THERMAL RESISTANCE OF WEAKFISH EGGS AND LARVAE

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and

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J.R. Schubel

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Abstract

Eggs and larvae of the Weakfish (*Cynoscion regalis*) were subjected in the laboratory to several different time-excess temperature histories chosen for construction of thermal resistance curves. Eggs acclimated to 22.3°C were in the late tail free stage; larvae were acclimated to 22.5°C and were at late yolk sac absorption. Excess temperatures ranged from 2.8°C to 14.0°C above base or acclimation temperature, exposure times to an excess temperature ranged from 3 to 180 minutes, and cooling was immediate.

Eggs showed a greater resistance than did larvae to equivalent thermal stresses; egg mortalities were no greater than 5% until they were exposed to the highest ΔT (14°C) for 15 minutes. Larvae exhibited mortalities greater than 60% for a ΔT of 11.2°C for 45 minutes. Response patterns and thermal resistance curves for 10, 50, and 90% mortality levels indicated a sudden onset of high mortality with a small increase in temperature for both stages. This sudden mortality increase occurred between 34°C and 36°C for eggs, and between 31.3°C and 36°C for larvae.

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INTRODUCTION

The impact resulting from mortalities of fish eggs and larvae carried by cooling waters through steam electric power plants is a major topic of recent environmental concern. Steam electric plants, which account for about 83% of the total electric power generated in the United States (EPA, 1974), often function as "artificial predators" to ichthyoplanktonic assemblages. In conjunction with naturally occurring mortality, such plant induced mortality may affect the success or failure of certain populations in the vicinity of a power plant.

Simply put, a steam electric plant uses a heat source and boiler to create steam. This steam will ultimately produce electricity by driving a turbine which drives an electric generator. To operate economically and efficiently, a plant requires large volumes of water to cool its condensers so that exhausted steam from the turbine can be condensed and reused.

Power plants employ either a closed cycle or open cycle system to accomplish this cooling. In closed cycle systems, water which has passed through the condensers is transported through an artificial cooling device (pond or tower) and then returned to the plant. More widely used is the "once-through" or open cycle cooling system, which is utilized by close to 500 plants operating in the U. S. today (Carter, et. al, 1977). In this method, water is removed from a natural water body (lake, river, estuary, ocean), passed through plant condensers and returned to its source at an elevated temperature. This temperature elevation above ambient, which varies from plant to plant, is designated ΔT.

Organisms which are small enough to pass through intake screens, such as larval fish and fish eggs, may be entrained (captured and included) in the cooling waters and subjected to several different stresses: 1) chemical (biocides), 2) physical (mechanical impact, pressure changes, abrasion) and 3) thermal (temperature change). Thermally, the organisms are subjected to a very rapid rise in temperature, which is the temperature rise across the condensers. They are exposed to the maximum ΔT during their passage through the plant to the point of discharge, and then to decreasing excess temperatures as they are carried down the plume. Organisms entrained in the thermal plume without having passed through the plant experience a less abrupt and excessive thermal shock. Their exposure depends on the intensity, i.e. the rate of dilution, of the mixing processes in the receiving waters.

The thermal resistance of ichthyoplankton is an important criterion to consider before water in a specific area is used for power plant cooling. Varying degrees of thermal shock experienced during entrainment could lead to physiological damage or debilitation. Such impairment has been shown to increase the organisms vulnerability to predation (Coutant, 1973; Yocum and Edsall, 1974), cause anomolies in later developmental stages (Frank, 1973; Hopkins and Dean, 1975), or lead to outright death (Schubel and Koo, 1976). Motalities caused by such stress could result in various economic and/or ecological consequences; these may include loss of a certain species from the vicinity of a plant (particularly if water is taken from a nursery area), possible harm to species in other regions if the cooling water source is used as a migratory pathway, and disruption of food chain dynamics by reducing the number of smaller food organisms.

Much of the vast amount of literature dealing with thermal tolerances of fish eggs and larvae is of little value in assessing the effects of thermal stress experienced during entrainment by power plants. Many experiments have failed to rapidly cool organisms at the end of an exposure period; this "cold shock" is a characteristic of entrainment which Hoss, et.al, (1974) has shown to be a possible source of damage. "Classical" exposure times of 24, 48, and 96 hours are inappropriate because of their length and can result in misinterpretation. Field studies may be useful site-specific assessors of entrainment damage but they usually do not permit the separation of thermal effects from physical and chemical ones.

