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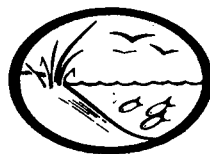
# Effects of Heat Shock on Predation of Striped Bass Larvae by Yearling White Perch

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Consolidated Edison Company of New York, Inc.  
Orange and Rockland Utilities, Inc.  
Power Authority of the State of New York



ECOLOGICAL ANALYSTS, INC.

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EFFECTS OF HEAT SHOCK  
ON PREDATION OF STRIPED BASS  
LARVAE BY YEARLING WHITE PERCH

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by 11-27-79  
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Prepared by:

Ecological Analysts, Inc.  
Middletown, New York

October 1979

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## CHAPTER 1: INTRODUCTION

Power plants located on the Hudson River employ once-through cooling systems to dissipate waste heat. In the cooling sequence, river water is pumped through a condenser, where heat is transferred from the exhaust steam to the cooling water, and the warmed water is then returned to the river. Once-through cooling systems expose planktonic organisms, including fish larvae, to abrupt temperature increases during two events: (1) entrainment through the power plant with the cooling water (i.e., plant entrainment), and (2) entrainment with the dilution water into the thermal plume created by the cooling water discharge (i.e., plume entrainment).

The direct effects of plant and plume entrainment on striped bass larvae have been extensively studied and are summarized in 316(a) and 316(b) demonstrations and supporting documents for Hudson River power plants (CHG&E 1977, 1978; ORU 1977, 1978; Con Edison 1977, 1978; EA 1977, 1978a). The results of these studies have generally shown high levels of survival for plant entrained striped bass, and have indicated little or no plume entrainment mortality. However, controlled laboratory experiments conducted by Coutant (1973), Yocum and Edsall (1974), and Deacutis (1978) indicated that, in some tests, thermally stressed fish were more susceptible to predation than control fish, implying that indirect mortality may result from increased predation on young fish exposed to sublethal thermal stress during entrainment.

The purpose of this report is to examine the extent to which preferential predation may occur on striped bass larvae surviving entrainment at Hudson River power plants. To supplement the results of studies performed by Coutant (1973), Yocum and Edsall (1974), and Deacutis (1978), laboratory experiments were conducted on the effects of heat shock on predation of striped bass larvae. The objectives of these experiments were two-fold: (1) to determine if striped bass larvae are more susceptible to predation immediately following a heat shock than control larvae under experimental conditions partially simulating conditions in the natural environment (i.e., natural turbidity, large tank size, and availability of alternative food sources), and (2) to determine the length of time after a heat shock that striped bass remain more susceptible to capture than control larvae (i.e., recovery time). The methods and results of these experiments are presented in Chapters 3 and 4, respectively. The extent to which preferential predation of entrained striped bass larvae would be expected to occur at Hudson River power plants is discussed in Chapter 5. An abstract of the experimental results and highlights of the discussion are presented in the report summary (Chapter 2).

## CHAPTER 2: SUMMARY AND CONCLUSIONS

To examine the extent to which preferential predation may occur on striped bass larvae surviving entrainment at Hudson River power plants, laboratory experiments were conducted on the effects of heat shock on predation of striped bass larvae by yearling white perch. Tests were conducted during the spring and summer of 1978 at Ecological Analysts' bioassay facility located at the Roseton Generating Station on the Hudson River. Two groups of experiments using different methodologies were conducted to detect and measure preferential predation.

The first group of experiments (preferential predation experiments) tested predation by white perch on thermally stressed and control striped bass larvae under conditions partially simulating conditions in the natural environment. Tests were conducted in large (1.9-m<sup>3</sup>) circular experimental tanks supplied with unclarified Hudson River water. Gammarus were included with the larvae as alternative prey in some tests. Just prior to predation, stressed larvae were exposed to a 10 minute heat shock at approximately 32 C (7.0 to 10.1 C above ambient river temperatures). The results indicated that predation of stressed larvae in preference to control larvae was statistically significant for only 4 of the 14 tests (overall  $\alpha = 0.05$ ) under these experimental conditions. The presence of Gammarus significantly ( $P < 0.005$ ) decreased the overall predation of striped bass larvae but had no apparent effect on preferential predation of stressed larvae.

The second group of experiments (recovery time experiments) tested the predation efficiency of white perch on thermally stressed striped bass larvae after the larvae had been allowed to recover from a heat shock (10-minute exposure to 32 C) for 0, 30, 60, 120, 180, and 240 minutes. Results of these experiments indicated that thermally stressed larvae were significantly ( $\alpha = 0.05$ ) more susceptible to capture for only 30 minutes after the heat shock. Consequently, any assessment of the extent to which preferential predation may actually occur as a result of power plant entrainment will likely overestimate mortality unless this recovery is taken into account.

The potential for preferential predation to occur with respect to thermal stresses other than the one tested was examined on the basis of the parallel relationship between the thermal tolerance response and the preferential predation response described by Coutant (1973). Based on this relationship, the difference between the exposure temperatures resulting in 50 percent mortality (TL50) and the approximate exposure temperature necessary to induce preferential predation was estimated to be 3.8 C for striped bass larvae. This application factor was combined with an empirical thermal tolerance prediction equation for striped bass larvae to predict minimum thermal stresses that would be sufficient to create a potential for preferential predation. A comparison between the time-temperature exposures that may be encountered by striped bass larvae entrained at Hudson River power plants and the estimated thermal stress required to induce selective predation indicates that most entrained striped bass are exposed to thermal stresses less than or only slightly greater than the minimum thermal stress resulting in increased vulnerability to predation. The limiting thermal stress used for this analysis (i.e., the minimum heat shock necessary to induce preferential predation) is based on the assumption that predation will occur within about 30 minutes

after return to the river (based on the results of the recovery time experiments), and thus, this assessment does not account for any decrease in the potential for preferential predation to occur as the amount of elapsed time between a heat shock and a predation event increases.

The results of these experiments, as well as other published studies on the effects of heat shock on predation of young fish (Coutant 1973, Yocum and Edsall 1974, Deacutis 1978), cannot be directly extrapolated to field situations without also considering the effects of important environmental factors that could substantially alter the potential for preferential predation to occur in and around cooling water discharges. The probable effects of some of these important natural variables are summarized below:

- Density of striped bass larvae - The larval densities tested in the preferential predation experiments were much higher than densities of striped bass larvae in the Hudson River (over 20 times higher than river densities during periods of peak occurrence). In the natural environment, the probability of a predator encountering an entrained striped bass larva prior to its recovery from the thermal stress is likely to be quite low.
- Density of alternative prey - The abundance of other food organisms far exceeds the abundance of striped bass larvae in the river. (For example, macrozooplankton densities typically exceed peak Morone spp. densities by over 10 times.) The extent to which the predation rate on larvae is reduced by the presence of other food organisms under natural conditions could substantially increase the probability that entrained larvae would avoid predation long enough to completely recover from the thermal stress.
- Density of predators - In the Hudson River, most fish predators likely to prey on larval fishes generally prefer bottom or shore-zone areas, and do not normally utilize offshore, surface waters characteristic of the thermal plumes from the Bowline Point, Roseton, and Indian Point power plants. Consequently, the probability that entrained striped bass larvae would encounter predators prior to recovery from the thermal stress would be expected to be quite low.
- Discharge velocities - The high discharge velocities and rapid dilution associated with the submerged, high-velocity diffusers at the Roseton, Bowline Point, and Indian Point plants would be expected to further reduce the potential for preferential predation to occur following an actual entrainment event by rapidly dispersing and mixing entrained larvae with other prey organisms in the river. In addition, the high discharge velocities actually exclude fish from inhabiting areas in the immediate vicinity of the discharge, where the highest plume temperatures occur, because the velocities in this area exceed the swimming speeds of most Hudson River fishes.
- Availability of cover - Another variable that may reduce the potential for preferential predation to occur in the natural environment is the availability of cover, such as vegetation, which may serve as a refuge for stressed larvae until they have recovered from the thermal shock.



In conclusion, increased predation on striped bass larvae entrained at Hudson River power plants is not expected to occur to any appreciable extent. The magnitude of the thermal exposure encountered by entrained larvae is usually insufficient to increase their susceptibility to capture. When time-temperature exposures are sufficient to increase susceptibility to predation, escape capabilities have been shown to quickly return to normal. Moreover, the probability that a predation event would occur on entrained striped bass larvae prior to recovery from the thermal stress at naturally occurring densities of striped bass larvae, alternative prey, and potential predators would be expected to be quite low in the natural environment in and around cooling water discharges at Hudson River power plants.

## CHAPTER 3: MATERIALS AND METHODS

### 3.1 PREDATORS

White perch were seined from the Hudson River for use as predators in these experiments. Although white perch have not been shown to prey heavily on fish larvae (TI 1976), they are voracious predators and are abundant in the Hudson River throughout the striped bass larval season (May-July). Four groups of predators were used during experimentation:

<u>Predator Group</u>	<u>Total Length (mm)</u>		<u>Experiments For Which Predator Group Was Used</u>
	<u>Mean</u>	<u>Range</u>	
1	85	76-98	Recovery time experiments
2	115	92-133	Preferential predation experiments (exploratory experiments only)
3	87	70-98	Recovery time and preferential predation experiments
4	87	71-100	Preferential predation experiments

White perch were acclimated to laboratory conditions in 600- and 1,000-liter holding tanks for 1-3 weeks prior to experimentation. During this time they were fed frozen brine shrimp each evening and treated 4-5 times per week with 2-3 ppt salt and 100 ppm Furacin (22 ppm active ingredient) for 1-4 hours to prevent disease.

Several tests were conducted with each predator group on consecutive days, using the same predators repeatedly. Predators were allowed to acclimate to the test tanks without feeding for 24 hours prior to each series of tests. The only food available to predators during each series of tests was the experimental prey. When testing was interrupted for more than 24 hours, the predators were removed from the experimental tanks to a large holding tank and fed frozen brine shrimp; prior to resuming experimentation, the predators were re-acclimated to the test tanks for 24 hours without feeding.

The normal feeding time for white perch has been reported to be from dusk to midnight, although significant daytime feeding has also been observed (Scott and Crossman 1973, p. 688). To increase the probability of obtaining a good feeding response by the predators, tests were conducted during the early evening hours prior to complete darkness (1700-2100 hours). Testing during complete darkness was avoided because of the need for some light, either artificial or natural, to conduct the tests.

### 3.2 PREY

Striped bass post-yolk-sac larvae were obtained from the Con Edison hatchery operated by Texas Instruments, Inc., at Verplanck, New York. All larvae were reared from eggs obtained from Hudson River striped bass. The larvae were held in the laboratory after transport to the bioassay facility for 3-4 days prior to testing to allow for handling mortality and recovery from stresses associated with transport. Larvae were held in continuous flow aquaria supplied with filtered Hudson River water and were fed live brine shrimp nauplii. Larvae used for testing ranged from 27 to 41 days old. Subsamples of 30-60

larvae were measured to the nearest millimeter on each day that tests were conducted; mean total lengths of larvae used in tests ranged from 12.1 to 26.0 mm. Gammarus were collected from the Hudson River on artificial substrates for use as alternative prey.

Prey were thermally stressed by exposure to an abrupt temperature increase from ambient river temperatures (22-25 C) to approximately 32 C for 10 minutes. Thermal shocks were accomplished by transferring larvae placed in cylindrical screen-bottomed containers (10 cm in diameter and 11 cm deep) to a water bath adjusted to the exposure temperature. The containers were transferred to the water bath in small bowls to prevent the fish from being exposed to the air. Temperature equilibration was typically achieved within 30 seconds after initiation of the thermal shock by flushing the container several times with heated water from the water bath; temperature fluctuations after equilibration were maintained within 0.1 C. Actual exposure temperatures ranged from 31.4 to 32.5 C, representing temperature increases above ambient river temperatures ( $\Delta T$ ) of 7.0-10.1 C. Few larvae died as a result of this exposure to these elevated temperatures, but larvae often exhibited signs of stress (i.e., erratic swimming and momentary loss of equilibrium). Larvae that died during the thermal exposure were not used for experimentation. Controls were handled in the same manner as experimental prey, but were not exposed to elevated temperatures.

### 3.3 PREFERENTIAL PREDATION EXPERIMENTS

Preferential predation experiments were conducted under conditions partially simulating the natural environment by using large experimental tanks (1.9 m<sup>3</sup>) supplied with naturally turbid water. Other experimental procedures were similar to those reported by Coutant (1973). Stressed and control larvae were simultaneously introduced into tanks containing the predators, and the number of surviving stressed and control larvae were recorded at the end of the test (Figure 1). Stressed and control larvae were differentiated by dyeing one of the groups with neutral red prior to the test. All tests were conducted in replicate, using dyed control larvae for the first replicate and dyed stressed larvae for the second replicate. Paired replicates were conducted on consecutive days using the same predators, and the results of the two replicates were combined into a single test result in order to examine preferential predation resulting from thermal stress without adjusting for prey selection related to the dye. Gammarus were introduced into the tanks with the larvae for some tests to simulate the presence of other prey organisms in the natural environment.

Dyeing was accomplished by exposing larvae to a 2.5-3.0 ppm neutral red solution for 2.5-4 hours, depending on the size and number of larvae. The dyed larvae were then transferred to a holding container supplied with a continuous flow of river water for 4-6 hours prior to the test to allow the dye to fade to a light pink color.

