TEMPERATURE PREFERENCES BY TWO SPECIES OF FISH AND THE INFLUENCE OF TEMPERATURE ON FISH DISTRIBUTION

By

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ON FISH DISTRIBUTION

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CHAPTER I

INTRODUCTION

The purpose of the study reported in this paper was to determine the preferred temperatures and the final preferenda of two Oklahoma fishes, *Pimephales promelas* (Rafinesque), the fathead minnow, and *Lepomis cyanellus* Rafinesque, the green sunfish. The study was conducted at the Aquatic Biology Laboratory of Oklahoma State University in Stillwater beginning January, 1960 and completed in August, 1962.

Interest was centered primarily with behavioral reactions of fishes to temperature changes rather than physiological effects of temperature. Fry (1952) and Doudoroff (1957) have made available excellent articles about the physiological effects of temperature on fishes.

Aquatic organisms are influenced by both physical and chemical limiting factors, such as dissolved gases and solids, hydrogen-ion concentration, chemical stratification, pressure, temperature, light, and turbidity. Temperature has been chosen by many workers to be the factor most likely to influence other factors. Chidester (1924) critically reviewed the literature on fish migration and concluded that temperature was the primary physical factor in the migration of fish. Sprugel (1951), while investigating the effect of temperature on the distribution of fish, found that bluegills would leave the higher oxygenated levels in lakes and penetrate lower strata where the dissolved oxygen was much reduced. The length of time spent at the lower levels was limited. Dendy (1946) found, in his studies of fish distribution in Norris Reservoir, Tennessee, that dissolved oxygen levels of 1.5 ppm did not necessarily constitute a barrier to fish. He also found that pressure did not influence distribution as strongly as did temperature. He stated that temperature was of more significance than depth in the distribution of fishes.

The thermal zone within which organisms are able to perform normal metabolic activities is known as the zone of tolerance. The upper and lower limits of the zone of tolerance beyond which the organisms begin to die are known as the upper and lower incipient lethal levels. The extent of the zone of tolerance can be shifted to a higher or lower temperature range by acclimation. Many workers agree (Fry, Hart, and Walker, 1946; Fry, 1947; Brett, 1952; Fry and Gibson, 1953; Ferguson, 1958) that as the acclimation temperature increases, the upper incipient lethal level also rises. Adjustment may continue until a further rise in acclimation temperature does not increase the upper lethal level. This final temperature is known as the ultimate upper incipient lethal level and no amount of acclimation will raise the temperature further. The lower lethal level also can be raised or lowered by acclimation.

At temperatures above the upper incipient lethal level, organisms can survive for a period of time, but will eventually be killed. The time of survival is known as the resistance time.

Somewhere between the upper and lower incipient lethal levels there is a preferred temperature for any particular organism. Fry (1947) has defined the preferred temperature as the "region, in an infinite range of temperature, at which a given population will congregate with more or less precision." The preferred temperature of an organism is also dependent upon the thermal history of that organism.

CHAPTER II

MATERIALS AND METHODS

The two species of fish used in the experiments were chosen because they were locally common, fairly hardy, and easily kept in the laboratory. Both species were collected from farm ponds near Stillwater, Oklahoma and transported to the laboratory in open tanks. After arrival, the fish were treated with terramycin to prevent finrot. This bacterial growth is common to fishes kept for periods of time under crowded laboratory conditions (Irwin, 1959). All fish were kept in tap water that had been vigorously aerated at least 24 hours.

After an adjustment and observation period of one week, the fish were transferred to aquaria for acclimation to the test temperatures. The acclimation aquaria were 16 x 9 x 10 inches. Fifteen fish whose average total length was 55 mm were placed in each. The largest fish tested was 74 mm in total length. Heated aquaria were kept at constant temperatures by using aquaria heaters with thermostats. Cooled aquaria were placed in standard household refrigerators. To attain near freezing temperatures, a refrigerator with a large compressor was used. This refrigerator was also used to store the cooled water for the actual experiments. Careful adjustment of the apparatus permitted a selection of desired temperatures with a variance of 0.5°C.

The fathead minnows were fed a diet of commercial poultry food and powdered egg, finely ground and mixed in a coffee grinder. Live *Daphnia* and a supplement of the poultry mixture were fed to the green sunfish.

Tests were begun after an acclimation period of 30 days and continued until some specimens were in the acclimation aquaria for as long as eighty days. The preferred temperature experiments were run in a gradient tank similar to one used by Doudoroff (1938). The gradient tank was divided into eight chambers, the outside dimensions being 81.5 x 9.5 x 9.75 inches. The material used was high-grade redwood which was economical, watertight, and easily shaped. The chambers were separated by aluminum sheets but openings (2 x 3 inches) permitted the specimens to move freely from one chamber to another. Each chamber was equipped with two inlet tubes located near the bottom to permit entrance of heated and cooled water. A wire screen was used as a false floor to bar the test fish from the inlet tubes and from the mixing water below the screen. The tank was designed to reduce corners and thus deny "hiding places" for the test fish (Figs. 1 and 2). An outlet tube was placed at the water line of each chamber to prevent horizontal currents. The tank was illuminated by two, four-foot, 30 watt fluorescent lamps placed end to end.

With this apparatus it was possible to produce a gradient of 2°C. between each chamber. The rate of flow to each chamber was controlled by 0.25- inch brass valves. The tests were conducted in an insulated room whose temperature ranges varied from 21.7 to 25.0°C.

Cooled water was supplied to the gradient tank from a large refrigerator. Heated water was supplied from a large refrigerator liner containing a 1320 watt immersion type water heater. Both water supplies were aerated constantly to insure ample dissolved oxygen. Warmed and cooled water was delivered to the gradient tank by gravity flow.