Since the body temperatures of aquatic organisms are usually regulated by their specific habitat, any large variation in environmental temperature has the potential to cause damage. Data which permits the separation of the effects of the different entrainment stresses and which can be used to predict the consequences of thermal shock alone are minimal for most Representative Important Species (RIS) of New York State. In many cases, such information is non-existant.

The Weakfish (Cynoscion regalis) is one such RIS for which there were no thermal response data. Weakfish, which spawn primarily from mid May to June near the bottom of shallow waters (from 3 to 5 fathoms), are found in abundance along the Atlantic coast from Cape Cod to Florida. The period of incubation of their eggs at water temperatures of from 21° to 22°C is 36 to 40 hours (Welsh and Breder, 1924). Commercial and recreational catches of weakfish have increased six-fold in New York waters from 1970 to 1975, making it an important food fish in the New York Fishery (McHugh, 1977).

Effects of thermal stress on two early life stages of Weakfish (one egg and one larvae) were examined by subjecting these stages to a variety of time-temperature histories. The mortality data were used to produce thermal resistance curves for 10, 50, and 90 percent mortalities. The information generated from this research will provide the thermal data necessary to reliably predict and assess the thermal effects of power plant entrainment for two stages of this increasingly important food fish.

METHODS AND MATERIALS

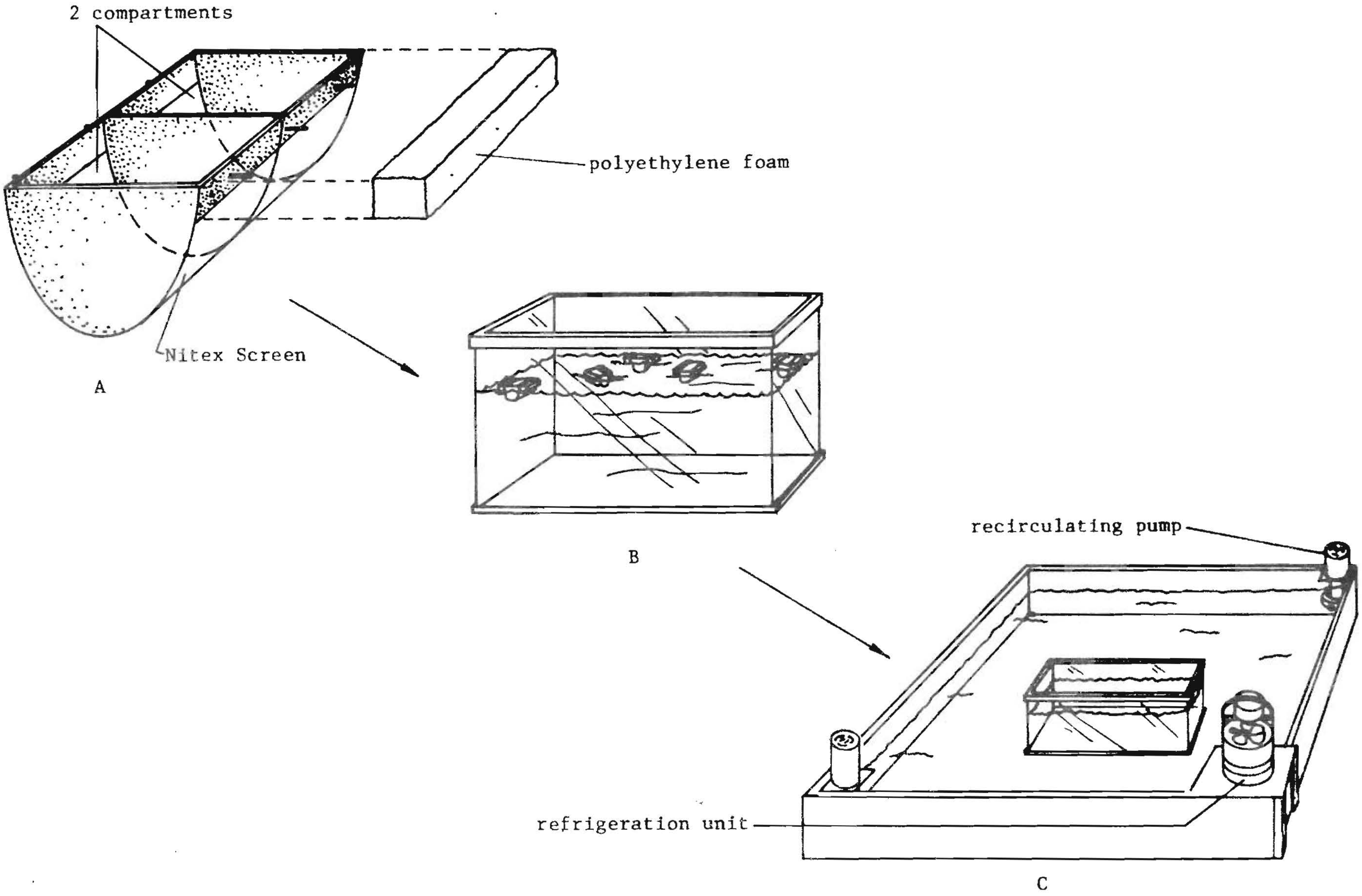
Collection and Handling of Eggs and Larvae

