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The Responses of Young American Shad to Rapid Temperature Changes

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ABSTRACT

Captive juvenile American shad (*Alosa sapidissima*) avoided rapid temperature increases of about 4° C above acclimatization temperatures in an experimental tank. Responses to rapid temperature changes of about 1.0° C were not consistent and did not result in demonstrable avoidances. It is concluded that young shad are capable of avoiding potentially lethal temperature changes.

INTRODUCTION

Although the metabolic consequences of environmental changes in temperature have been reasonably well defined for at least a few species of fish (Fry, 1964), the behavioral responses by fish to thermal changes are less well known. Teleost fish can discriminate temperature changes of 0.05° C (Bardach and Bjorklund, 1957), and most teleosts show temperature preferenda when presented with stable thermal gradients (Sullivan, 1954). Selection of temperature probably occurs regularly, particularly among stenothermal fish, but the exact mechanism of temperature selection over small thermal increments is not clear. Recent evidence indicates, however, that forebrain temperatures are important in eliciting thermoregulatory behavior in some fish (Hammel *et al.*, 1969).

Behavioral responses in unconditioned fish have been demonstrated to thermal differentials. For example, adult alewives (*Alosa pseudoharengus*) and blueback herring (*A. aestivalis*) selected warmer experimental channels on spawning migrations in fresh water when the differentials exceeded 0.5° C (Collins, 1952). The dwarf herring (*Jenkinsia lamprotaenia*) was found to avoid areas of a holding pool where the temperature was elevated by at least 0.1° C (Breder, 1951). There is, however, little available information on the responses of fish to abrupt and relatively large changes in temperature. Such information has become increasingly important as more and more industrially heated water is returned to rivers, lakes and estuaries, thus creating regions of steep and sharply defined thermal gradients.

A present source of concern is the possible effect of a new but typical industrial source of heated water, the Connecticut Yankee Atomic Power Company's Haddam Neck plant, on the behavior of juvenile American shad (*Alosa sapidissima*) in the Connecticut River. This nuclear-fueled electric generating plant which went into operation in October, 1967, is located 27 km (17 miles) from the mouth of the Connecticut River in Haddam, Connecticut. It is thus interposed between the major shad spawning and rearing grounds, approximately 67 to 135 km (40 to 80 miles) upstream, and the sea. At peak load this power plant is designed to pump approximately 23 cms (825 cfs) of condenser cooling water heated to about 12.5° C above ambient water temperature. Mixing and radiational heat loss quickly reduce the effluent temperature from its maximum. Intermediate temperatures, however, are measurable considerable distances from the point of discharge.

Preliminary unpublished experiments conducted in our laboratory have indicated that young American shad (40 to 90 mm S.L.) experience rapid mortality when temperatures are quickly raised from an ambient temperature of 24 to 28° C up to 32.5° C. Temperature increases of this magnitude ($\Delta T = 5$ to 9° C) are within the range predicted for portions of the Connecticut River that are affected by the Connecticut Yankee Atomic Power Company cooling water discharge. It is important, therefore, to learn how young shad behave upon encountering rapidly changing temperatures.

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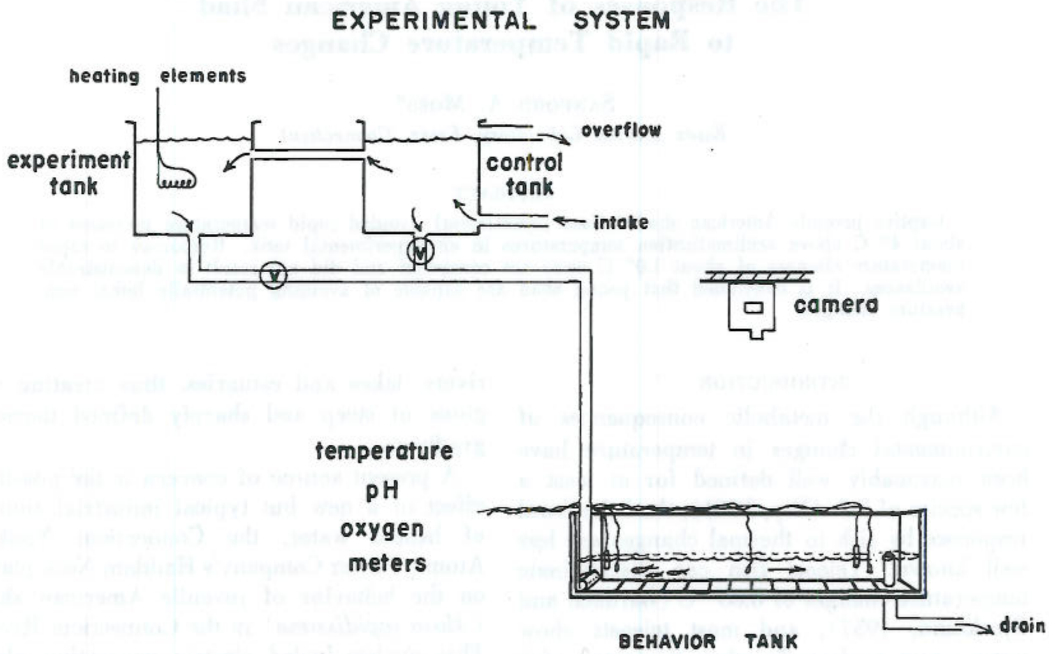

