissolved oxygen profile with an analysis of temperatures experienced by Fish 152A outside Mossy Creek refuge on June 7, 1977.

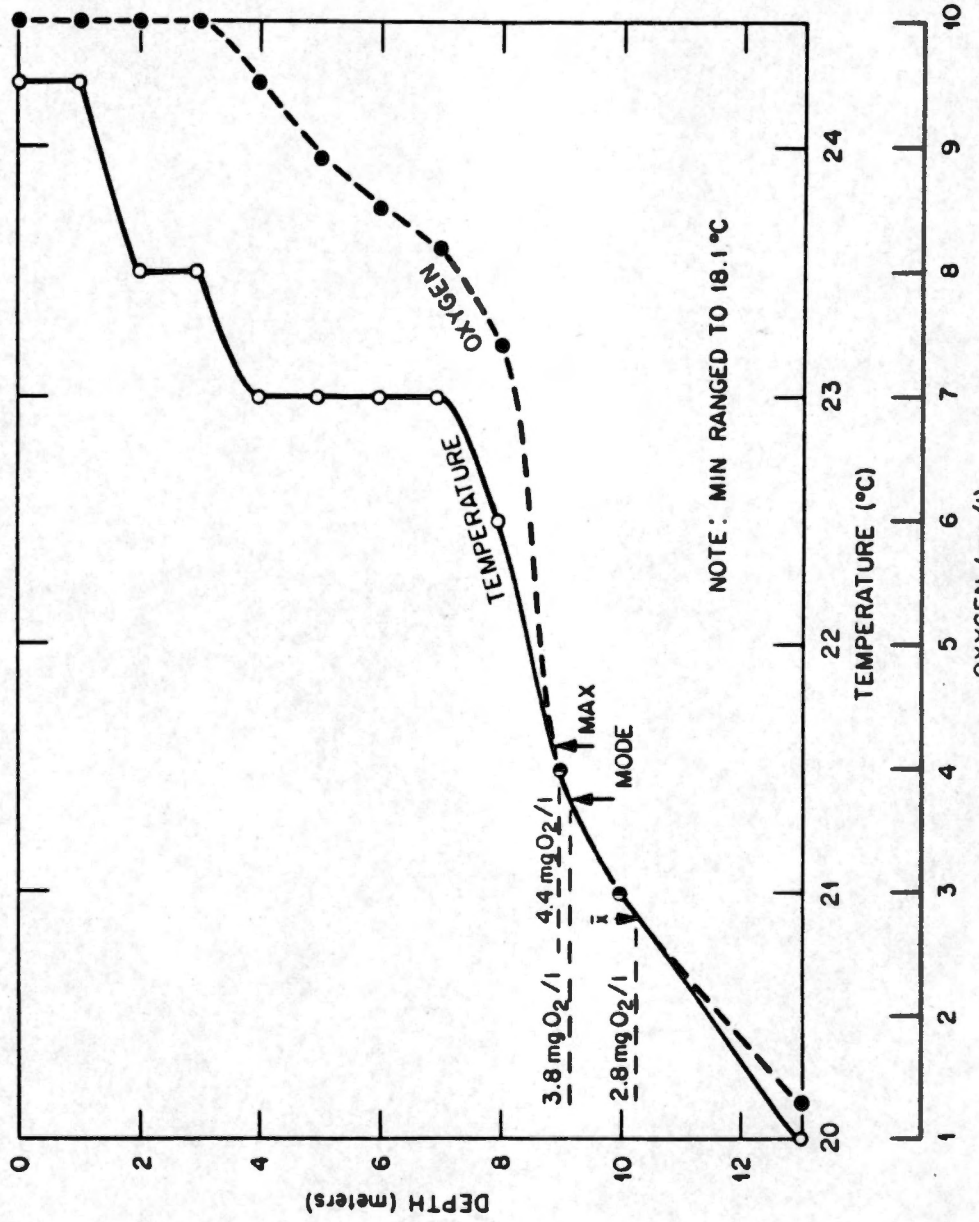


Figure 8. Temperature-dissolved oxygen profile with an analysis of temperatures experienced by Fish 155A outside Mossy Creek refuge on June 11, 1977.

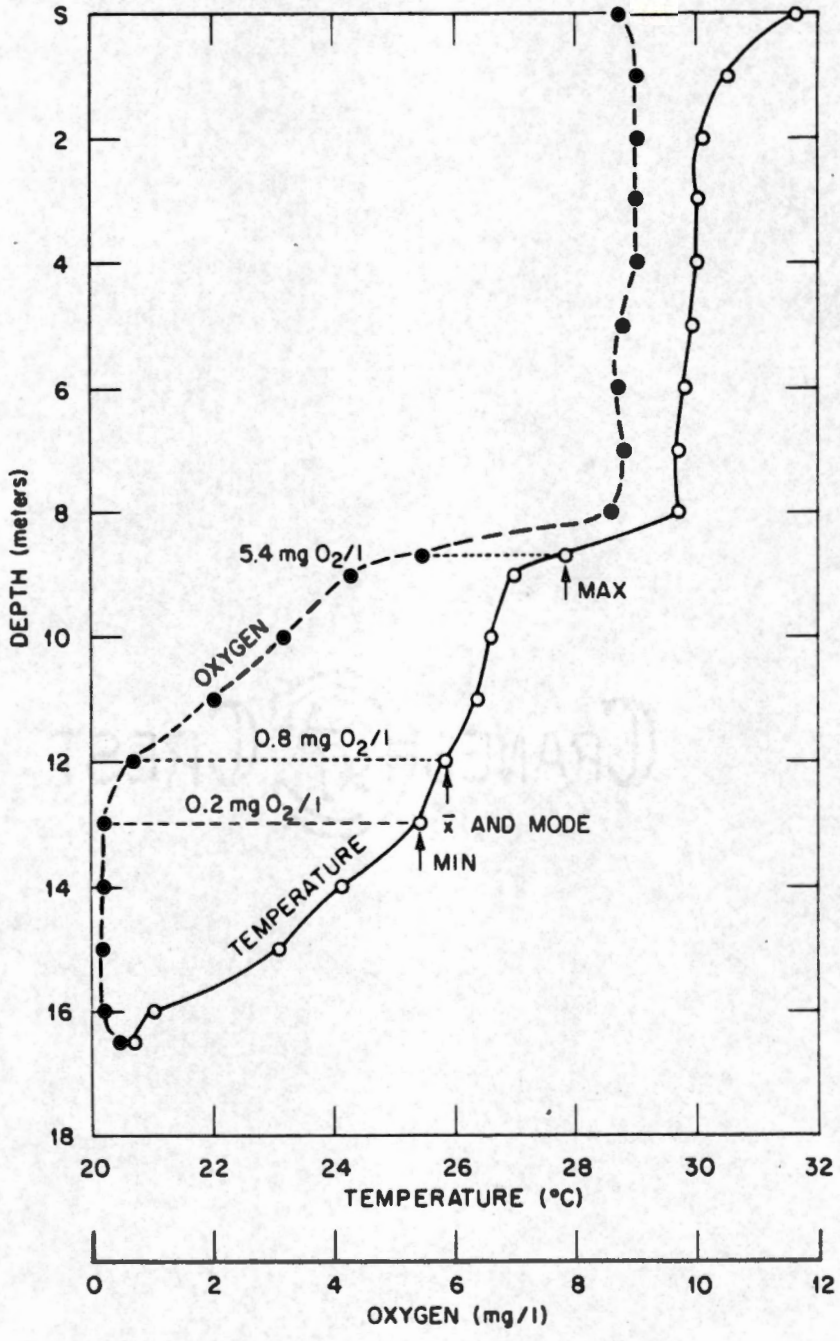


Figure 9. Temperature-dissolved oxygen profile with an analysis of temperatures experienced by Fish 152B outside Mossy Creek refuge on June 23, 1977.

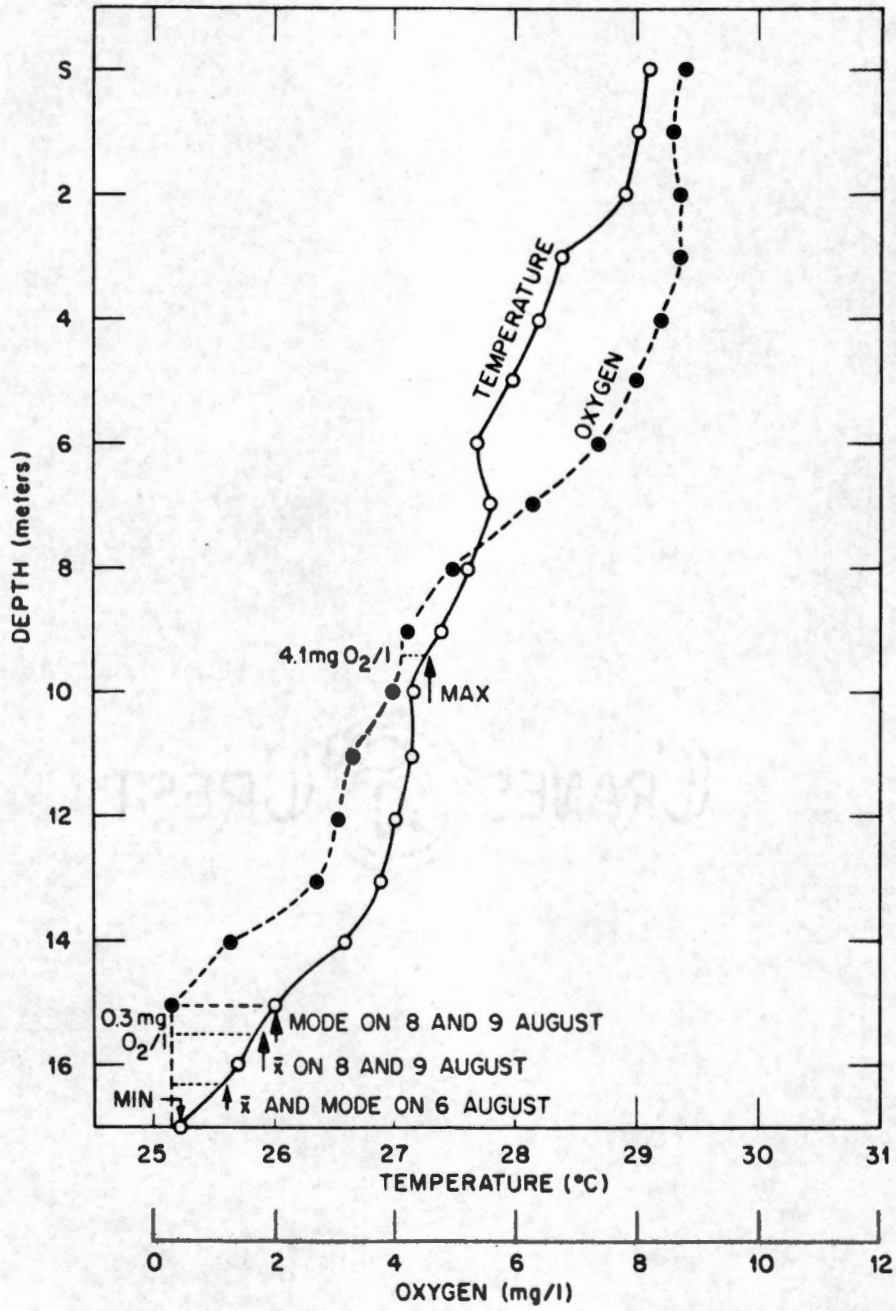


Figure 10. Temperature-dissolved oxygen profile with an analysis of temperatures experienced by Fish 155C outside Cedar Hill refuge on August 6, 8, and 9, 1977.

periods appeared to be related to temperatures near 22 C.

During electrofishing runs in refuges, many adult striped bass were observed. Usually, between 5 and 20 fish were noted, but on occasion their numbers were estimated at 50 or more.

Thermal Behavior of Fish

The 18 striped bass experienced temperatures mostly between 16 and 25 C during the cumulative period of time they were monitored. These values border the extremes of plus and minus one standard deviation from the mean for the pooled automatic and manual data sets (Figure 11). Mean temperatures of individual fish ranged from 18.0 to 22.2 C (Table 1, page 23; Figure 11), and their modal classes ranged from 16 to 23 C (Table 1; Figure 12). The grand mean was 20.4 C (Figure 11), and modal classes of 20 and 21 C were the most frequently occurring (Figure 12). These statistics represent 227 hours of pooled manual and automatic time-interval data.

The general range of temperatures experienced by these fish during monitoring periods was consistently below maximum temperatures available throughout most of the reservoir (Figure 13). Mean and modal temperatures of consecutive sets of monitored data for each fish generally varied by less than 2 C, although some differed by as much as 6 C (Figure 13; Tables in Appendix B). Average temperatures of tagged fish inhabiting Mossy Creek, Byrd Spring, and Cedar Hill refuges were 20.3, 20.8, and 20.6 C, respectively.

No diurnal temperature pattern was shown by manual data (Figure 14) or automatically recorded data. Automatic recordings on two fish

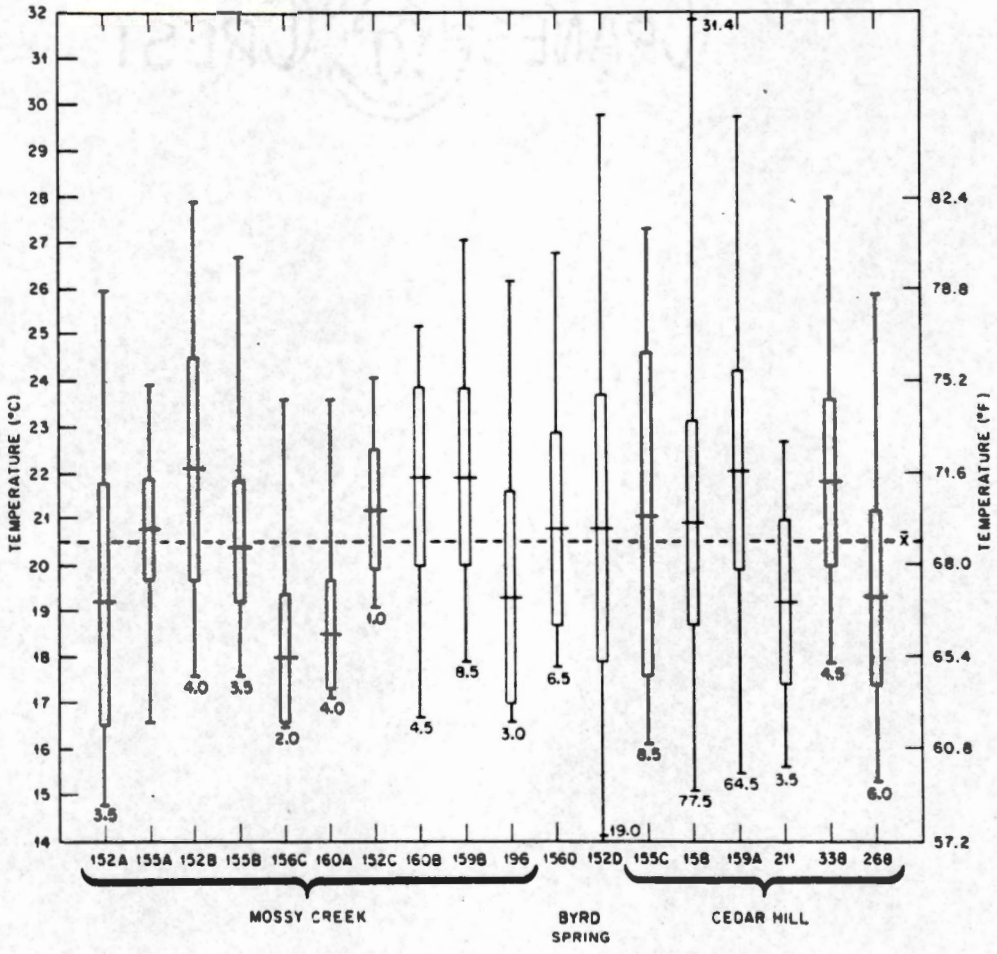


Figure 11. Mean (—), plus and minus one standard deviation (▯), and range (I) of temperatures experienced by each of the 18 tagged striped bass in Cherokee Reservoir during the summer of 1977.

Values below the vertical bars designate the total number of hours of temperature data for each fish.

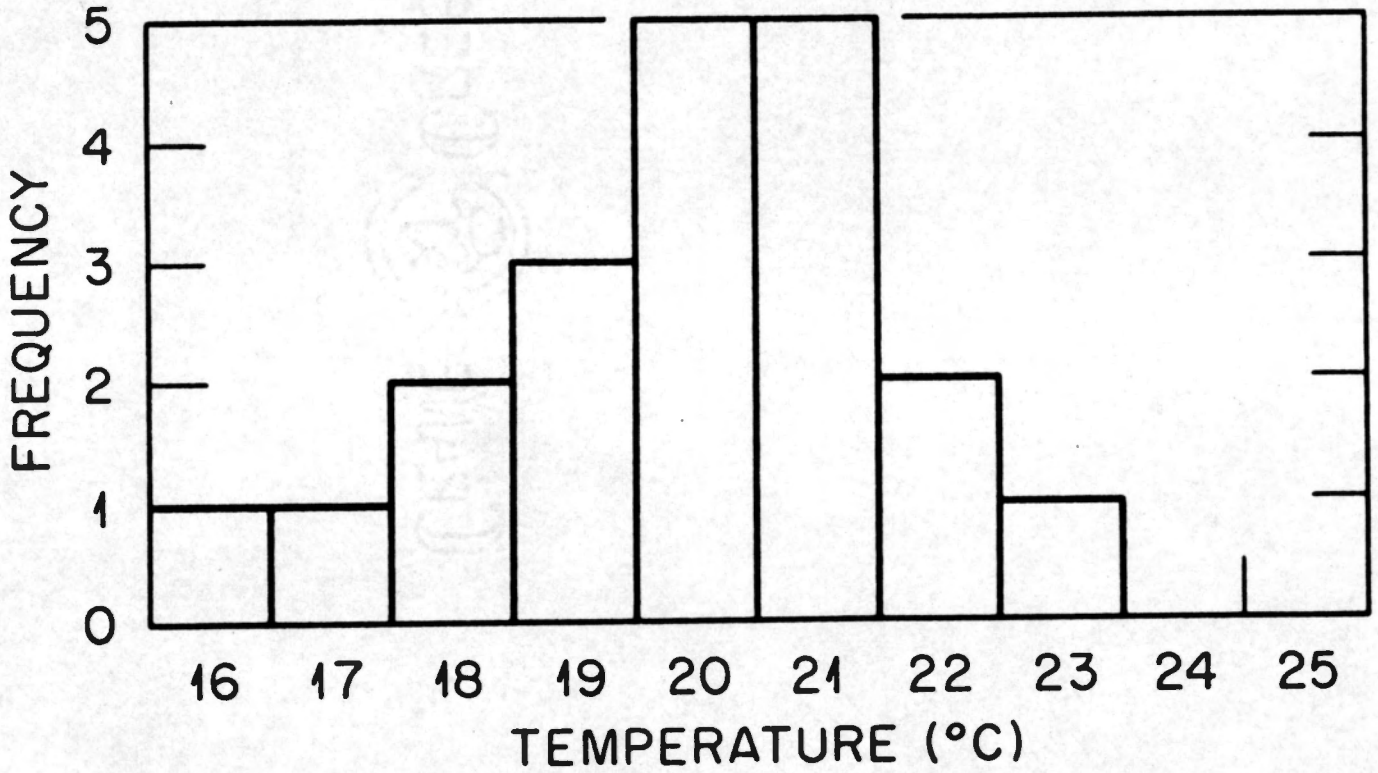


Figure 12. Distribution of modal temperatures in classes of 1 C for each of the 18 successfully monitored striped bass.

Two fish had bimodal distributions (refer to Table 1, page 23, or Appendix C).

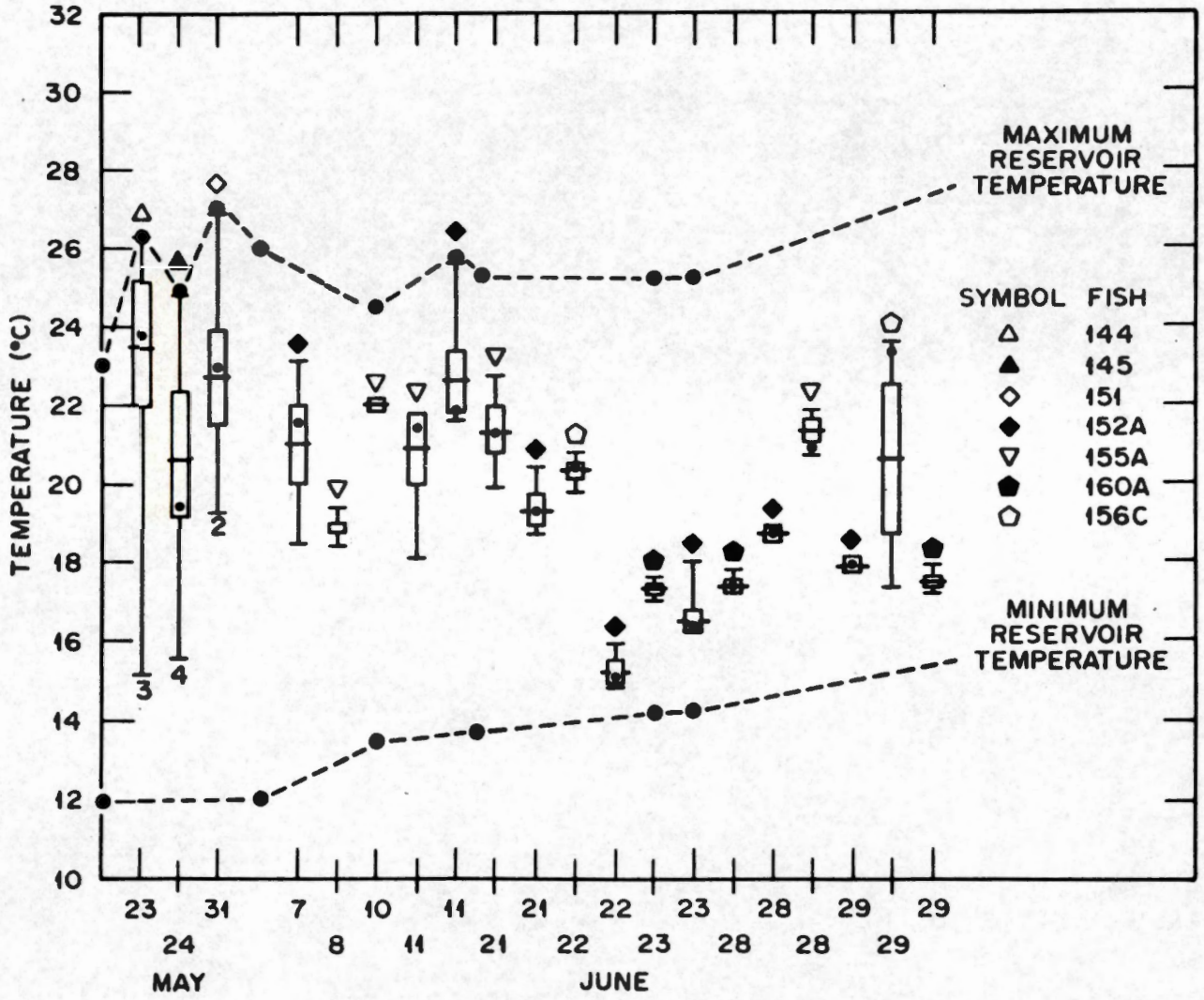


Figure 13. Mean (—), mode (•), plus and minus one standard deviation ([]), and range (I) of temperatures experienced by each of 20 tagged striped bass during monitoring periods.

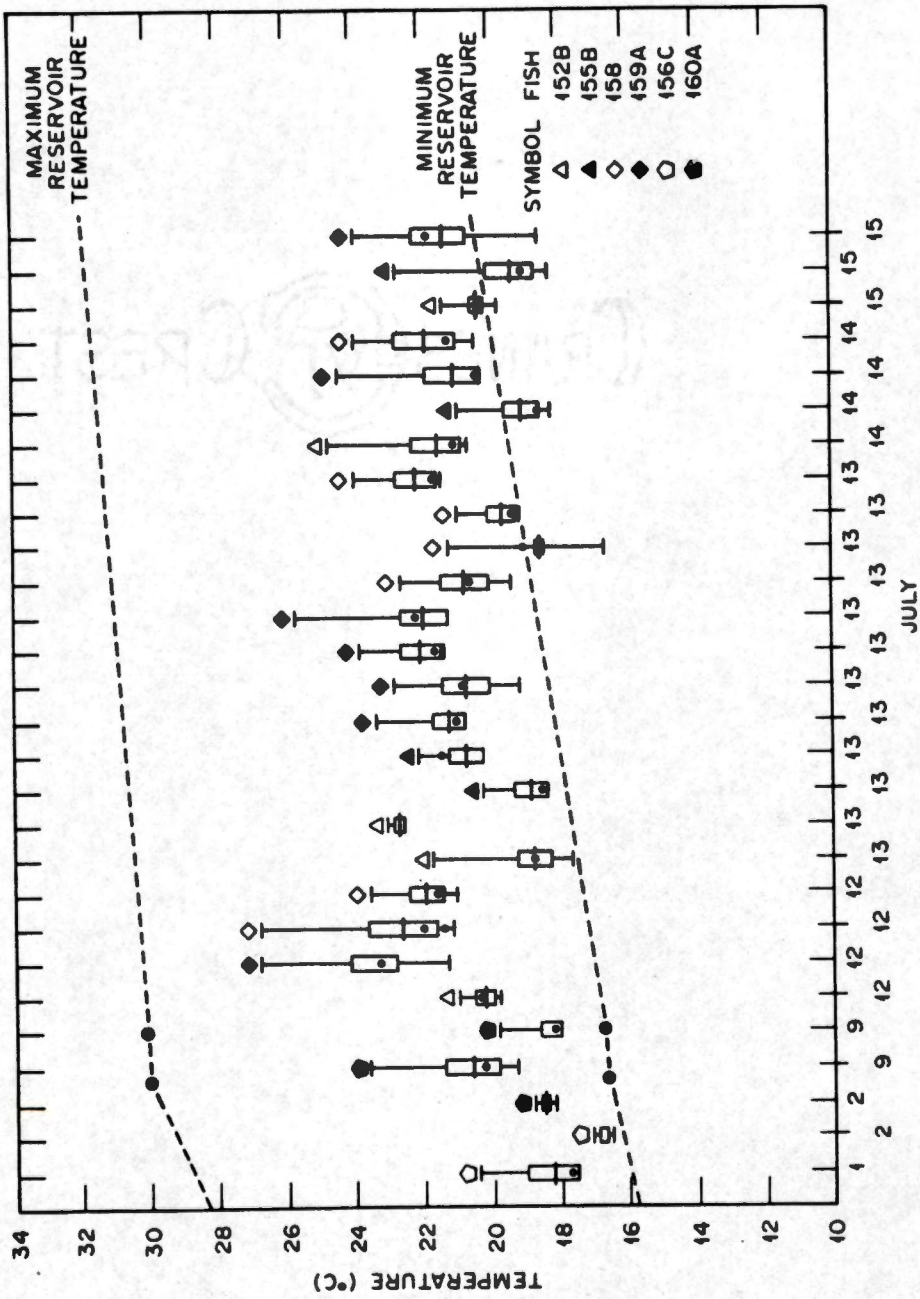
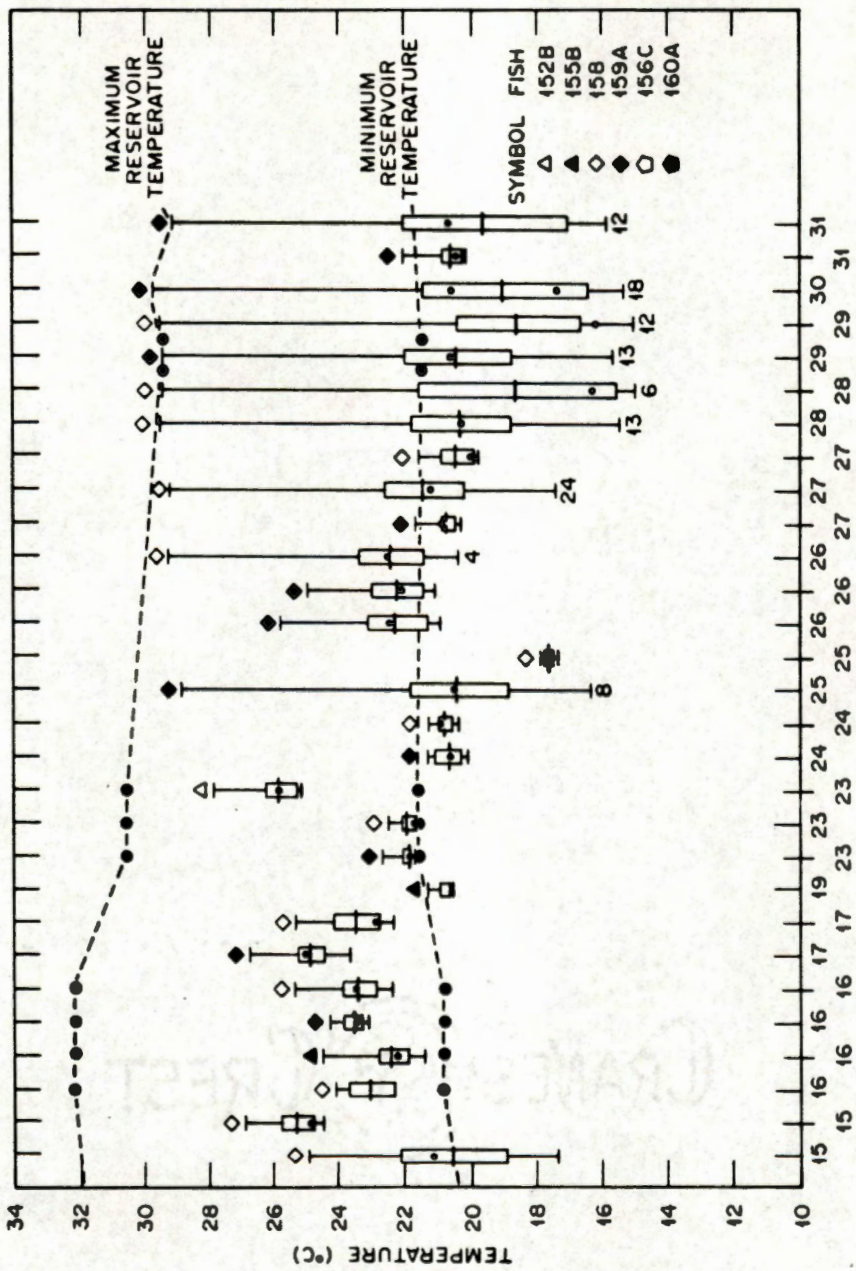


Figure 13, continued



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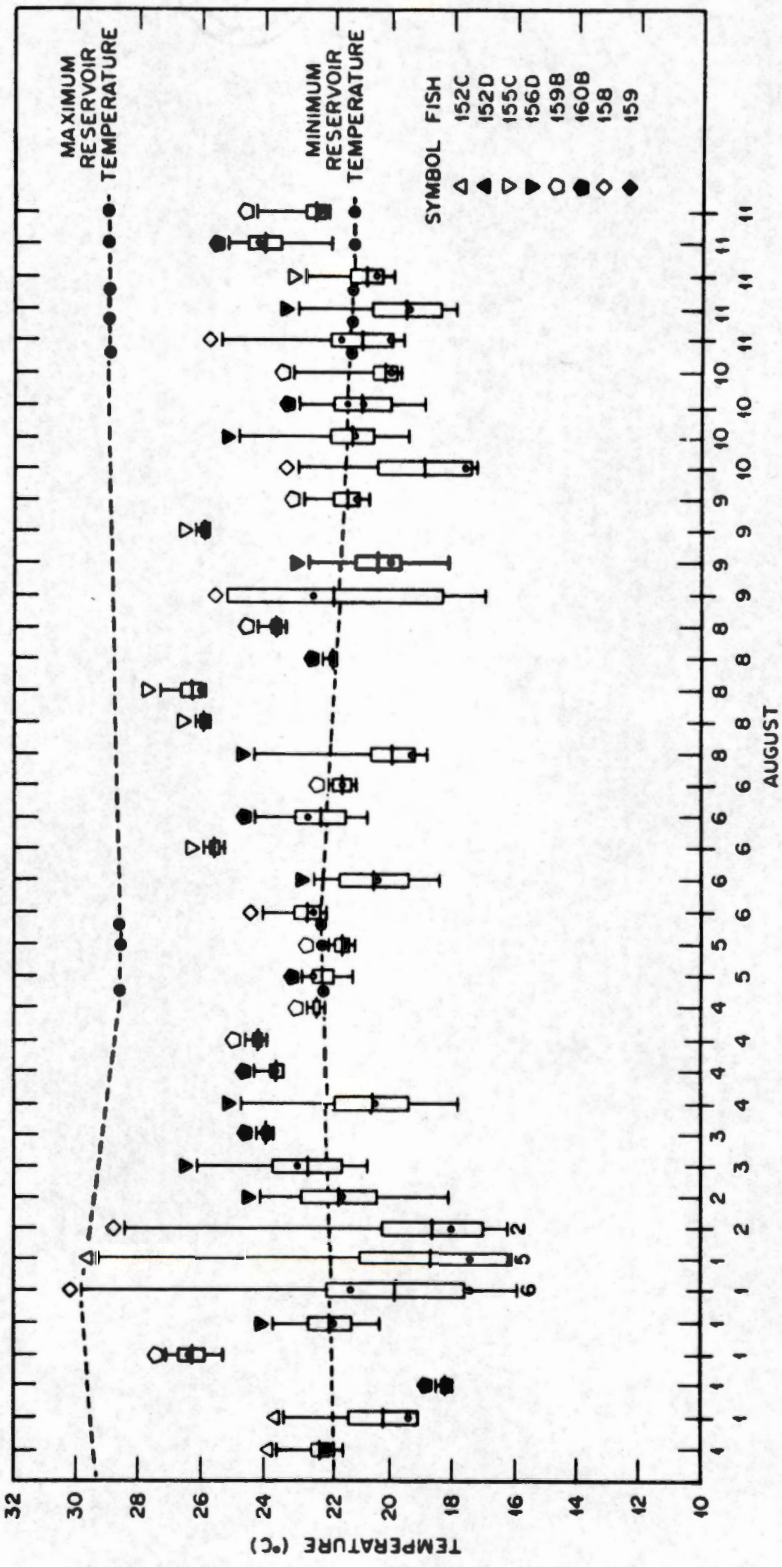

Figure 13, continued

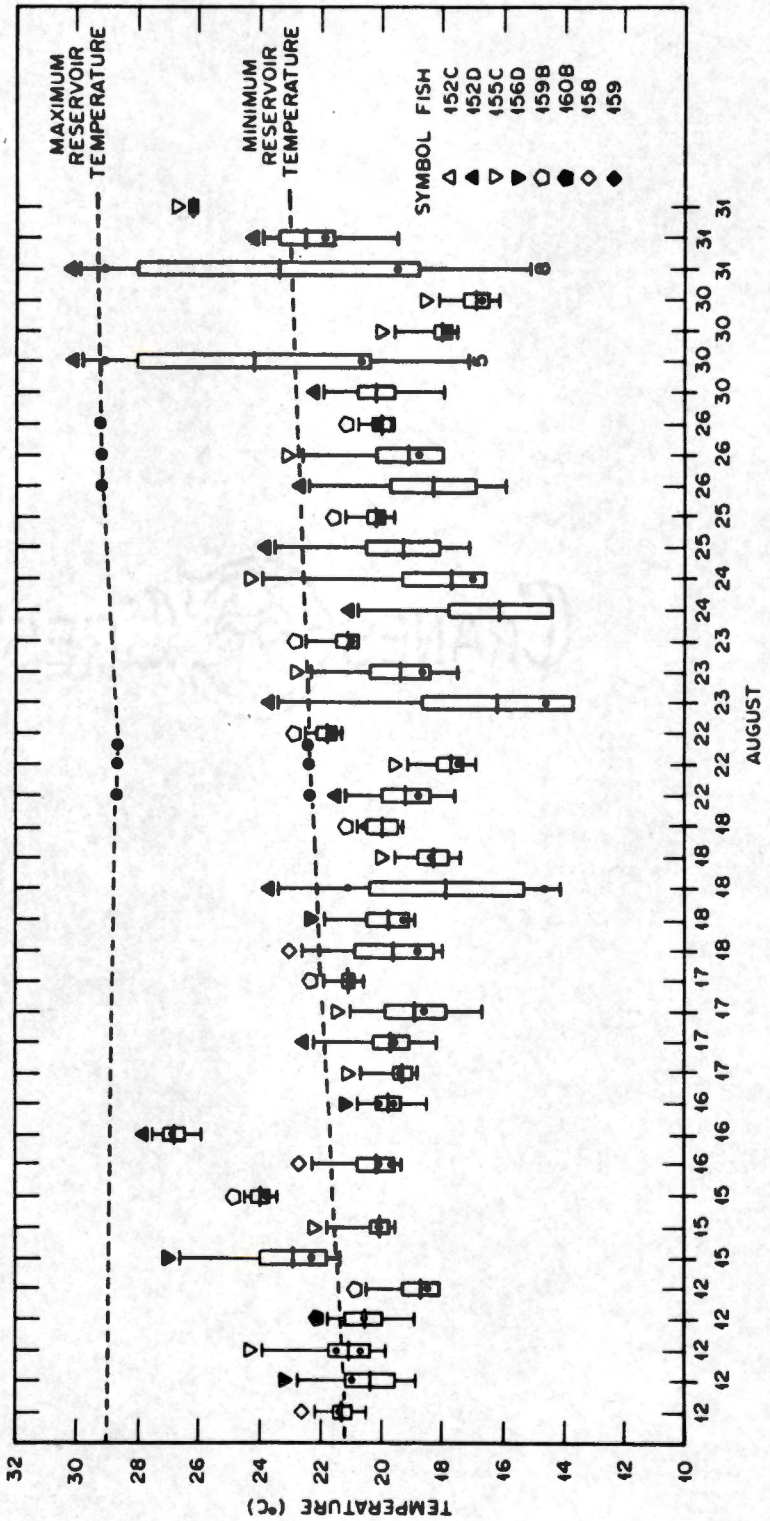

Figure 13, continued

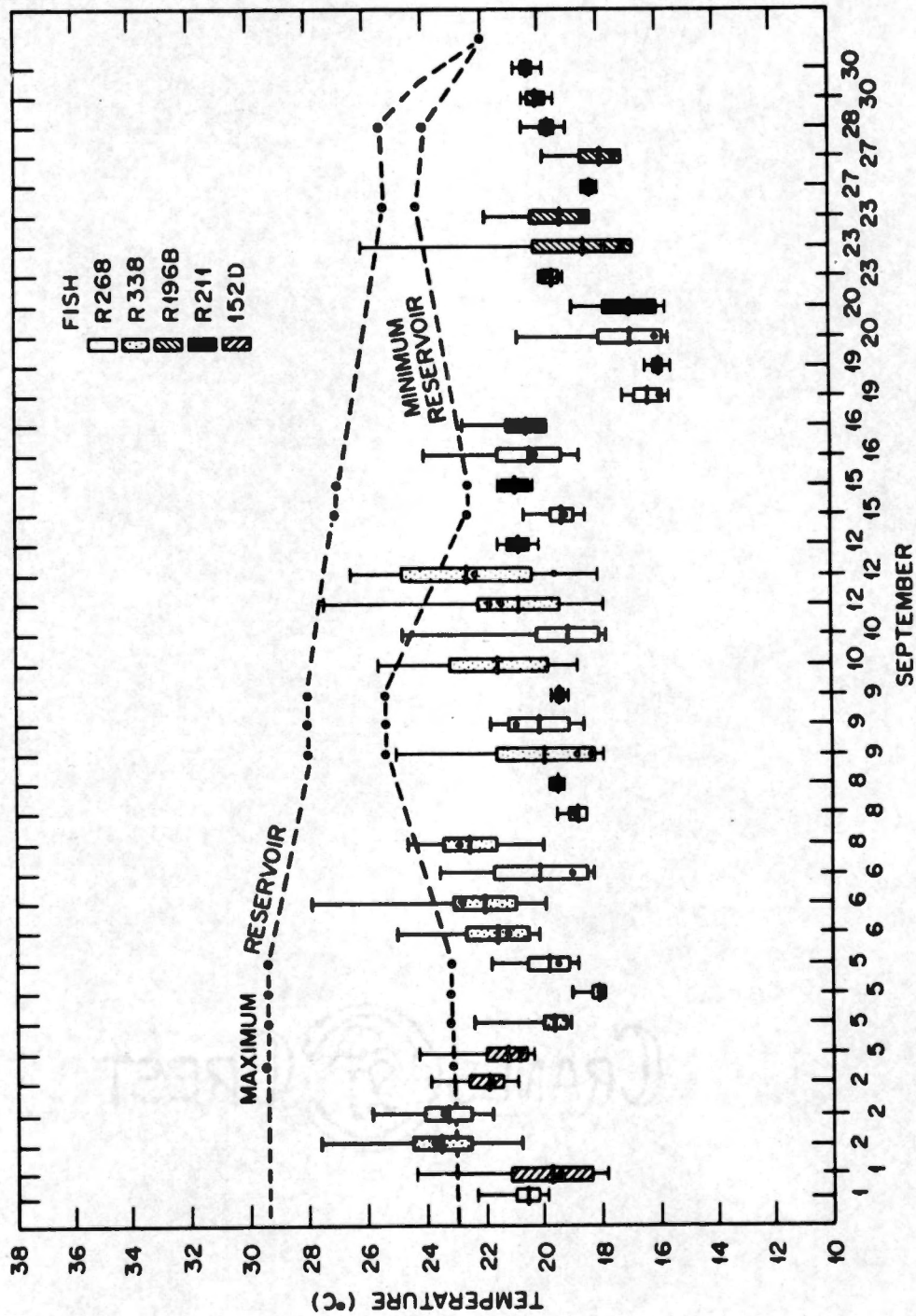

Figure 13, continued

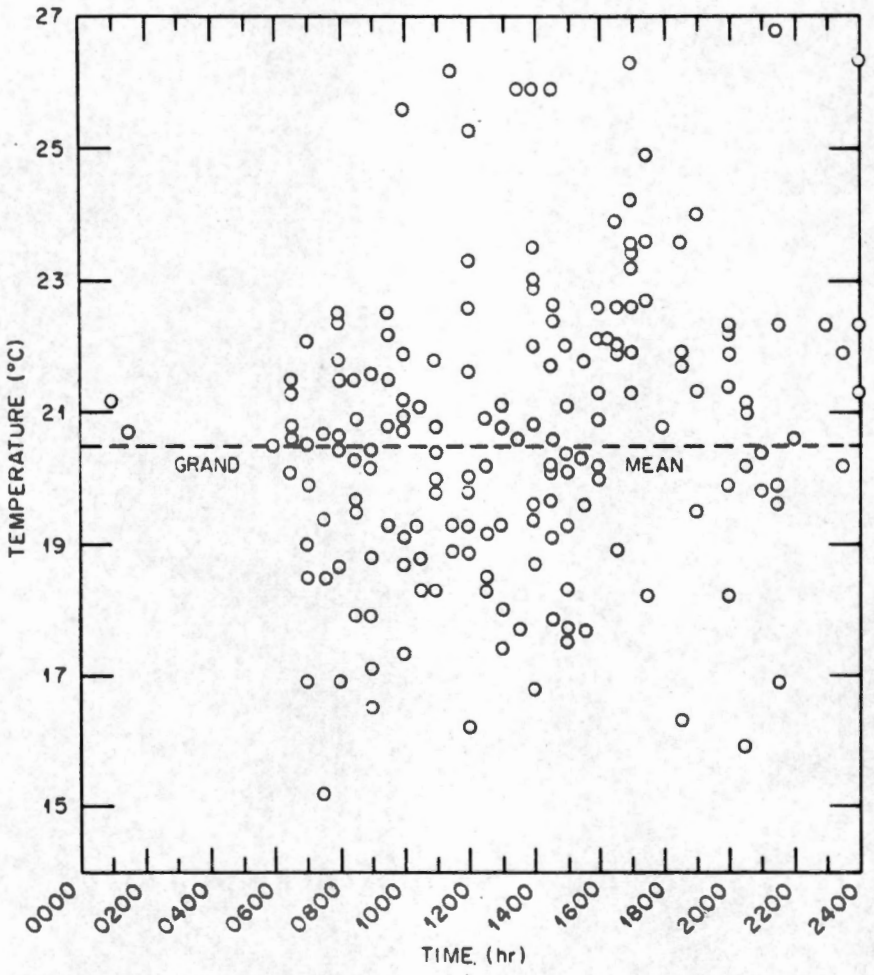

Figure 14. Distribution of manual data set means of the 18 tagged striped bass with time shows a lack of a diurnal relationship.

(158 and 159A) provided more nighttime data than was obtained manually, and it showed no consistent pattern (Figures in Appendix A). However, both fish, inhabiting Cedar Hill refuge, experienced temperatures between 16 and 17 C for periods usually spanning less than an hour. This was attributed to movement of the fish toward the spring in the refuge and not to erroneous data. A definite correlation of Fish 152D's location and thermal experience is shown in Figure 15. Verification of low temperatures experienced by Fish 158 and 159A is shown in frequency distributions of the cumulative manual data for these fish (Figure 16).

The majority of fish had higher thermal experiences during initial post-release monitoring periods than in later ones (Tables in Appendix B). In most cases, this was related to immediate post-release activity which resulted in their movement from the cooler refuge waters.

Most fish monitored outside refuges experienced higher temperatures than when they remained in them. Immediately after release, three fish (152D, 155C, and 159B) moved from refuges and experienced mean temperatures of at least 2 C greater than those of later monitoring periods when they had returned to refuges. Elevated thermal experiences of these fish were related to their movement from the cool water source in the refuges. However, two fish (152A and 155A), released in early June in Mossy Creek refuge, selected temperatures between 20 and 22 C after moving outside this refuge into the open reservoir near Cherokee Dam where a gradient of 12 to 26 C occurred in the water column.

