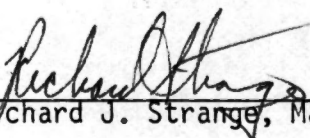
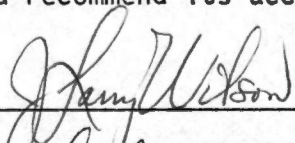
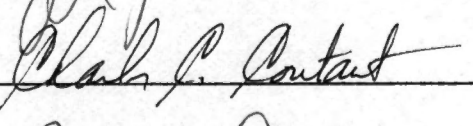
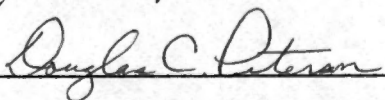


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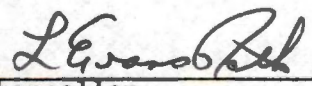
I am submitting herewith a thesis written by Mark S. Tisa entitled "Metal Residues, Hematology, and Liver Histology of Striped Bass." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Wildlife and Fisheries Science.


Richard J. Strange, Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:


Vice Chancellor
Graduate Studies and Research

METAL RESIDUES, HEMATOLOGY, AND LIVER HISTOLOGY
OF STRIPED BASS

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Mark S. Tisa

June 1981

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DEDICATION

This thesis is dedicated to my mother and father,
for it was because of their love and encouragement
that I have come this far in life.

ACKNOWLEDGMENTS

I wish to extend special thanks to Dr. Richard J. Strange who not only served as my major professor but also has been a close friend and is a credit to his profession. I also wish to thank especially my other committee members--Dr. J. Larry Wilson, Dr. Charles C. Coutant, and Douglas C. Peterson--who gave advice and were also good friends. I would also like to thank Dr. Charles C. Coutant for providing assistance in the cadmium residues analyses at Oak Ridge National Laboratory. Thanks are extended to Kirby Cottrell, Tennessee Wildlife Resource Agency manager for Eagle Bend Hatchery, for his help in the collection of striped bass. Thanks are also extended to Brian Card, Bob Curry, John Richardson, Bruce Saul and Glenn Thomas for their unselfish help on my collection trips. I would also like to thank Dr. Howard Freeman, my undergraduate advisor at Springfield College and the rest of the biology faculty for their friendship, encouragement and support.

I wish to acknowledge the sponsorship of this work by the Tennessee Wildlife Resources Agency made possible through the Dingell-Johnson Funds (Project F-61) administered by the U.S. Fish and Wildlife Service.

ABSTRACT

One hypothesis to explain adult striped bass (Morone saxatilis) mortalities observed from 1972 to 1977 during the summer months in Cherokee Reservoir was that fish were being abnormally crowded by temperature preference and low dissolved oxygen into a limited number of cool, well-oxygenated creek or spring fed coves (refuge areas) contaminated by zinc and cadmium from the watershed. The goal of this study was to determine if the adverse environmental conditions (high temperature and low dissolved oxygen) were the cause of striped bass mortalities either directly or in combination with zinc and/or cadmium. Zinc and cadmium residues in muscle, liver, and kidney tissues and hematology of adult striped bass from Cherokee were compared to striped bass from Norris and Watts Bar Reservoirs. Also, liver histology of Cherokee striped bass was compared to Norris striped bass.

Even though there were significant differences in tissue residues among seasons (summer 1979, spring 1980, summer 1980) in Cherokee Reservoir as well as among the three reservoirs during the same season (spring 1980), all the concentrations were well below those reported for fish exposed to maximum non-harmful concentrations of zinc and the lowest potentially harmful concentration of cadmium and were in the same approximate range typically reported for fish tissues. It is therefore believed that in at least the last two years,

zinc and cadmium in the tissues of striped bass from Cherokee Reservoir have not been harmful to the fish.

Hematological studies revealed statistically significant differences for several blood characteristics between seasons (spring and summer 1980) for striped bass from the same reservoir (Cherokee) and among the three reservoirs (Cherokee, Norris, Watts Bar) during the same season (spring 1980). These differences, however, are believed to be due to normal seasonal variations, different collection times during the spring season, and water quality differences among the reservoirs. No pathology was associated with any of the differences in blood characteristics.

Liver histology showed a high degree of heterogeneity for vacuolation, vascular stasis, and dilated and engorged sinusoids within livers of individual fish from both Norris and Cherokee Reservoirs. There were no signs of any necrosis and no pathology was associated with any of these findings.

Since July 1, 1979 when this study began, there have been no unexplained striped bass mortalities in Cherokee Reservoir. This investigation found no evidence of pathology and the striped bass collected from Cherokee in the last two years appeared as healthy as the ones from Norris and Watts Bar Reservoirs. Perhaps the most plausible explanation for the cause of striped bass mortalities in Cherokee Reservoir was high temperature and low dissolved oxygen with inadequate carrying capacity in the refuge areas to support the entire population those years. The author recommends continued

stocking of striped bass but perhaps in fewer numbers so that adequate space in the refuge areas is assured during the critical summer months.



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CHAPTER I

GENERAL INTRODUCTION

Striped bass (Morone saxatilis) were first introduced into Cherokee Reservoir in 1964 and by 1966 some were already being caught. Growth of the striped bass was excellent and there were no apparent problems prior to 1971. During the late summer of 1971, a few dead adult striped bass were reported in areas that received heavy fishing pressure and were thought to be hook and release mortalities. In 1972, as early as August 1, striped bass mortalities were reported in heavily fished areas; however, by mid-August dead and dying striped bass were reported in areas where little fishing occurred. Some of the striped bass had red sores and lesions. Also, that summer, large numbers of striped bass were reported in high densities in a spring-fed cove at Cedar Hill boat dock, a strong indication that the striped bass were suffering from some environmental problems. Striped bass in the 3 to 9 kg class continued to die until fall destratification took place. Striped bass were sent to Auburn University for disease analyses, but nothing was found that would explain the mortalities. Fish were also analyzed for mercury by Oak Ridge National Laboratory because of known mercury contamination in the upper Holston River, however, the concentrations found were not sufficient to have been the cause of the mortalities (Coutant 1978). Water quality analyses by the Tennessee Division of Water Quality Control found that only the

top 5 meters of the reservoir had dissolved oxygen concentrations above 5 mg/liter and that the temperature of this water was 27 C or higher (Coutant 1978).

The pattern continued to repeat itself in 1973, 1974, 1975, and 1976 with mortalities of adult striped bass beginning in mid-summer and ending when destratification took place in the fall. As a result, the problem was thought to be the low dissolved oxygen concentrations during the summer months until 1976 and 1977 when mortalities of adult striped bass continued through winter months when dissolved oxygen levels were high. Striped bass collected in 1977 showed signs of physical deterioration with sunken bellies, slim bodies, abnormally large gall bladders, large air bladders, and small yellowish livers (Coutant 1978). In addition, the growth rate of striped bass in Cherokee was slower than that of Norris and Watts Bar striped bass even though Cherokee had an abundant forage base. Also, initial stocking of Norris Reservoir took place two years later than Cherokee, yet Norris Reservoir has produced several fish over 18 kg while Cherokee produces few over 9 kg (Coutant 1978).

Biotelemetry studies done by Waddle (1979) on adult striped bass in Cherokee Reservoir found that these fish preferred temperatures between 19 to 23 C and avoided temperatures greater than 27 C. During the summer months when there was insufficient oxygen concentrations in the thermally preferable water of the hypolimnion, striped bass were attracted to the cool, well-oxygenated waters of creek and spring-fed coves (refuge areas) in Cherokee Reservoir. Waddle (1979) found that

the main refuge areas in the lower end of the reservoir were Mossy Creek, Byrd Spring, Hull Branch, and Cedar Hill Coves. Also, bio-telemetry studies done by Schaich (1979) during the winter revealed concentrations of striped bass in Mossy Creek Cove similar to those found in the summer. Striped bass were also found in Byrd Spring and Cedar Hill Coves during the winter. The creek and spring-fed waters of the refuge areas were substantially warmer during the winter months than those temperatures found in the main body of the reservoir, thus providing temperatures closer to what striped bass prefer (Coutant 1978). It is then possible that the winter mortalities may have been the result of temperature shock. When striped bass left the warmer temperatures of the refuges in search of food, without acclimation to the colder open reservoir temperatures, they perished.

Since the mortalities continued through the winter months in these refuge areas when there was no dissolved oxygen or temperature problem, another potential cause of mortalities seemed to be in the refuge areas themselves (Coutant 1978). Much of the rock underlying the region is rich in zinc and cadmium sulfide that is sought by mining operations. Recent increases in the acidity of rainfall may enhance leaching rates of zinc and cadmium from mine tailings and the underlying bedrock. Therefore, the tributary and ground water entering Cherokee Reservoir could then contain fairly high levels of zinc and cadmium (implicating these two metals as prime suspects in the unexplained mortalities). Coutant (1978) hypothesized that the striped bass mortalities might be due to chronic heavy metal toxicity

acting on fish that are abnormally crowded by temperature preference and avoidance of low dissolved oxygen into waters (refuge areas) contaminated by zinc ores.

The research presented here was to determine if the adverse environmental conditions (low dissolved oxygen and high temperature) are the cause of striped bass mortalities either directly or in combination with toxicants (zinc and/or cadmium). Striped bass from Norris and Watts Bar Reservoirs were selected as control fish because there were no apparent environmental problems or unexplained deaths associated with these two reservoirs. The zinc and cadmium concentrations of striped bass from Cherokee were compared to the concentrations found in Norris and Watts Bar striped bass. Eight hematological tests were conducted to assess the effects of environmental stress on striped bass health in Cherokee Reservoir and compared to fish from Norris and Watts Bar Reservoirs. Also, liver histology of striped bass from Cherokee was compared to the livers of striped bass from Norris for signs of heavy metal poisoning.

CHAPTER II

ZINC AND CADMIUM RESIDUES OF STRIPED BASS FROM CHEROKEE, NORRIS, AND WATTS BAR RESERVOIRS

I. INTRODUCTION

Zinc and cadmium are common components of industrial and mining wastes which are often discharged into aquatic environments (Eaton 1974; Munro 1978; Holcombe et al. 1979). The lethality of zinc and cadmium has been shown to increase with decreasing hardness of water (Pickering and Henderson 1966; Sinley et al. 1974). Also, Lloyd (1960, 1961) found that higher temperatures and low dissolved oxygen would reduce the median period of survival of fish exposed to zinc. In addition, fish were found to accumulate and retain zinc and cadmium in the liver and kidney tissues for prolonged periods of time (Joyner 1961; Mount and Stephan 1967). Zinc, an essential nutrient in trace amounts for mammals and fish (Frieden 1972; Giesy and Wiener 1977), is acutely toxic to fish at concentrations ranging from 0.1 to 10 mg Zn/liter, for the 96 hour median lethal concentration (LC50) (Brungs 1969; Hughes 1973). Cadmium, unlike zinc, is not a trace metal essential to animal nutrition (Schroeder 1973) and is generally observed as more toxic than zinc to fish. Hughes (1973) reported a 96 hour LC50 of 0.002 mg Cd/liter for striped bass fingerlings. In combination, the two metals were observed to act synergistically on

fish (Eisler and Gardner 1972) and antagonistically on mammals (Gunn et al. 1961; Fassett 1975).