For each experiment, eggs were stripped from a single female and artificially fertilized with the milt from several males. Fish were received from commercial trap fishermen from Long Island Sound and artificially spawned into 5 gallon polyurethane buckets containing about 50 mls. of seawater. Spawning was induced onboard ship. After leaving the eggs in the milt-seawater mixture for 1 to 5 minutes, the buckets were filled with water from the collection site. To prevent temperature change of the eggs while on deck and during transportation back to the lab, the buckets were placed in insulated coolers which were half filled with seawater. Bucket water was oxygenated with portable aerators and its temperature monitored and maintained by the addition of seawater when available. Temperature did not vary beyond + 1°C.

Upon arrival at the laboratory, eggs were removed from the buckets and placed in a constant temperature water bath system. This system consisted of four 30 gallon (114 liters) salt water aquaria situated in a rectangular plywood box measuring 8' x 4' x 1.5' (2.4m x 1.2m x .45m) and filled with fresh water. Water temperatures in the box were controlled by a thermostatically regulated refrigeration unit and monitored with a continuously recording thermometer. Water was circulated by two submersible pumps (Fig. 1).

Figure 1

(A) Compartmentalized hatching box consisting of polyvinylchloride frame covering 243 micron Nitex screen, using strips of polyethylene foam for floatation; placed in (B) 30 gallon aquaria situated in (C) freshwater plywood box containing refrigeration unit and recirculating pumps.


2 compartments
polyethylene foam
Nitex Screen
A
B
recirculating pump
refrigeration unit
C

Each batch of eggs from a spawning constituted a sample. Fifty to fity-two subsamples of approximately 100 viable eggs were carefully withdrawn from an egg sample with a pipette and placed in individual hatching boxes, two subsamples per box. Each box consisted of a PVC frame divided into two compartments and covered with Nitex monofilament nylon cloth of 243 micron mesh (design by Schubel, 1976). One of the hatching boxes was immediately returned to the constant temperature bath which was set at the base temperature (+ 0.5°C higher than the temperature at the collection site) to act as a control. Each of the remaining sub-samples of eggs were exposed to one of the time-excess temperature histories shown in Table 1, and then returned to the constant temperature bath. Hatching boxes floated in salt water aquaria for 24 hours, receiving continuous aeration.

All exposure and holding waters were collected from Flax Pond, a small (0.5 km^2) salt marsh located between Crane Neck and Oldfield Point on the north shore of Long Island. This predominantly intertidal marsh has an average salinity of 26 ‰, which is approximately equal to that of Long Island waters in this region (Woodwell and Pecan, 1973).

Dead eggs were counted, removed and preserved twice: once immediately after an exposure, and once after 24 hours when the experiment was terminated. The number of organisms that died over the 24 hour period was recorded, and the resulting percent mortalities were calculated for each exposure. Larvae used during the larval experiments were reared from eggs not used during this portion of

Table 1

Excess Temperatures and Exposure Times used in this Study

ΔT (°C)	Exposure Time (min)				
2.8	3	15	45	90	180
5.6	3	15	45	90	180
8.4	3	15	45	90	180
11.2	3	15	45	90	180
14.0	3	15	45	90	180

the research.

Time Temperature Exposures

Every sub-sample of eggs and larvae underwent a different time-temperature exposure. These particular "time-excess temperature histories" consisted of:

1) an initial period of constant temperature (base or acclimation temperature) followed by
2) an abrupt rise to a maximum ΔT (excess temperature) maintained for a specified time, which was followed by
3) an immediate cooling back to the base temperature.

Excess temperatures ranged from 2.8° to 14.0° above base (acclimation) temperature; exposure times ranged from 3 to 180 minutes. The time-temperature combinations used were based on previous thermal tolerance data for eggs and larvae of species other than weakfish (alewife, herring, perch, shad); they were selected for their suitability to produce thermal resistance curves for weakfish, rather than to simulate conditions at a particular power plant.