Water Quality of Refuges

Water temperatures below 20 C and DO concentrations greater than 5 mg/liter coexisted in Mossy Creek, Byrd Spring, and Cedar Hill refuges

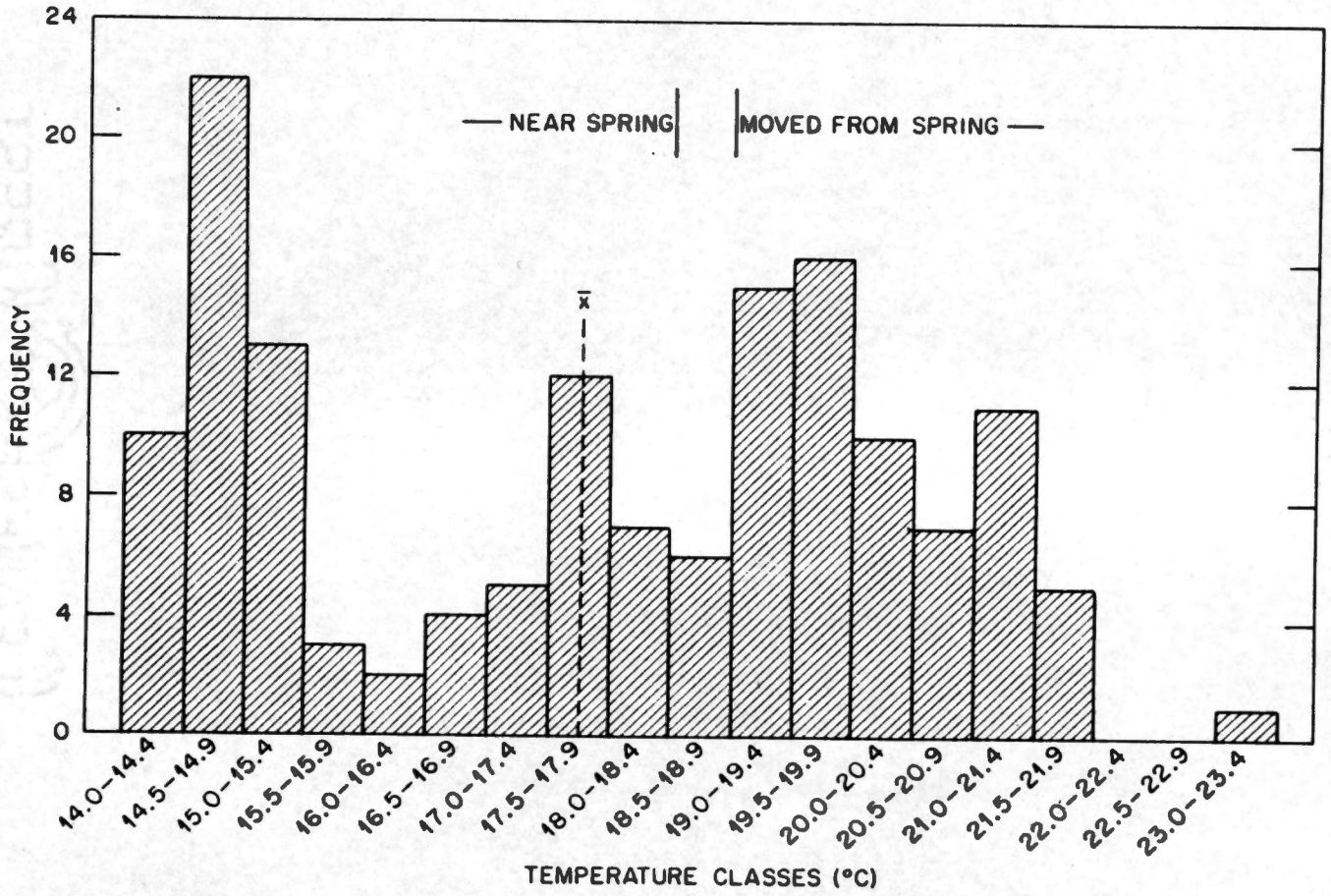

Figure 15. Movement of Fish 152D in Byrd Spring cove during a 30 min observation period resulted in wide range of experienced temperatures.

Lower temperatures were experienced when the fish was near the spring.

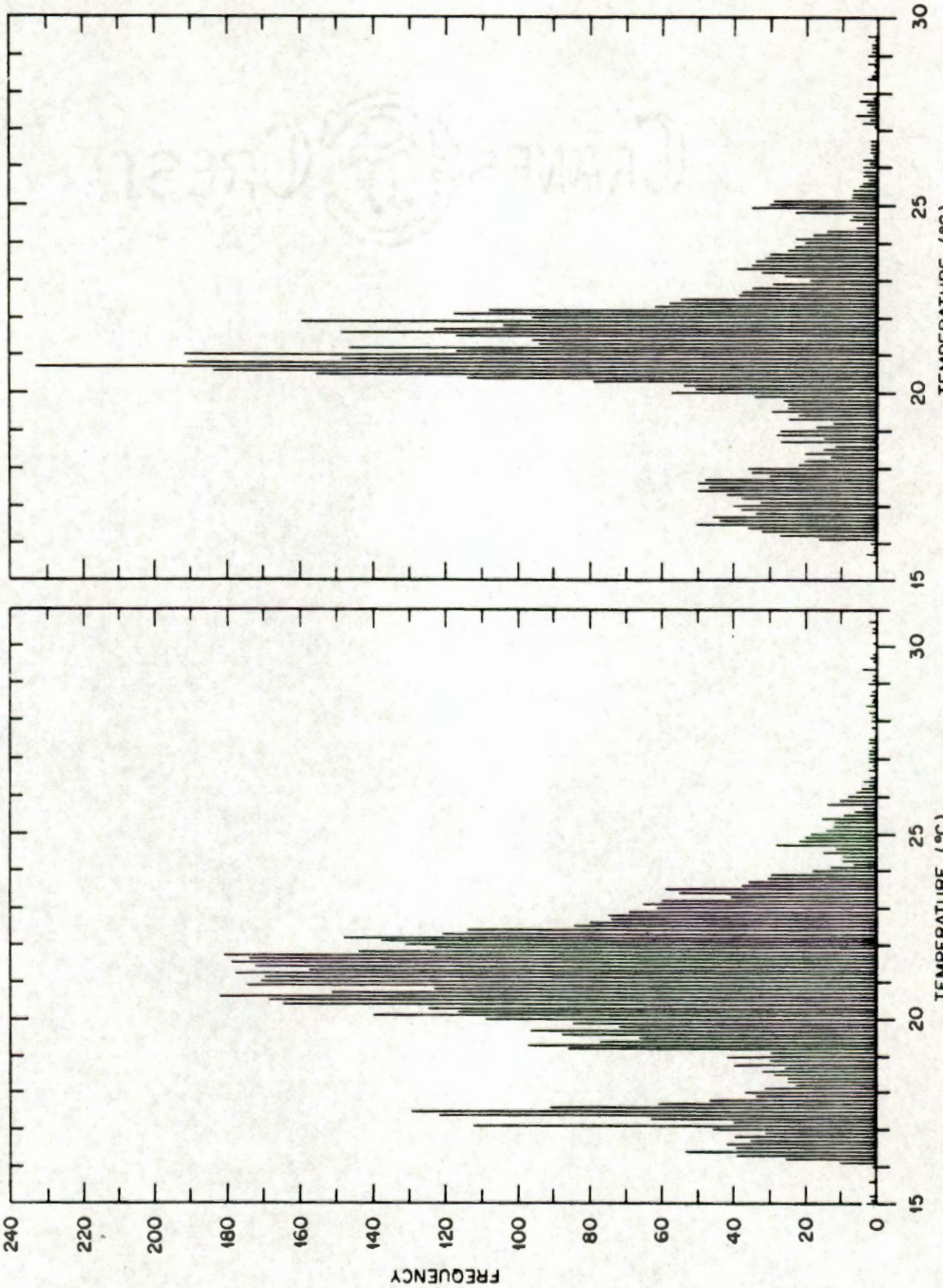

Figure 16. Frequency distributions of temperatures inhabited by Fish 158 (left) and Fish 159A (right) during periods of manual monitoring.

during each month of habitation by tagged striped bass. These conditions were a result of groundwater from springs in Byrd Spring and Cedar Hill coves and from a large spring and deep-mine seepages into Mossy Creek, which flow into Mossy Creek cove. In the submerged channels created by the flowing spring or creek velocities, the cooler water occupied areas nearest the source and adjacent to the bottom (Figures 17 and 18). Water quality parameters of the three refuges were very similar (Table 3).

Water Quality of Nonrefuge Areas

During March, temperatures of stations on the Holston River channel downstream from HRM 75 were below 16 C at all depths (temperature profiles of main channel stations throughout the study are presented in Appendix D). During April, surface temperatures rose from 11 to 13 C to a maximum of approximately 22 C. By April 19, a vertical temperature gradient was prevalent in the main channel downstream from HRM 75. This gradient exhibited a range from a maximum of 22 C at the surface to 10 C near the bottom. Continual warming of the water column at all stations occurred in May, with temperatures greater than 20 C occurring at depths less than approximately 5 m in the lower reservoir. Surface temperatures in May ranged from 19.5 to 26 C. Temperatures of stations upstream from and including HRM 91 exceeded 20 C at all depths in May. At the main stations in the lower reservoir on June 4-5, temperatures were 12 C near bottom and 26-28 C at the surface. The warming of the water column at all stations continued through June, July, and August, with the largest temperature gradient (surface to bottom) occurring in June

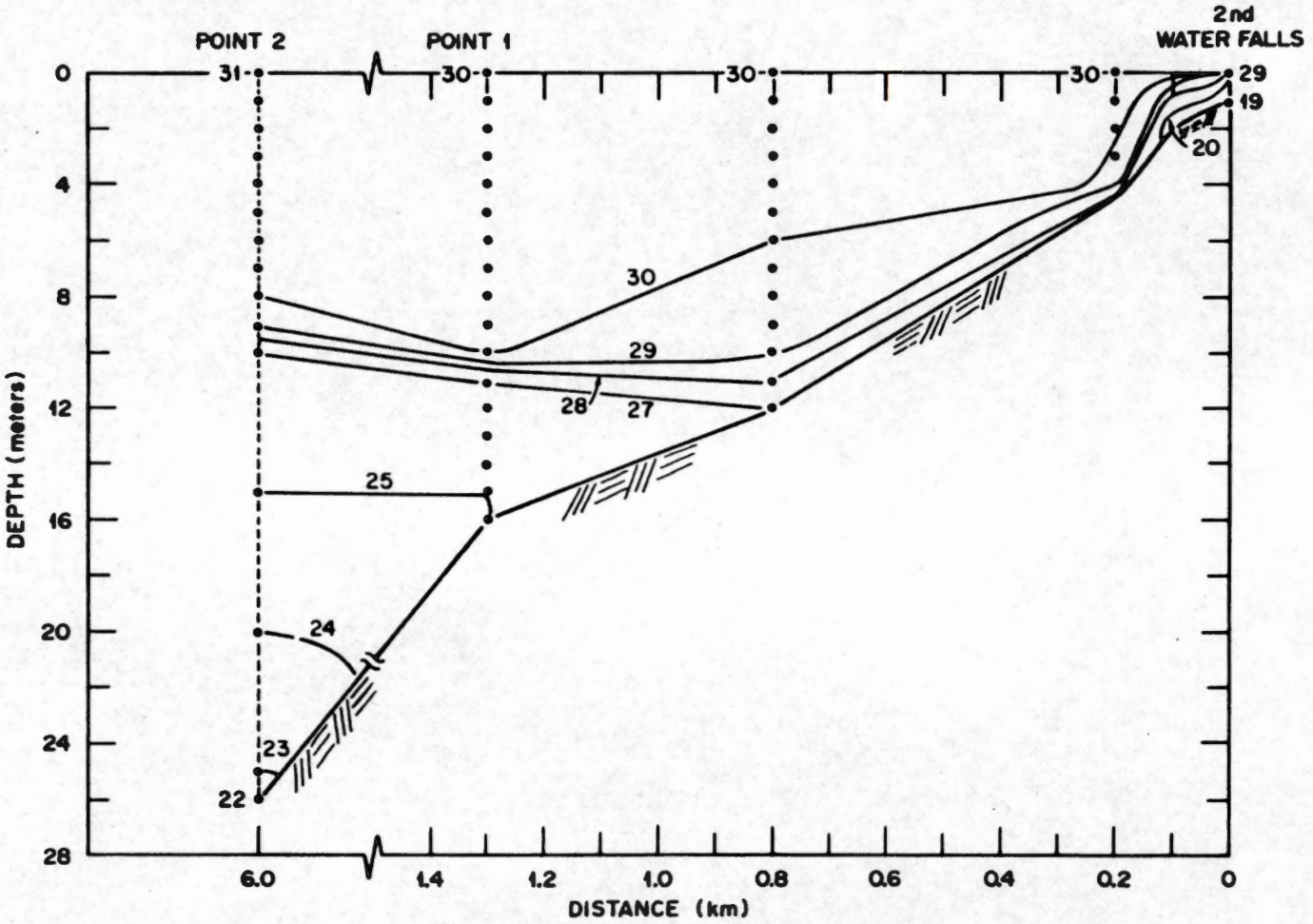

Figure 17. Temperature profile from a waterfall in Mossy Creek to the main channel of HRM 53 (near Point 2) on July 23, 1977.

The cooler water occurred only near the bottom and in close proximity of the creek.

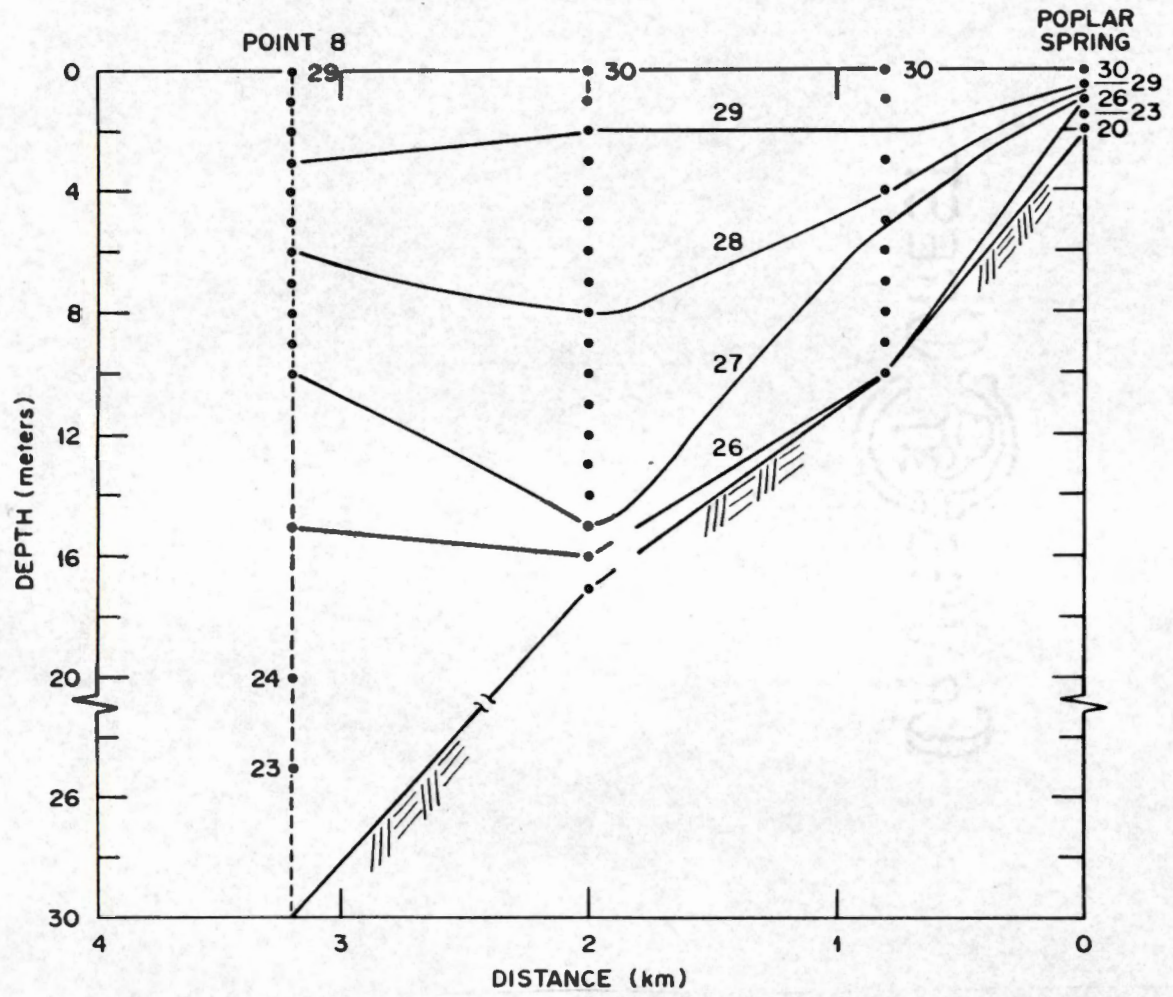

Figure 18. Temperature profile from the large spring in Cedar Hill cove to HRM 60 (near Point 8) on August 5, 1977.

The coolest water found in this cove was located in the narrow strata near the bottom near the spring.

Table 3. Mean Water Quality Parameters Measured at Refuges and Main Channel Stations of Cherokee Reservoir from July Through October 1977

	Refuges			Holston River Mile							
	Mossy Creek	Byrd Spring	Cedar Hill	53	60	65	70	75	80	91	98
pH	8.2	8.1	7.9	7.9	7.9	8.0	7.8	8.0	8.3	7.7	7.6
Total water hardness (mg/liter)	178	140	118	125	95	100	95	100	95	100	--
Transparency (cm)	86	79	110	174	168	128	125	122	104	64	58

(Figures 19-21). On June 23, surface temperature ranged from 25 and 26 C in the lower reservoir to 23 C at HRM 103. By July 7, temperatures below 24 C were found at depths greater than 10 m in the lower reservoir, and the upper 10 m exceeded 25 C at all stations. By July 29-30, the strata with temperatures less than 25 C in the lower reservoir occurred at depths greater than approximately 15 m. The surface to bottom temperature gradient continued to decrease as the water column continued to warm, and by mid-August to early September, this gradient was approximately 6 degrees. Maximum surface temperatures during August and early September were in the low 30's (C), and bottom temperatures exceeded 22 to 24 C at all main stations surveyed. On September 9-10, a gradient of approximately 5 degrees existed in the lower reservoir with an almost isothermal 27 C at HRM 91. By September 15-16, the water column at all stations showed a decrease of one to several degrees. On September 28-29, the upper reservoir showed 22 C water flowing into the slightly warmer lower reservoir water which was now an almost homogeneous 24-25 C. By October 6-7, the main channel of the reservoir was an isothermal 22 C.

From March through early May, DO concentrations were greater than 5 mg/liter at all depths sampled in the lower reservoir (DO profiles of main channel stations throughout the study are presented in Appendix E). By May 19-21, however, stations in the lower reservoir showed DO concentrations above 5 mg/liter only at depths less than 10 m. In the lower reservoir on June 4-5, DO concentrations below 5 mg/liter occurred at depths greater than 5 to 7 m, depending on the station. During most of the summer, the deeper water at stations from HRM 80 to 91 exhibited DO

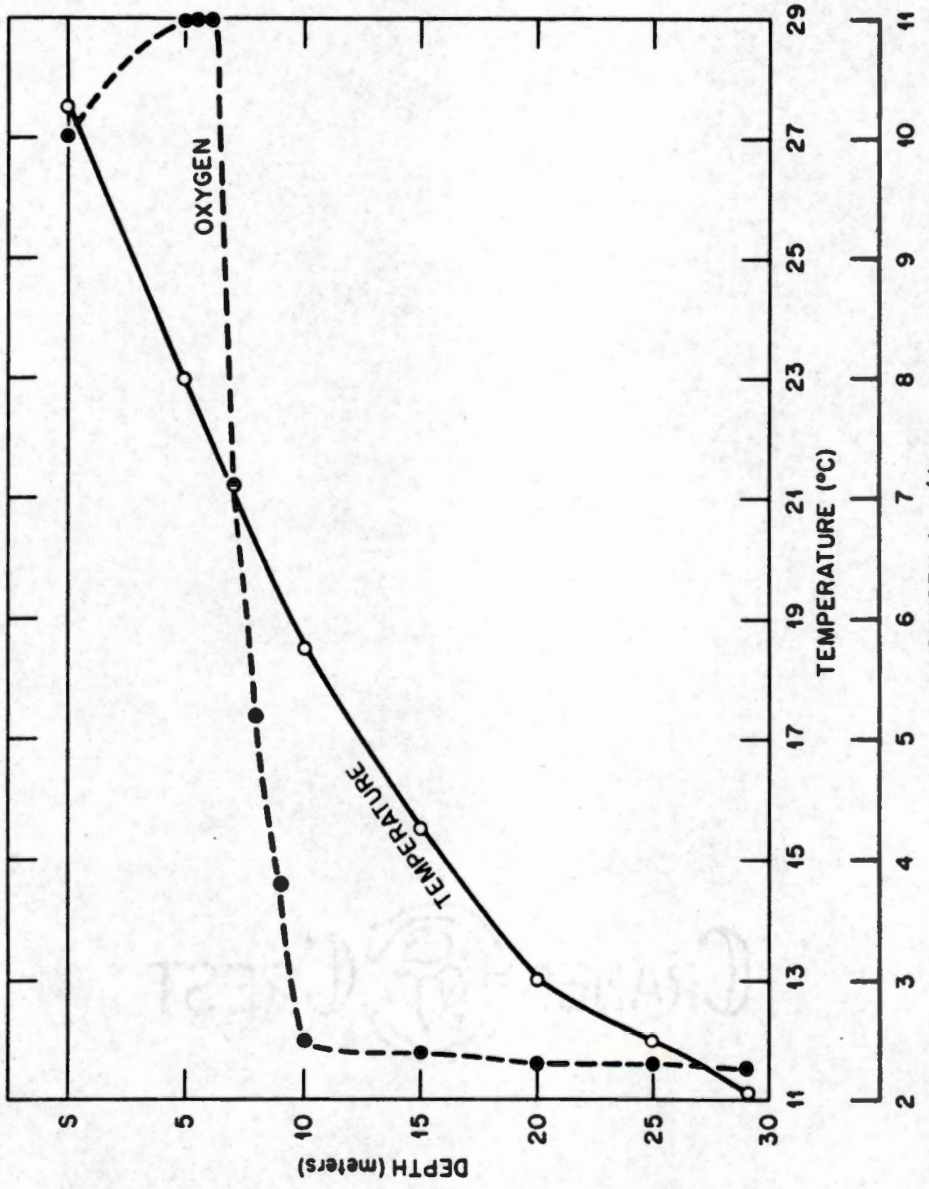

Figure 19. Temperature-dissolved oxygen profile near Cherokee Dam (HRM 53) on June 4 and 5, 1977.

This station was typical of main channel stations in the lower reservoir.

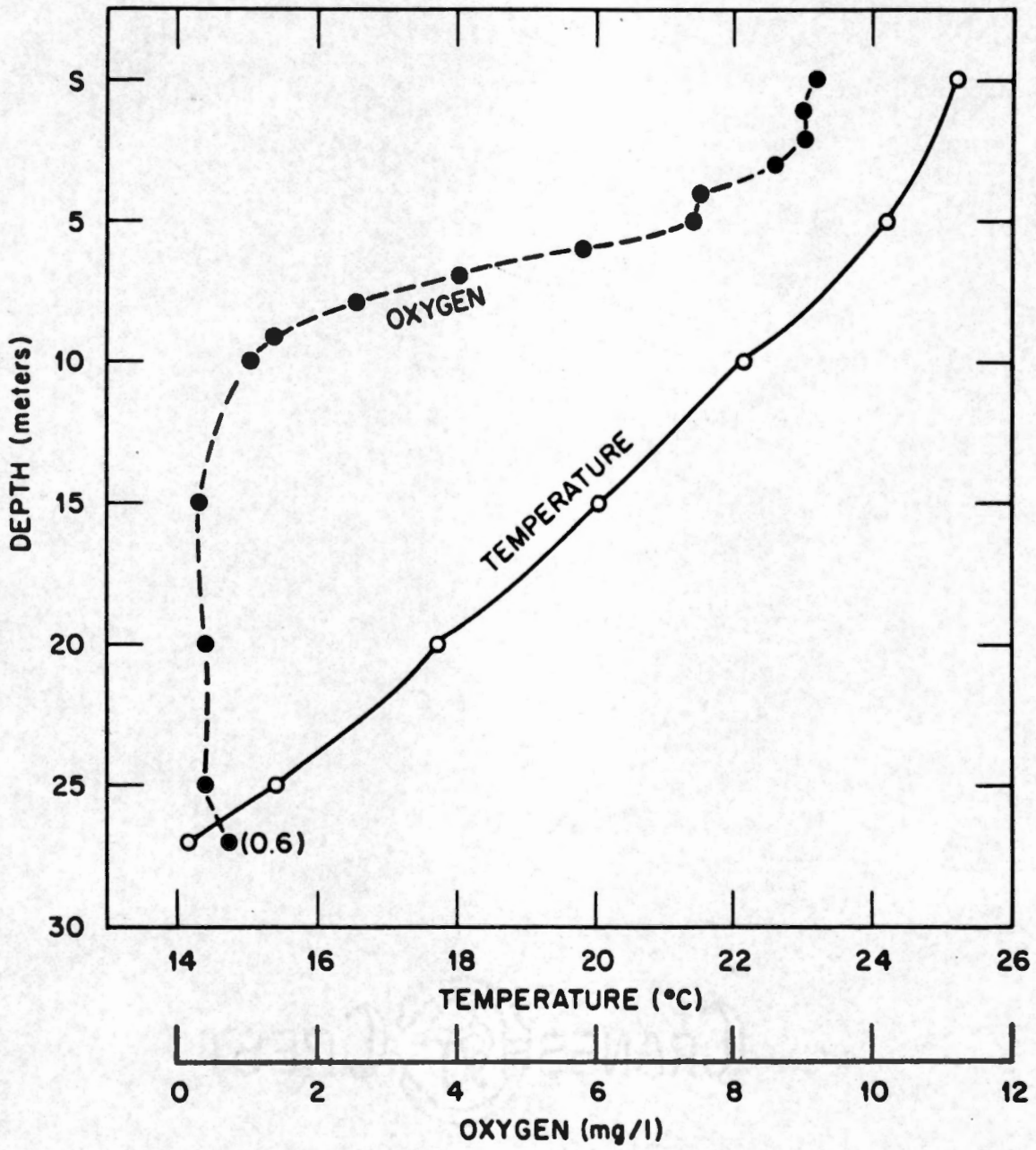

Figure 20. Temperature-dissolved oxygen profile near Cherokee Dam (HRM 53) on June 23, 1977.

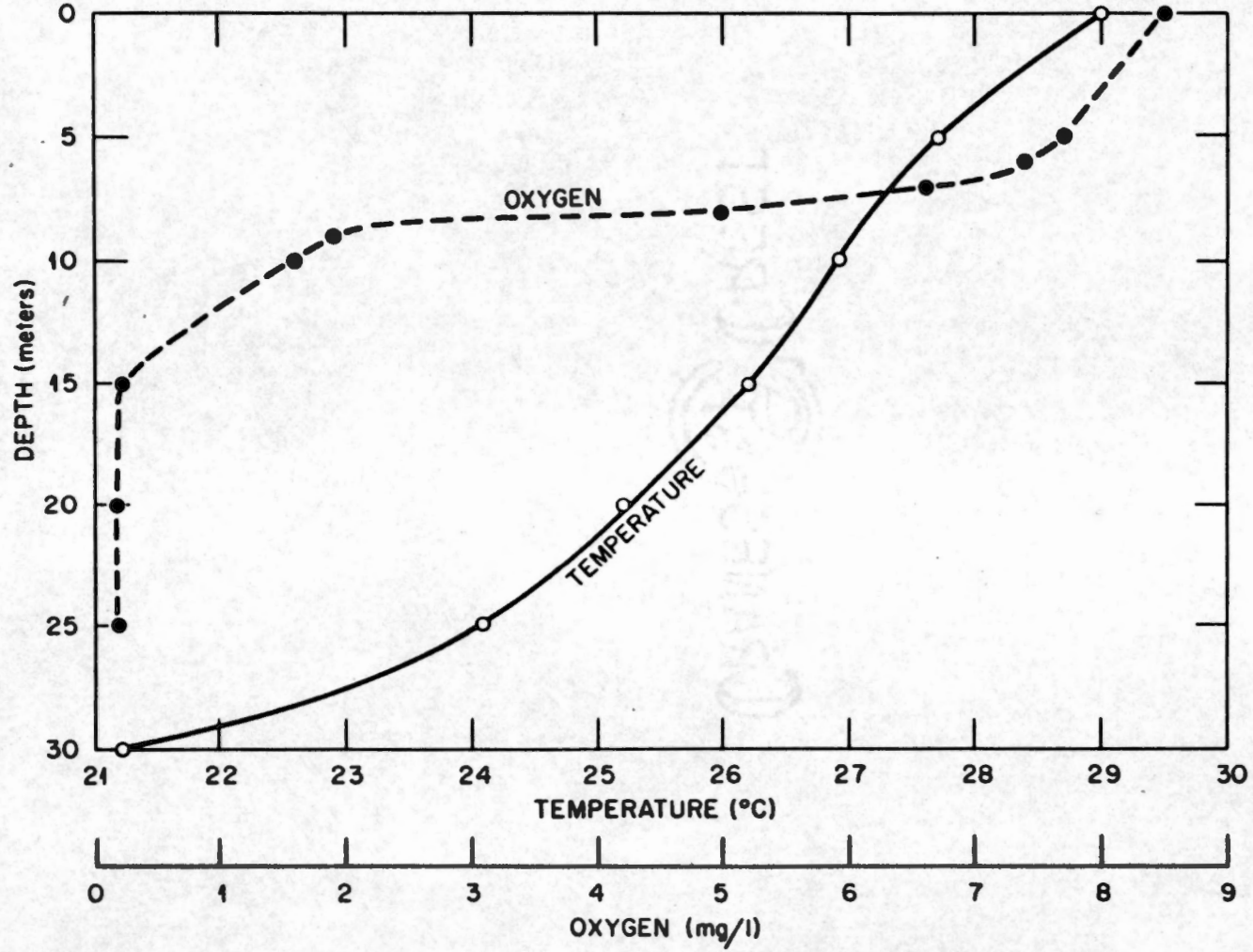

Figure 21. Temperature-dissolved oxygen profile near Cherokee Dam (HRM 53) on August 11, 1977.

concentrations less than 5 mg/liter. Stations at HRM 91, 98, and 103, all of which were more riverine in nature than stations located downstream, always had DO concentrations above 5 mg/liter at all depths from April through most of July. From July through August and early September, DO concentrations less than 5 mg/liter existed from depths of 5 to 15 m. Below a depth of 15 m, the reservoir was essentially anoxic during this period. Subsequent to early June, DO depletion became severe in the lower reservoir, and hypoxic conditions (less than 5 mg/liter) existed at depths less than 7-8 m (Figures 19-21). After the fall overturn in mid-September, DO concentrations increased in the deeper strata and slightly decreased in the surface waters.

CHAPTER VI

DISCUSSION

Limitations of the Data

The methodologies and events in the course of this study pose questions about the validity of the data and conclusions which can be interpreted from the results. First, did tagging alter the behavior of the 18 successfully monitored striped bass? Although this question cannot be answered conclusively, the fact that nontagged striped bass were found in refuge areas when tagged fish inhabited them suggested that tagging did not weaken the fish or cause reduced activity. In fact, several tagged fish moved from Byrd Spring to Mossy Creek refuge, and most fish were noted moving during the majority of observations. Also, the capture of 31% of the tagged fish by anglers suggested that their feeding behavior was not significantly different from nontagged fish which were also readily caught in refuges. Only one tagged fish was known to have been caught after being hooked in the body, suggesting the fish did not strike at the lure but was snagged. However, externally attached tags can affect activity levels and buoyancy of fish (Stasko & Pincock, 1977).

Was the behavior of tagged fish representative of all adult striped bass in the lower reservoir or throughout Cherokee Reservoir? This question also has no conclusive answer from these data. An unintentional bias was introduced in this study when fish could only be

acquired or successfully tagged from three refuges in the lower reservoir. Striped bass inhabited areas outside the three refuges at least in May and June, as indicated by fisherman catches throughout the reservoir. In late August and early September, nontagged striped bass were discovered at a submerged spring in Hull Branch cove (Figure 5, page 25). These fish were located near the bottom (11 m deep) in 21 C water. This temperature was near the mean temperature experienced by tagged striped bass during monitoring periods.

Cherokee Reservoir has very poor water quality in regard to temperature and DO as shown by this study and by others (Churchill, 1970; Wojtalik, 1970; Ungate & Hsieh, 1976; DWQC, 1977). Therefore, it is not illogical that the behavior of the striped bass in all of Cherokee Reservoir would be affected by the poor water quality as seen in the lower reservoir. However, interpretation of field distribution data on organisms with respect to their preference of habitat is often difficult to assess (Reynolds & Casterlin, 1978). It is possible that what the present study interpreted as "habitat preference" of tagged striped bass may actually have been "habitat correlation." Fish in refuges may have been present there for reasons other than habitat preference, such as avoidance of high temperatures and low DO concentrations outside refuges. In this case the three refuges or similar areas would provide the only suitable habitat in the reservoir.

The high likelihood that most adult striped bass in Cherokee Reservoir are contaminated with heavy metals, which may alter their

physiology and behavior, may also help explain their behavior. The general temperature selection and movement behavior of tagged striped bass in Cherokee Reservoir is quite similar to tagged striped bass in other freshwater studies.

Temperature Selection Behavior

The habitat selection pattern of the 18 successfully monitored striped bass appears to be directly related to water temperature. Because these fish experienced temperatures mostly from 18 to 22 C during observations and inhabited the few areas where this temperature range was available throughout the lower reservoir during the summer, it can be assumed this range was inhabited the majority of their tracking lives. This preference of a specific, rather narrow and cool, temperature range within the thermal regime of Cherokee Reservoir corroborates existing information on temperature-related behavior of striped bass in freshwater. Coutant and Carroll (submitted) found that during the summer, nine adult striped bass, carrying internally placed temperature-sensing transmitters, selected temperatures from 20 to 24 C in a small, thermally stratified, but well-oxygenated lake (DO concentrations exceeded 5 mg/liter at all depths). In the same study, their fish selected the warmest water available at depths below 1.5 m during cooler seasons. They also tracked one adult striped bass in Cherokee Reservoir in 1975 for 32 hr and discovered it experienced temperatures between 21 and 23 C. They concluded from their studies that temperature was a greater influence on striped bass habitat selection behavior than depth or light intensity. Stooksbury (1977) found that during the summer

striped bass with surgically implanted transmitters were mostly located at depths in Percy Priest Reservoir, Tennessee, where water temperatures were 18 to 24 C, although detailed data were not obtained.

Temperature has long been known to effect the behavior of fish. "Temperature can act as a proximate factor, i.e., cue, sign, stimulus, or directive factor, which will elicit the movement response of fishes" (Reynolds, 1977). It is generally accepted now that each species will select a specific temperature which is optimal for its biochemical processes (Fry & Hochachka, 1970; Weiser, 1973; Hazel & Prosser, 1974). This optimal temperature, called the final preferendum, is defined as that temperature to which a species will gravitate, regardless of their previous thermal history and where preferred temperature equals acclimation temperature (Fry, 1947). The physiological and theoretical behavior responses of fish to changing temperatures with tabulations of published results on preference and avoidance temperatures are presented by Richards et al. (1977). Coutant and Carroll (submitted) are first to suggest that the final preferendum of striped bass in freshwater is approximately 22 C.

Fish in the present study generally avoided temperatures greater than 27 C. Short excursions were made occasionally into warmer water, but usually they remained there for less than a minute (Figures in Appendix A). Merriman (1941) judged from field records that striped bass would not be found in water at temperatures greater than about 27 C. Gift (1970) observed five 4-year-old striped bass avoiding water at 26.7 C in an experimental apparatus, but two other fish showed an

upper avoidance temperature near 29 C. Dudley et al. (1977) hypothesized that post-spawning adult striped bass moved upstream in the Savannah River, Georgia, to cooler tailwaters of reservoirs rather than moving toward the warmer coastal water (26 to 30 C). Coutant and Carroll (submitted) found that subadult striped bass made more frequent excursions into cool water than warmer surface water and avoided water with temperatures greater than 25 C.

Most of the fish in the present study showed a preference for the cooler water of refuges, as indicated by the majority of time they were located at temperatures below 24 C and the relatively small volume of water with temperatures in their preferred range. Also, their avoidance of temperatures exceeding 27 C may explain why they rarely moved from refuges in July through much of September, or if they did, they returned to the refuge within a relatively short period. Temperatures less than 24 C were not readily available in well-oxygenated strata outside refuges during this period. Temperatures below 24 C were present in the hypolimnion until August, but depleted DO concentrations limited fish life.

The statistical non-normality of temperature distributions experienced by these fish was apparent in the present study. This appears to be a common occurrence with field biotelemetry temperature data on striped bass (Coutant & Carroll, submitted). Even in laboratory situations where there are many more environmental controls than in field studies, thermal responses of organisms are frequently skewed (Richards et al., 1977). Much of the skewness (Table 1, page 23) in

the present study was due to the nonuniformity of temperatures available or having necessary minimal levels of DO.

The high thermal experiences of several tagged fish which occurred for no apparent reason (e.g., boat activity or people swimming near the fish) may have been due to crowding by nontagged striped bass or other species in the relatively shallow, cool bottom strata within the narrow, submerged channels in refuge areas. Even short horizontal movements (20 m) of tagged fish resulted in significant elevation of their temperature, indicating the small volume of the cool strata (Figures 17-18, pages 48-49). Vertical crowding would have led to even more rapid thermal changes, although it would not be detected by location data. Electrofishing runs and the high fisherman success further showed the great number of nontagged striped bass in refuges.

It is noteworthy that only a very few small striped bass (i.e., fish less than 5 lb) were observed in refuges during this study. Although the possibility exists that electrofishing may have been ineffective in stunning these small fish if present in refuges, the knowledge that juveniles of many species have higher thermal preferenda (Coutant, 1975) would help explain the absences of small striped bass from refuges.

Effects of Nonthermal Factors on Fish Behavior

Little doubt exists that factors other than temperature also influenced the habitat selection pattern of striped bass in Cherokee Reservoir, because these fish did not inhabit the hypolimnion where temperatures equivalent to those in the refuges occurred. Much speculation

could be made as to why these fish avoided the hypolimnion, but in context with the information from the present study and knowledge about fish behavior, low DO concentrations are a logical explanation for striped bass not inhabiting strata in the hypolimnion having preferred temperatures. This study suggests that DO concentrations, within limits, is of importance second only to temperature in determination of acceptable habitat.

Very little information about the behavior of adult striped bass in relation to DO concentrations was found in the literature searched. From field observations, Chittenden (1971) suggested that under natural conditions the distribution of striped bass does not exist in water with DO concentrations less than 3 mg/liter. Meldrim et al. (1974) found juvenile striped bass to avoid water with DO concentrations of 44% saturation. This study also suggested that DO concentrations, within limits, is of secondary importance to temperature in determination of acceptable habitat.

Questions exist concerning the minimum concentrations of DO that striped bass will tolerate. Davis (1975) stated that the oxygen level where physiological, biochemical, and behavioral processes of fish become apparent, i.e., the incipient oxygen response threshold or critical oxygen concentration, is often contradictory in the literature. The critical oxygen concentration for juvenile striped bass at 22 C was 4.0 to 4.5 mg/liter (Klyashtorin & Yarzhombek, 1975). However, the criteria for the minimum DO concentration for supporting active warm-water fishes, such as the striped bass, is considered to be 5 mg/liter (NAS, 1973).

DO concentrations below 5 mg/liter appeared to affect striped bass in the present study. By June 5, DO concentrations in the lower reservoir, excluding refuges, at depths greater than approximately 8 m, had diminished below 5 mg/liter (Figure 19, page 52). Early June was also a period when adult striped bass were first discovered in Mossy Creek refuge. This was a period of rapidly rising water temperatures and rapid oxygen depletion. Several weeks prior to June 5, striped bass were readily caught by fishermen at depths of 7 to 10 m outside the refuges. Thermal experiences of several tagged fish monitored while outside refuges further shows that they did not inhabit depths greater than approximately 15 m, probably because of low DO concentrations (Figures 6-10, pages 29-33). Hypoxic water occurring in the hypolimnion of various temperate lakes or reservoirs has caused the upward shift in vertical distributions of many species (Dendy, 1945, 1946, and 1948; Colby & Brooke, 1969; Momot et al., 1977).

Exact DO concentrations that tagged fish were indicated as inhabiting in Figures 6-10 may have been somewhat erroneous, because these concentrations were derived separately from temperature-dissolved oxygen profiles taken near the fish and thermal statistics from monitored fish. The inability to sample the exact location where a tagged fish was monitored conceivably produced errors, because some fish were shown to be at DO concentrations below 1 mg/liter.

The areas of striped bass habitation in Mossy Creek, Byrd Spring, and Cedar Hill coves were arbitrarily designated as "refuges" due to the majority of time tagged fish spent there and not necessarily because

these areas were essential for fish survival (although this seems to be indicated). These refuges provided microhabitats where the cool and therefore dense water from groundwater sources flowed under the warmer reservoir pool water. The creation of such small volumes of water where temperatures approached 21 C and DO concentrations exceeded 5 mg/liter made the three refuges unique from all the main channel stations and most of the coves in the lower reservoir (downstream from HRM 70). Boat dock operators and fishermen noted several areas where groundwater springs were located in the lower reservoir, but only one, located in Hull Branch cove near HRM 54, was actually observed to attract adult striped bass during this study.

Light intensity did not appear to be a factor in depth distribution or habitat selected by fish, although refuges were slightly more turbid than other areas (Table 3, page 50). Tagged fish were found at depths ranging from less than 0.5 m to approximately 15 m at various locations and times.

Total dissolved solids (TDS) may have an effect on adult striped bass behavior. This parameter was not regularly checked during this study, but in October, water samples were collected at a depth of approximately 8 m at refuges and most of the main channel stations for TDS tests. All sites showed values between 240 and 300 mg/liter, which is low considering that the fall overturn was occurring. Radtke and Turner (1967) reported that TDS in excess of 350 mg/liter blocked upstream migrations of prespawning striped bass in the San Joaquin River, California. However, Summerfelt and Mosier (1976) found that prespawning striped

bass did not avoid TDS of 954 mg/liter in Keystone Reservoir, Oklahoma. Also, the Salt Creek area of Keystone Reservoir, which has an apparent aggregation of striped bass adults in the summer, has a very high TDS (1839 mg/liter).

Fish Activity and Movements

The movement of several tagged fish away from refuges to higher temperatures does not seem to fit the temperature selection hypothesis but may be related to the nomadic nature of adult striped bass. Coutant and Carroll (submitted) found that tagged fish were "generally active and roamed throughout the length and width of a small 2 ha lake" during daylight hours. Stooksbury (1977) also reported that striped bass moved considerably throughout the year, although they were inactive for periods up to a week during the summer and winter. Also, summertime aggregations of adult striped bass have been noted in areas of the main body of Keystone Reservoir, Oklahoma (Combs, personal communication). Therefore, it is not seemingly out of the ordinary for striped bass in the present study to remain within specific areas during their tracking lives.

Movements of three fish outside refuges shortly after their release may be explained by a post-release disorientation behavior. Stooksbury (1977) observed that tagged striped bass went through an orientation period of swimming in many directions as if looking for a familiar landmark or school upon their release.

Movement of fish from refuges some time after their release, especially during July, August, and early September when preferred

temperatures in the nonrefuge area were not available, cannot be explained by the general temperature selection pattern exhibited by most fish. The greater activity and distances moved by two of three fish released in Mossy Creek refuge in June seems plausible, because preferred temperatures still occurred this early in the year in the strata where DO concentrations were 3 to 5 mg/liter. Fish which moved from refuges either returned to refuges, died, or shed their tags (Table 1, page 23).

It is notable that each of the five fish released in Byrd Spring refuge moved to Mossy Creek refuge at various times in their tracking lives. Due to the relatively small volume of cool water from Byrd Spring as compared to the volume of cool water in Mossy Creek, fish movement may have been elicited by crowding of other striped bass or fish in the channels where the cool water existed. Two of these five fish were known to have been caught by fishermen in Mossy Creek refuge, and another fish was terminated due to a detached tag. It is possible the latter fish was also caught by a fisherman. Therefore, their movements may have been in search for food.

Predictive Model for Determining Habitat Selection

In view of these findings which indicated a relationship between water quality and behavior of striped bass in Cherokee Reservoir, a conceptual behavioral pattern during seasons other than summer can be predicted. During periods of low DO and high temperatures throughout the reservoir (July through September), these fish inhabited refuges where preferred temperatures and adequate DO concentrations occurred.

Considering that water temperature is the primary factor influencing striped bass behavior, changes in the reservoir's thermal regime with the seasons may cause the following scenario, modified also to reflect their restriction from zones with too little DO.

During periods of low DO and high temperatures throughout the reservoir (July through September), striped bass in Cherokee inhabit areas where preferred temperatures and adequate DO concentrations occur. After the fall overturn begins in September, the reservoir cools, and when it becomes an almost isothermal 22 C, these fish move from the summer habitat areas. Striped bass are no longer confined to their summer habitat areas because water temperatures fall below the fish's upper avoidance temperature of approximately 25 C. During the fall, the fish probably move in schools throughout the reservoir. Fishermen in past years have reported striped bass in the "jumps" during the fall. This occurs when the fish feed at the surface on large schools of gizzard shad. Also during the fall, DO concentrations no longer limit the fish to within 15 m of the surface, and they may be found at considerably greater depths than in the summer. As temperatures throughout the reservoir continue to drop with the approaching winter, these fish may again seek the milder temperatures of refuges which are again closer to their thermal preferendum of 22 C. Large striped bass have been caught by fishermen at Mossy Creek refuge during the winter months. Most of the fish may remain at locations outside refuges where they become lethargic due to the cool water and move very little during the winter. During the early spring, most adults begin moving upstream in an instinctive urge to spawn. Many fish successfully migrate to the tailwater of

John Sevier Dam, where many fish are caught by fishermen during much of the spring. As spring progresses, these fish probably move downstream, avoiding the warming river and steam plant effluents that exceed about 21-22 C. As in the fall, suitable conditions exist in the lower reservoir, and the fish probably move about in large schools throughout the lower reservoir. Findings from the present study indicated that in late May and early June, large schools of striped bass aggregated near submerged islands or bars at various locations in the reservoir. In late spring, the developing temperature-dissolved oxygen "squeeze" occurs when the striped bass are forced downward in seeking preferred temperatures, but low DO concentrations limit them from inhabiting the cooler water. This "squeeze" becomes more pronounced in late May and early June, and the fish are exposed to higher than their preferred temperatures (i.e., greater than 21-22 C). The fish react in a "kinesis" response (Doudoroff & Shumway, 1970) which results in their increased activity, as opposed to a "taxis" or direct avoidance response. Meldrim et al. (1974) discovered that juvenile striped bass responded to higher temperatures and/or low DO concentrations with increased activity. Therefore, the striped bass find the summertime refuges as they increase their movements.

CHAPTER VII

SUMMARY

1. Eighteen adult striped bass provided usable habitat selection data, with their tracking lives ranging from 2 to 37 days and averaging 17 days.

2. Adult striped bass were found to be sensitive to stress of hook and line capture and lengthy tagging procedures. Only electrofishing and external tagging proved successful.

3. The majority of tagged fish spent the majority of their tracking lives in submerged channels created by groundwater springs or creeks in Mossy Creek, Byrd Spring, or Cedar Hill coves, each located downstream from HRM 65.

4. The coexistence of temperatures below 24 C and DO concentrations greater than or equal to 5 mg/liter distinguished inhabited areas of tagged striped bass from uninhabited areas. Water temperature appeared to be a controlling factor in the habitat selection pattern of the 18 fish, while low DO concentrations limited their habitation of thermally preferable habitat in the hypolimnion. Concurrent conditions of suitable temperature and DO did not occur in the open reservoir during most of the summer and limited the adult striped bass to the few refuge zones.

5. Fourteen fish tagged with sonic transmitters were generally active, as indicated by movement in about 60% of the total number of monitoring periods on them. Fish rarely moved over 200 m during monitoring periods. Movement of three fish with radio transmitters was not

detectable until they left refuges at the fall overturn because these fish moved short distances (less than 100 m).

