

SOME EFFECTS OF THERMAL HISTORY ON THE LARGEMOUTH  
BLACK BASS, MICROPTERUS SALMOIDES (LACÉPÈDE),  
OF TWO CENTRAL TEXAS RESERVOIRS RECEIVING  
POWER PLANT EFFLUENTS

A Thesis Submitted to the Faculty of  
Baylor University  
in Partial Fulfillment of the  
Requirements for the Degree  
of  
Master of Science

By

Barney James Venables

Waco, Texas

December 1972

## ABSTRACT

Mean annual growth of the first three age classes of largemouth black bass from Tradinghouse Reservoir was near the average growth reported in the literature for southern waters. Largemouth black bass collected from the discharge canals of Tradinghouse Reservoir (which has received power plant effluent for only 2 years) and Lake Creek Reservoir (which has received power plant effluent for 20 years) showed no difference in male or female gonadal development, condition factor, or thyroid activity; however, the largemouth black bass collected from the Tradinghouse Reservoir discharge canal showed signs of decreased physiological activity with respect to the Lake Creek sample. No significant detrimental effects of the power plant effluents were detected.

## TABLE OF CONTENTS

	Page
LIST OF TABLES . . . . .	iv
LIST OF ILLUSTRATIONS . . . . .	v
INTRODUCTION . . . . .	1
METHODS AND MATERIALS . . . . .	5
Physical and Chemical Age and Growth Organ Weight, G.S.I., Egg Number, and Thyroid Acitivity	
TEMPERATURE ADJUSTMENT . . . . .	12
Definitions The Organismic Level The Systemic Level The Molecular Level	
RESULTS . . . . .	25
Physical and Chemical Age and Growth Organ Weights G.S.I. and Egg Number Thyroid Acitivity "K" Value	
DISCUSSION . . . . .	46
Physical and Chemical Characteristics Growth G.S.I. and Egg Number Organ Weight Analysis Thyroid Analysis	
CONCLUSION . . . . .	59
APPENDIX . . . . .	64
LITERATURE CITED . . . . .	66

## LIST OF TABLES

Table	Page
1. Number and Dates of Collection of Largemouth Black Bass from Tradinghouse Reservoir. . . . .	9
2. Tradinghouse Reservoir Physical and Chemical Data . . . . .	26
3. Chemical Data from Lake Creek Reservoir . . . . .	29
4. Comparison of Standard and Total Lengths of First Three Age Groups of Largemouth Black Bass From Tradinghouse Reservoir With Values Reported in the Literature. . . . .	38
5. Comparison of Growth Between First, Second, and Third Year Classes of Largemouth Black Bass from Tradinghouse Reservoir and the Mean of the Values Reported in the Literature . .	40
6. Comparison of Male and Female G.S.I. and Egg Number for Largemouth Black Bass from Tradinghouse Reservoir and Lake Creek Reservoir .	40
7. Mean Epithelium Heights of Thyroid Follicles of Largemouth Black Bass from the Discharge Canals of Tradinghouse Reservoir, Lake Creek Reservoir, and 3 Museum Specimens . . . . .	44
8. Mean K Factors for Largemouth Black Bass Used in this Study. . . . .	45

## LIST OF ILLUSTRATIONS

Figure	Page
1. Map of Tradinghouse Reservoir Showing Sampling Sites for Physical and Chemical Data. . . . .	6
2. Schematic Representation of the Electro- fishing Rig Used for Capture of Largemouth Black Bass in Tradinghouse Reservoir. . . . .	8
3. Hypothetical Zone of Tolerance . . . . .	14
4. Annual Temperature Fluctuations in Power Plant Intake and Discharge Waters on Tradinghouse Reservoir . . . . .	28
5. Water Temperatures of the Discharge Canals of Tradinghouse Reservoir and Lake Creek Reservoir for the Month of February, 1972. . . . .	30
6. Length-frequency Histogram for Samples 1 and 2. . . . .	31
7. Probability Scale Length-frequency Plot for Samples 1 and 2. . . . .	32
8. Length-frequency Plot for Individual Size Classes for Samples 1 and 2. . . . .	34
9. Length-frequency Histogram for Samples 5 and 6. . . . .	35
10. Probability Scale Length-frequency Plot for Samples 5 and 6. . . . .	36
11. Length-frequency Plot for Individual Size Classes of Samples 5 and 6 . . . . .	37
12. Relationship Between Total Weight and Kidney Weight for Largemouth Black Bass from Trading- house Reservoir and Lake Creek Reservoir . . . . .	41
13. Relationship Between Total Weight and Liver Weight for Largemouth Black Bass from Trading- house Reservoir and Lake Creek Reservoir . . . . .	42

Figure	Page
14. Relationship Between Total Weight and Spleen Weight for Largemouth Black Bass from Tradinghouse Reservoir and Lake Creek Reservoir. . . . .	43
15. Zone of Tolerance for Largemouth Black Bass. . . . .	61

## INTRODUCTION

Over the past ten years, the term "thermal pollution" has come into widespread use to describe the condition of unnaturally elevated temperatures in bodies of water. This can be caused by denuding a shoreline of its natural shading vegetation, irrigation runoff, and other minor sources, but the major source is the addition of industrial and power plant effluents to the water (Parker and Krenkel, 1969). Power plant discharges average approximately 11C above ambient temperatures and it is estimated that by 1980 one-fifth of the surface water in the United States will be affected by such discharges (Parker and Krenkel, 1969).

There has been much concern about the possible biological effects of power plant discharges. Temperature is probably the single most influential physical factor of an animal's environment. It is known to have significant effects at all levels of biological organization. This is especially true in an aquatic community composed almost entirely of poikilothermic life. Studies are appearing which are aimed toward questions of the relationship between thermal effluents and various members of the aquatic community. For example, Drew and Tilton (1970) concluded that the production of largemouth black bass, Micropterus salmoides (Lacépède), was enhanced in Texas reservoirs receiving thermal effluents.

The well being of the fishes of the aquatic community is of special interest because of the trophic dependence of fishes upon the other members of the community. Thus the health of fish populations can be used as an indication of the health of the entire aquatic community.

There are many possible indicators of temperature effects that could be used in the evaluation of the effect of thermal history on fish. The following indicators were considered in this study.

Numerous studies have related fish growth to ambient temperature. Kramer and Smith (1960) found the growth of largemouth black bass to be correlated with the temperature experienced up to the end of the growing season. A thermally influenced reservoir might produce a prolonged growing season and result in increased annual growth.

Temperature can also affect gonad maturation rate and spawning time. Wiebe (1968) found increased spermatogenesis with increased temperature in the sea perch, Cymatogaster aggregata (Gibbons). Berenbeim (1970) demonstrated a correlation between mean annual temperature and spawning time in some marine fishes. A reservoir receiving a heated discharge might produce fish with accelerated rates of gonad maturation leading to early spawning.

The relationship between temperature and metabolic rate has been a subject of much interest. Paloheimo and Dickie (1966) concluded that temperature affects primarily the level



of metabolism. That is, a change in temperature tends to translate (rather than rotate) a curve describing the relationship between body weight and metabolism. All other things being equal, an increase in ambient temperature would theoretically cause an increase in total metabolism.

Albrecht (1969) demonstrated an inverse relationship between organ weights and metabolic activity in carp, Cyprinus carpio (Linnaeus). This was primarily due to the shunting of blood from the viscera to the musculature. It might be expected that fish with different thermal histories would exhibit different organ weights as a reflection of differing levels of metabolic activity.

The role of thyroid activity in temperature acclimation has been controversial and is still undefined; however, the relationship between thyroid activity and ambient temperature is generally agreed upon. Drury and Eales (1968), in a comparison of histological and radio-chemical techniques of thyroid activity assay in brook trout Salvelinus fontinalis, (Mitchill) , concluded that thyroxin secretion is positively correlated with temperature. Thyroid activity too, then might be expected to reflect thermal history.

The purpose of this study was to evaluate the effect of thermal history on the largemouth black bass of two Texas reservoirs receiving power plant discharges using several indicators of temperature adjustment. Age and growth of largemouth black bass from Tradinghouse Reservoir (which

received thermal discharge for approximately two years prior to the study) were to be compared with literature values for other southern waters. Largemouth black bass from the discharge canals of Tradinghouse Reservoir and Lake Creek Reservoir (which received thermal discharge for approximately twenty years prior to the study) were to be compared on the basis of: (1) physiological activity as indicated by the relationship of organ weights (spleen, kidney, and liver) to total weights (2) the relative state of development of gonads as indicated by the gonosomatic index (G.S.I.) and egg number (3) thyroid activity as indicated by follicular epithelium height.

This study was funded by Office of Water Resources Research Grant B-091-TEX. I am indebted to Drs. Owen Lind, Harley Reno, and Thomas Franklin for their assistance throughout the study and their thoughtfull reviews of the manuscript. Mr. Mark Wysong, Mr. David Lukins, Mr. E. Norbert Smith, and Dr. David Eldridge kindly contributed much of their time and effort on my behalf. Special thanks go to Mr. Dwane Smith and Mr. Breed of the Texas Parks and Wildlife Commission for their patient cooperation, and to the Texas Power and Light personnel who made my job so much easier.

## METHODS AND MATERIALS

### Physical and Chemical

Tradinghouse Reservoir is located east of Waco, Texas in McLennan County ( $31^{\circ}34'N$ ,  $96^{\circ}57'W$ ). Routine chemical and physical data were taken from Tradinghouse Reservoir at monthly intervals from 8 March 1971, through 9 March 1972 at the four stations indicated in Figure 1. Dissolved oxygen and air and water temperature were measured in the field with a Weston and Stack Model 300 oxygen analyzer with a motorized sampler Model A15. Dissolved oxygen was determined in the laboratory by the Winkler method on two sampling dates (17 May 1972 and 9 March 1972).

Water samples, taken with a Kemmerer sampler, were iced down and returned to the laboratory for analysis. The pH was determined by a Coleman pH meter and specific conductance by a Helige conductance meter. Alkalinity, total hardness, calcium, magnesium, and silica concentrations were all determined by standard methods (American Public Health Association, 1965). Sulfate concentration was determined by the Hach turbidometric technique.

Lake Creek Reservoir is located southeast of Waco, Texas in McLennan County ( $31^{\circ}27'N$ ,  $96^{\circ}58'W$ ). The chemical data for Lake Creek Reservoir and temperature data for February 1972, for the discharge canals of both reservoirs were obtained from

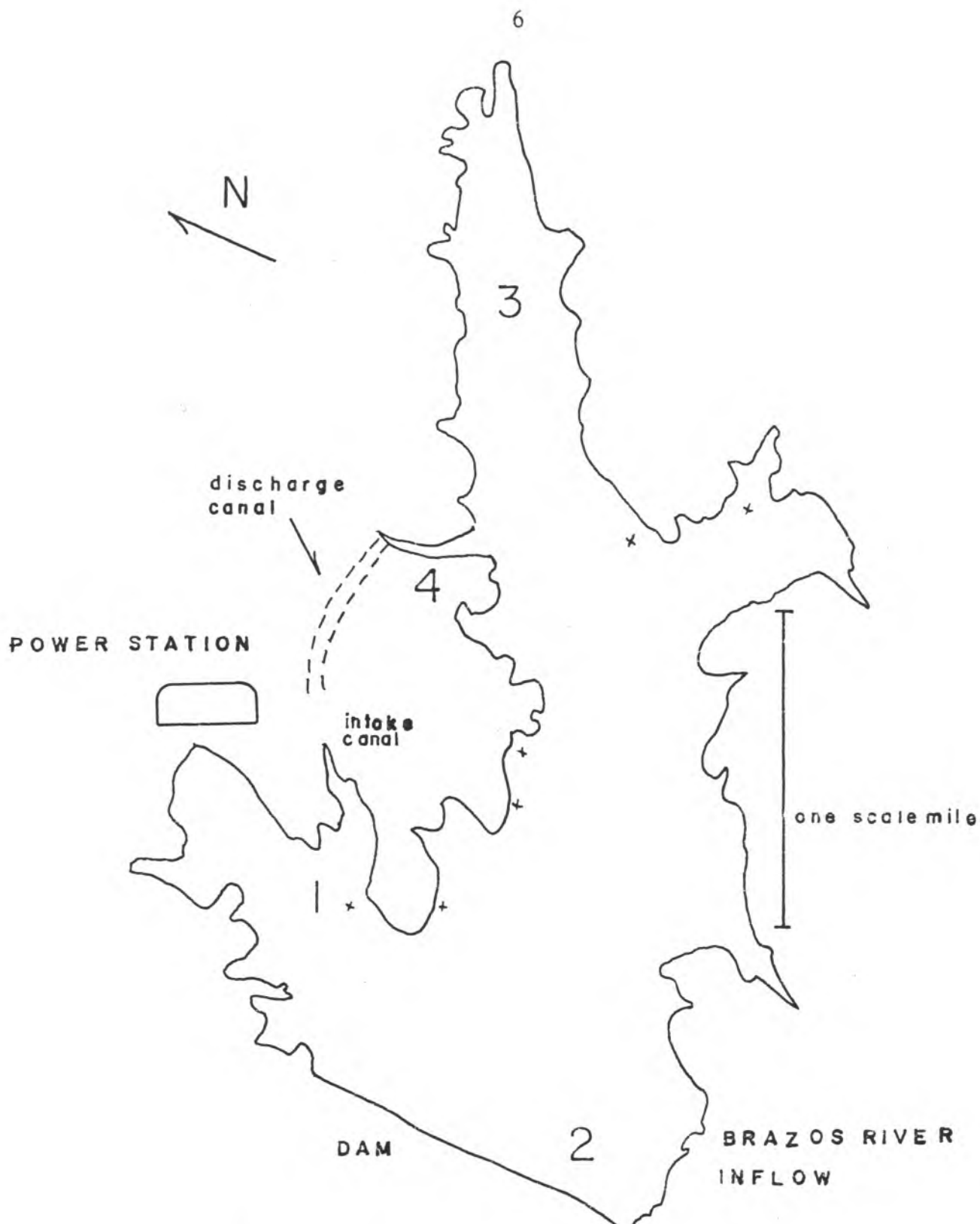


Figure 1. Map of Tradinghouse Reservoir showing sampling sites for physical and chemical data. Surface area= $7.96 \text{ km}^2$ ; mean depth= $5.7 \text{ m}$ . X=Electrofishing sites.

the records of Texas Power and Light Company.

#### Age and Growth

From 10 June 1971, to 13 December 1971, 263 largemouth black bass were collected in 6 samples (Table 1) from Trading-house Reservoir by alternating current (A.C.) electrofishing. A direct current (D.C.) variable voltage pulsator was designed and constructed in our laboratory (Smith, Venables, and Lind, 1973). The pulsator had an upper current limit of 10 amps and consequently could not be efficiently used due to the high conductivity of the reservoir water. The electrofishing rig consisted of a 16 ft. aluminum boat with a 3000 watt generator connected through a deadman switch to five metal spring electrodes suspended from a "T" shaped boom which extended 5 feet in front of the bow (Fig. 2). Electrofishing was done along the north and south shores at night with crews of three to six men. Collected fish were weighed to the nearest gram, measured for standard length (SL) (tip of the lower jaw to the end of the hypural plate) and total length (TL) to the nearest mm, and released. A mean condition factor or "K" value ( $\text{weight}/\text{length}^3$ ) was computed for the 263 fish.

The 263 fish lengths were grouped into size classes according to the Peterson method (Simpson, Roe, and Lewontin, 1960). Samples 1 and 2 were combined to give sufficient numbers for an early summer length-frequency analysis. Similarly samples 5 and 6 were combined for a late fall analysis which was assumed to represent the extent of the 1971 growth.

