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EFFECT OF THERMAL SHOCK ON VULNERABILITY TO PREDATION IN JUVENILE SALMONIDS

II. A DOSE RESPONSE BY RAINBOW TROUT TO THREE SHOCK TEMPERATURES

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EFFECT OF THERMAL SHOCK ON VULNERABILITY TO PREDATION IN JUVENILE SALMONIDS

II. A DOSE RESPONSE BY RAINBOW TROUT TO THREE SHOCK TEMPERATURES*

Charles C. Coutant**

November 1972

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ABSTRACT

Increased vulnerability to predation of juvenile rainbow trout thermally shocked at three temperatures was shown to depend upon the thermal dose (temperature and duration) received. At 30 °C, a 0.55 min duration of exposure produced an identifiable effect, while 2 min was required at 28 °C. The predation response paralleled dose responses of visible equilibrium loss and death.

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INTRODUCTION

Thermally shocked juvenile rainbow trout, *Salmo gairdneri* (Richardson) and Chinook salmon, *Oncorhynchus tshawytscha* (Walbaum), were found by Coutant (1969, and manuscript in preparation) to be selectively preyed upon by larger fishes when both shocked and unshocked (control) fish were offered simultaneously. Increased vulnerability to predation was observed at small of the lethal and equilibrium loss doses, and vulnerability increased with duration of sublethal exposure to the arbitrarily selected lethal temperatures, 28 °C for Chinook and 31.5 °C for rainbow. In order to use this information in predicting the likelihood of fish demise from the fluctuating temperatures of a thermal mixing zone or "plume," as described by Jaske *et al*. (in press), it is necessary to know the intrinsic character of fish response to thermal shock over a range of shock temperatures. A classic "dose response" would be indicated if the effect (i.e., differential predation) is demonstrated to be a function of shock temperature and duration of exposure, where the time required is inversely proportional to the temperature.

The objective of this study was to determine if the hypothesized "dose response" was, in fact, exhibited by juvenile rainbow trout exposed to various durations of exposure to three lethal temperatures: 26, 28 and 30 °C.

MATERIALS AND METHODS

The test fish, juvenile rainbow trout (*S. gairdneri*), were raised at the Pacific Northwest Laboratories' aquatic ecology facilities from a brood stock maintained for several generations. The stock originally came from the Naches Hatchery operated by the Washington State Department of Game. Our facilities were supplied with untreated Columbia River water. During these experiments, in the fall of 1969, the fish averaged 16.26 grams (S.D. 6.97) in weight and 95.03 mm (S.D. 15.74) in length from snout to hypural plate. They were acclimated to 15 °C for several weeks prior to testing.

Experimental methods and their rationale were described previously (Coutant, Nov., 1972). Briefly, the methods were as follows. Juvenile fish were first removed from a common stock tank and both test and control groups were marked with a cold brand. After a recovery period of at least 72 hours, each group was transferred to its test exposure, one being heated and the other unheated water at the acclimation temperature. Upon completion of the timed exposures, shocked and control fish were reunited at the acclimation temperature and offered simultaneously to the predators in a circular fiberglass tank 1.2 m in diameter with 65 cm water depth. Predator adult rainbow trout were allowed a maximum of 15 min to remove approximately 50% of the prey. The remainder was then removed, and test and control fish were counted. The statistic $d_p = \frac{i_1}{i_2}$ was used to express the difference in instantaneous predation rates upon the two groups (after Bams, 1967). The chi-square analysis was used to test for significant differences.

The only significant deviation from the established procedure was dictated by the larger size of prey fish during the fall of the year, following about 7 months growth. Because of the increase in size, only the smallest individuals were used. Non-random selection for size prior to experimentation is considered to be unimportant to test results, for it occurred prior to random separation of shocked and control groups. Predators were the same adult rainbow trout (now 3 years old) used previously in testing juvenile Chinook. No recovery period at acclimation temperature was allowed following thermal exposure to lethal temperatures.

RESULTS AND DISCUSSION

Heterogeneity χ^2 calculations for all test groups (i.e., specific combinations of shock temperature and time) indicated that test results for each group were consistent (Table 1). Conclusions regarding significance of differential predation could thus be made on the "combined" data for each group.

At the highest test temperature of 30 °C, a one-minute exposure yielded a group chi-square (3.373) that was only slightly below the 0.05 level of significance. Predation difference was highly significant (25.043) following an exposure time of 1.5 minutes. The trend in d_p ratios (Figure 1) suggests that there was an increase in relative vulnerability to predation (i.e., the ratio became greater than 1) near 0.55 minutes.

The supply of small test fish was exhausted before the lowest exposure time resulting in increased vulnerability at 28 °C could be determined. Tests at 4, 8, and 16 min yielded highly significant differences in predation (Table 1). The trend in d_p ratios suggests that the length of shock exposure required to illicit increased vulnerability to predation may be near 2 min (dotted line in Figure 1).