A temperature gradient was established and included the temperature

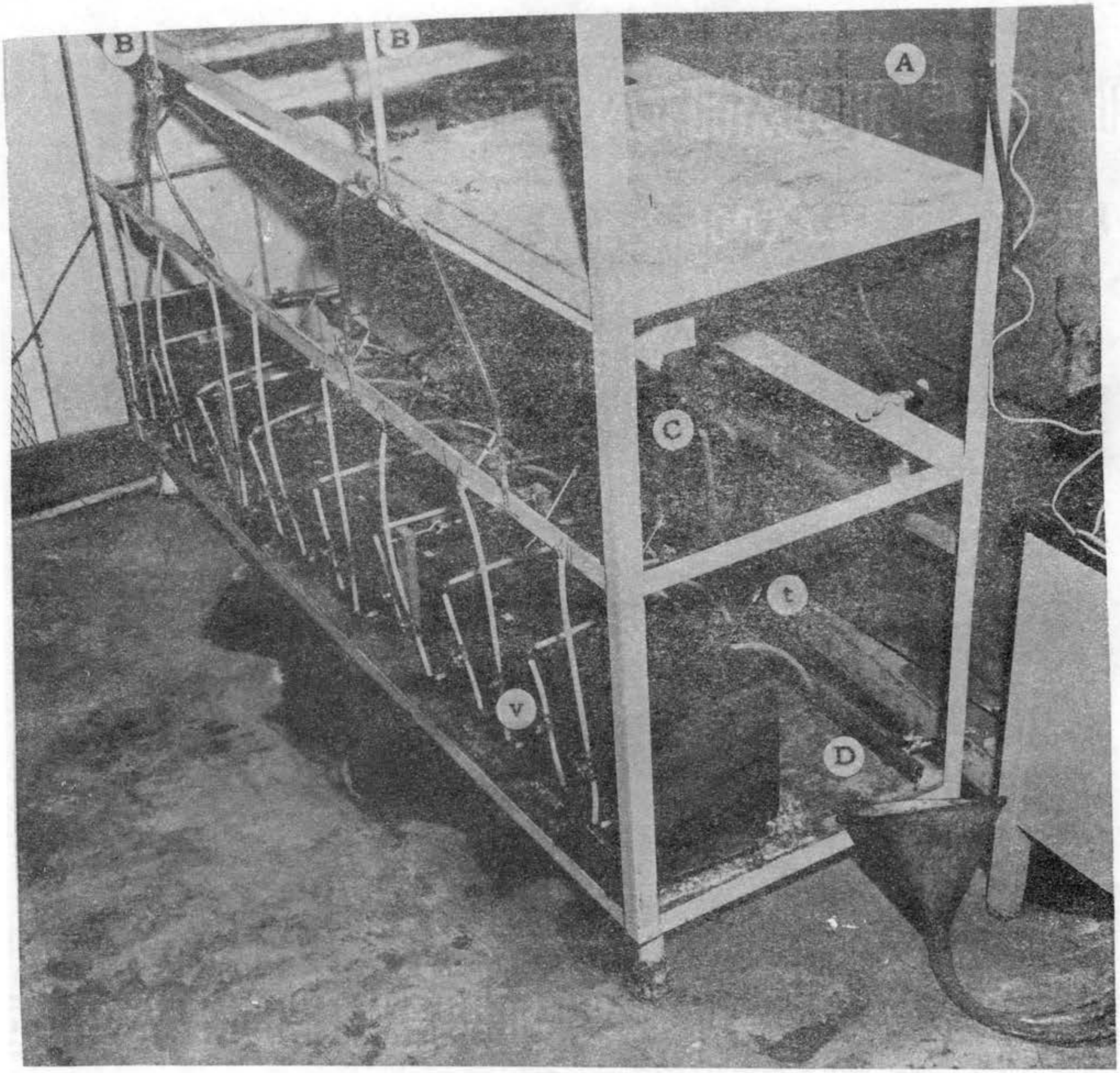

Figure 1: Photograph of gradient tank. A, refrigerator supplying cooled water; B, tubes leading from warm water supply; C, tube leading from cooled water supply; D, discharge tube; t, thermometer; v, valves controlling water supply.