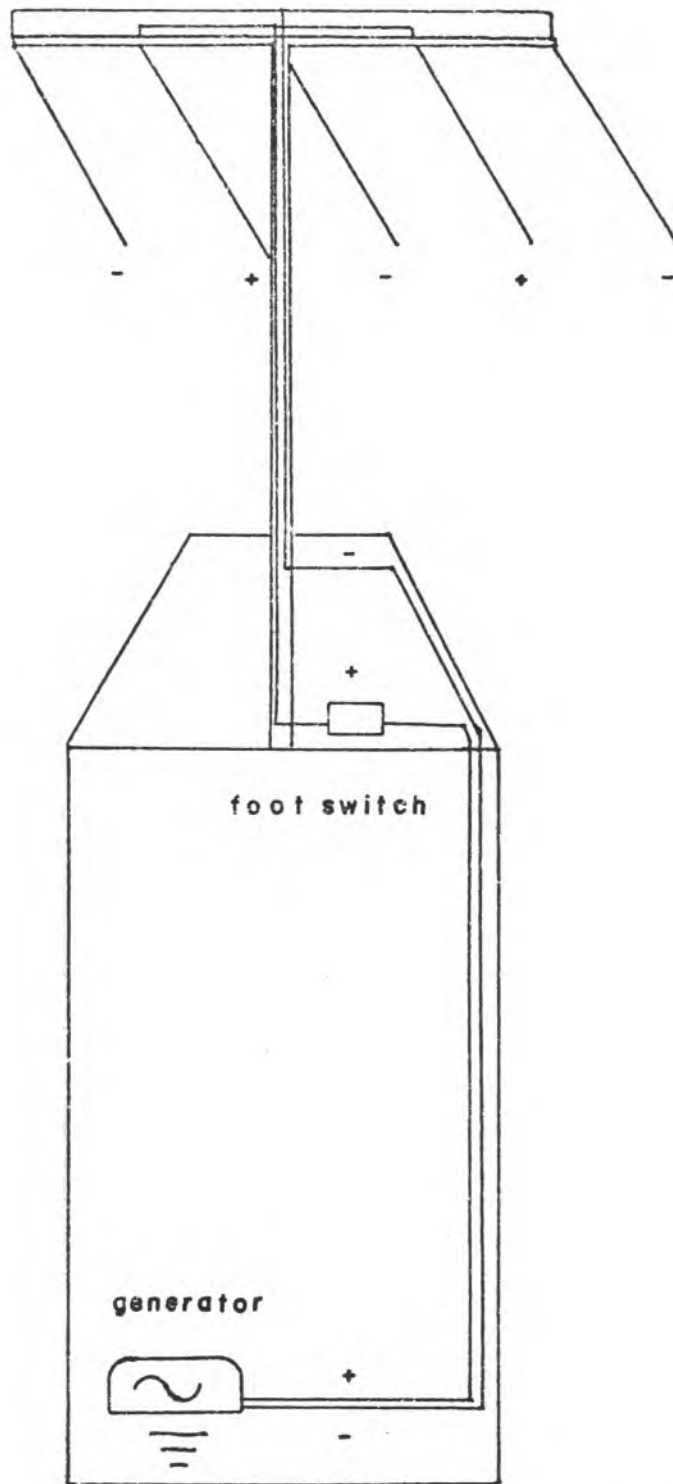


Figure 2. Schematic representation of the electrofishing rig used for capture of largemouth black bass in Tradinghouse Reservoir.

TABLE I  
NUMBER AND DATES OF COLLECTION OF  
LARGEMOUTH BLACK BASS FROM  
TRADINGHOUSE RESERVOIR

Collection Number	Number Collected	Date
1	18	10 June 1971
2	77	14 June 1971
3	41	7 Sept. 1971
4	16	15 Sept. 1971
5	64	8 Nov. 1971
6	47	13 Dec. 1971
Total	263	

Size classes were distinguished using the probability paper analysis of size frequency distribution described by Cassie (1954). Samples 3 and 4 had insufficient number for analysis, resulting in a probability plot too indistinct for the determination of inflection points.

The mean standard lengths of the size classes were assumed to represent the mean standard lengths of age classes I, II, III, and IV for 1971, representing fish having completed 1-4 years of life respectively.

The determination of annual growth by the scale method proved to be impractical due to the lack of distinct annulus formation.

Organ Weight, Gonosomatic Index, Egg  
Number, and Thyroid Activity

On 27 and 28 February 1972, 34 largemouth black bass

from Tradinghouse Reservoir and 43 from Lake Creek Reservoir were collected by angling from the discharge canals of the two reservoirs. They ranged from 145-315mm, SL. Water temperature in the canals was 31C and 22C for Tradinghouse Reservoir and Lake Creek Reservoir respectively. The fish were immediately preserved in 10% buffered formalin. Slits in the region of the throat thyroid and peritoneal cavity allowed rapid fixation. The SL, TL, and weight of the fish were determined as previously described. A mean "K" value was computed for the fish from each canal. The liver, kidney, spleen, gonad, and thyroid were excised and weighed wet to the nearest milligram. The regressions between body weight and each of the three organ weights (kidney, liver, and spleen) were plotted for the fish from each reservoir. The slope and Pearson coefficient of regression were calculated for each regression. A "t" test for the significance of difference between regression coefficients (Simpson, et al., 1960) was used to test for differences between the fish samples from the two canals.

The G.S.I. was calculated from the quotient of total weight and gonad weight. Eggs were counted by Simpson's (1959) dry method. The mean G.S.I. for each sex, and the mean egg number per gram of fish were compared between canals by the "t" test ( $p < 0.05$ ).

Twenty fish (5 males and 5 females from each canal) were used in the thyroid activity analysis. The fish ranged



from 150-220mm SL. The thyroid region was decalcified 7-10 days in picric acid, serially sectioned at  $10\mu$  between the first and second aortic arch and stained with Harrison's hematoxylin and eosin. Follicle epithelium height of 20-50 follicles per fish was measured with an ocular micrometer. The mean thyroid follicle epithelium heights of the two samples were compared by "t" test ( $p < 0.05$ ). As a basis of comparison, three additional large-mouth black bass collected from nonthermally affected central Texas water in March, June, and August of previous years, were obtained from the Baylor University Ichthyology Museum (B.U.I.M. 923, 895 & 860) and analyzed for thyroid activity as described above.

## TEMPERATURE ADJUSTMENT

In order to evaluate results of this study it is necessary to begin with a brief synopsis of what is known concerning the adjustment of poikilotherms to temperature. A description of some of the pertinent terminology is followed by specific examples of temperature adjustment.

### Definitions

There has been confusion over the terms describing various forms of biological adjustment induced by temperature change. Fry (1957) listed three main levels of adjustment for poikilotherms. Acclimation he defined as "day to day changes in systemic or cellular organization in direct response to temperature." These changes are reflected by shifts in temperature preference, metabolic rates, and lethal temperature limits. The shifts are generally in the direction which places the biokinetic range more in accord with the acclimation temperature.

Fry next considered "long term responses operating throughout the life of the individual" and termed this level of adjustment acclimatization. This included the composite effects of all environmental factors (such as photoperiod, salinity, etc.,) including temperature. Thus a direct response to temperature (acclimation) can be reinforced or opposed by long term response to photoperiod (acclimatization).

The final level of adjustment is that of adaptation. This is "on the phylogenetic level at which the mechanisms both for the production of direct responses to temperature and the mechanisms for anticipation of seasonal changes have been fixed in the heritage of the species." Extreme cases of this type of temperature adjustment are seen in the highly adapted thermophilic species inhabiting hot springs, *i.e.*, Crenicthys baileyi (Gilbert).

Although there is overlap and interplay among the three terms listed above, Fry's definitions serve as a good basis for the discussion of temperature adjustment and will be used throughout this paper. In addition to the confusion that has arisen from the various terms used to describe the general functional character of biological responses to temperature, there has been equal confusion over the limits and definition of indicator responses used for assessment of the degree of temperature adjustment. The following terms will be used in this paper.

Lethal temperature determinations are probably the single most used thermal characteristic of an organism. This is determined most simply by determining the lethal (L.D.50) temperature. A more complete description of lethal temperature is given by Brett's (1956) zone of tolerance (Fig. 3). Lethal temperatures (upper and lower) are plotted as a function of acclimation temperature and the size of the area bounded by the polygon plot is an indicator of the

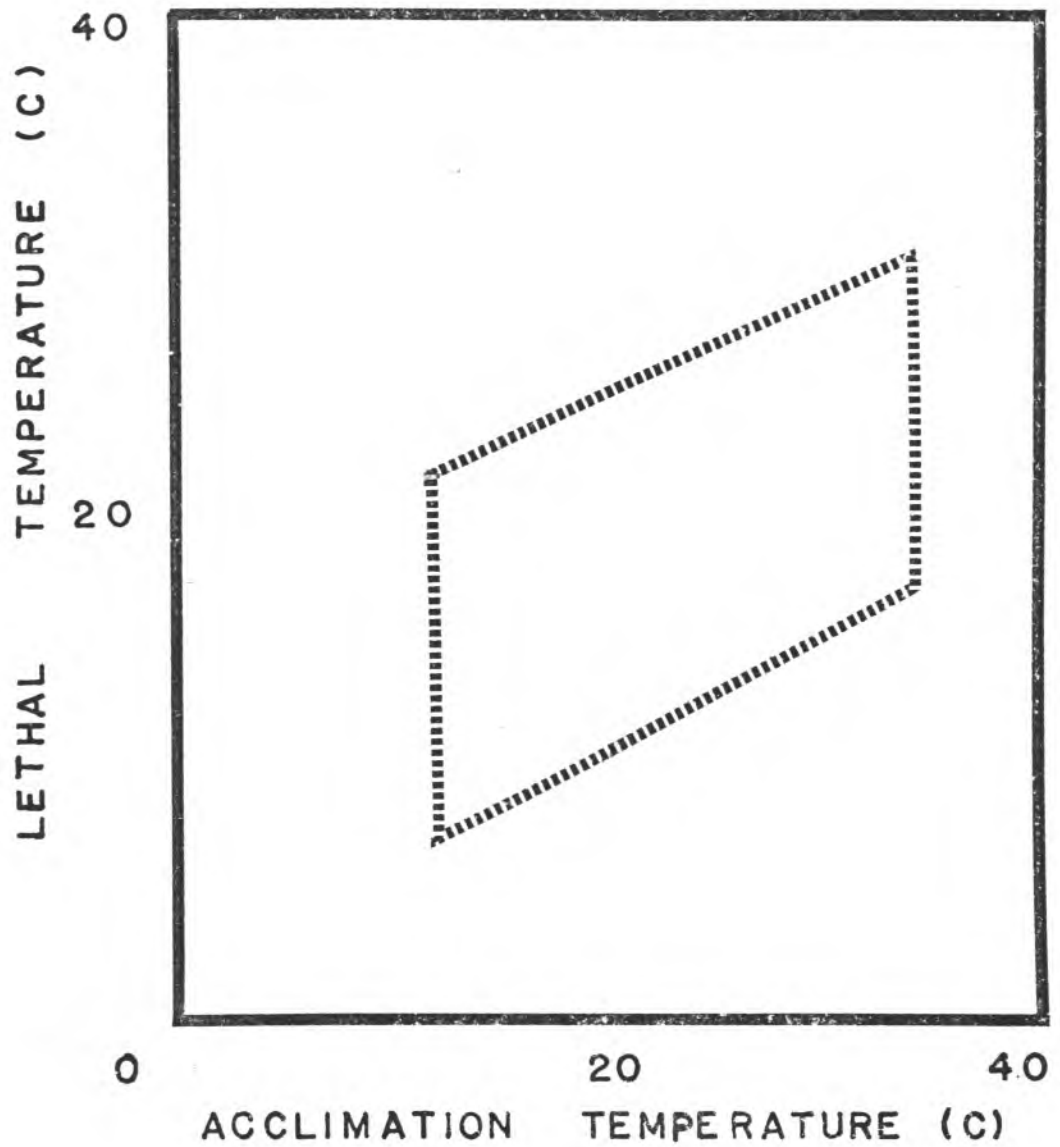


Figure 3. Hypothetical zone of tolerance. Upper and lower parallel lines described upper and lower lethal temperatures within limits set by the vertical lines.

eurythermicity of the organism (expressed as square centigrade degrees or  $C^2$ ). As can be seen in Figure 3, acclimation temperature has a significant effect on the lethal temperature. Thus Fry (1964) has defined the incipient lethal temperature as that temperature at which infinite acclimation results in the death of 50% of the animals. This point lies at the upper right hand corner of Brett's zone of tolerance polygon (Fig. 3). Further extension of the zone could only come about through a change in some environmental factor other than temperature (such as photoperiod—an acclimatization change) or a genetic change that would allow for further acclimation (an adaptive change).

In addition to the effects of temperature adjustments on lethal temperatures, there are several indicators of temperature adjustments used at sublethal levels. Temperature preference is generally positively correlated with the acclimation temperature. Fry (1950) defined final preferendum as that temperature at which acclimation temperature and preferred temperature are the same.

The influence of temperature acclimation on various biological rate functions (i.e., heart rate,  $O_2$  consumption,  $CO_2$  evolution, etc.) has been widely studied. Precht (1958) has described seven patterns of temperature-rate response. The most prevalent response is Precht's type 3. The type 3 response is exemplified by the typical respiratory response of a poikilotherm to an increase in temperature from  $T_1$  to  $T_2$ . As the temperature increases to  $T_2$ , oxygen consumption rapidly

increases to a point; then, as the organism acclimates to  $T_2$ , oxygen consumption decreases to a rate intermediate to the initial rate at  $T_1$  and the initial rate at  $T_2$ . This pattern is typical of most rate acclimation responses in fishes (Fry, 1964).

### The Organismic Level

Fishes often have the opportunity to choose a preferred temperature. Lakes may be thermally stratified, have cool stream inputs, warm shallows, or shaded banks. As noted earlier, preferred temperature usually increases with increased acclimation temperature. An exception to this usual relationship was reported by Garside and Tait (1958) for rainbow trout, Salmo gairdnerii (Gibbons). They reported a decrease in preferred temperature with increased acclimation temperature. Javaid and Anderson (1967), however, repeated the experiment and found the usual relationship for rainbow trout. The latter authors attributed the difference between the two studies to the types of temperature gradients used. The positive correlation between acclimation temperature and preferred temperature seems to be applicable to most fishes.

Fishes have the ability to discriminate amazingly small changes in temperature. Bull (1936), working with several species of fishes, demonstrated their ability to distinguish temperature differences ranging from 0.03 to 0.05C. Bardach and Bjorklund (1957), working with rainbow trout, goldfish [Carassius auratus (Linnaeus)], creek chubs [Semotilus atromaculatus (Mitchill)], bullheads [Ictalurus melas (Rafinesque)], and pumpkinseed sunfish [Lepomis gibbosus (Linnaeus)] found these fishes could discriminate temperature variations as small as 0.05C and that acuity of temperature

perception increased with learning.

The mechanism of this fine temperature discrimination has been puzzling, but recently some light has been shed on the subject. Hammel, Stromme, and Mhyre (1969) found that the rostral part of the brain that is important in the "escape" response (avoidance of lethal temperatures) of arctic sculpins, Myoxocephalus scorpioides (Fabricius).

Greer and Gardner (1970) have isolated seven positively temperature responding and five negatively temperature responding neurons in the brain of the brook trout. Fishes, then, have the ability (under special laboratory conditions) to perceive temperature variations of 0.05C or less and can distinguish between rising and falling temperatures.

Brett (1956) reported that despite the innate capability of fish to respond to such small temperature changes, they seldom do so in nature. Temperature preference in nature is blurred by the effects of light, social behavior, and feeding behavior. Natural temperature fluctuations often exceed the 0.05C level described above and such fluctuations are ignored under most conditions. However, Brett added gradient perception may become important in special situations such as migration or a condition of temperature stress (Brett, 1956).

In addition to seeking out preferred temperatures, fish can regulate their activity levels in an effort to attain the most metabolically efficient mix of food intake, growth and



muscular energy output. For example, spontaneous activity and performance (maximum sustained forced swimming speed) have been shown to be highest in the area of the preferred temperature (Brett, 1956; Beamish, 1964). Activity decreases above and below this temperature.

### The Systemic Level

It has been hypothesized that temperature adjustments observed at the organismal level might also be seen at the systemic level (Prosser, 1962). The nervous system is especially likely to exhibit such adjustments due to its regulatory role. Roots and Prosser (1962) demonstrated that the temperature of cold blockage of reflex responses (movement responses to electrical and physical stimulation) decreases with decreasing acclimation temperature in goldfish and bluegill. The cold blockage of a conditioned response (a learned temporary cessation in opercular movement in response to light stimulation) showed the same pattern as the reflex response with respect to decreasing acclimation temperature, but cold blockage of the conditioned response always occurred at temperatures 5-10C higher than the reflex response for a given acclimation temperature. They concluded that primary cold blockage occurred within the central nervous system. Konishi and Hickman (1964) measured a midbrain spike potential (evoked by electrical stimulation of the retina) of rainbow trout under acclimation to a new temperature. Transfer of fish acclimated at 10C to 4C resulted in an average

lengthening of the responses spike (slowing down) of 39%. This lengthening decreased with acclimation time up to 21 days when it was down to 18% above the 10C controls. Transfer of the 10C acclimated fish to 16C resulted in a shortening of the spike, but no compensatory lengthening with acclimation time was observed. They concluded that acclimation exhibits itself as a compensatory increase in biophysical properties of nervous tissue at low temperatures rather than a compensatory decrease at higher temperatures. They acknowledged the discrepancy between their findings and those based on metabolic rate which reflect a compensatory decrease in oxygen consumption upon warm acclimation (Evans, Pardue, and Hickman, 1962). Their results indicate independent nervous and metabolic acclimation compensation.