The lowest of the test temperatures, 26 °C, induced significantly different predation rates after an exposure of 64 min, but not after 16 or 32 min (Table 1). There were highly significant differences after 90 and 120 min exposures. The trend in d_p ratios (Figure 1) indicates that an exposure time of about 32 min first induced changes in fish behavior or performance that resulted in an increased vulnerability to predation by large trout.

The relationship of shock temperatures to the described "end points" for predation effects are shown in Figure 2. Although three test temperatures are inadequate to define the entire relationship (the dashed line was placed by inspection), there is evidence that this thermal shock response is similar to the pattern of thermal resistance with death as the primary criterion (such as Brett, 1952) or with loss of equilibrium as the primary criterion (Coutant and Dean, Nov., 1972). The three criteria for thermal shock effects are illustrated, all based upon data from tests using the same stock of juvenile rainbow trout. Regression lines were calculated for equilibrium loss and death. Figure 2 is arranged according to the pattern established by Fry, Hart and Walker (1946) and followed subsequently by other workers in this field, despite the reversed orientation of dependent and independent variables from general statistical practice. The end points for differential predation effects averaged 10.9% of the dose required to kill the fish directly by heat.

These results indicate the feasibility of quantitative description of the thermal dose (i.e., temperature administered for a length of time) required to increase the vulnerability of young fish to predation immediately following that exposure. The amount of data now available is inadequate to complete this description, which must await further testing. Quantitative relationships between thermal changes and various criteria for ecological effects have been shown to have utility in defining boundary conditions for designing safe thermal discharges into rivers (Jaske _et_ _al_. in press).

TABLE 1. Results of Predation on Thermally Shocked Juvenile Rainbow Trout by Adult Rainbow. Acclimation temperature, 15 °C; shock temperatures indicated. The number of fish in each group at start of predation was 25.

$$[i = -\log_e \text{(survival proportion)};\ d_p = \frac{i \text{ shocked}}{i \text{ control}}]$$

Length of Exposure (min)	Number Surviving Shocked	Number Surviving Control	Chi Square (1 d.f.)	i Shocked	i Control	d_p
		30 C SHOCK TEMPERATURE				
0.5	14	15	0.034	0.579	0.510	1.135
	15	16	0.032	0.510	0.446	1.144
	16	12	0.571	0.446	0.733	0.608
	14	14	0	0.579	0.579	1.000
Combined	59	57	0.034	0.527	0.562	0.938
Heterogeneity χ^2			0.603			
1.0	7	16	3.521	1.272	0.446	2.852
	15	16	0.032	0.510	0.446	1.144
	8	16	2.666	1.139	0.446	2.553
	14	15	0.034	0.579	0.510	1.135
Combined	44	63	3.373	0.820	0.462	1.776
Heterogeneity χ^2			2.888			
1.5	6	20	7.538	1.427	0.223	6.395
	9	19	3.571	1.021	0.274	3.722
	6	17	5.260	1.427	0.385	3.700
	8	13	1.190	1.139	0.653	1.742

TABLE 1. (contd)

Length of	Number Surviving		Chi Square	i		
Exposure (min)	Shocked	Control	(1 d.f.)	Shocked	Control	d_p
	3	11	4.571	2.120	0.820	2.582
	8	19	4.481	1.139	0.274	4.151
Combined	40	99	25.043	1.321	0.415	3.181
Heterogeneity χ^2			1.568			
			28 C SHOCK TEMPERATURE			
4	10	16	1.384	0.916	0.446	2.053
	8	22	6.533	1.139	0.127	8.913
	1	20	17.190	3.218	0.223	14.425
	4	24(a)	14.285	1.832	0.040	44.891
Combined	23	82	33.152	1.469	0.198	7.405
Heterogeneity χ^2			6.24			
8	11	20	2.612	0.820	0.223	3.679
	1	21	18.181	3.218	0.174	18.461
	6	22	9.142	1.427	0.127	11.163
Combined	18	63	25.000	1.427	0.174	8.185
Heterogeneity χ^2			4.94			

TABLE 1. (contd)

Length of Exposure (min)	Number Surviving		Chi Square (1 d.f.)	i		d_p
	Shocked	Control		Shocked	Control	
16	3	22	14.440	2.120	0.127	16.586
	5	24[1]	12.448	1.609	0.040	39.425
	7	23	8.533	1.272	0.083	15.266
Combined	15	69	34.714	1.609	0.083	19.302
Heterogeneity χ^2			0.707			
26 C SHOCK TEMPERATURE						
16	15	9	1.500	0.510	1.021	0.500
	18	17	0.028	0.328	0.385	0.851
	13	7	1.800	0.653	1.272	0.513
	17	16	0.030	0.385	0.466	0.864
Combined	63	49	1.750	0.462	0.713	0.647
Heterogeneity χ^2			1.608			
32	18	18	0	0.328	0.328	1.000
	12	14	0.153	0.733	0.579	1.265
Combined	30	32	0.065	0.510	0.446	1.144
Heterogeneity χ^2			0.088			