Preferential predation experiments took place in six 1.9-m<sup>3</sup> (1,900-liter) circular polyethylene tanks (132 cm in diameter and 162 cm deep) with cone-shaped bottoms to permit complete drainage (Figure 2). The tanks were located outside (partially sheltered by translucent fiberglass roofing), and therefore subject to natural light conditions. A continuous flow of Hudson River water filtered through a 0.5-mm screen to remove macrozooplankton, fish larvae, and

Replicate 1 (Day 1)

Replicate 2 (Day 2)

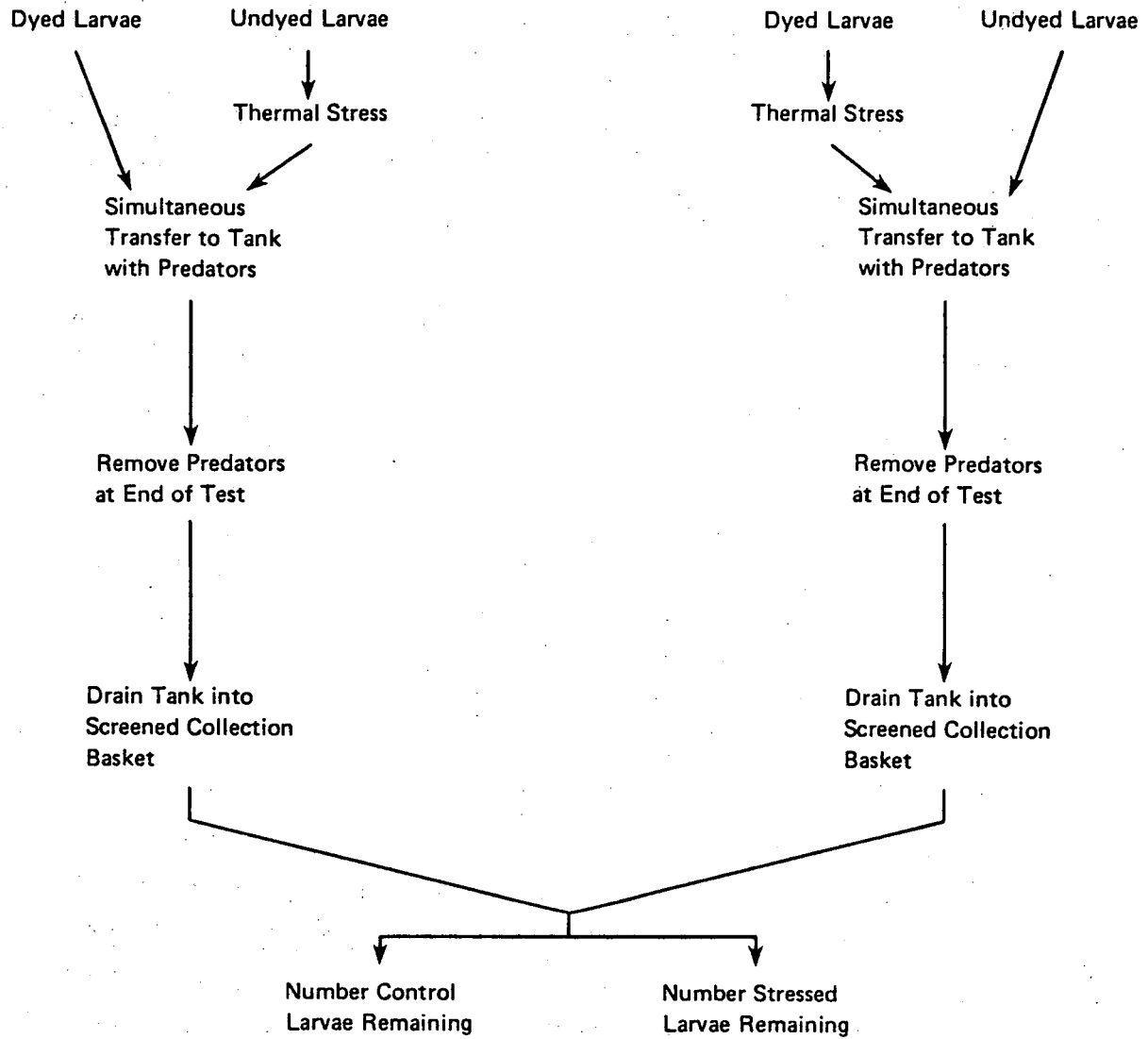


Figure 1. Flow diagram for conduct of each test to determine the relative vulnerability of thermally shocked and control larvae to predation.

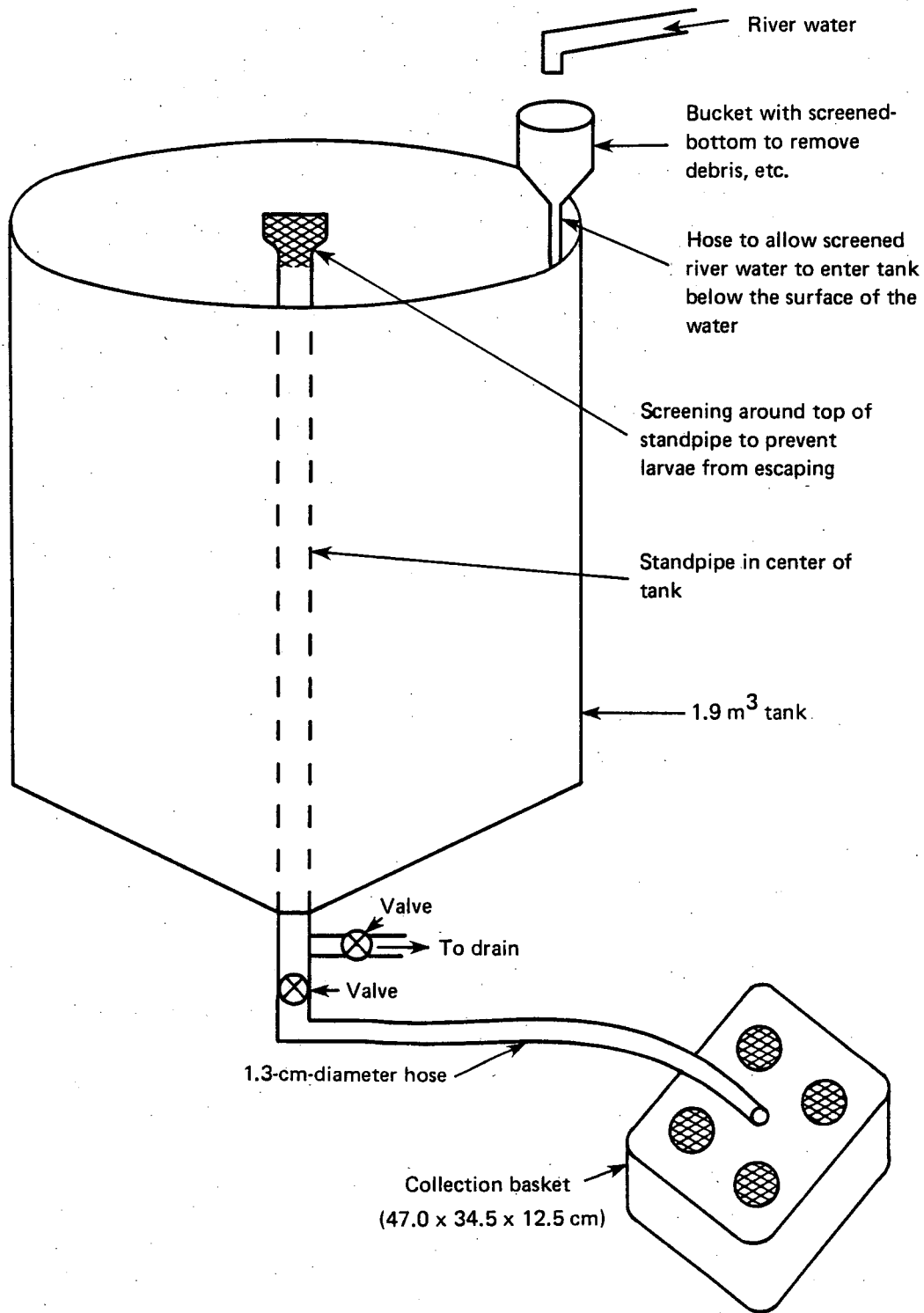


Figure 2. Illustration of apparatus used to conduct preferential predation experiments (not drawn to scale).

debris was maintained at approximately 4-6 liters/min, entering at the periphery of the tank below the surface of the water and leaving via a standpipe located in the center of the tank. The standpipe was provided with 0.5-mm-mesh screening to prevent the prey from escaping. There were no structures other than inlet hose, outflow standpipe, and tank walls to provide visual protection to the prey. Turbidity was measured prior to each test using a standard 20-cm-diameter Secchi disk. Secchi disk transparency within the test tanks ranged from 33 to 58 cm (13-23 in.) throughout the study. For perspective, New York University Medical Center (NYU 1978) reported Secchi disk transparencies ranging from 34 to 134 cm (13-53 in.) in the Hudson River during 1976.

Predators were removed at the end of the test using a 0.95-cm (3/8-in.) mesh drop net that was lowered into the tank along the sides, drawn across the bottom via draw strings, and then raised to the surface. Removal of the predators was usually accomplished within 5-10 minutes. It is unlikely that further predation occurred during this time, because of the disturbance created by the removal process. (Fish held in tanks supplied with clarified water were observed on many occasions to cease feeding when disturbed in this manner.) The drop net was rinsed thoroughly to remove any uneaten prey that may have adhered to the net. The predators were placed in 100-liter (30-gallon) pails containing water adjusted to 2-3 ppt salinity to reduce handling stress and 100 ppm Furacin as a precaution against disease. Predators remained in these holding vessels until the tanks were drained (approximately 5 hours) and were then returned to the same experimental tank from which they had been removed, in preparation for tests the following day.

After removal of the predators, the tanks were drained through a 1.3-cm diameter hose into a 47 x 34.5 x 12.5-cm collection basket. Four 11.5-cm diameter holes covered with 0.5-mm screening located in the lid of the collection basket retained the larvae as the tank drained. Nearly all larvae were recovered alive. The number of uneaten control and stressed larvae was recorded for each replicate. The number of uneaten supplemental prey (Gammarus) was also recorded for appropriate tests. Surviving prey were not used in subsequent tests.

The efficiency of retrieving prey from the tanks was determined by performing several tests without predators; recovery was determined to be 98.5 percent for striped bass larvae and 89.2 percent for Gammarus (Appendix B, Table B-1). In addition, two predator groups were sacrificed at the end of each series of tests and their stomach contents examined to determine the number of prey consumed; the average recovery of striped bass larvae from both stomachs and tanks was 96.4 percent (Table B-2).

The statistic chosen by Bams (1967) and Coutant (1973) and used in this study to express the difference in predation rates on the two groups of larvae is the ratio

$$d_p = \frac{i_1}{i_2},$$

where  $i_1$  and  $i_2$  are, respectively, the instantaneous mortality rates of the thermally stressed and control groups. The instantaneous mortality rate

when time is a unit interval is given by

$$i = -\log_e S,$$

where

$$S = \text{survival proportion, i.e., } \frac{\text{No. larvae at finish.}}{\text{No. larvae at start}}$$

Differential predation ratios ( $d_p$ ) greater than 1 indicate that stressed larvae were consumed at a faster rate than control larvae, and  $d_p$  ratios less than 1 indicate that control larvae were consumed faster than stressed larvae. The magnitude of the  $d_p$  ratio provides a relative measurement of the difference between the rates of predation on the two groups of larvae.

To determine if the difference between the number of control and stressed larvae consumed was statistically significant, the chi-square test for independence (2 x 2 contingency table, Model II) was used (Sokal and Rohlf 1969, pp. 585-590).

$$\chi^2 = \frac{\left[ \left( \begin{array}{c} \text{No.} \\ \text{surviving} \\ \text{control} \end{array} \right) \left( \begin{array}{c} \text{No.} \\ \text{consumed} \\ \text{stressed} \end{array} \right) - \left( \begin{array}{c} \text{No.} \\ \text{consumed} \\ \text{control} \end{array} \right) \left( \begin{array}{c} \text{No.} \\ \text{surviving} \\ \text{stressed} \end{array} \right) \right]^2 \left( \begin{array}{c} \text{Total} \\ \text{no. of} \\ \text{larvae} \end{array} \right)}{\left( \begin{array}{c} \text{No.} \\ \text{control} \\ \text{larvae} \end{array} \right) \left( \begin{array}{c} \text{No.} \\ \text{stressed} \\ \text{larvae} \end{array} \right) \left( \begin{array}{c} \text{No.} \\ \text{surviving} \\ \text{larvae} \end{array} \right) \left( \begin{array}{c} \text{No.} \\ \text{consumed} \\ \text{larvae} \end{array} \right)}$$

Because this analysis was performed separately on the results of 14 experiments, the alpha level for each chi-square test was adjusted to yield an overall alpha level of 0.05, according to the following formula (Kendall and Stuart, 1976):

$$\alpha_0 = 1 - (1 - \alpha_i)^m$$

where

- $m$  = number of comparisons (i.e., 14)
- $\alpha_i$  = alpha level of individual chi-square test
- $\alpha_0$  = overall alpha level ( $\alpha = 0.05$ ).

After adjusting for multiple comparisons using the above formula, an individual test result was significant at an overall alpha of 0.05 when the probability of obtaining a larger chi-square was less than 0.005 (the resulting critical value of chi-square was 7.88).

The changing ratio of prey availability during a test can create a discrepancy between the measured rate of predation and the actual predation rate on each group (Bams 1967, p. 1142). Since the preferred group decreases in relative abundance as the test proceeds, the measured rate of predation on the preferred group is lower than the actual instantaneous rate for that group. The predation rate difference ( $d_p$ ) is therefore biased to some degree, especially when the overall predation rate is high. For this reason, the results of tests in which 30 percent or less of the prey remained at the end of the test were not considered valid estimates of preferential predation. Similar

criteria were used by Coutant (1973) and Bams (1967) to keep the variation in availability ratios within limits.

Initial (exploratory) experiments were conducted with 5 predators ( $2.6/m^3$ ) and 10 larvae ( $5.3/m^3$ ) per tank to determine the length of time that tests should be conducted. These predator-prey densities were selected to approximate densities that might occur in the natural environment (see Discussion in Chapter 5). However, nearly complete predation occurred during these tests for test durations as short as 15 minutes. Other exploratory tests performed with 20 larvae per tank ( $10.5 \text{ larvae}/m^3$ ) and 3 predators per tank ( $1.6/m^3$ ) also resulted in predation of more than 80 percent of the larvae within a 15-minute test period.

In order to measure a preferential predation response, it was necessary to test much higher prey concentrations than would normally be found in the natural environment. Subsequent tests were performed with three predators per tank ( $1.6/m^3$ ) and 50 larvae per tank (25 stressed and 25 control, equivalent to  $26.3/m^3$ ). Predation was allowed to continue for 15 minutes, after which the predators were removed. One hundred Gammarus (50 stressed and 50 control, equivalent to  $52.6/m^3$ ) were included with the larvae in some tests to examine the effects of alternative prey on predation of striped bass larvae.

#### 3.4 RECOVERY TIME EXPERIMENTS

The period of time following the thermal shock beyond which the potential for preferential predation no longer exists was determined for striped bass larvae by comparing the predation efficiency of yearling white perch on thermally stressed larvae with that for control larvae. Thermally stressed larvae were allowed to recover from the thermal shock for the following time intervals prior to testing: 0, 30, 60, 120, 180, and 240 minutes. The predation efficiency of the predators on larvae from each treatment group (recovery time) was measured by observing the number of attacks and captures during a 15-minute test period, according to procedures similar to those reported by Yocum and Edsall (1974).

Experiments were conducted in six 110-liter glass aquaria 73.5 cm long, 30.5 cm wide, and 43.5 cm deep, using clarified Hudson River water. Fluorescent lights were suspended above each tank to provide illumination, and the tanks were enclosed in a shrouded area of the laboratory to keep the observation area dark. The bottom and three sides of each aquarium were covered with black plastic to increase the visibility of the prey to the observer. The front of each tank was covered with a transparent plastic sheet that had been silvered on one side to allow the observer to view the fish without being seen.

Tests were conducted by releasing 23-30 larvae into a tank containing two predators and counting the number of attacks made on the larvae within 15 minutes. The larvae were released below the surface of the water by flushing them gently through a 2.5-cm-diameter tube inserted into the tank, or through a 2.5-cm-diameter tube permanently fixed to the front side of the tank. At the end of the tests, the predators were removed and the number of surviving prey was recorded. The predators were treated with a 2-ppm malachite green solution for 10 minutes to control ichthyophthiriasis (a condition observed among some fish) and then transferred to a common holding tank adjusted to



2-3 ppt salinity with 100 ppm (22 ppm active ingredient) Furacin to reduce handling stress and further reduce the potential for disease. The predators were held in this tank for 1-4 hours, and were then randomly redistributed among the six test aquaria in preparation for tests the following day. Randomizing the distribution of predators among the test tanks enabled statistical comparisons to be made between predation efficiencies observed among treatment groups without adjusting for differences in individual predator effectiveness. Surviving prey were not used in subsequent tests.