Both cold and heat death in fishes have been attributed to osmoregulatory failure. Doudoroff (1945) and Brett (1952) found evidence of osmoregulatory failure in the cold death of the killifish Fundulus parvipinnis (Girard) and the sockeye salmon, Oncorhynchus nerka (Walbaum). Heinicke and Houston (1965a) found a marked decrease in plasma chloride and an increase in tissue hydration accompanied heat death in the goldfish.

Within the normal temperature tolerance zones of fishes there is some disagreement over the relationship between temperature and the various aspects of osmoregulation. Hoar and Cottle (1952) reported a direct relationship between tissue

water content and acclimation temperatures from 5 - 35C in the goldfish. Heinicke and Houston (1965b) reported a slight decrease (4.3%) in plasma chloride, and an increase (36.1%) in plasma potassium in goldfish upon acclimation at 30C from an initial temperature of 20C. They found no difference in plasma sodium, tissue potassium, tissue chloride or tissue water content. The lack of change in tissue water content demonstrated in study is in disagreement with the previously cited work of Hoar and Cottle (1952). Heinicke and Houston (1965b) attributed the disagreement to incomplete acclimation in the fish of Hoar and Cottle (1952). The time required for complete osmoregulatory acclimation was approximately 10-12 days (except tissue water content which took approximately three weeks to stabilize), according to Heinicke and Houston (1965b). These authors concluded that though a change in acclimation temperature induces initial changes in osmoregulatory ability, upon completion of acclimation, compensatory changes in osmoregulatory activities result in a steady state condition virtually the same as the original ionic status.

Parvatheswararao (1967), working with Etropus maculatus, (Gill), reported several osmoregulatory changes upon a change in acclimation temperature from 10 to 35C. Tissue water content in the brain, liver, and muscle increased by 4, 6, 8, and 3% respectively. Plasma  $Mg^{++}$  and  $Ca^{++}$  increased (8 and 10% respectively), while  $Na^{+}$ ,  $K^{+}$ , and  $Cl^{-}$  decreased

(16, 8, and 40% respectively). Based on the effects of these ions on cellular metabolism (Boyer, 1953; Kaye and Mommaerts, 1960; Walser, 1960; Pampathi Rao, 1963) Parvatheswararao concluded that the observed ionic changes would tend to retard nerve and muscle activity at the higher acclimation temperature. This would be the expected effect of ionic changes if they were assumed to enhance the Prect type three acclimation previously discussed.

Among systemic responses to temperature, oxygen affinity of the blood has been one of the greatest areas of interest. Anthony (1961) reported that though high temperature acclimation increased erythrocyte number, a compensatory decrease in erythrocyte size gave a net result of no change in  $O_2$  affinity. More recent studies (Slicher and Pickford, 1968; Houston and DeWilde, 1968; Grigg, 1969) indicated an increase in oxygen affinity as well as erythrocyte number upon high temperature.

Fishes are very efficient in the utilization of blood oxygen. Itazawa (1970) demonstrated 60-80% utilization in fish tissue as opposed to 24-34% in mammals. This is evidenced by their ability to tolerate low oxygen concentrations. Hubbs, Clark, and Hettler (1964) reported the presence of Crenichthys baileyi (Gilbert) in thermal springs at a temperature of 37.3C and oxygen concentration of 0.9ppm. C. baileyi showed no signs of stress and were obviously highly adapted to their environment. However, even fishes adapted

to a much less stressful environment have been shown to be tolerant of a wide range of temperature-oxygen concentration combinations. Spitzer, Marvin and Heath (1969) found bluegill oxygen consumption to be independent of oxygen concentration over a wide range of concentrations at temperatures up to 25C. At 30C the oxygen consumption showed oxygen concentration dependence as evidenced by a rapid decline in oxygen at the lower oxygen concentrations (below 3ppm).

#### The Molecular Level

It has been hypothesized that enzyme systems must reflect typical Precht acclimation curves (Read, 1964). This conceivably could be accomplished by quantitative changes in enzymic reaction rates or by qualitative shifts in enzyme pathways or a combination of both. Ekberg (1958) demonstrated a qualitative enzymic change. Upon cold acclimation there was a shift from the usual Embden Meyerhoff pathway to the hexose monophosphate shunt in the gills of goldfish. Similar results for the goldfish were reported by Hochachka and Hayes (1962). Freed (1965) demonstrated a quantitative change. Cold acclimation caused a translation to the left in the cytochrome oxidase rate curve but no rotation (no change in acutely measured  $Q_{10}$ ). Similar results were reported by Dean and Vernberg (1965) for carbohydrate metabolism in several crab species.

The mechanism of such enzymic changes has been attributed to various things. The thermostability of certain enzyme

systems has been shown to be positively correlated with environmental temperature (Mutchmor and Richards, 1961; Ushakov, Vinogradov, and Kusakina, 1962; Kusakina, 1963). However, Ushakov and Kusakina (1962) and Freed (1964) demonstrated no correlation between acclimation temperature and enzyme thermostability. At any rate, in all these studies the range of enzyme thermostability far exceeded the lethal limits for the whole organism and it is unlikely that changes in enzyme thermostability have any direct effects in the acclimation process.

Somero (1969) demonstrated that in some enzyme systems, the enzyme-substrate affinity is reduced with an increase in temperature. This would tend to decrease the reaction rate in the compensatory fashion of Precht type three acclimation.

From the preceeding discussion it is evident that all levels of biological organization show at least some characteristics of the compensatory nature of temperature adjustment.



## RESULTS

### Physical and Chemical

Tradinghouse Reservoir was well mixed throughout the year and had no chemical or thermal stratification (Table 2). The difference between inflow and outflow temperatures (stations 1 and 3) averaged about 9C for the year (Fig. 4). The temperature of the main body of the reservoir was rarely influenced by the thermal plume and was never raised more than one or two degrees. The high conductivity of the 17 May 1972 sample was due to Brazos River water pumped in near station 2 (Fig. 1). Conductivity was lower on 9 March 1972, due to lack of pumping and dilution from rainfall. Alkalinity, hardness, silica, and sulfate concentrations were typical for this area. No factors known to be detrimental to fishes were observed.

From the scant data available on Lake Creek Reservoir, it appeared to be very similar to Tradinghouse Reservoir (Table 3). The temperature profiles of the discharge canals of the two reservoirs indicated Tradinghouse Reservoir was at a higher temperature by about 8C throughout February 1972 (Fig. 5).

### Age and Growth

The histogram and probability plot of the largemouth black bass from samples 1 and 2 appear in Figures 6 and 7.

TABLE 2

TRADINGHOUSE RESERVOIR PHYS-  
ICAL AND CHEMICAL DATA,  
B=BOTTOM; S=SURFACE

Date	Sta- tion	Temp. (°C)		Dissolved Oxygen (ppm)		Conduc- tivity (μmhos)		pH	
		B	S	B	S	B	S	B	S
8 March 1971	1	11.0	11.0	11.5	12.0	---	---	8.5	8.5
	2	11.0	12.0	12.0	10.0	---	---	8.7	8.7
	3	11.0	11.0	10.0	10.0	---	---	8.7	8.7
	4	11.0	11.0	10.0	10.0	---	---	8.6	8.6
12 April 1971	1	16.0	16.0	8.8	9.0	---	---	8.5	8.5
	2	17.0	18.0	9.4	9.5	---	---	8.6	8.6
	3	21.0	21.0	8.4	8.4	---	---	8.6	8.5
	4	27.0	27.0	9.0	9.0	---	---	8.6	8.7
17 May 1971	1	21.5	22.5	6.8	7.4	990	990	7.4	7.4
	2	23.5	24.0	8.8	8.7	990	920	7.6	7.6
	3	29.0	29.0	---	8.3	---	910	---	7.8
	4	32.5	32.5	8.5	8.3	960	980	7.8	7.8
18 Sept. 1971	1	29.0	29.0	10.0	10.0	---	---	8.6	8.5
	2	29.0	29.0	5.8	10.0	---	---	8.0	8.4
	3	29.0	29.0	10.0	10.0	---	---	8.2	8.4
	4	33.0	33.0	9.4	9.2	---	---	8.4	8.4
6 Nov. 1971	1	21.0	21.0	7.0	7.0	---	---	---	---
	2	20.0	20.0	7.2	7.2	---	---	---	---
	3	22.0	23.0	7.5	7.5	---	---	---	---
	4	---	29.0	---	6.6	---	---	---	---
8 Dec. 1971	1	13.0	13.0	9.8	9.8	---	---	7.5	7.5
	2	13.0	13.0	10.1	10.1	---	---	7.5	6.3
	3	14.0	14.0	10.2	10.2	---	---	---	7.0
	4	---	23.0	---	9.4	---	---	---	7.0
27 Jan. 1972	1	---	12.3	---	10.0	---	---	---	---
	2	---	12.5	10.0	9.8	---	---	---	---
	3	---	14.0	---	9.8	---	---	---	---
	4	---	22.0	---	9.6	---	---	---	---
9 March 1972	1	17.0	17.0	9.3	9.3	600	600	8.2	8.3
	2	17.0	17.0	9.3	9.4	650	625	8.0	8.2
	3	---	17.0	---	9.3	---	600	---	8.2
	4	---	32.0	---	9.3	---	720	---	8.3



TABLE 2 (continued)

Date	Sta- tion	Alkalinity ppm $\text{CaCO}_3$		Total Hardness ppm $\text{CaCO}_3$		$\text{SiO}_2$ ppm		$\text{SO}_4$ ppm	
		B	S	B	S	B	S	B	S
8 March 1971	1	140	141	224	220	1.0	1.0	---	---
	2	140	140	220	220	0.8	0.8	---	---
	3	138	140	220	224	0.3	0.3	---	---
	4	138	138	220	216	0.3	0.5	---	---
12 April 1971	1	144	141	232	230	none		90	90
	2	139	139	224	224	detec-		84	84
	3	132	134	224	226	table		84	90
	4	138	140	232	228			84	86
17 May 1971	1	134	131	224	216	1.7	1.5	97	96
	2	126	125	216	216	1.5	1.5	98	101
	3	---	130	---	216	---	1.5	---	103
	4	125	126	224	240	1.5	1.5	103	101
18 Sept. 1971	1	106	105	---	---	---	---	---	---
	2	109	107	---	---	---	---	---	---
	3	107	105	---	---	---	---	---	---
	4	107	104	---	---	---	---	---	---
6 Nov. 1971	1	---	---	187	181	2.5	2.3	76	64
	2	---	---	181	182	2.3	2.4	64	70
	3	---	---	---	184	---	2.4	---	76
	4	---	---	---	184	---	2.2	---	83
8 Dec. 1971	1	117	105	182	183	2.4	2.4	50	51
	2	115	115	184	183	2.0	2.4	53	64
	3	---	115	---	179	---	2.1	---	55
	4	---	115	---	182	---	2.4	---	61
27 Jan. 1972	1	---	110	---	176	---	3.0	---	59
	2	115	110	173	172	3.0	2.7	65	45
	3	---	100	---	174	---	2.9	---	65
	4	---	115	---	173	---	3.0	---	50
9 March 1972	1	125	124	175	176	3.0	2.9	95	91
	2	125	124	177	177	2.8	3.0	90	66
	3	---	125	---	178	---	3.0	---	75
	4	---	125	---	175	---	2.9	---	92

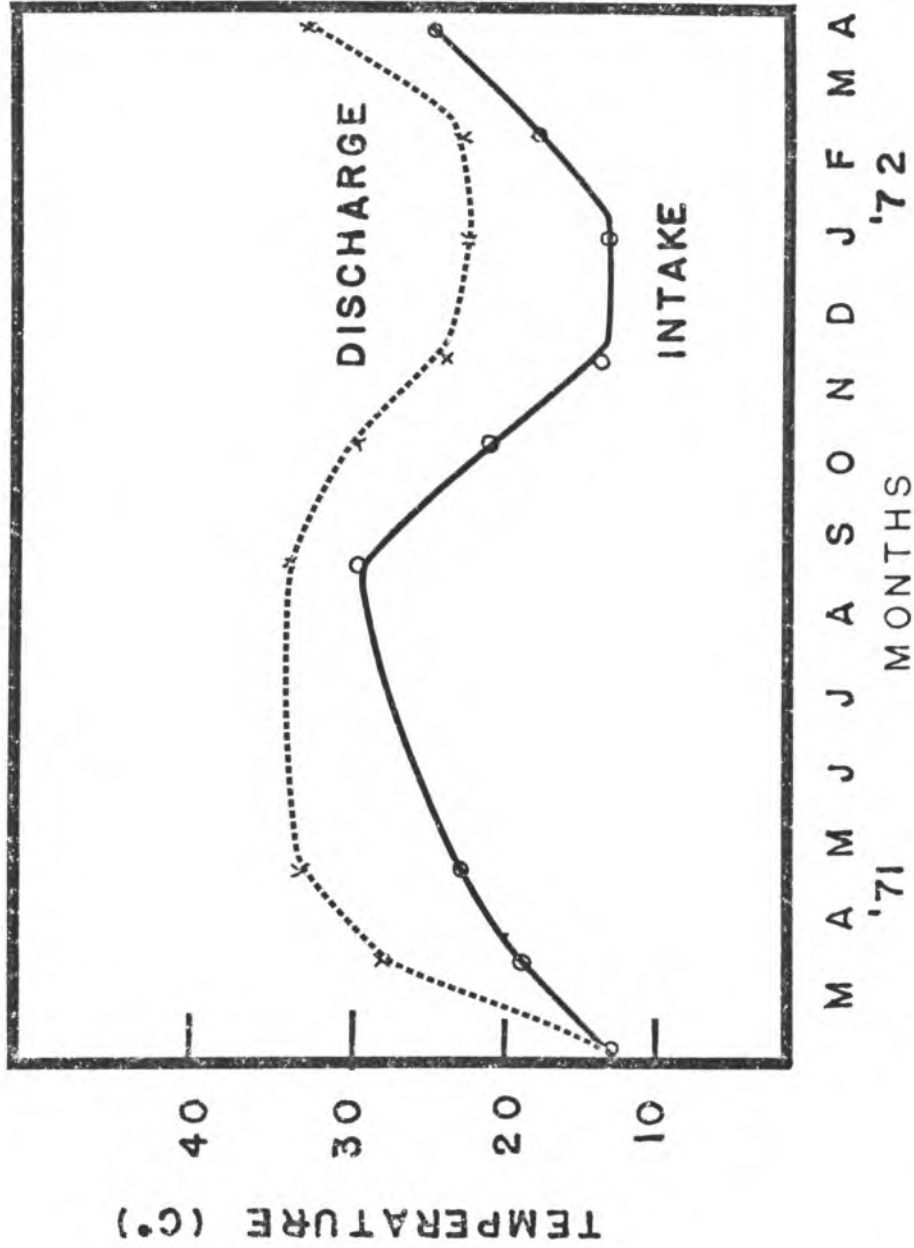


Figure 4. Annual temperature fluctuations in power plant intake and discharge waters on Tradinghouse Reservoir.