FIGURE 1.—Schematic diagram of the experimental apparatus. River water was continually supplied to the control tank by means of a ⅓ H. P. centrifugal pump. Two valves (v) controlled the flow of water to the behavior tank. See text for further description.

MATERIALS AND METHODS

Juvenile shad were obtained by seine in the Connecticut River near Essex, Connecticut, and were transported in tubs to the Essex Marine Laboratory. Here they were maintained in an outdoor circular tank 3 m in diameter and 45 cm in depth. Unfiltered river water was pumped continuously through the tank. In general, two to four days elapsed between capture and use of the fish in experiments. To guard against conditioning, each fish was discarded after use in only one experiment.

Experiments were performed in an open shed constructed beside the holding tank on the river bank. The experimental apparatus consisted of a tank constructed of epoxy-coated plywood. This tank measured 120 cm × 60 cm × 30 cm deep. Unfiltered river water was introduced at one end through a horizontal manifold connected to reservoir tanks each of 80 liter capacity, one for treatment, the other control. These two tanks were connected to a common overflow which maintained a constant gravity head (Figure 1). All plumbing and fixtures were non-metallic. Water depth in the behavior tank was maintained at 10 cm by an overflow drain standpipe located at the end of the tank opposite to the input manifold. It took approximately 80 seconds for a substance introduced at the input end to appear in the drain, but because of mixing, the turnover time was three to four minutes. Thermistors were arranged at the front, middle and rear of the tank at mid-depth and were connected to a common thermistometer through a junction box. Galvanic-cell oxygen electrodes (lead-silver, Precision Scientific) were placed in the behavior tank and were calibrated daily by standard Winkler oxygen determinations. The pH was monitored continuously in the behavior tank by a recording pH meter (Analytical Instruments, Inc.). Salinities were measured at the beginning and end of each experiment by standard Mohr titration. The behavior of the fish was recorded on 16 mm movie film by an overhead camera remotely controlled to expose frames at one second intervals. To ensure accurate time records, a clock was visible to the camera.

TABLE 1.—*The mean AFL values and 95% confidence intervals of the mean for six experiments representing three levels of temperature differential. Significant distributional changes are indicated by asterisks. The vertical arrows indicate when introduction of heated water was begun*

Number of fish	Maximum ΔT	Pooled time intervals (seconds)								
		0–20	21–40	41–60	61–80	81–100	101–120	121–140	141–160	161–180
4	0°	2.5 ± 0.14	2.3 ± 0.02	2.4 ± 0.12	2.4 ± 0.25	↓ 2.5 ± 0.16	2.4 ± 0.18	2.5 ± 0.16	2.7 ± 0.14	2.6 ± 0.08
5	0°	5.9 ± 0.20	5.2 ± 0.39	5.6 ± 0.18	↓ 6.0 ± 0.29	6.0 ± 0.20	5.4 ± 0.20	5.7 ± 0.33	—	—
6	1°	2.6 ± 0.35	2.4 ± 0.43	2.6 ± 0.20	2.9 ± 0.29	↓ 3.6 ± 0.44	3.4 ± 0.19	3.8 ± 0.16	4.4 ± 0.98	3.6 ± 0.52
6	1°	2.1 ± 0.16	2.0 ± 0.16	2.2 ± 0.22	2.3 ± 0.18	↓ 2.3 ± 0.19	2.4 ± 0.19	2.8 ± 0.31*	2.5 ± 0.24	2.1 ± 0.18
5	4.5°	4.1 ± 0.12	4.0 ± 0.20	4.1 ± 0.14	4.1 ± 0.18	↓ 4.3 ± 0.14	4.2 ± 0.16	4.2 ± 0.16	7.7 ± 1.1*	7.3 ± 1.2*
5	4.7°	3.6 ± 0.12	3.6 ± 0.16	3.7 ± 0.22	3.4 ± 0.12	↓ 3.2 ± 0.18	3.2 ± 0.16	4.4 ± 0.49	4.0 ± 0.22	6.8 ± 0.59*