The predation efficiency of the predators was measured by the ratio of captures per attack. Two categories of predator behavior were classified as attacks: (1) actual strikes at prey, and (2) active pursuit of prey. The second behavioral category, active pursuit, was classified as an attack because evasive behavior by the prey often prevented an actual strike from occurring. Predators were also observed to slowly approach a prey, but not engage in active pursuit or strike at the prey. This lack of predatory response occasionally appeared to be the result of anticipatory evasive behavior by the prey, but was not included as an attack. Although most captures could be readily ascertained by visual observations, a more accurate measurement of captures was obtained by determining the difference between the number of larvae remaining in the tank at the end of the test and the initial number.

Low feeding responses by the predators occasionally resulted in erratic measurements of predator efficiencies. Therefore, a successful test was defined as one in which the predators made 15 or more attacks and captured more than 20 percent of the prey. Feeding responses not meeting this criterion were not included in the analysis of the results. (Yocum and Edsall [1974] also observed low feeding responses in some tests, and promulgated a similar criterion for successful tests.)

Analysis of variance was used to determine if recovery time was a significant variable among predation efficiencies (captures/attack) determined for each treatment group. The Student--Newman-Keuls multiple range test (for unequal sample sizes) was used to determine if differences between pairs of treatment means were significant (Steel and Torrie 1960, p. 114). Bartlett's test for homogeneity among treatment variances was performed prior to the analysis of variance to assure compliance with the assumption of homogeneity of variances (Sokal and Rohlf 1969, p. 370).

## CHAPTER 4: RESULTS

### 4.1 PREFERENTIAL PREDATION

The results of predation experiments conducted in large (1.9-m<sup>3</sup>) circular tanks supplied with naturally turbid Hudson River water were variable, but most tests resulted in higher numbers of stressed larvae consumed than control larvae (Table 1). The  $d_p$  ratios were greater than one for 10 of the 14 tests that resulted in acceptable levels of predation,\* indicating that more stressed larvae were consumed than control larvae; however, statistical analysis of the data indicated that predation of stressed larvae was significantly greater than control larvae in only 4 of the 14 tests (overall  $\alpha = 0.05$ ). The  $d_p$  ratios were less than one (indicating that more control larvae were consumed than stressed larvae) in 4 of the tests, although these differences were not statistically significant.

The presence or absence of Gammarus as an alternative prey had no discernable effect on the preferential predation observed on stressed larvae during these tests (Table 1). However, the overall level of predation on both control and stressed striped bass larvae was lower for tests in which Gammarus were present than for tests without Gammarus. The mean percentage consumption of larvae in the presence of Gammarus was 23.5, whereas the mean percentage consumption without Gammarus was 43.7. Chi-square analysis indicated that this difference was significant at  $\alpha = 0.005$  ( $\chi^2 = 64.174$ , 1 d.f.).

There was some indication during the exploratory tests that predators might have been selecting dyed larvae in preference to undyed larvae. Dyeing procedures were subsequently refined to minimize the intensity of color at the time of the test such that it could still be accurately detected after the surviving larvae were retrieved from the tanks. For the 14 tests resulting in acceptable levels of predation, a two-way analysis of variance (Sokal and Rohlf 1969, p. 302) was conducted on the number of surviving larvae from each replicate to determine if any interaction between the condition of the larvae and the dye existed. As shown in Table 2, there was no significant difference in the number of surviving larvae due to the dye, or due to interaction

\* Tests resulting in acceptable levels of predation (i.e., more than 30 percent of the larvae remained uneaten at the end of test) were conducted with three predators per tank (87 mm mean total length, predator groups 3 and 4) and 50 striped bass larvae per tank (25 stressed and 25 control). Exploratory experiments conducted with 3-5 white perch and 10-20 striped bass larvae per tank resulted in the consumption of more than 80 percent of the larvae, and tests performed with 50 larvae per tank and 3 of the larger predators (115 mm mean total length) resulted in nearly complete predation (see Table B-4). Although no preferential predation was observed on either stressed or control larvae among these exploratory tests, it is possible that the rate of predation on the preferred group may have been underestimated as a result of the high levels of predation (see previous discussion on changing ratios of prey availability during a test). Thus, the results of these exploratory tests were not considered valid for purposes of detecting and measuring preferential predation.

TABLE 1 NUMBER OF CONTROL AND STRESSED STRIPED BASS LARVAE (COMBINED FOR PAIRED REPLICATES) SURVIVING PREDATION BY YEARLING WHITE PERCH (87 mm MEAN TOTAL LENGTH), AND RATIOS OF INSTANTANEOUS PREDATION RATES (dp) (a) (FROM TABLE B-4)

Predator Group	Total Length of Larvae (mm) ( $\bar{x} \pm S.D.$ )	Presence (P) or Absence (A) of Alternative Prey (b)	Total No. Larvae at Start		Total No. Larvae Surviving		Total Larvae Surviving (%)	dp Ratio	Chi-Square (1 d.f.)
			Control	Stressed	Control	Stressed			
3	16.9 ± 1.03	A	50	50	20	24	44.0	0.801	0.649
		A	50	50	42	30	72.0	2.929	7.143
		P	50	50	37	27	64.0	2.046	4.340
		P	51	50	40	32	71.3	1.837	2.569
		P	50	50	33	36	69.0	0.791	0.421
		P	50	50	45	50	95.0	<1	5.263
3	19.3 ± 1.52	A	50	50	42	28	70.0	3.319	9.333*
		A	50	50	45	30	75.0	4.848	12.000*
		P	50	50	40	26	66.0	2.931	8.734*
		P	50	50	47	29	76.0	8.800	17.763*
		P	50	50	44	35	79.0	2.791	4.882
		P	50	50	47	45	92.0	1.703	0.543
4	17.4 ± 1.46	A	50	50	22	21	43.0	1.057	0.041
		A	50	50	16	18	37.0	0.897	0.178

(a) Tests were conducted at a larval density of 26.3/m<sup>3</sup> (½ stressed, ½ control) and a predator density of 1.6/m<sup>3</sup> (3 predators per tank). Thermally stressed larvae were exposed to elevated temperatures ranging from 32.0 to 32.5 C for 10 minutes, representing temperature increases above ambient river temperatures (delta-T) of 7.0-10.0 C.

(b) 100 *Gammarus* (50 stressed, 50 control) were included with the larvae in each replicate as alternative prey.

Note: Asterisk (\*) denotes significance at an overall alpha level of 0.05; after adjusting for multiple comparisons, the critical value for each chi-square test (one degree of freedom) was 7.88 (i.e.,  $P \leq 0.005$ ).

TABLE 2 ANALYSIS OF VARIANCE<sup>(a)</sup> FOR DIFFERENCES IN PREDATION BETWEEN DYED AND UNDYED LARVAE (DATA FOR INDIVIDUAL REPLICATES ARE FROM TABLE B-4, PREDATOR GROUPS 3 AND 4, 50 LARVAE PER TANK)

Number Larvae Surviving Predation for Each Replicate

	<u>Control Larvae</u>	<u>Stressed Larvae</u>
Dyed larvae	10, 23, 20, 18, 13, 23, 18, 20, 19, 22, 20, 22, 6, 3.	13, 12, 11, 14, 18, 25, 17, 20, 13, 16, 17, 25, 13, 12.
Undyed larvae	10, 19, 17, 22, 20, 22, 24, 25, 21, 25, 24, 25, 16, 13.	11, 18, 16, 18, 18, 25, 11, 10, 13, 13, 18, 20, 8, 6.

<u>Source</u>	<u>Degrees of Freedom</u>	<u>Sum of Squares</u>	<u>Mean Square</u>	<u>F</u>
Dye effects	1	11	11.000	0.3934
Thermal stress effects	1	141	141.000	5.0426*
Interaction	1	81	81.000	2.8968
Error	52	1,454	27.962	--
Total	55	1,687		

(a) Bartlett's test for homogeneity of variances resulted in a nonsignificant chi-square (3 df) of 2.85 ( $0.50 > P > 0.25$ )

Note: Asterisk (\*) denotes significance at  $\alpha = 0.05$ .

between the condition of the larvae and the dye; significant differences did exist between the stressed and control groups, as previously indicated by the chi-square tests.

#### 4.2 RECOVERY TIME

The predation efficiencies (captures per attack) of yearling white perch on striped bass larvae were determined for groups of thermally stressed larvae allowed 0, 30, 60, 120, 180, and 240 minutes recovery time prior to predation (treatment groups), and for larvae not subjected to a thermal stress (control group). These tests were conducted in small aquaria (110 liters) supplied with clarified Hudson River water and designed to allow direct observation of fish behavior. Because of occasional low feeding responses by predators, successful tests were defined as those in which the predators made 15 or more attacks and captured more than 20 percent of the prey (see Section 3.4). From 4 to 8 successful tests were completed with each treatment group, and 11 successful tests were completed with control larvae (Table 3).

After being released into the aquarium with the predators, the prey rapidly distributed themselves throughout the entire tank. The predators typically responded by immediately feeding on the larvae for the first 3-5 minutes of the test, after which the predators exhibited only occasional interest in the remaining prey. The prey responded to predation, in most cases, by segregating themselves in areas of the tank seldom frequented by the predators (i.e., along the bottom, sides, or in the corners). This predator avoidance behavior, as well as the partial satiation of the predators, probably contributed to the lower feeding response generally observed during the last 10 minutes of the test.

The average predation efficiency on treatment groups steadily decreased from 0.615 captures per attack for larvae allowed no recovery time to 0.326 captures per attack for larvae allowed 4 hours (240 minutes) recovery time (Table 3). The predation efficiency of predators on control larvae averaged 0.341 captures per attack. Analysis of variance (Table 4) indicated that the predation efficiency of predators varied significantly according to treatment groups. The Student--Newman-Keuls multiple range test indicated that the average predation efficiency for the control group was similar to predation efficiencies for all treatment groups except the 0- and 30-minute recovery time groups ( $\alpha = 0.05$ ).

The initial behavior of larvae allowed 0- and 30-minute recovery times prior to predation was different from the behavior of larvae allowed longer recovery times. They often exhibited signs of disorientation early in the test, characterized by little swimming movement and an abnormal posture with the head pointed towards the surface and the tail angled downward. Larvae with longer recovery times usually exhibited a strong avoidance of predators almost immediately, whereas larvae with 0- and 30-minute recovery times often did not actively avoid predators until later in the test. These signs of stress were much less apparent for larvae allowed a 30-minute recovery time than for those allowed no recovery time.

TABLE 3 CAPTURES PER ATTACK BY WHITE PERCH YEARLINGS FED STRIPED BASS LARVAE THAT WERE ALLOWED TO RECOVER FROM A THERMAL SHOCK<sup>(a)</sup> FOR VARIOUS TIME PERIODS BEFORE TESTING. (FROM TABLES C-1 AND C-2).

Mean Total Length of Prey (mm)	Captures Per Attack						Control
	Recovery Time in Minutes						
	0	30	60	120	180	240	
Predator Group 1 (85 ± 7.0 mm total length)							
13.8	0.769	0.556	0.610	0.346	--	0.535	0.325
14.7	0.735	0.452	0.380	0.352	--	0.295	(b)
15.5	0.654	0.606	(b)	0.521	--	0.190	0.444
15.8	--	--	0.625	0.676	--	0.395	0.366
15.8	--	--	--	--	--	--	0.324
Predator Group 3 (87 ± 7.4 mm total length)							
15.4	--	(b)	--	0.192	0.281	0.180	(b)
15.9	0.412	(b)	0.429	--	0.263	0.362	0.288
16.3	0.599	(b)	0.397	0.476	0.248	--	0.541
17.8	(b)	0.641	0.281	0.382	0.599	--	(b)
18.9	--	(b)	0.291	--	--	--	(b)
16.6	0.541	0.472	(b)	0.324	--	--	0.424
18.2	0.592	0.395	--	--	--	--	0.200
18.2	--	--	--	--	--	--	0.346
18.2	--	--	--	--	--	--	0.189
18.2	--	--	--	--	--	--	0.303
Mean	0.615	0.520	0.430	0.409	0.348	0.326	0.341
Range bars spanning mean values not significantly different <sup>(c)</sup>							

- (a) Thermally stressed larvae were exposed to elevated temperatures ranging from 31.4 to 32.4 C for 10 minutes, representing increases above ambient river temperatures (delta-T) of 7.9-10.1 C.  
 (b) Test results omitted from analysis because of low predator response.  
 (c) Results of Student-Newman-Keuls mutiple-range test at  $\alpha = 0.05$ .

Note: Dashes (--) indicate no data.

TABLE 4 ANALYSIS OF VARIANCE<sup>(a)</sup> AMONG PREDATION EFFICIENCIES (CAPTURES PER ATTACK) ON THERMALLY STRESSED AND CONTROL STRIPED BASS LARVAE ALLOWED VARIOUS RECOVERY TIMES (TREATMENT GROUPS)

<u>Source</u>	<u>Degrees of Freedom</u>	<u>Sum of Squares</u>	<u>Mean Square</u>	<u>F</u>
Treatment groups	6	0.4689	0.07815	4.8390*
Error	42	0.6783	0.01615	
Total	48	1.1472		

(a) The chi-square for Bartlett's homogeneity of variance test was 2.33 (6 df), which was not significant ( $P > 0.50$ ).

Note: Asterisk (\*) denotes significance at  $\alpha = 0.001$ .

## CHAPTER 5: DISCUSSION

### 5.1 DISCUSSION OF EXPERIMENTAL RESULTS

Two methodologies were used during this study to detect and measure the susceptibility of striped bass larvae to predation; the preferential predation experiments were patterned after methods used by Coutant (1973), whereas methodology used by Yocum and Edsall (1974) was used to conduct the recovery time experiments. The most important difference between the two methodologies is that stressed and control larvae are presented to the predators simultaneously with the Coutant (1973) methodology, whereas stressed and control larvae are tested separately with the Yocum and Edsall (1974) methodology. The methodology used by Yocum and Edsall (1974) thus detects and measures the "susceptibility of prey to capture," and also permits behavioral observations. The methodology used by Coutant (1973) detects and measures actual "preferential" or "selective" predation because the predators are presented with a choice of stressed or control prey. The Coutant (1973) methodology does not require behavioral observations, and thus experimental conditions can be manipulated to some extent in order to simulate natural conditions, as was attempted in this study.

Although results of the two types of predation experiments are not directly comparable because of the differences in methodology, thermally stressed striped bass larvae tested under conditions partially simulating the natural environment did not appear to be "preferentially" or "selectively" preyed upon to as great an extent as expected solely on the basis of the predation efficiency tests. Predation efficiencies (captures per attack) determined in small (110-liter) aquaria supplied with clarified water indicated that striped bass larvae tested immediately after a heat shock were nearly twice as easy for yearling white perch to capture as control larvae. On the other hand, in preferential predation experiments where both stressed larvae (also tested immediately after a heat shock) and control larvae were simultaneously available to predators in large (1,900-liter) tanks supplied with turbid water, stressed larvae were significantly preyed upon in preference to control larvae in only 4 of the 14 tests (overall  $\alpha = 0.05$ ). Thus, although thermally stressed striped bass larvae were shown to be more susceptible to capture than control larvae, yearling white perch predators were not always able to take advantage of this increased susceptibility in experiments designed to detect and measure preferential predation under less artificial conditions.