TABLE 3  
CHEMICAL DATA FROM LAKE  
CREEK RESERVOIR

	8 August 1971	30 August 1971	9 Sept. 1971
pH @ 25°C	8.50	8.21	8.48
Conductivity @ 25°C ( mhos)	1070	1295	1098
Sulfite as SO <sub>3</sub> (ppm)	0	0	0
Chloride as Cl (ppm)	150.0	137.5	212.0
Chromium as Cr (ppm)	0	0	0
Zinc as Zn (ppm)	0	0	0
Phenols (ppm)	0.24	0	0.06
Total Hardness (ppm CaCO <sub>3</sub> )	-----	-----	216
Alkalinity (ppm CaCO <sub>3</sub> )	-----	-----	140

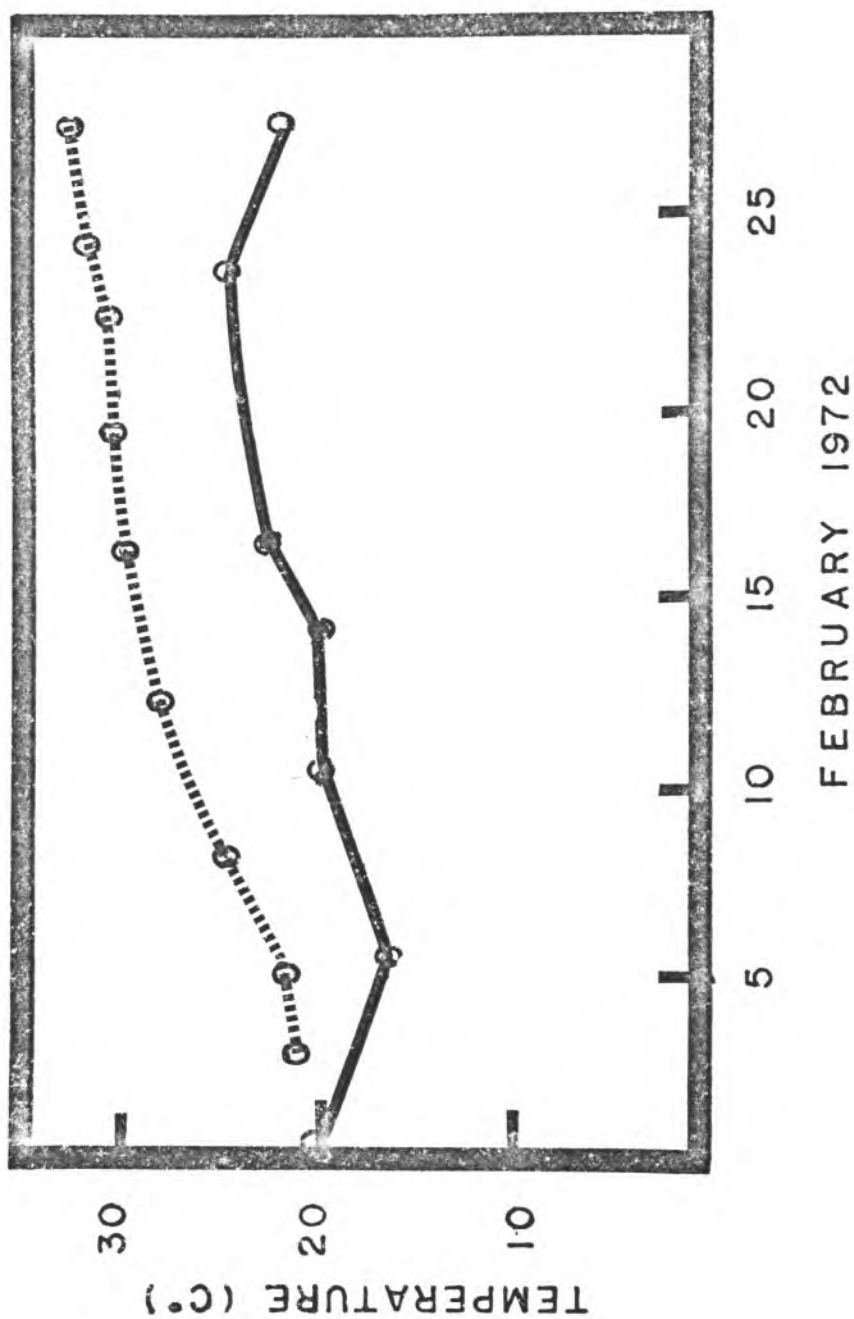


Figure 5. Water temperatures of the discharge canals of Tradinghouse Reservoir and Lake Creek Reservoir for the month of February, 1972.

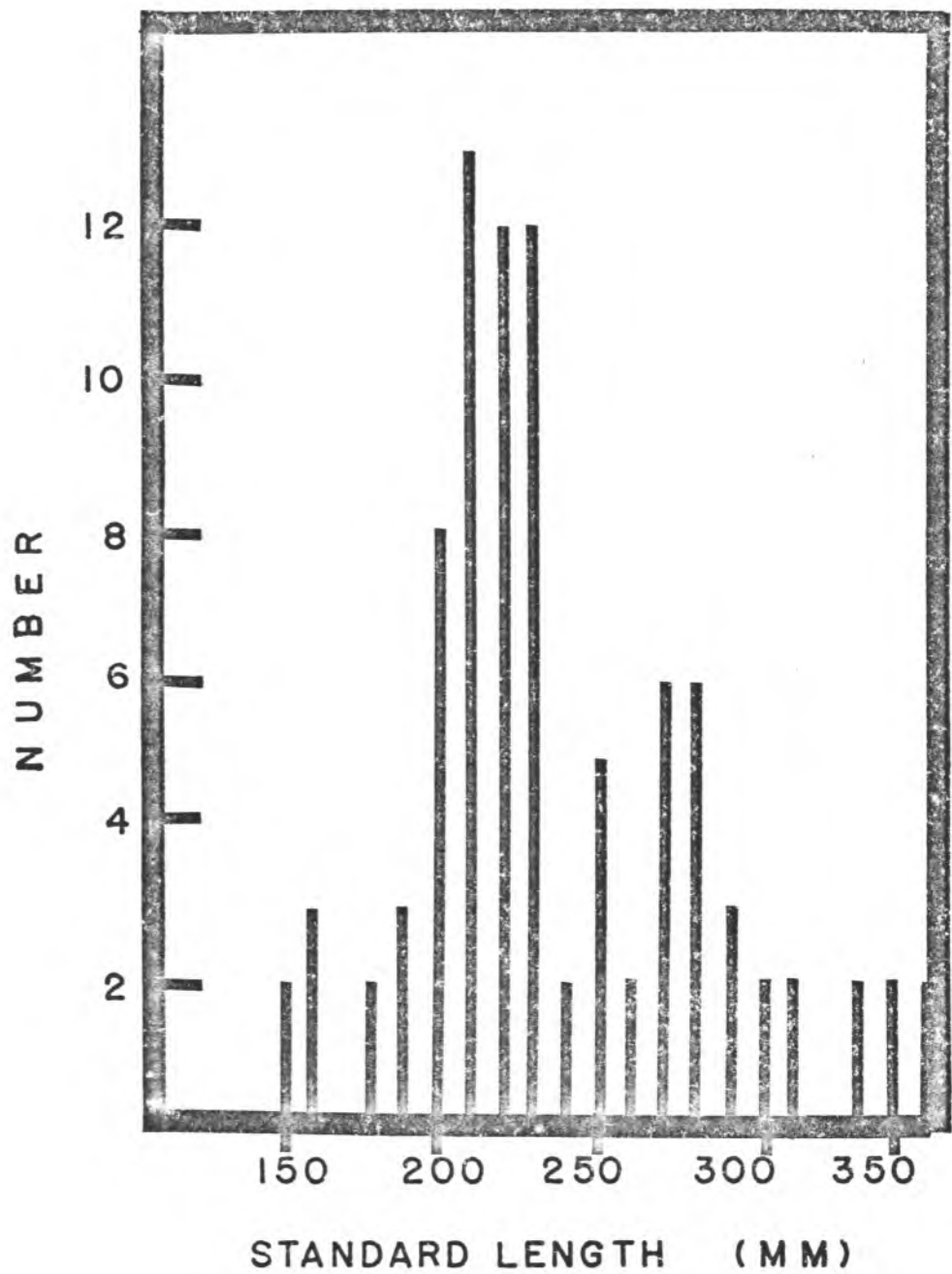


Figure 6. Length-frequency histogram for samples 1 and 2. N=95.

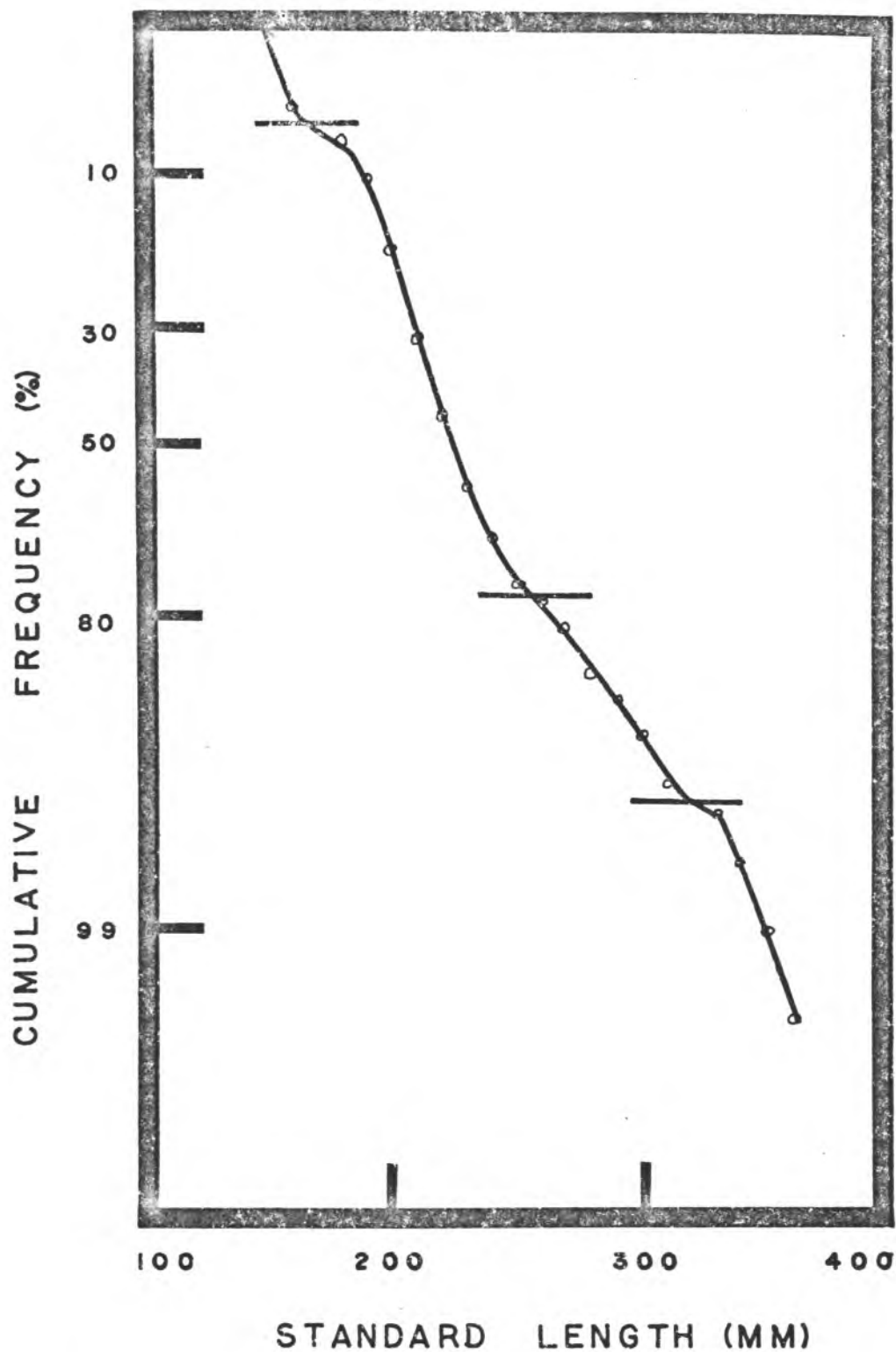


Figure 7. Probability scale length-frequency plot for samples 1 and 2. Horizontal bars indicate points of inflection.

Inflection points in Figure 5 are indicated by the vertical bars. Individual size classes are replotted on an expanded scale (Fig. 8). Mean SL for each age group are given ( $\pm$  1 standard deviation). Samples 5 and 6 are treated similarly and are shown in Figures 9, 10, and 11. On 20 May 1969, 100,000 largemouth black bass fry were stocked in Tradinghouse Reservoir by Texas Parks and Wildlife. These fish are represented by age group III. Age group IV did not show up in samples 6 and 7 due to insufficient numbers of the larger fish. The growth from early summer through late fall (as indicated from differences in mean standard lengths) was 35, 67, and 80mm for age groups I, II, and III respectively.

Since samples 5 and 6 were taken in late fall, when presumably the 1971 growth was complete, it is assumed that the standard lengths obtained from those samples are comparable with back-calculated annual lengths based on scale annulus formation. For comparison with other southern waters, my data are converted to inches in both standard and total lengths. The sites listed above Tradinghouse Reservoir in Table 4 attained greater calculated lengths. The third group contains sites varying in length among age groups with respect to Tradinghouse Reservoir. Means for all data listed, excluding Tradinghouse Reservoir, are given at the bottom. There is no difference between each mean and that of Tradinghouse Reservoir ("t" test,  $p < 0.05$ ). There is no difference

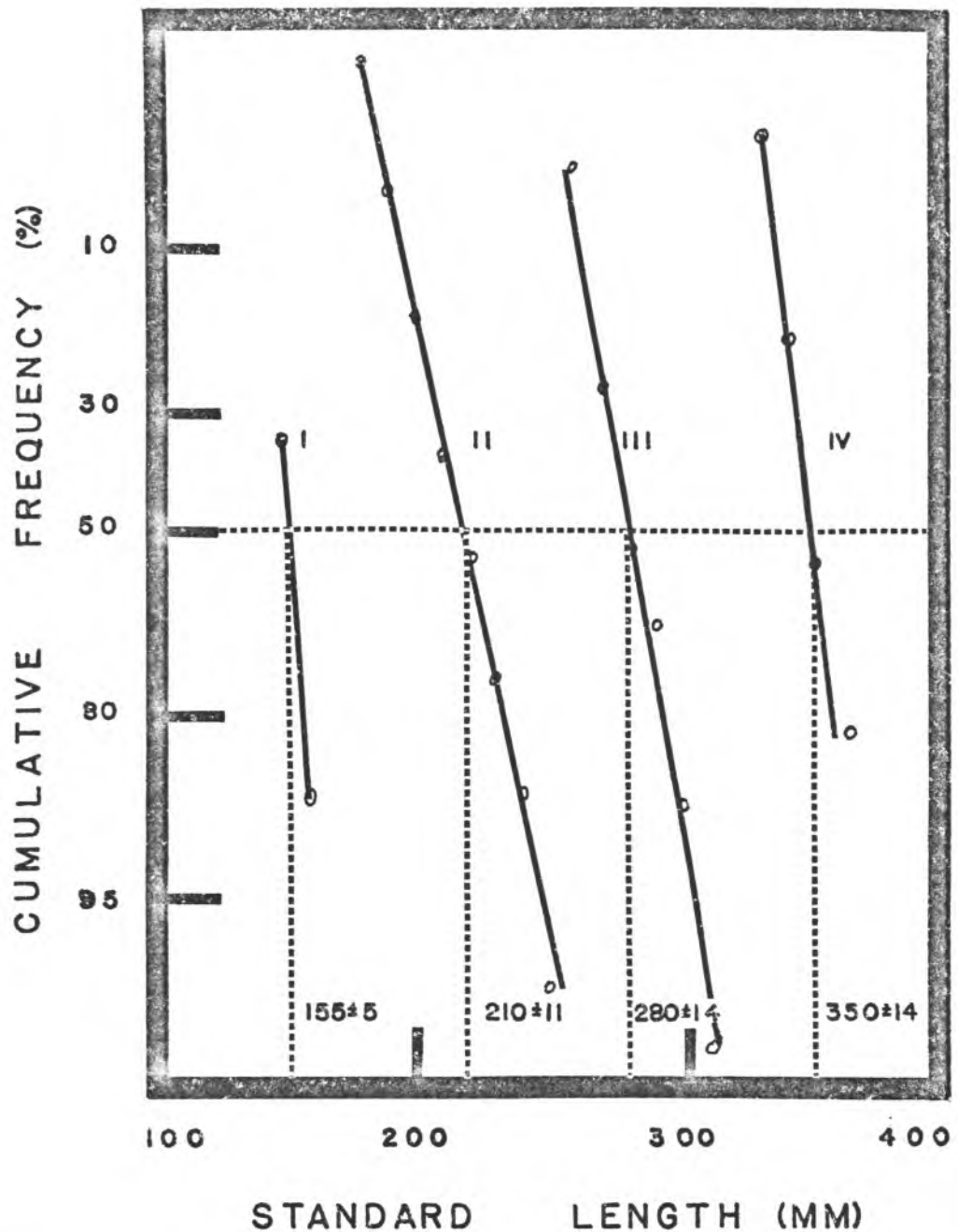


Figure 8. Length-frequency plot for individual size classes for samples 1 and 2. The length corresponding to the 50% point is the mean length of the size class. Means are given  $\pm 1$  S.D.