It was first thought that the mortality of fish exposed to lethal concentrations of heavy metals was the result of coagulation or precipitation of mucus on the gills causing suffocation (Carpenter 1930; Jones 1935; Westfall 1945). Recent investigations by Lloyd (1960), Skidmore (1970), and Burton et al. (1972) attribute the mortality to asphyxia caused by damage to the gill epithelium and not to mucus coagulation or precipitation. The effects of sublethal concentrations of zinc and cadmium on fish have been reported to reduce fecundity (Brungs 1969), decrease larval survival and retard growth (Spehar 1976), and cause convulsions and paralysis (Cearley and Coleman 1974). Hiltibran (1971) found that 0.0004 and 0.0021 mg of zinc and cadmium per ml of reaction medium, respectively, can disrupt energy production by the inhibition of oxygen uptake within liver cells of fish. In addition, Jackim et al. (1970) found that cadmium inhibited several enzymes in the livers of fish, while Saltman and Boroughs (1960) found the liver cells can take up zinc and accumulate it against a sevenfold concentration gradient without the expenditure of metabolic energy.

The objectives of this study were to determine if there were any differences in the concentrations of zinc and cadmium in striped bass from Cherokee, Norris, and Watts Bar Reservoirs and if any of the concentrations were within the range reported to be harmful to the fish.

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II. MATERIALS AND METHODS

Adult striped bass of both sexes ranging in length from 57-97 cm total length, in weight from 2 to 10.2 kg, and in age from 3 to 7 years were collected by electrofishing (see Appendix A for length, weight, age, and sex of individual fish). Fish were collected during the spring of 1980 on their spawning run from Cherokee (March 24; 1.6 kilometers below the John Sevier Dam, N=10), Norris (May 22; at the 25-E bridge on the Clinch River, N=9) and Watts Bar (June 9; 8 kilometers below the Melton Hill Dam, N=9) Reservoirs. Striped bass were also collected in Cherokee Reservoir during the summers of 1979 (September 4; N=16) and 1980 (August 4; N=16) from Mossy Creek Cove. Attempts to obtain fish in the summer from Norris and Watts Bar Reservoirs were unsuccessful because the fish apparently were in the cool, well-oxygenated hypolimnion and are difficult to obtain by electrofishing. Immediately upon capture the livers and head kidneys were removed using a stainless steel knife, placed in individual polyethylene bags, and frozen on dry ice. The remainders of each fish were placed on wet ice and brought back to the laboratory where a whole fillet was taken from the left side of each fish and then stored along with the livers and kidneys at -10 C prior to analyses.

Muscle was prepared for analyses by taking a sample of tissue from the anterior, middle, and posterior portions from each fillet, mincing them, and combining the portions. Two samples from each fish were then dried at 110 ± 5 C until there was a consistent weight; they were then dry ashed at 550 C and reweighed. The ash was dissolved in

6 N HCl and brought to a final dilution with double distilled, deionized water. Livers were prepared for analyses by taking two samples from two different portions from the large lobe of the liver, mincing them and combining the portions. Kidney samples were so small that the samples were simply split into two portions for analyses. Liver and kidney samples were dried, ashed, and dissolved in the same way as the muscle samples. Each tissue (muscle, liver, and kidney) for each fish, was analyzed in duplicate by atomic absorption spectrophotometry. Zinc analyses were conducted at The University of Tennessee, Knoxville, on an Instrumentation Laboratory aa/ae Spectrophotometer Model 551. Cadmium analyses were run at Oak Ridge National Laboratory on a Perkin-Elmer Model 603 atomic absorption spectrophotometer with a HGA-1200 graphite furnace. Muscle, liver, and kidney residues for each collection period were subjected to a nested analysis of variance followed by a Duncan's multiple range test (on significant F-values) with Kramer's adjustment (Kramer 1956) for unequal cell frequencies.

Temperature, dissolved oxygen concentrations, alkalinity (as CaCO_3), and pH of the lake water were measured during each collection with the exception of 1979 from Cherokee Reservoir. A 100 ml water sample was also taken at each collection site, placed in a Nalgene bottle, and acidified with 2 ml of nitric acid (1:1) for later analyses of zinc and cadmium concentrations by atomic absorption spectrophotometry. The Norris Reservoir water sample for zinc and cadmium analyses was forgotten at the time of the spring collection and was taken in the fall of that same year.

III. RESULTS

Zinc residue analyses indicated the greatest concentrations in liver and kidney with levels in muscle tissue an order of magnitude lower (Figure II-1). (Metal concentrations are based on dry weight of tissue unless otherwise stated. See Appendix B for concentrations on wet tissue and ashed tissue basis.) There were statistically significant ($P=0.05$) differences in the muscle tissue concentrations between seasons from Cherokee Reservoir as well as differences among the reservoirs. The significant differences, however, depended on low variability rather than large differences in means (Figure II-1). Comparing the three sample periods (summer 1979, spring 1980, summer 1980) from Cherokee Reservoir, the mean concentrations of zinc in the muscle from fish collected during the summer of 1979 and spring 1980 were both statistically higher than those from fish taken during the summer of 1980; yet the difference between the highest and lowest mean concentration was only 2.7 mg Zn/kg dry weight. Looking at the three reservoirs (Cherokee, Norris, Watts Bar) sampled in the same season (spring 1980), the mean concentrations of zinc in the muscle tissue from fish from Watts Bar were not significantly different from Cherokee and Norris fish. The concentrations of zinc in the muscle from Cherokee fish were statistically higher than those levels found in Norris fish; the difference between the two means, however, was only 1.87 mg Zn/kg dry weight.

In contrast to muscle, when comparing the three sample periods (summer 1979, spring 1980, summer 1980) from Cherokee Reservoir, the

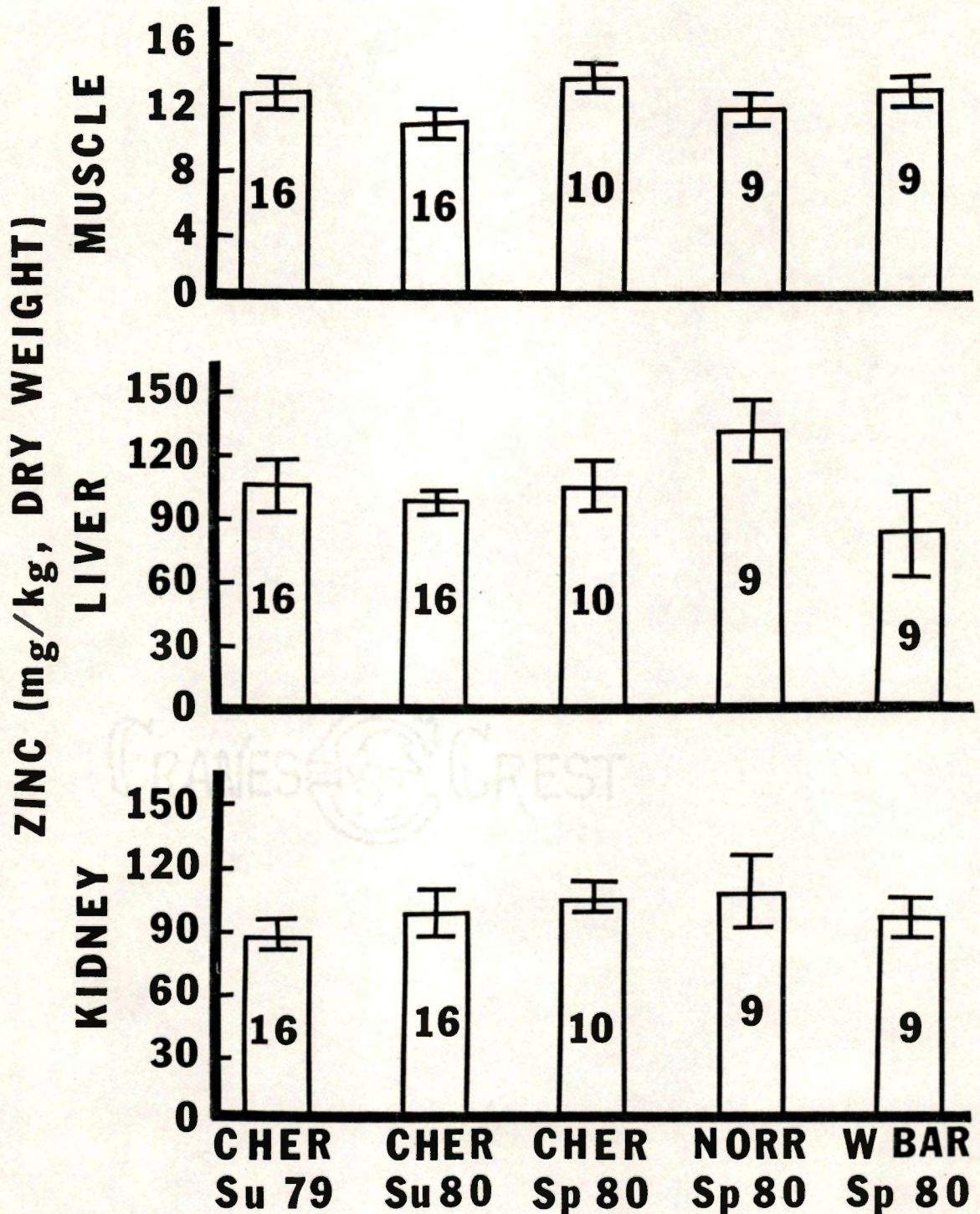


Figure II-1. Mean concentrations $\pm$ 95% confidence intervals for zinc residues (mg/kg) on a dry weight basis in striped bass muscle, liver, and kidney tissues. Sample size indicated inside bars (Cher = Cherokee; Norr = Norris; W Bar = Watts Bar; Su = Summer; Sp = Spring; 79 = 1979; 80 = 1980).

mean concentrations of zinc in the livers were not statistically different. However, the concentration of zinc in the kidneys of striped bass collected during the spring were significantly higher than the levels in striped bass collected during the summer of 1979, with spring fish containing 19% more zinc than summer 1979 fish. Also, the relative proportions of zinc from one tissue to another were inconsistent. Looking at Cherokee, Norris, and Watts Bar Reservoirs during the same season (spring 1980) the inconsistency was evident again. Striped bass collected from Cherokee Reservoir contained the highest mean levels of zinc in the muscle; however, liver or kidney did not contain the highest level of zinc. Instead, fish taken from Norris which had the second lowest mean concentration of zinc in the muscle tissue, had the highest levels in both liver and kidney tissues (Figure II-1). The mean concentration of zinc in the livers of striped bass collected from Norris was significantly higher than the concentrations in both Watts Bar and Cherokee striped bass livers; however, there were no significant differences in the concentrations of zinc in the kidneys among the three reservoirs.