TABLE 1. (contd)

Length of	Number Surviving		Chi Square	i		
Exposure (min)	Shocked	Control	(1 d.f.)	Shocked	Control	d_p
64	10	21	3.903	0.916	0.174	5.255
	9	15	1.500	1.021	0.510	2.000
Combined	19	36	5.254	0.967	0.328	2.945
Heterogeneity χ^2			0.149			
90	6	20	7.538	1.427	0.223	6.395
	7	24	9.322	1.272	0.040	31.183
	11	21	3.125	0.820	0.174	4.708
Combined	24	65	18.887	1.139	0.143	7.962
Heterogeneity χ^2			1.098			
120	5	22	10.703	1.609	0.127	12.590
	4	24(a)	14.285	1.832	0.040	44.891
Combined	9	47	25.785	1.714	0.061	27.713
Heterogeneity χ^2			0.797			

a. No fish eaten, but one assumed eaten for purposes of calculation.

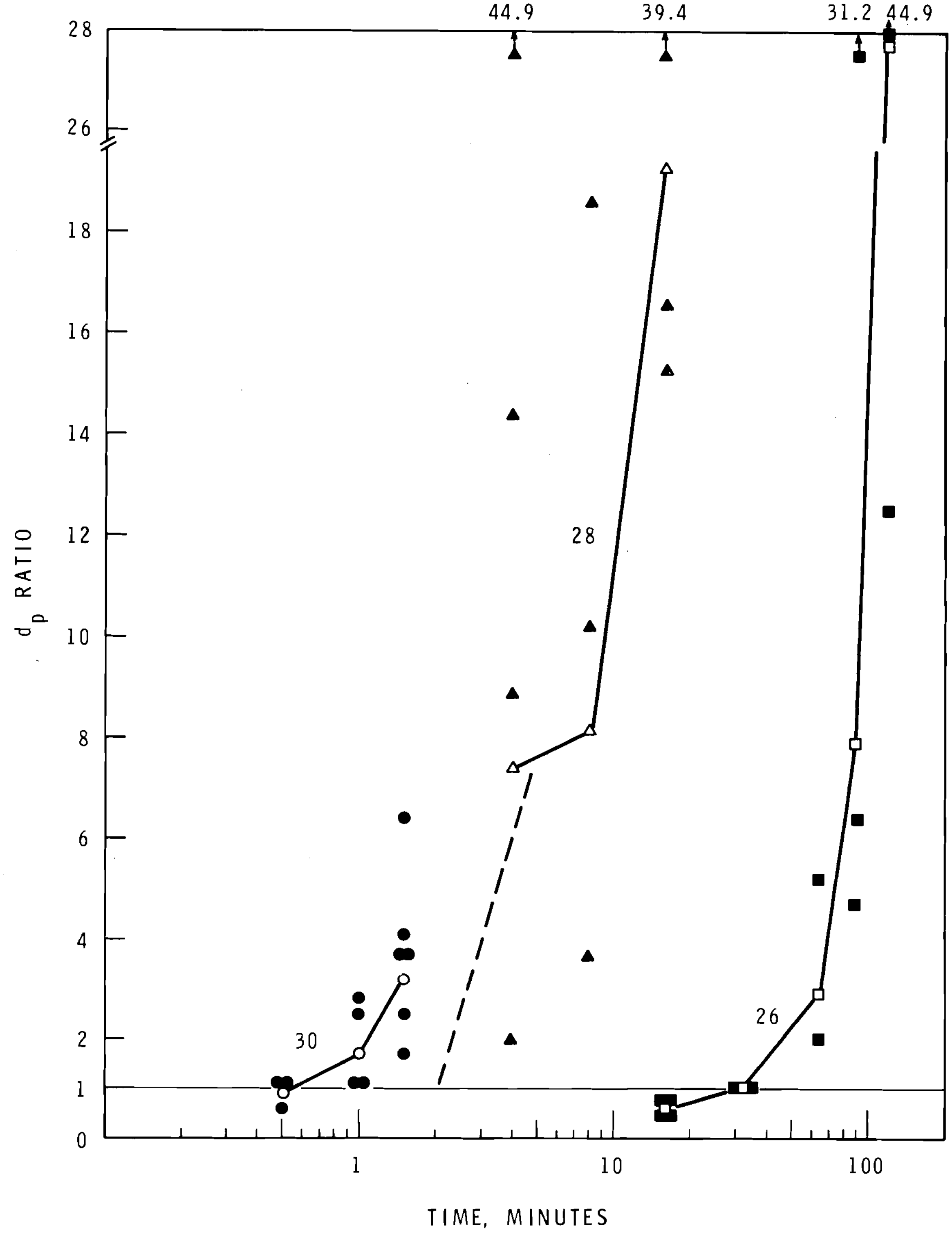

FIGURE 1. Patterns of d_p Ratios for Timed Exposures of Juvenile Rainbow Trout to 26, 28 and 30 °C. Solid points are ratios for individual tests; open points are for "combined" tests for the exposure time.