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APPENDIXES

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APPENDIX A

THERMAL EXPERIENCES OF FISH FROM AUTOMATIC MONITORING DATA

Table A-1. Statistical Summary of Automatically Recorded Data Sets from Five Tagged Striped Bass in Cherokee Reservoir in Degrees Celsius

Fish number	Date	Time	N	Mean	SD	Mode	Min	Max	Skewness	Kurtosis
152B	JL 18	2300	51	22.9	0.7	22.9	22.1	26.2	2.6	9.2
152D	AU 30	1500	82	24.2	3.8	20.7	17.2	29.8	0.1	-1.5
		2100-2300				29.1				
	AU 31	0000-0700	233	23.4	4.6	19.5	15.1	29.8	0.0	-1.6
						29.1				
156C	JL 2	1000	16	16.6	0.1	16.5	16.4	17.1	0.8	8.2
158	JL 26	2000-2300	229	22.5	1.0	22.6	20.5	29.4	1.2	7.6
	JL 27	0000-2300	1337	21.5	1.2	21.3	17.9	29.4	1.9	9.5
	JL 28	0000-1200	713	20.4	1.5	20.4	15.6	29.7	0.9	8.8
	JL 28	1800-2300	286	18.7	3.0	16.4	15.1	29.6	1.6	2.0
	JL 29	0000-1100	540	18.7	1.9	16.3	15.2	29.7	1.3	4.5
						19.6				
	AU 1	1800-2300	277	19.8	2.2	17.4	15.9	29.8	0.7	1.5
						21.2				
	AU 2	1000-1100	76	18.6	1.6	18.0	16.2	28.4	3.5	18.9
159A	JL 25	1500-2200	451	20.4	1.5	20.5	16.4	28.9	2.5	10.6
	JL 29	1200-2300	664	20.6	1.6	20.7	15.8	29.5	0.8	7.2
	JL 30	0000-1300								
		2000-2300	805	19.1	2.5	17.5	15.5	29.5	1.1	1.5
	JL 31	0000-0300								
		0900-1000	509	19.7	2.5	16.5	15.9	28.9	0.6	0.2
		2000-2300				20.7				
	AU 1	0000-0400	208	18.7	2.3	17.4	16.1	29.3	2.4	7.1

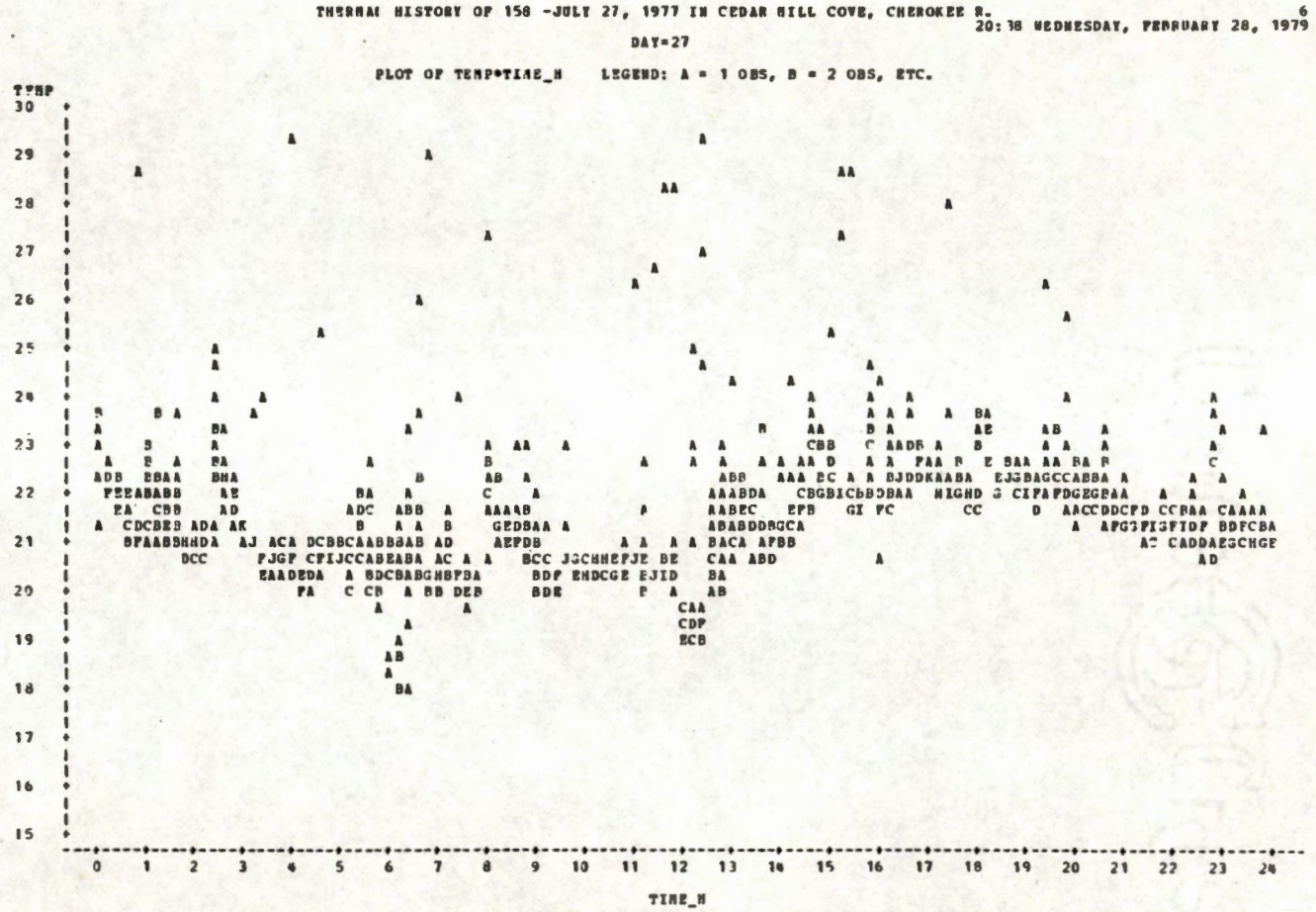


Figure A-1. Computer plot of an automatically recorded data set from Fish 158 taken on July 27, 1977.

Hours are indicated on the x-axis and temperature (C) on the y-axis.

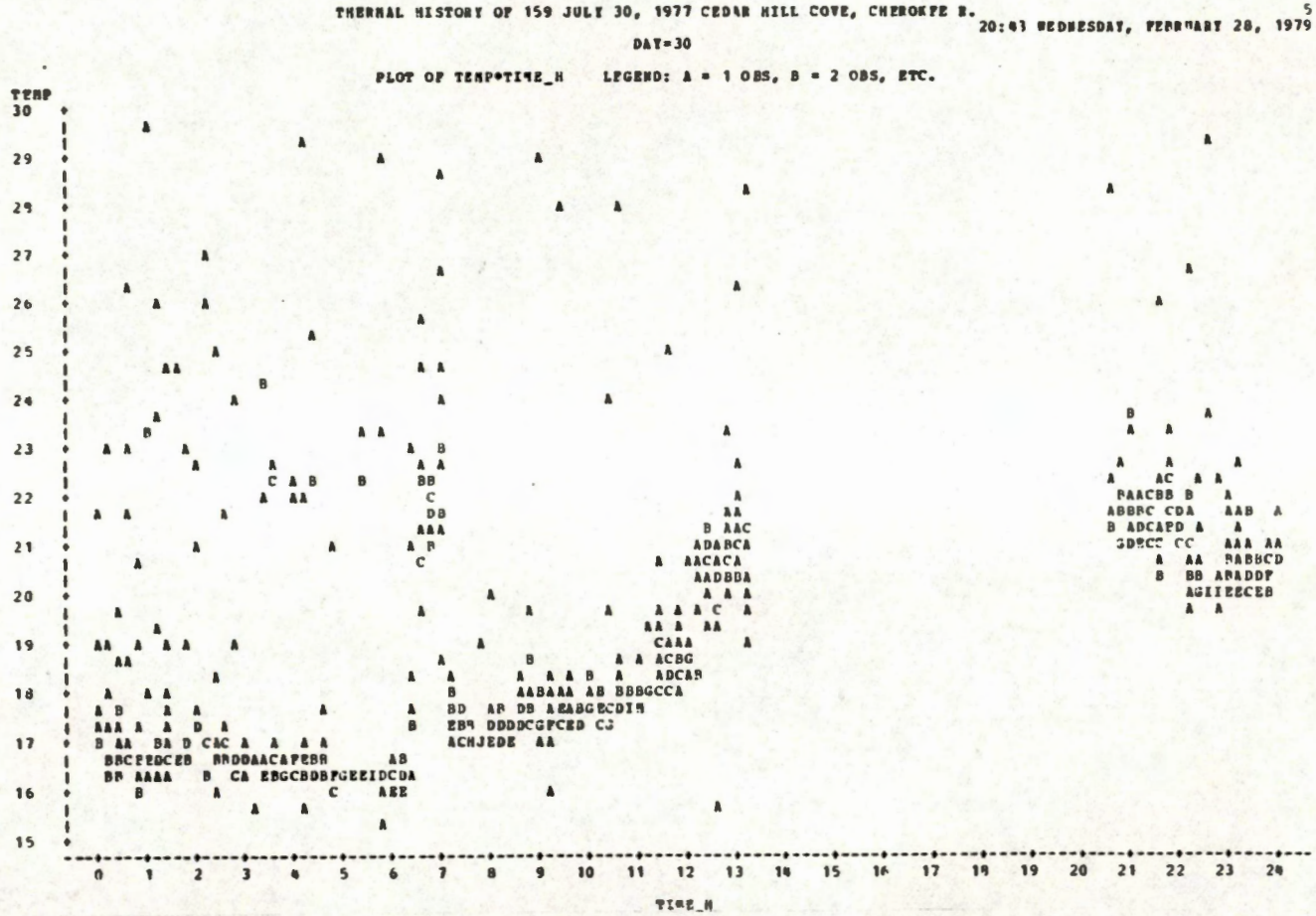


Figure A-2. Computer plot of an automatically recorded data set from Fish 159 taken on July 30, 1977.

Hours are indicated on the x-axis and temperature (C) on the y-axis. Hours with no data indicate movement of the fish out of range of the hydrophone.

APPENDIX B

INDIVIDUAL HISTORY OF SUCCESSFULLY TRACKED FISH

FISH 152A (FIGURE B-1; TABLE B-1)

This 10-15 lb fish was obtained from Mossy Creek channel near a submerged water fall (Site 1 in Figure B-1) on June 6 at dusk. This area, located at the creek and reservoir confluence, was about 4 m deep. Immediately after being tagged and released, the fish moved approximately 175 m downstream in the channel to Site 2, located near another submerged waterfall. These small waterfalls were less than 3 m high and were discovered when the reservoir pool surface was low. The fish remained at Site 2 almost an hour before moving back to Site 1, where it remained during the night. At these two sites, it was estimated to be in water between 18.5 and 22.5 C. These temperatures were obtained from sampling in the channel and not by telemetry. On June 7, the fish was located at Site 3, located 1.2 km downstream from Site 1. During this monitoring period, it moved in the immediate vicinity and remained at an average temperature of 21.0 C (mean of a 30 min period of observations). According to a temperature profile taken near this site 2 days before, depths greater than 10 m were not frequented by this fish during this period (Figure 7, page 30). Depths greater than 10 m were less than 18.5 C and had DO concentrations below 2.3 mg/liter. By June 8, the fish had moved 1.3 km from Site 3 to Site 4, located near a small island. A spot check, an observation period less than 30 min, showed the fish to be at 19 C and moving in the vicinity. The next observation period was on June 10 when the fish was found at Site 5, where it was estimated to be located at a depth of approximately 9 m. The temperature at this depth was approximately 22 C, and DO was 4.7 mg/liter. The surface was 23 C

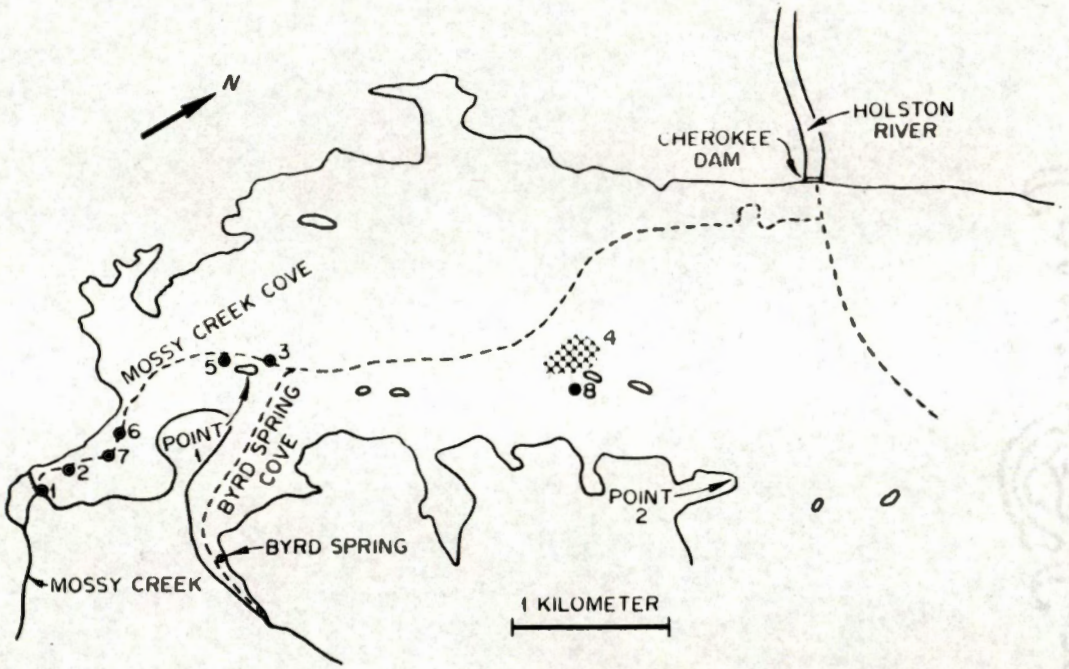


Figure B-1. Map showing observed locations of Fish 152A during its tracking life. The reservoir is shown with a surface elevation of 328 m.

Table B-1. Thermal History of Fish 152A in Degrees Celsius with Location Data from Figure B-1

Date	Site	Time	Mean	Mode	Range	SD
JU 7	3	2030	21.0	21.5	18.5-23.1	1.0
JU 8	4	1210	19.3*			
JU 10	5	0800	22.1*			
JU 11	2	1130	22.6	21.7	21.6-25.6	0.8
JU 21	6	1500	19.3	19.1	18.7-20.4	0.4
JU 22	2	0730	15.2	15.1	14.8-15.9	0.3
JU 23	2	0900	16.5	16.4	16.2-18.0	0.3
JU 28	7	1330	18.7	18.7	18.4-18.9	0.1
JU 29	7	1430	17.9	17.9	17.8-18.0	0.1

*Spot check (less than 30 min of time-interval observations)

and contained 8.6 mg/liter of DO. By noon of June 11, this fish had moved back to Site 2, where it experienced temperatures near 23 C during an observation period. It was located in the channel at a depth of 3.5 m where DO exceeded 10 mg/liter. The next search for this fish was made on June 21 when it was found at Site 6 in water at 19.3 C (mean of observations). During the following 2 days, the fish was located at Site 2 at temperatures between 15 and 17 C. It was situated near the bottom (3 m deep) during the monitoring period on both days. Temperatures at the surface and 2 m deep at Site 2 were 23.6 and 20.8 C, respectively, on June 22. This fish was not monitored again until June 28 when it was found at a new location (Site 7), near another submerged waterfall in the submerged Mossy Creek channel. The next day the fish was again found at Site 7 where it showed no discernible movement. While at Site 7, the fish was monitored at 18 to 19 C. During the next observation period on July 1, the tag was thought to have become detached from the fish at Site 8, located about 2.5 km from Site 1. The standard deviation of the time-interval data was much less than those of previous data sets. Also, disturbances made in the water at this site did not result in any noticeable movement of the fish. The tag with intact harness was recovered from the bottom several days later.

FISH 152B (FIGURE B-2; TABLE B-2)

During the afternoon on July 12, this 5-10 lb fish was obtained at Site 1 (Figure B-2) located in a deeper pool in the Mossy Creek channel below a submerged waterfall. It was held about 10 min before

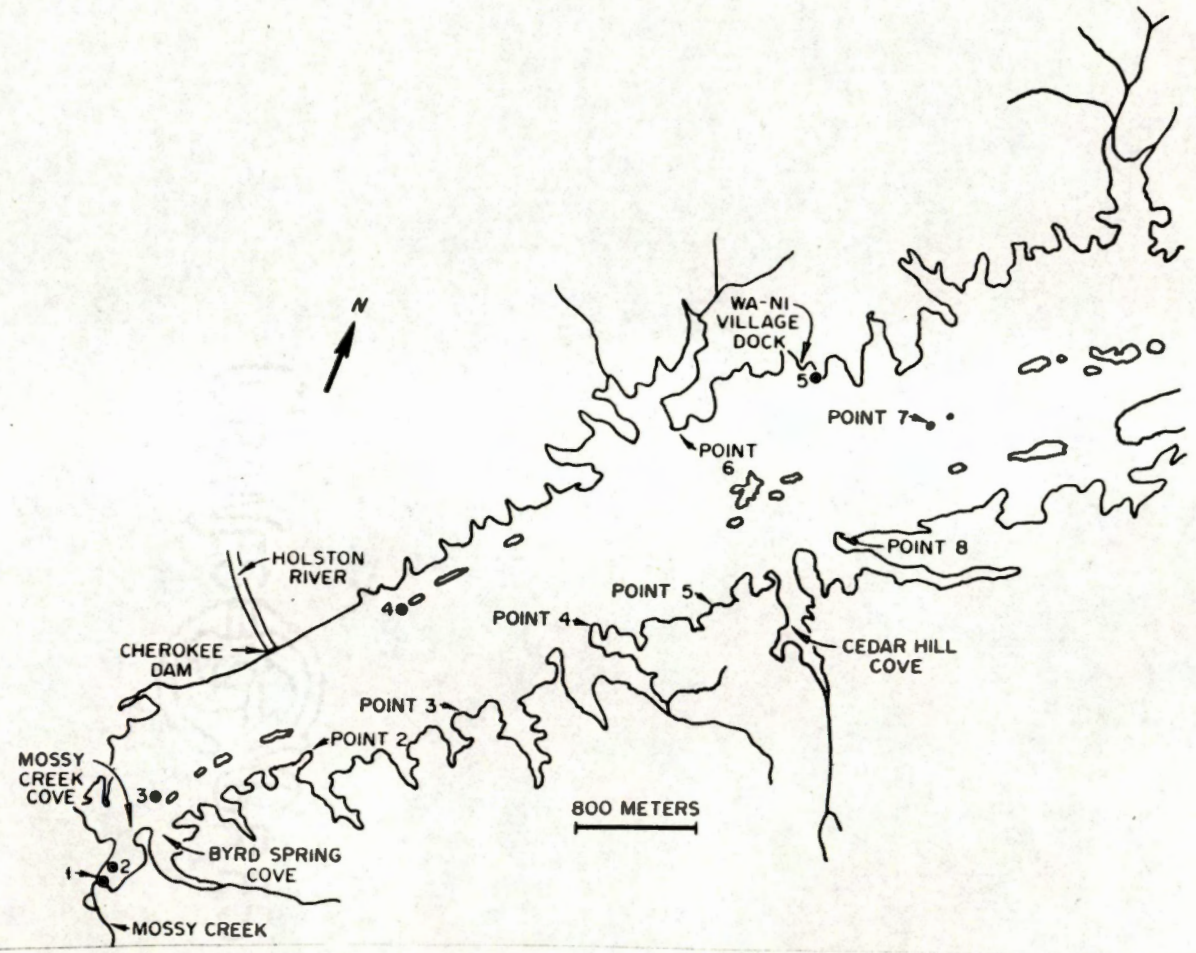


Figure B-2. Map showing observed locations of Fish 152B during its tracking life. The reservoir is shown with a surface elevation of 328 m.

Table B-2. Thermal History of Fish 152B in Degrees Celsius with Location Data from Figure B-2

Date	Site	Time	Mean	Mode	Range	SD
JL 13	2	1000	18.7	18.6	17.6-21.7	0.5
JL 13	2	1400	20.5*			
JL 13	2	1730	22.7	22.7	22.5-23.2	0.1
JL 14	2	0630	21.5	21.0	20.6-24.7	0.7
JL 15	2	0830	20.3	20.3	19.7-21.3	0.2
JL 15	2	1100	24.1*			
JL 16	2	1330	23.0	22.5	22.3-24.1	0.7
JL 18	2	2300 2400+	22.9	22.9	22.1-26.2	0.7
JL 19	2	0800	19.3*			
JL 19	2	0900	19.6*			
JL 19	3	2000	24.8*			
JL 19	3	2100	25.7*			
JL 20	2	0430	20.5*			
JL 20	2	0730	19.4*			
JL 23	4	1300	25.9	25.9	25.4-27.9	0.4

*Spot check (less than 30 min of time-interval observations)

+Automatically recorded data

release. No time-interval data were recorded on this date due to interference from signals of Fish 155B, which was located in the near vicinity of Fish 152B. On July 13, the fish was found at the upstream portion of Site 2, an area along the submerged channel. At 1100 hr it experienced temperatures near 18.7 C, and at 1400 hr a spot check revealed it to be at 20.5 C. Then at 1730 hr it was monitored at 22.7 C in the same vicinity. The fish was not moving during the first and last observations made on this day. At dawn on July 14, it was found moving frequently in Site 2 and experiencing temperatures between 20.1 and 24.7 C. The latter value approached the surface temperature. During this monitoring period, a school of large striped bass broke surface in the direction of Fish 152B as they were feeding on the abundant shad. No movement of this fish was detected on July 15 as it experienced 20.3 C at Site 2. A spot check 3 hr later showed it to be at 24 C. Then on July 16, it moved slowly around the refuge but remained between 22 and 24 C. On July 18 at 2300 hr (night), it was located about 50 m downstream from its previous position and was monitored an hour by the recorder. During this hour, it experienced temperatures between 22.1 and 26.2 C, and the average was 22.9 C. On July 19, two spot checks were made in the morning and two in the evening. The fish was located at Site 2 at approximately 19 C during the morning checks and at Site 3, located about 1 km downstream from Site 2, at about 25 C during the evening checks. According to several temperature and DO measurements made at Site 3, the fish was occupying a depth of approximately 14 m where DO concentrations were 3 mg/liter. Many boat

fishermen were catching large striped bass occasionally in this area. These fish were being caught at depths of 10 to 15 m, according to several fishermen questioned. Before dawn on July 20, this fish had moved to the upstream portion of Site 2 below the now visible upper waterfall. This waterfall undoubtedly blocked movements of large striped bass upstream in Mossy Creek, for no other tagged fish were subsequently found above this fall. At 0430 and 0730 hr on July 20, it was monitored at temperatures between 19 and 20 C. On July 23, this fish was found at Site 4, located near a small island on the northwest side of the inundated Holston River channel near Cherokee Dam. It had moved at least 5 km from its previous location. At Site 4 it experienced temperatures averaging 25.9 C and ranging between 25.4 and 27.9 C. Temperature and DO measurements taken at this site showed the fish to be inhabiting depths between 12 and 13 m (Figure 9, page 32). Below these depths DO concentrations fell below 1 mg/liter, and temperatures reached a minimum of 21 C. This fish was not discovered alive again, for on July 26 its carcass with intact tag and harness was found at Site 5, located 6.5 km up the reservoir from Site 4. It is possible the fish died near Site 4 and drifted to Site 5 by wave action. Therefore, this distance was not considered in the total movements of this fish. Although the body was badly decomposed, it took considerable force to pull the tag and harness from the body. This fish was located the furthest distance of any live fish from a refuge.

FISH 152C (FIGURE B-3; TABLE B-3)

This 5-10 lb fish was obtained downstream from a submerged waterfall in the Mossy Creek channel on August 1 at Site 1 (Figure B-3). It had lesions on its fins but was tagged anyway. Upon release, it immediately moved 175 m downstream to Site 2, remaining near, if not in, the submerged channel. About 3 hr after release, it was monitored at 22.1 C during a period in which it remained stationary at Site 2. At midnight, it was at Site 2 in 20 C water. On August 2, a spot check revealed the fish to be at the same site and at 20 C. On August 3, this fish was caught by a fisherman in the same area. The fish was reported "fighting very hard, and its stomach contained several small shad."

FISH 152D (FIGURE B-4; TABLE B-4)

This fish, weighing approximately 10 lb, was obtained in water less than 2 m deep at Site 1, located at the Byrd Spring and reservoir confluence, on August 16. Another fish, captured and tagged after this fish, moved from the refuge and was never found again. Just prior to electrofishing this area, two striped bass were caught by anglers near the spring. The author noted external lesions on the two angler-caught fish, as well as on the two tagged fish. Fish 152D was held about 15 min before it was released after dusk. It remained in a spot about 100 m downstream from the spring and showed no movement. It experienced a small range of temperatures averaging 26.8 C. At 0830 hr the next day, it was located near the spring where it experienced temperatures between 18 and 22 C. On August 18 the cove was turbid, except for the

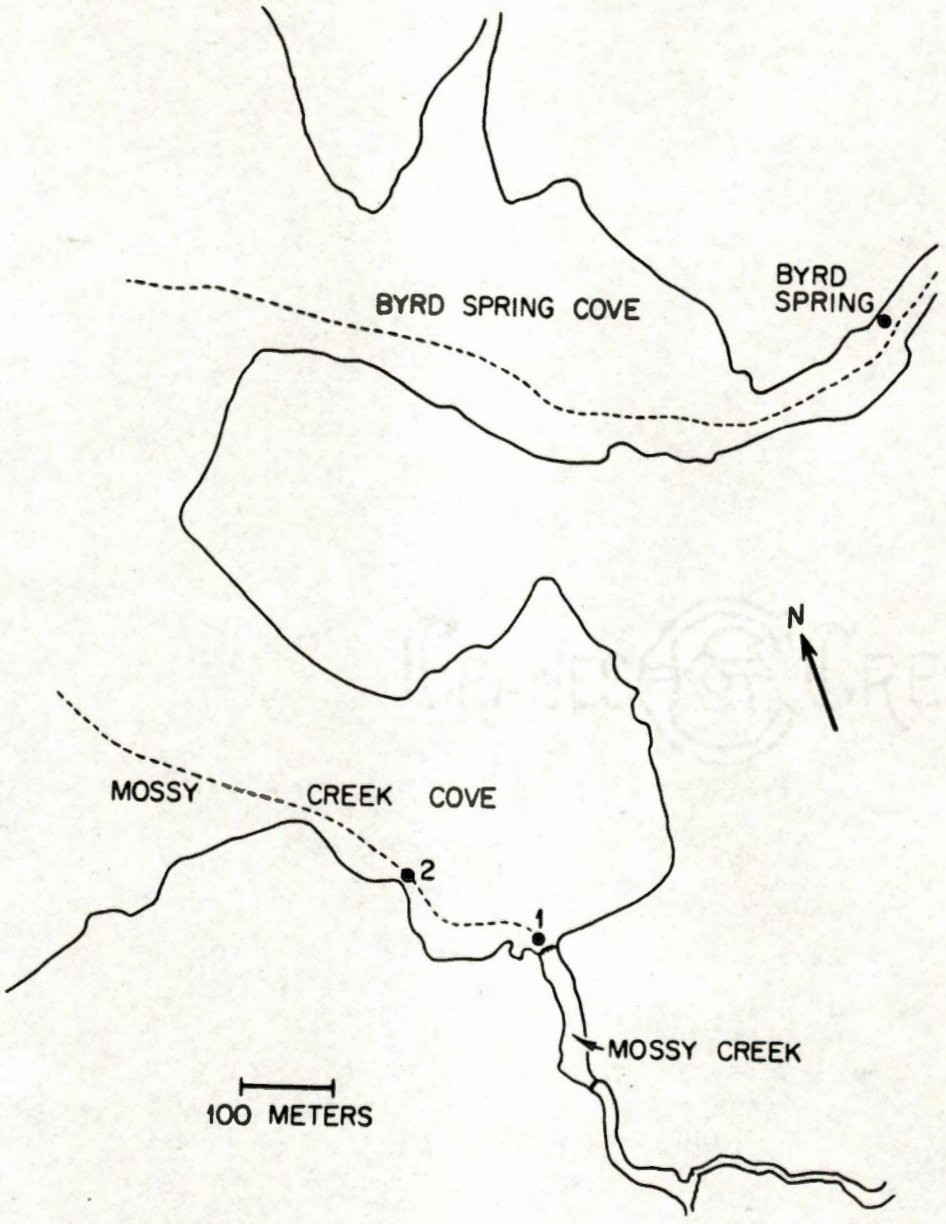


Figure B-3. Map showing observed locations of Fish 152C during its tracking life.

The reservoir is shown with a surface elevation of 319 m.

Table B-3. Thermal History of Fish 152C in Degrees Celsius with Location Data from Figure B-3

Date	Site	Time	Mean	Mode	Range	SD
AU 1	2	2000	22.2	22.1	21.5-23.6	0.3
AU 1	2	2330	20.2	19.4	19.1-23.7	1.1
AU 2	2	1030	20.8*			

*Spot check (less than 30 min of time-interval observations)

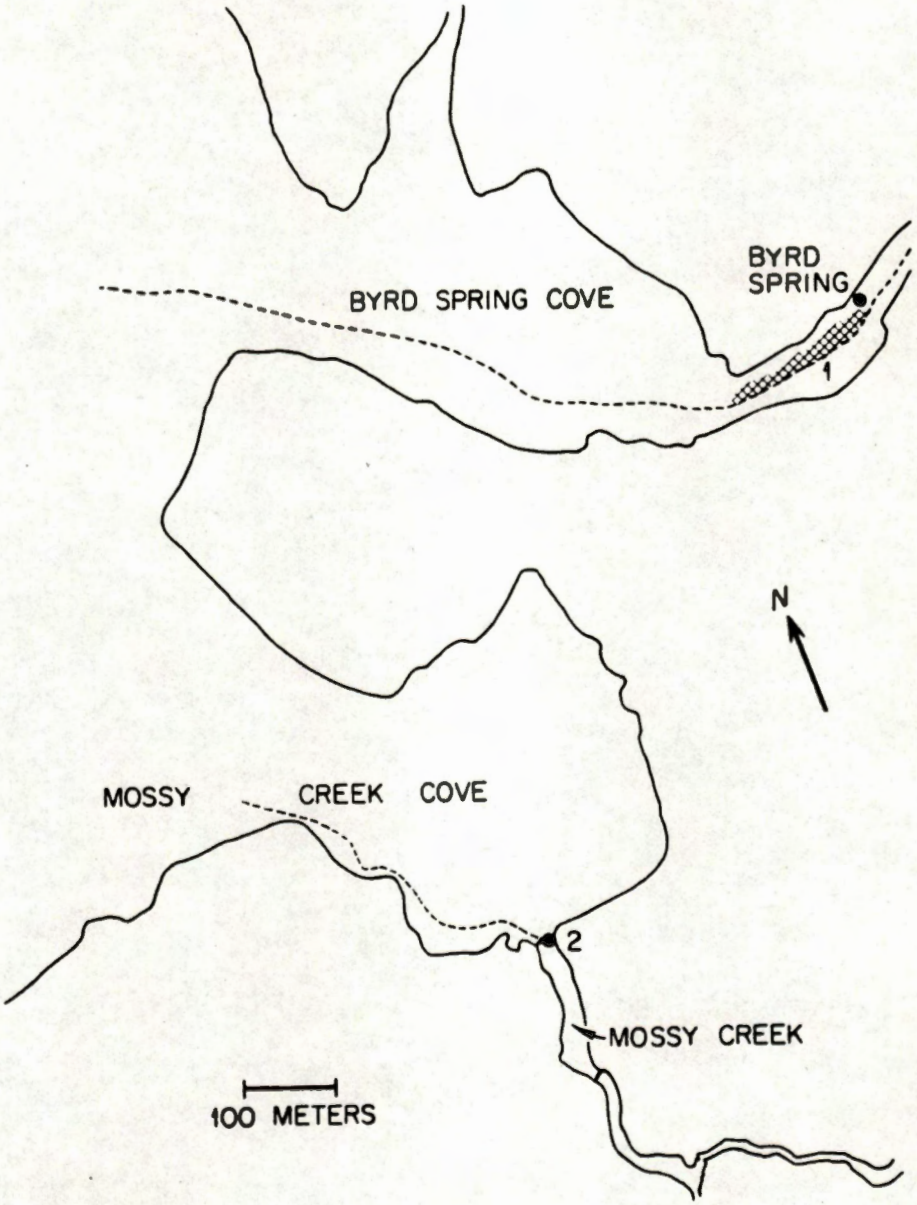


Figure B-4. Map showing observed locations of Fish 152D during its tracking life.

The reservoir is shown with a surface elevation of 319 m.

Table B-4. Thermal History of Fish 152D in Degrees Celsius with Location Data from Figure B-4

Date	Site	Time	Mean	Mode	Range	SD
AU 16	1	2130	26.8	26.9	25.9-27.5	0.3
AU 17	1	0830	19.7	19.6	18.2-22.2	0.6
AU 18	1	0900	17.9	14.6 21.1	14.1-23.4	2.5
AU 22	1	1230	19.2	18.8	17.6-21.2	0.8
AU 23	1	1200	16.2	14.6	14.4-23.4	2.5
AU 24	1	1430	16.1*			
AU 25	1	1130	19.3	19.0	17.1-23.5	1.2
AU 26	1	1230	18.3	17.0 18.5	15.9-22.4	1.4
AU 30	1	1500 2300+	24.2	20.7 29.1	17.2-29.8	3.8
AU 30	1	1430	20.2	20.1	17.9-21.9	0.7
AU 31	1	0000 0700+	23.4	19.5 29.1	15.1-29.8	4.6
AU 31	1	0800	22.5	21.9	19.5-23.9	0.9
SE 1	1	2130	19.9	19.5	17.9-24.4	1.4
SE 2	1	1000	21.9	21.9	20.9-23.9	0.7
SE 5	1	0000	21.3	20.9	20.2-24.3	0.7

*Spot check (less than 30 min of time-interval observations)

+Automatically recorded data

spring effluents, from heavy rains during the preceding night, and the fish experienced temperatures between 14.1 and 23.4 C. A frequency distribution of time spent by this fish at various temperatures during this August 18 monitoring period indicated how the fish's location influenced its thermal history (Figure 15, page 45). Temperatures and DO concentrations within 20 m downstream from the spring on August 18 showed a low of 18.4 C at the bottom and 7.4 mg/liter at the bottom, respectively. Automatic time-interval data on August 30 and 31 encompassing 13 hr showed distributions with peaks of approximately 20 and 29 C on both days (Table A-1, page 79). The peak at 29 C was also found in the cumulative manual data distribution (Appendix C). It can only be speculated that this fish spent considerable time at depths less than 1 m from the bottom where water temperatures were approximately 29 C. This fish was not found outside of Site 1 until September 6 when it was caught by a fisherman at Site 2, located in Mossy Creek refuge. In Byrd Spring refuge, it moved frequently and experienced temperatures between 14 C, the lowest available, to approximately 29 C. It is not known what caused this fish to move from Byrd Spring refuge, but its search for food may be speculated. The fisherman indicated that it was caught after swallowing a hook baited with earthworms. It was taken from the bottom at a depth of about 3 m. Mention was made by the fisherman of an "infection on the fish where the wires were attached."

FISH 155A (FIGURE B-5; TABLE B-5)

This single fish, weighing between 5 and 10 lb was captured at Site 1 on June 7. This site was directly below a submerged waterfall, about 4 m high, where Mossy Creek emptied into the reservoir pool. Fish 152A was tagged at this site on the previous day. Fish 155A, like Fish 152A, immediately moved downstream to Site 2, near another small submerged waterfall on the Mossy Creek channel. On June 8, it was found at Site 1, but as the tracking boat approached, it moved to Site 2 where it was monitored at an average of 18.9 C. On June 10 at 0800 hr, this fish was located at Site 1 where the surface and bottom temperatures were 18.0 and 15.0 C, respectively. At 1400 hr, this fish was found at Site 3, located about 1.2 km downstream from Site 1 and near where Fish 152A had been located earlier in the day. Temperature measurements taken near this fish showed the bottom and surface to be about 24 C, and DO concentrations were approximately 10 mg/liter at the surface and 8.3 mg/liter at the bottom (6.5 m deep). During the monitoring period, it showed very little lateral movement and remained at an almost constant 22.0 C. The temperature and DO measurements were apparently not taken directly over this fish, which was no doubt located in a deeper channel with lower temperatures than those presented. An hour later a spot check revealed this fish to be at 22 C at Site 4. On the morning of June 11, this fish was again located at Site 4, where it was observed moving within a 20 m diameter area and experiencing temperatures between 18.1 and 21.6 C. A temperature-DO profile of the channel near this fish indicated it to

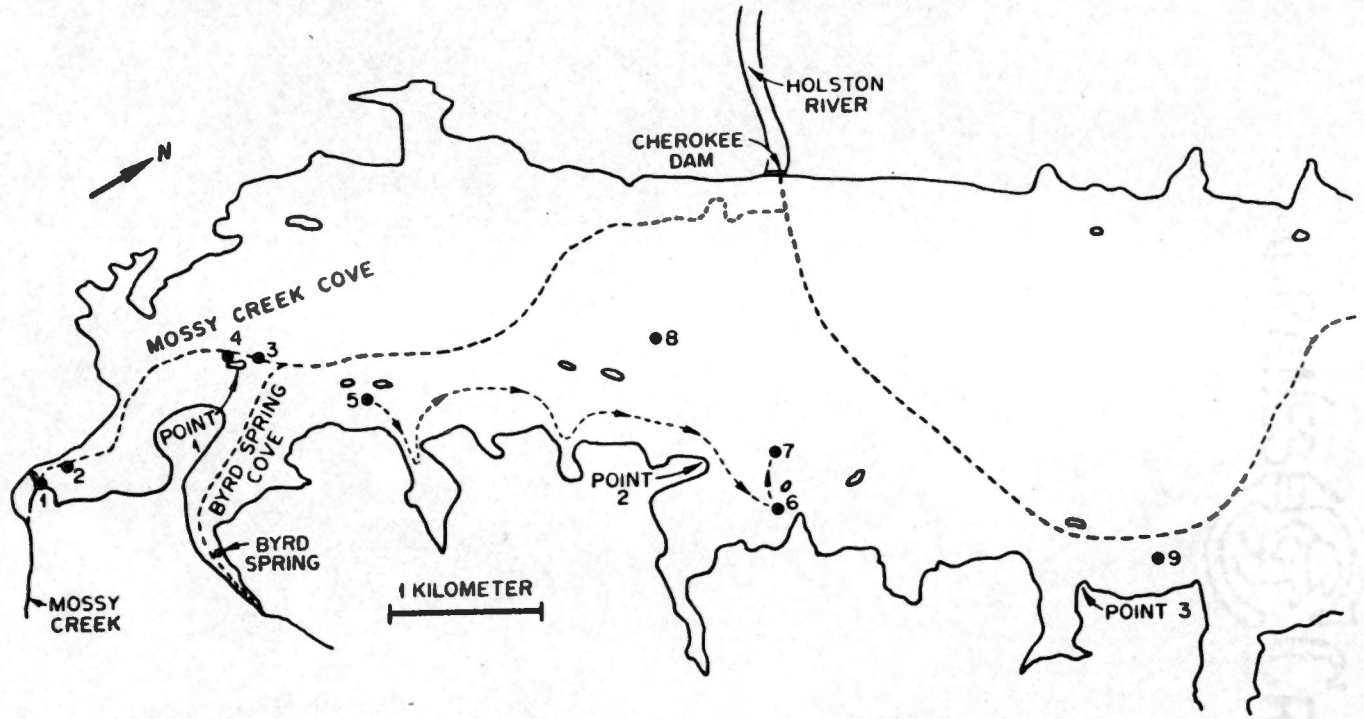


Figure B-5. Map showing observed locations of Fish 155A during its tracking life. The reservoir is shown with a surface elevation of 328 m.

Table B-5. Thermal History of Fish 155A in Degrees Celsius with Location Data from Figure B-5

Date	Site	Time	Mean	Mode	Range	SD
JU 8	2	1630	18.9	18.8	18.4-19.4	0.1
JU 10	1	0800	18.4*			
JU 10	3	1400	22.0	22.0	21.9-22.1	0.0
JU 10	4	1500	22.0*			
JU 11	4	0930	20.9	21.4	18.1-21.6	0.9
JU 21	5-6	1700	21.3	21.3	19.9-22.7	0.5
JU 21	6	1900	21.3	20.9 21.7	20.7-21.9	0.4
JU 21	7	2030	21.1	20.8	19.3-21.9	0.4
JU 22	8	0630	20.8	20.8	20.5-20.8	0.1

*Spot check (less than 30 min of time-interval observations)

be at a depth of 9-10 m where DO concentrations were between 3 and 4 mg/liter (Figure 8, page 31). Temperatures approached 20 C at the bottom (13 m deep) and were greater than 22 C at depths less than 9 m. This fish was not searched for again until June 21 when it was initially found at Site 5 at 1700 hr and then proceeded in the cove and along the shoreline as shown in Figure B-5. By 1900 hr, it had moved to Site 6 where it remained approximately 1 hr before moving to Site 7. It traveled 2.6 km from Site 5 to 6 in 3.5 hr. During this period, it experienced temperatures between 19.9 and 22.7 C, inclusively. These temperatures occurred at depths between 5 m and the bottom. Temperature and DO measurements taken at Site 7 on June 22 indicated the fish frequented a depth of 12 to 13 m in a gradient of 24.4 C at the surface and 17.0 C at the bottom (20 m deep). By dawn of June 22, it had moved to Site 8 where it was monitored at an almost constant 20.8 C. It was stationary during the monitoring period. This fish was not located again until June 29 when the fish was found at Site 9, located 2 km from Site 8. The tag was believed to have become detached or the fish had died at this location. Several days later it was apparent that disturbances at the bottom of this site could not result in any lateral movement or temperature change of the fish. The tag with harness was recovered from the bottom by SCUBA diving in an area where boulders with crevices were abundant. Abrasions on the outer coating of the tag lends support to speculation that the fish lost it by hanging it in a rock crevice.

FISH 155B (FIGURE B-6; TABLE B-6)

This fish, weighing approximately 10 lb, was captured and released at Site 1 (Figure B-6), located in the Mossy Creek channel directly downstream from a submerged waterfall on July 12. Fish 152B was also captured and released in this vicinity during this same afternoon. Fish 155B experienced temperatures ranging from 20.7 to 22.2 C as it displayed much activity at Site 1. An hour before dusk, it was found stationary at Site 1 at an average temperature of 20.2 C. At 1030 hr on July 13, it was found inactive at Site 2, located downstream from another submerged waterfall in the Mossy Creek channel. About 8 hr later, it initially occupied Site 2 but moved to Site 1 during the monitoring period. The morning observations showed the fish to be at 21 to 23 C, and later observations revealed it to experience a maximum of several degrees higher than during the morning observation period. On July 14, this fish moved constantly in the area from Site 2 downstream to Site 1 upstream. Likewise, Fish 152B exhibited movements in this area at about the same time. Each fish experienced different temperature ranges, and these coincided at approximately 21 C. Then on July 15, Fish 155B remained stationary at Site 2 during a monitoring period but moved a short distance within Site 2 immediately after this period. On the 2 previous days, it was in water averaging approximately 19 C and not exceeding 24 C. The temperature at 3 m deep near, but not in, the channel in Site 2 was 26 C. This indicates the drastic temperature change from channel water to bottom water outside the channel. During the monitoring period on July 16, this fish was inactive in water

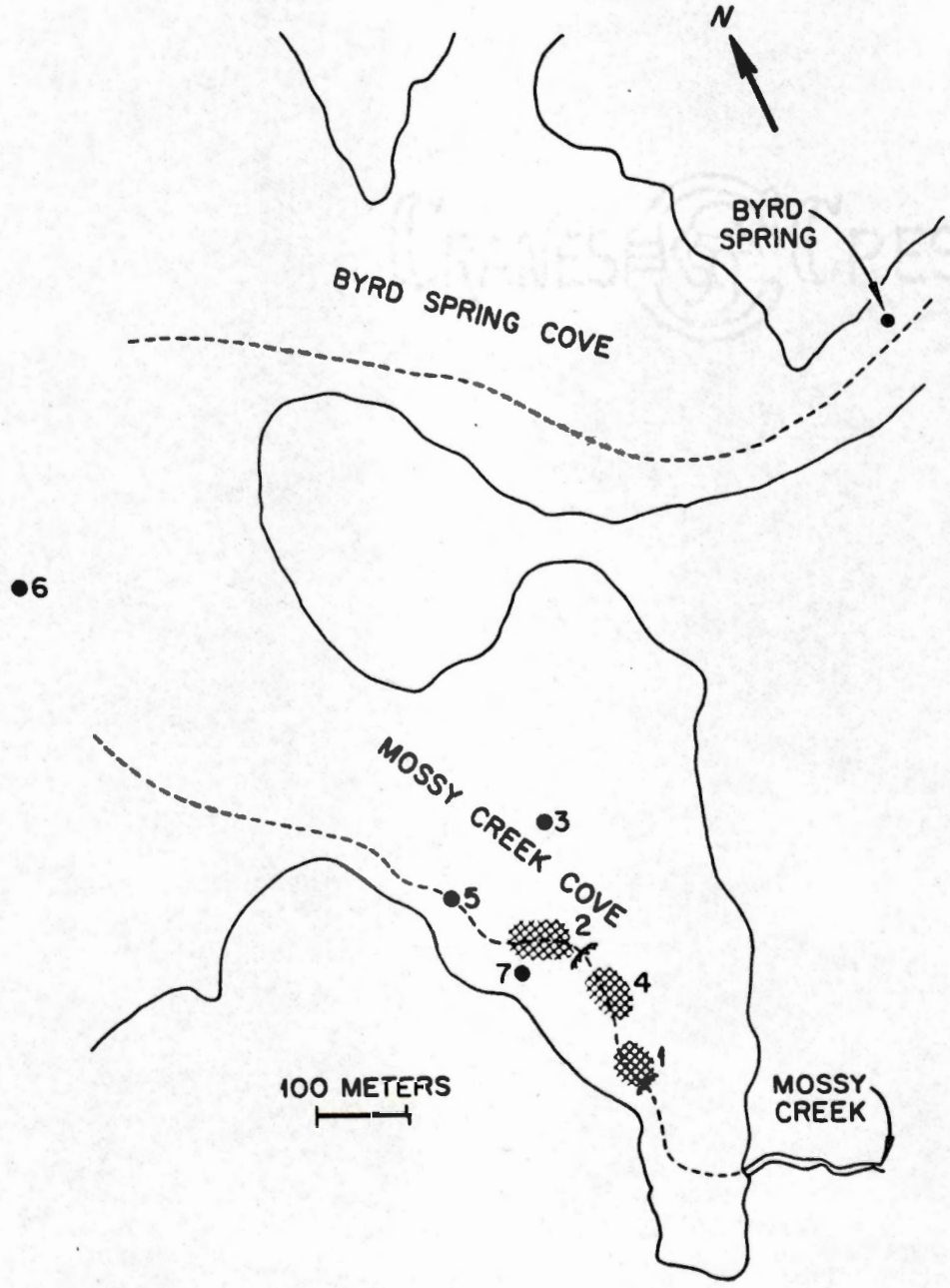


Figure B-6. Map showing observed locations of Fish 155B during its tracking life.