Comparisons among the three sample periods (summer 1979, spring 1980, summer 1980) from Cherokee Reservoir indicated that the mean concentrations of cadmium in the muscle tissue were not statistically different between summers (Figure II-2). The levels of cadmium in the muscle tissue from the spring, however, were significantly higher than those from the summer of 1980. The three sample periods from Cherokee Reservoir did not contain statistically

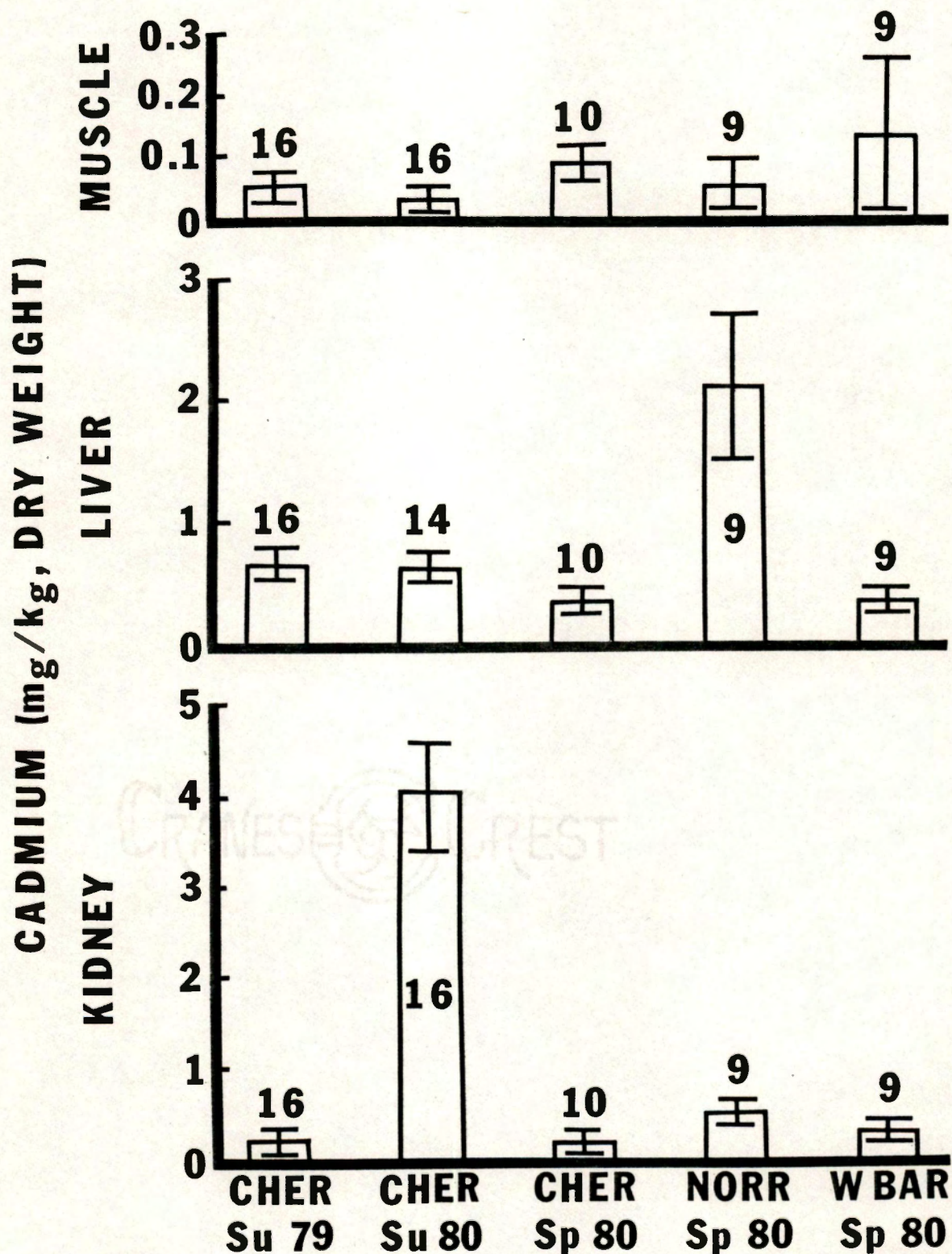


Figure II-2. Mean concentrations $\pm$ 95% confidence intervals for cadmium residues (mg/kg) on a dry weight basis in striped bass muscle, liver, and kidney tissues. Sample size indicated inside bars (Cher = Cherokee; Norr = Norris; W Bar = Watts Bar; Su = Summer; Sp = Spring; 79 = 1979; 80 = 1980).

significant differences in the mean concentrations of cadmium in the livers. The levels of cadmium in the kidneys of Cherokee fish from the summer of 1980, however, were as much as 24 times higher than the mean concentrations found in summer 1979 and spring 1980 fish (Figure II-2). Comparisons of the three reservoirs (Cherokee, Norris, Watts Bar) during the same season (spring 1980) revealed inconsistencies in the relative proportions of cadmium in the tissues. Striped bass from Cherokee Reservoir had the second highest mean concentration of cadmium in the muscle, but had the lowest concentration of cadmium in the kidneys during the spring. Fish from Watts Bar, which contained the highest mean concentration of cadmium in the muscle tissue and contained 3 times as much cadmium in the muscle as Norris fish, did not have the highest levels of cadmium in the livers or kidneys. Norris fish contained 6 times the amount of cadmium in the livers than the levels found in Cherokee and Watts Bar fish (Figure II-2).

The concentrations of zinc and cadmium in the water collected during the various sampling times were at the limit of detection for the procedure used (0.0001 mg Zn/liter and 0.00002 mg Cd/liter, respectively). See Table II-1 for temperature, alkalinity (as CaCO_3), pH, and dissolved oxygen concentrations for each of the sample periods.

IV. DISCUSSION

Laboratory studies of zinc and cadmium have established the maximum concentrations of each metal that can be carried in the tissues without apparent harm to the fish. Tissue concentrations for

Table II-1. Water quality analyses of Cherokee, Norris, and Watts Bar Reservoirs.

Depth (m)	Temperature (C)	Dissolved Oxygen (mg/l)	pH	Alkalinity (mg/l)	Zinc (mg/l)	Cadmium (mg/l)
Cherokee Spring 1980 (March 24)						
Surface	17.0	10.7	7.2	100	0.0001	0.00002
Cherokee Summer 1980 (August 4) (Mossy Creek Embayment)						
Surface	30.0	11.9	8.0	103	0.0001	0.00002
0.3	29.4	11.8	-	-	-	-
0.6	29.4	11.8	-	-	-	-
0.9	28.2	11.9	-	-	-	-
1.8	29.0	12.0	-	-	-	-
3.0	28.0	8.9	-	-	-	-
4.6	27.0	7.6	-	-	-	-
6.1	25.5	10.4	-	-	-	-
6.7	25.5	8.0	-	-	-	-
(Cherokee Dam)						
Surface	28.2	8.4	8.0	86	0.0001	0.00002
1.5	28.2	8.4	-	-	-	-
3.0	27.9	8.2	-	-	-	-
4.6	27.8	8.2	-	-	-	-
6.1	27.7	7.8	-	-	-	-
7.6	27.5	7.6	-	-	-	-
10.4	27.3	6.8	-	-	-	-
11.6	26.5	2.8	-	-	-	-
12.2	26.5	2.6	-	-	-	-
Norris Spring 1980 (May 22)						
Surface	19.5	8.2	8.0	120	0.0001	0.00002
Watts Bar Spring 1980 (June 9)						
Surface	23.5	7.5	7.5	120	0.0001	0.00002

wild fish populations can be used to determine if there has been exposure to harmful concentrations of zinc and cadmium. Holcombe et al. (1979) found 300 mg Zn/kg dry weight in the livers and 200 mg Zn/kg dry weight in the kidneys of brook trout exposed for 24 weeks to the highest concentration of zinc (0.534 mg Zn/liter) that did not result in any harmful effects (unexposed fish contained half those concentrations). Levels in the muscle tissue did not differ from the unexposed fish (approximately 14-20 mg Zn/kg wet weight). Striped bass collected in Cherokee, Norris, and Watts Bar Reservoirs had about 1/3 the amount of zinc in the liver and 1/2 the amount in the kidneys (average mean concentrations for the three reservoirs), than the concentrations reported for the same tissues in Holcombe's brook trout exposed to the highest, non-harmful concentration of zinc. Striped bass from all three reservoirs contained similar concentrations of zinc in muscle tissue as those found by Holcombe in exposed and control brook trout.

All mean concentrations of zinc in the tissues of striped bass from this study fell within or below the range of concentrations reported for apparently healthy saltwater striped bass (with one exception, livers of Norris fish had a mean of 132 mg Zn/kg dry weight). Concentrations of zinc in apparently healthy saltwater striped bass have been reported to range from 77 to 140 mg Zn/kg dry weight in the kidneys, from 77 to 124 mg Zn/kg dry weight in the livers, and muscle concentrations ranged from 12 to 34 mg Zn/kg dry weight (Kohlhorst 1973; Windon et al. 1973; Zawacki and Briggs 1976).

Zinc concentrations in the muscle tissues of striped bass sampled by McKinney and Melgaard (1979) from Cherokee Reservoir in 1977 and Norris Reservoir in 1979 ranged from 3.15 to 4.7 mg Zn/kg wet weight and 2.71 to 6.71 mg Zn/kg wet weight, respectively. Although these figures compare with the concentrations found in muscle tissue from this study, zinc has been shown not to accumulate in any substantial amount in muscle tissue (Joyner 1961; Holcombe 1979). Therefore, low zinc concentrations in muscle tissue from striped bass sampled in past years would not necessarily rule out exposures to harmful concentrations. Zinc concentrations from fish in this study were within the range of concentrations for other species of apparently healthy fresh- and saltwater fishes collected throughout North America (Lucas and Edgington 1970; Uthe and Bligh 1971; Tong et al. 1972; Windon et al. 1973; Heit 1979; McKinney and Melgaard 1979).

Zinc concentrations in the liver and kidney tissues were well below reported concentrations of zinc known to be harmful. In addition, the concentrations in the muscle, liver, and kidney tissues were all within the range of concentrations (with the one exception noted) for saltwater striped bass as well as other species of fresh- and saltwater fishes. It then follows that striped bass from these three study reservoirs do not contain concentrations of zinc that would result in detrimental effects. Although there were significant differences between samples from Cherokee Reservoir, as well as significant differences among the reservoirs, no consistent pattern could be established for the slightly, though significantly different, tissue concentrations.