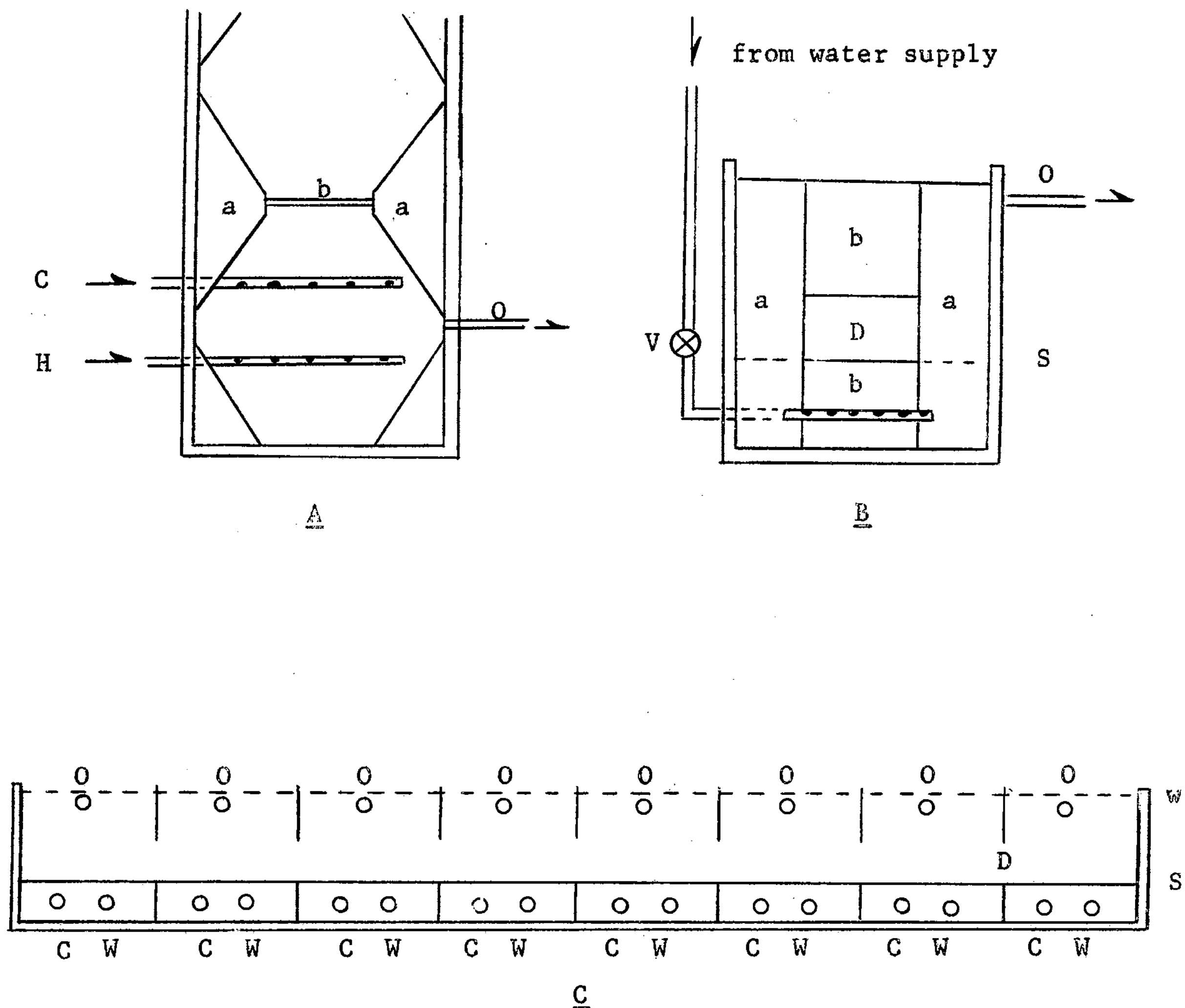

Figure 2: Diagram of gradient tank. A, top view; B, end view; C, side view. a and b represent partitions, D is the opening between chambers, S is the screen, V is the valve controlling the water supply, and w represents the water level. W, C, and O represent the warm water supply, cooled water supply, and the outlet tubes, respectively.

CHAPTER III

PREFERRED TEMPERATURE AND THE FINAL PREFERENDUM

General Considerations

Both species adjusted readily to temperature change. Dobie, et al. (1956) stated that the fathead minnow can tolerate sudden temperature changes as great as 11°C. I found that both species were able to tolerate temperature changes from room temperature to as high as 30°C. and as low as 10°C. in a twenty-four hour period, but in dealing with temperatures lower than 10°C., it was found that the fish required a holding period of two weeks near 10°C., before becoming acclimated to lower temperatures.

Particular caution was taken with the gradient tank to avoid any sort of gradient other than temperature. Dissolved oxygen determinations were made for each test. All determinations showed that the oxygen level was always near or above the saturation level. Whitmore, et al. (1960) found, in avoidance reactions to oxygen levels, that there was no avoidance to oxygen levels above 6 ppm. Moss and Scott (1961) found that the highest critical level of dissolved oxygen was 1.4 ppm at 35°C. for the largemouth bass. No oxygen concentrations in the preferred temperature studies were below 7.5 ppm. Therefore, it was assumed that there was no effect of oxygen variation in the gradient tank.

No evidence was found of a gradient in the hydrogen-ion concentration. The pH varied between 7.8 and 8.5 but was the same in the end chambers in each test.

Tests were conducted in the tank without a temperature gradient to learn if one or more chambers were preferred by the fish. No evidence of a preference was found. The high points at the ends of the graph (Fig. 3) are believed to be caused by the greater distance a fish had to travel to enter and leave the end chambers. These chambers may have afforded a false sense of security for the test fish.

Fathead Minnow

Specimens of the fathead minnow were acclimated to 4°C., 10°C., 15°C., 22°C., and 30°C. The preferred temperatures found for specimens acclimated to the above temperatures were 8.8°C., 15.2°C., 23.3°C., 20.7°C., and 22.6°C., respectively (Figs. 4-8). The preferred temperatures did not coincide with the peaks of the respective graphs because the modes obtained from each individual test for each acclimation temperature were averaged to obtain the preferred temperature.

The movements of the specimens were deliberate and slow to moderate in speed. Back-and-forth movements of the specimens in the gradient tank were common throughout the experiments with more time being spent in the chambers of preferred temperature. Fathead minnows were judged to be fairly good test fish because they adjusted rapidly to laboratory conditions and ate readily.

Green Sunfish

Specimens of the green sunfish were acclimated to 4°C., 10°C., 22°C., and 30°C. The preferred temperatures found for the specimens acclimated to the above temperatures were 10.6°C., 15.2°C., and 27.0°C., and 26.8°C. respectively (Figs. 9-12).

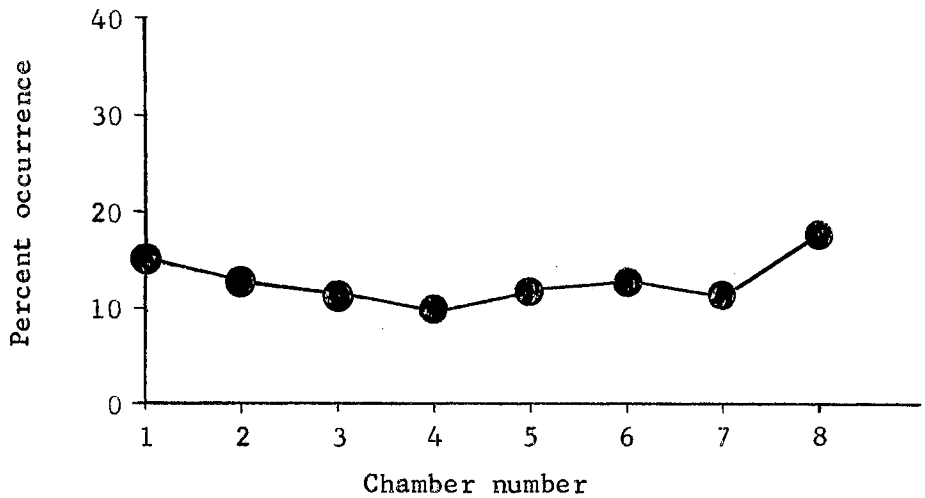

Figure 3: Average frequency of occurrence in chambers for five fish tested without a gradient.