Another important finding of this study is that increased susceptibility of thermally stressed fish to predation is dependent on the amount of elapsed time between the heat shock and a predation event. The results of the recovery time experiments indicated that thermally stressed striped bass larvae were significantly more susceptible to capture ( $\alpha = 0.05$ ) for only 30 minutes after the 10-minute heat shock. Similarly, Coutant (1973) found that 30- and 60-minute recovery times following heat shocks up to 9 minutes in duration resulted in a pronounced decrease in the magnitude of preferential predation observed on juvenile rainbow trout and chinook salmon. Thus, the components of performance affected by brief heat shocks appear to return to normal soon after the heat shock. Consequently, any assessment of the extent



to which preferential predation may actually occur as a result of power plant entrainment will likely overestimate mortality unless this recovery is taken into account.

A limitation inherent in both methodologies used during this study may lead to an overestimate of the potential for preferential predation to occur following an actual entrainment exposure. The time-temperature exposures used during this study actually consisted of two thermal shocks: the first was an abrupt rise in temperature at the time of transfer to the heated water, and the second was an abrupt decrease of similar amount upon return to ambient temperatures. The latter "cold shock" has been shown to create additional stress resulting in momentary loss of equilibrium in some fish exhibiting no signs of stress due to the initial "heat shock" (Coutant 1973; Hoss et al. 1974). Entrained organisms are seldom subjected to secondary cold shocks as severe as those employed during this study. For example, upon return to the river following entrainment at most Hudson River power plants, organisms are exposed to a fairly rapid decrease in temperature as the temperature cools to about 30-50 percent of the maximum discharge temperature, after which they are exposed to a gradual, fluctuating temperature decrease until ambient river temperatures are reached (Con Edison 1978; CHG&E 1978; ORU 1978). Although the effects of this secondary cold shock on the measurement of preferential predation could not be determined in these experiments, it is recognized that the unduly severe temperature decrease may have been an important factor contributing to the level of preferential predation observed during the study, since it occurred just prior to predation.

## 5.2 RELATIONSHIP BETWEEN THERMAL EXPOSURES ENCOUNTERED BY ORGANISMS DURING ENTRAINMENT THROUGH HUDSON RIVER POWER PLANTS AND THE POTENTIAL FOR PREFERENTIAL PREDATION OF ENTRAINED STRIPED BASS LARVAE

Because only a single time-temperature exposure was tested during this study, the direct application of these results to the assessment of additional entrainment mortality resulting from preferential predation is limited. However, Coutant (1973) studied the effects of various exposure times and shock temperatures on the increased vulnerability of small fish to predation by larger fish and found that a predictable relationship existed between the magnitude and duration of a heat shock and the magnitude of preferential predation. It is, therefore, possible to estimate the potential for preferential predation to occur with respect to plant-specific thermal stresses by applying this relationship to the results of the preferential predation experiments conducted during this study and time-temperature exposures encountered by organisms entrained through Hudson River power plants.

Coutant (1973) investigated the effects of various exposure times and shock temperatures on the vulnerability of juvenile salmon and trout to predation and found that, at a given exposure temperature, there was a minimum exposure duration necessary to induce increased predation on the shocked fish. Fish exposed to a given test temperature for shorter durations were less susceptible to predation than control fish. Beyond this minimum exposure time, the vulnerability of stressed fish relative to controls increased almost exponentially. Furthermore, the exposure time necessary to increase the susceptibility of thermally stressed fish to predation depended on the magnitude of the thermal shock. For example, Coutant reported that an exposure temperature of 26 C induced preferential predation of stressed juvenile trout acclimated to

15 C only after exposures exceeding 60 minutes, whereas preferential predation on stressed fish was observed after a 1-minute exposure to 30 C. Coutant concluded that the increased susceptibility of thermally stressed fish to predation immediately after the thermal shock followed the time-temperature response pattern similar to that exhibited by the death response (i.e., thermal tolerance). After plotting exposure temperature against the minimum exposure times necessary to induce selective predation, Coutant further observed that the response pattern for increased susceptibility to predation paralleled that for the median death response (TL50).

The parallel relationship determined by Coutant (1973) between the median death response and the time-temperature exposures necessary to induce selective predation can be used to approximate entrainment exposures other than the single time-temperature exposure used in this study that might result in an increased susceptibility of striped bass larvae to predation. For this purpose, the following prediction equation was derived empirically to estimate the median death response (TL50) of striped bass larvae on the basis of thermal tolerance tests conducted by Ecological Analysts, Inc. during 1976, 1977, and 1978 (see Appendix A for a description of the derivation of the thermal tolerance prediction equation):

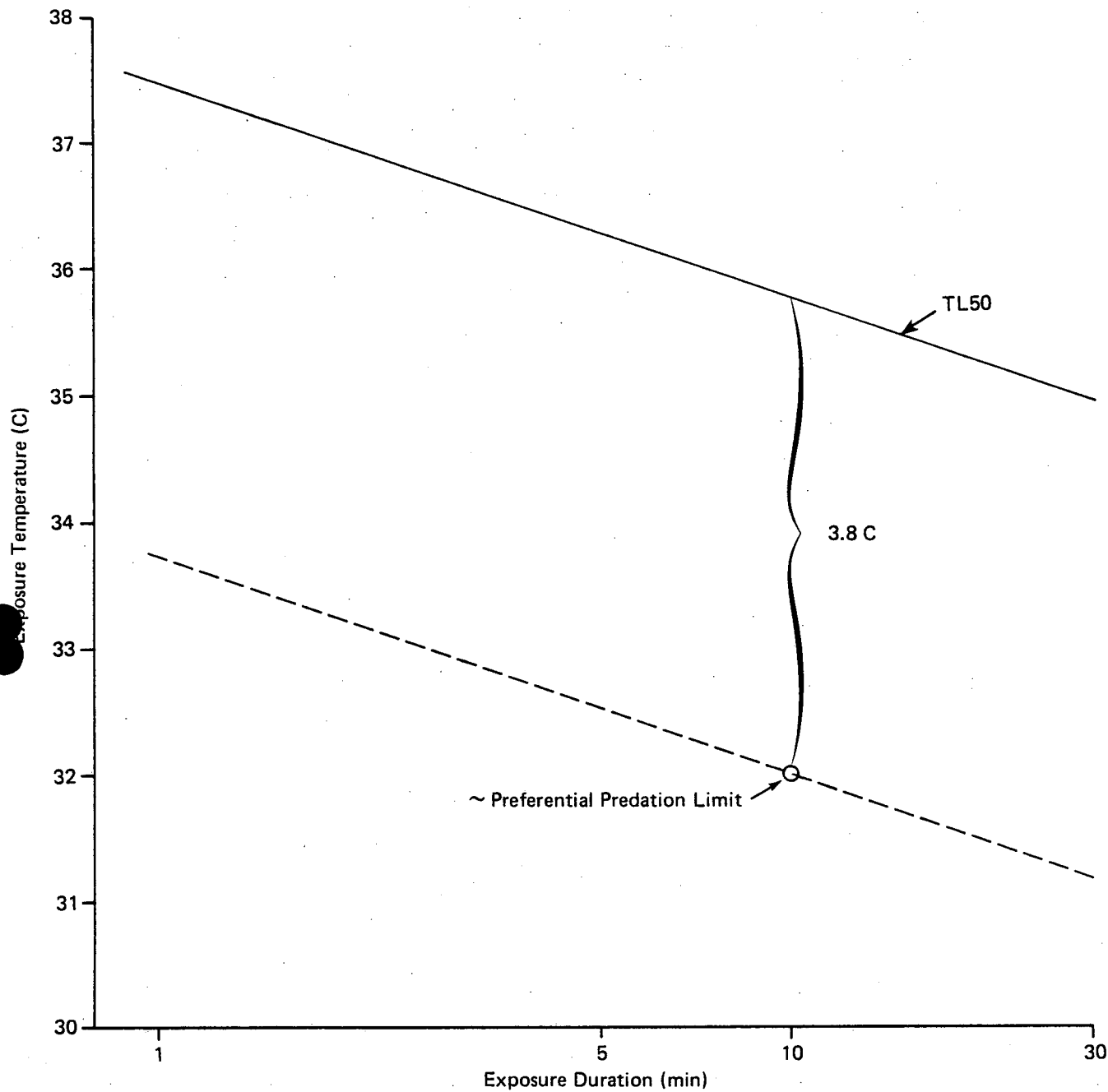
$$TL50 (C) = \frac{27.99 - 3.692(x_2x_4) + 47.92(x_3) + 0.8174(x_3x_4) - 0.2773(x_4)}{1.601(x_3)}$$

where

- $x_1$  = exposure temperature (C)
- $x_2$  = exposure duration ( $\log_{10}$  minutes)
- $x_3$  = acclimation temperature (C)
- $x_4$  = total length (mm).

In order to equate the TL50 with the time-temperature exposure used during the preferential predation experiments, this equation was used to calculate TL50s for exposure durations ranging from 1 to 30 minutes after incorporating into the equation the acclimation temperature and length of larvae that best represented the acclimation temperatures and lengths of larvae tested in the preferential predation experiments (i.e., acclimation temperature = 24 C and mean total length = 18 mm). The median death response determined for these variables is shown in Figure 3.

Assuming that the parallel relationship observed by Coutant (1973) is also applicable for striped bass larvae, a parallel line intersecting the time-temperature exposure at which the preferential predation experiments were conducted (i.e., 10-minute exposure to 32 C), also shown in Figure 3, represents the estimated time-temperature exposure at which increased susceptibility of striped bass larvae to predation would be similar to that observed during the preferential predation experiments. Because significant preferential predation was detected in only 4 of the 14 tests conducted, the time-temperature exposure used during the preferential predation experiments is considered here to approximate the minimum thermal stress necessary to induce preferential predation. In spite of the 4 tests that resulted in statistically significant preferential predation of stressed larvae under these experimental conditions, this limiting time-temperature exposure may be underestimated, because of the unduly severe temperature decrease to which



**Figure 3.** Estimated minimum time-temperature exposure necessary to induce selective predation on striped bass larvae, based on the relationship between the predation response and the median death response reported by Coutant (1973). The median death response shown was predicted based on an acclimation temperature of 24.0 C and a larval length of 18 mm.

heat-shocked larvae were exposed just prior to predation. In addition, this limiting thermal stress was based on the assumption that predation will occur within about 30 minutes after return to the river (based on results of the recovery time experiments), and thus does not account for any decrease in the potential for preferential predation to occur as the amount of elapsed time between a heat shock and a predation event increases (i.e., recovery time).

The difference between the exposure temperatures resulting in 50 percent mortality and the approximate exposure temperature necessary to induce preferential predation was 3.8 C. To approximate the magnitude and duration of thermal stress required to induce preferential predation for other acclimation temperatures and sizes of larvae, the thermal tolerance prediction equation was modified by subtracting 3.8 C from the predicted TL50. Using this modified equation, the time-temperature exposures that approximate the minimum thermal stress necessary to induce selective predation were calculated at three acclimation temperatures (spanning the range of acclimation temperatures that are found in the striped bass larval season) for both 10- and 20-mm larvae (Figure 4).

Discharge temperature and exposure duration, which determine, in part, the potential for increased susceptibility to predation of entrained fish larvae, vary among the Hudson River power plants and also depend upon operating conditions and ambient river temperatures. The transit times from the condenser inlet to the discharge of the cooling water as it passes through power plants located on the Hudson River, together with maximum delta-Ts (temperature elevations above ambient river temperatures) that would be generated by the power plants at 100 percent operating capacity, are presented in Table 5. Transit times for plant-entrained organisms are between 3 and 10 minutes, and maximum delta-Ts generally range from 8 to 11 C under normal operating conditions during the striped bass larval season (May-July). Upon return to the river, organisms are exposed to rapidly decreasing temperatures as the cooling water is diluted by ambient river water; transit times from the discharge port to a point within the thermal plume where the temperature has been reduced to less than half of the maximum discharge temperature are a few seconds (5-10) at the Roseton and Bowline Point plants (ORU 1978; CHG&E 1978) and varies from 1 to 3 minutes (depending on tidal conditions) at the Indian Point plant (Con Edison 1978).

Thus, the 10-minute exposure duration used in the preferential predation experiments approximates the maximum length of time that striped bass larvae would be subjected to elevated temperatures during plant entrainment, and far exceeds exposures to high temperatures during plume entrainment. Furthermore, the 32 C shock temperature used is generally applicable only for fish entrained when ambient temperatures are about 22 to 25 C, which usually occur near the end of the season for striped bass larval occurrence in the Hudson River (late June and July).

A comparison between the time-temperature exposures that may be encountered by striped bass larvae entrained at Hudson River power plants (Table 5) and the estimated thermal stress required to induce selective predation (Figure 4) indicates that most entrained striped bass are exposed to thermal stresses less than or only slightly greater than the minimum thermal stress resulting in increased vulnerability to predation. Discharge temperatures less than about 30.0 C would not be expected to induce any preferential predation on