Benoit et al. (1976) determined that the maximum acceptable toxicant concentration (MATC) for brook trout exposed to cadmium was between 0.0017 and 0.0034 mg Cd/liter and that an equilibrium was reached in tissue concentrations after 20 weeks of exposure. Brook trout exposed for 70 weeks to a concentration of 0.0034 mg Cd/liter contained 65 mg Cd/kg dry weight in the kidneys and 9 mg Cd/kg dry weight in livers. These values were approximately 50 and 20 times higher, respectively, than those concentrations found in unexposed fish. Muscle tissue levels were not significantly different from those in unexposed fish (approximately 0.05 mg Cd/kg dry weight). Brook trout that were exposed to the lowest potentially harmful concentration of cadmium (Benoit et al. 1976) contained 4.5 times more cadmium in the livers and 16 times more in the kidneys, than the highest concentrations in similar tissues of striped bass from Cherokee, Norris, and Watts Bar Reservoirs. With one exception, kidneys of striped bass collected from Cherokee during the summer of 1980 had a mean of 4.0 mg Cd/kg dry weight, all mean concentrations of cadmium in the tissues of striped bass in this investigation fell within, or below, the range of concentrations reported for apparently healthy striped bass. Concentrations of cadmium in apparently healthy saltwater striped bass have been reported to range from 1.2 to 3.6 mg Cd/kg dry weight in the kidneys, from 1.4 to 2.1 mg Cd/kg dry weight in the livers, and muscle concentrations ranged from less than 0.1 to 0.8 mg Cd/kg dry weight (Kohlhorst 1973; Windon et al. 1973; Zawacki and Briggs 1976; Rehwoldt et al. 1978). McKinney and

Melgaard (1979) also reported very similar concentrations of cadmium in muscle tissues of striped bass collected from Cherokee Reservoir in 1977 and from Norris Reservoir in 1979, but like zinc, cadmium does not accumulate in substantial amounts in muscle (Mount and Stephen 1967; Rowe and Massaro 1974). Therefore, these low cadmium concentrations in muscle tissue may not indicate exposure to harmful levels in past years. Again, like zinc, striped bass from all of the study reservoirs fell within the range of concentrations (with the one exception noted) of cadmium found for other species of apparently healthy fish from both fresh- and saltwater collected throughout North America (Lucas and Edgington 1970; Uthe and Bligh 1971; Tong et al. 1972; Lovett et al. 1972; Windon et al. 1973; Heit 1979; McKinney and Melgaard 1979). As was the case for zinc, the evidence suggests that the concentration of cadmium in the tissues of striped bass from the three reservoirs were well below those concentrations reported to be harmful to fish and were similar to other concentrations reported for apparently healthy fish.

Even though the concentrations of cadmium found in the striped bass from the three reservoirs were not believed to be harmful, there were substantially higher concentrations of cadmium in the livers of Norris striped bass and in the kidneys of striped bass collected during the summer of 1980 from Cherokee Reservoir. These concentrations may seem inconsistent because the levels were not reflected in any of the other tissues; however, other investigators have shown

similar inconsistencies. Rowe and Massaro (1974) and Benoit et al. (1976) found that the kidneys of fish exposed to cadmium had substantially higher concentrations than the livers, whereas Mount and Stephan (1967) and Eaton (1974) found substantially higher levels of cadmium in the liver. Mount and Stephan (1967) also found that the concentration of cadmium in the liver was correlated with cadmium exposure and found as much as 500 mg Cd/kg dry weight in livers of bluegills that had been exposed to subacute levels of cadmium, but not killed. Since only one collection was made on Norris Reservoir, there was no way of knowing if those concentrations of cadmium in the liver accumulated over a short period of time or over years. However, in Cherokee Reservoir, the striped bass collected during the spring of 1980 contained 24 times less cadmium in the kidneys than those collected 6 months later in the same reservoir. The water samples from the summer collection did not reveal high concentrations of cadmium where fish were collected (see Table II-1, page 14). Much of the rock underlying the region, however, is rich in zinc and cadmium sulfide that is mined in the Cherokee Reservoir drainage basin (Coutant 1978). Zinc and cadmium are known to be released into waters from tailings; with increasing acidic rainfall, this process could be enhanced. Then, if striped bass were in a location such as Mossy Creek embayment that was a drainage area for one of the mines, heavy rain might result in isolated episodes where fish were exposed to acute doses.

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To summarize, even though there were differences among samples between seasons in Cherokee Reservoir as well as among the three reservoirs during the same season (spring 1980), all the concentrations were well below those reported for fish exposed to maximum non-harmful concentrations of zinc and the lowest potentially harmful concentration of cadmium and were within the range (with two exceptions noted earlier) typically reported for fish tissues. The high concentrations of cadmium in the kidneys of striped bass collected during the summer of 1980, and the concentrations of cadmium in the livers of Norris striped bass may be the result of periodic exposures to cadmium in the surface run-off.

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CHAPTER III

HEMATOLOGY OF STRIPED BASS

I. INTRODUCTION

The introduction of striped bass into freshwater has provided a popular new dimension to our inland sport fisheries and the number of waters containing these fish is increasing each year. As a result, striped bass are facing a wide range of environmental conditions very different from their original saltwater habitat. Hematology is an important tool in human and veterinary medicine and could be equally as valuable in the evaluation of fish health (see Table III-1) when normal ranges of blood characteristics have been established for individual species (Hesser 1960). While the hematology of saltwater striped bass has been measured on a number of occasions (Engel and Davis 1964; Hunn and Robinson 1966; Courtois 1974; Westin 1978), no published values exist for wild, adult freshwater striped bass.

The objective of this study was to determine the hematology of striped bass from three East Tennessee reservoirs. The three reservoirs were: Cherokee, a highly eutrophic tributary reservoir with industry and mining in the drainage basin; Norris, a mesotrophic tributary reservoir with a predominantly undeveloped drainage basin; and Watts Bar, a mainstream reservoir receiving water from both Norris and Cherokee.

Table III-1. Interpretation of hematological test results to assess effects of environmental stress on fish health (modified from Wedemeyer and Yasutake 1977).

Hematological Test	Possible Significance	
	Too Low	Too High
1. Hematocrit	Anemias, hemodilution due to gill damage	Hemoconcentration, stress polycythemia (may be an indication of low dissolved oxygen concentrations)
2. Hemoglobin	Anemias, hemodilution due to gill damage, nutritional disease	(Same as hematocrit)
3. Osmolality	External parasite infection, heavy metal exposure, hemodilution	Hemoconcentration, salinity increases in excess of osmoregulatory capacity, stress induced diuresis, lactic acidosis
4. Chloride	Gill chloride cell damage, compromised osmoregulation	Hemoconcentration, compromised osmoregulation
5. Glucose	Lack of nourishment	Acute or chronic stress
6. Cortisol	None	Acute stress
7. Total Protein	Infectious disease, kidney damage, nutritional imbalance	Hemoconcentration, impaired water balance
8. Cholesterol	Impaired lipid metabolism	Fish under chronic stress, dietary lipid imbalance

II. MATERIALS AND METHODS

Chapter II contains the basic techniques for method of capture, numbers of striped bass collected, and time and location of various collections. Blood samples were not taken, however, from fish collected during the summer of 1979 in Cherokee Reservoir. Also, see Table II-1, page 14, for water quality analyses. Immediately upon capture a 5 ml blood sample was taken from each striped bass from the caudal artery using 5 ml commercially available Vacutainer tubes containing ethylenediaminetetracetic acid (EDTA). Immediately after each blood sample was taken, a microhematocrit was centrifuged on the boat at 5000 rpm's for 5 minutes and the packed cell volume was determined. Blood was also fixed on the boat in Drabkin's Reagent to form stable cyanmethemoglobin for colorimetric determination of hemoglobin at the laboratory. The remainder of the blood was spun down on the boat, the plasma poured off, frozen (plasma) on dry ice and stored at -10 C for later analyses of glucose, cortisol, osmolality, chloride, total protein, and cholesterol.

Plasma glucose and cholesterol concentrations were determined by enzymatic assays (Sigma Chemical Company, Saint Louis, Missouri). Chloride and total protein were run according to Wedemeyer and Yasutake (1977) and cortisol was analyzed following the procedure outlined by Strange and Schreck (1978). Osmolality was measured by freezing point depression on an Advanced Instruments Osmometer Model 3W. Each blood characteristic for the five sample periods was subjected to a one-way analysis of variance ($P=0.05$) followed by a Duncan's multiple range

test (on significant F-values) with Kramer's adjustment (Kramer 1956) for unequal cell frequencies.

III. RESULTS

Mean microhematocrits for the sample periods ranged from 31% to 38% packed red cell volume and mean hemoglobin concentrations ranged from 7 to 11 g/100 ml (Figure III-1). Significant correlation ($P=0.05$) was found between microhematocrits and hemoglobin ($r=0.7027$, $N=40$). Significant correlation was also found between chloride and osmolality ($r=0.7333$, $N=40$) with mean chloride values ranging from 129 to 156 mEq/liter and osmolalities ranging from 321 to 381 mOsm/kg. Mean total protein and cholesterol concentrations ranged from 4.3 to 4.9 g/100 ml and 322 to 499 mg/100 ml, respectively (Figure III-2). Female striped bass were found to contain significantly higher protein and cholesterol concentrations than those levels found in the males. (No female fish were collected during the spring of 1980 from Norris or during the summer of 1980 from Cherokee.) Average glucose concentrations for the samples ranged from 77 to 118 mg/100 ml and mean cortisol concentrations ranged from 0.77 to 6.33 μ g/100 ml. Glucose and cortisol were significantly correlated ($r=0.6545$, $N=40$).

The most noticeable aspect of the hematology of these freshwater striped bass was the low variability associated with each of the blood characteristics for each sample period. The statistically significant differences in several of the blood characteristics between seasons (spring and summer 1980) from the same reservoir (Cherokee) and among