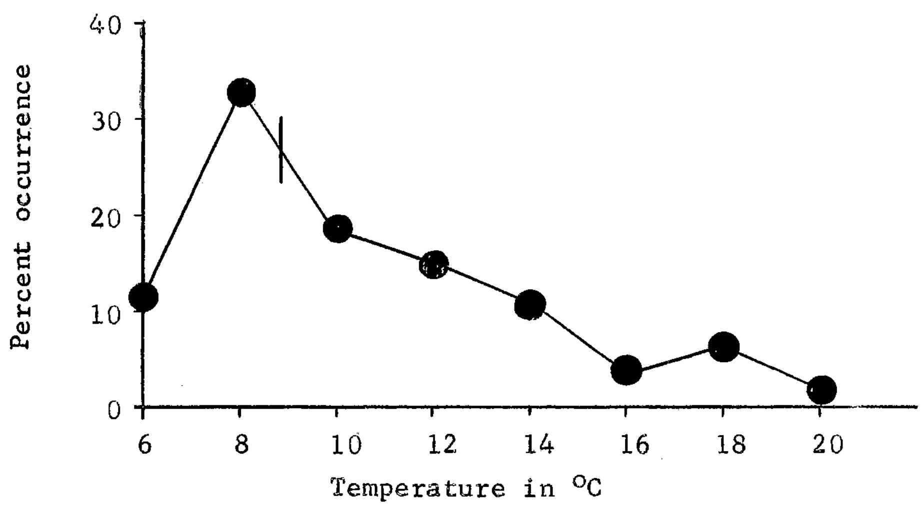

Figure 4: Average frequency of occurrence in chambers at different temperature levels for P. promelas acclimated to 4°C. Vertical slash indicates computed preferred temperature.

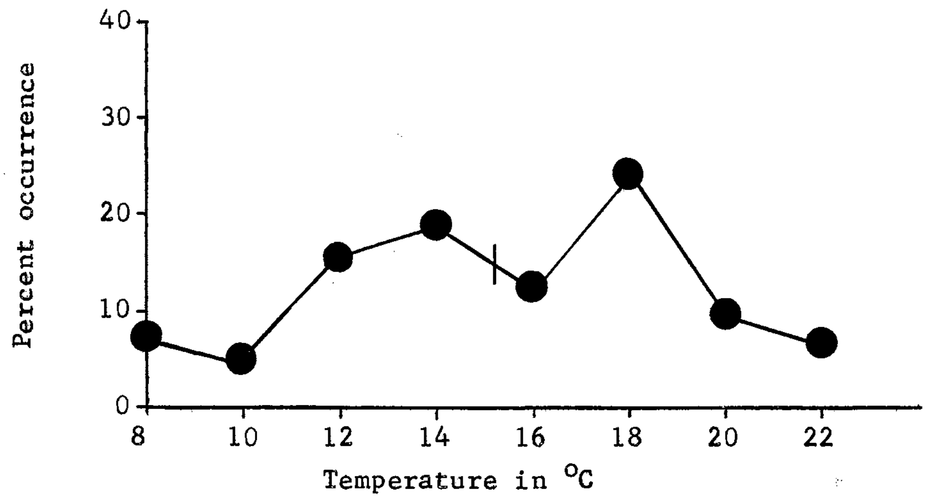

Figure 5: Average frequency of occurrence in chambers at different temperature levels for P. promelas acclimated to 10°C. Vertical slash indicates computed preferred temperature.

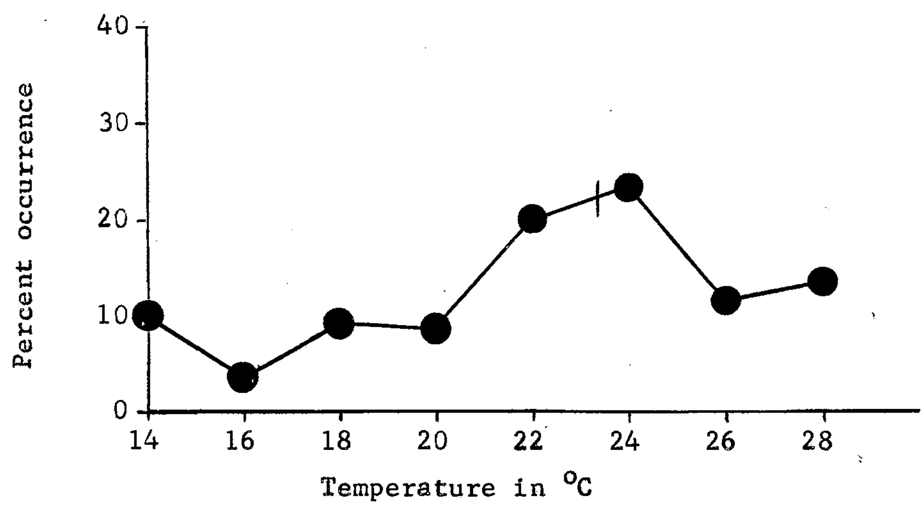

Figure 6: Average frequency of occurrence in chambers at different temperature levels for P. promelas acclimated to 15°C. Vertical slash indicates computed preferred temperature.