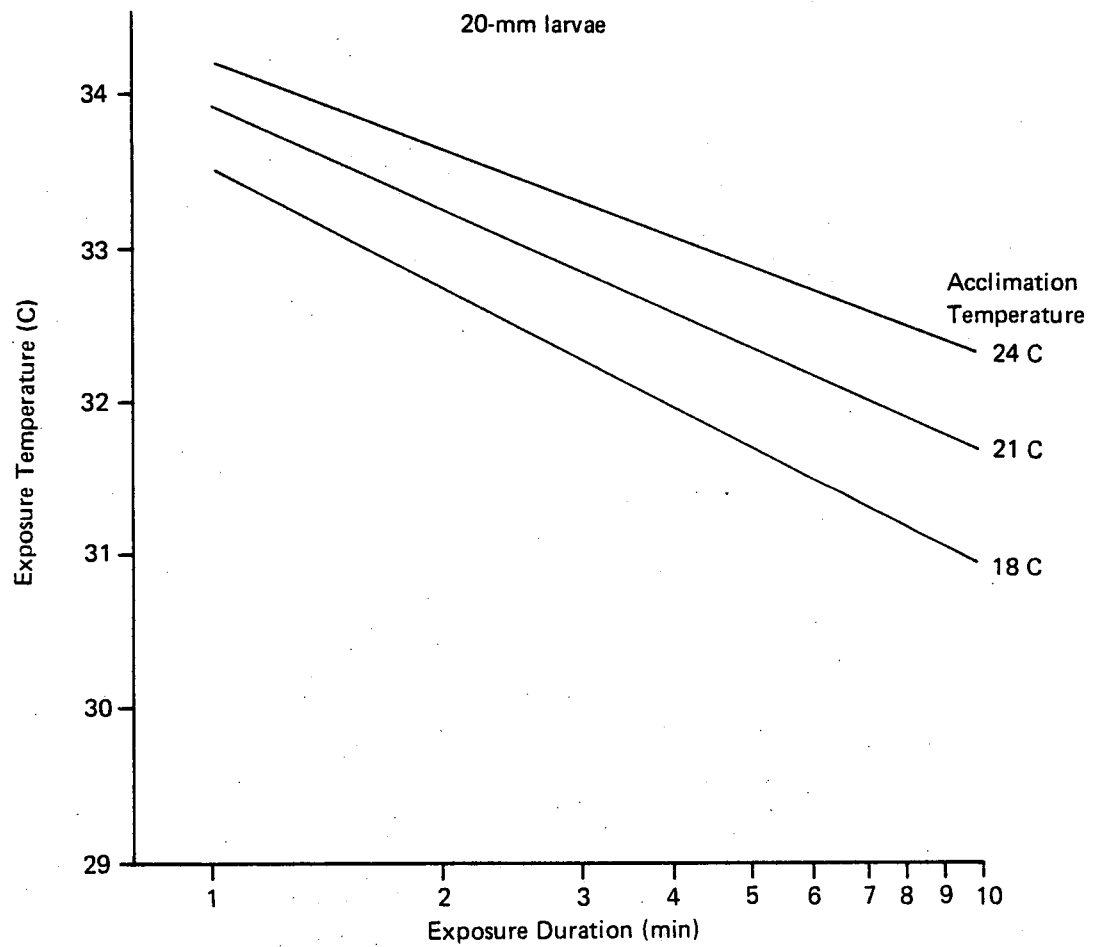
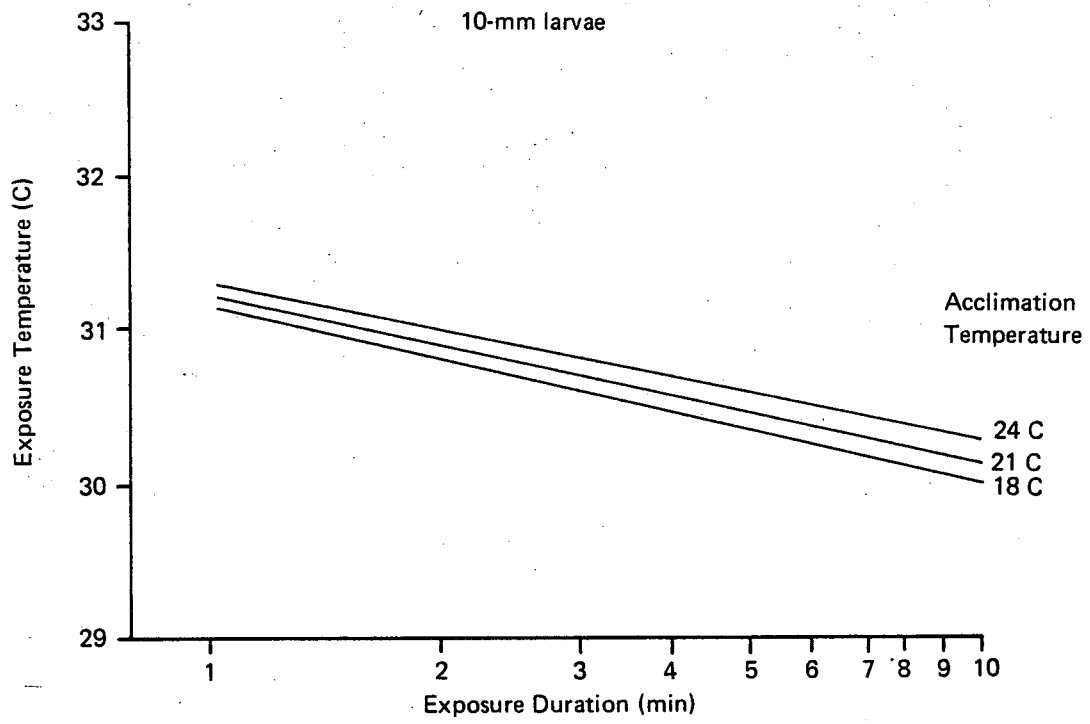


Figure 4. Estimated time-temperature exposures necessary to induce selective predation on entrained striped bass larvae.

TABLE 5 DURATION OF EXPOSURE TO HEATED WATER IN THE CIRCULATING WATER SYSTEMS AND RISE IN COOLING WATER TEMPERATURES (DELTA-T) AT HUDSON RIVER POWER PLANTS

Plant	No. of Pumps <sup>(a)</sup>	Exposure Time (min)	Delta-T <sup>(b)</sup> (C)
Roseton <sup>(c)</sup>	2	5.3	15.3
	3*	4.1	11.4
	4*	3.5	10.0
Bowline Point <sup>(d)</sup>	2 throttled	7.4	11.9
	2*	6.4	10.1
	3*	5.3	8.5
Indian Point Unit 2	4	13.1 <sup>(e)</sup>	13.2 <sup>(g)</sup>
	5*	10.1 <sup>(e)</sup>	10.6 <sup>(g)</sup>
	6*	8.2 <sup>(e)</sup>	8.9 <sup>(g)</sup>
Indian Point Unit 3	4	7.0 <sup>(f)</sup>	14.5 <sup>(g)</sup>
	5*	5.2 <sup>(f)</sup>	11.6 <sup>(g)</sup>
	6*	4.1 <sup>(f)</sup>	9.6 <sup>(g)</sup>

(a) Full mode operation, unless otherwise noted.

(b) Maximum delta-T at 100 percent capacity.

(c) Units 1 and 2 operating.

(d) Applies to either unit.

(e) Unit 2 with Unit 3 operating at an identical flow (Unit 1 not operating).

(f) Unit 3 with Unit 2 operating at an identical flow (Unit 1 not operating).

(g) Condenser temperature rise with river ambient temperature at 21.1 C.

Note: Asterisks indicate normal operation during striped bass larval season.

Source: EA (1977, Tables 3.2-1 and 3.2-2), Con Edison (1977, Tables 1-3, 1-6, 1-13 and 1-14), and NYU (1978, Table 1-1).

entrained striped bass larvae early in the season (river temperature = 18 C). As the season progresses, increasing ambient river temperatures and greater larval size results in progressively greater time-temperature exposures necessary to induce selective predation.

Thus, time-temperature exposures encountered by striped bass larvae during entrainment at Hudson River power plants would not be sufficient to increase their susceptibility to capture under most conditions. During the summer months, when the potential for preferential predation is probably greatest because of higher ambient river temperatures and, consequently, higher discharge temperatures, few striped bass larvae are entrained. Furthermore, the limiting thermal stress used in this evaluation does not account for the amount of elapsed time between a heat shock and a predation event (i.e., recovery time), and thus can lead to an overestimate of the potential for preferential predation to occur for predation events occurring beyond about 30 minutes after return to the river.

### 5.3 ASSESSMENT OF THE POTENTIAL FOR PREFERENTIAL PREDATION OF ENTRAINED STRIPED BASS LARVAE UNDER NATURAL CONDITIONS

An important aspect of the preferential predation experiments was the measurement of preferential predation under experimental conditions partially simulating conditions in the natural environment. Materials and methods designed to approximate natural conditions during these tests were the following:

1. Large experimental tanks were used to reduce possible effects of spatial constraints on the normal evasive behavior of larval prey.
2. Experimental tanks were supplied with naturally turbid water from the Hudson River.
3. Alternative prey (Gammarus) were included in some tests.
4. Tests were conducted in the presence of natural lighting and at dusk, an important feeding time for many fish predators (including white perch).

However, a number of important factors were not adequately simulated during these tests, such as naturally occurring densities of prey and possibly predators, the velocity and turbulence in and around the discharges of power plants, and the availability of cover. Thus, the results of the preferential predation experiments cannot be directly extrapolated to field situations without also considering these and possibly other important variables that could substantially alter the potential for preferential predation to occur.

One of the most important variables not adequately simulated during the preferential predation tests was prey density. The density of striped bass larvae tested during the preferential predation experiments was much greater than densities that would normally be present in the Hudson River.\*

\* The original objectives of this study included testing for preferential predation using lower prey densities; however, nearly complete predation of both stressed and control larvae was observed during these tests, precluding the detection or measurement of selective predation.

Preferential predation experiments were conducted at a larval density of  $26.3/m^3$ . In contrast, river concentrations of Morone spp. larvae (striped bass and white perch combined) seldom exceed  $1/m^3$  (TI 1977, pp. B7-B34). The actual probability of a predator encountering an entrained striped bass larva prior to its recovery from the thermal stress is likely to be quite low in the natural environment. Under these conditions, appreciable preferential predation of entrained striped bass larvae might not occur, regardless of the extent to which larval performance was impaired by sublethal entrainment stresses.

Moreover, the abundance of other food organisms far exceeds the abundance of Morone spp. larvae in the river. In the vicinity of Indian Point, for example, river concentrations of macrozooplankton (predominately Gammarus, Neomysis, and Monoculodes) during June and July often exceed  $10/m^3$  (Con Edison 1977, Figures 8-5 and 8-6)--over 10 times the concentrations of Morone spp. larvae during periods of peak abundance. Although the presence of alternative prey did not appear to influence the degree of preferential predation observed during this study, the presence of alternative prey did result in a significant ( $P < 0.005$ ) decrease in the overall predation rate on striped bass larvae. The extent to which the predation rate on larvae is reduced by the presence of other food organisms under natural conditions could substantially increase the probability that entrained larvae would avoid predation long enough to completely recover from the thermal stress.

The abundance of predators in the vicinity of a cooling water discharge would also have a pronounced impact on the extent to which indirect mortality would result from thermal stress encountered by larvae during entrainment. In the Hudson River, most fish predators capable of preying on larval fishes generally prefer bottom or shore-zone areas, and do not normally utilize offshore, surface waters characteristic of the thermal plumes from most Hudson River power plants. For example, available data on the Roseton plant plume indicated that few fish likely to prey upon striped bass larvae were present in the thermal plume area (EA 1978b); only six juvenile striped bass and no white perch were collected during 9 sampling efforts totaling 135 minutes of electrofishing during the spring and summer months (May-August). Consequently, the probability that entrained striped bass larvae would encounter predators prior to recovery from the thermal stress would be expected to be quite low.

In addition, the high discharge velocities associated with the submerged, high velocity diffusers at the Roseton, Bowline Point, and Indian Point plants exceed the swimming speeds of many Hudson River fishes in the immediate vicinity of the discharge (Con Edison 1978; ORU 1978; CHG&E 1978), preventing predators from inhabiting these areas, and perhaps even impeding their predation efficiencies in surrounding waters where discharge velocities are not excessive. Critical swim speed data indicate that velocities greater than 4 fps are unlikely to be negotiated continuously by most Hudson River fishes (see ORU 1978, Table 3.4-1). At the Roseton and Bowline Point plants, initial discharge velocities are 12.6 and 15.0 fps, respectively, and are reduced to less than 4 fps within about 9-15 meters from the diffuser ports (plume temperatures at this point are reduced to less than 30 percent of the maximum discharge temperature). At the Indian Point plant, initial velocities of 10 fps reduce to less than 4 fps within about 12 meters of the discharge ports (where plume temperatures are approximately 80 percent of the maximum



discharge temperature). The rapid dispersion and mixing of entrained larvae with other prey organisms in the river at these power plants would be expected to further reduce the potential for preferential predation to occur following an actual entrainment event.

Another variable that may reduce the potential for preferential predation to occur in the natural environment is the availability of cover, such as vegetation, which may serve as a refuge for stressed larvae until they have recovered from the thermal shock.

Thus, the results of this study, together with an assessment of some important natural variables not adequately simulated during the study, indicate that increased predation on striped bass larvae entrained at Hudson River power plants is not expected to occur to any appreciable extent. The magnitude of the thermal exposure encountered by entrained larvae is usually insufficient to increase their susceptibility to capture. When time-temperature exposures are sufficient to increase susceptibility to predation, escape capabilities have been shown to quickly return to normal. Moreover, the probability that a predation event would occur on entrained striped bass larvae prior to recovery from the thermal stress at naturally occurring densities of striped bass larvae, alternative prey, and potential predators would be expected to be quite low in the environment in and around cooling water discharges at Hudson River power plants.

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APPENDIX A: THERMAL TOLERANCE DATA  
FOR YOUNG STRIPED BASS AND DEVELOPMENT  
OF AN EMPIRICAL PREDICTION EQUATION

## APPENDIX A: THERMAL TOLERANCE DATA FOR YOUNG STRIPED BASS AND DEVELOPMENT OF AN EMPIRICAL PREDICTION EQUATION

### A.1 INTRODUCTION

Thermal tolerance experiments were conducted on early juvenile striped bass during July 1978 to supplement thermal tolerance data collected on post-yolk-sac larvae during 1976 and 1977. These data were combined to generate a prediction equation describing thermal mortality with respect to exposure temperature, exposure duration, acclimation temperature, and length. Methods and results for experiments conducted in 1978 are presented in this Appendix, along with a description of the thermal mortality prediction model. Experiments conducted in 1976 and 1977 were performed according to procedures similar to those used in 1978; the results of the 1976 and 1977 tests were reported in "Hudson River Thermal Effects Studies for Representative Species - Final Report" (EA 1978a).

### A.2 METHODS AND MATERIALS

Experiments were conducted at Ecological Analysts' bioassay laboratory located on the Hudson River (River Mile 67). Young striped bass were obtained from a Con Edison hatchery operated by Texas Instruments, Inc., at Verplanck, New York. All striped bass used for testing were reared from eggs artificially spawned from adult striped bass collected from the Hudson River. After transport from the hatchery to the laboratory, fish were held for a minimum of 2-3 days prior to testing to allow for recovery from stresses associated with transport and handling. Holding tanks were supplied with a constant flow of clarified Hudson River water.

There were 24 series of tests conducted on striped bass ranging from 43 to 59 days old. The mean total length of fish for each series of tests was determined by measuring a subsample of 30 fish from each group tested; mean total lengths ranged from 20.0 to 26.1 mm. Striped bass were exposed to thermal shocks for 0.17 (10 seconds), 1, 5, 10, 30, and 60 minutes. One group of juveniles was held at ambient river temperatures (24.0-25.5 C), while the remaining fish were reacclimated to 18.0-18.5 C from an ambient temperature of 22.5 C at a rate of 1 C per day, and held at 18.0-18.5 C for 4-8 days prior to testing.

Each series of tests consisted of 4-6 test temperatures and a control. Tests were conducted by transferring approximately 20 fish placed in screen-bottomed containers 10 cm in diameter and 11 cm deep to aquaria adjusted to a series of test temperatures with submersible heaters. All 10-second and 1-minute tests were conducted by completely removing the larvae from the water for 1-2 seconds during transfer. Fish tested for longer exposure durations were transferred to the heated water without exposing them to the air, and containers were flushed several times with heated water from the test aquaria immediately after transfer to achieve rapid temperature equilibration; temperature equilibration was typically achieved within 60 seconds after initiation of these tests. Test temperatures were recorded with a calibrated mercury thermometer placed directly in the test container after equilibration. Temperature fluctuations during the test were maintained within 0.1-0.3 C, depending on the length of the exposure.

At the end of the exposure, fish were returned to flow-through water baths adjusted to the acclimation temperature and held without feeding for 24 hours prior to the mortality assessment to account for latent mortality that may have resulted from the thermal shock. Juveniles were transferred to small plastic buckets 20 cm in diameter and 15 cm deep which were immersed in the water bath. Each bucket was provided with light aeration and had perforations in the sides to allow exchange of water between the water bath and the bucket.

Controls were performed with each series of test temperatures. Control fish were treated in the same manner as experimental fish, except that the test aquaria contained water adjusted to the acclimation temperature rather than a higher test temperature. Control mortality averaged 10 percent and ranged from 0 to 35 percent for specific series of tests.

The percent mortality at each test temperature was determined from the original sample size and the number of live fish at the end of the 24-hour holding period, and corrected for control mortality using the following equation:

$$\text{Corrected Mortality (\%)} = \left[ 1 - \frac{\text{proportion surviving test temperature}}{\text{proportion surviving control}} \right] \times 100$$

Fish that were alive but exhibited loss of equilibrium were excluded from the live count. The correction for control mortality occasionally produced negative mortality values for tests where the control mortality exceeded the mortality observed for thermally shocked fish. These negative values were retained, rather than adjusting them to 0 percent mortality, to avoid biasing the data toward higher mortality values than were actually observed at those test temperatures.