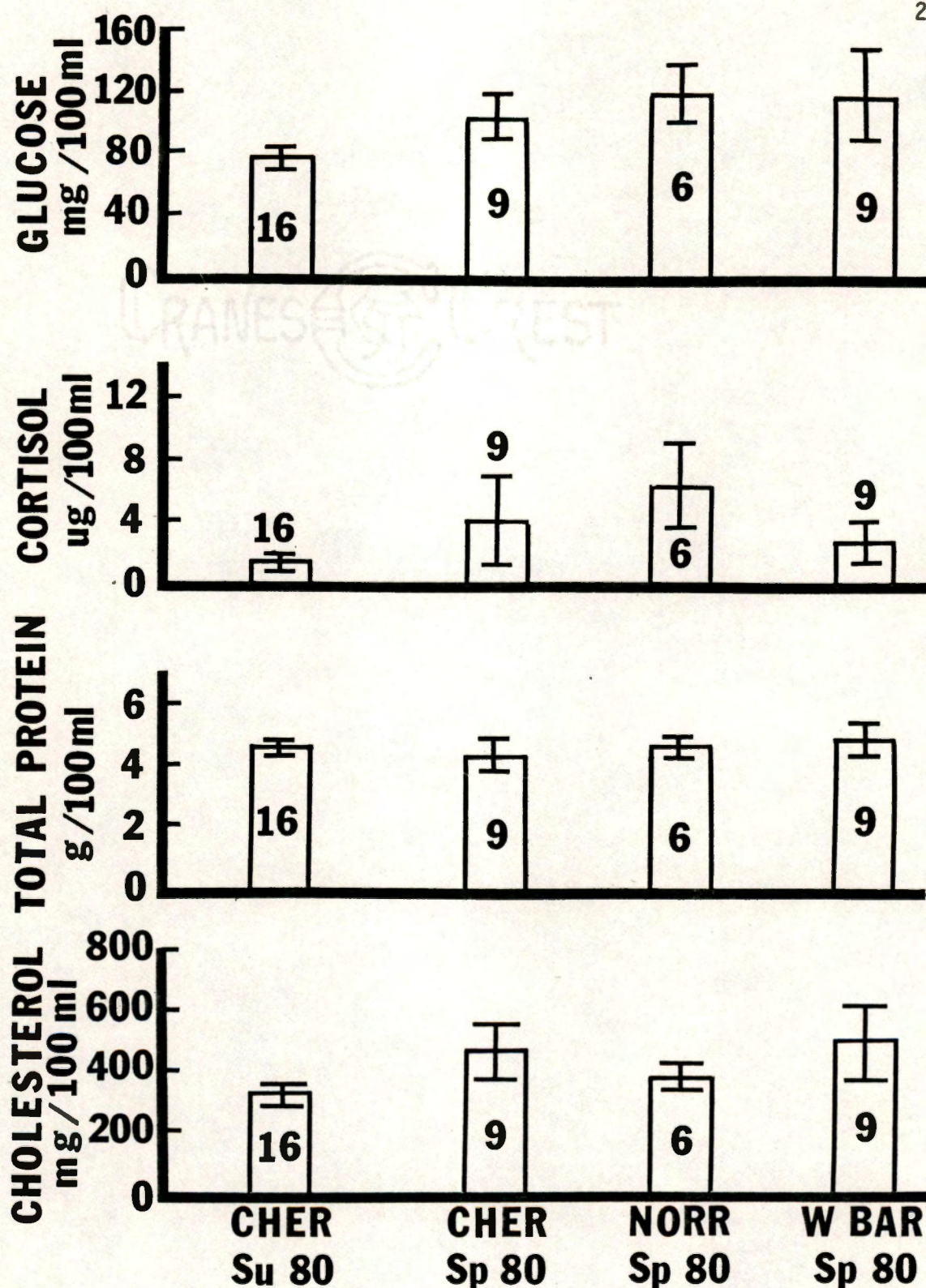


Figure III-1. Mean concentrations $\pm$ 95% confidence intervals for hematocrit, hemoglobin, osmolality, and chloride in striped bass. Sample size indicated inside bars (Cher = Cherokee; Norr = Norris; W Bar = Watts Bar; Su = Summer; Sp = Spring; 80 = 1980).

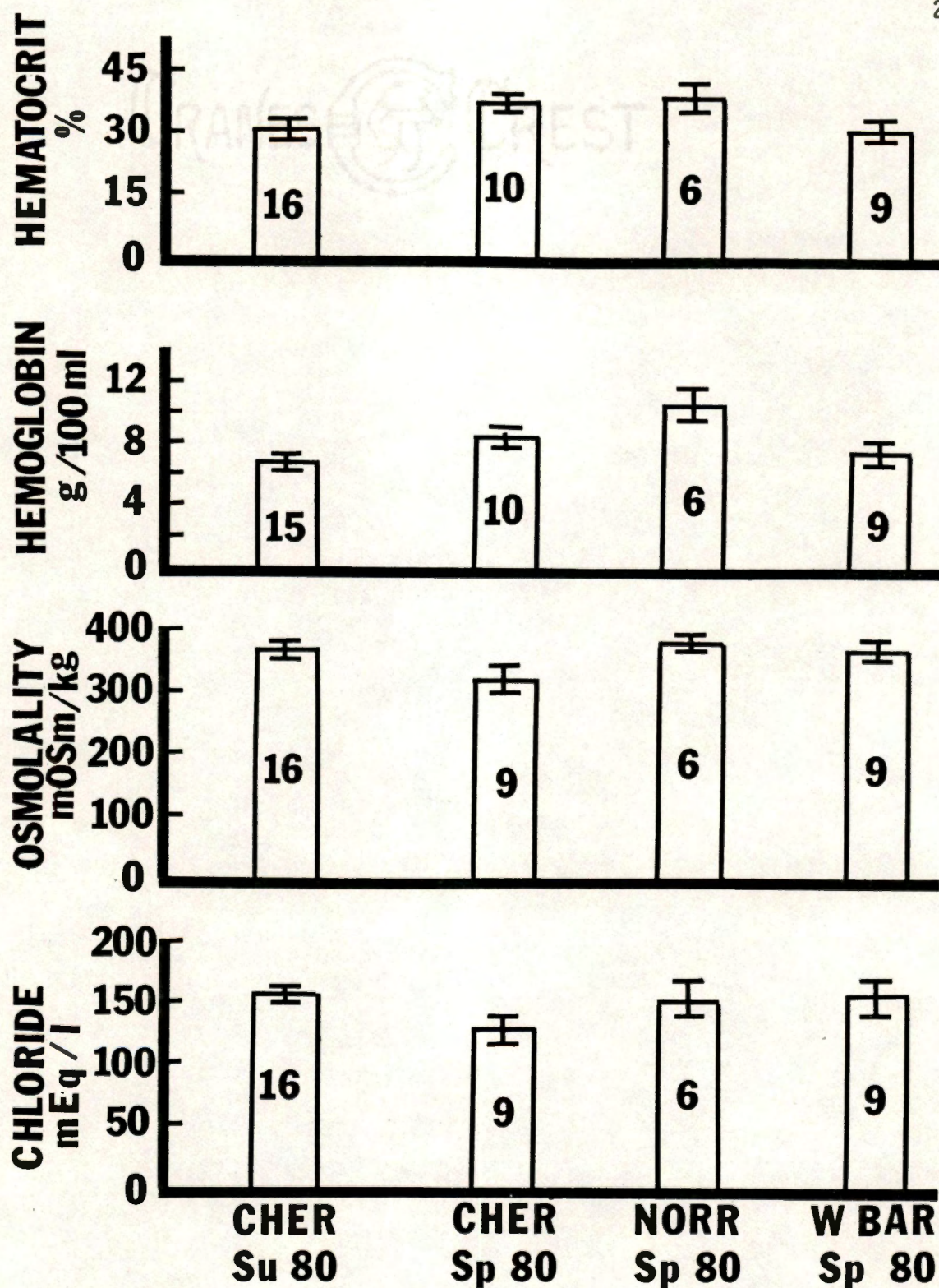


Figure III-2. Mean concentrations $\pm$ 95% confidence intervals for glucose, cortisol, total protein, and cholesterol in striped bass. Sample size indicated inside bars (Cher = Cherokee; Norr = Norris; W Bar = Watts Bar; Su = Summer; Sp = Spring; 80 = 1980).

the three reservoirs (Cherokee, Norris, Watts Bar) during the same season (spring 1980) were due to extremely low variability rather than large differences in means (Figures III-1 and III-2). Looking at Cherokee Reservoir during different seasons (spring and summer 1980), striped bass collected during the spring had statistically higher microhematocrits, hemoglobin, glucose, cortisol, and cholesterol values than fish collected during the summer. Striped bass from the summer, however, had higher osmolality and chloride values than spring fish. There was no difference in total protein concentrations between striped bass collected during the two seasons. Comparing Cherokee, Norris, and Watts Bar Reservoirs during the same season (spring 1980), there were no significant differences for glucose and total protein concentrations. There were several significant differences among the three reservoirs for the other 6 blood characteristics; however, no one reservoir was consistently different from the other two.

IV. DISCUSSION

Hematological ranges determined in this study fell within or partially overlapped the range of blood values reported for apparently healthy saltwater striped bass (only 5 of the 8 blood characteristics measured in this study were measured by other investigators in saltwater striped bass). Microhematocrits in apparently healthy saltwater striped bass have been reported to range from 16% to 70% packed cell volume, hemoglobin concentrations ranged from 4.0 to 12.3 g/100 ml, glucose and chloride concentrations ranged from 105 to 525 mg/100 ml

and 80 to 186 mEq/liter, respectively, total protein varied from 4.2 to 13.0 g/100 ml, and cholesterol concentrations ranged from 285 to 750 mg/100 ml (Engel and Davis 1964; Hunn and Robinson 1966; Courtois 1974; Westin 1978). Ranges in striped bass blood values determined in this study not only fell within or overlapped the range of blood values for saltwater striped bass, but also fell within or partially overlapped the ranges reported for juvenile coho salmon, northern pike, and rainbow trout (Barnhart 1969; Mulcahy 1970; Wedemeyer and Chatterton 1971; McCarthy et al. 1973).

Unlike the narrow range of blood values reported in this study on adult freshwater striped bass, Courtois (1974) and Westin (1978) found large ranges in several of the blood characteristics for adult saltwater striped bass. Courtois (1974) and Westin (1978) collected their fish in fyke traps and gill nets, respectively. Fletcher (1975) demonstrated stress effects by confining flounder to a small hand net and moved it back and forth in a tank of water for 15 minutes and found that the stress produced significant increases in hematocrits, mean cell volumes, and plasma osmolalities and decreased mean cell hemoglobin concentrations. Strange (1980) found significant increases in cortisol and glucose concentrations in severely confined channel catfish. The large range in hematological values reported by Courtois (1974) and Westin (1978) may, therefore, be the result of stress from confinement in fyke traps and entanglement in gill nets.

Bouck and Ball (1966) investigated the effects of angling, seining, and electroshocking on the blood characteristics of rainbow

trout and found that variability of blood characteristics was the lowest in electroshocked fish. Also, Schreck et al. (1976) found that electroshocking did not significantly affect packed cell volumes, plasma proteins, calcium, magnesium, and androgen levels in rainbow trout while glucose did not significantly increase until 3 hours after electroshock. Schreck et al. (1976) did, however, find an immediate increase in plasma corticoids. Like Schreck, Burns (1978) also found that electroshocking did not significantly affect packed cell volume, hemoglobin concentrations, or plasma protein levels in largemouth bass. Also, if the blood samples are stored on ice, even for a short time, there will be an increase in packed cell volumes because of CO₂-induced swelling of erythrocytes (Fletcher 1975, Wedemeyer and Yasutake 1977). It is believed that the extremely low variability in the various blood characteristics measured in this study as compared to others, was due to the use of electroshock as a method of capture and the immediate preparation of blood on the boat.

Total protein was the only blood characteristic measured in this study that was not significantly different between seasons (spring and summer 1980) in striped bass from Cherokee Reservoir. Although samples were only collected during two seasons, the differences in blood values between the seasons are believed to be the result of normal physiological responses to such things as changes in photoperiod, temperature, spawning season, and diet. Other investigators have noted seasonal variations in blood values for rainbow trout (DeWilde and Houston 1967; Denton and Yousef 1975) and flounder

(Umminger and Mahoney 1972; Bridges et al. 1976). Denton and Yousef (1975) found the lowest hematocrit in the spring (March) and the highest in the winter (January). In this study, however, striped bass collected between two different seasons (spring and summer 1980) in Cherokee Reservoir showed that spring fish had the highest micro-hematocrit and summer fish had the lowest. Denton and Yousef (1975) also found that even when rainbow trout remained in water at a constant temperature for 10 months, seasonal variations were still evident.

Although striped bass were collected from the three study reservoirs during the same season (spring 1980), they were collected at different times during the spring. Striped bass from Cherokee were collected during the end of March (beginning of their spawning period), Norris striped bass were collected in mid-May (well into the spawning period), and Watts Bar fish were collected the first half of June (toward the end of the spawning period). Blood values for fish have been found to change from the start of a spawning period to the end of that period (Love 1970). This could very well explain the differences in blood values among the three reservoirs during the same season. Another possible explanation is that the hematology of these fish was reflecting differences in water quality among Cherokee, Norris, and Watts Bar Reservoirs.