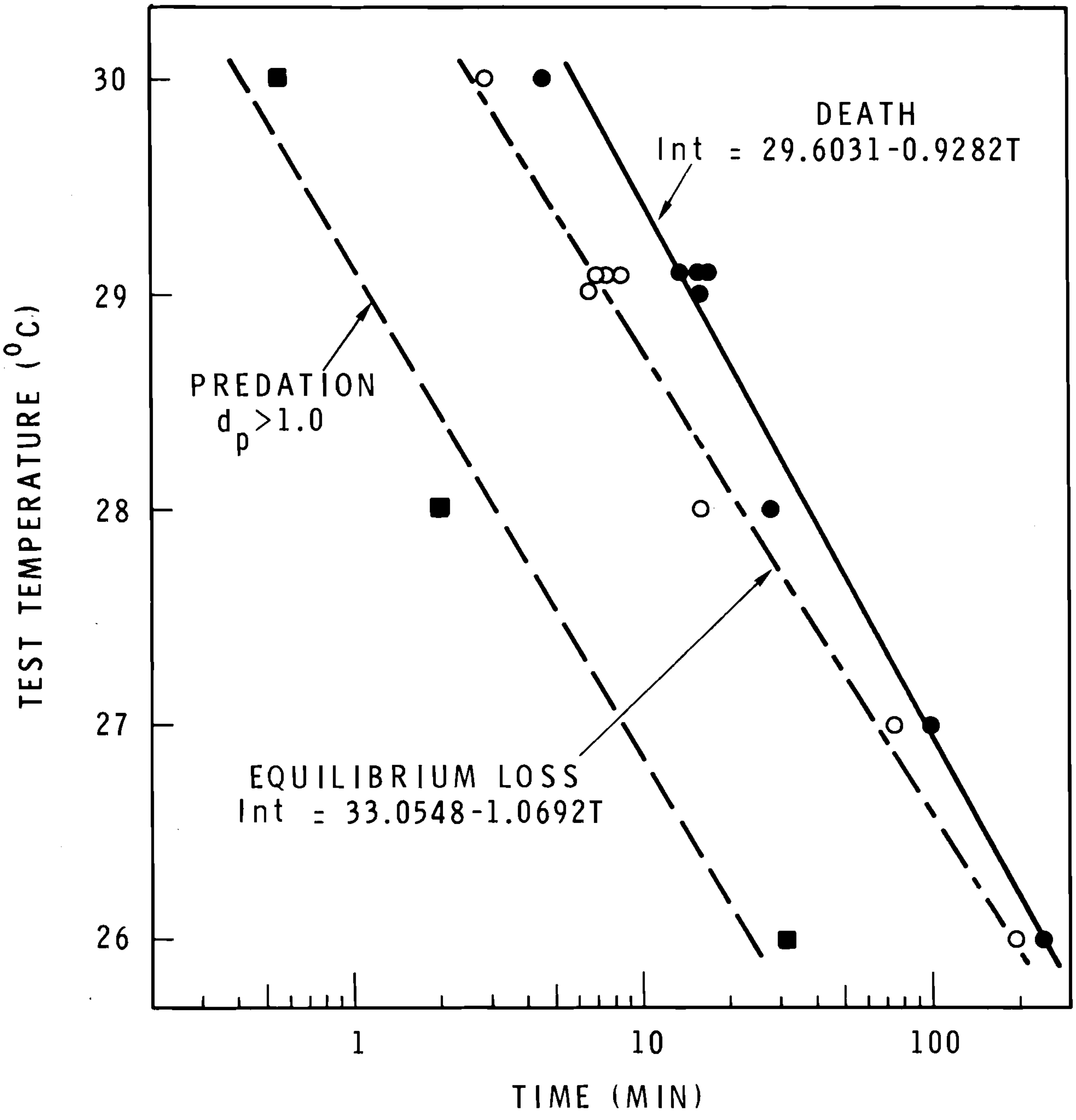

FIGURE 2. Relationships Among Three Effects of Acute Thermal Shock on 15 °C-Acclimated Juvenile Rainbow Trout: Death, Equilibrium Loss, and Increased Vulnerability to Predation. Regression equations are shown for equilibrium loss and death (t = time, T = temperature).

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