The reservoir is shown with a surface elevation of 328 m.

Table B-6. Thermal History of Fish 155B in Degrees Celsius with Location Data from Figure B-6

Date	Site	Time	Mean	Mode	Range	SD
JL 12	1	1400	21.6*			
JL 12	1	2030	20.2	20.3	19.8-21.0	0.3
JL 13	2	1030	18.8	18.5	18.3-23.1	0.5
JL 13	2-1	1800	21.7	21.4	21.3-23.1	0.5
JL 14	2-1	0700	19.0	18.5	18.2-21.1	0.5
JL 15	2	1000	19.3	19.0	18.2-22.7	0.7
JL 16	4	1430	22.4	22.2	21.5-23.9	0.5
JL 19	6	1300	20.8	20.8	20.6-21.7	0.1
JL 20	7	1100	21.0*			

*Spot check (less than 30 min of time-interval observations)

averaging 22.4 C at Site 4. Then on July 19, as another fish was being monitored, Fish 155B was caught by a fisherman's lure at Site 5. The fish was pulled to the boat where the hooks, entangled in the tag and harness, were freed. The author, unaware of this event until several hours later, discovered this fish at Site 6, located about 600 m downstream from Site 5. It remained stationary and experienced temperatures of an almost constant 20.8 C during the monitoring. The next day it was found at Site 7, stationary, and at 21 C (spot check). It was not found alive again, for on July 29, the detached tag was found at Site 7. The harness was still intact which suggests that the tag was pulled from the carcass or body. It is of equal possibility that the fish died and deteriorated, leaving the tag with harness attached.

FISH 155C (FIGURE B-7; TABLE B-7)

On August 4, this fish, weighing between 5 and 10 lb, was captured in Cedar Hill cove at Site 1 (Figure B-7). This site was located approximately 150 m from the spring. Fish 158 which had been previously tagged in the cove remained very close to the spring during this activity. The next day, Fish 155C was found at Site 2, located near the mouth of Cedar Hill cove at a distance of 1.2 km from the spring. A spot check revealed this fish to be at an almost constant 25.7 C. This temperature was found in the strata near the bottom (17 m deep) (Figure 10, page 33). The bottom had the minimum value of 25.2 C at this site. DO concentrations below 14 m were less than 2 mg/liter at this site. At 1000 hr on August 6, the fish was found moving slowly out of the cove from Site 3, but after nearing Site 2,

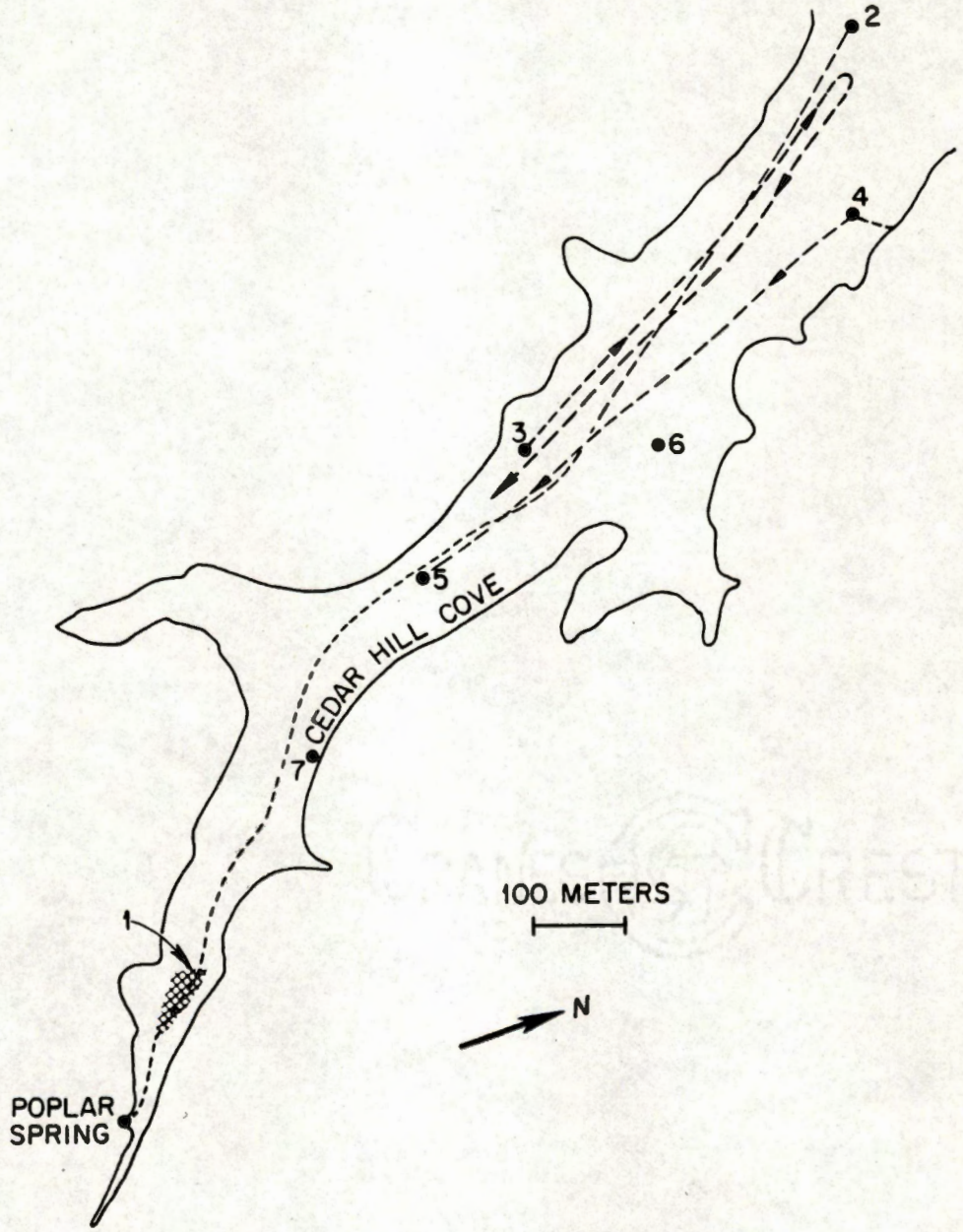


Figure B-7. Map showing observed locations of Fish 155C during its tracking life.

The reservoir is shown with a surface elevation of 319 m.

Table B-7. Thermal History of Fish 155C in Degrees Celsius with Location Data from Figure B-7

Date	Site	Time	Mean	Mode	Range	SD
AU 6	3	1000	25.6	25.6	25.3-25.9	0.1
AU 6	3	1530	25.9*			
AU 8	4-5	1330	25.9	26.0	25.8-26.2	0.1
AU 8	5	1700	26.3	26.0	22.6-27.3	0.3
AU 9	6	1430	25.9	26.0	25.8-26.2	0.1
AU 11	1	1100	20.8	20.5	19.9-23.7	0.5
AU 12	1	1500	21.1	20.7	19.9-23.9	0.7
				21.5		
AU 15	1	1500	20.1	20.1	19.7-21.8	0.3
AU 16	1	1200	19.8	20.1	18.5-20.8	0.4
AU 17	1	1200	18.9	18.6	16.7-21.0	1.1
AU 18	1	1430	18.3	18.4	17.2-19.6	0.6
AU 22	1	1500	17.7	17.5	16.9-19.1	0.4
AU 23	1	1400	19.4	18.7	17.5-27.3	1.0
				20.1		
AU 24	1	1330	17.7	17.0	16.7-23.9	1.6
AU 25	1	1300	17.5*			
AU 26	1	1430	19.4	18.6	18.1-22.6	1.3
AU 30	1	1300	18.0	17.9	17.5-19.6	0.3
AU 30	1	2130	16.9	16.7	16.1-18.1	0.4

*Spot check (less than 30 min of time-interval observations)

it returned to Site 3. During this period of activity, it experienced an almost constant 25.6 C (SD = 0.08). At 1330 hr, it was located at Site 3 where a spot check revealed it to be at 25.9 C. Then during the next observation period on August 8 beginning at 1330 hr, it moved approximately 625 m from Site 4 to Site 5 in advance of a developing thunderstorm. After the storm passed (3 hr later), the fish was found stationary at Site 5 where it remained at temperatures between 25.8 and 27.3 C. On August 9, it was initially found near Site 6 but moved to the middle of the cove before the monitoring period began and remained there at an average temperature of 25.9 C. By 1100 hr on August 10, this fish had returned to the refuge at Site 1. No time-interval data was obtained due to a malfunctioning automatic recorder and a frequency counter with discharged batteries. During the period that Fish 155C was located outside this refuge, Fish 158 remained near the spring in the refuge. Fish 155C remained at Site 1 where it was found until August 31.

It was always monitored in the refuge at temperatures between 17 and 20 C. In the early afternoon on August 30, with the sun almost directly overhead, this fish was seen in company of a nontagged striped bass at the spring-reservoir confluence at Site 1. This area was less than 50 cm deep and transparent. Monitoring was conducted from the bank due to poor signal reception from the boat located about 20 m downstream from the fishes' location. Both fish moved downstream when the author approached within 5 m of them. Fish 155C, with its tag clearly visible, moved downstream but not out of monitoring range. It experienced an

average of 18.0 C. The nontagged fish returned to its original position while Fish 155C was being monitored. During an observation that night, Fish 155C remained stationary at the spring-reservoir confluence at temperatures ranging between 16.1 and 18.1 C. At 1130 hr on August 31, this fish was located at a depth of approximately 4 m at Site 7, where it was monitored at an almost constant 26.2 C. It remained motionless at this site, even with repeated disturbances created to make it move. These data were not included in its thermal history results, for the fish was believed to have expired. It was not found after this date. The spring-reservoir confluence area was still inhabitable, for a nontagged striped bass was again viewed at this site on August 31.

FISH 156C (FIGURE B-8; TABLE B-8)

This fish, weighing approximately 10 lb, was captured at Site 1 (Figure B-8), located near a submerged waterfall on the Mossy Creek channel, at 1300 hr on June 29. During a monitoring period immediately after release, it moved back and forth between Sites 1 and 2, both located near submerged waterfalls, and experienced temperatures between 17.3 and 23.6 C. On July 1, it was located at Site 2 at an average temperature of 16.8 C, and no movement was noted. Then on July 2, it was monitored for 1 hr by the automatic recorder whose data revealed it to range between 16.4 and 17.0 C at Site 1. This fish was mistaken for Fish 152A on one occasion, because both fish had sonic tags with frequencies which overlapped each other. Fish 156C was caught by a fisherman during the morning of July 22 near Site 2. The fish weighed

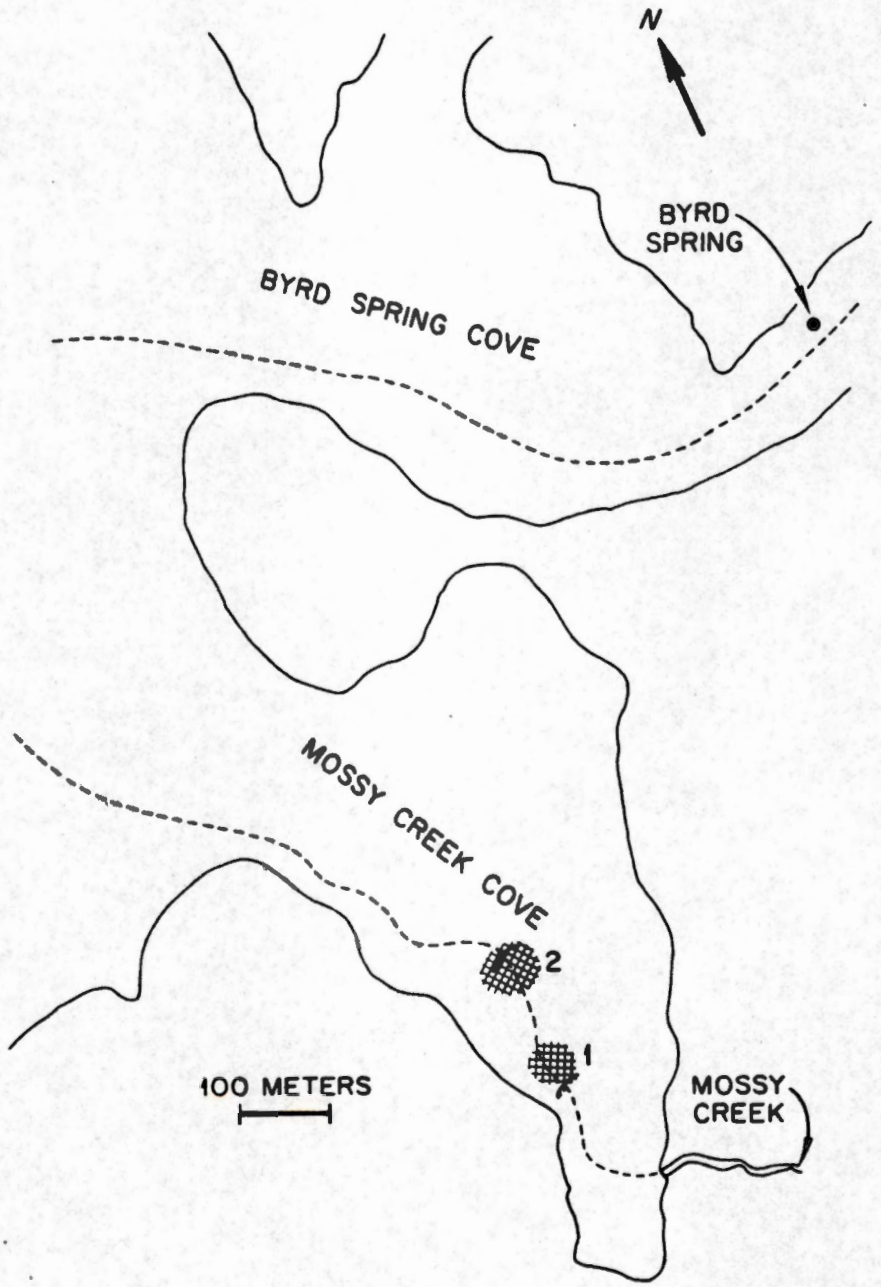


Figure B-8. Map showing observed locations of Fish 156C during its tracking life.

The reservoir is shown with a surface elevation of 328 m.

Table B-8. Thermal History of Fish 156C in Degrees Celsius with Location Data from Figure B-8

Date	Site	Time	Mean	Mode	Range	SD
JU 29	1-2	1300	20.6	21.5	17.2-23.6	1.9
JL 1	2	1330	16.8	21.4 23.4	16.6-17.1	0.1
JL 2	1	1000+	16.6	16.5	16.4-17.0	0.1

+Automatically recorded data

11.25 lb, and its stomach contained three 4-in shad (total length) and one 5-in bluegill. Bluegill were frequently used as bait by fishermen. The tag was in good working condition, and the reason why it was not located during searches of the reservoir in July before its capture was not determined.

FISH 156D (FIGURE B-9; TABLE B-9)

On August 1, this 5-10 lb fish was captured at 2300 hr (night) near Byrd Spring at Site 1 (Figure B-9). Fish 159B was also tagged at Site 1 but moved from the cove upon release. Fish 156D remained near the spring and experienced temperatures averaging 21.9 C. On August 2, this fish was located at Site 1 where it moved continuously during a monitoring period. It experienced temperatures between 18.1 and 24.1 C. During monitoring periods from August 3 to 12, it remained at Site 1 and exhibited mean temperatures from 19.5 to 22.6 C. Then sometime between August 12 and 15, it moved to Site 2, located upstream from a submerged waterfall in the Mossy Creek channel. This fish traveled a distance of at least 2.2 km (the distance of the most direct route between the two sites). The reservoir's surface had receded to a depth of less than 1 m near the spring by mid-August. On August 15, the fish experienced a range of temperatures between 21.3 and 26.6 C at Site 2. In the morning of August 17, it was found at Site 2 at an average of 19.3 C. Temperatures at the surface and bottom were 27.0 and 18.0 C, respectively. This fish was caught by a fisherman on August 20 in Site 3, an area heavily utilized by fishermen. It was captured by rod and

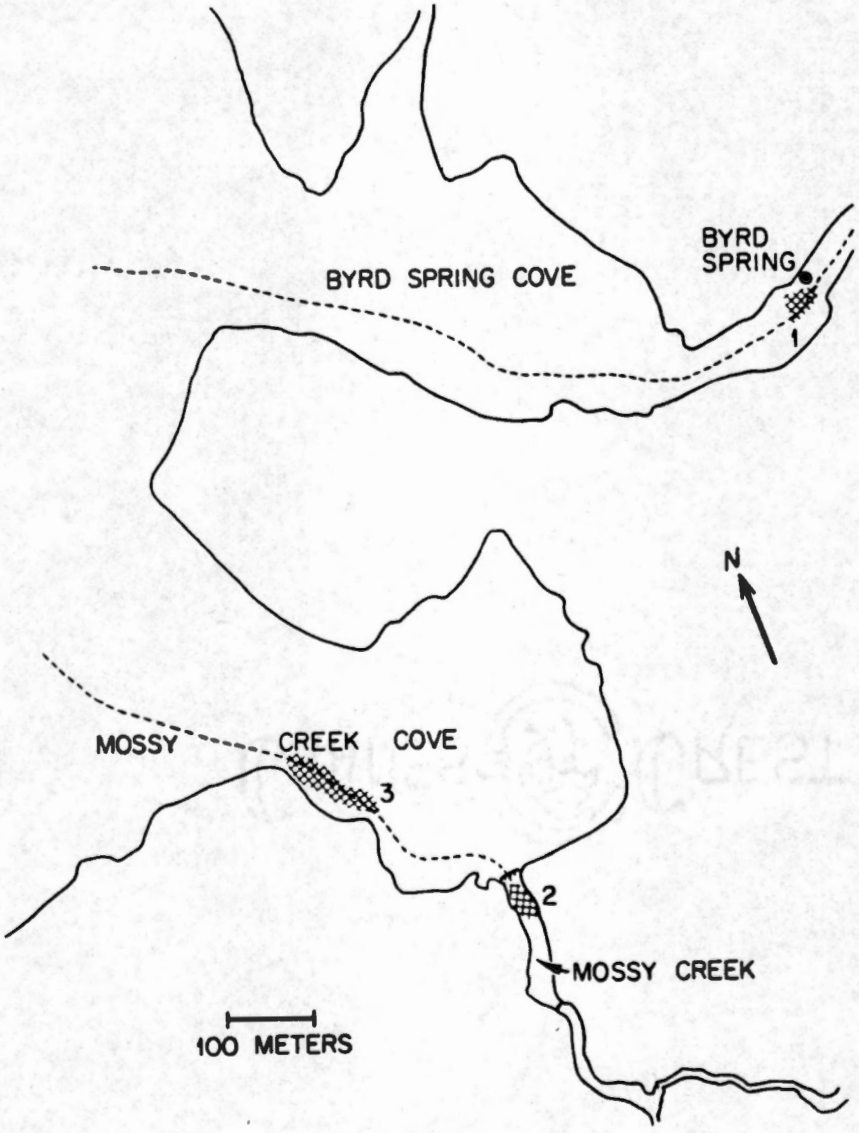


Figure B-9. Map showing observed locations of Fish 156D during its tracking life.

The reservoir is shown with a surface elevation of 319 m.

Table B-9. Thermal History of Fish 156D in Degrees Celsius with Location Data from Figure B-9

Date	Site	Time	Mean	Mode	Range	SD
AU 1	1	2300	21.9	21.8	20.3-24.9	0.7
AU 2	1	0830	21.6	21.5	18.1-24.1	1.2
AU 3	1	1430	22.6	22.9	20.7-26.1	1.1
AU 4	1	2200	20.6	20.5	17.8-24.7	1.2
AU 6	1	0830	20.5	20.4	18.2-22.4	1.1
AU 8	1	1930	19.9	19.3	18.8-24.3	0.8
AU 9	1	2100	20.4	20.2	18.1-22.3	0.7
AU 10	1	0930	21.2	21.1	19.4-24.8	0.7
AU 11	1	0830	19.5	19.4	17.9-23.9	1.1
AU 12	1	0900	20.4	21.0	18.9-22.8	0.8
AU 15	2	1400	22.9	22.3	21.4-26.6	1.1
AU 17	2	0930	19.3	19.4	18.8-20.7	0.3
AU 18	2	1100	19.8	19.4	18.9-21.9	0.7

reel after swallowing chicken liver baited on a hook, and the tag was returned. It was described as fighting very hard and as being in good condition. In fact, its condition was so good that it was going to be mounted by a taxidermist.

FISH 158 (FIGURE B-10; TABLE B-10)

This fish, weighing an estimated 10 lb, was obtained at Site 1 (Figure B-10), directly over the submerged spring in Cedar Hill cove on July 12. Fish 159A was also tagged and released at this site. Fish 158 remained laterally stationary at the spring at about 2.5 m deep. It must have moved vertically, for it experienced temperatures between 21.1 and 26.4 C. Fish 159A, monitored immediately after this fish, experienced an equivalent range of temperatures. Both Fish 158 and 159A exhibited similar behavior during their tracking lives. Fish 158 was located at Site 1 until July 14 at 0800 hr when it was disturbed by fishermen casting lures from a boat near the spring. It moved to and from the spring in the area denoted by Site 1 during an observation period after this event. At 1000 hr, it was initially located at Site 2 but moved to Site 3 where it remained less than 15 min before returning toward the spring. Prior to July 14, this fish had mean temperatures less than 22 C, except for the first monitoring period which was 22.6 C. It experienced a mean temperature of 24.3 C while moving from Site 2 to Site 3. On July 24, people swimming in the water near Site 2 disturbed this fish which moved to Site 3 again. On July 14, the minimum temperature at Site 3 was 22.5 C and was found at the

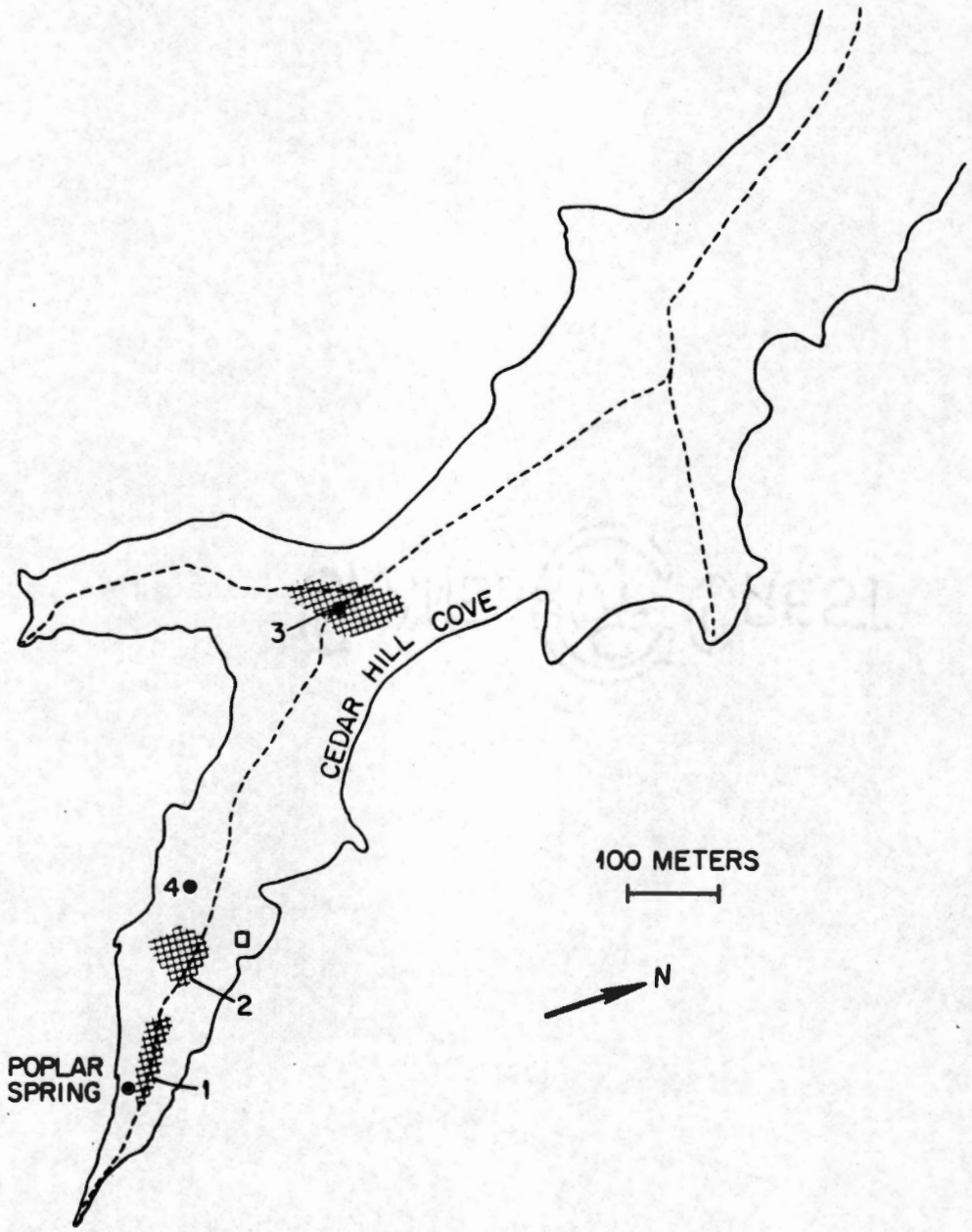


Figure B-10. Map showing observed locations of Fishes 158 and 159A during their tracking lives.

The reservoir is shown with a surface elevation of 328 m.

Table B-10. Thermal History of Fish 158 in Degrees Celsius with Location Data from Figure B-10

Date	Site	Time	Mean	Mode	Range	SD
JL 12	1	1600	22.6	21.4 22.0	21.1-26.4	1.0
JL 12	1	1830	21.9	21.6	21.0-23.5	0.5
JL 13	1	0130	20.7	20.6	19.4-22.6	0.7
JL 13	1	0630	18.5	19.0	16.6-21.2	0.9
JL 13	1	1530	19.6	19.3	19.1-20.9	0.4
JL 13	1	1600	22.1	21.6	21.4-23.9	0.6
JL 14	1	0800	21.8	21.2	20.4-23.9	0.9
JL 14	2-3	1100	24.3*			
JL 15	1	0600	20.5	21.1	17.3-24.9	1.6
JL 15	2	1200	25.3	24.9	24.5-26.9	0.5
JL 16	2	1630	23.4	23.5	22.4-25.4	0.5
JL 17	1	1700	23.5	22.9 24.7	22.4-25.4	0.7
JL 19	2	1430	26.0*			
JL 20	1-3	1700	26.6*			
JL 23	1	1630	21.1	21.7	21.6-22.5	0.2
JL 24	1	1400	20.8	20.9	20.4-21.3	0.2
JL 25	1	1530	17.7	17.5	17.2-17.9	0.1
JL 26	2	2000	22.3*			
JL 26	2	2000- 2300+	22.5	22.6	20.5-29.4	1.0
JL 27	2	0000 2300+	21.4	21.3	17.9-29.4	1.2
JL 27	2	0700	20.5	20.1	19.9-21.7	0.5
JL 28	2	0000- 1200+	20.4	20.4	15.6-29.7	1.5
JL 28	2	1800- 2300+	18.7	16.4	15.1-29.6	3.0
JL 29	2	0000 1100+	18.7	16.3 19.6	15.2-29.7	1.9
JL 31	2	0900	17.1	17.1	16.8-17.2	0.1
AU 1	2	1800 2300+	19.8	17.4 21.2	15.9-29.8	2.2
AU 2	2	1000- 1100+	18.6	18.0	16.2-28.4	1.6
AU 5	2	1330	21.5*			
AU 6	2	1800	22.6	22.4	22.2-24.0	0.5
AU 9	2	1530	21.8	22.4	16.9-31.4	3.4
AU 10	2	1130	18.9	17.6	17.2-22.9	1.5
AU 11	2	1600	20.9	20.0 21.6	19.6-25.4	1.0
AU 12	2	1600	21.3	21.4	20.5-22.2	0.3
AU 16	2	1600	20.2	19.7 20.1	19.4-22.3	0.6
AU 17	2	1230	20.0*			
AU 18	2	1400	19.6	18.8	18.0-22.6	1.3

*Spot check (less than 30 min of time-interval observations)

+Automatically recorded data

bottom (10 m deep). The DO concentration was 4.7 mg/liter at this depth. The mean of 25.3 C recorded at 1200 hr on July 15 resulted from this fish's movement to Site 2 where it was monitored. Fish 159A also moved to Site 2 on this day where it experienced a mean of 23.6 C. During the remainder of July and early August, Fish 158 was usually found in the spring-reservoir confluence area which was continuously moving downstream from the spring due to the receding water level of the reservoir. Even though depths in this refuge dropped to well below 2 m, this fish remained at temperatures of approximately 21 C in the shallow water. On August 10 at 1130 hr, this fish was seen at the spring-reservoir confluence, located at Site 2 at that time. Depths there were less than 50 cm.

Automatic data recordings were taken from an anchored boat during several days in late July and early August. These results are shown in Appendix A. Automatic data means were within the range of manual data means, but minimum and maximum temperatures of the automatic data were several degrees lower and higher, respectively. Because the range of automatically recorded temperatures occurred in this area during these monitoring periods, erroneous data (if present) within this range could not be distinguished. Automatic data also indicated movement of this fish by various discrete periods of poor data which were recorded. On August 4, Fish 155C was captured and tagged in this refuge area. Fish 158 and 155C experienced similar temperatures while in the refuge. After the monitoring period on August 18, Fish 158 was not found alive again. Its carcass with attached harness was discovered

washed ashore near Site 4. A trauma area was prevalent where the wire harness pierced the flesh, yet the tag was difficult to remove by pulling the intact tag-harness assembly.

FISH 159A (FIGURE B-10; TABLE B-11)

This 10 lb fish was captured at Site 1 (Figure B-10), located at the large spring in Cedar Hill cove, on July 12. It was tagged and released at 1600 hr and immediately after Fish 158 was released here. It remained in the channel near the spring at a depth of approximately 1.5 m during a monitoring period immediately after its release. It showed no movement during this period, and it experienced temperatures between 21.3 to 26.8 C. Three hours later, it was found at Site 2, a slightly deeper area off the spring channel. A spot check of the fish at this location revealed it to be at 28.7 C. Then several monitoring periods on July 13 showed it experienced higher temperatures at Site 2 than at Site 1. On July 14, this fish was found at Site 1 at an average temperature of 21.0 C. It remained stationary and was not apparently disturbed by bank fishermen near the spring. At dawn on July 15 after the tracking boat was motored over Fish 158 and 159A, both moved downstream from Site 1. Fish 159A returned to Site 1 within 15 min, while Fish 158 remained at Site 2 until at least 1230 hr. On July 16, both fish were located at Site 2, near a floating boatdock which had frequent boat traffic. Both fish moved a short distance downstream when a swimmer approached them, and both experienced slightly higher temperatures after they moved. At 1730 hr on July 17, both fish were again

Table B-11. Thermal History of Fish 159A in Degrees Celsius with Location Data from Figure B-10

Date	Site	Time	Mean	Mode	Range	SD
JL 12	1	1630	23.2	23.3	21.3-26.8	0.9
JL 12	2	1930	28.7*			
JL 13	2	0100	21.2	21.0	20.7-23.3	0.5
JL 13	1	0730	20.7	20.8	19.1-22.8	0.8
JL 13	2	1500	22.0	21.6	21.3-23.8	0.6
JL 13	2	1630	21.9	21.6	21.4-25.7	0.7
JL 14	1	1000	21.0	20.4	20.4-24.4	0.8
JL 15	1-2	0630	21.3	21.7	18.5-23.9	0.9
JL 15	2	1230	23.6*			
JL 16	2	1730	23.6	23.4	23.1-24.3	0.3
JL 17	1	1730	24.9	24.9	23.7-26.8	0.4
JL 19	1-2	1600	24.1*			
JL 20	1-2	1600	23.0*			
JL 23	1	1600	22.1	21.9	21.8-22.7	0.2
JL 24	1	1430	21.7	21.6	21.1-22.3	0.5
JL 25	1	1500	20.4	20.5	16.4-28.9	1.5
		2200+				
JL 25	1	1430	19.5*			
JL 26	2	2130	22.3	21.1	21.0-25.8	0.9
				22.5		
JL 26	2	2330	22.3	22.2	21.2-25.1	0.8
JL 27	2	0630	20.8	21.0	20.4-21.8	0.2
JL 29	2	1200	20.6	20.7	15.8-29.5	1.6
		2300+				
JL 30	2	0000	19.1	17.5	15.5-29.5	2.5
		1300				
		2000				
		2300+				
JL 31	2	0000	19.7	16.5	15.9-28.9	2.5
		0300		20.7		
		0900				
		1200				
		2000				
		2300				
JL 31	2	1000	20.7	20.6	20.3-22.2	0.3
AU 1	2	0000	18.7	17.4	16.1-29.3	2.3
		0400				

*Spot check (less than 30 min of time-interval observations).

+Automatically recorded data

located at the lower portion of Site 1, but each moved toward the spring where they experienced temperatures near 23.5 C. On July 19, Fish 158 and 159A were located near the spring in Site 1, but both fish moved to Site 2 when the tracking boat neared them. The depth at Site 2 averaged 2.5 m. On July 20, Fish 159A was disturbed from Site 1 by swimmers, but after they had departed, it moved back to its original location. Between July 12 and 23, the reservoir's surface fell approximately 1 m, and the depth at the spring was less than 1 m. On July 24, fishermen downstream from the spring did not spook either Fish 158 or 159A, as both remained at Site 1. By July 26, the pool's surface was at an elevation where the spring-reservoir confluence was very shallow at Site 1, and both fish inhabited Site 2 for the remainder of their tracking lives. Automatic data in late July and August 1 provided long-term thermal data, as well as some indication of movement. This fish moved short distances during most manual observation periods, and it was suspected to have moved behind stumps or bottom debris or out of range of the hydrophone during the automatic observation periods which resulted in blocks of erroneous data. After dawn on August 1, this fish was hooked in the mouth by a fisherman's lure at Site 2. The fish apparently struck at the lure. The fisherman noted this fish had no infections at the tag attachment site.

FISH 159B (FIGURE B-11; TABLE B-12)

This 10-15 lb fish was obtained at Site 1 (Figure B-11), located in the near vicinity of Byrd Spring on August 1 at 2230 hr (night).

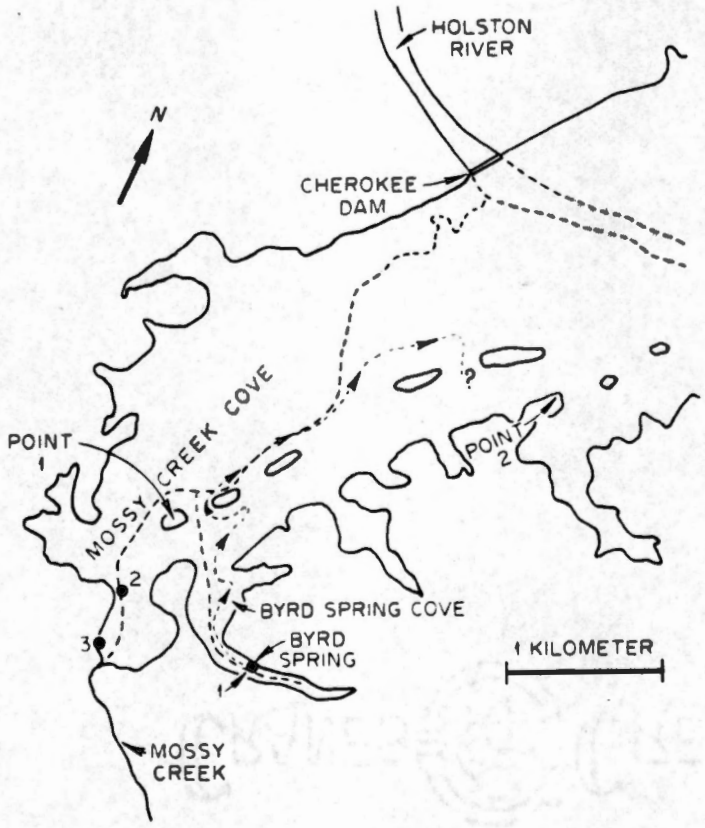


Figure B-11. Map showing observed locations of Fish 159B during its tracking life.

The reservoir is shown with a surface elevation of 319 m.

Table B-12. Thermal History of Fish 159B in Degrees Celsius with Location Data from Figure B-11

Date	Site	Time	Mean	Mode	Range	SD
AU 1	1	0000	26.3	26.4	25.3-27.1	0.4
AU 4	2	1700	24.2	24.2	23.9-24.6	0.1
AU 4	2	2300	22.3	22.2	22.1-22.6	0.1
AU 5	2	0730	21.5	21.4	21.1-21.9	0.2
AU 6	2	0830	21.5	21.5	21.2-21.9	0.2
AU 8	2	1830	23.6	23.7	23.3-24.2	0.1
AU 9	3	1930	21.4	21.1	20.8-22.7	0.4
AU 10	2	0900	20.2	20.0	19.8-23.1	0.5
AU 11	3	0800	22.4	22.3	22.0-24.3	0.3
AU 12	3	0800	18.7	18.5	18.1-20.5	0.6
AU 15	2	1000	24.0	24.3	23.5-24.5	0.3
AU 17	2	1030	21.1	21.1	20.6-21.9	0.2
AU 18	3	1130	20.0	19.6 20.6	19.3-20.8	0.5
AU 22	2	1100	21.8	21.6	21.3-22.5	0.3
AU 23	2	1300	21.1	21.0	20.8-22.2	0.3
AU 25	3	1200	20.2	20.1	19.6-21.2	0.3
AU 26	3	1100	20.0	20.2	19.7-20.8	0.4

Fish 156D was also captured there on this day. Fish 159B was apparently chased from this area by the continued electrofishing to obtain Fish 156D, for it moved slowly out of Byrd Spring cove following the path as shown. It was lost by the tracking party due to weakening batteries in the receiver at 0130 hr on August 2 after moving between two small islands near the mouth of Black Oak cove. The mean temperature it experienced during this 3 hr migration was 26.3 C, and the range was 25.3 to 27.1 C. At 1300 hr on August 3, it was located at Site 2, situated near the head of Mossy Creek cove where Fish 159 and 160B were located. No temperature data were obtained, because the close proximity of these fish resulted in indistinguishable signals. A temperature-DO measurement made near these fish revealed the minimum temperature to be approximately 26.0 C, which was found at the bottom. DO concentrations at the bottom were 6.4 mg/liter. Fish 159B remained at this location (Site 2) until August 9. During this period, it was observed at temperatures between 21 and 24 C, and it displayed little, if any, movement during the monitoring periods. On August 9, it was found at Site 3, located below a submerged waterfall which was only slightly inundated by the reservoir pool. In the morning of August 10, it was again located at Site 2 at a mean temperature of 20.2 C. A temperature profile taken near this fish indicated the coolest water (21.2 C) occupied the strata nearest the bottom (4 m deep). On August 11, this fish was located in the channel at Site 3 at an average temperature of 22.4 C. For the remainder of this fish's tracking life, it was found at various locations in the Mossy Creek channel where it experienced temperatures

near 20 and 21 C, except on August 12 and 15 when it was at 18.7 and 24.0 C, respectively. On August 12, Fish 159B was located at Site 3, now the Mossy Creek and reservoir confluence area. During most of the monitoring periods, this fish was stationary. However, on two occasions it was noted moving along the channel. This fish was not monitored again after August 26. The tag with harness was found near Site 3 on August 31.

FISH 160A (FIGURE B-12; TABLE B-13)

At 1430 hr on June 21, this 10-15 lb striped bass was obtained at Site 1 (Figure B-12) located below a submerged waterfall in the Mossy Creek channel. Four other striped bass surfaced while electrofishing at Site 1, and two were also tagged. However, both died shortly after release. On June 22, Fish 160A was monitored while moving from near the mouth of Byrd Spring cove (Site 2) to Site 3, located immediately downstream from another submerged waterfall in Mossy Creek channel. During this observation, it moved approximately 650 m in 25 min and experienced temperatures ranging from 19.7 to 20.9 C. On June 23, this fish was found at Site 4 where it remained stationary during a monitoring period for which temperature data averaged 17.3 C. The lowest temperature surveyed near this fish was 18.6 C. The next observation was made on June 28 when this fish was located at Site 3 at 17.4 C (mean). Again, there was a discrepancy in the minimum temperature surveyed near the fish and its monitored minimum. The latter was several degrees less. These discrepancies may be explained

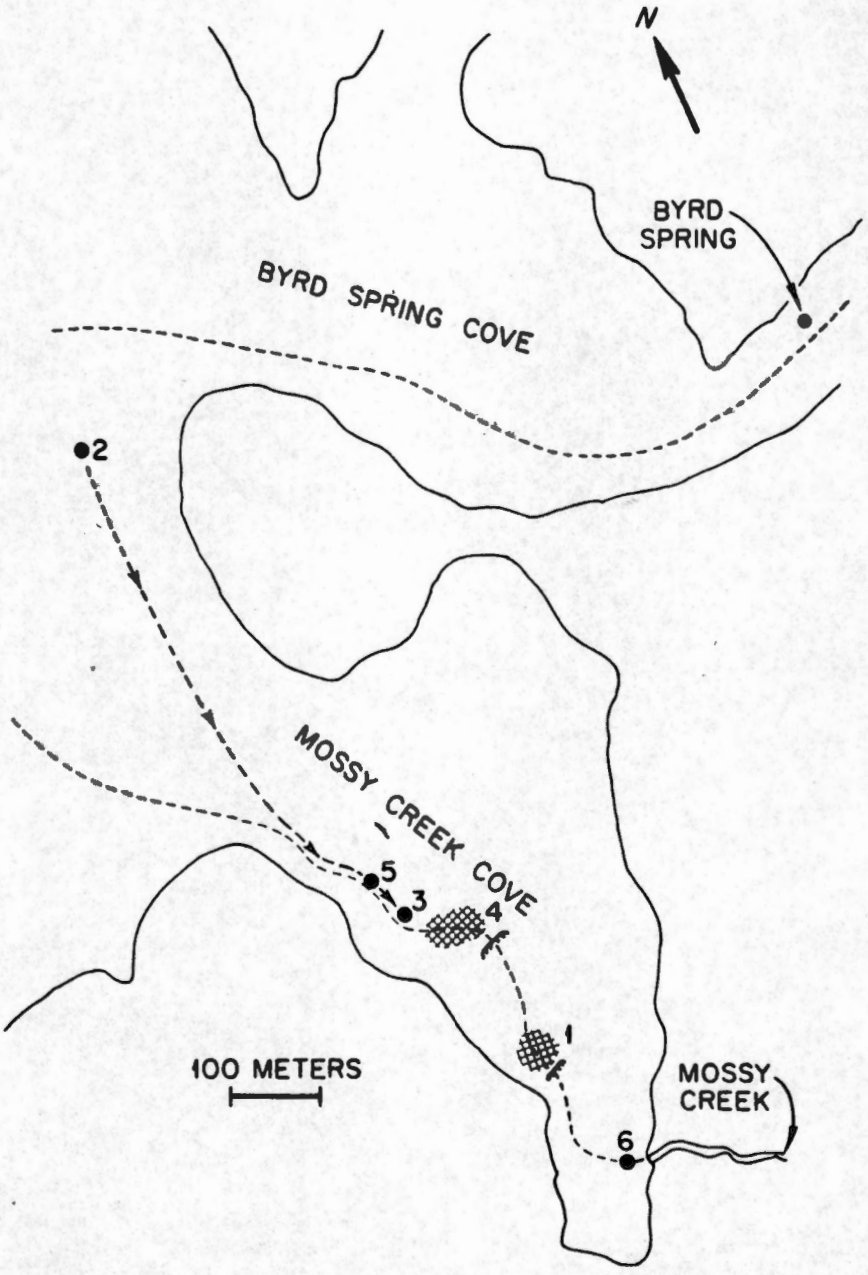


Figure B-12. Map showing observed locations of Fish 160A during its tracking life.

The reservoir is shown with a surface elevation of 328 m.

Table B-13. Thermal History of Fish 160A in Degrees Celsius with Location Data from Figure B-12

Date	Site	Time	Mean	Mode	Range	SD
JU 22	2-3	1530	20.3	20.4	19.7-20.9	0.2
JU 23	4	1000	17.3	17.2	17.1-17.6	0.1
JU 28	3	1300	17.4	17.4	17.3-17.7	0.2
JU 29	4	1500	17.5	17.4	17.3-17.9	0.1
JL 1	1-5	1230	18.3	17.8	17.5-20.4	0.7
JL 2	4	1200	18.5	18.6	18.2-18.8	0.1
JL 7	4	0930	17.3*			
JL 9	3-4	0630	20.6	20.2	19.3-23.6	0.8
JL 9	4	1030	18.3	18.2	18.0-19.8	0.3

*Spot check (less than 30 min of time-interval observations)

by the fact that the temperature probe of the electronic meter was not lowered into the difficult-to-find channel. Then on June 29, the fish was again located at Site 4 where it experienced an average 17.5 C. After the monitoring period, the tracking boat was motored around this fish without causing it to move any noticeable distance. However, on the next day, it moved from Site 4 as the tracking boat approached, but it moved less than 50 m toward Site 1. At noon on July 1, it was initially found at Site 1 but moved slowly downstream in the channel to Site 5 during a 55 min monitoring period. It experienced temperatures from 17.5 to 20.4 C, and its average was 18.3 C. On July 2, Fish 160A was located at Site 4 where it was monitored at an almost constant 18.5 C. It did not move, or if it did, the distance was less than about 20 m. At Site 4 on July 2, the temperature and DO concentration on bottom were 18.0 C and 9.0 mg/liter, respectively. The fish was estimated to be suspended in the water column about 1 m from the bottom, 5 m deep. A spot check at 0930 hr on July 7 showed it to be at approximately 17.3 C at Site 4. An hour later when the tracking boat was motored near the fish, it immediately moved a short distance upstream in the submerged creek channel. The bottom temperature and DO concentration near the fish were 18.4 C and 9.6 mg/liter, respectively. Temperatures outside of 1.5 m of the bottom exceeded 23 C, the maximum value this fish experienced during this observation period. At dawn on July 9, it experienced temperatures between 19.3 and 23.6 C as it moved up and down the submerged creek channel between Sites 3 and 4. Four hours later, it was found moving upstream from Site 4, where it was monitored at 18.3 C

(mean). On July 11, Fish 160A was not located, and on the following day, the tag was found lying on the bottom of the shallow, flowing creek channel at Site 6. The tag-harness assembly was still intact, and pieces of vegetation clung to it. This raises the high probability that the tag was loosened from the body of the fish by its movement through aquatic plants.