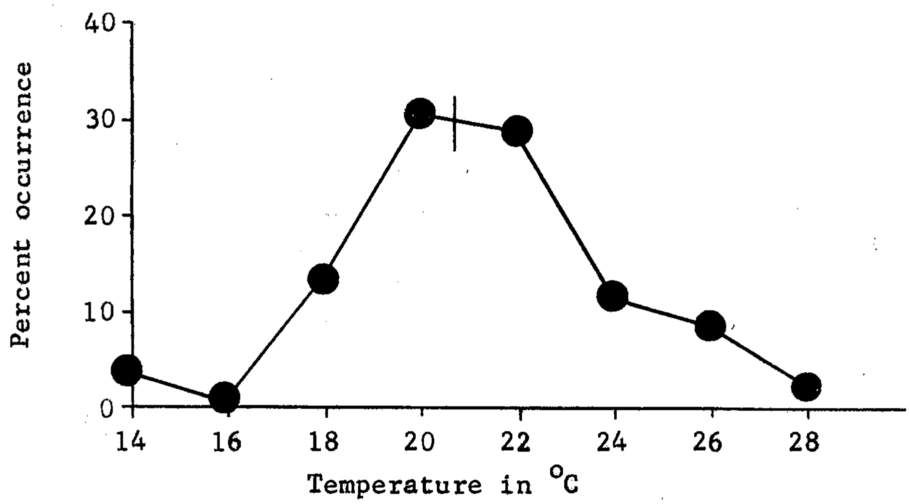

Figure 7: Average frequency of occurrence in chambers at different temperature levels for P. *promelas* acclimated to 22°C. Vertical slash indicates computed preferred temperature.

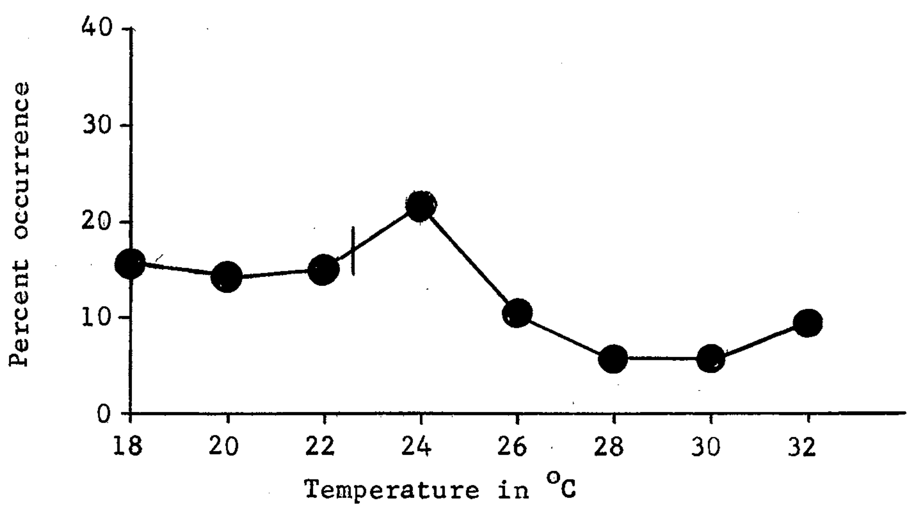

Figure 8: Average frequency of occurrence in chambers at different temperature levels for P. *promelas* acclimated to 30°C. Vertical slash indicates computed preferred temperature.

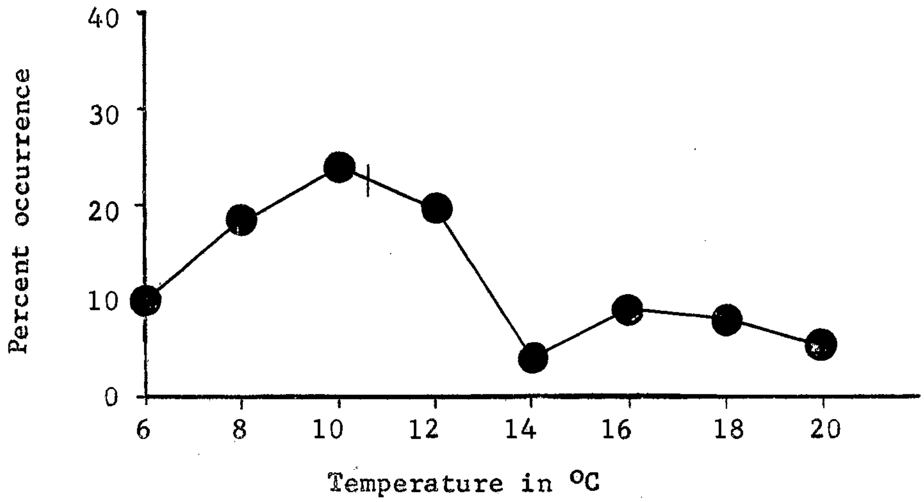

Figure 9: Average frequency of occurrence in chambers at different temperature levels for L. *cyanellus* acclimated to 4°C. Vertical slash indicates computed preferred temperature.

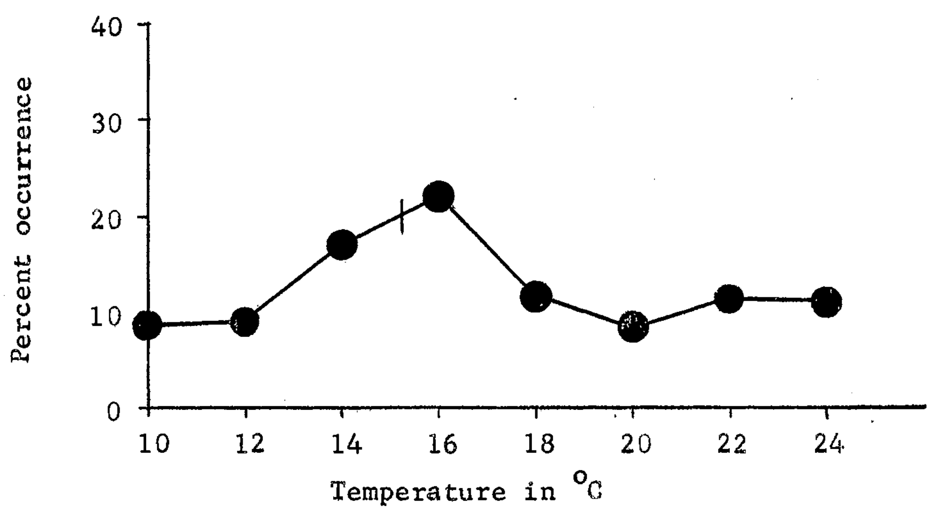

Figure 10: Average frequency of occurrence in chambers at different temperature levels for L. *cyanellus* acclimated to 10 °C. Vertical slash indicates computed preferred temperature.