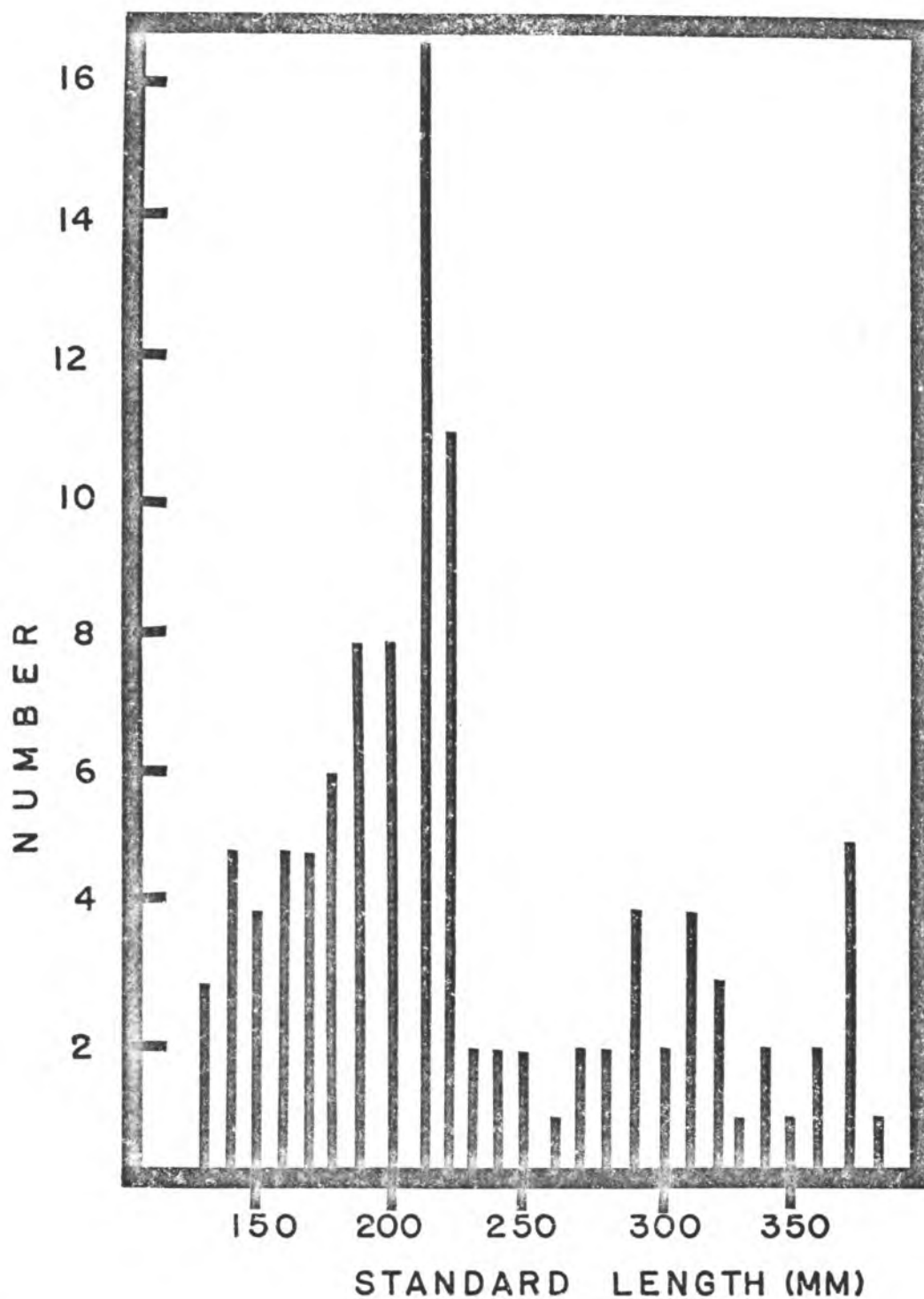


Figure 9. Length-frequency histogram for samples 5 and 6.  $N=101$ .

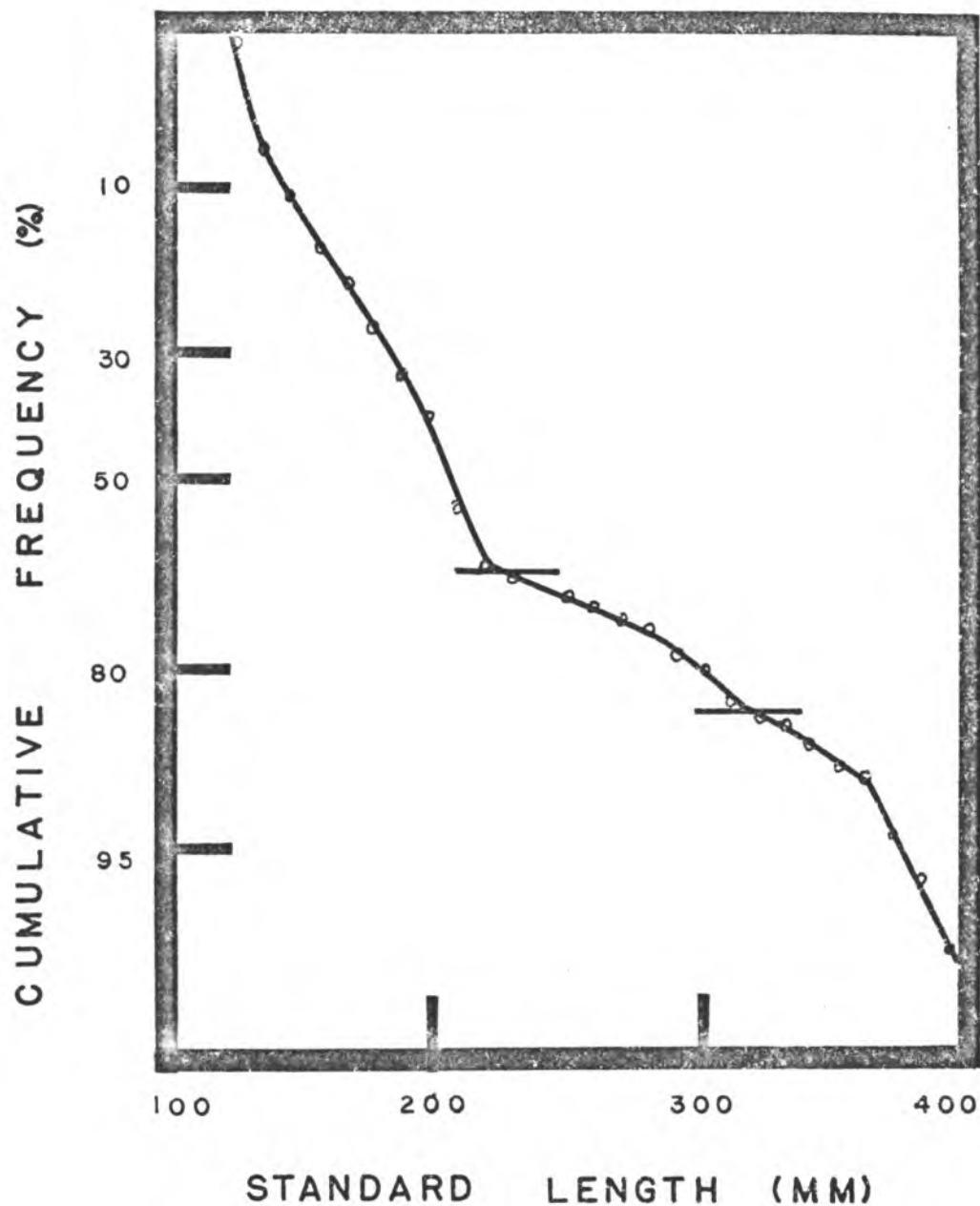


Figure 10. Probability scale length-frequency plot for samples 5 and 6. Horizontal bars indicate points of inflection.

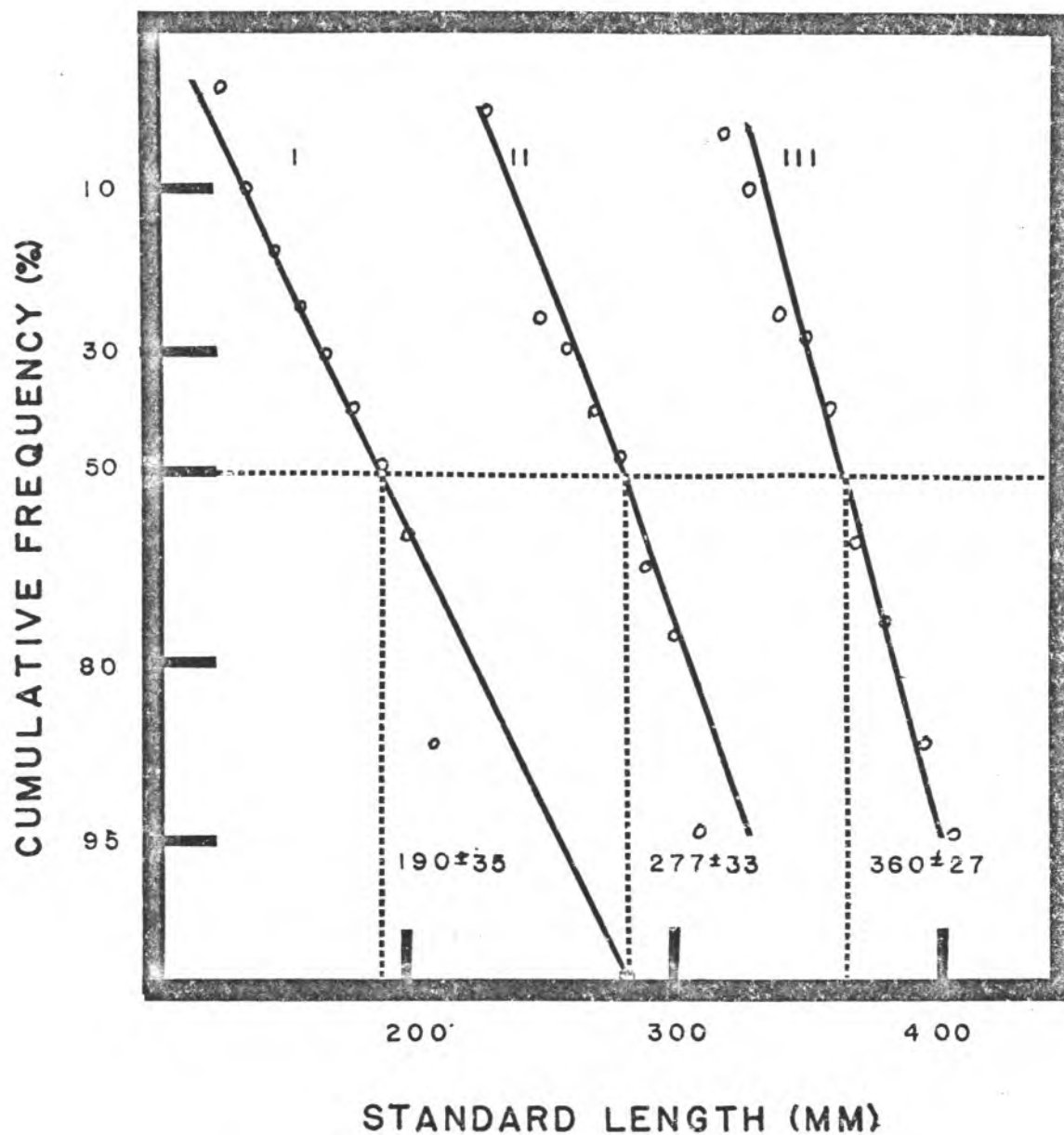


Figure 11. Length-frequency plot for individual size classes for samples 5 and 6. The length corresponding to the 50% point is the mean length of the size class. Means are given  $\pm 1$  S.D.

TABLE 4

COMPARISON OF STANDARD SL AND TOTAL TL LENGTHS  
OF FIRST THREE AGE GROUPS OF LARGEMOUTH  
BLACK BASS FROM TRADINGHOUSE RESER-  
VOIR WITH VALUES REPORTED IN  
THE LITERATURE (UNITS  
ARE INCHES)

Water	State	I		II		III	
		SL	TL	SL	TL	SL	TL
L. Texoma <sup>1</sup>	Okla.	---	8.7	----	12.4	----	15.3
L. Auburn <sup>2</sup>	Ala.	7.0	---	10.6	----	13.1	----
L. Auburn <sup>2</sup>	Ala.	6.6	---	10.3	----	13.2	----
Lousiana <sup>3</sup>	La.	---	7.6	----	11.3	----	14.5
Grand L. <sup>4</sup>	Okla.	---	---	----	9.9	----	13.8
Tradinghouse	Tex.	5.9	7.3	7.8	9.8	10.1	12.3
L. Shawnee <sup>5</sup>	Okla.	---	5.0	----	8.0	----	11.1
*L. Ozarks <sup>6</sup>	Mo.	---	4.8	----	7.7	----	10.5
Illinois R. <sup>7</sup>	Okla.	---	4.6	----	7.8	----	10.4
Silver L. <sup>2</sup>	Ala.	3.2	---	7.1	---	8.8	----
L. Claremore <sup>8</sup>	Okla.	---	3.7	----	7.8	----	10.4
**L. Ozarks <sup>6</sup>	Mo.	---	2.3	----	4.1	----	5.8
Chickamauga R. <sup>9</sup>	Tenn.	---	6.9	----	10.5	----	----
Silver L. <sup>2</sup>	Ala.	5.1	---	9.1	----	11.5	----
Norris Res. <sup>10</sup>	Tenn.	---	6.9	----	12.2	----	14.7
Mean		5.5	5.6	9.3	9.2	11.2	11.8

See appendix for numbered footnotes.  
\*1933-1935; \*\*1936-1938.

in growth increment (difference in length between size classes) between the Tradinghouse Reservoir values and the literature means ("t" test,  $p < 0.05$ ) (Table 5).

#### Organ Weights

Liver, kidney, and spleen weights were each significantly smaller with respect to total weight in Lake Creek Reservoir than in Tradinghouse Reservoir ("t" test,  $p < 0.05$ ) (Figs. 12-14). These results suggest that the largemouth black bass of Lake Creek Reservoir were in a state of increased physiological activity compared with the largemouth black bass of Tradinghouse Reservoir. Kidney weights were closely related to body weight whereas spleen weight had considerable scatter. The reason for this difference is unknown.

#### Gonosomatic Index and Egg Number

Gonad comparisons between largemouth black bass from Lake Creek Reservoir and Tradinghouse Reservoir discharge canals indicate there was no difference between either male or female G.S.I. means or between mean egg numbers per gram of fish for the two reservoirs (Table 6). Thus there was no indication of differing gonad maturation rates in the largemouth black bass of Tradinghouse Reservoir and Lake Creek Reservoir.

#### Thyroid Activity

There was no difference among the mean thyroid epithelium heights of bass from Tradinghouse Reservoir, Lake

TABLE 5

COMPARISON OF GROWTH BETWEEN FIRST, SECOND, AND  
THIRD YEAR CLASSES OF LARGEMOUTH BLACK  
BASS FROM TRADINGHOUSE RESERVOIR AND  
THE MEAN OF THE VALUES REPORTED  
IN THE LITERATURE

Water	I — II	II — III
	*SL TL	SL TL
Tradinghouse	3.4 4.0	3.3 3.6
Mean	3.8 3.6	1.9 2.6

\*SL = standard length, TL = total length in inches.