Results of these tests were combined according to similar exposure durations, acclimation temperatures, and size of larvae tested. The temperature resulting in 50 percent survival (TL50) was interpolated from a linear regression of percentage mortality versus temperature for each group of similar tests. Responses at test temperatures markedly above or below the general range of test temperatures resulting in fractional mortality were excluded from the regression analysis. In addition, questionable responses resulting in large negative values after calculating the correction for control mortality were excluded.

### A.3 RESULTS

The percentage mortality at each test temperature (after correcting for control mortality) was plotted for results that were combined according to similar exposure durations and acclimation temperatures, as shown in Figure A-1.

TL50s for striped bass juveniles ranged from 32.1-34.9 C for 60-minute exposures to 41.1-42.7 C for 10-second exposures, representing temperature increases above acclimation temperatures ( $\Delta T_s$ ) of 10.4-24.7 C (Table A-1). With the exception of the 10-second exposures, TL50s for fish acclimated to 24.0-25.5 C were higher than TL50s for fish acclimated to 18.0-18.5 C. The difference between TL50s at each exposure duration generally became more pronounced as exposure duration increased; TL50s for fish acclimated to the two temperature groups differed by 2.8 C for 60-minute exposures, but differed by only 0.7 C for 1-minute exposures (Table A-1).

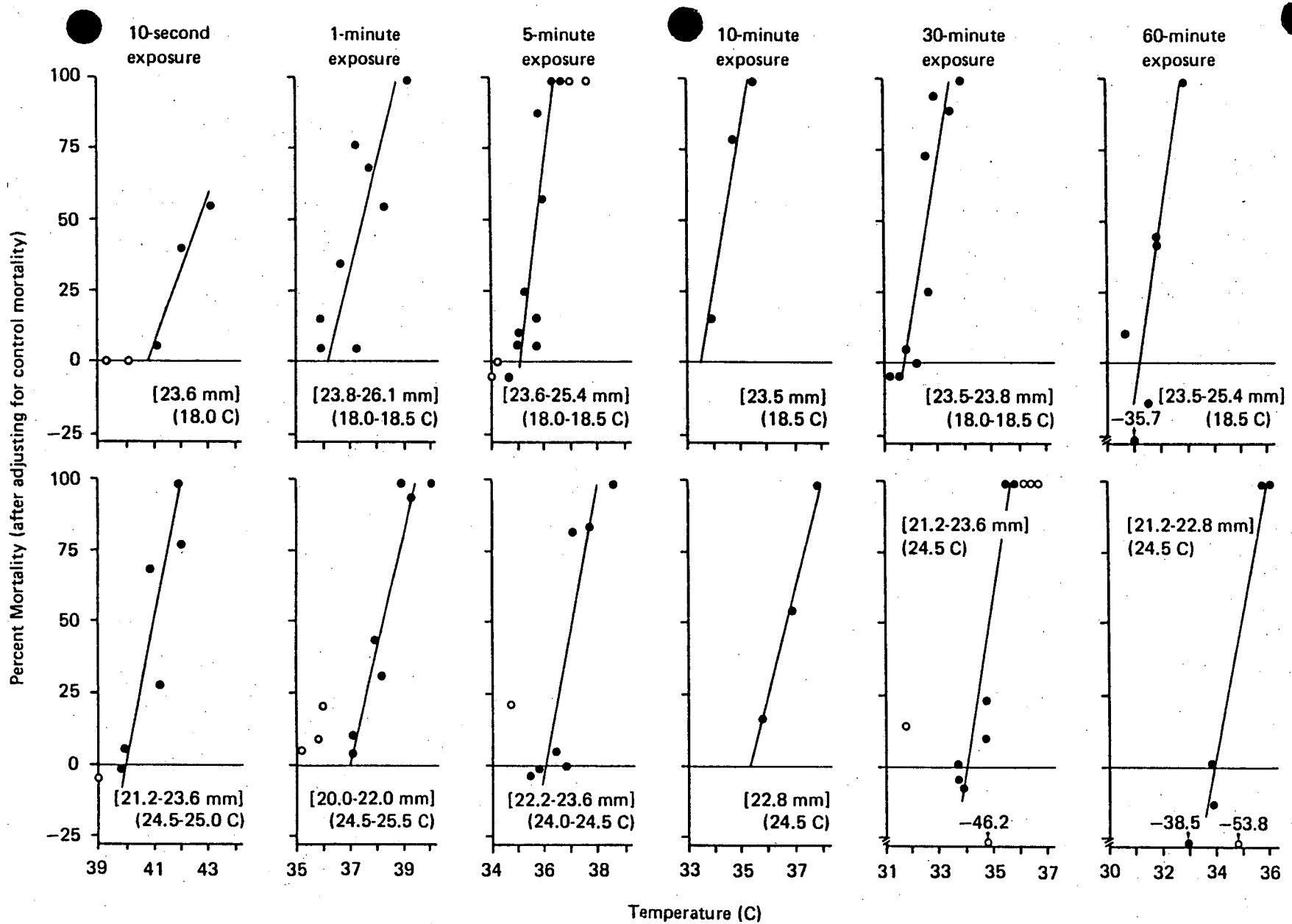


Figure A-1. Percent mortality versus test temperature for striped bass juveniles thermally shocked for 10-second, 1-, 5-, 10-, 30-, and 60-minute exposure durations. The mean total lengths of larvae tested and the acclimation temperatures are enclosed in brackets and parentheses, respectively. The linear regression line used to calculate the TL50s is also shown. Closed symbols denote test results included in the linear regression analysis; open symbols denote additional data points that were excluded from the linear regression analyses.

TABLE A-1 TL50s FOR YOUNG STRIPED BASS EXPOSED TO SHORT-TERM THERMAL SHOCKS, BASED ON MORTALITY OBSERVATIONS MADE 24 HOURS AFTER THE THERMAL EXPOSURE

	Length (mm)	Acclimation Temperature (C)	TL50 (C)					
			Exposure Duration (min)					
			0.17	1	5	10	30	60
Juveniles (a)	23.5-26.1	18.0-18.5	42.7	37.5	35.8	34.5	32.8	32.1
	20.0-23.6	24.0-25.5	41.1	38.2	37.0	36.6	34.9	34.9
Post-yolk-sac larvae (b)	8.7-9.2	20.0-22.0	--	--	33.8	33.2	33.1	--
	11.4	23.5	--	--	34.8	34.4	33.7	--
	14.4	23.0	--	--	--	36.5	35.0	34.0

(a) 1978 tests.

(b) 1976 and 1977 tests.

Note: Dashes (--) indicate no data.



In contrast to results of tests performed at longer exposure durations, the 10-second TL50 for fish acclimated to 18.0 C was actually higher than the TL50 for fish acclimated to 24.5-25.0 C. This inverse relationship between acclimation temperature and thermal tolerance was probably observed because the interval temperature of a fish acclimated to 18.0 C may not have increased as high as the internal temperature of a fish acclimated to 24.5-25.0 C during the brief exposure duration, and therefore was not exposed to the same maximum temperature.

#### A.4 DEVELOPMENT OF PREDICTION MODEL

Thermal tolerance data on striped bass post-yolk-sac larvae obtained in 1976 and 1977 were combined with the 1978 results for multiple linear regression analysis and development of a prediction model. In 1976 and 1977, 17 series of tests with exposure durations ranging from 5 to 60 minutes were completed on post-yolk-sac larvae ranging from 18 to 35 days old (EA 1978a, Tables B-123 through B-149). The majority of tests were conducted on larvae 8.7-9.2 mm mean total length (18-30 days old) and acclimated to 20-22 C. Three series of 5-minute exposures and four series of both 10- and 30-minute exposures were conducted on larvae averaging 11.4 mm (30 days old) and acclimated to 23.5 C, and one series each of 10-, 30- and 60-minute exposures were conducted on larvae averaging 14.4 mm (35 days old) and acclimated to 23.0 C. These data were re-analyzed according to slightly different analytical procedures than described in Ecological Analysts (1978a); negative values resulting from control mortality corrections were retained and results were combined according to similar exposure durations, acclimation temperatures, and size of larvae tested, as shown in Figure A-2 (the 60-minute exposure results are not shown). TL50s were calculated according to procedures described for 1978 tests. The revised TL50s for post-yolk-sac larvae are presented in Table A-1.

An empirical predictive equation was constructed with multiple linear regression analysis (Draper and Smith 1966, Chapter 7) using the data points selected for calculation of the TL50s (i.e., responses at test temperatures markedly above or below the general range of test temperatures resulting in fractional mortality were omitted from the regression analysis, as shown in Figures A-1 and A-2). Ten-second data were not included in the regression analysis. The independent variables were exposure temperature, exposure duration, acclimation temperature, and length; the dependent variable was percentage mortality. Exposure duration was transformed to a logarithm because of a pronounced curvilinear relationship between exposure duration and mortality. Additionally, the cross-products and squares of the four independent variables were included in the initial model to account for possible variation resulting from interaction between the variables or possible curvilinear responses. Thus, the following model with 14 variables was considered for development of an empirical predictive equation:

$$y = b_0 + b_1(X_1) + b_2(X_1)^2 + b_3(X_1X_2) + b_4(X_1X_3) + b_5(X_1X_4) + b_6(X_2) \\ + b_7(X_2)^2 + b_8(X_2X_3) + b_9(X_2X_4) + b_{10}(X_3) + b_{11}(X_3)^2 + b_{12}(X_3X_4) \\ + b_{13}(X_4) + b_{14}(X_4)^2$$

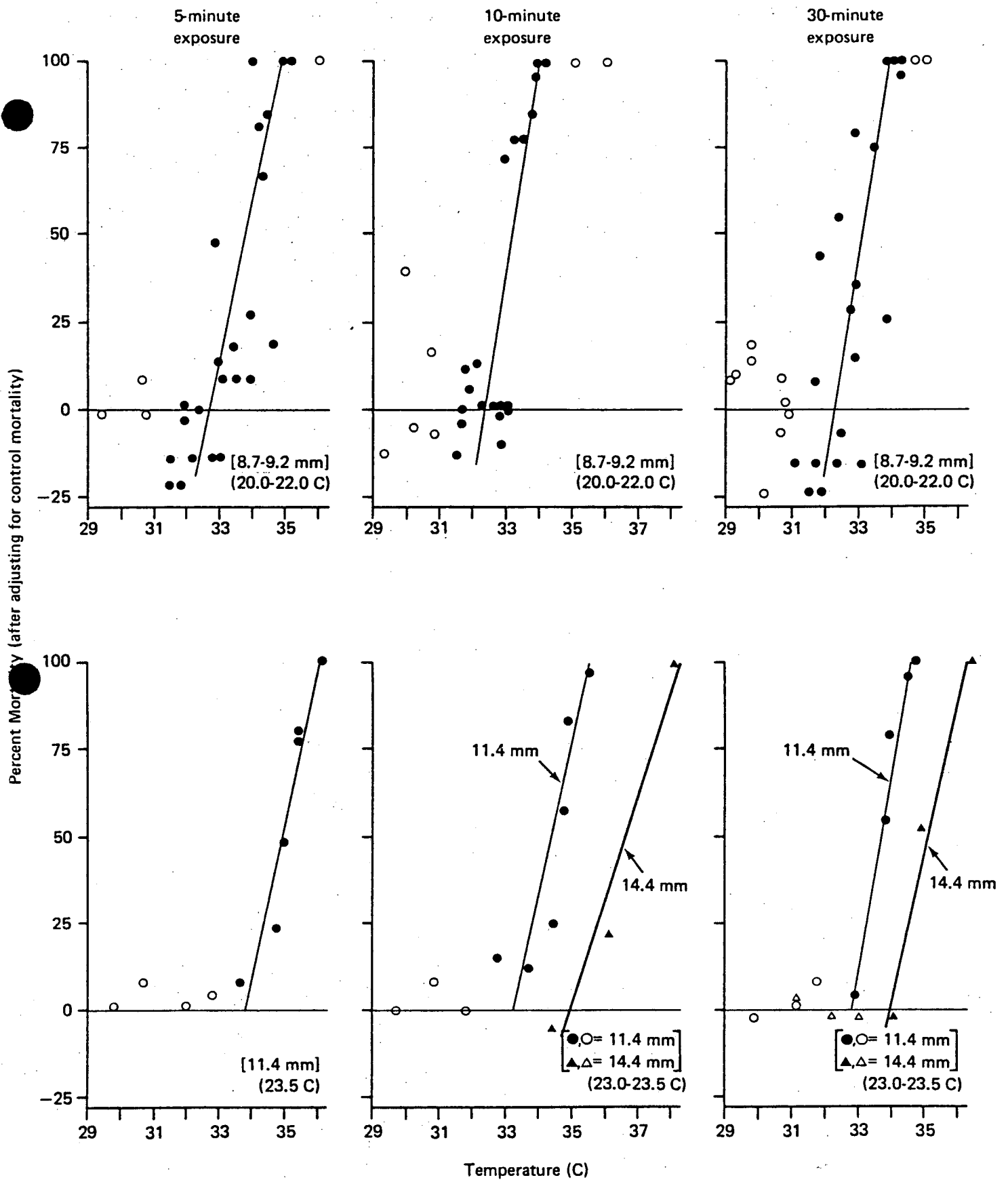


Figure A-2. Percent mortality versus test temperature for striped bass post-yolk-sac larvae thermally shocked for 5-, 10-, and 30-minute exposure durations. The mean total lengths of larvae tested and the acclimation temperatures are enclosed in brackets and parentheses, respectively, in the lower right-hand corner of each plot. The linear regression line used to calculate the TL50s is also shown. Closed symbols denote test results included in the linear regression analysis; open symbols denote additional data points that were excluded from the linear regression analyses.

where

- y = percentage mortality
- X<sub>1</sub> = exposure temperature (C)
- X<sub>2</sub> = exposure duration (log<sub>10</sub> minutes)
- X<sub>3</sub> = acclimation temperature (C)
- X<sub>4</sub> = total length (mm)

The variable selection procedure was based on backward elimination (Draper and Smith 1966, pp. 167-169) and Mallow's Cp statistic (Mosteller and Tukey 1977, pp. 385-387). The backward elimination procedure begins with the full model and eliminates unimportant variables in order from the least important to the most important. The "best" model is derived when no further variables can be eliminated from the model without significantly decreasing the regression sum of squares. Of the 14 variables considered here, the important variables chosen by backward elimination were acclimation temperature (X<sub>3</sub>), length squared (X<sub>4</sub><sup>2</sup>), and the cross-products of exposure temperature and acclimation temperature (X<sub>1</sub>X<sub>3</sub>), log exposure duration and length (X<sub>2</sub>X<sub>4</sub>), and acclimation temperature and length (X<sub>3</sub>X<sub>4</sub>). To determine if any of the variables rejected during the backward elimination procedure were important in terms of reducing bias, each was added to the 5-variable model, one at a time, and the Cp statistic was examined. The Cp statistic--a measure of total squared error--represents an alternative criterion to the backward selection procedure for identifying important variables. The last variable rejected by the backward elimination procedure--length (X<sub>4</sub>)--resulted in a slightly lower Cp statistic than the 5-variable model. However, the 5-variable model was retained as the best predictive equation because the difference between Cp values for the two models was negligible. The resulting predictive equation for striped bass thermal tolerance was:

$$\begin{aligned} \text{Percent Mortality} = & 22.01 + 1.601(X_1X_3) + 3.692(X_2X_4) - 47.92(X_3) \\ & - 0.8174(X_3X_4) + 0.2773(X_4)^2. \end{aligned}$$

The statistics associated with this model are presented in Table A-2. Over the range of variables used to derive the regression equation (see Table A-1), the 95 percent confidence limits for the predicted values (percent mortality) ranged from ±6.1 to ±16.9.