The correlations found between microhematocrit and hemoglobin, and chloride and osmolality were expected, as these correlations are typically found in hematological studies in vertebrates. The correlation between glucose and cortisol suggests that with an

increase in cortisol concentration, there is an increase in gluconeogenesis. Also, substantially increased levels of cortisol are known to occur in fish at spawning time. Higher protein and cholesterol levels are believed to be needed in females during the spawning period because of greater energy expenditures in the build-up and maintenance of gonads (Love 1970).

To summarize, freshwater striped bass hematological ranges fell within or overlapped the ranges of blood values reported for apparently healthy saltwater striped bass and other species of fish. Low variability in blood values in this study are attributed to capture method, immediate microhematocrit analyses, preparation of blood for hemoglobin analyses on the boat, and immediate separation and storage of plasma on dry ice. Differences between striped bass blood values collected during the spring and summer of 1980 from Cherokee Reservoir are believed to be normal seasonal variations. Differences in blood values for striped bass among reservoirs (Cherokee, Norris, Watts Bar) during the same season (spring 1980) are believed to be due to differences in collection times of fish during their spawning period, although there may have been important water quality differences among reservoirs.

CHAPTER IV

LIVER HISTOLOGY OF STRIPED BASS FROM CHEROKEE AND NORRIS RESERVOIRS

I. INTRODUCTION

In recent years, heavy metal and pesticide contamination of our aquatic environments has become a serious problem. Despite increased interest in the effects of these toxicants on fish, relatively few studies have been conducted concerning the morphology of the livers (Hinton et al. 1972), a vital metabolic and detoxification organ (Hogan and Knowles 1968; Rhodin 1974). Liver histology can be a useful tool in helping to evaluate the health of fish (Couch 1975) once the normal, unstressed, and cyclic changes in the liver have been established for individual species (Cahn 1975). While Groman (1980) examined the histology of liver from apparently healthy adult salt-water striped bass, nothing has been published on the histology of the liver of adult freshwater striped bass. The objective of this study was to compare the livers of striped bass from two environmentally different reservoirs in East Tennessee. Norris, a mesotrophic reservoir with a predominantly undeveloped drainage basin, and Cherokee, a highly eutrophic reservoir with industry and mining in the drainage basin.

II. MATERIALS AND METHODS

Histological slides of striped bass livers were prepared by The University of Tennessee Veterinary School from samples provided by the Tennessee Valley Authority. Liver samples were taken from striped bass collected by electrofishing during the summers of 1978 and 1979 from Cherokee (Mossy Creek Cove) and during the spring of 1979 from Norris (Clinch River) and Cherokee (Holston River) Reservoirs. Samples provided by the Tennessee Valley Authority were fixed in Bouin's solution or 10% buffered formalin and slides prepared by the veterinary school were stained with hematoxylin and eosin. Slides were examined using a Zeiss Microscope (X 100) and microphotographs were taken with Kodachrome 40.

III. RESULTS

There were no signs of any necrosis in the livers of striped bass collected from Cherokee or Norris Reservoir. Each hepatocyte nucleus appeared homogeneous with a prominent centrally located nucleolus. The most noticeable aspect of this histology, however, was the heterogeneity of vacuolation of cells and the concentration of blood in sinusoids and veins found within the livers of striped bass from both reservoirs. When examining one part of a section of a liver, there would sometimes be little or no sign of vacuolation in hepatocyte cells (Figure IV-1), while examination of another part of the same section would reveal light vacuolation (vacuoles are believed to be composed of either lipid or glycogen) of hepatocyte

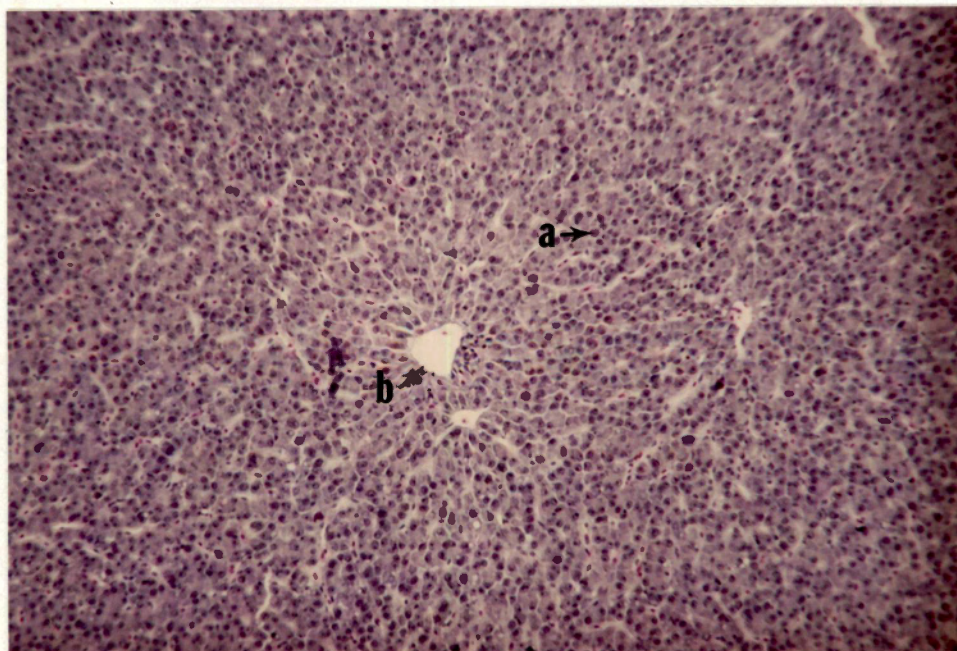


Figure IV-1. Liver tissue from a striped bass from Cherokee Reservoir showing little or no vacuolation of hepatocyte cells (a). In the center of the field is a central vein (b). Hematoxylin and eosin; X 100.

cells (Figure IV-2). Examination of livers from other striped bass would reveal a moderate degree of vacuolation in one part of the section (Figure IV-3), and in another part of the same section, there would be extensive vacuolation (Figure IV-4). Again, looking at other livers, there would be dilated and engorged sinusoids and vascular stasis (apparent in histological sections was the engorgement of blood vessels with red blood cells caused by localized pooling of blood in the tissues) in one part of a section (Figure IV-5), and within another part of the same section, there would be no dilated and engorged sinusoids and no vascular stasis (Figure IV-6).

IV. DISCUSSION

Livers of striped bass from Cherokee and Norris Reservoirs showed no signs of necrosis. The most striking aspect of this study was the high degree of heterogeneity for vacuolation of hepatocytes, vascular stasis of veins, and engorged sinusoids found within the livers of Norris and Cherokee striped bass. Groman (1980) examined the livers of apparently healthy saltwater striped bass and found light to extensive vacuolation among striped bass livers. Hinton et al. (1972) also found light to extensive vacuolation in the livers of largemouth bass, while Grizzle and Rogers (1976) found extensive vacuolation in well-fed channel catfish and little or no vacuolation in starved specimens. In this study of adult freshwater striped bass, the degree of vacuolation may vary from virtually none to light, light to moderate, and moderate to extensive within livers. While

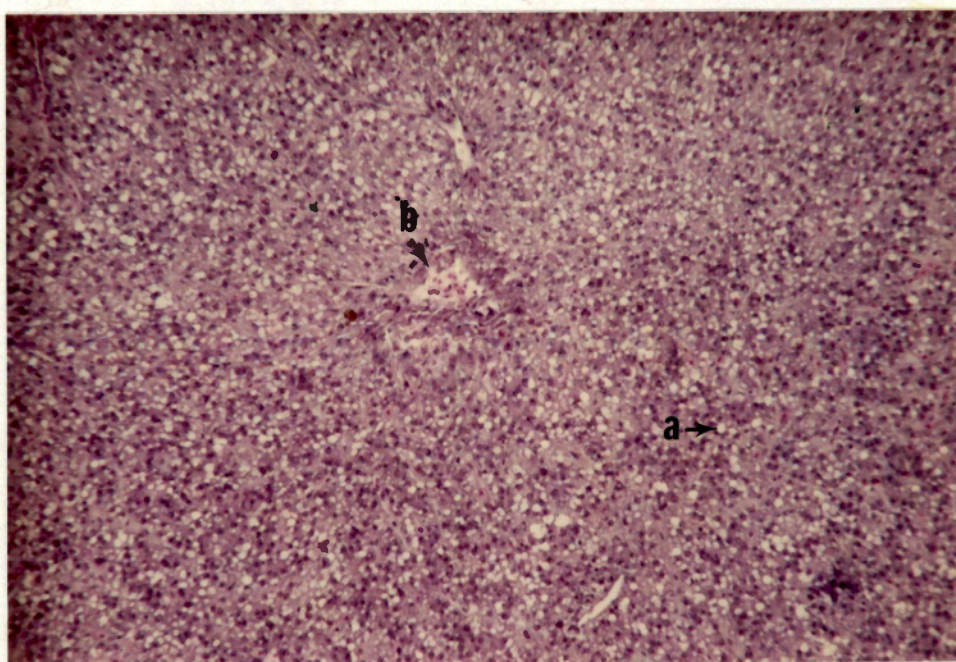


Figure IV-2. Different part of the same section of liver as in Figure IV-1 showing light vacuolation of hepatocyte cells (a). In the center of the field is a central vein (b). Hematoxylin and eosin; X 100.

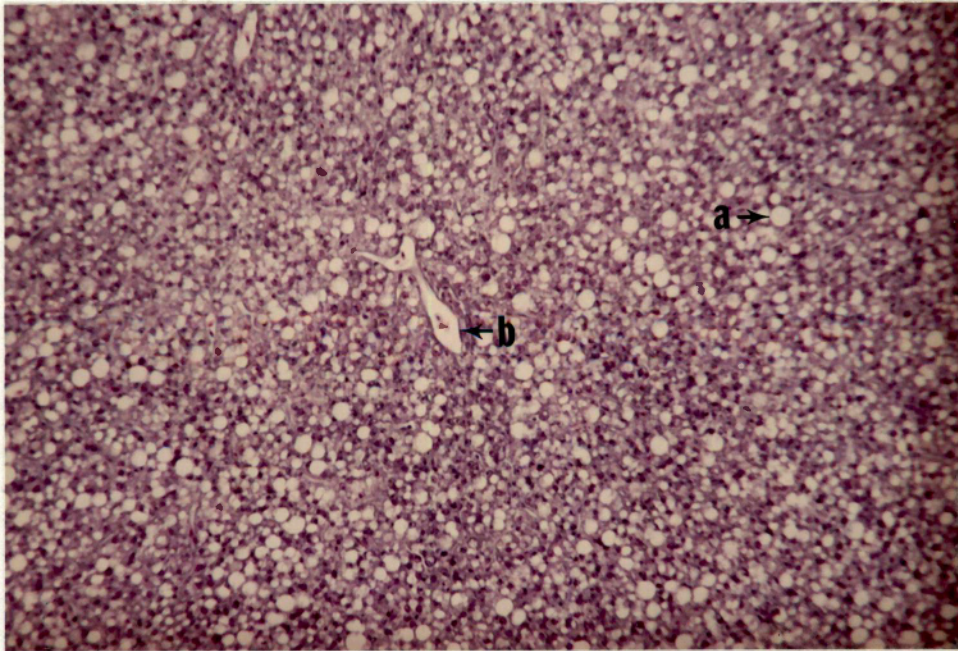


Figure IV-3. Liver tissue from a striped bass from Cherokee Reservoir showing moderate vacuolation of hepatocyte cells (a). In the center of the field is a central vein (b). Hematoxylin and eosin; X 100.