TABLE 6

COMPARISON OF MALE AND FEMALE G.S.I. AND EGG  
NUMBER FOR LARGEMOUTH BLACK BASS FROM  
TRADINGHOUSE RESERVOIR AND  
LAKE CREEK RESERVOIR

	Male *G.S.I. (%)	Female G.S.I. (%)	**Egg Number Per Gram X10 <sup>3</sup>
Tradinghouse	.127 ± .031	.569 ± .221	.108 ± .090
Lake Creek	.139 ± .051	.380 ± .147	.122 ± .103

\*G.S.I. (gonosomatic index) =  $\frac{\text{gonad weight (g)}}{\text{total weight (g)}} \times 100.$

\*\*Egg number =  $\frac{\text{total number of eggs}}{\text{total weight (g)}} \pm 1 \text{ SD}$

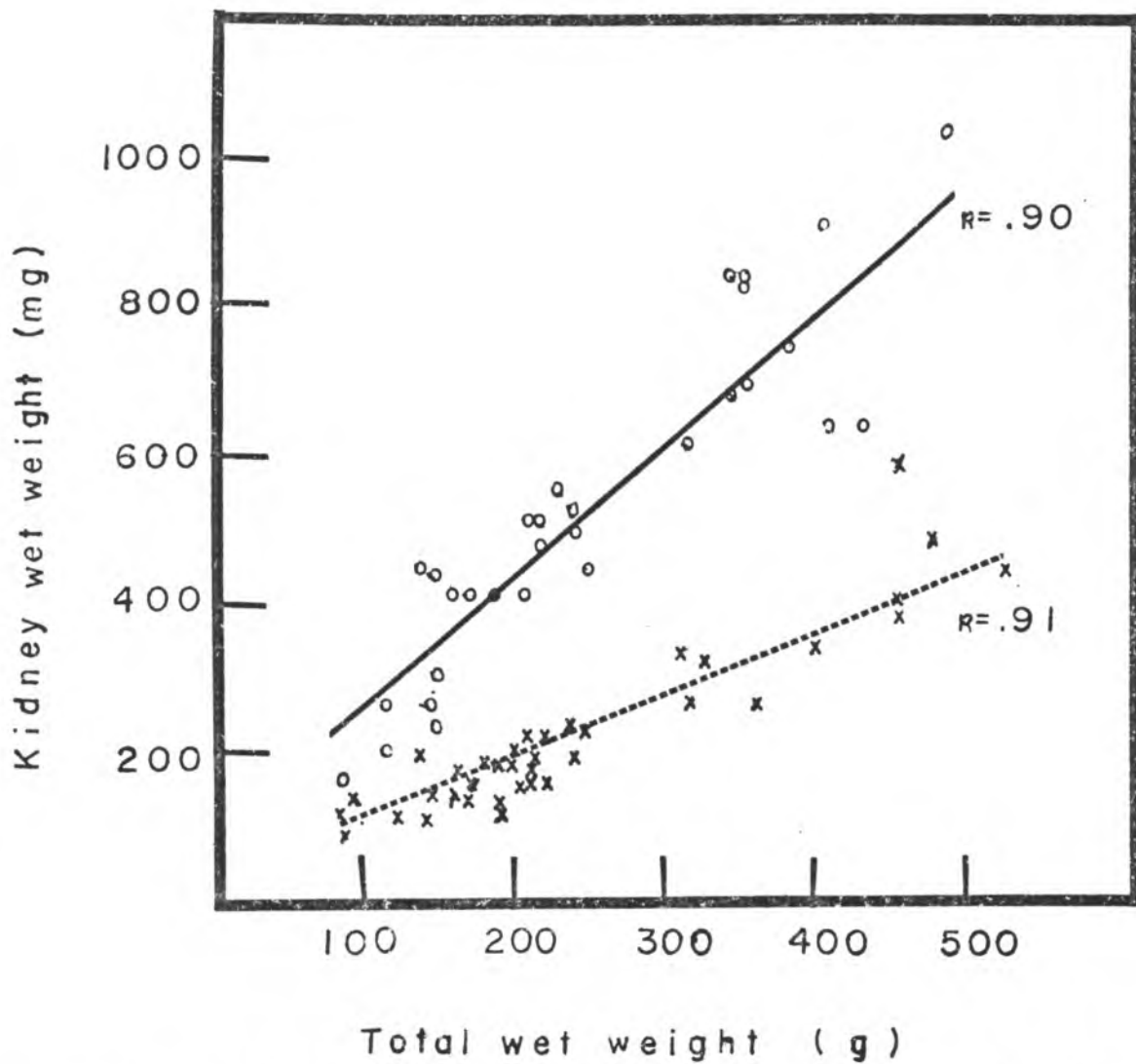


Figure 12. Relationship between total weight and kidney weight for largemouth black bass from Tradinghouse Reservoir (o) and Lake Creek Reservoir (x).  $R$  = Pearson correlation coefficient.

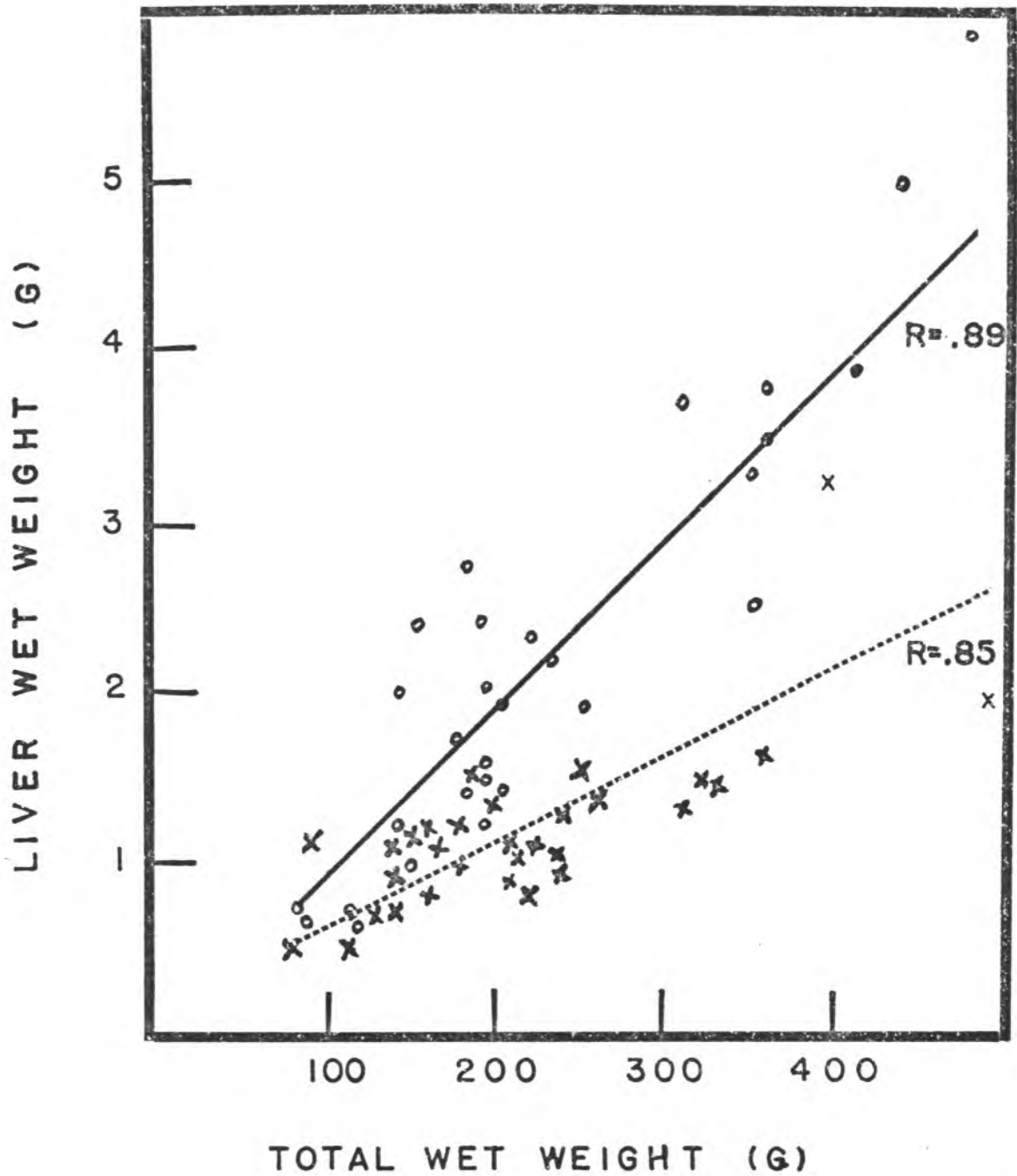


Figure 13. Relationship between total weight and liver weight for largemouth black bass from Tradinghouse Reservoir (o) and Lake Creek Reservoir (x). R = Pearson correlation coefficient.



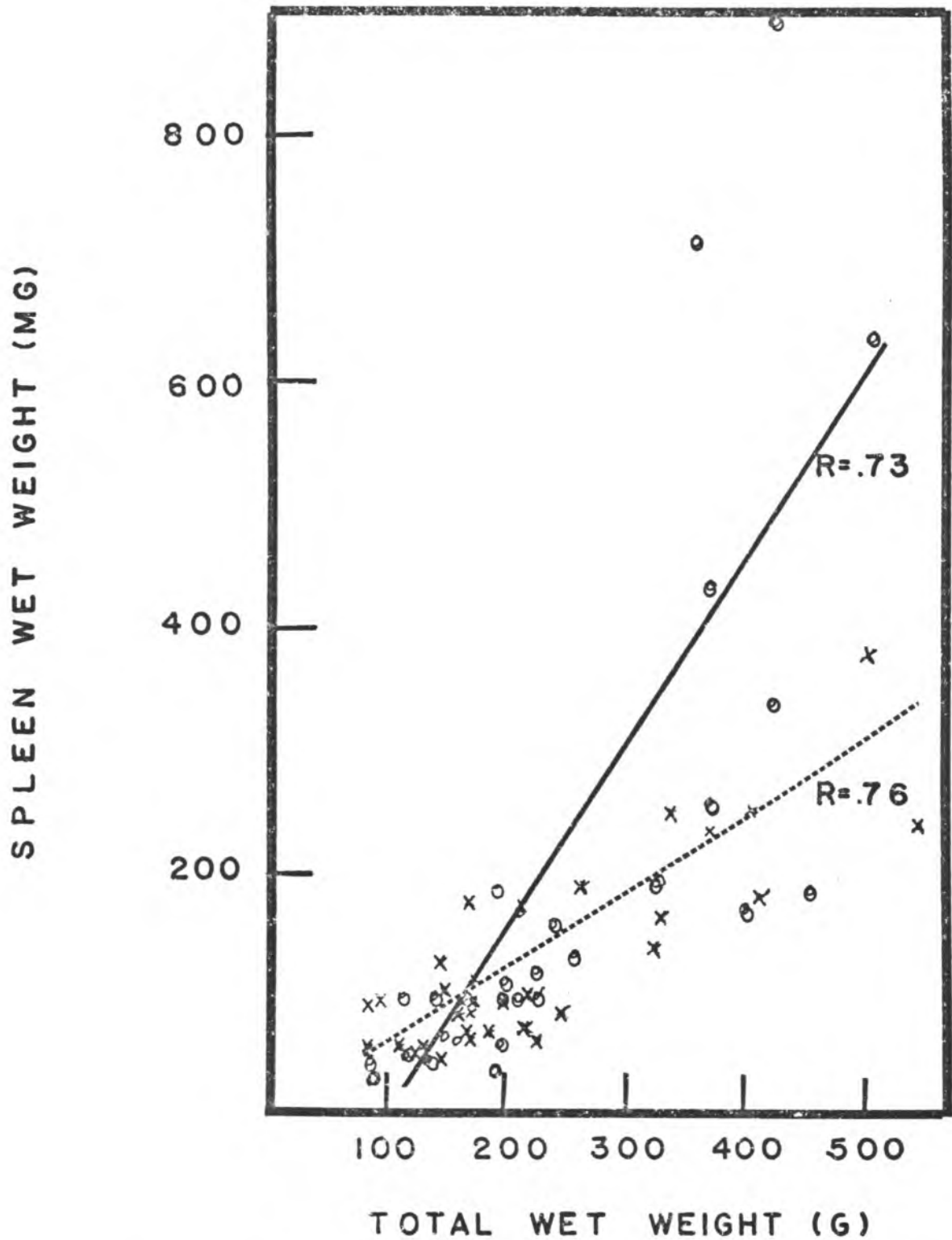


Figure 14. Relationship between total weight and spleen weight for largemouth black bass from Tradinghouse Reservoir (o) and Lake Creek Reservoir (x).  $R$  = Pearson correlation coefficient.

TABLE 7

MEAN EPITHELIUM HEIGHTS OF THYROID FOLLICLES OF  
LARGEMOUTH BLACK BASS FROM THE DISCHARGE  
CANALS OF TRADINGHOUSE RESERVOIR AND  
LAKE CREEK RESERVOIR AND 3 MUSEUM  
SPECIMENS. N = NUMBER OF FISH  
EXAMINED IN EACH CASE

Source	Collection Date	N	Mean ( $\pm$ 1 S.D.) Epithelial Height ( $\mu$ )
Tradinghouse	28 Feb. 1972	20	1.2 $\pm$ 0.4
Lake Creek	27 Feb. 1972	20	1.4 $\pm$ 0.6
Museum	March 1972	1	1.2 $\pm$ 0.7
Museum	July 1968	1	0.8 $\pm$ 0.7
Museum	Aug. 1970	1	0.7 $\pm$ 0.6

Creek Reservoir, or the three museum specimens (Table 7). All tissue examined had anatomical evidence of low thyroid activity. The epithelium was low cuboidal and the follicles were spherical. The June and August museum specimens exhibited complete hypertrophy, as evidenced by a lack of follicular colloid and near squamous follicular epithelium.

#### K Value

There was no significant difference among the mean ("t" test,  $p < 0.05$ ) K values for the fish taken from the discharge canals of the Tradinghouse Reservoir and Lake Creek Reservoir and from the main body of Tradinghouse Reservoir (Table 8).

TABLE 8  
MEAN K FACTORS (COEFFICIENT OF CONDITION)  
FOR LARGEMOUTH BLACK BASS GROUPS  
USED IN THIS STUDY

	K
Tradinghouse Canal	0.252
L. Creek Canal	0.248
Tradinghouse Lake	0.266

## DISCUSSION

### Physical and Chemical Characteristics of Tradinghouse Reservoir

One of the important physical characteristics of Tradinghouse Reservoir is the absence of both summer and winter thermal stratification. However, this is not unique to Tradinghouse Reservoir among other central Texas reservoirs. Kimmel (1968) reported a similar condition in Lake Waco. He attributed the condition to shallowness and the lack of wind protection. Drew and Tilton (1968) suggested that continuous mixing is characteristic of Texas reservoirs receiving power plant effluents. They further suggested that the increased nutrient availability caused by such continuous mixing was responsible for retarding the characteristic decline in sport fishing that is seen in non-thermally influenced water. This does not appear to be all that is involved in view of the fact that good largemouth black bass fishing failed to ever develop in continuously mixing Lake Waco (Chen, 1969).

Though the total ion concentration, as measured by conductivity in Tradinghouse Reservoir, is somewhat high (990  $\mu$ mhos) at times, this probably plays a relatively minor role in the growth of largemouth black bass. Indirectly, however, these ions may contribute to largemouth black bass growth by stimulating primary production which can lead to a generally more productive ecosystem.

## Growth

The growth of largemouth black bass in Tradinghouse Reservoir is average compared with the literature reviewed for other southern waters. The estimated condition factor ("K") of 0.266 is somewhat higher than the 0.245 (average for first three age groups) values reported by Stroud (1948) for the largemouth black bass of Norris Reservoir (Tennessee). Growth of bass in Norris Reservoir and Tradinghouse Reservoir (somewhat higher in one age class and lower in two age classes--see Table 4) were very similar. Cooper, Hidu, and Anderson (1963) demonstrated a correlation between growth rate and the "K" factor in largemouth black bass. If this were true for Tradinghouse and Norris Reservoirs, it further indicates that Tradinghouse Reservoir lies near the center of the range of growth reported in the literature.

The complex interrelationships between growth and temperature have been recently reviewed by Paloheimo and Dickie (1966). By reworking the data of many investigations and fitting them to a common equation, they found good agreement (for values relating total metabolism, weight, and ingestion) between studies based on food consumption and those based on the measurement of total metabolism. An increase in temperature will cause an increased metabolism for a given size fish without changing the slope of a line describing the relationship between weight and metabolism. An increased metabolism might cause an increase in feeding rate which in turn could

lead to greater growth.

There have been many field studies relating environmental temperatures to growth in fishes. For example, mean annual temperature has been positively correlated with growth in smallmouth bass, [Micropterus dolomieu (Lacepede)] (Watt, 1959; Latta, 1963). Kramer and Smith (1960) found the annual growth in largemouth black bass to be correlated with the temperature experienced up to the first day of August (when growth ceased in Minnesota). Coble (1967) found conflicting results on the relation of annual temperatures to growth in smallmouth bass, but it seemed that the growth of the older fish was the least affected by environmental temperature. Kramer and Smith (1960) found the growth rates of largemouth black bass embryos, fry, and fingerlings to be positively correlated with temperature. Strawn (1961), also working with largemouth black bass fingerlings, found increased growth with temperature increases up to 30C, but a decrease at 32.5C.

Largemouth black bass of Tradinghouse Reservoir could conceivably move in and out of the thermally affected portions of the reservoir and thus increase their mean annual temperature. Drew and Tilton (1970) noted that the largemouth black bass in thermally affected Texas reservoirs migrate into warmer waters in the winter months and leave during the hot summer months. This type of migration was confirmed in this study through a number of conversations with local fishermen. The extent of this type of migration throughout Tradinghouse

Reservoir is unknown. Radio-tagging and tracing of fish movement with relationship to the thermally affected portion of the reservoir would help establish the significance of the thermal effluent with respect to the mean annual temperature experienced by the "average fish."