FISH 160B (FIGURE B-13; TABLE B-14)

This fish, weighing between 10 and 15 lb, was obtained at Site 1 (Figure B-13), located in the Mossy Creek channel downstream from a submerged waterfall, on August 1. Several large striped bass were noted in this area, and another one (Fish 152C) was also tagged and released. Fish 160B was held in the livewell for approximately 15 min during the tagging procedure and was accidentally dropped into the boat while being released. This poor handling did not apparently affect this fish because it survived 12 days before being caught by a fisherman. After its release, it immediately moved upstream to Site 2, located below a visible waterfall in the Mossy Creek channel. This waterfall blocked upstream movements of tagged fish during August. This fish remained at an almost constant 18.2 C while displaying no movement at this site. The next day, it was again found at Site 2, where it experienced temperatures of approximately 16.4 C during a spot check. No movement was detected. Then on August 3, it was located at Site 3, located about 500 m downstream from Site 1. No time-interval data were taken because Fish 159B was located so close to this fish that their

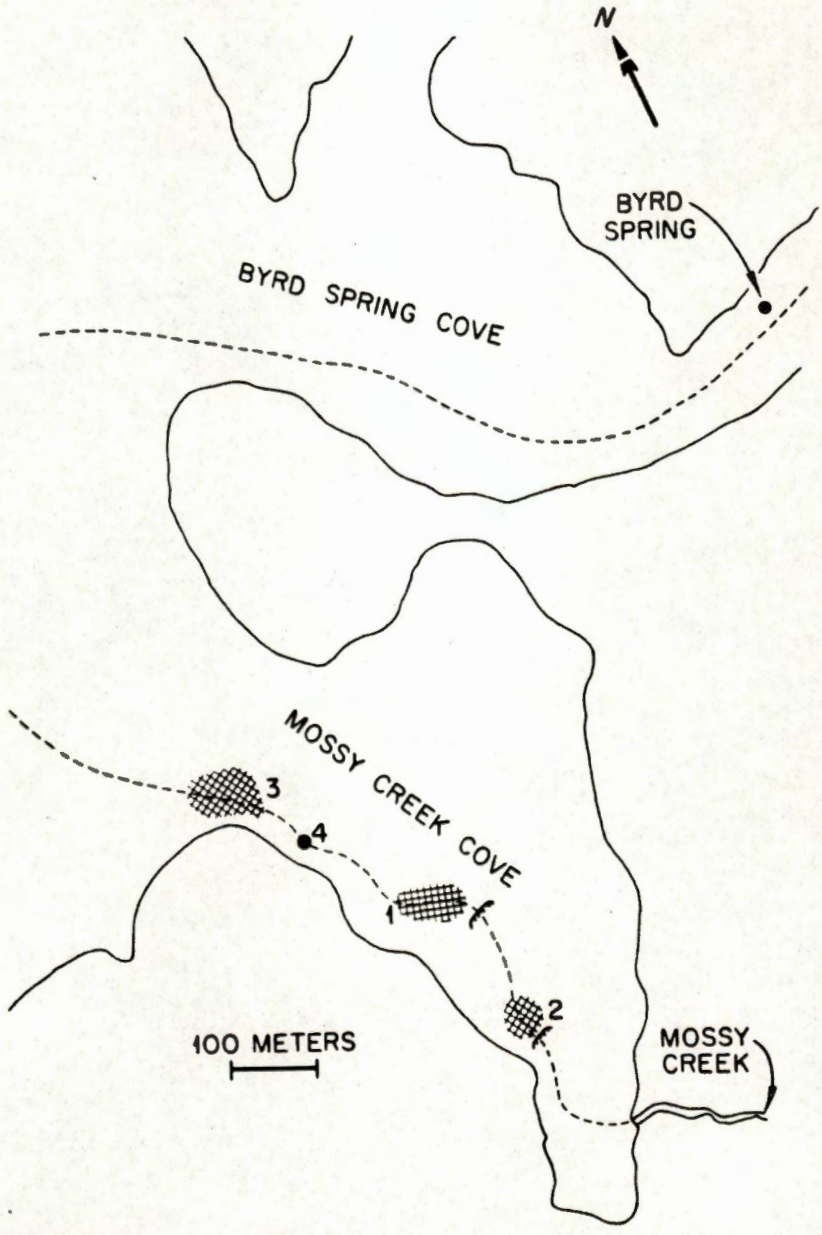


Figure B-13. Map showing observed locations of Fish 160B during its tracking life.

The reservoir is shown with a surface elevation of 328 m.

Table B-14. Thermal History of Fish 160B in Degrees Celsius with Location Data from Figure B-13

Date	Site	Time	Mean	Mode	Range	SD
AU 1	1-2	1730	18.2	18.1	18.0-18.5	0.1
AU 2	2	0000	16.4*			
AU 4	3	1630	23.9	24.0	23.7-24.2	0.1
AU 4	3	2400	23.7	23.6	23.4-24.4	0.2
AU 5	3	0700	22.1	22.4	21.2-22.8	0.3
AU 6	3	0930	22.2	22.6	20.7-24.3	0.8
AU 8	4	2000	21.9	21.9	21.6-22.2	0.1
AU 10	1	0830	20.9	20.9 21.4	18.9-22.9	0.9
AU 11	1	1900	24.0	24.2	21.9-25.2	0.5
AU 12	1	0800	20.6	20.6	18.9-21.8	0.6

*Spot check (less than 30 min of time-interval observations)

signals were indistinguishable. Tag frequencies of the two fish differed by only 5 KHz. On August 4, Fish 160B was located at Site 3 during a mid-afternoon and a nighttime monitoring period when mean temperatures were 23.9 and 23.7 C, respectively. This fish did not move during either monitoring period. Fish 159B was located not more than 20 m away. For comparison, the mean temperatures for Fish 159B on August 4 at about the same time as monitoring periods of Fish 160B were 24.2 and 22.3 C, respectively. On August 5 and 6, Fish 160B was again located at Site 3, where many large striped bass were being caught by fishermen. Then on August 8, it was found at Site 4, located in the submerged creek channel. It experienced temperatures averaging 21.9 C. The next day, this fish was located at Site 1, now below another visible waterfall. Automatic data recorded on this fish during the August 9 monitoring was inaccurate due to equipment failure. At 0830 hr on August 10, this fish was located in water less than 1 m deep in the channel at Site 1. During a monitoring period, it was active and experienced temperatures between 18.9 and 22.9 C. At dawn on August 11, it was again found at Site 1, where several large schools of small shad were noted. This fish experienced temperatures between 21.9 and 25.2 C, and its average temperature was 24.0 C. No activity was noted during the monitoring period. Then on August 12, this fish was located at Site 1 where it ranged between 18.9 and 21.8 C. Fish 160B was caught by a fisherman on August 13 at an undisclosed location in Mossy Creek cove. No other information was obtained.

FISH 196 (FIGURE B-14; TABLE B-15)

This fish, weighing approximately 10 lb, was captured and tagged with a radio tag at Site 1 (Figure B-14) in Mossy Creek cove on September 23. This area was located at the creek-reservoir confluence. This fish remained at this site during the remainder of its tracking life which was terminated after September 30 when it could no longer be found. During its brief tracking life, it experienced temperatures averaging between 18 and 21 C. This fish, unlike other radio-tagged fish in Cedar Hill cove, did not experience lower temperatures (near 16 C) before its loss. On February 1, 1979, this tag was found along the northwest shore of the reservoir near HRM 68 by field crews of TVA. The considerable distance from Mossy Creek cove (approximately 20 km) suggests that the fish left the cove after September 30 (after the fall overturn) and occupied the open reservoir. An alternative, namely, that the fish died and its carcass floated from Mossy Creek to the point of the tag recovery, is unlikely due to the large number of islands between the points which would have intercepted a floating carcass.

FISH 211 (FIGURE B-15; TABLE B-16)

This fish, weighing between 5 and 10 lb, was captured and tagged with a radio tag at Site 1 in Cedar Hill cove on September 8 (Figure B-15). During its tracking life, it remained at Site 1 but was not found there after September 20. Because this radio tracking system was not as sensitive as the sonic system, small movements of fish could not be detected. The loss of this fish and also of Fish 268 from this

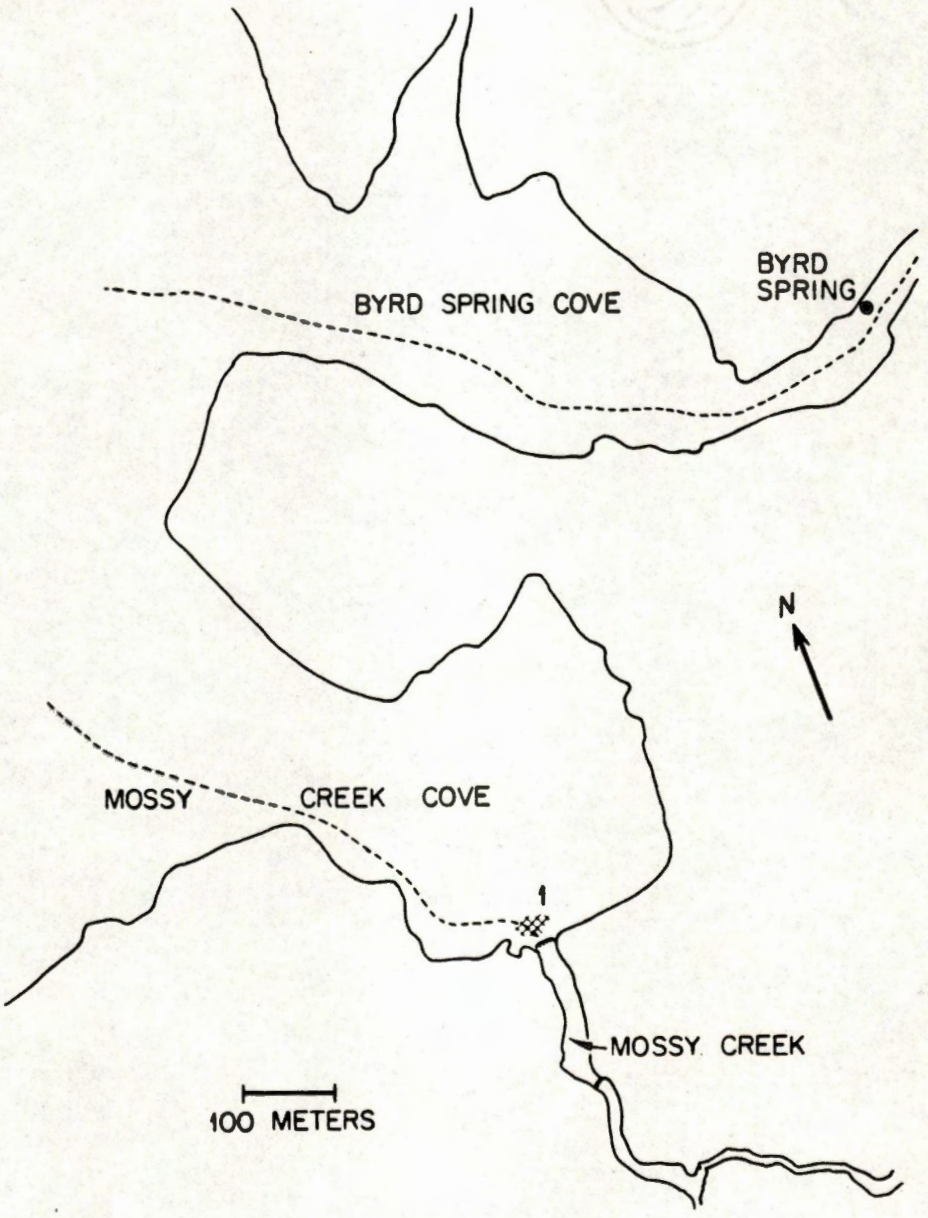


Figure B-14. Map showing observed locations of Fish 196 during its tracking life.

The reservoir is shown with an elevation of 319 m.

Table B-15. Thermal History of Fish 196 in Degrees Celsius with Location Data from Figure B-14

Date	Site	Time	Mean	Mode	Range	SD
SE 23	1	0730	18.5	17.6	16.8-26.1	1.7
SE 23	1	1200	19.3	18.5	18.3-21.9	1.1
SE 27	1	0830	17.9	17.5	17.3-19.9	0.7
SE 28	1	1430	19.7	19.6	19.1-20.6	0.2
SE 30	1	1430	20.1	20.0	19.5-20.6	0.3
SE 30	1	1500	20.4	20.5	19.9-20.9	0.2

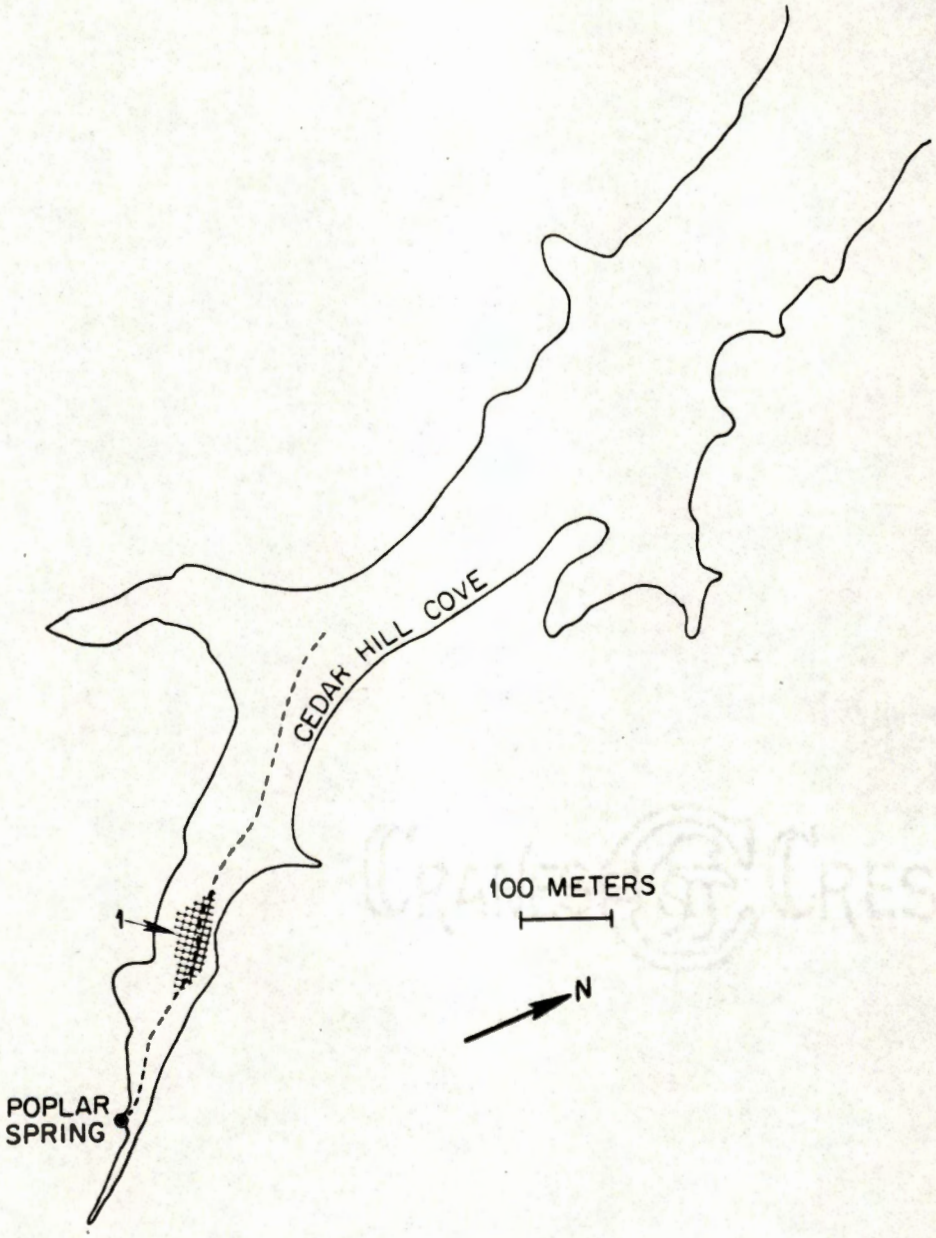


Figure B-15. Map showing observed locations of Fishes 211, 268, and 338 during their tracking lives.

The reservoir is shown with a surface elevation of 319 m.

Table B-16. Thermal History of Fish 211 in Degrees Celsius with Location Data from Figure B-15

Date	Site	Time	Mean	Mode	Range	SD
SE 8	1	1900	19.5	19.4	19.3-19.7	0.1
SE 9	1	0730	19.4	19.3	19.2-19.7	0.1
SE 9	1	1600	23.2*			
SE 10	1	1030	25.7*			
SE 12	1	0900	20.4*			
SE 12	1	1800	20.8	20.9	20.1-21.5	0.4
SE 15	1	1230	20.9	20.6 21.2	20.3-21.5	0.5
SE 16	1	1030	20.5	20.1	19.9-22.7	0.7
SE 19	1	2000	15.9	16.0	15.6-17.6	0.1
SE 20	1	0700	16.9	16.2	15.8-19.6	0.9

*Spot check (less than 30 min of time-interval observations)

area at the same date indicated that they probably migrated from the cove or moved downstream into much deeper water. Signals from radio tags at depths greater than approximately 3 m were greatly attenuated. This fish generally remained in water at approximately 20 C, but during the latter two observation periods on September 19 and 20, it experienced temperatures near 16 C.

FISH 268 (FIGURE B-15; TABLE B-17)

This fish, weighing between 5 and 10 lb, was also captured and tagged with a radio tag at Site 1 (Figure B-15) in Cedar Hill cove on September 8. This fish, as Fish 211, remained at this location until after September 20 when it could no longer be found. This fish generally experienced temperatures between 18 and 21 C, but on September 19 and 20, it was found at an average 16 C. This same thermal experience was noted for Fish 211. It was suspected that this fish, as well as other radio-tagged fish, moved from refuges in the fall when the reservoir had cooled to approximately 20 C.

FISH 338 (FIGURE B-15; TABLE B-18)

This fish, weighing between 5 and 10 lb, was captured and tagged at Site 1 (Figure B-15), located about 30 m downstream from the spring-reservoir confluence at Cedar Hill cove, on September 1. The fish remained in this area throughout its tracking life which ended on September 13 when the tag was believed to have become detached from its body. The consistent time-interval observations which resulted

Table B-17. Thermal History of Fish 268 in Degrees Celsius with Location Data from Figure B-15

Date	Site	Time	Mean	Mode	Range	SD
SE 1	1	1430	20.6	20.4	19.9-22.3	0.5
SE 2	1	1200	23.3	23.5	21.8-25.9	0.8
SE 5	1	2000	18.3	18.1	17.9-20.0	0.7
SE 6	1	1600	20.1	19.0	18.3-23.6	1.6
SE 8	1	0900	18.8	18.9	18.1-19.5	0.3
SE 9	1	0630	20.1	18.9 20.9	18.6-21.8	1.0
SE 10	1	1000	19.1	18.6	17.8-24.8	1.1
SE 15	1	1300	19.3	19.2	18.5-20.6	0.4
SE 16	1	1100	20.4	19.3 20.2	18.7-24.0	1.1
SE 19	1	1830	16.3	15.9	15.5-17.7	0.5
SE 20	1	0730	16.9	16.0	15.6-20.8	1.1

Table B-18. Thermal History of Fish 338 in Degrees Celsius with Location Data from Figure B-15

Date	Site	Time	Mean	Mode	Range	SD
SE 2	1	1400	23.5	23.8	20.8-27.6	1.1
SE 5	1	2130	19.6	21.2	19.1-22.4	0.4
SE 6	1	1200	21.6	22.8	20.1-25.0	0.9
SE 8	1	0930	22.0	22.1	19.9-27.9	1.1
SE 9	1	0700	22.5	18.5	20.0-24.6	0.9
SE 9	1	1600	19.9	19.5	17.9-25.0	1.7
SE 10	1	0900	21.5	=	18.8-25.6	1.7
SE 12	1	0930	20.8	21.6	17.9-27.4	1.4
SE 12	1	1700	22.6	19.6 22.3	18.1-26.5	2.2

= No distinct mode

in that belief proved to be correct, for this tag was recovered from this site during February 1978 when the reservoir's surface elevation was very low. The tag was still functioning. It had apparently become detached because of an insecure harness wire. During this fish's tracking life, however, it experienced temperatures between 18 and 28 C with the 18 to 22 C range being inhabited mostly.

APPENDIX C

FREQUENCY DISTRIBUTIONS OF TEMPERATURES INHABITED BY EIGHTEEN TAGGED STRIPED BASS DURING ALL MONITORING PERIODS FOR EACH FISH

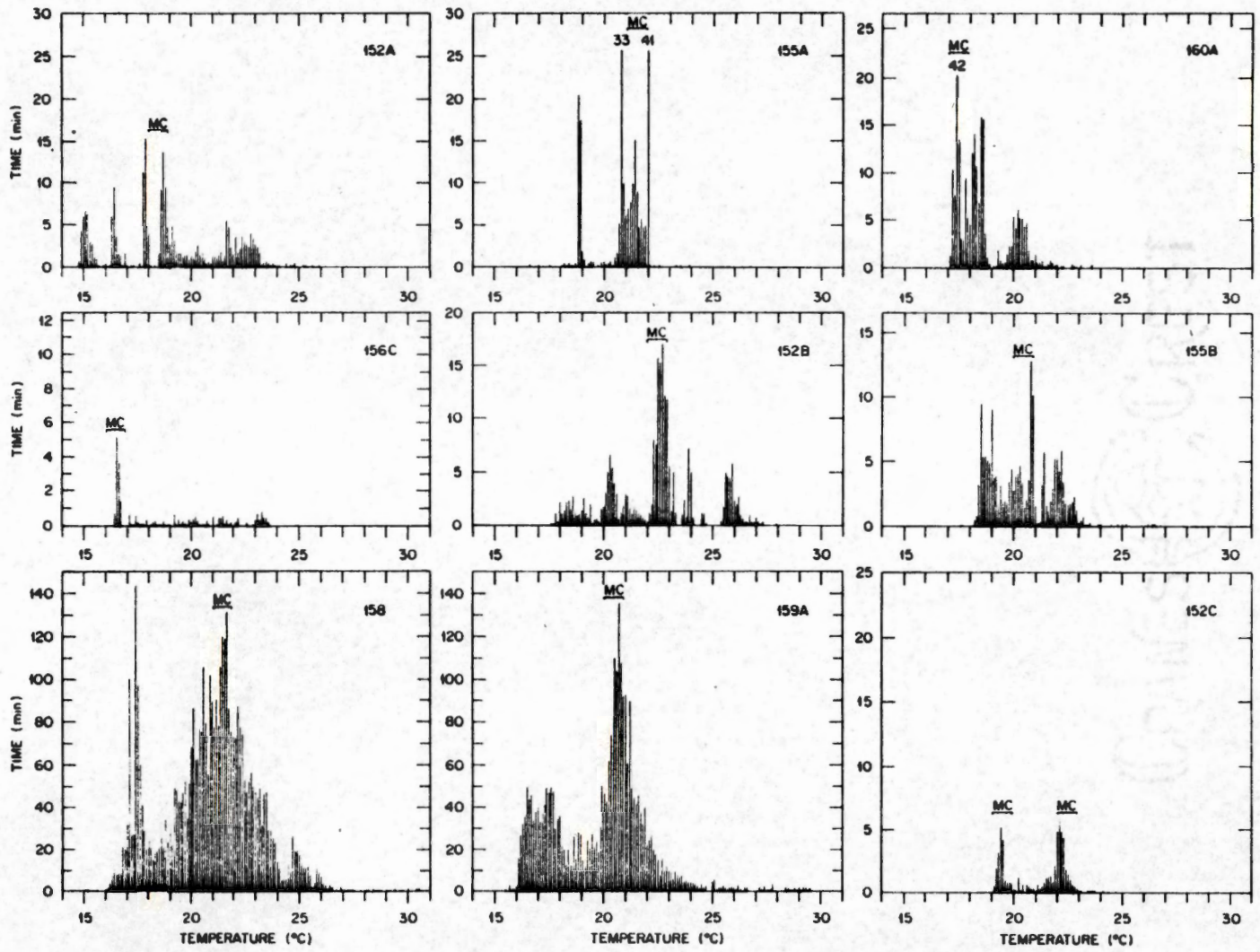


Figure C-1. Histograms of temperatures at 0.1 C intervals experienced by tagged fish (fish numbers are indicated in the upper right corner of each frequency distribution). Modal classes (MC) at 1 C intervals are shown for each fish with some fish showing a bimodal distribution.

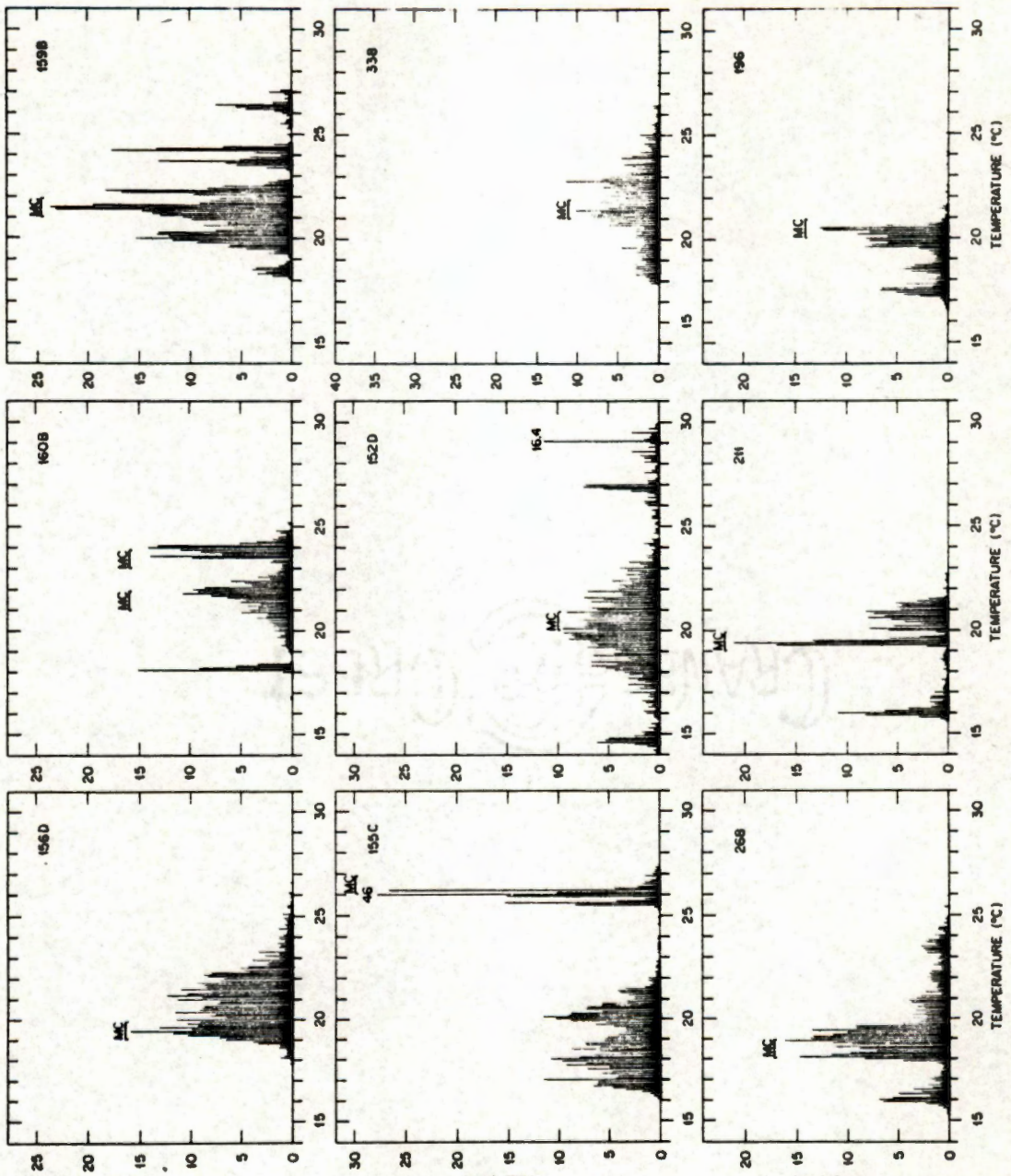


Figure C-1, continued

APPENDIX D

TEMPERATURE PROFILES OF MAIN CHANNEL STATIONS, MARCH-OCTOBER, 1977

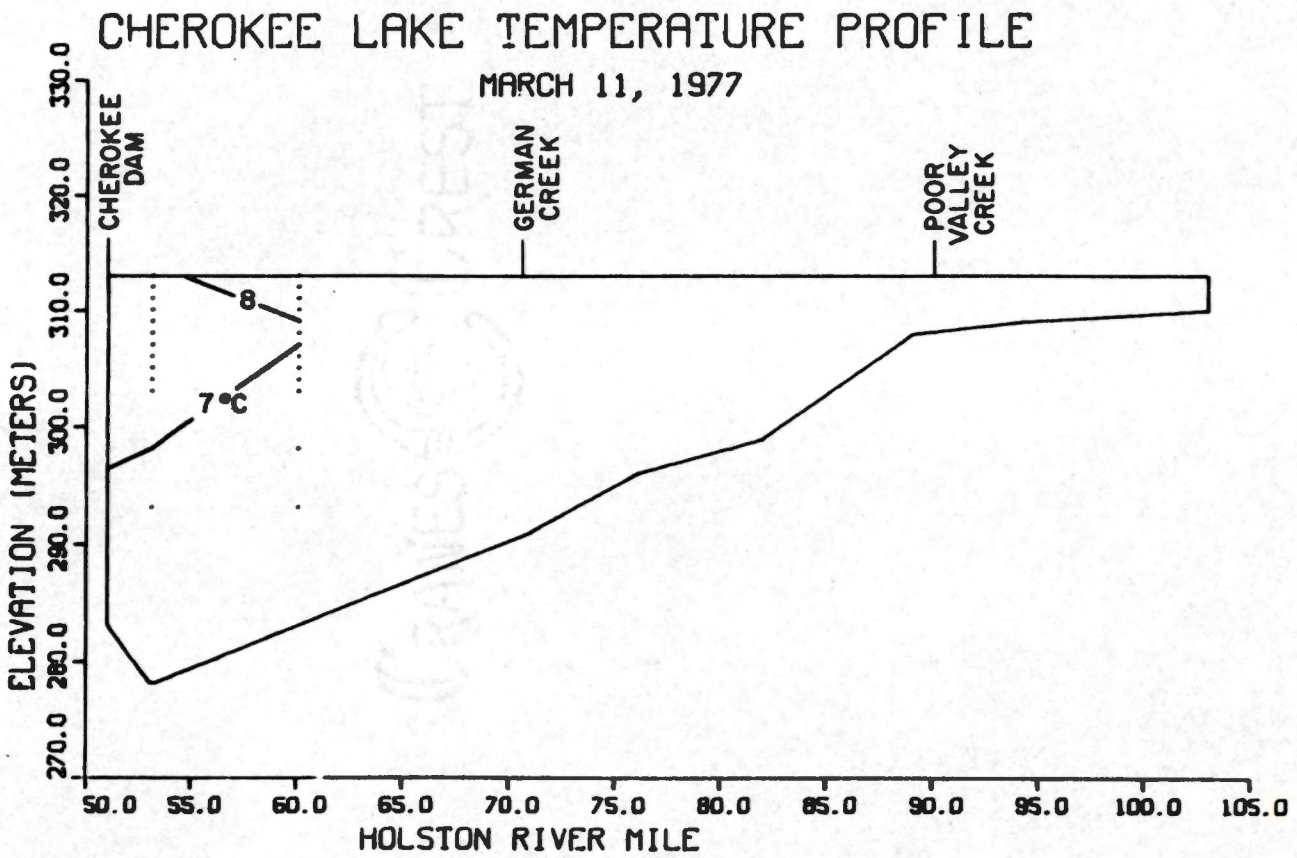
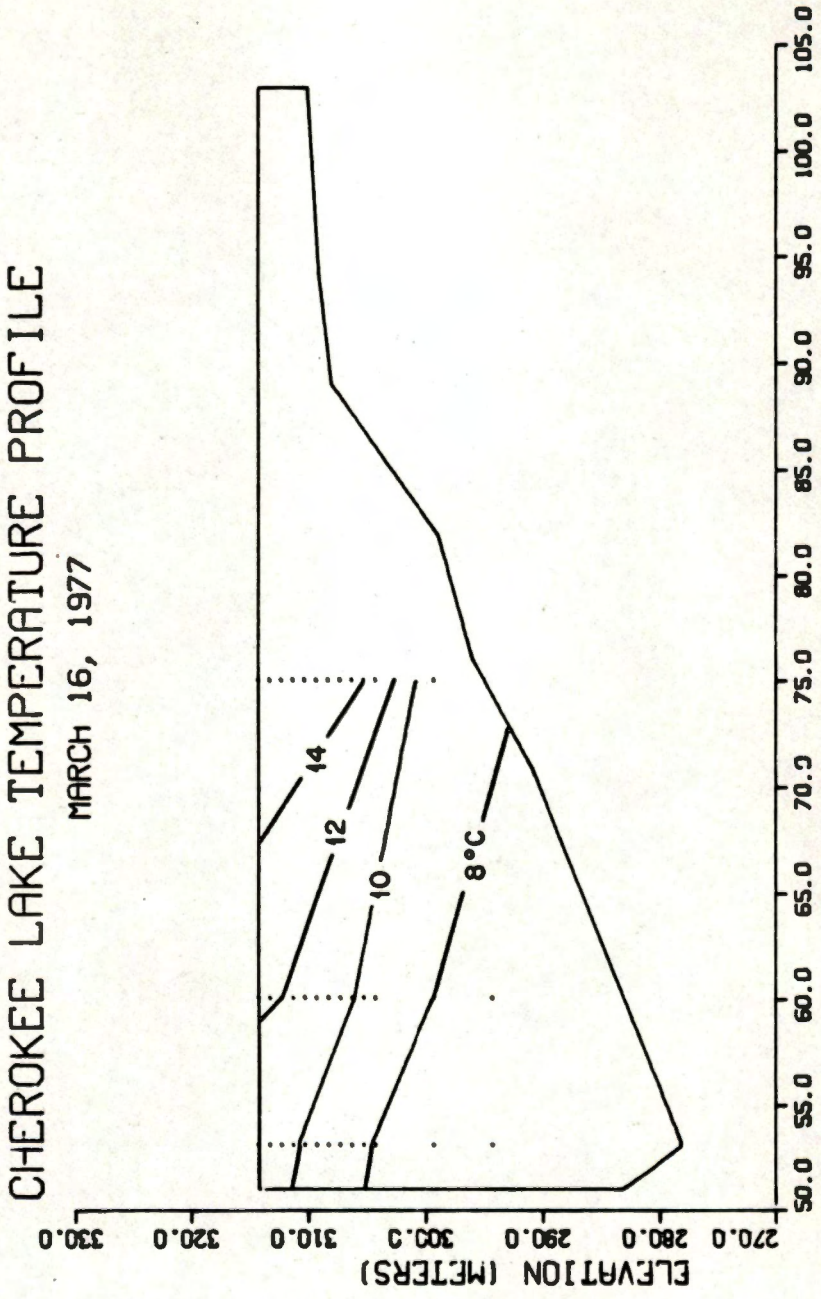


Figure D-1. Isotherms plotted by computer on a longitudinal section of Cherokee Reservoir.



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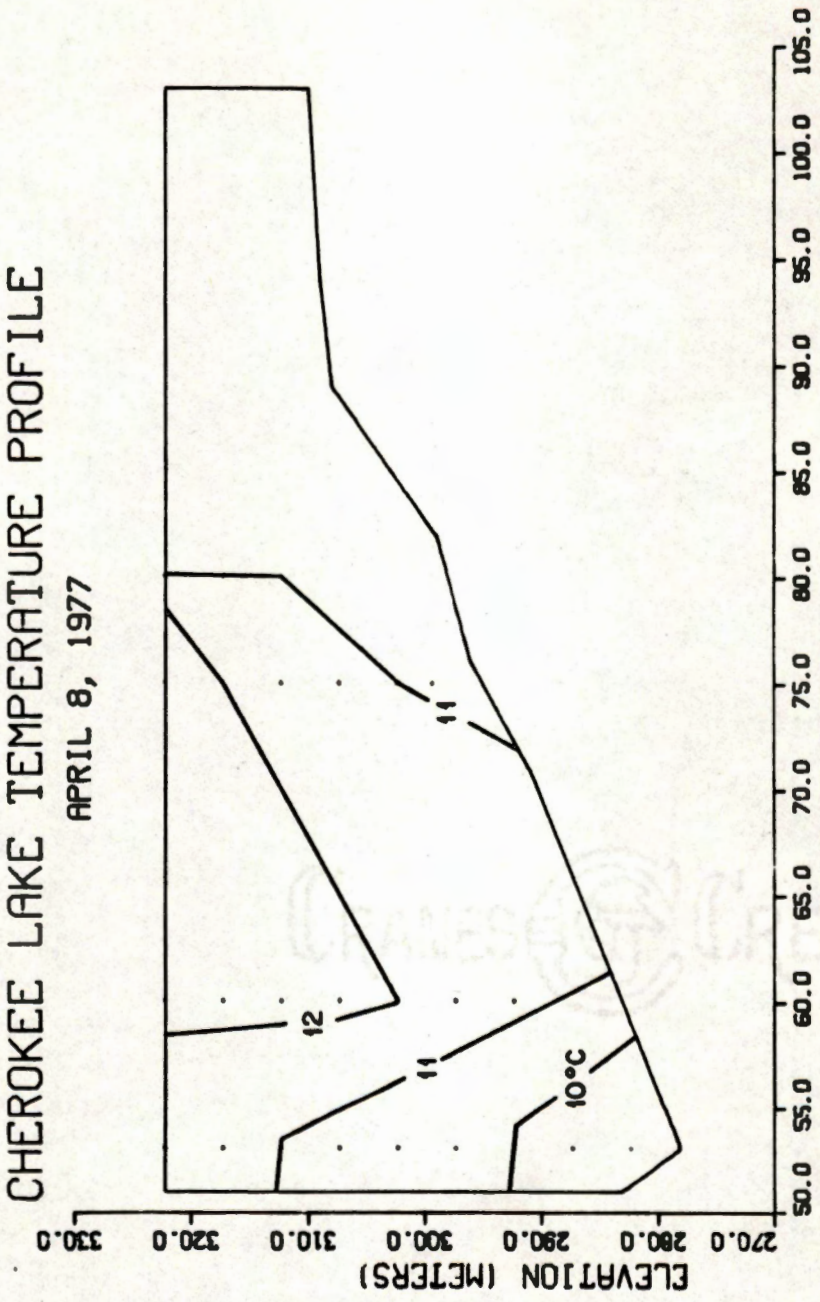

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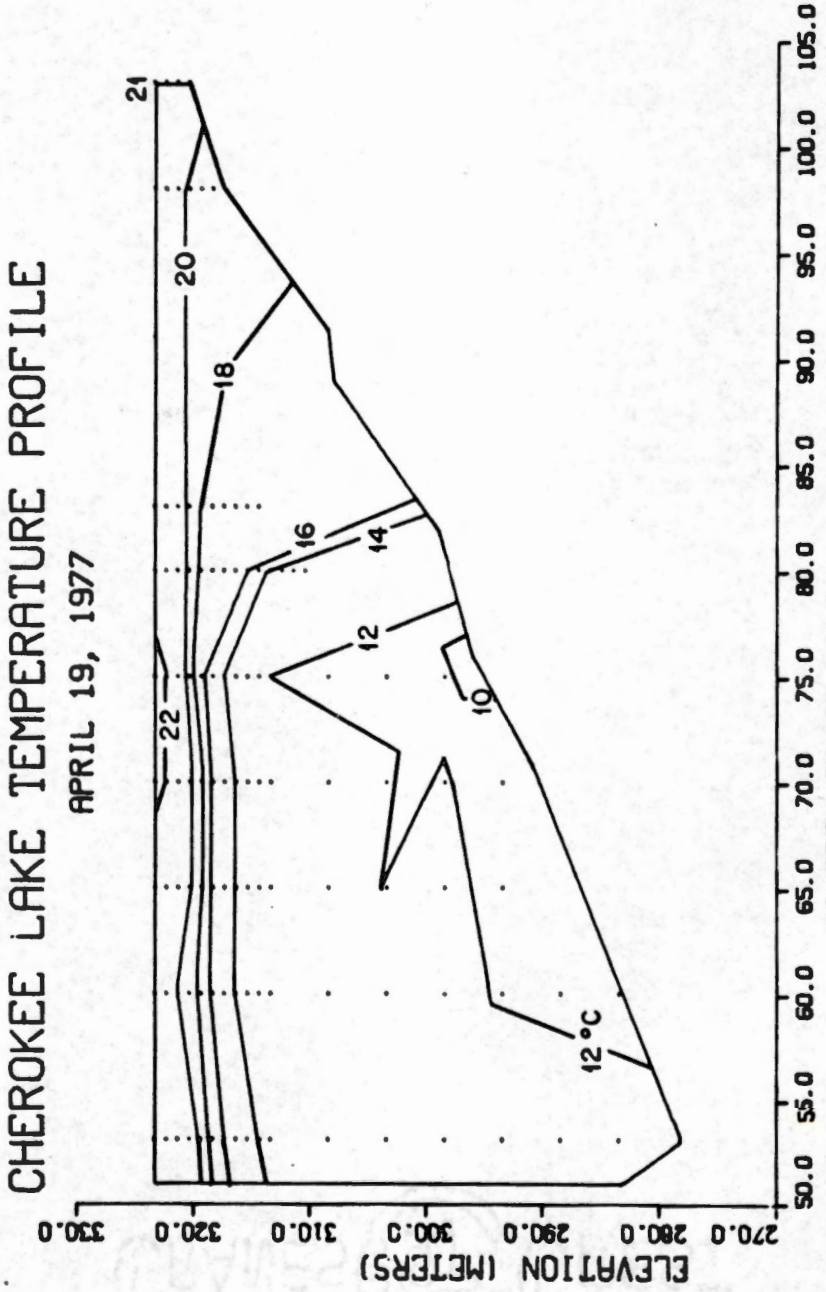

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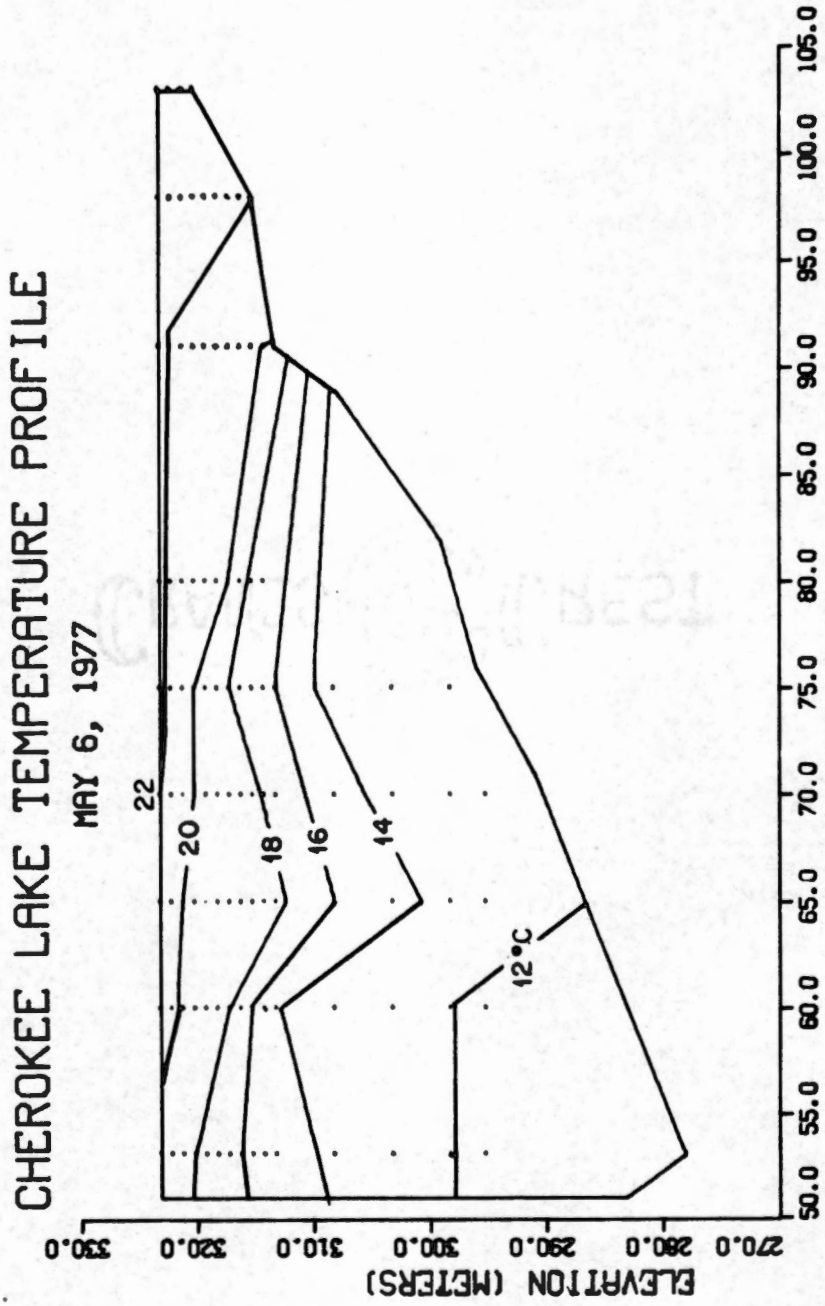