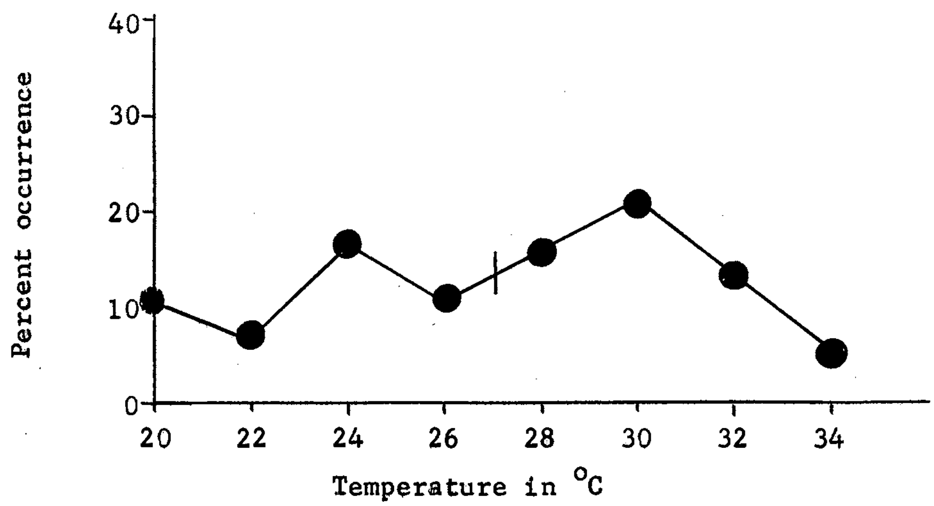

Figure 11: Average frequency of occurrence in chambers at different temperature levels for _L. cyanellus_ acclimated to 22°C. Vertical slash indicates computed preferred temperature.

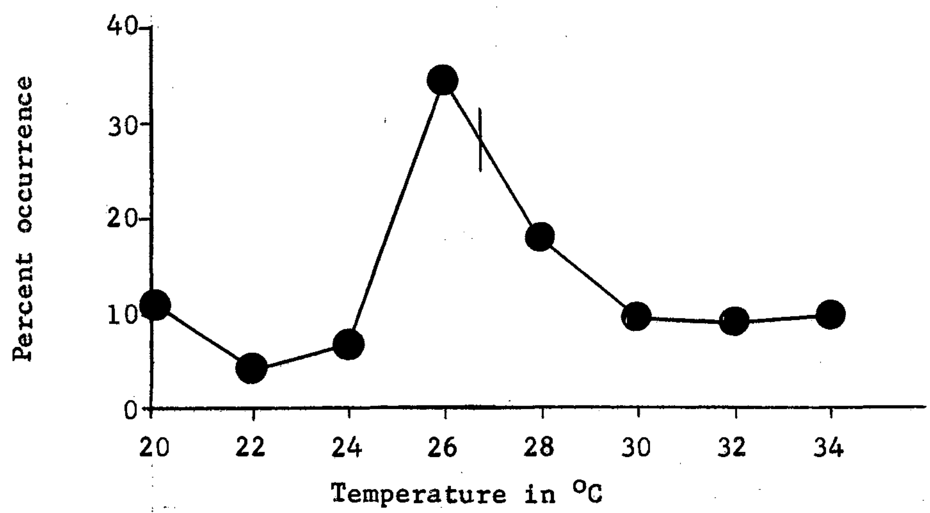

Figure 12: Average frequency of occurrence in chambers at different temperature levels for _L. cyanellus_ acclimated to 30°C. Vertical slash indicates computed preferred temperature.

All test fish moved erratically with short jerky movements after being placed in the gradient tank. The degree of excitement of the fish could be estimated by the rate of movement of the pectoral fins. During periods of rapid movement or when the specimen was beginning to move, the pectorals moved rapidly, whereas, if the specimens were in a resting position, there was little or no movement of the pectorals.

The green sunfishes appeared to be curious concerning their surroundings. Specimens were observed many times trying either to enter or to bite the small piece of exposed outlet tube. At times the fish would actually put its snout into the tube of 0.25- inch diameter. Although this action did not lend itself to the test, it proved to be an interesting and an unusual incident observed in nearly all the tests with the green sunfish.

The green sunfish was rated as a fairly good test fish. The species seemed quite nervous when suddenly approached but became quite accustomed to laboratory feedings.

Determination of the Final Preferendum

This paper supports the opinion that fishes acclimated to a low temperature select a preferred temperature somewhat higher than their acclimation temperature. The converse is true at high temperatures, that is, fishes acclimated to a high temperature select a preferred temperature somewhat lower than their acclimation temperature. Somewhere between the high and low temperatures lies what is known as the final preferendum. Fry (1947) refers to the final preferendum as that "temperature around which all individuals will ultimately congregate, regardless of their experience before being placed in the gradient."

The diagonal line in figures thirteen and fourteen is determined by points where the acclimation and preferred temperatures coincide. Therefore, the intersection of this line and the preferred temperature curve is the final preferendum.

The overall shapes of the curves in figures thirteen and fourteen representing the green sunfish and the fathead minnow were similar to those of other workers (Doudoroff, 1938; Fry, 1947; Brett, 1952; Pitt, et al., 1956), but the actual final preferenda varied greatly. The final preferenda for the green sunfish and the fathead minnow were found to be 27.3°C. and 23.4°C., respectively (Figs. 13 and 14).