The water flow pattern through the behavior tank was determined on each experimental day by introducing a dye into the water in the treatment reservoir. Pictures were then taken of the resultant flow patterns when this water was released in a simulated experiment. The known flow patterns were then available for interpolation of temperature conditions (from thermistor point recordings) at any point in the behavior tank at any time during an experiment. Following this daily calibration the entire system was flushed to remove all dye, and the successive experiments were then run.

Because shad are a schooling fish, groups of four to six were used in each experiment (Table 1). They were introduced into the behavior tank and allowed to remain undisturbed until they appeared to behave in a regular manner (at least 30 minutes). During this period, water flowed from the control reservoir through the behavior tank. Water in the treatment reservoir was raised to a predetermined temperature by 1000 watt stainless steel immersion heaters. At the onset of the experiment, the camera was turned on for a "preinjection" period of 85 seconds. The control water was then turned off and the valve controlling the heated water was simultaneously opened, allowing heated water to flow through the system. When the resultant wall of heated water had traversed the length of the behavior tank, the experiment was ended.

Three kinds of experiments were performed, each one in duplicate, including: (1) control experiments in which the water in the treatment reservoir was not heated, and (2) thermo-gradient experiments in which the introduced temperature changes were relatively large or (3) were small.

The resultant movie film strips were then projected frame by frame onto a grid that divided the behavior tank into 12 transverse sections, each 10 cm × 60 cm in area. Each section was assigned a number beginning with 1 and ending with 12 at the downstream end of the tank. The distribution of the fish in each frame was recorded by assigning every fish a value equal to the number of the section over which the tip of its snout fell. The values for all the fish in each frame were averaged to produce a distribution index, the "Average Fish Location" (AFL) for each picture. These data were then pooled into consecutive 20-second intervals for statistical comparison.

RESULTS AND DISCUSSION

The method of analysis provided a measure of distributional changes that occurred in relation to the long axis of the behavior tank. If the fish were either attracted toward or repelled by a temperature gradient passing along this axis, it was expected that this behavior would be reflected in a significant change in the AFL.

The control experiments showed that in the absence of temperature changes the experimental fish remained distributed between sections 1 and 6 in the upstream section of the tank (Table 1). No statistical differences could be seen between the preinjection and post-injection segments of the experiments.

When water heated to 4.5° C above ambient was introduced, however, the fish responded by showing a significant change in distribution, favoring the areas farther downstream in the tank (Table 1). Experiments conducted at smaller increases in temperature are not as easily interpreted. An avoidance of a thermal gradient of 1.0° C was seen in one experiment. A duplicate experiment, however, produced what was interpreted statistically as no response (Table 1). When the experimental films were viewed it was subjectively apparent that the fish responded to the treatment in this latter experiment by quickened movements which did not result in a distributional change.

The narrow range of AFL's associated with the preinjection periods were the result of an apparent positive rheotaxis on the part of the fish. During this time they faced into the current and the school slowly moved back and forth from one side of the tank to the other. Turns were made slowly and resulted in tight circles. Significant responses to heated water were correlated with more rapid swimming movements and greater exploratory behavior, including displacement toward the downstream end of the tank. Any applied stimulus such as increased temperature had to be large enough to outweigh the positive rheotaxis before it could be observed as a measurable influence. It is probable that the transient distributional changes that were observed with the smaller temperature changes (Table 1) resulted from this kind of behavioral conflict.

Although captive young shad tend to respond minimally to rapid temperature changes of about 1° C, the data presented on their responses to temperature changes of on the order of 4° C, however, show that these fish avoid sudden changes of this sort in the experimental system used. Although field observations on their behavior in and around heated effluents are needed, it can be concluded that they are behaviorally capable of avoiding temperature changes of a kind which could otherwise prove lethal.

ACKNOWLEDGMENTS

I thank the staff of the Connecticut River Study; Director, Dr. Daniel Merriman, Associate Director, Lyle M. Thorpe. Drs. James W. Atz, Melbourne R. Carriker, David M. Pratt, Edward C. Raney and Richard R. Whitney gave advice and critically reviewed the manuscript. I thank Mr. William A. Boyd and the Essex Marine Laboratory for providing space and many services. This study was supported by a grant from the Connecticut Yankee Atomic Power Company to the Connecticut River Study.

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