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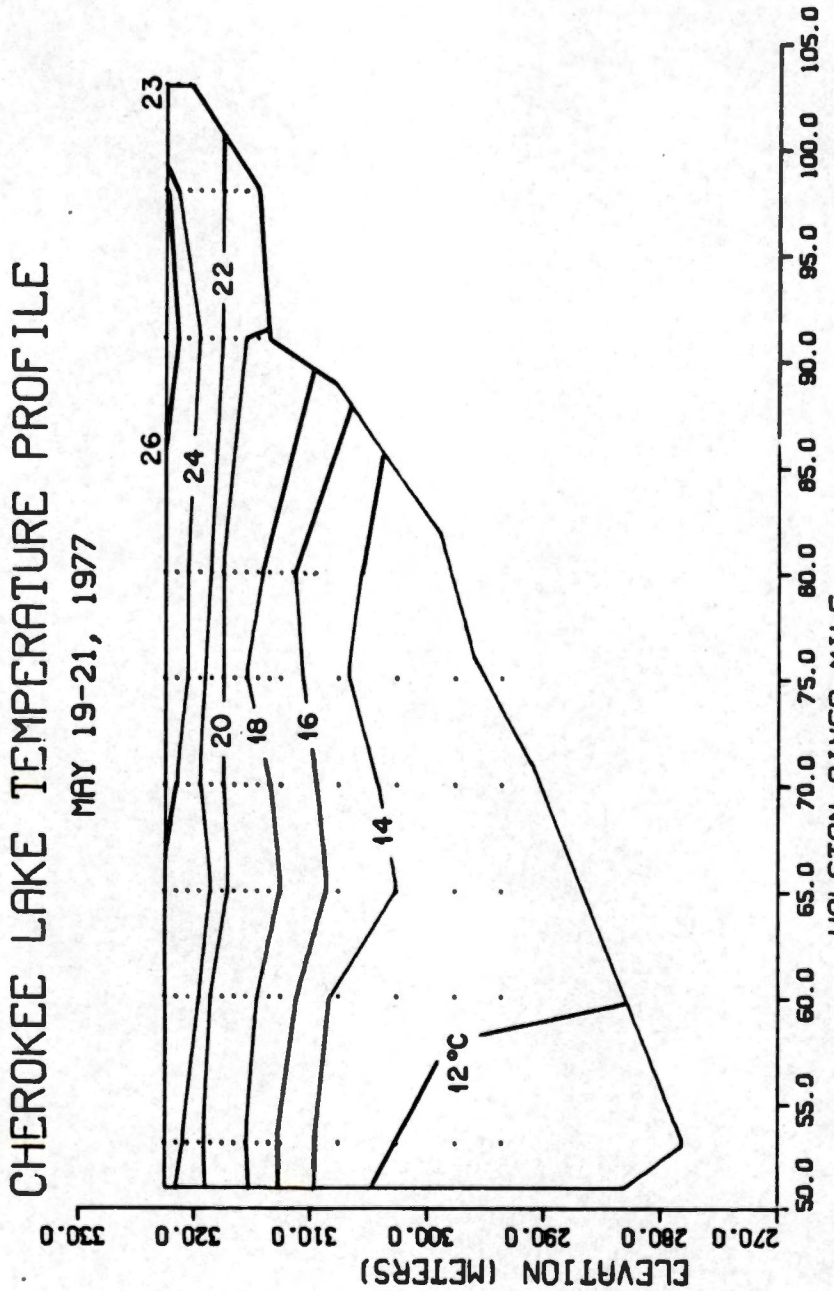
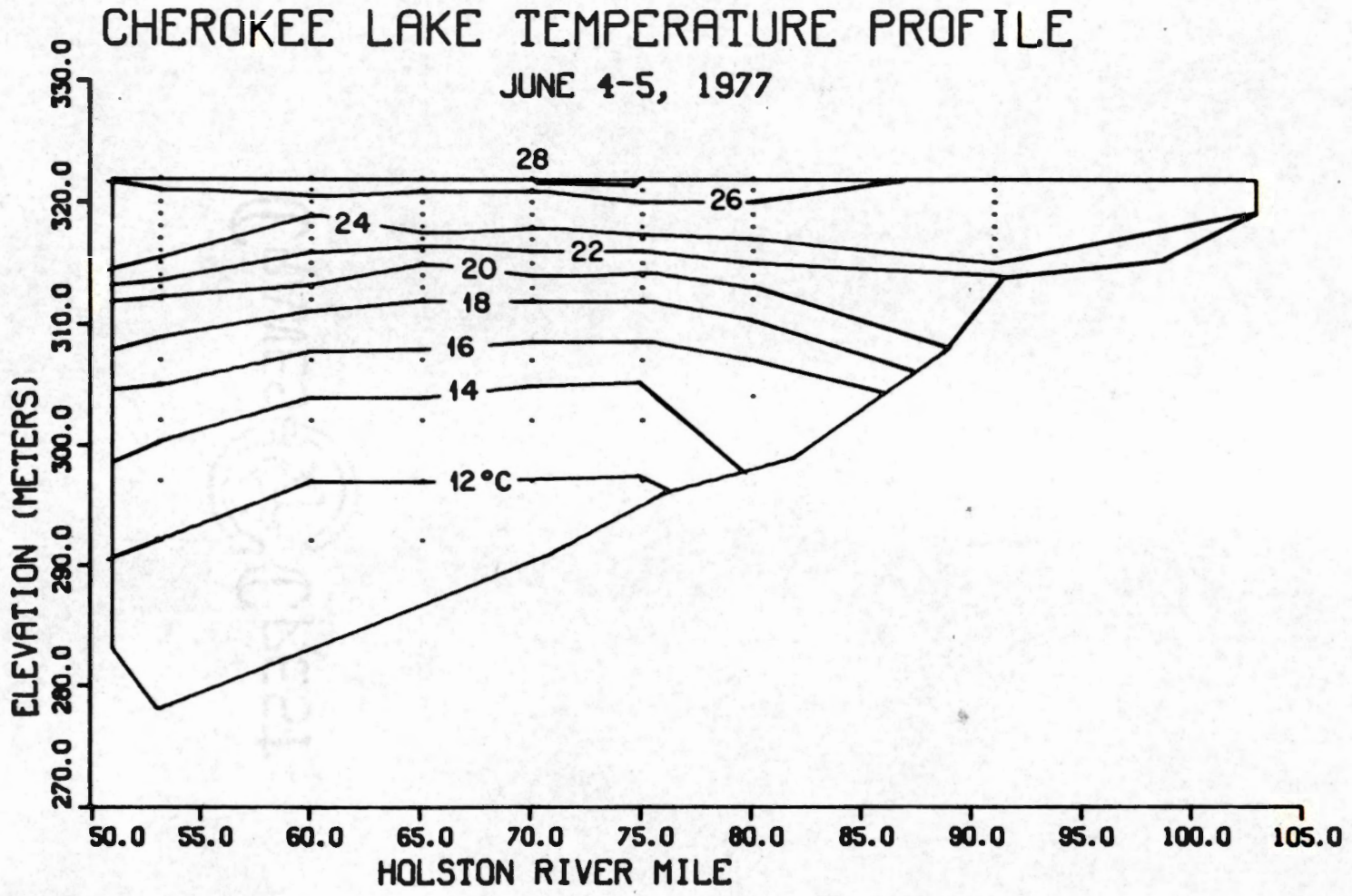


Figure D-1, continued



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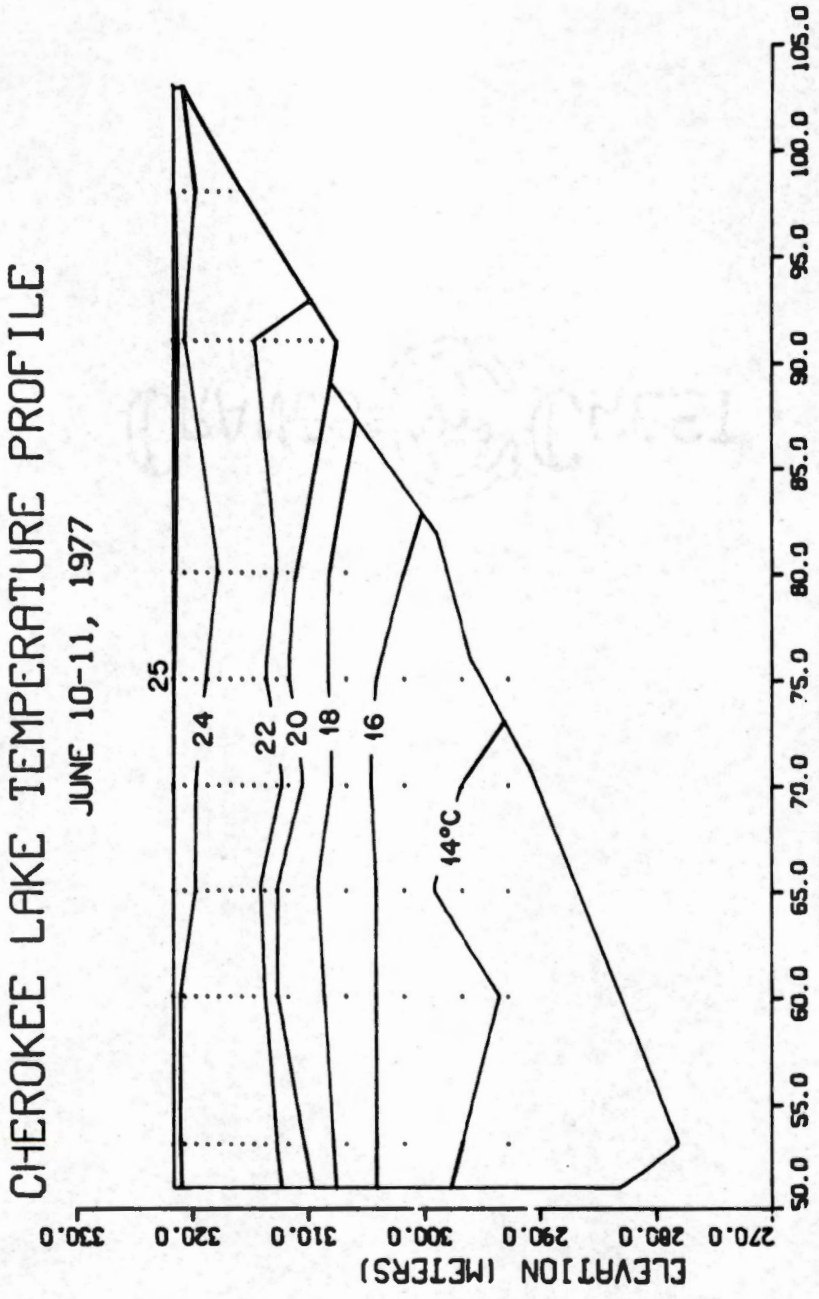

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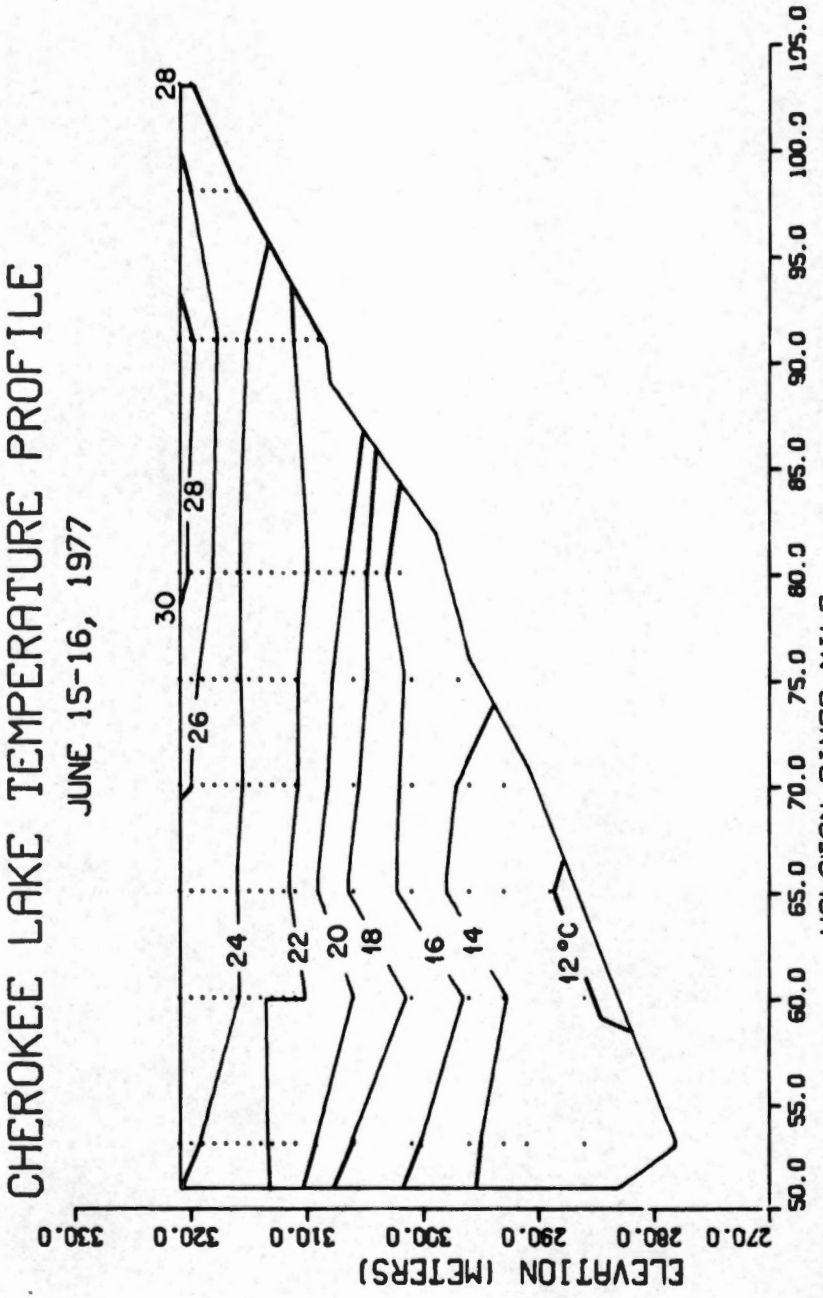

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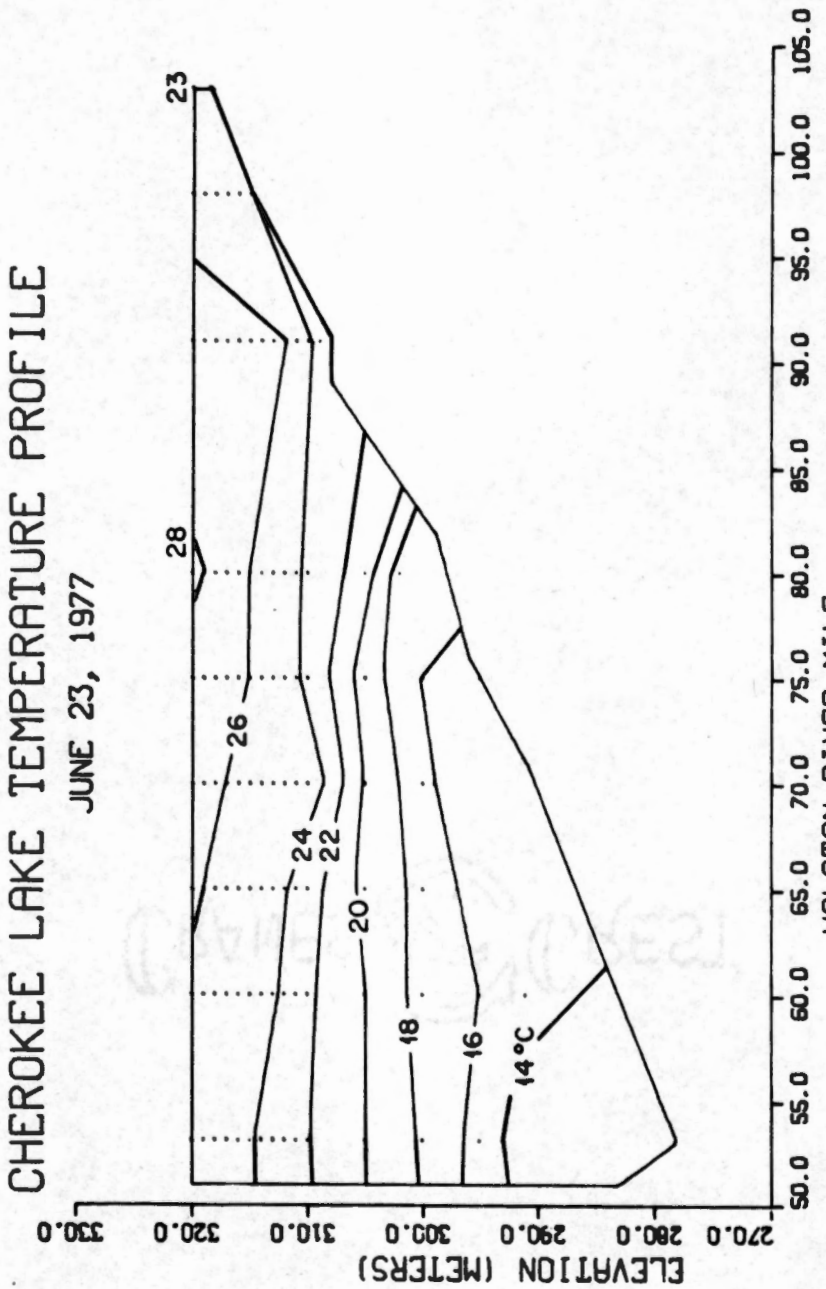

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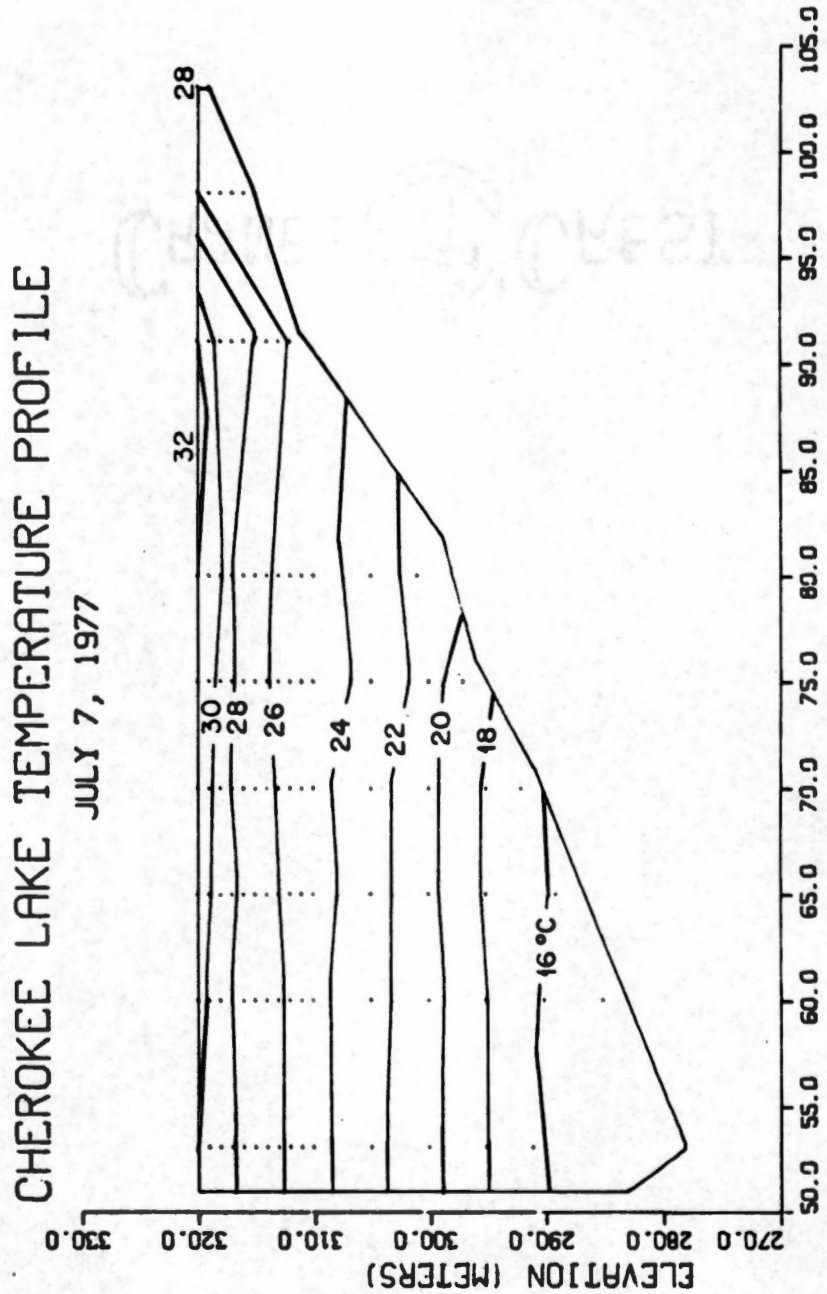

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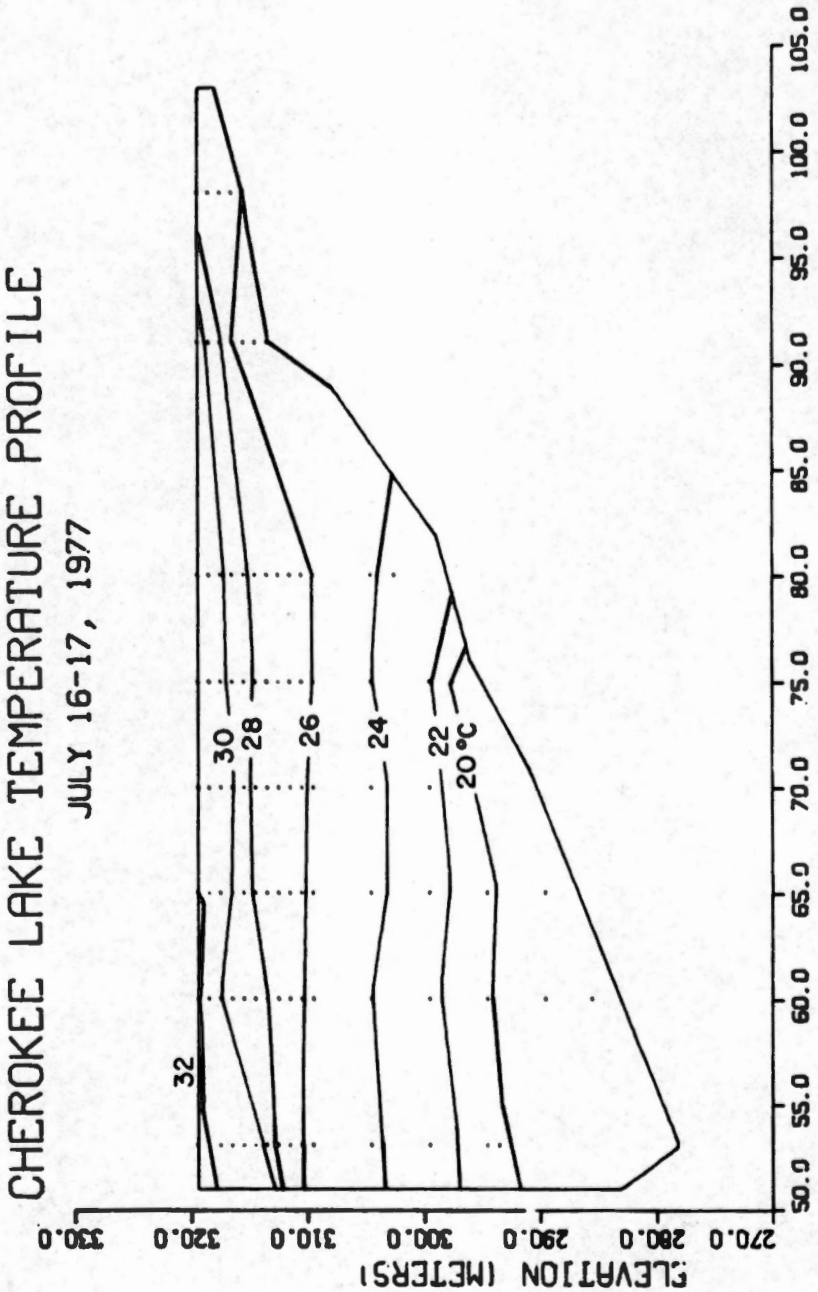

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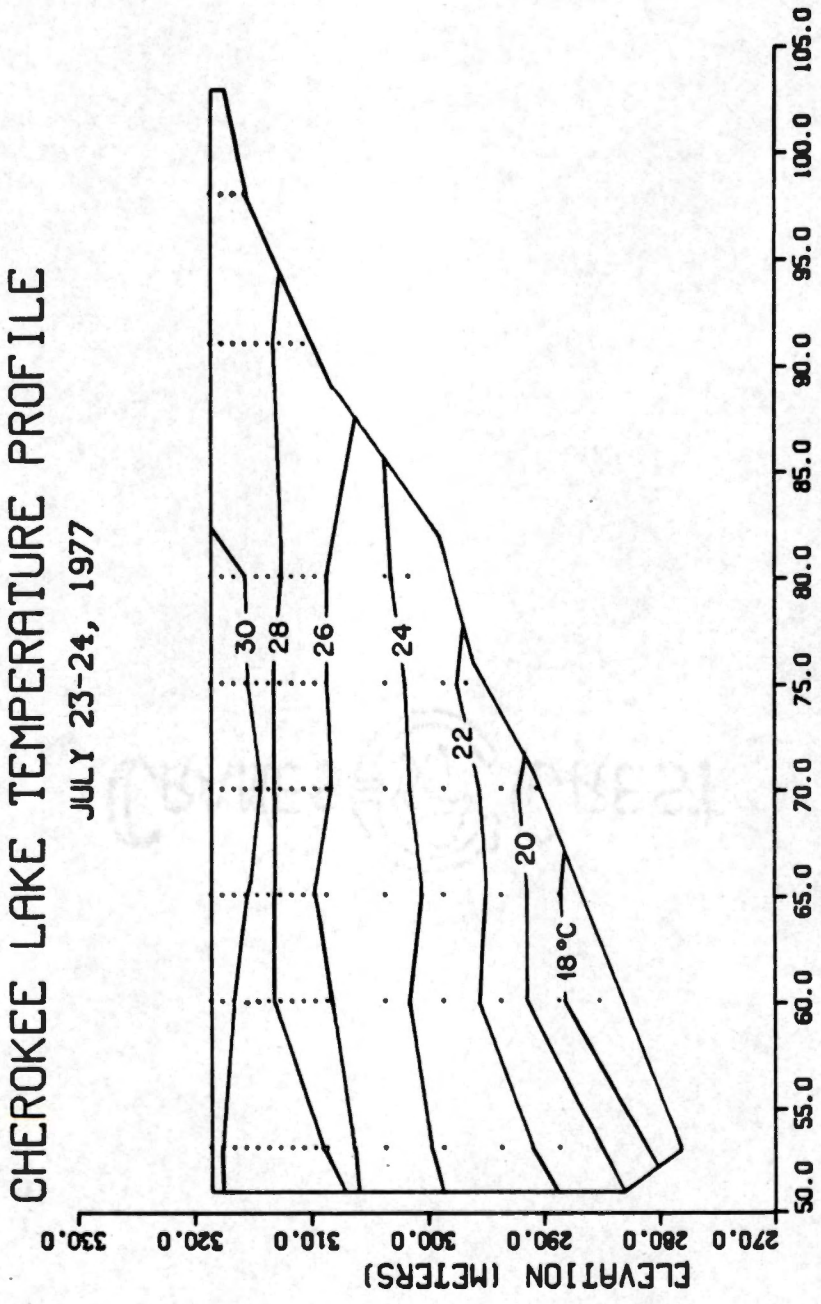

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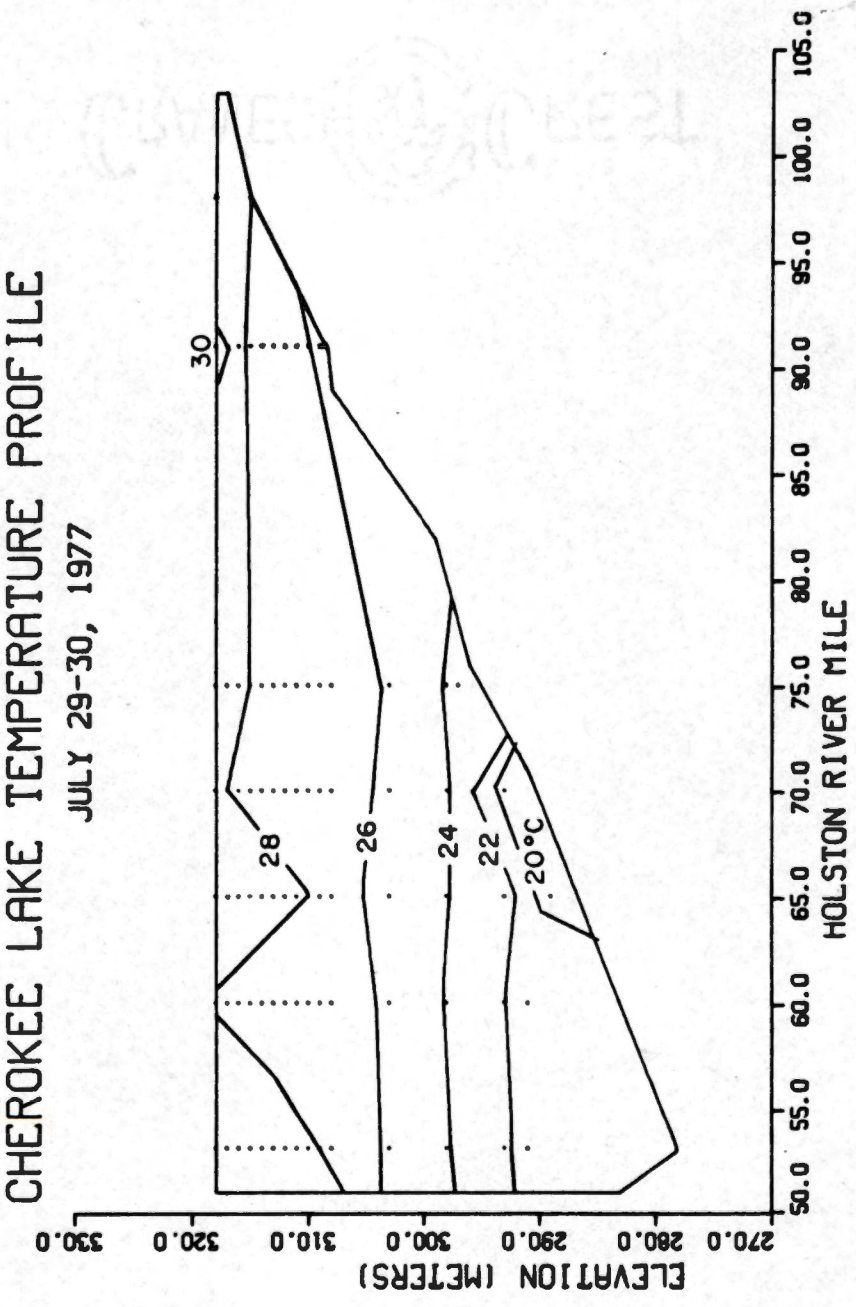

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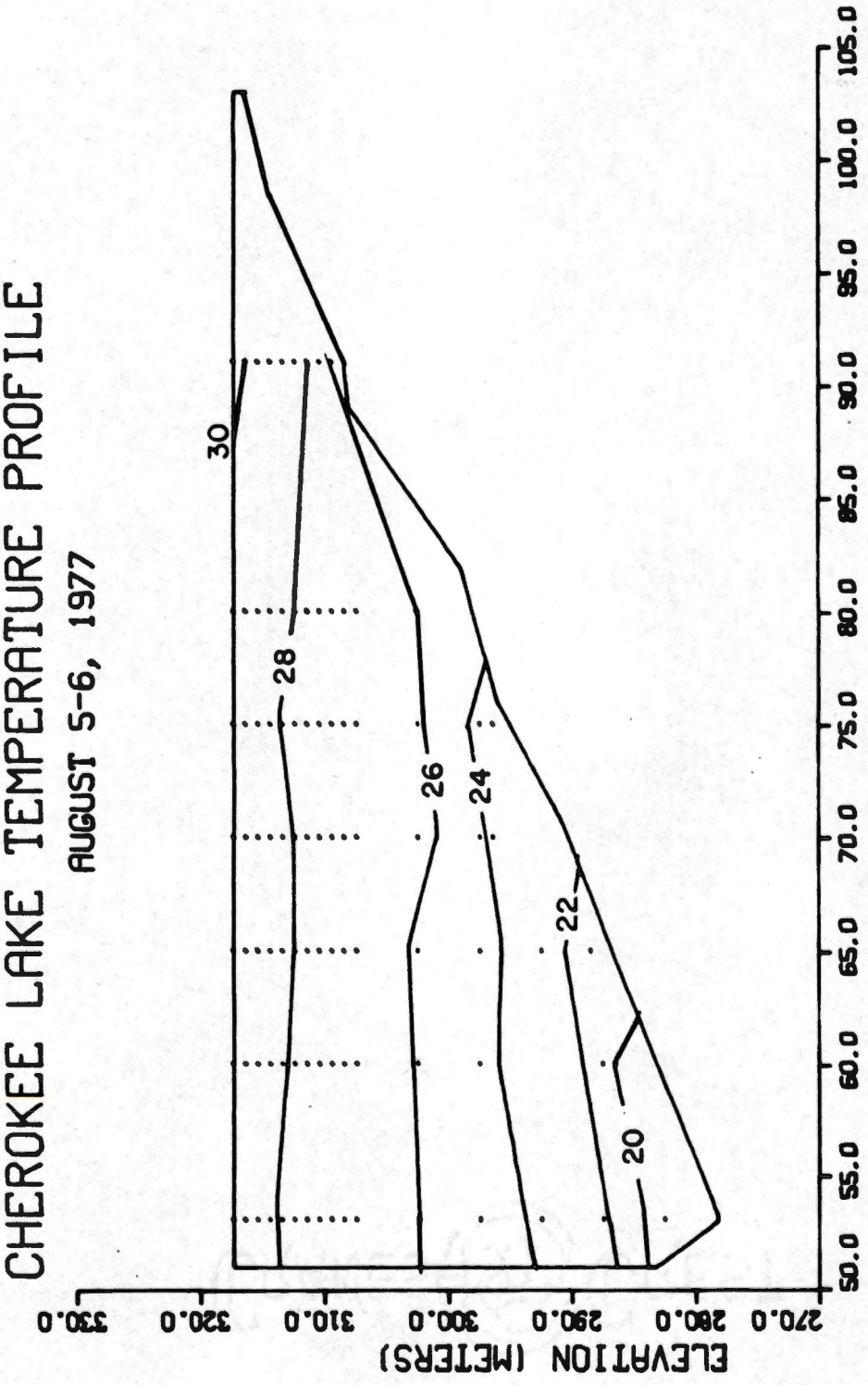

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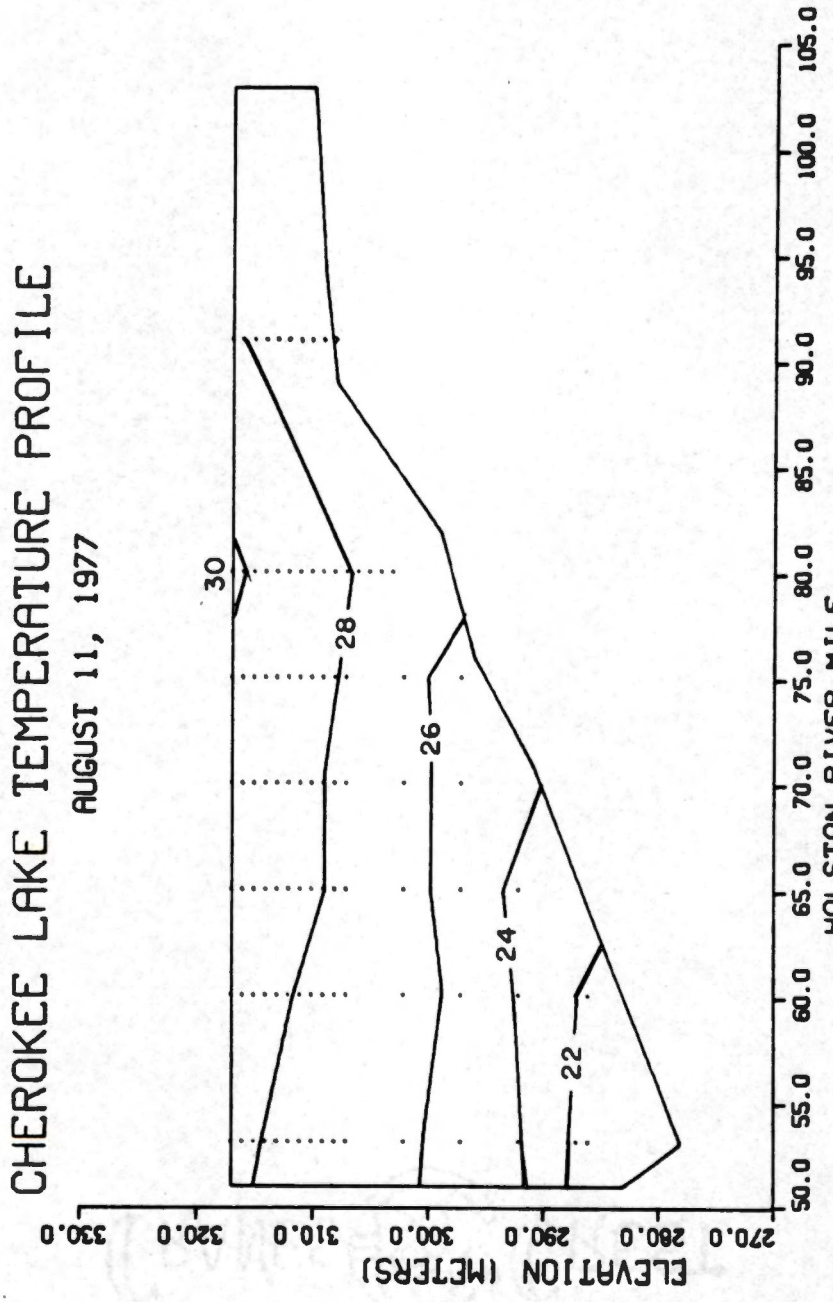

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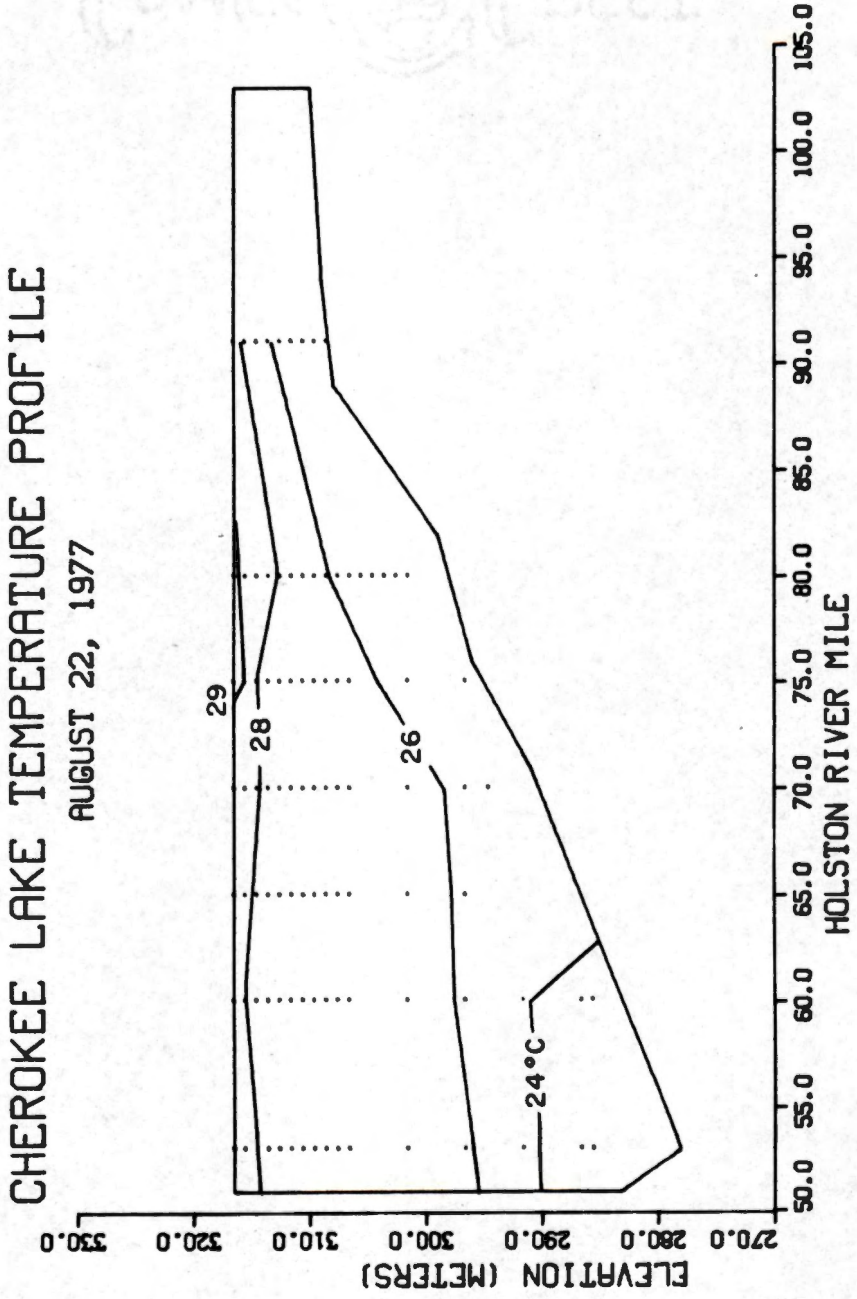

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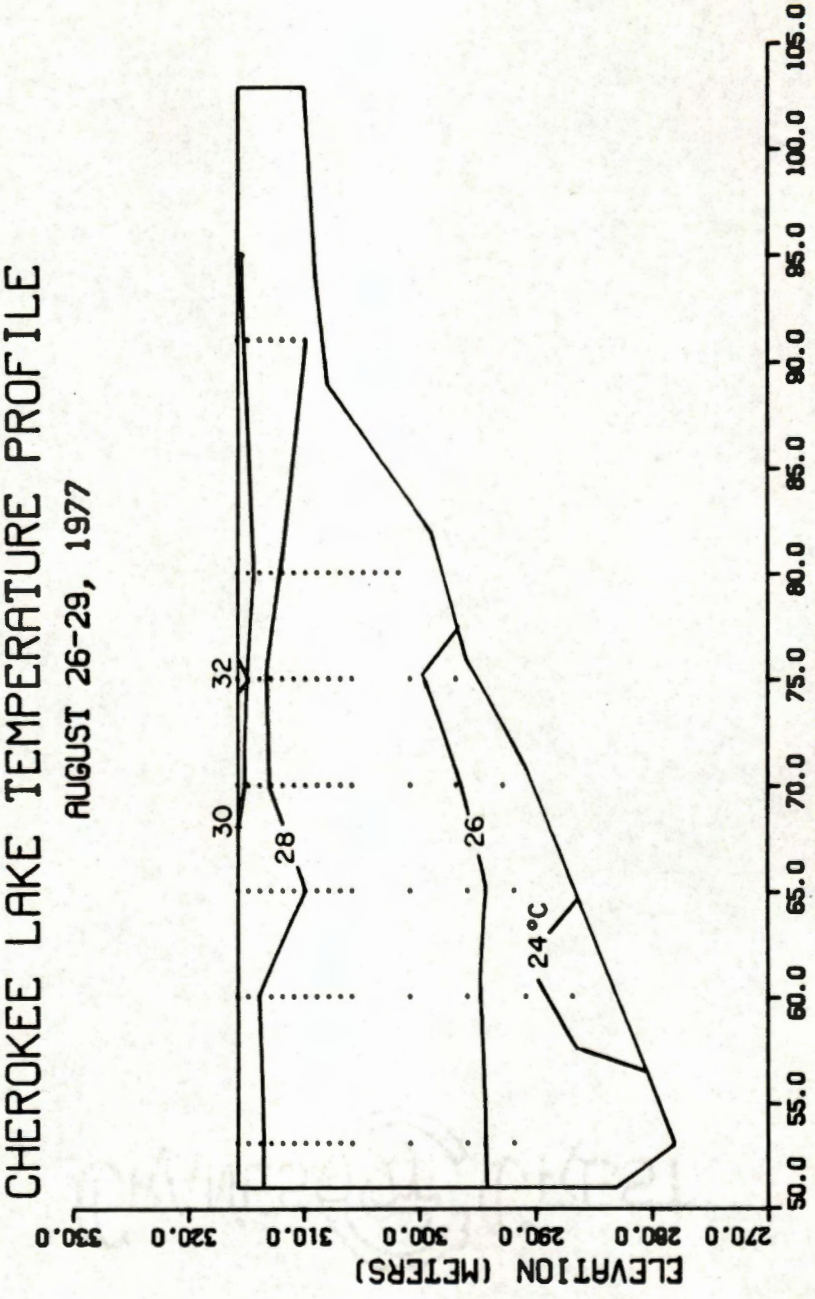

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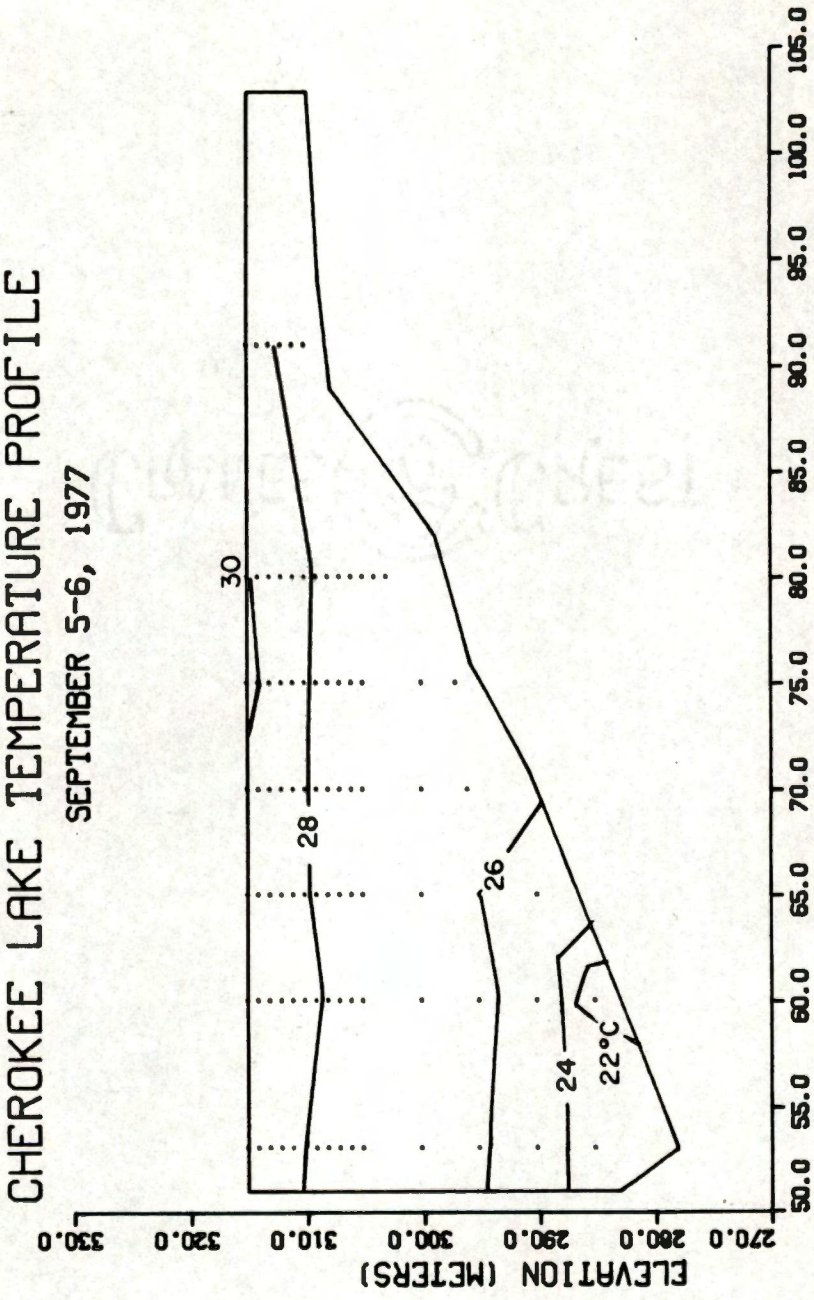