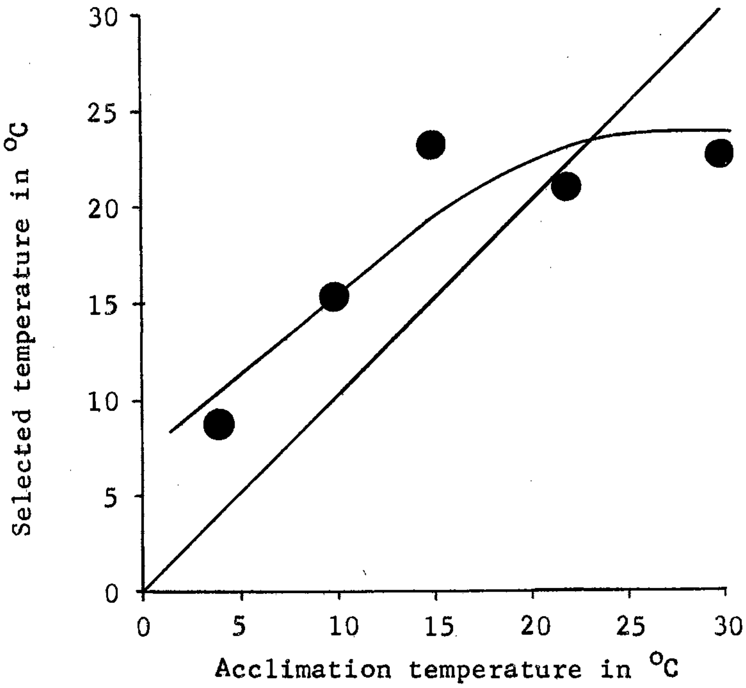

Figure 13: Preferred temperature in relation to acclimation temperature for P. promelas. The final preferendum is located at the intersection of the preferred temperature curve and the 45° line.

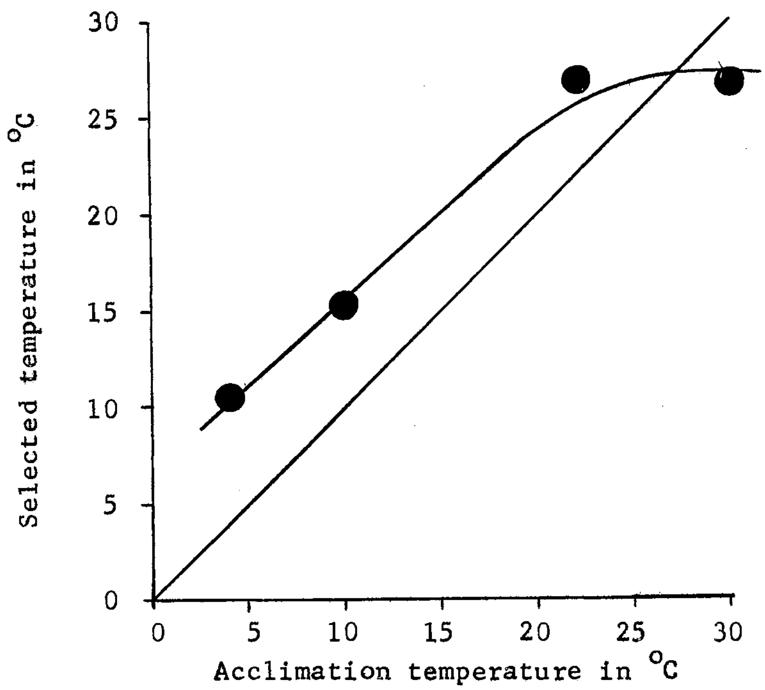

Figure 14: Preferred temperature in relation to acclimation temperature for L. cyanellus. The final preferendum is located at the intersection of the preferred temperature curve and the 45° line.

CHAPTER IV

DISCUSSION

A question concerning the length and rate of acclimation among fishes arose early in the study. Brett (1956) mentioned that the rate of change in the ability to tolerate higher temperatures was relatively rapid. Less than twenty-four hours was required at temperatures above 20°C., while the rate of change in the ability to resist lower temperatures is a much slower process requiring, at times, twenty days to approach completion in some species. He concluded that the ability to acclimate was governed by the rate of metabolism of the fish. If the rate of metabolism is decreased by low temperatures, the ability to acclimate to these low temperatures also decreases (Brett, 1956). Doudoroff (1942, 1945) came to the same conclusions while studying marine species. My results support these conclusions.

The ability to tolerate temperature extremes in Oklahoma is emphasized throughout the life history of the green sunfish and the fathead minnow. Wallen (1955), in reporting a temperature study on Oklahoma farm ponds, found the maximum and minimum surface temperatures ranged from 35.8°C. to 0.4°C. and bottom temperatures, at five foot depths, from 27.22°C. to 4.9°C. Any species of fish living and reproducing in a pond and whose life history covers a span of one or more years must be capable of adapting, over a period of time, to wide temperature ranges.

It has been concluded by other workers and shown here that thermal acclimation plays a major role in the determination of preferred temperatures. Doudoroff (1938), considered the effect of acclimation to be temporary. He stated that "a specimen could become 'adapted' to, and establish an apparent 'preference' for any temperature within a fairly wide range."

The tests conducted here were not sufficiently long to validate Doudoroff's statement, although it seems likely that an organism with a great ability to acclimate could adapt to any temperature within its zone of tolerance. The preferred temperature of an organism is of interest in laboratory experiments while its function in field conditions seem less important. However, the preferred temperature is a means of determining the final preferendum which is of major importance.

Value of the Final Preferendum

By definition, for every preferred temperature, there must be a corresponding acclimation temperature. The concept of "preferred temperature" is applicable only in the laboratory, because rarely in an aquatic environment is there a situation that would correspond to the laboratory acclimation design. One preferred temperature contributes little information toward the thermal requirements of an organism. A series of preferred temperatures for a particular species offers the approach to the determination of the final preferendum. It must be remembered that the preferred temperature of an organism is dependent upon that organism's thermal history, while the final preferendum is not. The final preferendum has an application value beyond experimentation since aquatic organisms have available a certain amount of temperature selection throughout their life. Therefore, the final preferendum, determined in the laboratory, of a species, could play an important role in the vertical distribution of fishes in larger bodies of water.