To predict TL50s, a constant of 50 percent was substituted for percentage mortality (y) and the equation was rearranged to solve for temperature (X<sub>1</sub>), as shown below:

$$\text{TL50(C)} = \frac{27.99 - 3.69^2(X_2X_4) + 47.92(X_3) + 0.8174(X_3X_4) - 0.2773(X_4)^2}{1.601(X_3)}$$

TABLE A-2 ANALYSIS OF VARIANCE TABLE AND TESTS OF SIGNIFICANCE OF THE REGRESSION COEFFICIENTS FOR THE STRIPED BASS THERMAL TOLERANCE PREDICTION EQUATION<sup>(a)</sup>

<u>Variable</u>	<u>Regression Coefficient</u>	<u>Standard Deviation</u>	<u>t-statistic</u>	<u>Probability of a Greater t</u>
Test Temperature x Acclimation Temperature	1.601	0.0983	16.28	P<<0.001
Log <sub>10</sub> Exposure Duration x Length	3.692	0.3242	11.39	P<<0.001
Acclimation Temperature	-47.92	5.609	-8.543	P<0.001
Acclimation Temperature x Length	-0.8174	0.2003	-4.080	P<0.001
Length Squared	0.2773	0.1247	2.223	0.05>P>0.02

<u>Source</u>	<u>Sum of Squares</u>	<u>Degrees of Freedom</u>	<u>Mean Square</u>	<u>F</u>	<u>Probability of a Greater F</u>
Regression	192,100	5	38,420	54.57	P<<0.001
Error	105,600	150	704.1		

(a) Multiple correlation coefficient (r) = 0.8033; standard error of regression = 26.53; y-intercept = 22.01.

APPENDIX B: DATA TABLES FOR PREFERENTIAL PREDATION EXPERIMENTS

TABLE B-1 NUMBERS OF PREY RETRIEVED FROM EXPERIMENTAL TANKS WITHOUT PREDATORS

Date	Tank	Recovery of Larvae				Recovery of Gammarus		
		Mean Total Length (mm)	No. Larvae Per Tank	No. Larvae Recovered	Percent Recovery	No. Gammarus Per Tank	No. Gammarus Recovered	Percent Recovery
16 JUN 1978	A	12.1	10	10	100.0	0	NA	NA
23 JUN 1978	A	15.8	10	9	90.0	0	NA	NA
	B	15.8	10	10	100.0	0	NA	NA
	C	15.8	10	10	100.0	0	NA	NA
	D	15.8	10	9	90.0	0	NA	NA
	E	15.8	10	10	100.0	0	NA	NA
	F	15.8	10	10	100.0	0	NA	NA
30 JUN 1978	C	14.2	50	48	96.0	0	NA	NA
	F	14.2	50	50	100.0	0	NA	NA
11-14 JUL 1978	A	22.0	50	50	100.0	100	96	96.0
	B	22.0	50	50	100.0	100	76	76.0
	C	22.0	50	48	96.0	100	81	81.0
	D	22.0	50	53	106.0 <sup>(a)</sup>	100	94	94.0
	E	22.0	50	50	100.0	100	92	92.0
	F	22.0	50	49	98.0	100	96	96.0
Total			470	463	98.5	600	535	89.2

(a) Percent recovery greater than 100 due to enumeration errors at start of test. The three "extra" larvae were not included in the calculation of the total percent recovery.

Note: NA indicates not applicable.

TABLE B-2 NUMBERS OF PREY RETRIEVED FROM THE EXPERIMENTAL TANKS AND THE STOMACHS OF THE PREDATORS USED IN EACH TANK

Tank	No. Larvae Per Tank	No. Gammarus Per Tank	Total Length of Predator (mm)	Recovery from Stomachs			Recovery from Tank			Total Percent Recovery			
				No. Stressed Larvae	No. Control Larvae	No. of Gammarus	Percentage of Available Larvae	Percentage of Available Gammarus	No. Stressed Larvae	No. Control Larvae	No. Gammarus	Larvae	Gammarus
Predator Group 3													
A	50	0	88	5	10	NA	30	NA	13	8	NA	96.0	NA
			83	1	3	NA	8	NA					
			82	6	2	NA	16	NA					
			Total	12	15		54						
F	50	0	83	4	4	NA	16	NA	11	19	NA	98.0	NA
			87	5	1	NA	12	NA					
			99	4	1	NA	10	NA					
			Total	13	6		38						
B	50	100	95	3	2	8	10	8	11	16	59	98.0	80.0
			92	6	4	1	20	1					
			76	5	2	12	14	12					
			Total	14	8	21	44	21					
C	50	100	82	2	1	13	6	13	14	22	27	102.0(a)	85.0
			87	2	1	18	6	18					
			89	7	2	27	18	27					
			Total	11	4	58	30	58					
D	50	100	70	2	1	6	6	6	17	20	62	98.0	94.0
			90	3	3	16	12	16					
			95	2	1	10	6	10					
			Total	7	5	32	24	32					
E	50	100	86	0	3	13	6	13	24	20	25	94.0	89.0
			98	0	0	21	0	21					
			90	0	0	30	0	30					
			Total	0	3	64	6	64					

TABLE B-2 (CONT.)

Tank	No. Larvae Per Tank	No. Gammarus Per Tank	Total Length of Predator (mm)	Recovery from Stomachs					Recovery from Tank			Total Percent Recovery		
				No. Stressed Larvae	No. Control Larvae	No. of Gammarus	Percentage of Available Larvae	Percentage of Available Gammarus	No. Stressed Larvae	No. Control Larvae	No. Gammarus	Larvae	Gammarus	
Predator Group 4														
A	50	0	86 85 85	3 4 5	3 0 6	NA NA NA	12 8 22	NA NA NA						
			Total	12	9		42		13	10	NA	88.0	NA	
D	50	0	90 90 88	3 5 5	2 6 4	NA NA NA	10 22 18	NA NA NA						
			Total	13	12		50		12	10	NA	94.0	NA	
Predator Group 4														
B	20	0	71 77 85	1 3 2	4 4 3	NA NA NA	25 35 25	NA NA NA						
			Total	6	11		85		3	0	NA	100.0	NA	
E	20	0	88 94 92	4 4 2	2 4 3	NA NA NA	30 40 25	NA NA NA						
			Total	10	9		95		0	1	NA	100.0	NA	
C	20	100	90 100 87	5 0 5	2 3 1	11 18 6	35 15 30	11 18 6						
			Total	10	6	35	80	35	1	4	74	105.0 <sup>(a)</sup>	109.0 <sup>(a)</sup>	
F	20	100	89 77 86	2 1 6	3 2 5	11 9 0	25 15 55	11 9 0						
			Total	9	10	20	95	20	1	0	95	100.0	115.0 <sup>(a)</sup>	
Grand Total				117	98	230	44.8	38.3	120	130	342	96.4 <sup>(a)</sup>	91.3 <sup>(a)</sup>	

(a) Percent recovery greater than 100 due to enumeration errors at start of test. These "extra" prey were not included in the calculation of percent recovery for the grand totals.

Note: NA indicates not applicable.



TABLE B-3 RESULTS OF PREFERENTIAL PREDATION EXPERIMENTS

Date	Total Length of Larvae (mm)		Predator Group	No. Predators Per Tank	Tank	Length of Test (min)	Secchi Disk (cm)	Tank Temp. (C)	Thermal Stress		No. Stressed Larvae At Start	No. Stressed Larvae At End	No. Control Larvae At Start	No. Control Larvae At End	Total No. Larvae At End	No. Gammarus At Start	No. Gammarus At End
	Mean	S.D.							Ambient Temp. (C)	Shock Temp. (C)							
15 JUN 1978	12.1	1.06	2	5	B	720	--	21.0	21.0	30.9	5	1	5	0*	1	0	0
					C	480	--	21.2	21.2	31.0	5	1	5	0*	1	0	0
					D	360	--	21.8	21.2	31.0	5	0	5	0*	0	0	0
					E	240	--	21.0	21.5	31.0	5	1	5	0*	1	0	0
					F	120	--	20.2	22.5	31.0	5	0	5	0*	0	0	0
16 JUN 1978	12.1	1.06	2	5	B	720	--	22.0	21.4	30.8	5	0*	5	0	0	0	0
					C	480	--	22.0	22.0	31.0	5	0*	5	3	3	0	0
					D	360	--	21.8	22.5	30.8	5	0*	5	3	3	0	0
					E	240	--	21.5	22.5	31.0	5	0*	5	3	3	0	0
					F	120	--	21.2	22.5	31.0	5	0*	5	0	0	0	0
20 JUN 1978	13.8	0.88	2	5	A	70	33	24.0	23.0	31.8	5	0	5	0*	0	0	0
					B	87	37	24.0	23.0	31.8	5	0	5	0*	0	0	0
					C	109	35	23.5	23.0	31.9	5	0	5	0*	0	0	0
					D	95	37	23.8	23.0	31.8	5	0	5	0*	0	0	0
					E	107	35	23.5	23.0	32.0	5	1	5	1*	2	0	0
					F	122	35	24.0	23.0	31.9	5	0	5	0*	0	0	0
21 JUN 1978	14.7	0.99	2	5	A	33	41	23.0	23.0	31.8	5	0	5	0*	0	0	0
					B	35	39	23.0	23.0	31.5	5	0	5	0*	0	0	0
					C	45	40	23.0	23.0	31.8	5	3	5	0*	3	0	0
					D	42	40	22.8	23.0	32.0	5	0	5	0*	0	0	0
					E	47	41	22.8	23.0	32.0	5	0	5	0*	0	0	0
					F	54	41	23.0	23.0	32.0	5	0	5	0*	0	0	0
22 JUN 1978	15.5	1.25	2	5	A	17	33	23.2	23.2	31.8	5	0	5	0*	0	0	0
					B	15	34	23.2	23.2	31.9	5	0	5	1*	1	0	0
					C	15	35	23.0	23.2	31.5	4	0	5	0*	0	0	0
					D	19	36	23.2	23.2	31.8	5	1	5	0*	1	0	0
					E	15	36	23.2	23.2	31.8	5	0	5	0*	0	0	0
					F	15	39	23.5	23.2	31.9	5	0	5	0*	0	0	0
26 JUN 1978	15.6	1.31	2	3	A	23	40	23.0	23.0	31.5	10	5	10	0*	5	0	0
					B	15	40	23.0	23.0	31.5	9	1	10	0*	1	0	0
					C	15	36	23.0	23.0	31.5	10	3	10	0*	3	0	0
	24.1	1.85	2	3	D	18	40	23.0	22.8	31.5	10	0	10	0*	0	0	0
					E	15	41	23.0	22.8	31.5	10	0	10	1*	1	0	0
					F	15	44	22.8	22.8	31.5	10	1	10	1*	2	0	0
27 JUN 1978	15.6	1.31	2	3	A	18	40	24.2	23.8	31.5	10	0*	10	0	0	0	0
					B	15	42	24.0	23.8	31.8	10	1*	10	1	2	0	0
					C	15	38	24.0	23.8	31.8	10	1*	10	0	1	0	0
	24.1	1.85	2	3	D	15	45	24.0	23.8	31.5	10	0*	10	0	0	0	0
					E	15	45	24.2	23.8	31.8	10	0*	10	3	3	0	0
					F	15	50	25.0	23.8	31.8	10	0*	10	2	2	0	0

TABLE B-5 (CONT.)

Date	Total Length of Larvae (mm)		Predator Group	No. Predators Per Tank	Tank	Length of Test (min)	Secchi Disk (cm)	Tank Temp. (C)	Thermal Stress		No. Stressed Larvae At Start	No. Stressed Larvae At End	No. Control Larvae At Start	No. Control Larvae At End	Total No. Larvae At End	No. Gammarus At Start	No. Gammarus At End		
	Mean	S.D.							Ambient Temp. (C)	Shock Temp. (C)									
29 JUN 1978	14.2	0.91	2	3	B	15	41	24.0	23.8	31.8	25	0	25	1*	1	0	0		
					E	15	42	24.0	23.8	32.0	25	4	25	0*	4	0	0		
					C	17	40	24.0	23.8	32.0	24	0	25	1*	1	0	0		
	26.0	0.94	2	3	F	15	41	24.5	23.8	32.0	25	0	25	0*	0	0	0	0	
					A	25	37	24.0	23.8	32.0	8	0	10	0*	0	100	52		
					D	15	41	24.0	23.8	31.8	10	0	10	0*	0	100	63		
30 JUN 1978	14.2	0.91	2	3	B	15	42	24.2	23.5	31.8	25	0*	25	3	3	0	0		
					E	15	45	24.2	23.5	31.8	25	0*	25	1	1	0	0		
					C	16	41	24.2	23.5	32.0	25	0*	25	1	1	0	0		
	26.0	0.94	2	3	A	15	42	24.0	23.5	31.8	9	0*	10	1	1	100	22		
5 JUL 1978	19.3	1.52	3	3	A	15	47	23.2	24.1	32.2	25	11	25	18*	29	0	0		
					F	15	50	24.0	24.1	32.0	25	10	25	20*	30	0	0		
					B	15	50	23.2	24.1	32.0	25	13	25	19*	32	100	72		
					C	15	47	23.2	24.1	32.0	25	13	25	22*	35	100	75		
					D	15	52	23.8	24.1	32.0	25	18	25	20*	38	100	61		
					E	15	48	23.5	24.1	32.0	25	20	25	22*	42	100	64		
6 JUL 1978	19.3	1.52	3	3	A	15	50	23.9	24.1	32.2	25	17*	25	24	41	0	0		
					F	15	54	24.9	24.1	32.5	25	20*	25	25	45	0	0		
					B	15	51	24.1	24.1	32.0	25	13*	25	21	34	100	77		
					C	15	50	24.1	24.1	32.0	25	16*	25	25	41	100	84		
					D	15	52	24.5	24.1	32.0	25	17*	25	24	41	100	81		
					E	15	58	24.3	24.1	32.0	25	25*	25	25	50	100	90		
7 JUL 1978	16.9	1.03	3	3	A	15	48	24.8	24.8	32.3	25	11	25	10*	21	0	0		
					F	15	50	25.2	24.8	32.5	25	18	25	23*	41	0	0		
					B	15	45	24.8	24.8	32.3	25	16	25	20*	36	100	73		
					C	15	45	24.8	24.8	32.4	25	18	25	18*	36	100	59		
					D	15	46	24.8	24.8	32.4	25	18	25	13*	31	100	82		
					E	15	45	24.6	24.8	32.4	25	25	25	23*	48	100	40		
8 JUL 1978	16.9	1.03	3	3	A	15	51	25.6	25.2	32.4	25	13*(a)	25	10*(a)	23*(a)	0	0		
					F	15	50	26.0	25.2	32.4	25	12*(a)	25	19*(a)	31*(a)	0	0		
					B	15	51	25.7	25.2	32.4	25	11*(a)	25	17*(a)	28*(a)	100	79*(a)		
					C	15	52	25.7	25.2	32.2	25	14*(a)	26	22*(a)	36*(a)	100	42*(a)		
					D	15	53	25.6	25.2	32.4	25	18*(a)	25	20*(a)	38*(a)	100	68*(a)		
					E	15	53	25.6	25.2	32.4	25	25*(a)	25	22*(a)	47*(a)	100	36*(a)		
3 JUL 1978	17.4	1.46	4	3	B	15	46	22.8	24.1	32.0	10	1	10	2*	3	0	0		
					E	15	45	23.0	24.1	32.0	10	0	10	1*	1	0	0		
					C	15	45	23.0	24.1	32.0	10	3	10	0*	3	100	63		
					F	15	44	23.0	24.1	32.0	10	0	10	1*	1	100	51		
					A	15	45	23.0	24.1	32.0	25	8	25	6*	14	0	0		
					D	15	45	23.0	24.1	32.0	25	6	25	3*	9	0	0		

TABLE B-5 (CONT.)