Though temperature obviously plays an important role in the control of bass growth, especially in the young, there are many other factors involved as well. Pardue and Hester (1961), working with experimental largemouth black bass populations under a variety of conditions, demonstrated a range of variation in the first year's growth of 1.9X-20.3X (factor relating smallest fish to largest fish). The variation was positively correlated with population density and negatively correlated with rate of growth.

Since Tradinghouse Reservoir is a relatively young reservoir, it is doubtful that it has developed a high density largemouth black bass population; thus an average or above growth rate would be expected. This was demonstrated in the comparison of bass growth in Tradinghouse Reservoir and other southern waters.

One unusual aspect of the growth data presented in this study is the increasing growth increment with increasing age groups (Tables 4 & 5). This can only be explained by the presence of conditions which favored the growth of the larger fish of this study. Such a situation might be brought about by an unusual condition of food availability. When



Tradinghouse Reservoir was first stocked (the age group II fish of this study), there were probably good feeding conditions for young largemouth black bass. Young largemouth black bass eat primarily nauplii, rotifers, cladocerans, and occasionally algae. At about 30mm they shift to large cladocerans, immature and adult insects, and some small fish (Kramer and Smith, 1960). These kinds of organisms would be expected to abound in water over fertile, newly inundated, land. As the lake has grown older these food items may have decreased in density under heavy grazing. Gill net surveys indicate Tradinghouse Reservoir presently has an unusually abundant (as high as 22% by weight of total catch) shad population (Lind and Venables, unpubl. data). This large food source is unavailable to the smaller fish of this study. Thus, under the preceeding conditions, there is a situation which is highly favorable for the older (age groups II and III) fish of this study.

Similar situations are presented in Table 4. Lake Shawnee (Oklahoma) has growth increment of 3.0 and 3.1 between age groups I-II and II-III, respectively. The two studies on the Lake of the Ozarks (Missouri) show almost identical growth increments between age I-II and II-III (2.9-2.8 and 1.8-1.7).

Despite the evidence for the influence of temperature on growth related rate functions, temperature effects in Tradinghouse Reservoir are probably masked by density



dependent factors (especially availability of food). The growth of largemouth black bass in Tradinghouse Reservoir is apparently within the limits of variation expected from such density dependent factors.

#### Gonosomatic Index and Egg Number

There are numerous studies relating gonad maturation to environmental temperature. This might be expected from the general increase in rate functions that accompany increased temperature as previously discussed. However, photoperiod effects and hormonal involvement complicate the temperature relationship with gonad maturation rate.

Bullough (1939) reported that both temperature and photoperiod regimes had to be right for spawning in Nortropus cornutus (Agassiz). Courier (1922) reported that the correct temperature alone was necessary for spawning in the threespine stickleback, Gasterosteus aculeatus (Linnaeus). Berenbeim (1968 and 1970) demonstrated a high correlation between mean annual temperature and the onset of spawning in several marine fishes. Billard (1968) found that increasing temperatures from 20-30 C caused an increase in spermatogenesis in the guppy, Poecilia reticulata. Wiebe (1968), on the other hand, found increasing both temperature and photoperiod were necessary to increase spermatogenesis and oogenesis in the sea perch. Schneider (1969) found that increased temperature accelerated gametogenesis in both male and female threespine sticklebacks, when exposed to long

photoperiods. Exposure to short photoperiods at the same temperature resulted in a cessation of gametogenesis. Low temperatures decreased gametogenesis regardless of the photoperiod regime. It appears from the preceding that while increasing temperature can increase the rate of gametogenesis, photoperiod ultimately sets the limits on the time period over which gametogenesis occurs.

The results of this study indicate that there was no difference in gonad maturation rates of the largemouth black bass from the two canals. This is in spite of the fact that the fish from the Tradinghouse Reservoir canal had been exposed to temperatures averaging 8-10C higher for a month prior to the study. This supports the primacy of photoperiod in governing gonad maturation rate, in that the photoperiod regime was common to both canals.

Though there was no difference in the gonad maturation rates of the fish from the two canals, the maturation rate of the canal fish may have been different from the rate of bass from waters unaffected by thermal effluent. Thus it is possible that, though the temperature difference between the two canals had effects too subtle to detect, the increased temperature of both canals may have significantly altered the gonad maturation from the rate at "normal" temperatures for this area. Unfortunately, I was unable to find any data to test this hypothesis.

### Organ Weight Analysis

The results of the organ weight analysis in this study indicated a higher rate of physiological activity in the largemouth black bass from Lake Creek Reservoir discharge canal than in the Tradinghouse Reservoir discharge canal. This is based on the assumption that the relationship between organ weight and physiological activity demonstrated for other fishes (Albrecht, 1969; Peak, 1970; DeWaide, 1970) is valid for largemouth black bass. The basis for the relationship lies in the fact that increased temperature generally results in increased activity as previously discussed. The increased activity causes a shunting of blood from the viscera to the musculature to provide the extra energy needed. This causes a decrease in organ weights. It seems, then, that this relationship would hold for any fish within temperature limits that allow for increasing activity with increased temperature. While other factors (diet, salinity, etc.) could affect the relationship between organ weights and total weight, it is unlikely that any factor other than a general loss of blood (through shunting) would effect all three organ weights as was demonstrated in this study. Assuming the validity of the above relationship for largemouth black bass, this study demonstrated that though the fish of the Tradinghouse Reservoir canal were at a higher temperature (and had been so for at least a month prior to capture), they exhibited a rate of physiological activity lower than that exhibited by the fish

from the cooler Lake Creek Reservoir discharge canal. This can be interpreted a number of ways.

The largemouth black bass from Tradinghouse Reservoir canal might be better acclimated to warm temperatures than those of the Lake Creek Reservoir canal. If this were the case, they might be exhibiting typical Precht type 3 compensation (see section on Temperature Adjustment) allowing a decrease in physiological activity even at the higher temperature. However, this seems unlikely due to the fact that there is no reason for Tradinghouse Reservoir fish to be any better acclimated to their warmer water temperature than for Lake Creek Reservoir fish to be acclimated to their somewhat cooler temperature. In fact, it might be expected that the Lake Creek Reservoir fish would be better adapted for warm water acclimation due to their longer history of exposure to the power plant effluent.

If the fish from Lake Creek Reservoir are assumed to be better acclimated to warm water temperatures, then their increased physiological activity (over that of the fish of Tradinghouse Reservoir) would logically be viewed as an example of inverse compensation (Precht type 5 acclimation). This type of compensation is typified by an increase in activity upon an increase in temperature (after the initial rate increase upon the temperature change) as the animal acclimates.

Inverse temperature compensation seems to be an exception rather than the rule in poikilotherms. Fry (1964)

noted that tissues generally show expected temperature compensation (Precht type 3) but whole animals may not due to various behavioral effects. These behavioral effects include swimming activity and thus could be responsible for the results obtained in this study. However, the scarcity of reports of inverse compensation make this explanation doubtful.

There is a third explanation of the results. As stated earlier, one of the prerequisites for the validity of a relationship between organ weights and temperature, is that the animal must be within temperature limits that allow for increased activity with increasing temperature. It seems likely that the largemouth black bass of Tradinghouse Reservoir canal were beyond the upper end of such limits. Charlton (1960) reported that the scope of activity (difference between active and basal metabolic rates) for largemouth black bass increased from 10-20C and leveled off from 20-30C (30C was highest temperature tested). He reported the maximum cruising speed was at 25C. Beamish (1970) reported increase maximum sustained swimming speed increased with temperature increases up to 30 C, then decreased at 34C. From the preceeding it seems likely that largemouth black bass from Tradinghouse Reservoir canal, which experienced temperatures above 30C for much of the month preceeding capture, were in a temperature zone of decreasing activity. Since the fish from the Lake Creek Reservoir discharge canal had been exposed to much lower

temperatures and were probably not in such a zone of decreasing activity, this would adequately explain the larger organ weights of the Tradinghouse Reservoir discharge canal fish sample.

This last explanation seems to best explain the results. It is likely that rather than demonstrating a greater degree of thermal acclimation in either of the two fish groups, the study demonstrates that the largemouth black bass of Tradinghouse Reservoir canal are in a temperature zone which disallows the greatest activity.

#### Thyroid Analysis

The results of the thyroid analysis indicated that there was no difference in thyroid activity between the fish collected from Tradinghouse Reservoir canal and those collected from the Lake Creek canal. This indicates that the thyroid activity of the largemouth black bass is independent of water temperature. Further, it indicates that thyroxin (TH) probably plays no role in temperature acclimation. There are, however, other ways to interpret the results.

The basis for the analysis of thyroid activity in this study was the measurement of follicular epithelium height. With the advent of radio-iodine techniques, there has been concern over disagreement between the two techniques.

Drury and Eales (1968) reported 3 groups of studies showing positive, negative and no correlation of thyroid



activity (as based on epithelial height of the follicle) to temperature; however, they concluded that thyroid activity, as measured by the uptake and release of radio-iodine, increases with increased temperature. Eales (1964) suggested that thyroid epithelial height is regulated primarily by levels of thyroid stimulating hormone (TSH), mediated through the pituitary. The uptake and release of radio-iodine is independent of the pituitary and can lower the TSH-TH ratio in a situation with rising TH (due to increased temperature) and decreasing TSH. The consequence would be high thyroid activity with low follicular epithelium.

If the preceeding is a valid mechanism, the fish used in this study could have had active thyroid secretion, at levels the same or different from each other. Accordingly, the August museum specimen, though also captured in warm water (undoubtedly it was collected at a temperature in the range represented by the canals), showed very low follicular epithelium and other signs of atrophy due to photoperiod changes. The March museum sample, even though collected in water much cooler than the canal temperatures, had follicular epithelium very similar to the canal samples, again indicating the influence of photoperiod on epithelium height.

It seems likely that photoperiod acts through the brain-pituitary axis to regulate follicular epithelium height. The combined effects of temperature and photoperiod operate in the

manner described above by Eales (1964) with TH secretion rate being governed by temperature within the limits of follicular capability as established by the photoperiod.



## CONCLUSION

From the preceeding discussion it is evident that the addition of thermal effluent from power plants on Tradinghouse Reservoir and Lake Creek Reservoir has had no outstanding effects on the bass populations of the reservoirs. This is due primarily to two characteristics of largemouth black bass.

The first characteristic is the mobility of the largemouth black bass populations. As stated earlier, the largemouth black bass tend to move in and out of the thermally affected areas of the reservoir seasonally. Within the limits of the availability of food, they are at liberty to choose preferred temperatures or to avoid detrimental temperatures. One of the most important questions yet to be answered is, how much time does what percentage of the reservoir's largemouth black bass population experience abnormally high temperatures? This physical link between the hot water and the object of study must be established with much more precision. Only then can the mean annual temperature of the largemouth black bass (not the discharge canal or the open water or some other arbitrary location) be determined and begin to have significance with relation to growth. Bennett (1971) has taken an important step in this direction. He took body temperatures of largemouth black bass in an artificially heated reservoir and tried to correlate the body temperatures to the coefficient of

condition. Though he found no such correlation, he was measuring the only biologically significant temperature.

The second characteristic is the eurythermicity of largemouth black bass. As discussed earlier, increased temperature may result in changes in enzyme-substrate affinity, enzyme pathways, ionic regulation, blood affinity for oxygen, neural and muscular activity. All the preceeding in turn contribute to the sum of effects on total metabolism which in turn affects food conversion efficiency and thus growth.

Thus fish subjected to an increase in temperature would be expected to show an initial general increase in activity. As the animal acclimates, this increase might be eventually partially compensated for by all the various compensatory mechanism previously discussed. Decreased enzyme-substrate affinity in conjunction with quantitative and/or qualitative changes in enzymatic rates and pathways would be expected. The increased oxygen demands brought about by increased activity would be met with increases in erythrocyte number and oxygen affinity of the blood. Neural and muscular activity rates would gradually decrease as impeding ionic shifts occurred. While this compensation is never complete, it greatly extends the temperature zone in which the animal can live and grow.

Largemouth black bass have the ability to withstand a wide range of environmental temperatures. Their eurythermicity is demonstrated by the zone of tolerance shown in Figure 15. The tolerance value of  $965C^2$  is the 19th highest in a list of

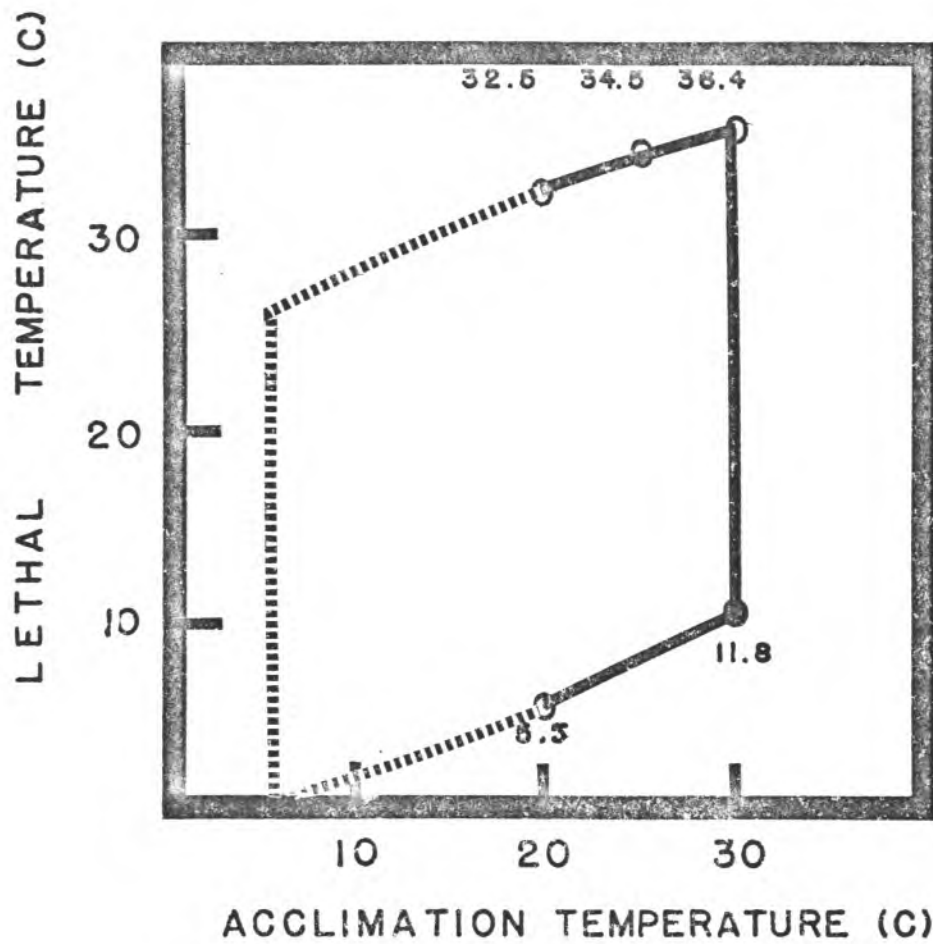


Figure 15. Zone of tolerance for largemouth black bass. Dotted lines indicate interpolations; data from Brett (1956).

23 fishes given by Brett (1956). The upper incipient lethal temperature of 36.4C is well above the hottest temperatures encountered in Tradinghouse Reservoir. Drew and Tilton (1970) reported survival of largemouth black bass after temporary exposure to temperatures as high as 39C. Even preferred temperatures for largemouth black bass can be relatively high. Dendy (1948) reported temperature preference in Norris Reservoir (Tennessee) to be 26.6-27.7C, but Fry (1950) gave a final preferred value of 30-32C.

The highest temperatures encountered by largemouth black bass in Tradinghouse Reservoir during the course of this study are not close to lethal levels and are even in the range of preferred temperature according to Fry's preferendum. It is not surprising then that the indicators used in this study showed few signs of stressful thermal influence in view of the various compensatory mechanisms discussed which are operable within thermal zone of tolerance. Though one interpretation of the organ weight analysis suggested that the fish in Tradinghouse Reservoir discharge canal were in a temperature zone of decreasing physiological activity, it seems unlikely from the preceding discussion that the temperatures experienced were greatly stressful.

One of the greatest possible threats of artificially heated reservoirs comes not from the upper end of the temperature scale, but from the lower. As can be seen from the zone of tolerance polygon for largemouth black bass, the lower

lethal temperature increases considerably with increasing acclimation temperature. Power plants often abruptly drop the temperature of the discharge canal when they shut down for repairs or are under low load conditions. As Brett (1956) pointed out, while acclimation to warm temperature is relatively rapid (hours), acclimation to low temperatures can take weeks. Thus, it is possible to conceive of a situation where winter bass acclimated to summer temperatures might suddenly be exposed to lethally cold winter temperatures.