Fry and Hart (1948) found that the temperature at which the highest activity of goldfish occurred was near its preferred temperature. They concluded that there is usually a close correlation between the optimum for activity and the final preferendum.

Ferguson (1958) found a correlation between the final preferenda of laboratory studies and the temperature selections in the field by the same species of fish particularly in the lower temperature range. The laboratory temperatures were consistantly higher than the field temperatures. The variations were attributed in part to the use of fry and fingerlings in almost all laboratory experiments. (Ferguson, 1958).

These results reveal the importance of the final preferendum in relation to field work. It was found, in this study, that the final preferendum for the fathead minnow was significantly lower than the final preferendum for the green sunfish. It is probable that their vertical distribution in farm ponds and other bodies of water is significantly separated.

Future Problems for Investigation

The restricted scope of the study has left unanswered ideas that will require further investigation. A laboratory condition should be provided that would afford to future investigators the possibility of conducting long-term preferred temperature tests. These tests would reveal if "preferred temperature" is a valid or only a temporary phenomenon. Since municipal and industrial pollution is increasing in its effect on inland waters, experiments should be conducted to determine the effects of pollution upon the thermal requirements of fishes.

Although workers have studied temperature selection by fishes in lakes, a great deal more should be done, especially in southern and southwestern reservoirs. Field studies should not only include the determination of vertical stratification of fish by species, but should answer questions about the effects of industrial and municipal wastes in temperature selection, the influence of temperature in habitat selection, and the effects of severe temperature changes on the physiological functions of fishes.

It is certainly possible that in the near future, information regarding temperature requirements of fish will not only be of value to the sport fisherman, but will also be an aid to the commercial fisheries industry and to workers investigating the effects of pollution in the aquatic environment.

CHAPTER V

SUMMARY

1. Experiments were conducted to determine preferred temperatures and the final preferendum for two species of fish, *Pimephales promelas* (Rafinesque) and *Lepomis cyanellus* Rafinesque.
2. A gradient tank was designed and built to conduct the experiments.
3. Specimens of *P. promelas* were acclimated to 4^{o}C., 10^{o}C., 15^{o}C., 22^{o}C., and 30^{o}C. Specimens of *L. cyanellus* were acclimated to 4^{o}C., 10^{o}C., 22^{o}C., and 30^{o}C.
4. A total of 1600 observations were made per species per acclimation level to determine preferred temperatures.
5. From the preferred temperatures the final preferendum for each species was computed.
6. The final preferendum for *P. promelas* was found to be significantly lower than the final preferendum for *L. cyanellus*.
7. The importance of preferred temperature and the final preferendum is discussed.
8. Problems for further consideration are suggested.

LITERATURE CITED

Brett, J. R. 1952. Temperature tolerance in young Pacific salmon, genus Oncorhynchus. J. Fish. Res. Bd. Can. 9:265-323.

_____. 1956. Some principles in the thermal requirements of fishes. Quart. Rev. Biol. 31:75-87.

Chidester, F. E. 1924. A critical examination of the evidence for physical and chemical influences on fish migration. J. Exp. Biol. 2:79-118.

Dendy, J. S. 1946. Further studies of depth distribution of fish, Norris Reservoir, Tennessee. J. Tenn. Acad. Sci. 21:94-104.

Dobie, J., O. L. Meehean, S. F. Snieszko, and G. N. Washburn. 1956. Raising bait fishes. U. S. Fish and Wildl. Serv. Circ. 35. 124 p.

Doudoroff, P. 1938. Reactions of marine fishes to temperature gradients. Biol. Bull. 75:494-509.

_________. 1942. The resistance and acclimazation of marine fishes to temperature changes. I. Experiments with Girella nigricans (Ayers). Biol. Bull. 88:219-244.

_________. 1945. The resistance and acclimazation of marine fishes to temperature changes. II. Experiments with Fundulus and Atherinops. Biol. Bull. 88:194-206.

_________. 1957. Water quality requirements of fishes and effects of toxic substances. p. 403-430. In M. E. Brown (ed.), The physiology of fishes, Vol. 2. Academic Press, New York.

Ferguson, R. G. 1958. The preferred temperature of fish and their mid-summer distribution in temperate lakes and streams. J. Fish. Res. Bd. Can. 15:607-624.

Fry, F. E. J. 1947. Effects of the environment on animal activity. Univ. Toronto Stud., Biol. Ser. No. 55. 62 p.

_____. 1958. Temperature compensation. Ann. Rev. Physiol. 20:207-224.

Fry, F. E. J., and M. B. Gibson. 1953. Lethal temperature experiments with speckled trout X lake trout hybrids. J. Heredity 44:56-57.

Fry, F. E. J., and J. S. Hart. 1948. Cruising speed of goldfish in relation to water temperature. J. Fish. Res. Bd. Can. 7:169-175.

Fry, F. E. J., J. S. Hart, and K. F. Walker. 1946. Lethal temperature relations for a sample of young speckled trout, Salvelinus fontinalis. Univ. Toronto Stud., Biol. Ser., No. 54. 9-35.

Irwin, W. H. 1959. Terramycin as a control for fin rot in fishes. Prog. Fish-Cult. 21:89-90.

Moss, D. D., and D. C. Scott. 1961. Dissolved-oxygen requirements of three species of fish. Trans. Am. Fish. Soc. 90:377-393.

Pitt, T. K., E. T. Garside, and R. L. Hepburn. 1956. Temperature selection of the carp (Cyprinus carpio Linn.). Can. J. Zool. 34:555-557.

Sprugel, G., Jr. 1951. An extreme case of thermal stratification and its effect on fish distribution. Iowa Acad. Sci. 58:563-566.

Wallen, I. E. 1955. Some limnological considerations in the productivity of Oklahoma farm ponds. J. Wildl. Mgmt. 19:450-462.

Whitmore, C. M., C. E. Warren, and P. Doudoroff. 1960. Avoidance reactions of salmonid and centrarchid fishes to low oxygen concentrations. Trans. Am. Fish. Soc. 89:17-26.

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