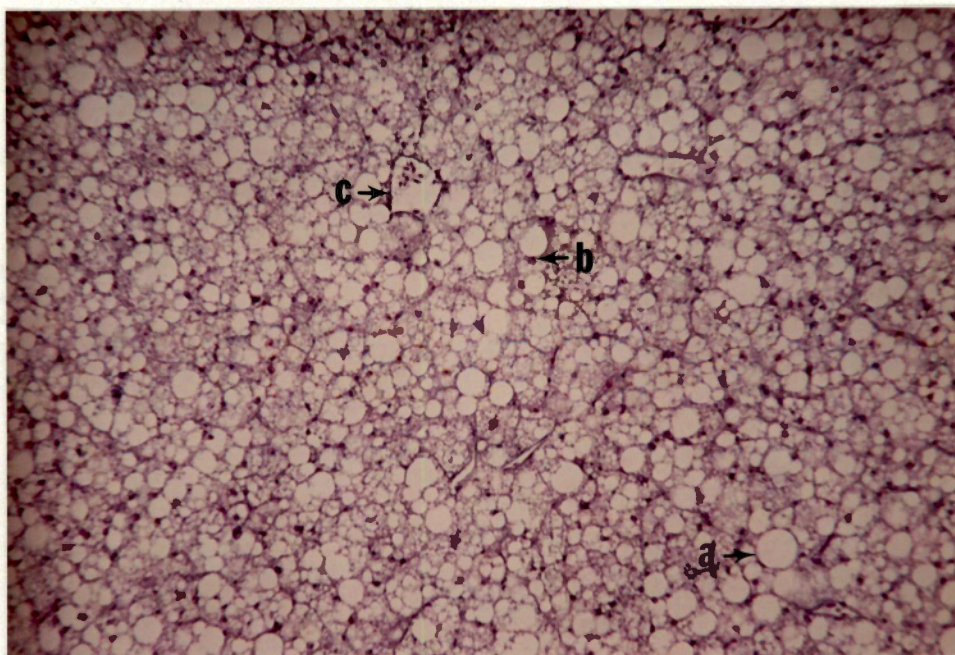


Figure IV-4. Different part of the same section of liver as in Figure IV-3 showing extensive vacuolation of hepatocyte cells (a) with nuclei crowded toward the side of the cells because of high lipid or glycogen content (b). Central vein (c). Hematoxylin and eosin; X 100.

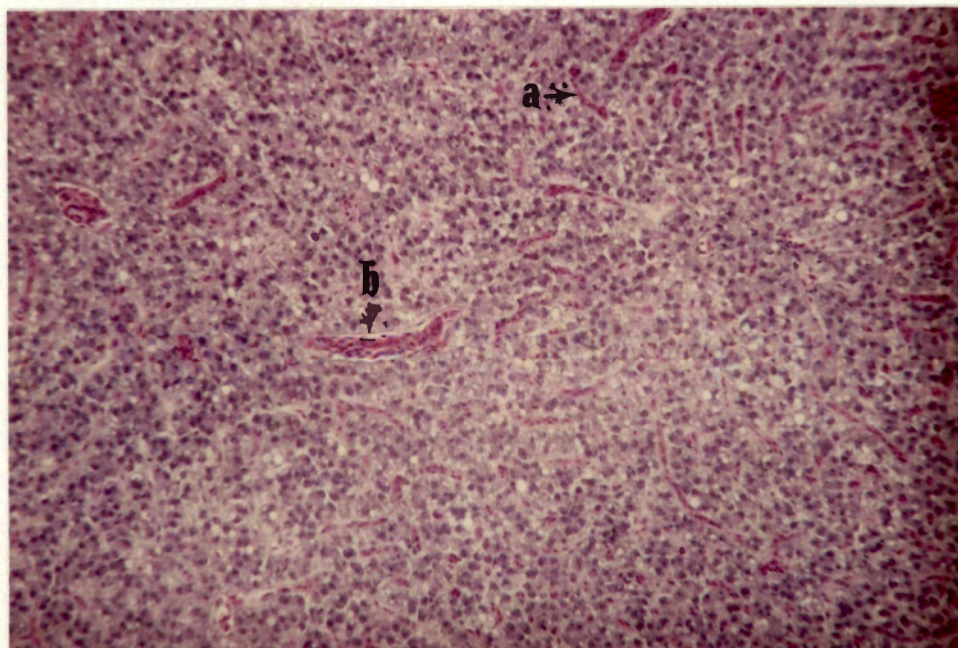


Figure IV-5. Liver tissue from a striped bass from Cherokee Reservoir showing dilated and engorged sinusoids (a) and vascular stasis (b). Hematoxylin and eosin; X 100.

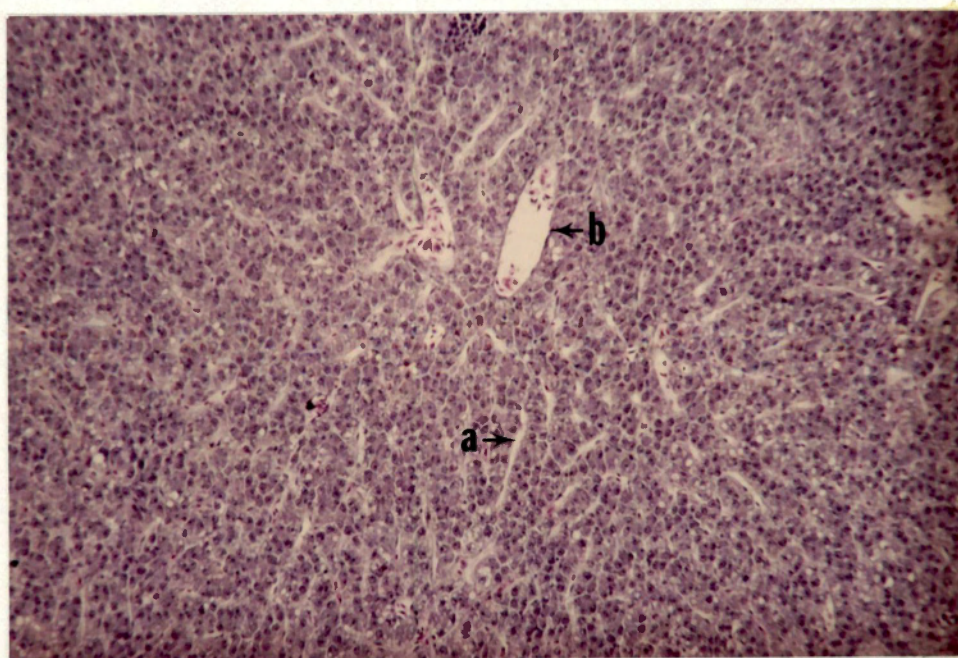


Figure IV-6. Different part of the same section of liver as in Figure IV-5 showing no dilated and engorged sinusoids (a) and no vascular stasis (b). Hematoxylin and eosin; X 100.

the degree of vacuolation of the liver may be related to the fish's diet (Grizzle and Rogers 1976), vacuolation may also be an indication of pesticide poisoning (Couch 1975). Grant and Mehrle (1970), however, reported that fish exposed to endrin (a pesticide) had noticeably less vacuolation than that of the controls. There is no apparent pesticide toxicity or lack of forage in Norris Reservoir, yet the striped bass from this reservoir (the control fish) had the same heterogeneous vacuolation of the livers as Cherokee fish. Therefore, it was believed that the degree of vacuolation in both Cherokee and Norris striped bass livers were related to whether the fish had recently fed prior to capture and not a sign of starvation or pesticide toxicity.

Like vacuolation, engorged sinusoids, and vascular stasis in the livers may result from the stress of capture (Couch 1975) or the length of time before the liver was removed after capture. Engorged sinusoids and vascular stasis, however, may also be caused by pesticide toxicity (Couch 1975) and viral infections (Wolf et al. 1972). Again, because of the heterogeneity within livers of striped bass from both Cherokee and Norris Reservoirs, dilated and engorged sinusoids and vascular stasis are believed to be the result of stress from capture and subsequent handling of fish and not the result of any pathology.

Even though vacuolation, engorged sinusoids, and vascular stasis may indicate some type of pathology, caution must be taken in using these signs to evaluate the health of freshwater striped bass because these signs were not found to be homogeneous throughout the liver. When using vacuolation, engorged sinusoids and vascular stasis of the

liver as signs of pathology, care must be taken to insure that several different sections of the liver are taken from each fish, and that comparisons are made on the range of these signs for evaluating possible pathologies.

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CHAPTER V

GENERAL CONCLUSIONS

Since the beginning of the study (July 1, 1979), there have been no striped bass mortalities in Cherokee Reservoir. Zinc and cadmium analyses indicated greatest concentrations in livers and kidneys with no significant accumulation in muscle tissue (see Figures II-1 and II-2, pages 10 and 12, respectively) for striped bass from all three reservoirs (Cherokee, Norris, and Watts Bar). Even though there were significant differences between samples among seasons (summer 1979, spring 1980, summer 1980) in Cherokee Reservoir as well as among the three reservoirs during the same season (spring 1980), all the concentrations were well below those reported for fish exposed to maximum non-harmful concentrations of zinc and the lowest potentially harmful concentration of cadmium. Also, almost all of the zinc and cadmium concentrations in the muscle, liver, and kidney tissues were within the range typically reported for fish tissues. It is therefore believed that in the last two years, zinc and cadmium in the tissues of striped bass from Cherokee Reservoir have not been harmful to the fish.

Hematological studies revealed statistically significant differences in several blood parameters between seasons (spring and summer 1980) for striped bass from the same reservoir (Cherokee) and among the three reservoirs during the same season (spring 1980).

These differences are due to extremely low variability rather than large differences in means (see Figures III-1 and III-2, pages 25 and 26, respectively). Striped bass collected in the spring of 1980 from Cherokee Reservoir had significantly higher microhematocrits, hemoglobin, glucose, cortisol, and cholesterol values than fish collected during the summer of 1980 from Cherokee. Striped bass from the summer, however, did have higher osmolality and chloride values than spring fish. These differences between striped bass blood parameters collected during the spring and summer of 1980 from Cherokee Reservoir are believed to be normal seasonal variations. Among the three reservoirs during the same season (spring 1980), there were several statistically significant differences for six of the eight blood parameters measured; however, no one reservoir was consistently different from the other two. No pathology was associated with any of the differences in blood characteristics. These differences in blood parameters among the reservoirs are believed to be due to differences in collection times of striped bass during their spawning season and possibly water quality differences among the reservoirs.