Date	Total Length of Larvae (mm)		Predator Group	No. Predators Per Tank	Tank	Length of Test (min)	Secchi Disk (cm)	Tank Temp. (C)	Thermal Stress		No. Stressed Larvae At Start	No. Stressed Larvae At End	No. Control Larvae At Start	No. Control Larvae At End	Total No. Larvae At End	No. Gammarus At Start	No. Gammarus At End
	Mean	S.D.							Ambient Temp. (C)	Shock Temp. (C)							
4 JUL 1978	17.4	1.46	4	3	B	15	37	21.8	22.0	32.0	10	3#(a)	10	0(a)	3(a)	0	0
					E	15	40	21.8	22.0	32.0	10	0#(a)	10	1(a)	1(a)	0	0
					C	15	37	22.5	22.0	32.0	11	1#(a)	10	4(a)	5(a)	100	65(a)
					F	15	41	21.5	22.0	32.0	10	1#(a)	10	0(a)	1(a)	100	80(a)
					A	15	35	22.0	22.0	32.0	25	13#(a)	25	16(a)	29(a)	0	0
					D	15	40	21.5	22.0	32.0	25	12#(a)	25	13(a)	25(a)	0	0

(a) Recovery based on stomach contents. See Table B-2.

Note: Asterisk (\*) denotes the dyed group of larvae; dashes (--) indicate no data.

TABLE B-4 PERCENTAGE OF LARVAE SURVIVING PREDATION FOR PAIRED REPLICATES (SUMMARY OF RESULTS FROM TABLE B-3; TEST DURATIONS WERE 15 MINUTES UNLESS NOTED OTHERWISE)

Predator Group	Mean Total Length of Predators (mm)	No. of Predators Per Tank	Mean Total Length of Larvae (mm)	Replicate 1(a)			Replicate 2(b)			Combined Replicates			Total Larvae Surviving (%)
				No. Larvae(c) Per Tank	No. Larvae Surviving		No. Larvae(c) Per Tank	No. Larvae Surviving		Total(c) No. Larvae	No. Larvae Surviving		
					Control	Stressed		Control	Stressed		Control	Stressed	
2(d)	115	5(e)	12.1	10	0	1	10	0	0	20	0	1	5.0*
				10	0	1	10	3	0	20	3	1	20.0*
				10	0	0	10	3	0	20	3	0	15.0*
				10	0	1	10	3	0	20	3	1	20.0*
				10	0	0	10	0	0	20	0	0	0.0*
2	115	3	15.6	20	0	5	20	0	0	40	0	5	12.5*(f)
				19(g)	0	1	20	1	1	39	1	2	7.7*
				20	0	3	20	0	1	40	0	4	10.0*
2	115	3	24.1	20	0	0	20	0	0	40	0	0	0.0*(f)
				20	1	0	20	3	0	40	4	0	10.0*
				20	1	1	20	2	0	40	3	1	10.0*
2	115	3	26.0	20	0	0	18(h)	1	0	38	1	0	2.7*(f,1)
				20	0	0	N.D.	N.D.	N.D.	20	0	0	0.0*(1)
2	115	3	14.2	50	1	0	50	3	0	100	4	0	4.0*
				50	0	4	50	1	0	100	1	4	5.0*
				49(j)	1	0	50	1	0	99	2	0	2.0*(f)
				50	0	0	N.D.	N.D.	N.D.	50	0	0	0.0*
3	87	3	16.9	50	10	11	50	10	13	100	20	24	44.0
				50	23	18	50	19	12	100	42	30	72.0
				50	20	16	50	17	11	100	37	27	64.0(1)
				50	18	18	51(k)	22	14	101	40	32	71.3(1)
				50	13	18	50	20	18	100	33	36	69.0(1)
				50	23	25	50	22	25	100	45	50	95.0(1)
3	87	3	19.3	50	18	11	50	24	17	100	42	28	70.0
				50	20	10	50	25	20	100	45	30	75.0
				50	19	13	50	21	13	100	40	26	66.0(1)
				50	22	13	50	25	16	100	47	29	76.0(1)
				50	20	18	50	24	17	100	44	35	79.0(1)
				50	22	20	50	25	25	100	47	45	92.0(1)

TABLE B-4 (CONT.)

Predator Group	Mean Total Length of Predators (mm)	No. of Predators Per Tank	Mean Total Length of Larvae (mm)	Replicate 1 <sup>(a)</sup>			Replicate 2 <sup>(b)</sup>			Combined Replicates			Total Larvae Surviving (%)
				No. Larvae Per Tank	No. Larvae Surviving		No. Larvae Per Tank	No. Larvae Surviving		Total <sup>(c)</sup> No. Larvae	No. Larvae Surviving		
					Control	Stressed		Control	Stressed		Control	Stressed	
4	87	3	17.4	20	2	1	20	0	3	40	2	4	15.0*
				20	1	0	20	1	0	40	2	0	5.0*
				20	0	3	21 <sup>(1)</sup>	4	1	41	4	4	19.5 <sup>(1)</sup>
				20	1	0	20	0	1	40	1	1	5.0 <sup>(1)</sup>
				50	6	8	50	16	13	100	22	21	43.0
				50	3	6	50	13	12	100	16	18	37.0

(a) Control larvae dyed.

(b) Stressed larvae dyed.

(c) 50 percent of the larvae were stressed; 50 percent were control larvae (unless noted otherwise).

(d) Test durations for these tests ranged from 2-12 hours.

(e) Three additional replicates were performed with 5 predators and 10 larvae per tank, but since the control group was dyed in all three replicates, replicates could not be paired in this manner (see Table B-3). The total percent of larvae surviving these three replicates combined was 4 percent. Test durations ranged from 15 minutes to 2 hours.

(f) Actual test duration of one or both replicates deviated from 15 minutes by 1-10 minutes.

(g) Number of stressed larvae at start was 9.

(h) Number of stressed larvae at start was 8.

(i) 100 *Gammarus* (50 stressed, 50 unstressed) were included with the larvae for each replicate.

(j) Number of stressed larvae at start was 24.

(k) Number of control larvae at start was 26.

(l) Number of stressed larvae at start was 11.

Note: N.D. indicates no data.

Asterisk (\*) indicates test results where the overall predation rate was too high for valid estimates of preferential predation (less than 30 percent survival).

APPENDIX C: DATA TABLES FOR RECOVERY TIME EXPERIMENTS

TABLE C-1 RESULTS OF RECOVERY TIME EXPERIMENTS CONDUCTED WITH PREDATOR GROUP 1(a)

Date	Total Length of Larvae (mm)			Tank	Thermal Stress			Tank Temp. (C)	Recovery Time (min)	No. Larvae Per Tank	No. Attacks	No. Captures	Percent Capture	Captures Per Attack
	Mean	S.D.	Range		Ambient Temp. (C)	Shock Temp. (C)	Delta-T (C)							
20 JUN 1978	13.8	.877	12-16	1	22.0	NA	NA	27.0	Control	30	40	13	43.3	0.325
				2	22.0	32.0	10.0	27.3	0	30	39	30	100.0	0.769
				3	22.0	32.0	10.0	27.2	30	30	45	25	83.3	0.556
				4	22.0	32.0	10.0	27.3	60	30	46	28	93.3	0.610
				5	22.0	32.0	10.0	26.8	120	30	26	9	30.0	0.346
				6	22.0	32.0	10.0	27.1	240	30	43	23	76.7	0.535
21 JUN 1978	14.7	.985	13-17	1	21.9	NA	NA	24.6	Control	30	3	3	10.0	1.00 <sup>(b)</sup>
				2	21.9	32.0	10.1	25.0	0	30	30	22	73.3	0.735
				3	21.9	32.0	10.1	24.1	30	30	31	14	46.7	0.452
				4	21.9	32.0	10.1	25.0	60	29	50	19	65.5	0.380
				5	21.9	32.0	10.1	24.8	120	30	54	19	63.3	0.352
				6	21.9	31.9	10.0	25.1	240	30	61	18	60.0	0.295
22 JUN 1978	15.5	1.253	13-19	1	23.3	NA	NA	24.7	Control	27	27	12	44.4	0.444
				2	23.3	32.1	8.8	24.9	0	30	46	30	100.0	0.654
				3	23.3	32.0	8.7	24.8	30	28	43	26	92.8	0.606
				4	23.3	31.9	8.6	25.1	60	30	14	10	33.3	0.714 <sup>(b)</sup>
				5	23.3	31.9	8.6	24.5	120	29	52	27	93.1	0.521
				6	23.3	31.9	8.6	24.7	240	24	42	8	33.3	0.190
23 JUN 1978	15.8	.981	14-18	2	23.4	NA	NA	24.6	Control	24	41	15	62.5	0.366
				3	23.4	NA	NA	24.6	Control	23	68	22	95.6	0.324
				4	23.4	32.0	8.6	24.8	60	25	40	25	100.0	0.625
				5	23.4	31.9	8.5	24.2	120	23	34	23	100.0	0.676
				6	23.4	32.0	8.6	24.5	240	23	43	17	73.9	0.395

(a) Mean total length 85 mm; standard deviation 7.0 mm; range 76-98 mm.

(b) These data were not included in the analysis of results because of low predator response (i.e., less than 15 attacks or less than 21 percent capture).

Note: NA indicates not applicable.

TABLE C-2 RESULTS OF RECOVERY TIME EXPERIMENTS CONDUCTED WITH PREDATOR GROUP 3(a)

Date	Total Length of Larvae (mm)			Tank	Thermal Stress			Tank Temp. (C)	Recovery Time (min)	No. Larvae Per Tank	No. Attacks	No. Captures	Percent Capture	Captures Per Attack
	Mean	S.D.	Range		Ambient Temp. (C)	Shock Temp. (C)	Delta-T (C)							
26 JUN 1978	15.4	1.405	12-18	1	22.7	NA	NA	24.4	Control	30	12	4	13.3	0.333 <sup>(b)</sup>
				2	22.9	31.8	8.9	24.7	30	30	13	4	13.3	0.308 <sup>(b)</sup>
				3	23.0	31.8	8.8	24.6	120	30	52	10	33.3	0.192
				4	22.8	31.8	9.0	24.7	180	30	32	9	30.0	0.281
				6	22.7	31.7	9.0	24.3	180	30	12	4	13.3	0.333 <sup>(b)</sup>
5	22.9	31.8	8.9	24.5	240	30	39	7	23.3	0.180				
27 JUN 1978	15.9	1.550	13-18	2	23.2	NA	NA	24.8	Control	30	104	30	100.0	0.288
				1	23.3	31.8	8.5	24.7	0	30	17	7	23.3	0.411
				3	23.2	31.4	8.2	24.8	30	30	11	3	10.0	0.272 <sup>(b)</sup>
				4	23.2	31.6	8.4	24.9	60	30	21	7	30.0	0.429
				5	23.2	31.8	8.6	24.6	180	30	38	10	33.3	0.263
				6	23.2	31.8	8.6	24.7	240	30	58	21	70.0	0.362
28 JUN 1978	16.3	1.331	14-19	2	23.4	NA	NA	24.7	Control	29	24	13	44.8	0.541
				1	23.3	32.2	8.9	24.5	0	29	15	9	31.0	0.599
				3	23.5	32.0	8.5	24.6	30	29	1	0	0.0	0.000 <sup>(b)</sup>
				4	23.5	32.0	8.5	24.8	60	29	63	25	86.2	0.397
				5	23.3	32.0	8.7	24.5	120	30	21	10	33.3	0.476
				6	23.3	32.2	8.9	24.6	180	30	93	23	76.7	0.248
29 JUN 1978	17.8	1.261	14-20	2	23.8	NA	NA	25.4	Control	30	16	5	16.7	0.312 <sup>(b)</sup>
				1	23.8	32.0	8.2	25.3	0	25	14	10	40.0	0.714 <sup>(b)</sup>
				3	23.9	32.0	8.1	25.4	30	29	36	23	79.3	0.641
				4	23.9	32.2	8.3	25.5	60	30	57	16	53.3	0.281
				5	23.8	32.1	8.3	24.9	120	26	42	16	61.5	0.381
				6	23.8	32.1	8.3	25.1	180	27	20	12	44.4	0.599
30 JUN 1978	18.9	1.303	15-21	1	24.1	NA	NA	24.3	Control	30	10	3	10.0	0.300 <sup>(b)</sup>
				5	24.1	NA	NA	24.1	Control	30	15	6	20.0	0.400 <sup>(b)</sup>
				4	24.1	32.1	8.0	24.0	30	29	16	4	13.8	0.188 <sup>(b)</sup>
				2	24.1	32.0	7.9	24.4	60	29	31	9	31.0	0.291
3 JUL 1978	16.6	1.027	15-19	1	24.4	NA	NA	24.9	Control	30	38	6	20.0	0.158 <sup>(b)</sup>
				6	24.4	NA	NA	25.0	Control	30	33	14	46.7	0.424
				4	24.2	32.3	8.1	25.1	0	30	37	20	66.7	0.541
				2	24.4	32.4	8.0	25.1	30	30	17	8	26.7	0.472
				3	24.4	32.3	7.9	25.1	60	28	38	4	14.3	0.105 <sup>(b)</sup>
5	24.4	32.4	8.0	24.8	120	28	34	11	39.3	0.324				



TABLE C-2 (CONT.)

Date	Total Length of Larvae (mm)			Tank	Thermal Stress			Tank Temp. (C)	Recovery Time (min)	No. Larvae Per Tank	No. Attacks	No. Captures	Percent Capture	Captures Per Attack
	Mean	S.D.	Range		Ambient Temp. (C)	Shock Temp. (C)	Delta-T (C)							
4 JUL 1978	18.2	1.39	15-21	1	22.9	NA	NA	22.9	Control	30	35	7	23.3	0.200
				2	22.9	NA	NA	23.0	Control	30	26	9	30.0	0.346
				3	22.9	NA	NA	23.1	Control	30	37	7	23.3	0.189
				6	22.9	NA	NA	22.9	Control	29	33	10	34.5	0.303
				4	23.0	32.3	9.3	23.0	0	30	22	13	43.3	0.592
				5	23.0	32.3	9.3	22.8	30	30	43	17	56.7	0.395

(a) Mean total length 87.3 mm; standard deviation 7.4 mm; range 70-98 mm.

(b) These data were not included in the analysis of results because of low predator response (i.e., less than 15 attacks or less than 21 percent capture).

Note: NA indicates not applicable.

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