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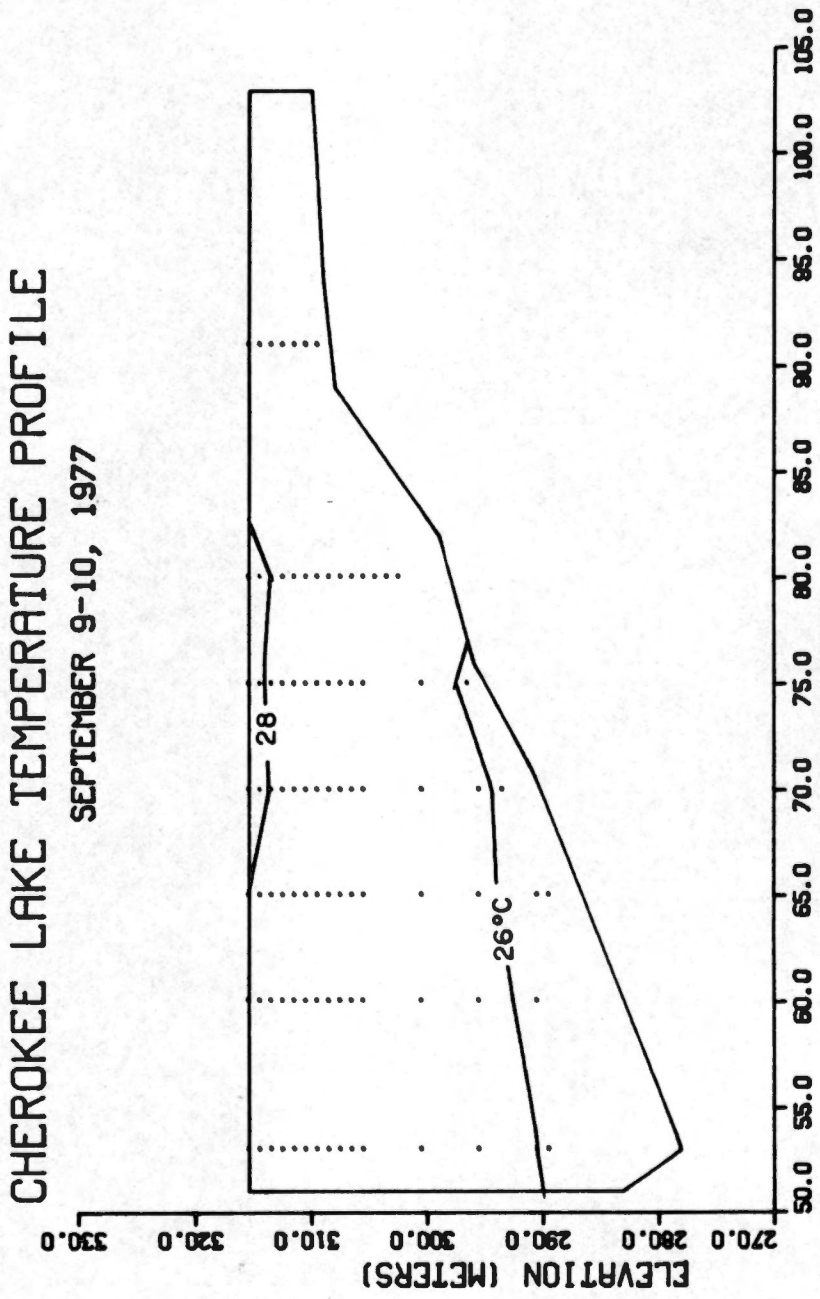

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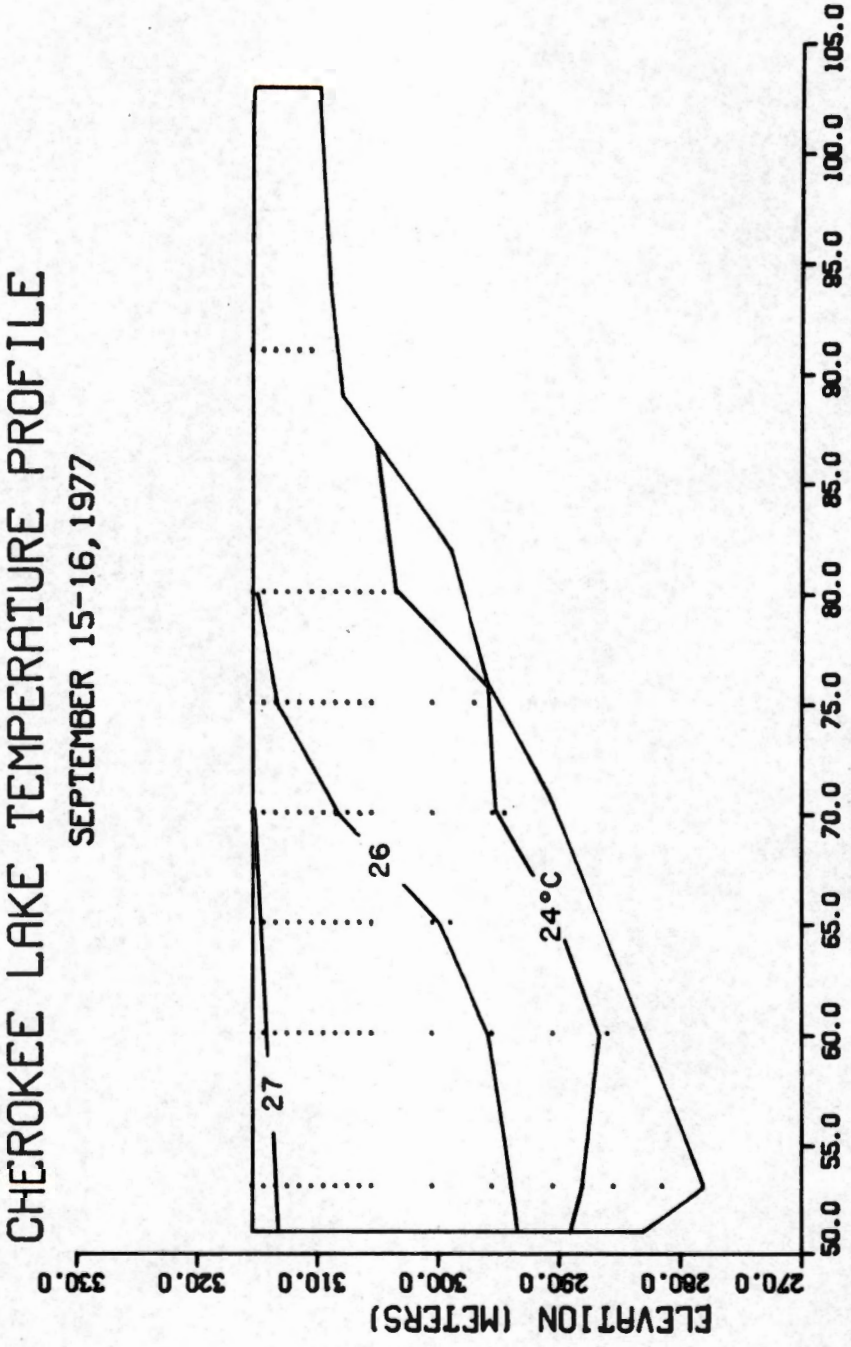

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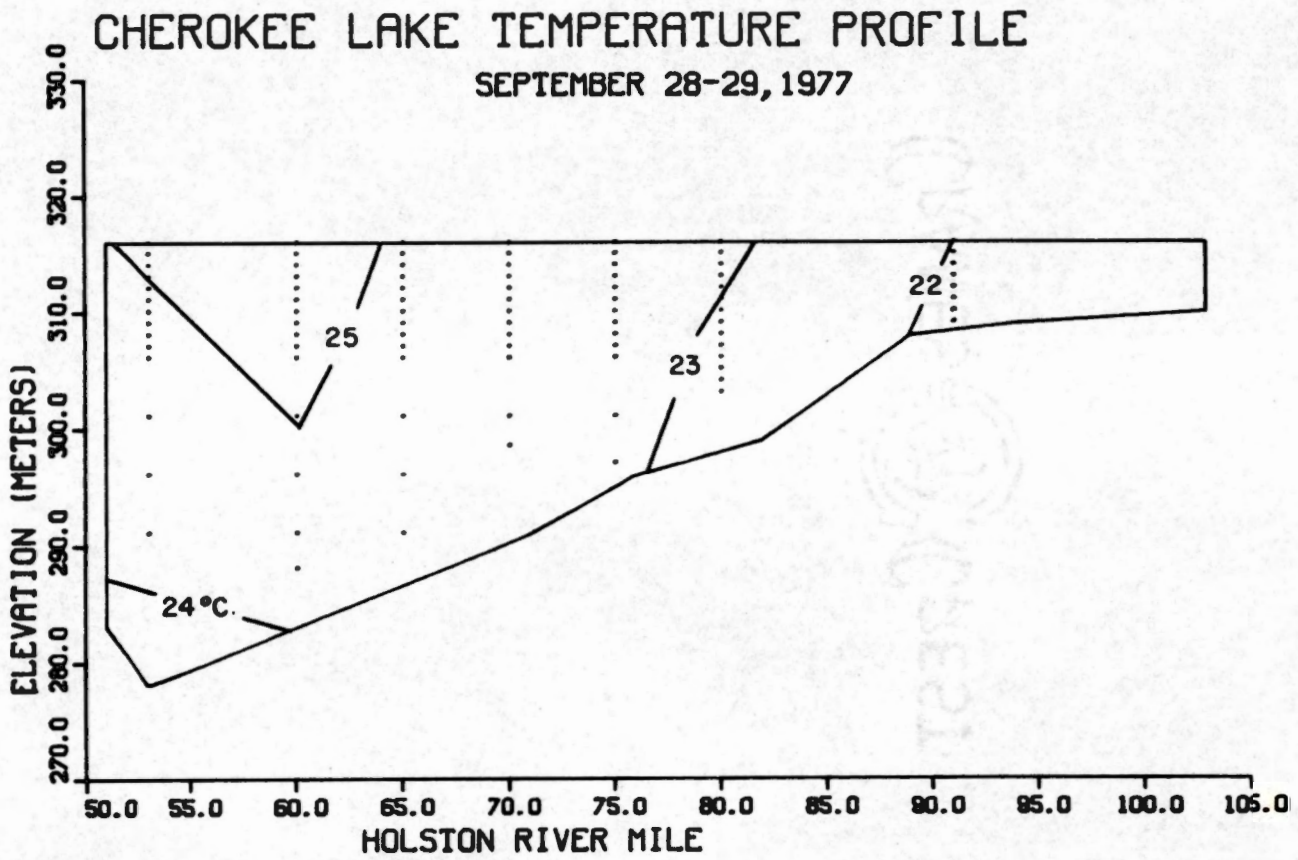

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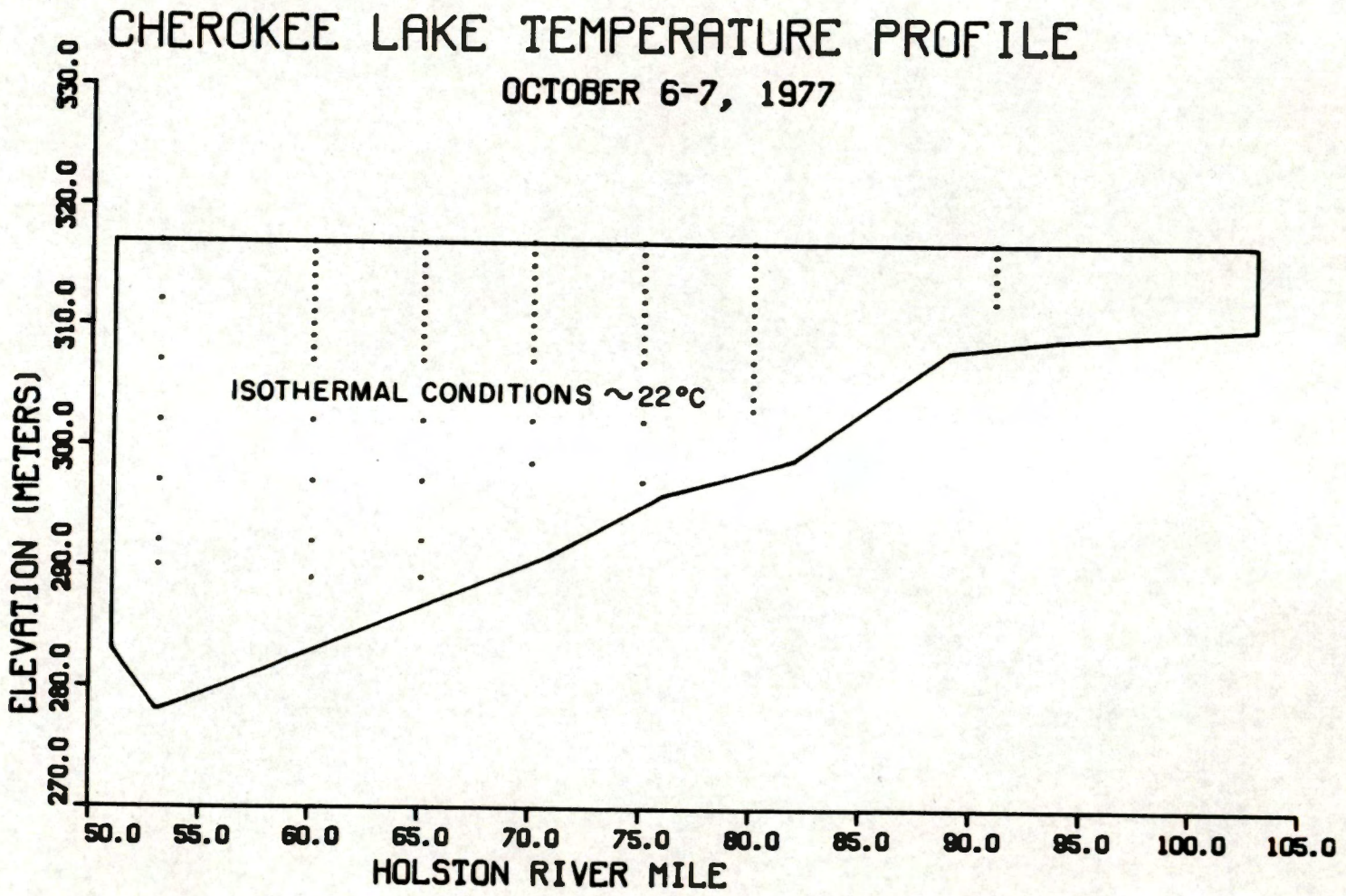

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APPENDIX E

DISSOLVED OXYGEN PROFILES OF MAIN CHANNEL STATIONS, MARCH-OCTOBER, 1977

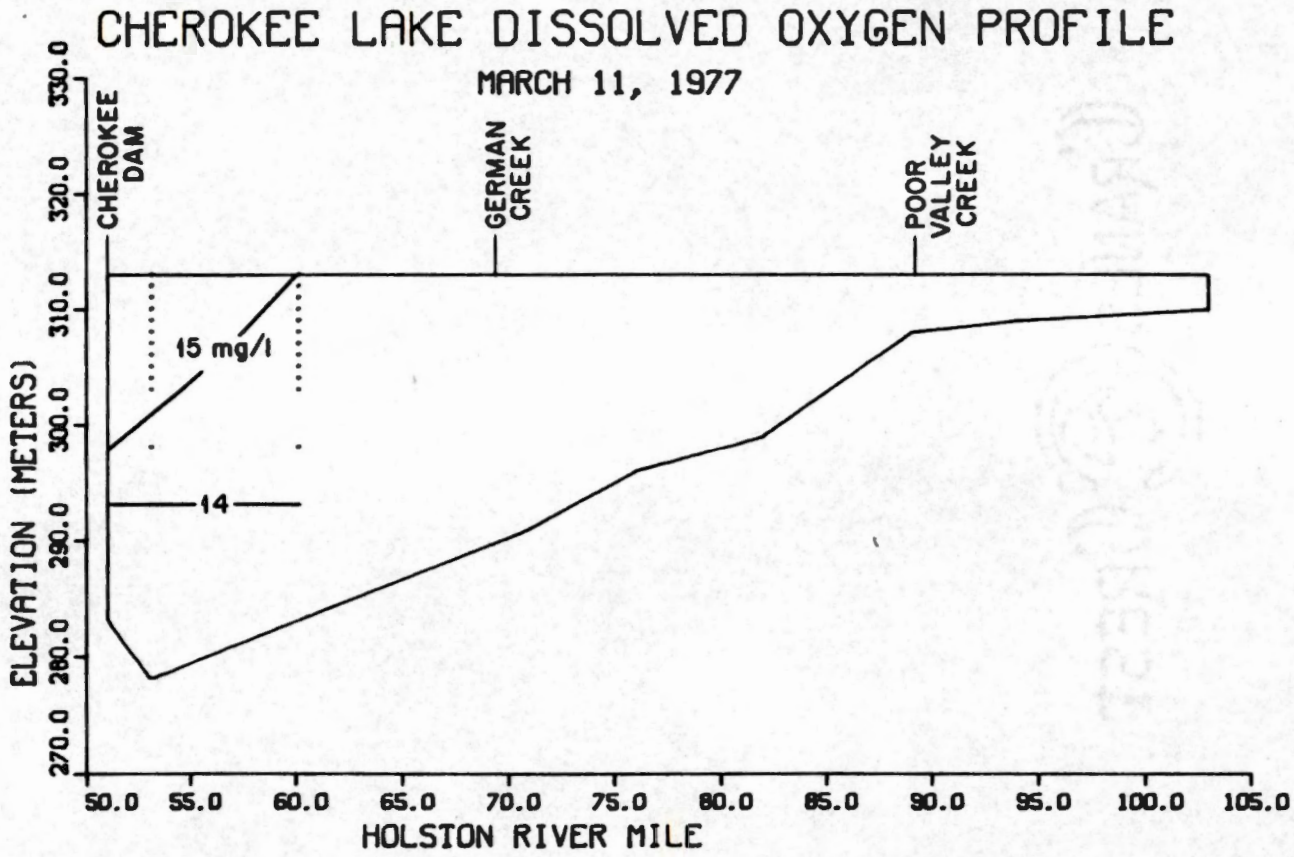
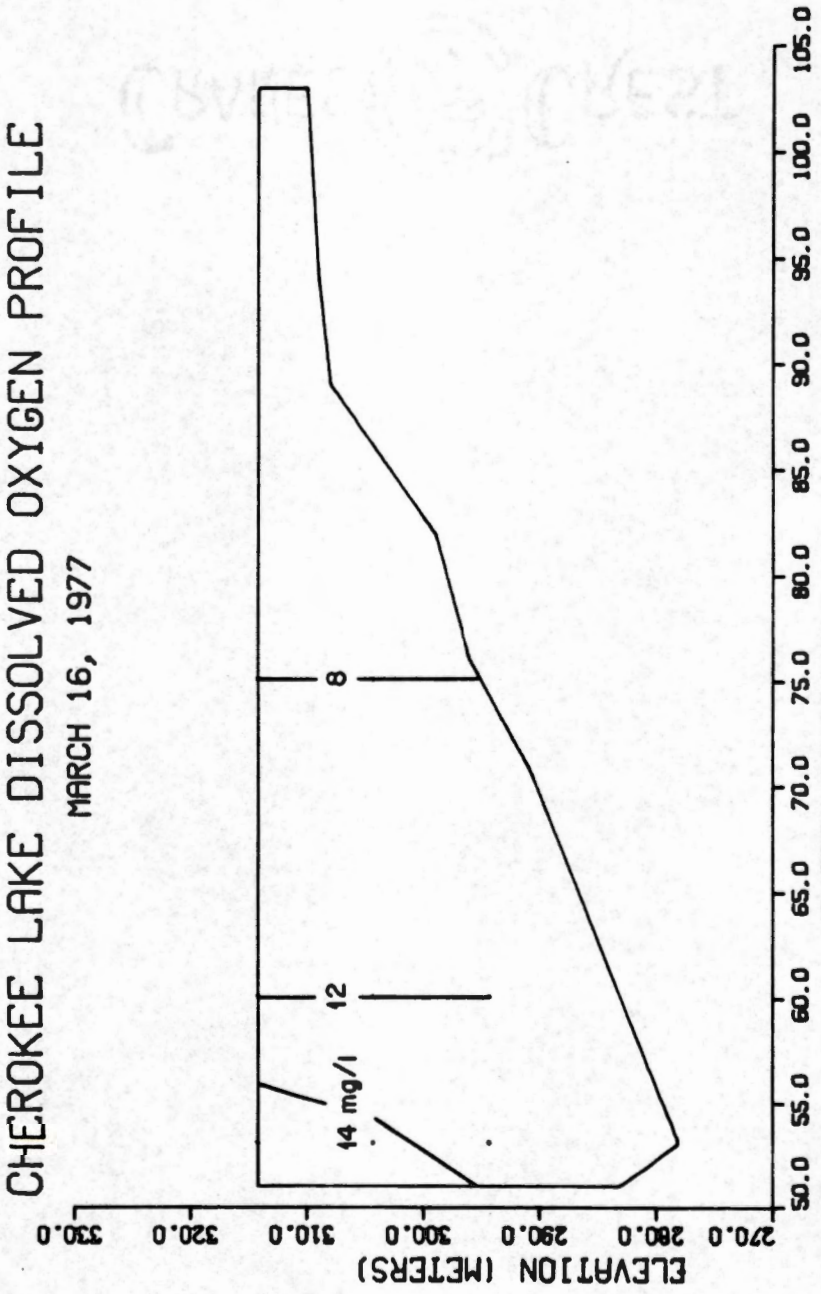


Figure E-1. Isopleths of dissolved oxygen plotted by computer on a longitudinal section of Cherokee Reservoir.



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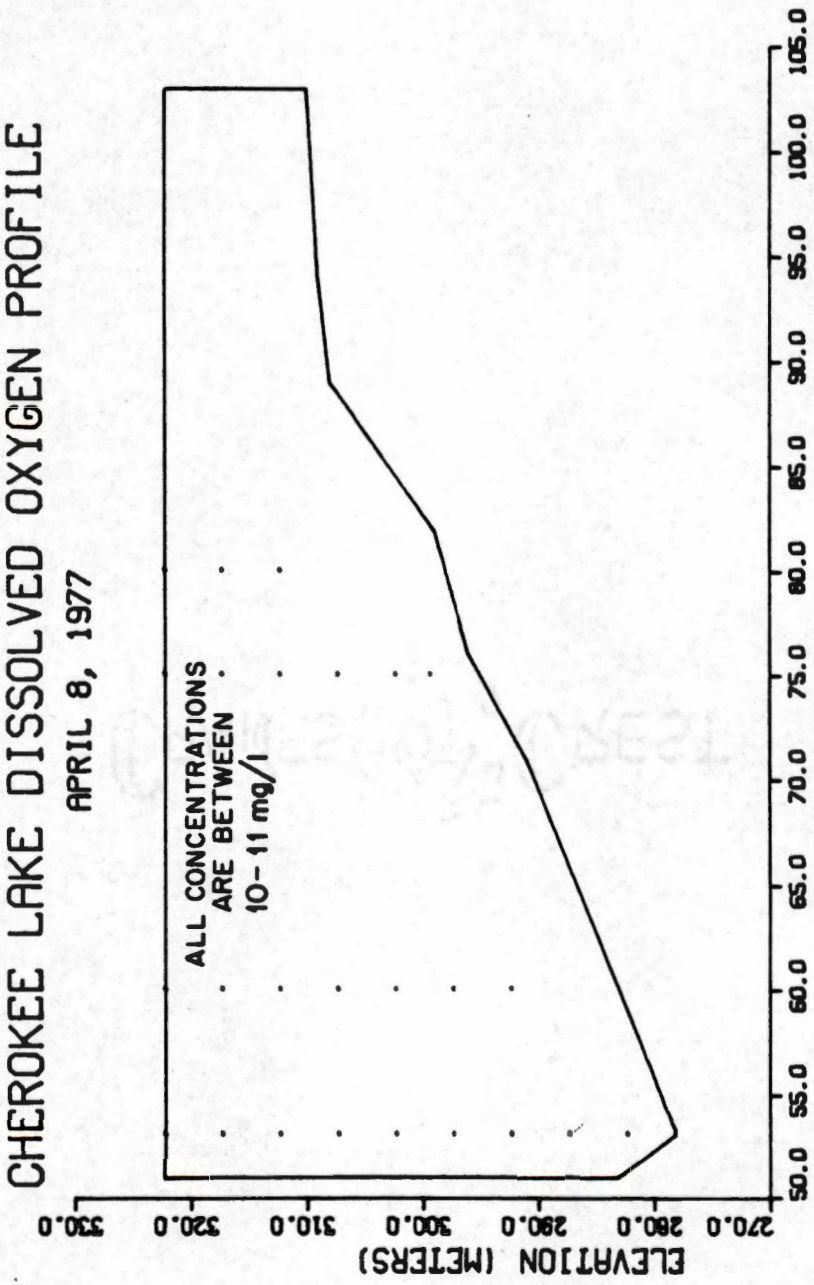

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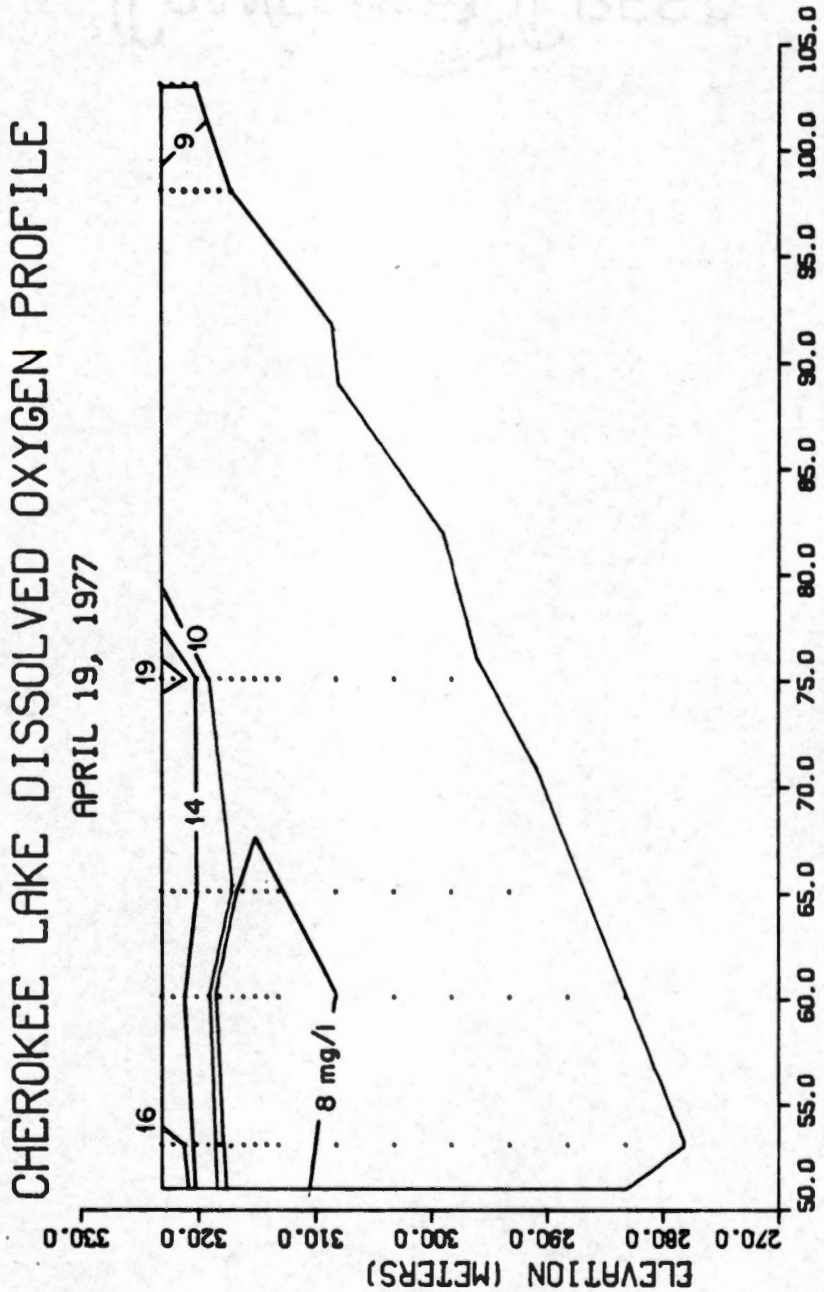

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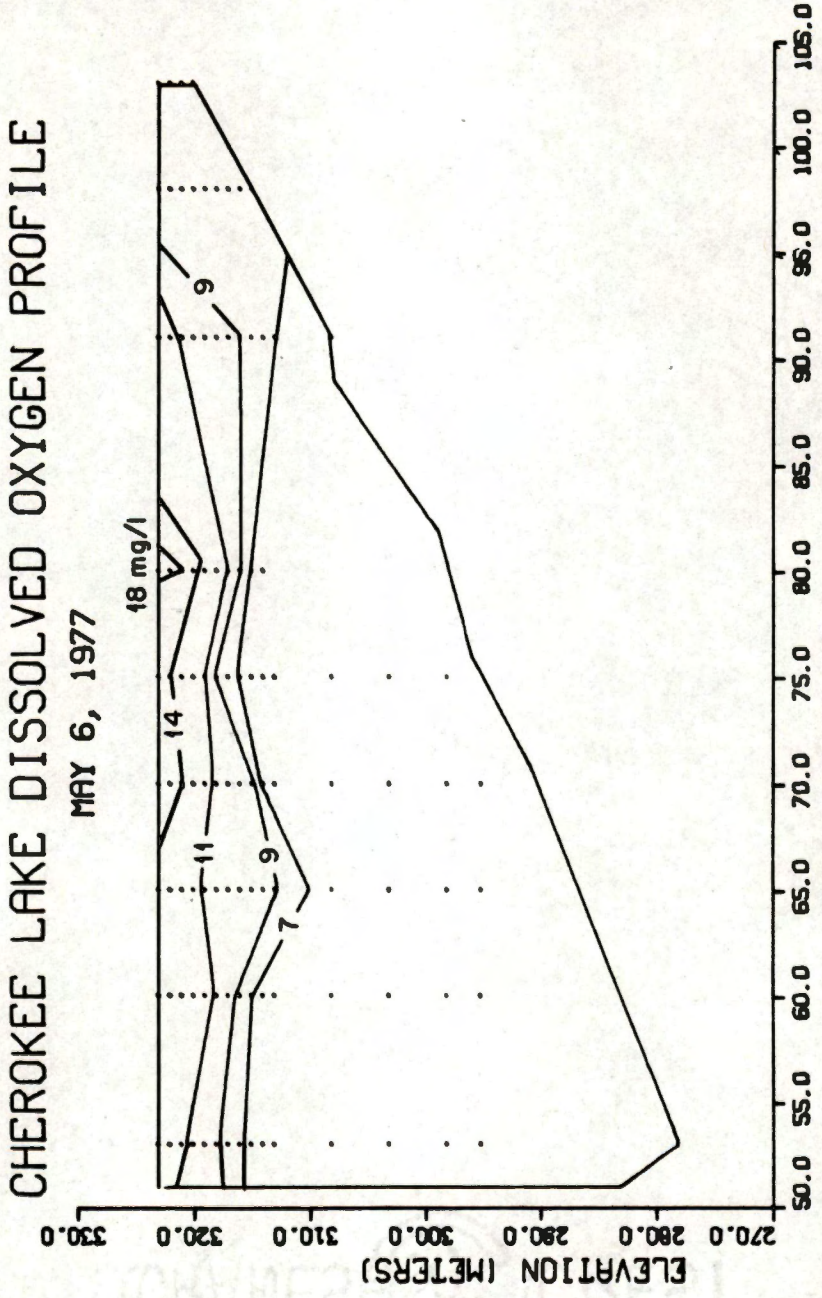

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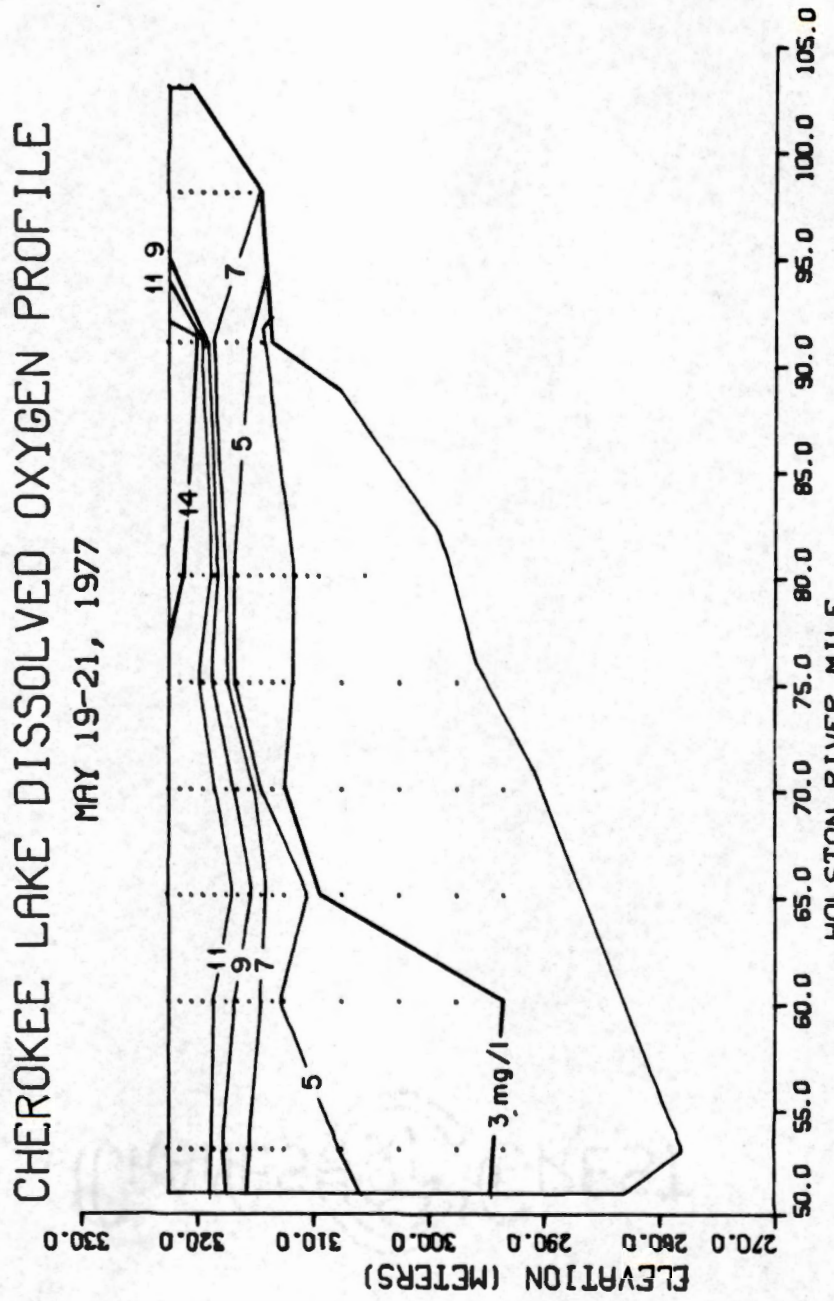

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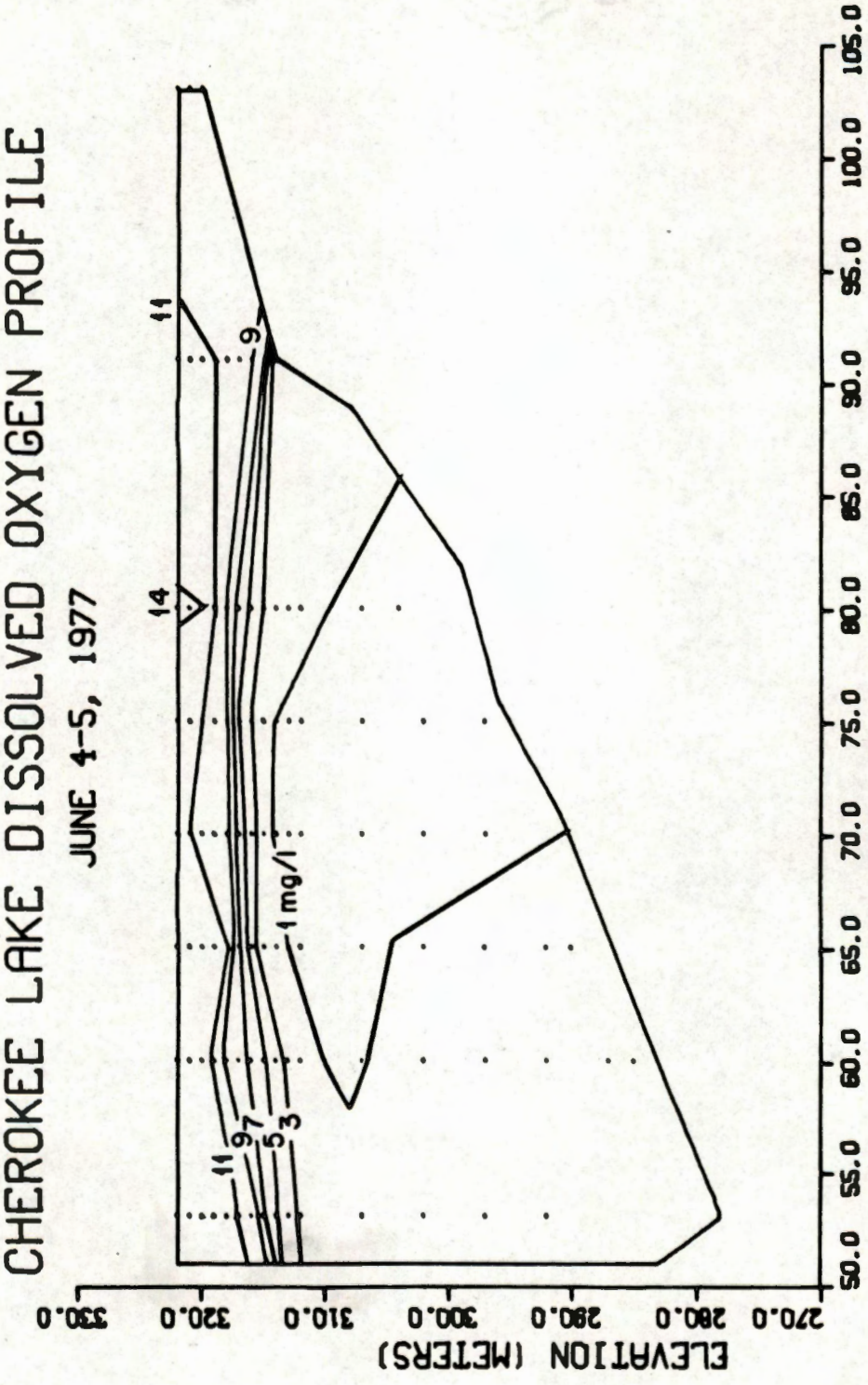

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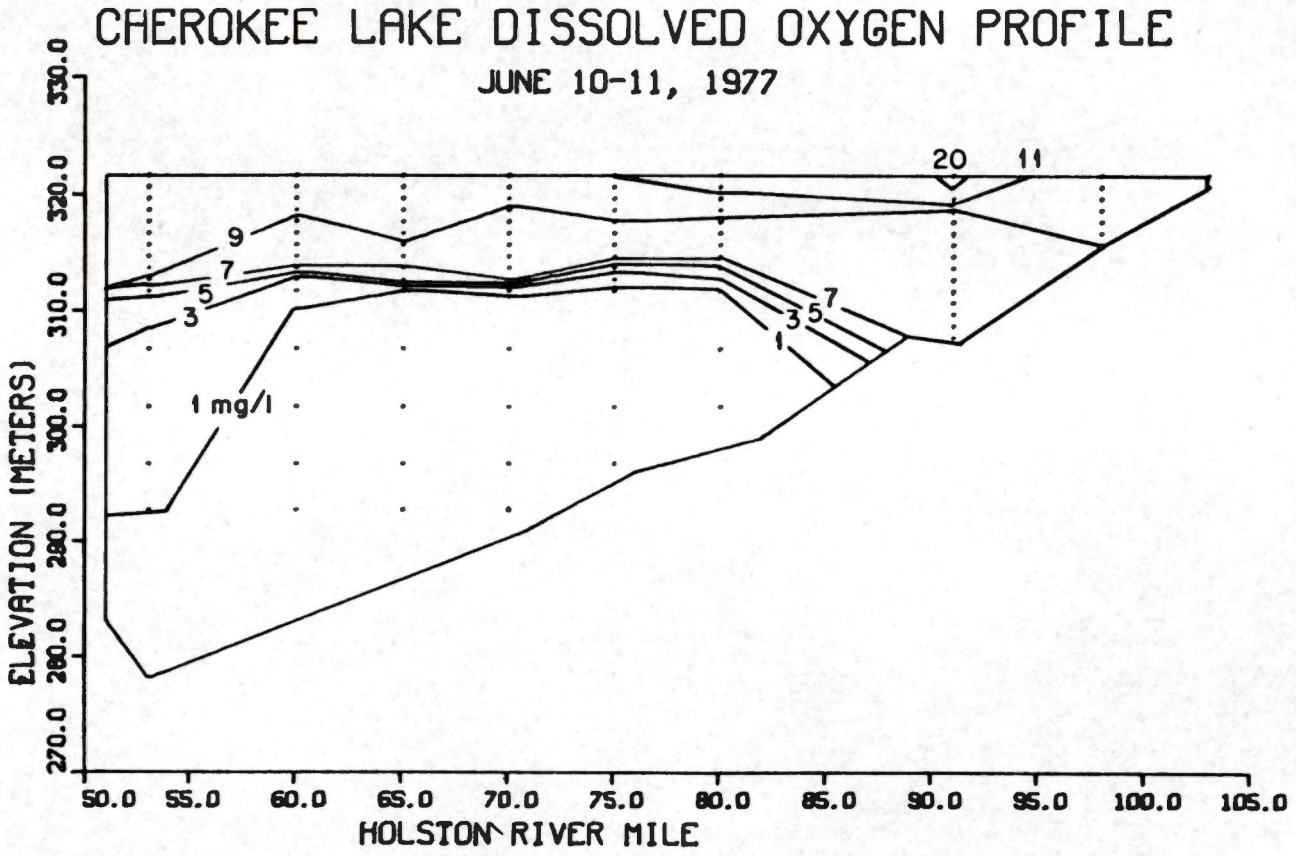

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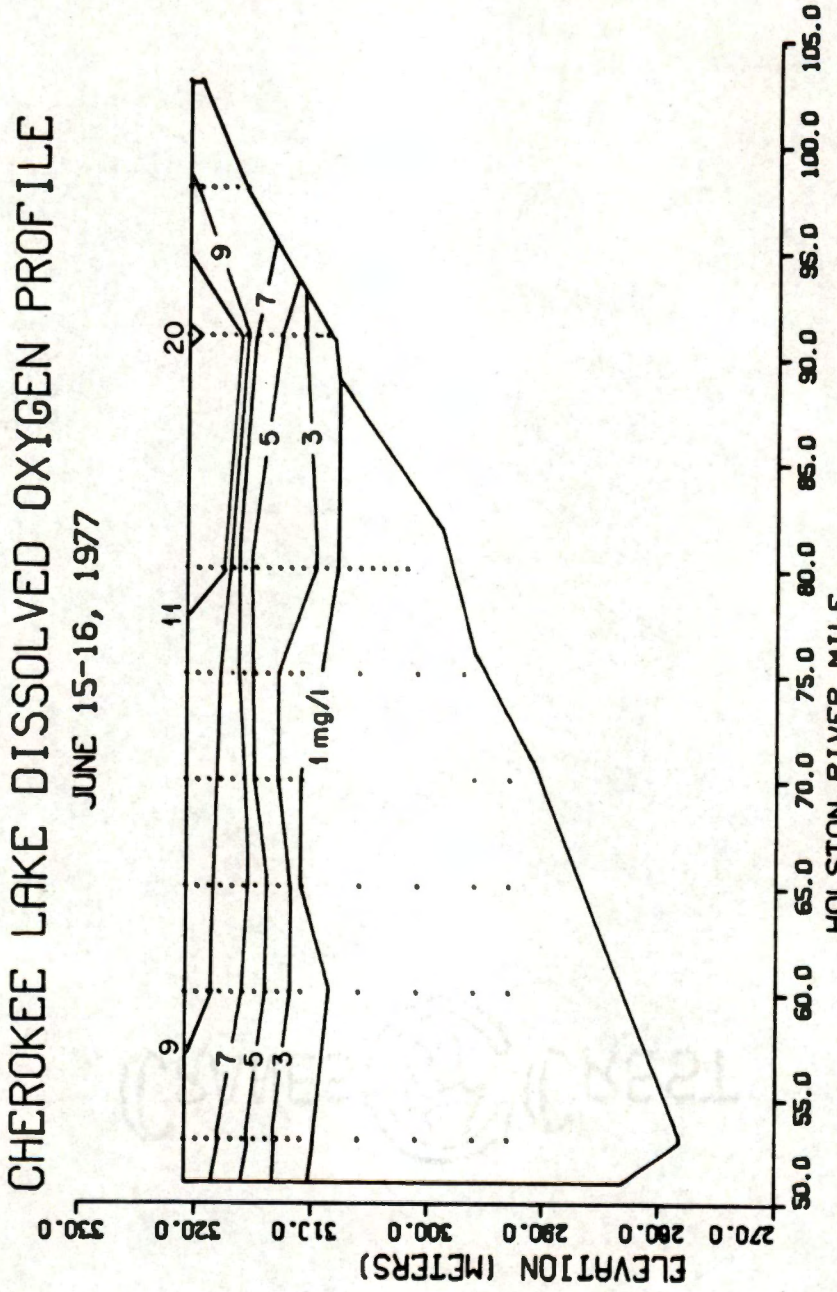

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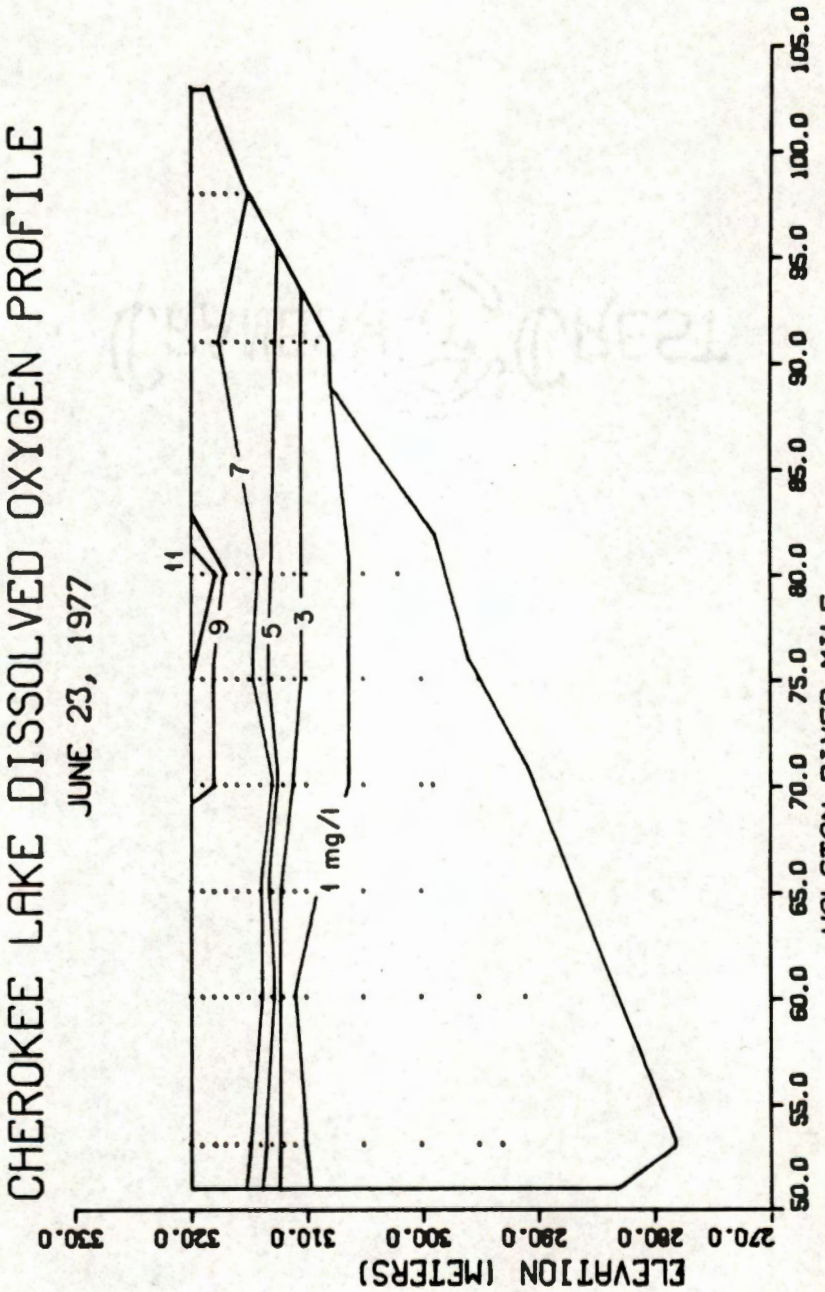