It was originally thought that the hematology of striped bass from Norris and Watts Bar Reservoirs (the control fish) would be similar and that those values could then be compared to the hematology of Cherokee fish. As it turned out, there were significant differences in the hematology between striped bass from Norris and Watts Bar as well as differences among striped bass from all three reservoirs. Since no normal range of blood characteristics has been established

for this species, and since there were significant differences between control fish, no pathology could be associated with any of the differences in blood characteristics. The hematological work done in this study may prove to be of value as baseline data for future comparisons.

No pathology was attributed to the findings in the liver histology of Cherokee or Norris striped bass. Livers showed no signs of necrosis and hepatocyte nuclei (one per cell) appeared homogeneous with a prominent centrally located nucleolus, however; there was a high degree of heterogeneity found within livers. In one part of a section of liver, there may be no vacuolation, yet in another part of that same section there may be light vacuolation. Another liver may have a moderate degree of vacuolation in one section, and in another section vacuolation may be extensive. This same thing was true as well for vascular stasis and dilated and engorged sinusoids. When using vacuolation, engorged sinusoids, and vascular stasis of the liver as signs of pathology, care must be taken to insure that several different sections of liver are taken from each fish, and that comparisons are made on the range of these signs.

This study did not reveal any pathology in striped bass from Cherokee Reservoir; however, no mortalities occurred during the course of the investigation. Striped bass collected from Cherokee Reservoir in the past two years appeared as healthy as the ones from Norris and Watts Bar. Average condition factors (K) were calculated using the expression $\text{weight (grams)} \times 10^5 \div \text{total length}^3$ for each of

the sample periods in this study. Comparing condition factors for fish collected during the same season (spring 1980) from Cherokee, Norris and Watts Bar Reservoirs, striped bass from Cherokee had significantly ($P=0.05$) higher condition factors (1.48) than fish from Norris (1.02) and Watts Bar (1.17). Looking at Cherokee Reservoir during different seasons (spring and summer 1980), spring fish had significantly higher condition factors (1.48) than fish from the summer (1.26). Higher condition factors in spring fish are probably due to increased gonad development during the spawning season.

Perhaps the most plausible explanation for the cause of striped bass mortalities in Cherokee Reservoir was high temperature and low dissolved oxygen and was related to the size of the refuge areas as first suggested by Coutant (1978). Axon (1979) reported adult striped bass mortalities in a Kentucky lake during the summer months and attributed the mortalities to high temperature and low dissolved oxygen. As most of the Cherokee Reservoir becomes intolerable for the striped bass (Schaich 1979; Waddle 1979), nearly all these fish will have to seek refuge areas in order to survive. The refuge areas may have been insufficient for the whole reservoir striped bass population, as no estimate of the size of the striped bass population in Cherokee Reservoir exists. There may have been twice the number of striped bass (compared to population size in the past two years) during years heavy mortality occurred and the striped bass that exceeded the carrying capacity of the refuges were forced into the hostile reservoir environment where they perished. Some striped bass may have also died

because they were overcome by unfavorable environmental conditions before they were able to find refuge areas. Striped bass that leave the refuge areas in search of food may be unable to find their way back from the hostile environmental conditions and die. Also, striped bass caught and released from the refuge areas may be so fatigued from being played on hook and line that they sink into anoxic water and die (Coutant 1978). Cherokee may not produce as many large fish as Norris because the growth may be inhibited by low oxygen concentrations during the summer months. Herman et al. (1962) found that fish exposed to low oxygen concentrations for long periods of time would grow little, or not at all, and even lose weight in the presence of abundant supply of food.

In support of the water quality explanation, the two summers this study was conducted were extremely different from each other as far as weather conditions and were not like any of the previous summers when the heavy mortalities occurred. During the first summer of the study (1979), it was rainy and cool with water levels much higher than normal. Temperature and dissolved oxygen conditions were better than in past summers when heavy mortalities occurred. The second summer (1980) was one of the hottest summers in Tennessee, and there was little rainfall. Also, the water level was kept much lower than normal because of barge traffic of heavy equipment to upriver sites. All this led to a much shorter retention time of water in Cherokee with little chance for the reservoir to stratify and deplete oxygen supplies. Despite the extremely hot weather conditions,

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the temperature and dissolved oxygen conditions were better than the years in which the heavy mortalities occurred.

Despite these problems, the author recommends the continued stocking of striped bass in Cherokee, but in fewer numbers to assure adequate space in refuge areas during the critical summer months and, perhaps, an increase in the number of hybrids (white bass x striped bass) because of their presumed greater tolerance of the harsh summer environment.

Should mortalities occur again, the following procedures are recommended: (1) measure hematological characteristics from striped bass in areas which mortalities are occurring and compare to those measured from striped bass in the summer of 1980 from Cherokee (when no mortalities occurred), (2) determine heavy metal concentrations (lead, copper, mercury, zinc, and cadmium) in tissues of striped bass and water quality characteristics for the reservoirs, and (3) analyze for pesticides, particularly organochlorines because they have been shown to accumulate in the liver and fatty tissues of fish. Since the water levels were unusually high one summer and low the next summer during this study, this may have had a diluting and flushing effect, respectively, on the heavy metal concentrations in Cherokee Reservoir. Therefore, even though the concentrations of zinc and cadmium in this study were well below those concentrations reported to be harmful to fish, these metals should be analyzed again because of the unusual conditions during the summers of this study.

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APPENDIXES



APPENDIX A

LENGTH, WEIGHT, AGE, AND SEX OF INDIVIDUAL FISH

Table A-1. Length, weight, age, and sex of individual fish collected from Cherokee, Norris, and Watts Bar Reservoirs.

Number	Total Length (cm)	Weight (kg)	Age (Years)	Sex (M=Male) (F=Female)
Cherokee Summer 1979				
1	81	6.1	5	F
2	69	3.5	4	M
3	84	8.8	7	F
4	61	2.9	3	M
5	69	3.6	4	M
6	67	3.2	4	M
7	71	4.1	4	M
8	73	4.3	4	F
9	71	3.8	4	M
10	78	5.2	4	F
11	70	3.9	4	M
12	69	2.7	4	F
13	70	4.2	4	M
14	72	4.2	4	M
15	74	5.1	4	F
16	70	3.7	4	M

Cherokee Spring 1980

1	71	6	5	M
2	79	7	5	F

Table A-1 (Continued)

Number	Total Length (cm)	Weight (kg)	Age (Years)	Sex (M=Male) (F=Female)
3	76	6	5	M
4	74	6	5	F
5	81	8	5	M
6	76	6	5	F
7	76	8	5	F
8	76	6	5	M
9	76	6	5	F
10	71	5	4	M
Cherokee Summer 1980				
1	75	5.0	5	M
2	74	5.0	5	M
3	76	5.4	5	M
4	76	5.0	5	M
5	72	5.0	5	M
6	70	4.5	4	M
7	81	6.4	5	M
8	84	7.3	6	M
9	81	7.3	6	M
10	76	5.9	5	M
11	76	5.9	5	M
12	71	4.8	4	M
13	71	4.1	5	M
14	86	7.3	6	M

Table A-1 (Continued)

Number	Total Length (cm)	Weight (kg)	Age (Years)	Sex (M=Male) (F=Female)
15	76	5.9	5	M
16	84	7.3	6	M
Norris Spring 1980				
1	62	2.5	3	M
2	79	5.5	6	M
3	81	5.7	6	M
4	79	4.7	6	M
5	79	5.0	6	M
6	86	6.5	6	M
7	79	4.8	6	M
8	81	5.3	6	M
9	79	5.0	6	M
Watts Bar Spring 1980				
1	61	2.6	3	M
2	76	5.6	5	M
3	79	5.6	5	F
4	85	7.5	5	F
5	62	3.4	4	M
6	97	10.2	6	F
7	81	5.6	5	F
8	57	2.0	3	M
9	60	2.3	3	M

APPENDIX B

ZINC AND CADMIUM RESIDUES ON A WET AND
ASHED WEIGHT BASIS

Table B-1. Mean concentrations $\pm$ 95% confidence intervals for zinc residues (mg/kg) on a wet and ashed weight basis in striped bass muscle, liver, and kidney tissues.

Reservoir	Wet Weight (mg/kg)			Ashed Weight (mg/kg)		
	Muscle	Liver	Kidney	Muscle	Liver	Kidney
Cherokee Summer 1979 N = 16	3.2 $\pm$ 0.2	44.0 $\pm$ 4.3	22.3 $\pm$ 1.4	220 $\pm$ 20	4730 $\pm$ 800	1710 $\pm$ 110
Cherokee Summer 1980 N = 16	2.7 $\pm$ 0.1	43.9 $\pm$ 2.1	22.7 $\pm$ 1.3	210 $\pm$ 10	3950 $\pm$ 350	1640 $\pm$ 170
Cherokee Spring 1980 N = 10	3.3 $\pm$ 0.2	34.2 $\pm$ 2.5	23.6 $\pm$ 2.2	260 $\pm$ 20	2380 $\pm$ 310	1700 $\pm$ 250
Norris Spring 1980 N = 9	2.8 $\pm$ 0.2	46.3 $\pm$ 4.4	24.3 $\pm$ 3.6	240 $\pm$ 20	4990 $\pm$ 1550	1720 $\pm$ 370
Watts Bar Spring 1980 N = 9	3.1 $\pm$ 0.1	31.9 $\pm$ 6.0	22.1 $\pm$ 1.7	240 $\pm$ 20	4200 $\pm$ 1130	1990 $\pm$ 520

Table B-2. Mean concentrations $\pm$ 95% confidence intervals for cadmium residues (mg/kg) on a wet and ashed weight basis in striped bass muscle, liver, and kidney tissues.

Reservoir	Wet Weight (mg/kg)			Ashed Weight (mg/kg)		
	Muscle	Liver	Kidney	Muscle	Liver	Kidney
Cherokee Summer 1979 N = 16	0.01 $\pm$ 0.01	0.26 $\pm$ 0.04	0.06 $\pm$ 0.01	0.8 $\pm$ 0.3	29.7 $\pm$ 9.6	4.5 $\pm$ 0.7
Cherokee Summer 1980 N=16	0.01 $\pm$ 0.01	0.28 $\pm$ 0.04	0.94 $\pm$ 0.12	0.4 $\pm$ 0.2	24.1 $\pm$ 3.7	69.0 $\pm$ 10.3
Cherokee Spring 1980 N = 10	0.02 $\pm$ 0.01	0.11 $\pm$ 0.02	0.04 $\pm$ 0.01	1.6 $\pm$ 0.5	8.2 $\pm$ 2.1	2.8 $\pm$ 1.0
Norris Spring 1980 N = 9	0.01 $\pm$ 0.01	0.72 $\pm$ 0.16	0.12 $\pm$ 0.02	0.9 $\pm$ 0.8	78.3 $\pm$ 24.3	8.2 $\pm$ 1.6
Watts Bar Spring 1980 N = 9	0.02 $\pm$ 0.01	0.14 $\pm$ 0.02	0.07 $\pm$ 0.02	1.3 0.5	19.3 $\pm$ 6.5	6.2 $\pm$ 1.7

VITA

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