As cited repeatedly there is much not yet understood about the relationship of temperature to the various levels of biological organization. Only through continued monitoring of such systems can we hope to gain insight into their internal functional relationships, and thereby wisely manage the addition of thermal effluents to our natural waters.

## APPENDIX

1. Snead, K. E. and W. H. Thompson. 1950. The age growth of white crappie and largemouth black bass in Lake Texoma, Oklahoma. Fisheries Mgt. Rep. No. 19, Oklahoma Fisheries Experiment Station: 32(Mimeo).
2. Padfield, J. H. 1951. Age and growth differentiation between the sexes of the largemouth black bass, Micropterus salmoides (Lacépède). J. Tenn. Acad. Sci. 26:42-54.
3. Bennett, G. 1937. The growth of the largemouthed black bass, Huro salmoides (Lacépède), in the waters of Wisconsin. Copeia, 2:104-118.
4. Thompson, W. H. 1950. Investigations of the fisheries resources of Grand Lake. Fisheries Mgt. Rep. No. 18, Oklahoma Fisheries Experiment Station: 46(Mimeo).
5. Thompson, W. H. 1949. Fisheries investigation of Lake Shawnee. Fisheries Mgt. Rep. No. 13, Oklahoma Fisheries Experiment Station: 13(Mimeo).
6. Weyer, A. E. 1940. The Lake of the Ozarks: a problem in fishery management. Prog. Fish Cult., U. S. Fish and Wildlife Service Memo, 51:1-131.
7. Leonard, E. M. and R. M. Jenkins. 1954. Growth of basses of the Illinois River, Oklahoma. Proc.

Okla. Acad. Sci. 53:21-29.

8. Jenkins, R. M. 1951. A fish population study of Clarmore City Lake. Proc. Okla. Acad. Sci. 31:84-93.
9. Eschmeyer, R. W., R. H. Stroud, and A. M. Jones. 1944. Studies of the fish population on the shoal area of a TVA main-stream reservoir. J. Tenn. Acad. Sci. 19(1):70-122.
10. Stroud, R. H. 1948. Growth of the basses and black crappie in Norris Reservoir, Tennessee. J. Tenn. Acad. Sci. 23:31-91.

#### LITERATURE CITED

- Albrecht, M. 1969. Spleen and kidney mass--a measure of physiological activity of the carp. *Z. Fisherei*; NF Band 17 Heft 1-4:70-100.
- Anthony, E. H. 1961. Oxygen capacity of goldfish (Carassius auratus) in relation to thermal environment. *J. Exp. Biol.* 38:93-107.
- Bardach, J. E. and R. G. Bjorklund. 1957. The temperature sensitivity of some American freshwater fishes. *Amer. Natur.* 91(859):233-251.
- Beamish, F. W. H. 1964. Respiration of fishes with special emphasis on standard oxygen consumption. II. Influence of weight and temperature on respiration of several species. *Can. J. Zool.* 42:177-188.
- Beamish, F. W. H. 1970. Oxygen consumption of largemouth bass, Micropterus salmoides, in relation to swimming speed and temperature. *Can. J. Zool.* 48:177-188.
- Bennett, D. H. 1971. Preliminary examination of body temperature of largemouth bass, Micropterus salmoides, in artificially heated reservoirs. *Arch. Hydro. Biol.* 68(3):376-381.
- Berenbeim, D. Ya. 1968. Effects of water temperature on the swimming seasons of marine fishes within the limits of their habitat. Second Intl. Oceanogr. Congress, Summ. of Repts. (U.S.S.R.) 35. *Biol. Abs.*, 49:60288.



- Berenbeim, D. Y. 1970. The effect of water temperature on the spawning time of the Atlantic and Pacific mackerel. Tr. Kaliningrad. Tckh. Inst. Ryb. Prom. Khoz. (U.S.S.R.). Biol. Abs., 51:53070.
- Billard, R. 1968. Influence of temperature on the duration and efficacy of the spermatogenesis of the guppy, Poecilla reticulata. C. R. Hebd. Seances Acad. Sci. Ser. D. Sci. Natur. (France), 266,2287 Biol. Abs., 50:125073.
- Boyer, P. D. 1953. The role of potassium and related cations in the action of pyruvic phosphoferase and other enzymes. J. Lancet. 195-196.
- Brett, J. R. 1956. Some principles in the thermal requirements of fish. Quart. Rev. Biol. 31(2):731-1741.
- Brett, J. R. 1967. Swimming performance of sockeye salmon (Oncorhynchus nerka) in relation to fatigue time and temperature. J. Fish. Res. Board Can. 24(8):1731-1741.
- Bull, H. D. 1936. Studies in conditioned responses of fish. VII. Temperature perception in Teleosts. J. Mar. Biol. Ass. U. K. 21:1-27.
- Bullough, W. S. 1939. A study of the reproductive cycle in the minnow in relation to its environment. Proc. Zool. Soc. (London). 109:79-102.
- Cassie, R. M. 1954. Some uses of probability paper in the analysis of size frequency distributions. Australian

- J. Mar. and Freshwater Res. 5(3):513-522.
- Chen, T. H. 1969. Age and growth of the white crappie, Pomoxis annularis, in Lake Waco, Texas. M.S. Thesis. Baylor Univ. 64 P.
- Coble, D. W. 1967. Relationship of temperature to total annual growth in adult smallmouth bass. J. Fish. Res. Board Can. 24(1):87-99.
- Cooper, E. L., H. Hidu, and J. K. Anderson. 1963. Growth and production of largemouth bass in a small pond. Trans. Amer. Fish. Soc. 92:391-400.
- Courier, R. 1922. Sur l'independce de la glande seminale et des caracteres sexveles seconaires chez les poissons. C. R. Acad. Sci. (Paris.) 174-70.
- Dean, J. M. and F. J. Vernberg. 1965. Effects of temperature acclimation on some aspects of carbohydrate metabolism in decapod crustacea. Biol. Bull. 129(1): 87-94.
- DeWaide, J. H. 1970. Species differences in hepatic drug oxidation in mammals and fishes in relation to thermal acclimation. Comp. Gen. Pharm. 1(3):375-385.
- Doudoroff, P. 1945. The resistance and acclimitization of marine fishes to temperature changes. II. Experiments with fundulus and atherinops. Biol. Bull. 88(2):194-206.
- Drew, H. R. and J. E. Tilton. 1970. Thermal requirements to protect aquatic life in Texas Reservoirs. J. Water Pollut. Contr. Fed. 43(4):562-572.

- Drury, D. E. and J. G. Eales. 1968. Influence of temperature on histological and radiochemical measurements of thyroid activity in the eastern brook trout, Salvelinus fontinalis M. Can. J. Zool. 46(1):1-9.
- Eales, F. G. 1964. The influence of temperature on thyroid histology and radio-iodine metabolism of yearling steelhead trout, Salmo gairdneri. Can. J. Zool. 42: 829-841.
- Ekberg, D. R. 1958. Respiration in tissues of goldfish adapted to high and low temperatures. Biol. Bull. 114(3):308-316.
- Evans, R. M., F. C. Pardue, and C. P. R. Hichman, Jr. 1962. The effect of temperature and photoperiod on the respiratory metabolism of rainbow trout (Salmo gairdnerii). Can. J. Zool. 40:107-188.
- Freed, J. 1965. Changes in activity of cytochrome oxidase during adaptation of goldfish to different temperatures. Comp. Biochem. Physiol. 14:651-659.
- Fry, F. E. J. 1950a. Effects of the environment on animal activity. Univ. Toronto Stud. Biol. Ser. 55:1-62.
- . 1950b. Temperature preference and cruising speed of largemouth and smallmouth bass in relation to acclimation temperature. Graphs in Ontario Fisheries Research Laboratory Library, Toronto; no date.
- . 1957. Temperature compensation. Ann. Rev. Physiol. 20:207-224.

- . 1964. Animals in aquatic environments: Fish. 715-728. In: D. B. Dill, Handbook of physiology. Amer. Physiol. Soc. Was., D. C.
- Garside, E. T. and J. S. Tait. 1958. Preferred temperature of rainbow trout and its unusual relationship to acclimation temperature. Can. J. Zool. 36:563-567.
- Greer, G. L. and D. R. Gardner. 1970. Temperature sensitive neurons in the brain of the brook trout. Science 169: 1220-1222.
- Grigg, G. C. 1969. Temperature induced changes in the oxygen equilibrium curve of the blood of the brown bullhead, Ictalurus nebulosus. Com. Biochem. Physiol. 28:1203.
- Hammel, H. T., S. B. Stromme, and K. Myhre. 1969. Fore-brain temperature activates behavioral thermoregulatory response in arctic sculpins. Science 165:83.
- Heineke, E. A. and A. H. Houston. 1965a. A note on water balance in the goldfish, Carassius auratus L., during lethal heat shock. Can. J. Zool. 30:49-54.
- . 1965b. Effect of thermal acclimation and sub-lethal heat shock upon ionic regulation in the goldfish, Carassius auratus L. J. Fish. Res. Board Can. 22(6): 1455-1470.
- Hoar, W. S. and M. K. Cottle. 1952. Some effects of temperature acclimatization on the chemical constitution of goldfish tissues. Can. J. Zool. 30:49-54.
- Hochachka, P. W. and I. R. Hayes. 1962. The effect of

- temperature acclimation on pathways of glucose metabolism in trout. Can. J. Zool. 40(2):261-270.
- Houston, A. H. and M. A. DeWilde. 1968. Thermoacclimatory variation in the haematology of the common carp, *Cyprinus carpio*. J. Exp. Biol. 49:71.
- Hubbs, C. and W. F. Hettler. 1964. Observation on tolerance of high temperatures and low dissolved oxygen in natural waters by Crenichthys baileyi. Southwest. Natur. 9(4): 245-248.
- Itazaw, Yaso. 1970. Characteristics of respiration of fish considered from the arterio-phenus difference of oxygen content. Bull. Jap. Soc. Sci. Fish. 36(6):571-577.
- Javaid, M. V. and J. M. Anderson. 1967. Thermal acclimation and temperature selection in Atlantic salmon, Salmo salar, and rainbow trout, S. gairdneri. J. Fish. Res. Board Can. 24(7):1501-1503.
- Johnson, M. G. and W. H. Charlton, 1960. Some effects of temperature on the metabolism and activity of the largemouth bass, Micropterus salmoides, (Lacépède). Prog. Fish-Culturist. 22(4):155-163.
- Kaye, L. and W. F. H. M. Momaerts. 1960. The role of calcium ions in the acceleration of the resting glycolysis by extracellular potassium. J. Gen. Physiol. 44:405-413.
- Kimmel, B. L. 1969. Phytoplankton production in a central Texas reservoir. M.S. Thesis. Baylor Univ. 113p.
- Konishi, J. and C. P. Hickman. 1964. Temperature acclimation

- in the central nervous sytem of rainbow trout. Comp. Biochem. Physiol. 13:433-442.
- Kramer, R. H. and L. L. Smith. 1960. First year growth of largemouth bass, Micropterus salmoides, and some related ecological factors. Trans. Amer. Fish. Soc. 89:222-233.
- Kusakina, A. A. 1963. Relation of muscle and cholinesterase thermostability in certain fishes to specific environmental temperature conditions. Fed. Proc. 22:T123-T126.
- Latta, W. C. 1963. The life history of the smallmouth bass, Micropterus d. dolomieu, at Waugoshance Point, Lake Michigan. Michigan Dept. Conserv. Bull. Inst. Fish. Res. 5:56.
- Mutchmor, J. A. and A. G. Richards. 1961. Low temperature tolerance of insects in relation to the influence of temperature on muscle apyrase activity. J. Ins. Physiol. 7:141-158.
- Palcheimo, J. E. and L. M. Dickie. 1966. Food and growth of fishes. II. Effects of food and temperature on the relation between metabolism and body weight. J. Fish. Res. Board Can. 23(6):869-908
- Pampathi, R. 1963. Physiology of low temperature acclimation in tropical poikilotherms. Indiana Acad. Sci. Proc. B. 57:290-295.
- Pardue, G. B. and F. E. Hester. 1967. Variation in the growth rate of known-age largemouth bass (Micropterus salmoides) under experimental conditions. Proc. 20th

- Ann. Conf. Southeast Ass. Game Comm. 300-310.
- Parker, F. L. and P. A. Krenkel. 1969. Thermal pollution: Status of the art. Vanderbilt Univ., Dep. Environmental and Water Resources. Rep No. 3.
- Parvatheswararao, V. 1967. Some mechanisms underlying thermal acclimation in freshwater fish, Etroplus maculatus. Comp. Biochem. Physiol. 21(3):619-626.
- Peak, M. J., N. R. Fuller, and J. G. Peak. 1969. Temperature acclimation in Tilapia sparmanii: Some effects of thiourea. Zool. Afr. (S. Africa), 3:95. Biol. Abst., 50:30993.
- Precht, H. 1958. Concepts of temperature adaptation of the unchanging reaction systems of cold-blooded animals. In: Physiological Adaptation. (C. L. Prosser, Ed.) Amer. Physiol. Soc. Wash., D. C.
- Prosser, C. L. 1958. The nature of physiological adaptation. In Physiological Adaptation (C. L. Prosser, Ed.). Amer. Physiol. Soc. 167-180.
- . 1962. Acclimation of poikilothermic vertebrates to low temperatures. In: Comparative Physiology of Temperature Regulation (J. P. Hannon and E. Vierbeck, Ed.). Arctic Aeromedical Laboratory 1-34.
- Read, K. R. H. 1964. Comparative biochemistry of adaptations of poikilotherms to the thermal environment. In: Experimental Marine Ecology. Occ. Pub. No. 2 Graduate School Oceanography, University of Rhode Island. 39-47.



- Roots, B. I. and C. L. Prosser. 1962. Temperature acclimation and the nervous system in fish. *J. Exp. Biol.* 39:617-629.
- Schneider, L. 1969. Experimental investigation on the influence of day length and temperature on gonad development in the three-spined stickleback, Gasterosteus aculeatus. *Oecologia* (Germany). 3:249.
- Simpson, A. C. 1959. Method used for separating and counting the eggs in fecundity studies on the plaice (Pleuronectes platessa) and herring (Clupea harengus). *Occ. Pap. F. A. O. Indo-Pacific Fisheries Council*. No. 59/12.
- Simpson, G. G. and A. Roe, and R. Lewontin. 1960. *Quantitative Zoology*. Harcourt Brace and Co., New York 229-230.
- Slicher, A. M. and G. E. Pickford. 1968. Temperature controlled stimulation of hemopoiesis in a hypophysectomized cyprinodont fish: Fundulus heteroclitus. *Physiol. Zool.* 41:293.
- Smith, E. N., B. J. Venables, and O. T. Lind. 1973. A versatile and inexpensive variable voltage pulsator for electrofishing. *Trans. Amer. Fish. Soc.* 102(2).
- Somero, G. N. 1969. Enzymic mechanisms of temperature compensation: Immediate and evolutionary effects of temperature on enzymes of aquatic poikilotherms. *Amer. Natur.* 130:51.



- Spitzer, K. W., D. E. Marvin, and A. G. Heath. 1969. The effect of temperature on the respiratory and cardiac response of the bluegill sunfish to hypoxia. *Comp. Biochem. Physiol.* 30:83-90.
- Standard Methods for the Examination of Water and Waste Water. 1905. New York (1st edition).
- Strawn, K. 1961. Growth of largemouth bass fry at various temperatures. *Trans. Amer. Fish. Soc.* 90(3):334-335.
- Stroud, R. H. 1948. Growth of the basses and black crappie in Norris Reservoir, Tennessee. *J. Tenn. Acad. Sci.* 23:31-91.
- Ushakov, B. P. and A. A. Kusakina. 1962. Liability and conservation of adaptation in animal cells at the protein level. *Biol. Abstr.*, 37:4145.
- Ushakov, B. P., A. N. Vinogradov, and A. A. Kusakina. 1962. Cytophysical analysis of intraspecies differentiation in the whitefish and grayling of Lake Baikal. *Biol. Abstr.*, 40:4229.
- Walser, M. 1960. Ion association. I. The effects of multivalent ions on the protein-bound and complexed calcium in serum. *J. Cell. Comp. Physiol.* 55:245-250.
- Watt, K. E. F. 1959. Studies on population productivity. II. Factors governing productivity in a population of smallmouth bass. *Ecol. Monographs* 29:367-392.
- Wiebe, J. P. 1968. The effects of temperature and day length on the reproductive physiology of the viviparous

sea perch, Cymatogaster agregata, Gibbons. Can. J.  
Zool. 48:221.

Winberg, G. G. 1960. Rate of metabolism and food requirements of fishes. Fish. Res. Board Can., Trans. Ser. 194:1-202.