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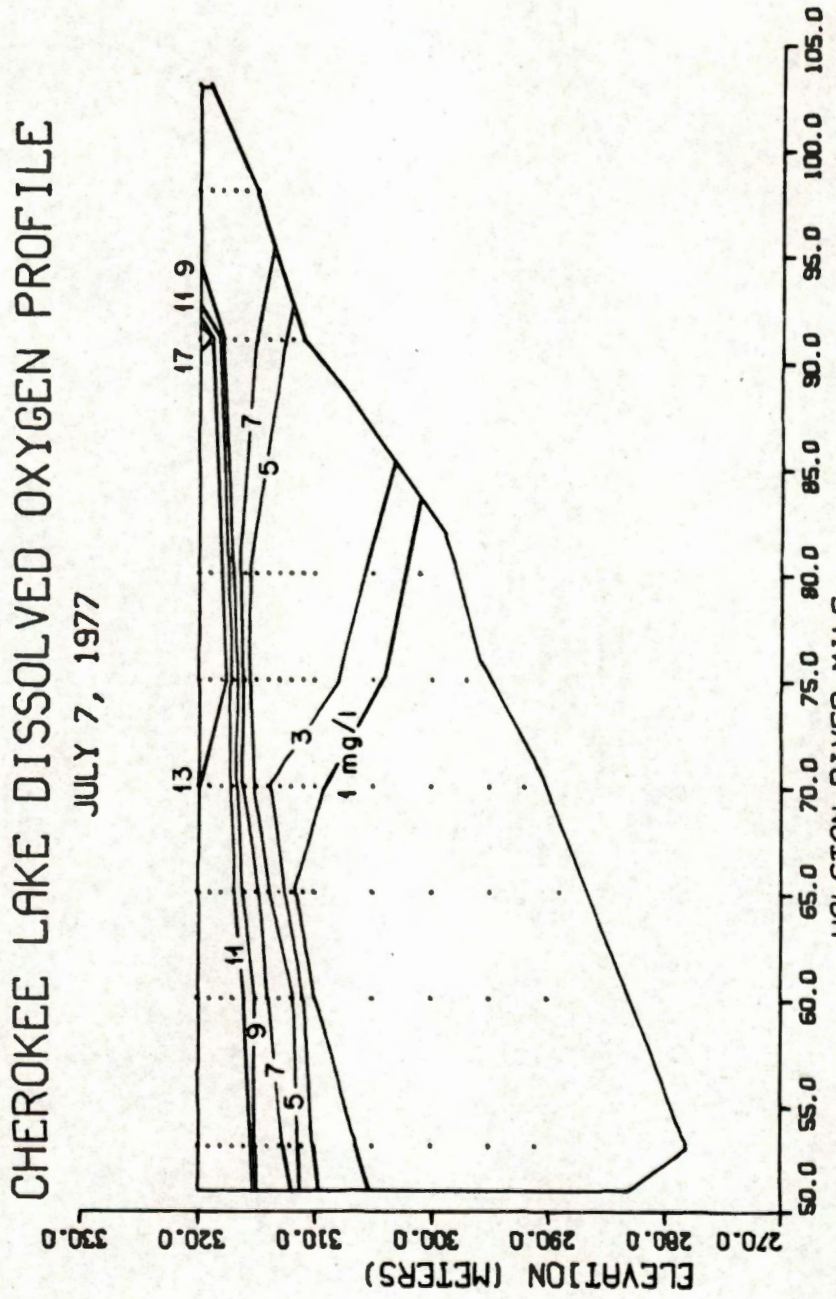

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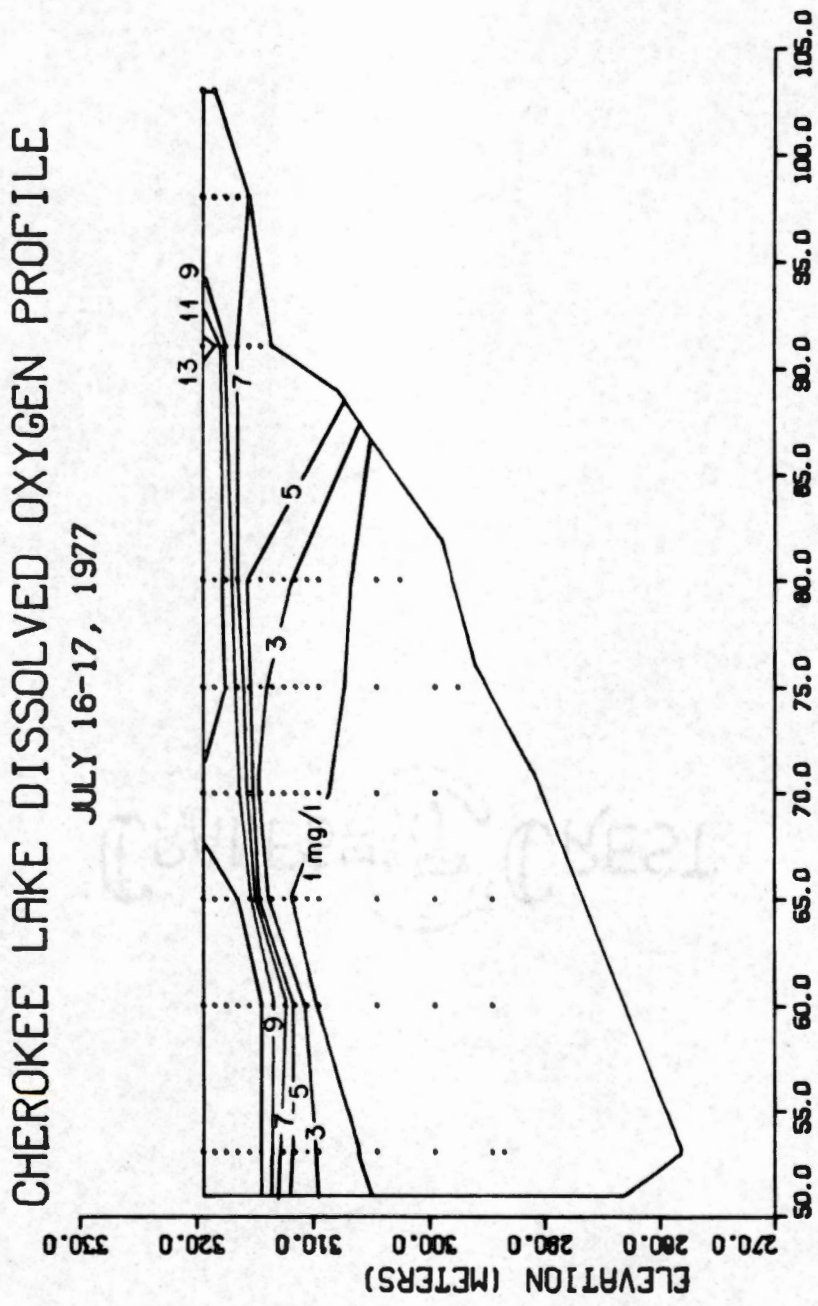

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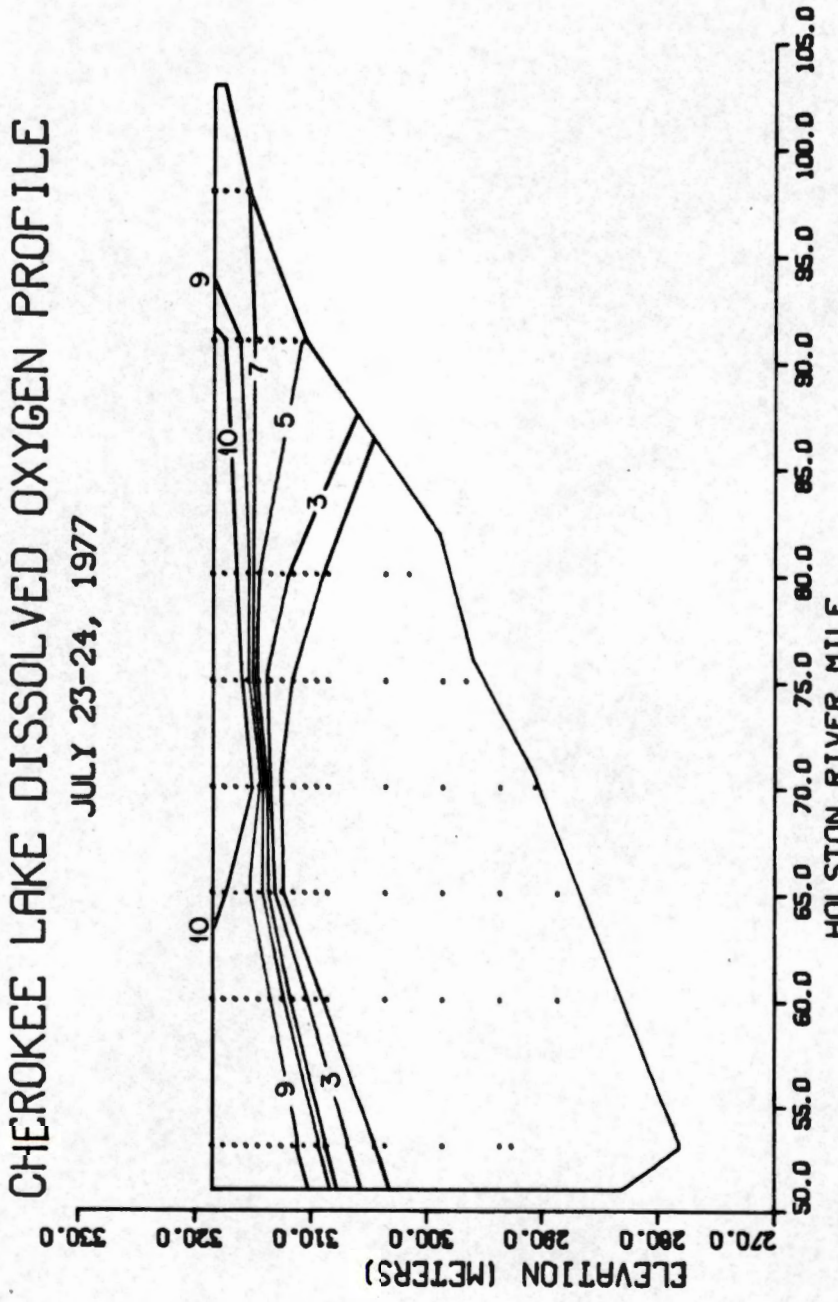

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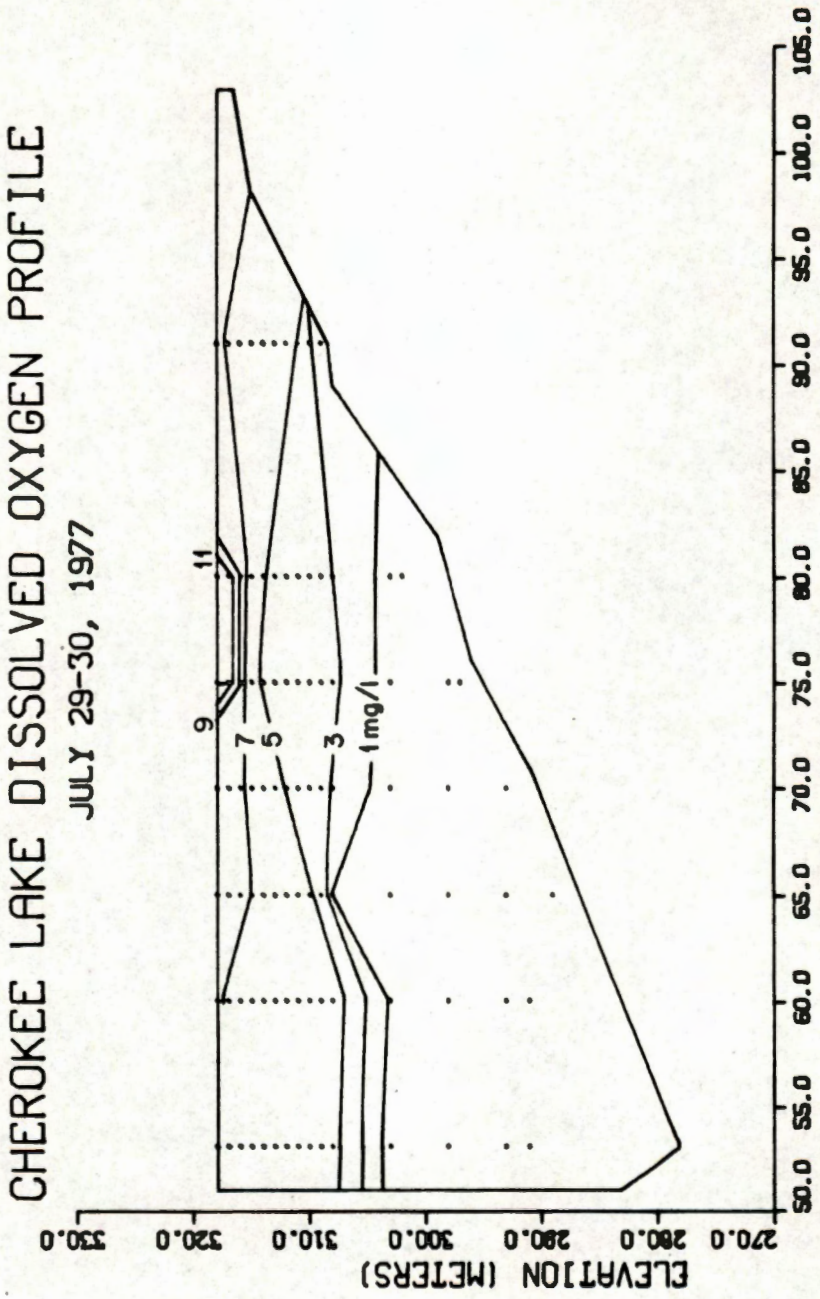

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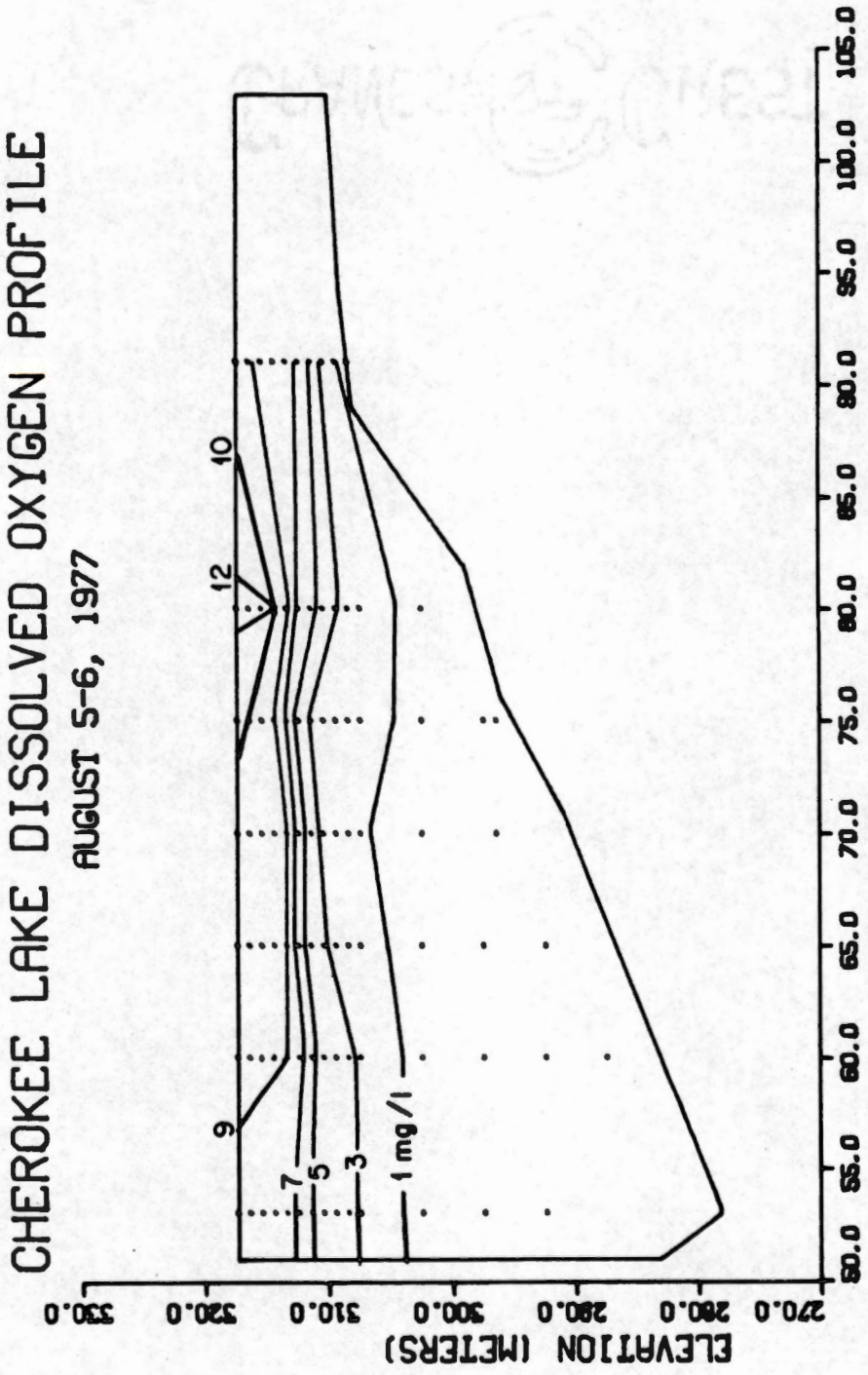

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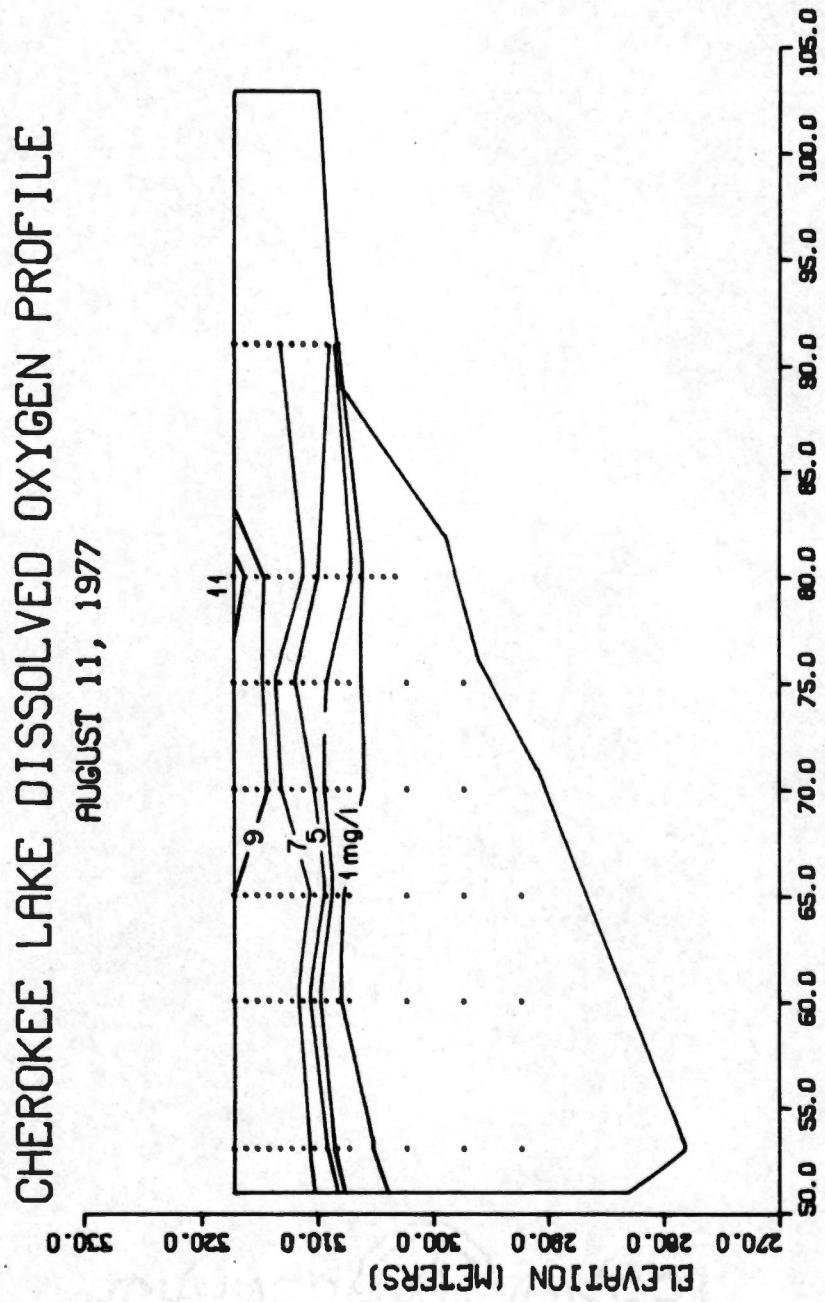

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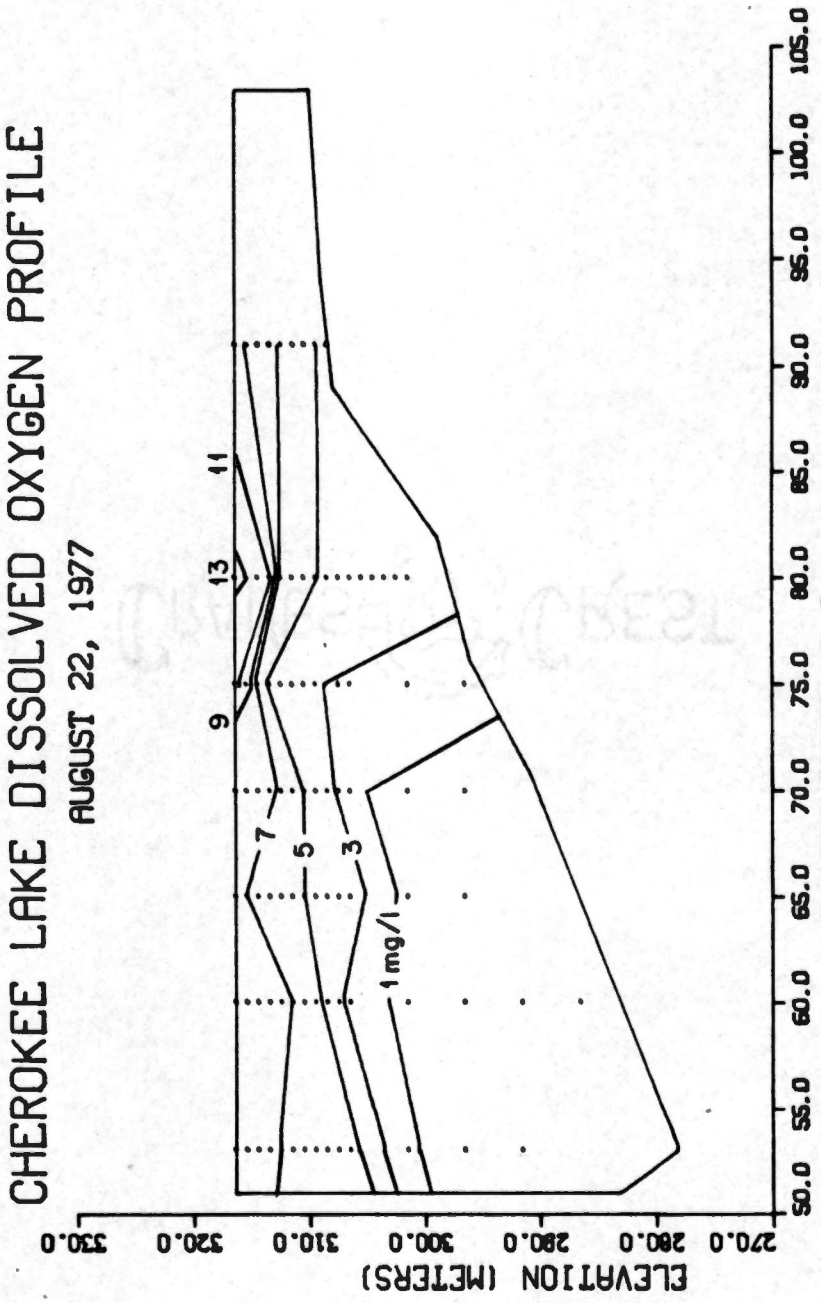

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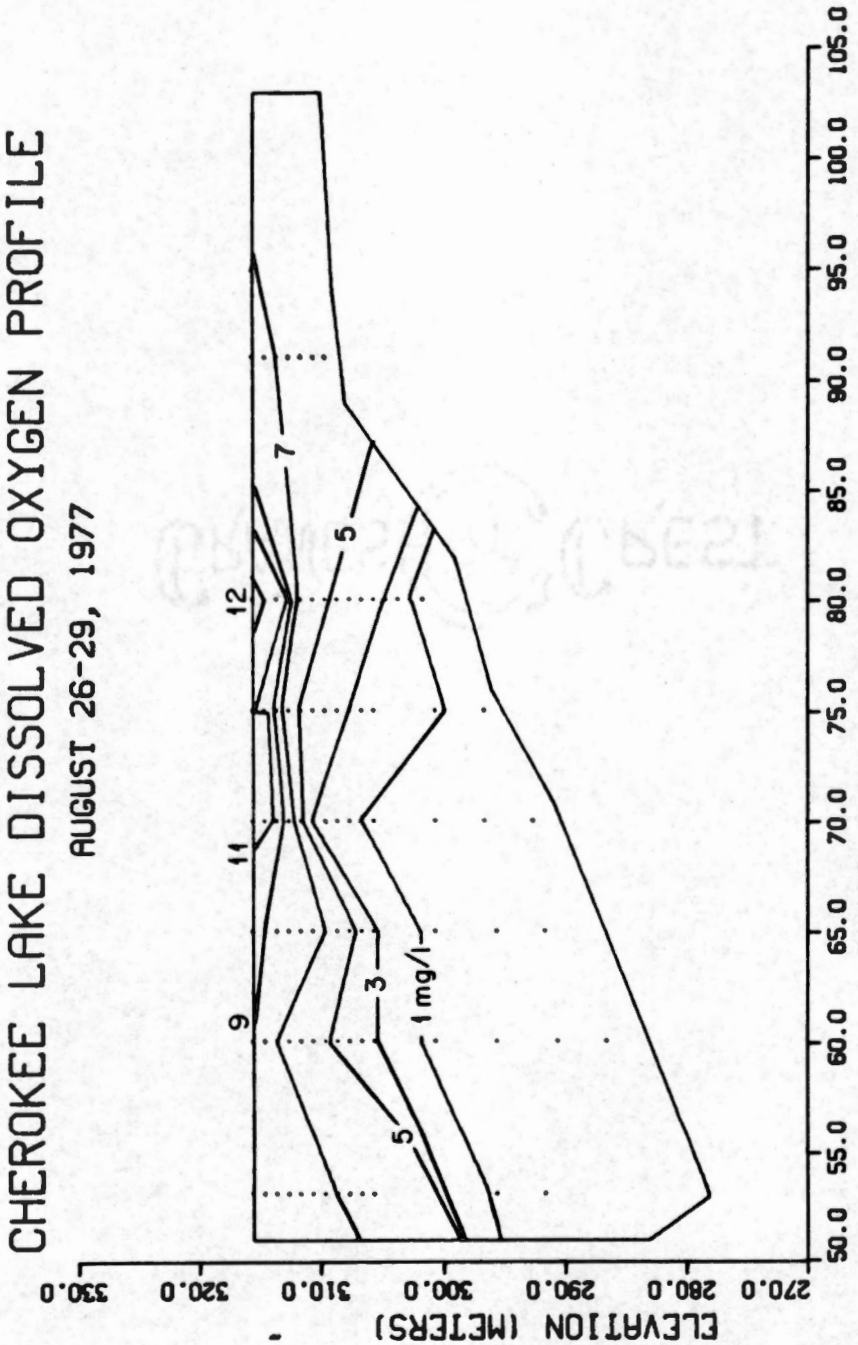

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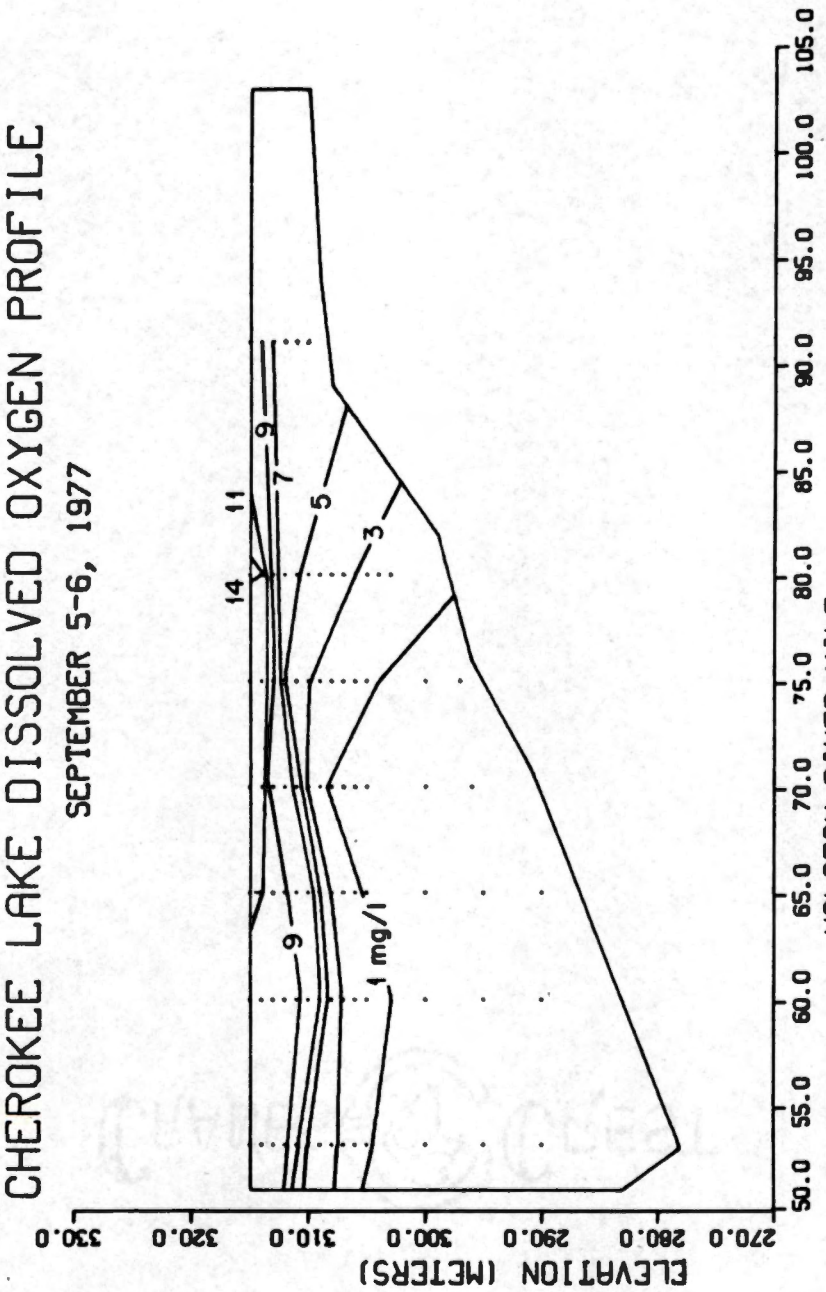

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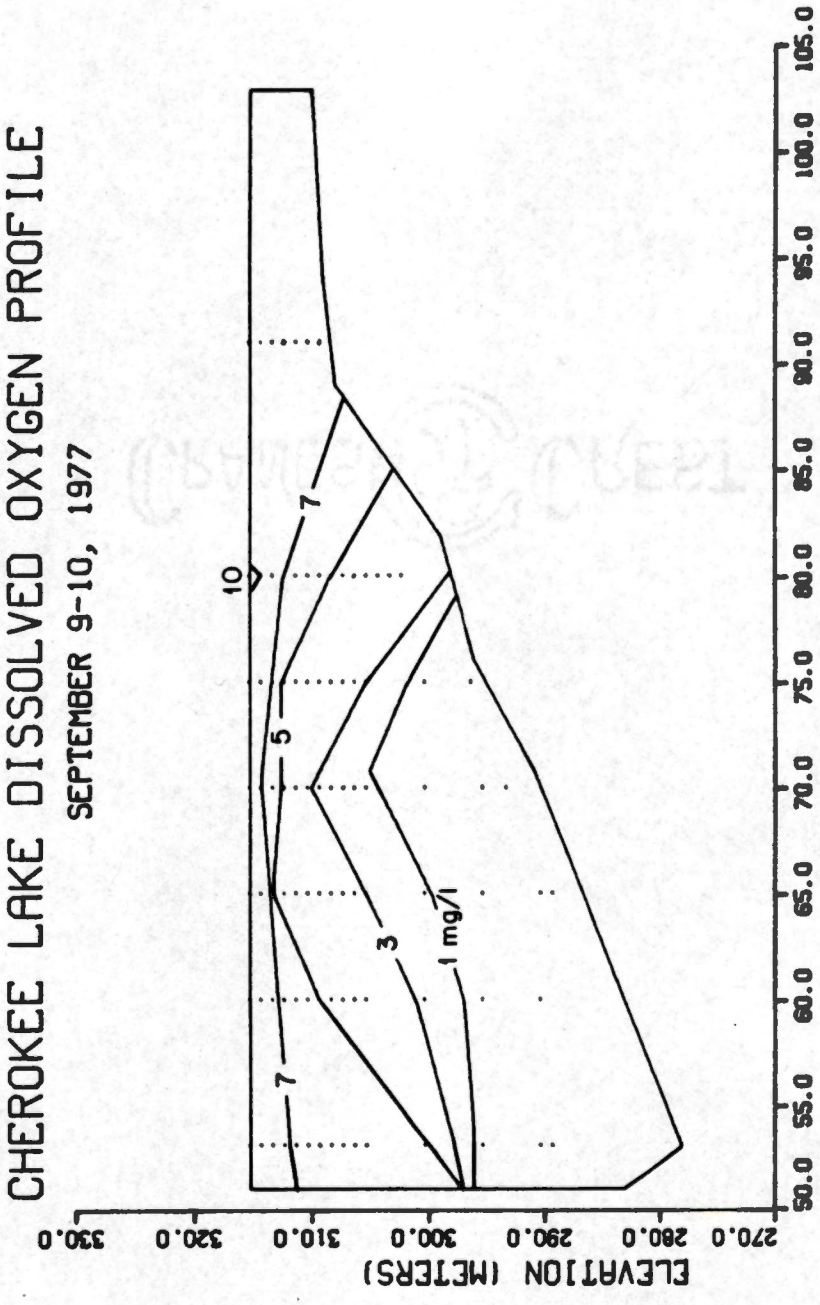

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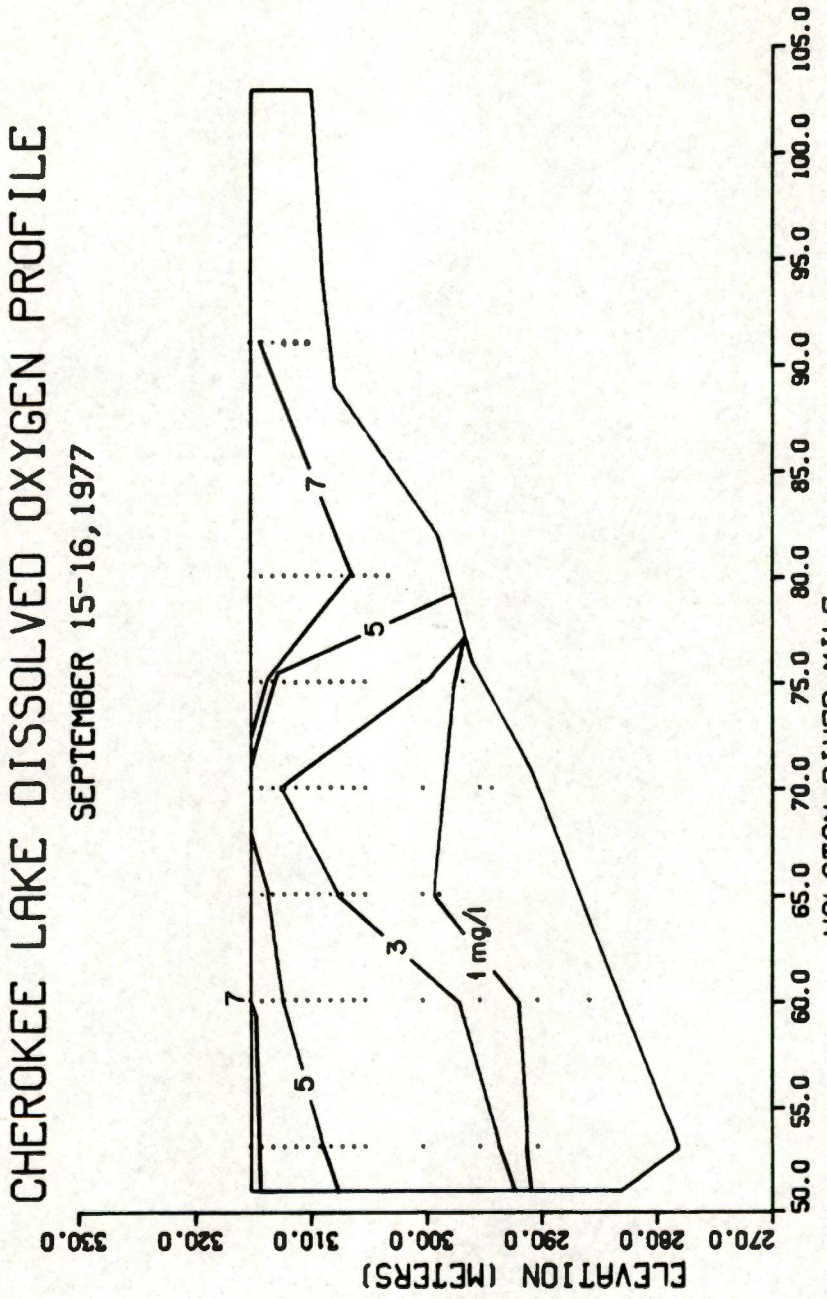

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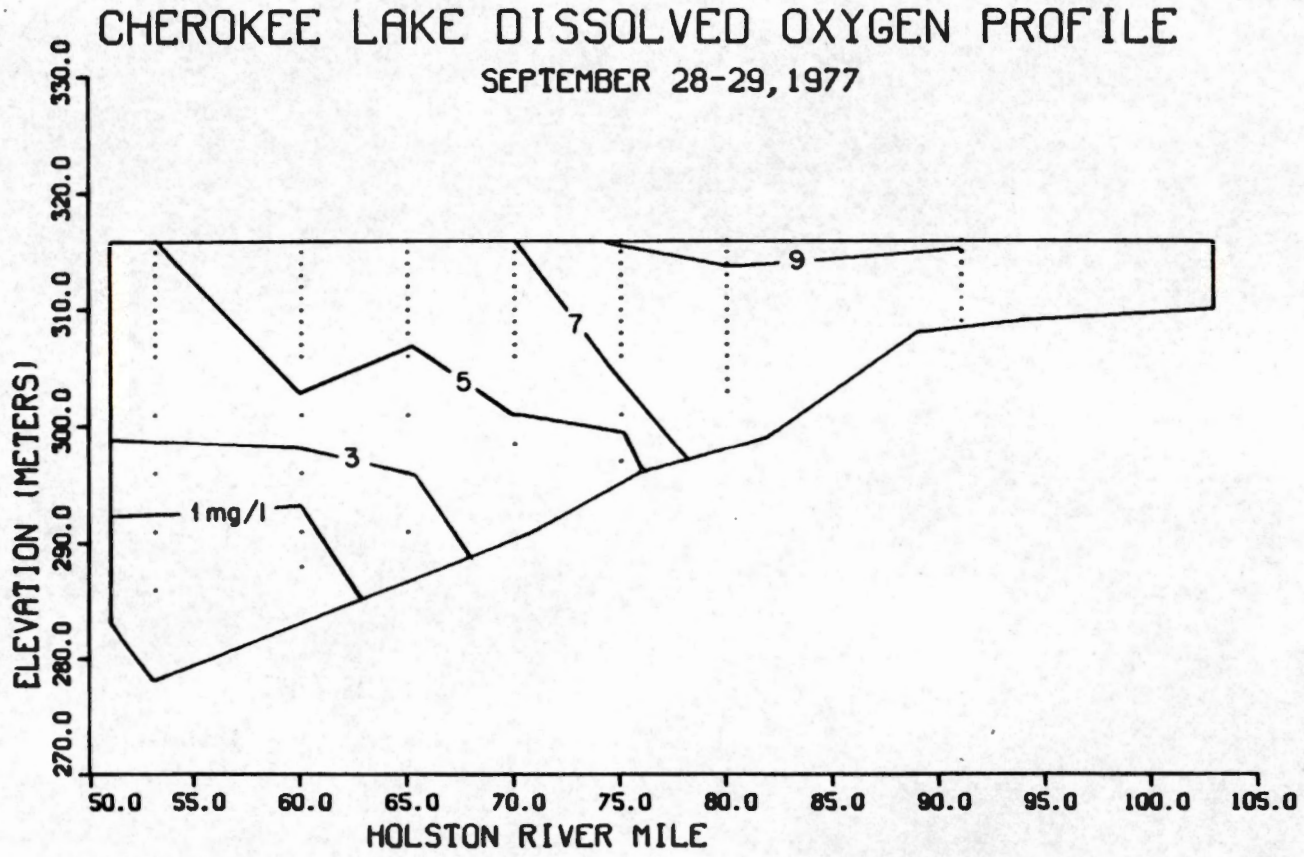

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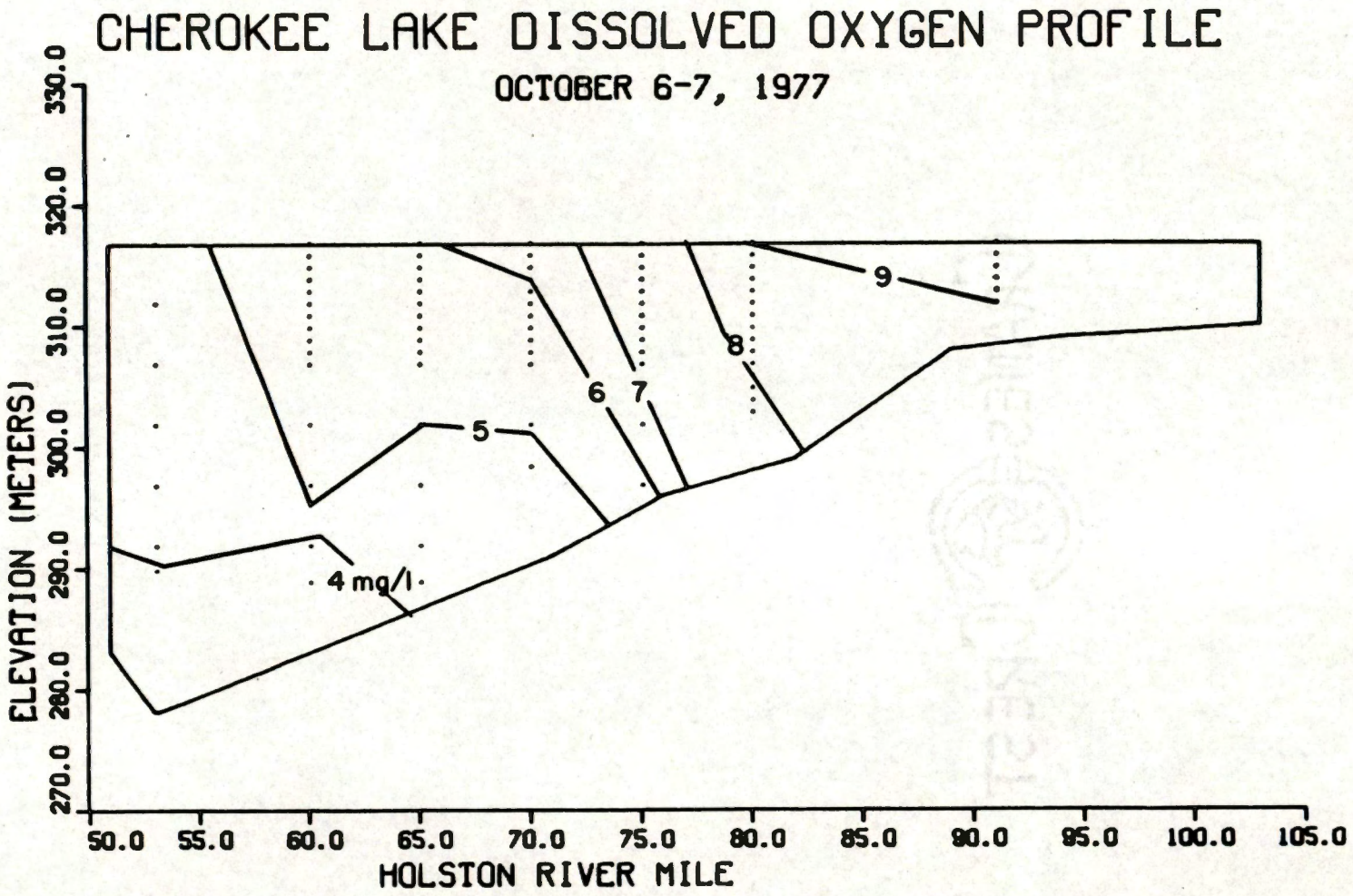

Figure E-1, continued

VITA

Harold Ronald Waddle was born in Somerset, Kentucky, on March 31, 1954. His family moved to Chattanooga, Tennessee, where he attended elementary schools in that city and graduated from Central High School in June 1972. The following September he entered Tennessee Technological University at Cookeville, and in June 1976, he received a Bachelor of Science degree in Wildlife Management. In the summer of 1976, he enrolled as a graduate student at The University of Tennessee, Knoxville, and that fall accepted a research assistantship in his study toward a Master's degree. This degree was awarded in March 1979.

The author is a member of Beta Beta Beta, Gamma Sigma Delta, and the American Fisheries Society.

He is married to the former Susan Sneed of Nashville, Tennessee.