Each of the exposures shown in Table 1 was simulated in the following manner. Five 19 liter styrofoam containers were filled with 12 to 15 liters of seawater; each container was brought to the desired exposure temperature by further additions of hot or cold seawater. Hatching boxes containing eggs were removed from the constant temperature holding bath and quickly immersed in the exposure containers for a specified amount of time. Water in the exposure baths was maintained at its particular ΔT by the addition of hot seawater directly to the exposure tank, followed by careful hand mixing. The water in each exposure tank was aerated and temperature monitored throughout each experiment.

RESULTS

Two experiments were run with weakfish ichthyoplankton. The first used eggs in the late tail free stage (12 hours after fertilization); the second used larvae which were at mid to late yolk sac absorption (24 hours after hatching). Time-temperature histories, live/dead counts, spawning ground temperatures and base temperatures used during these experiments are shown in Tables 2 and 3. Percent mortalities for each exposure are indicated in Tables 4 and 5.

Figures 2 and 3 show response surface graphs which were generated from the experimental data. Using isometric graph paper, time, temperature and percent mortality were plotted on a three dimensional axis. The slope of the response surface of the figure conveys a general mortality pattern: the parts of the surface over which the slopes change gently indicate ranges of values of time and temperature for which the variations in mortality are linearly related to the variables. An abrupt change in the slope of the surface demonstrates a failure of the costant linear dependence and is associated with the sudden onset of high mortalities. Figure 3 (weakfish eggs) clearly illustrates the latter response.

The thermal resistance curves for each experiment, shown in Figures 4 and 5, were drawn using percent mortality data which were corrected for the control mortality (mortalities determined 24 hours after exposure). The following equation:

$$\text{Corrected percent mortality} = 1 - \frac{\text{\% surviving an exposure}}{\text{\% survivng in control}}$$

was used to normalize all experimental exposure mortalities. Mortalities at experimental time-temperature points were then plotted on the thermal resistance graph. Two mortalities were plotted at each exposure point, representing the mortalities found in each side of one hatching box subjected to a particular time-temperature exposure.

The generation of 10, 50, and 90 percent mortality curves was attempted using several computer methods: BMD02R Stepwise Regression, BMD03R Multiple Regression with Case Combinations (both on the Univac 1110), and simple polynomial regression on the HP 9866A. Contouring the resistance curves by eye, however, was found to give the most reasonable fit to the data (see Discussion).

Data for weakfish eggs acclimated to a base temperature of 22.3°C showed:

1) No significant mortalities (above 5%) for time exposures of 3 to 180 minutes using ΔT's ranging from 2.8° to 11.2°C.
2) Zero mortality for any 3 minute exposure for all ΔT's used.
3) Mortalities of 15% and 18% from an exposure of 45 minutes at the highest ΔT used (14°C). Doubling the exposure time to 90 minutes at the same ΔT resulted in an average mortality of 94%.
4) The longest exposure time (180 minutes) at the highest ΔT (14°C) did not result in complete mortality of the eggs.

Data for weakfish larvae acclimated to a base temperature of 22.3°C showed:

1) A general increase in mortality with increasing ΔT for all time exposures.
2) No apparent change in mortality due to an increase in time for ΔT's of 2.8°, 5.6°, and 8.4°C.
3) An average mortality of 16% for the first two time exposures (3 and 15 minutes) at a ΔT of 11.2°C. Average mortality for the next three time exposures (45, 90, and 180 minutes) was 61%.
4) A ΔT of 14°C caused mortalities of 4% and 14% during a three minute exposure. Increasing the time to 15 minutes at the same ΔT resulted in 78% and 88% mortalities. 100% mortality was recorded for at least one side of each hatching box when exposure times were increased to 45, 90, and 180 minutes.

Table 2

Exposure Times, Exposure Temperatures, ΔT's, Live/Dead Counts for Weakfish Eggs. (R denotes right side of hatching box, L denotes left side)

Weakfish Eggs

Spawning Ground Temperature: 22°C

Base Temperature used during Experiment: 22.3°C

Exposure Time (min)	Exposure Temperature /ΔT (°C)	side of hatching box	number live	number dead
3	25.1/2.8	R	65	2
		L	106	0
15	25.1/2.8	R	66	2
		L	125	1
45	25.1/2.8	R	88	0
		L	46	3
90	25.1/2.8	R	89	8
		L	89	16
180	25.1/2.8	R	81	2
		L	76	0
3	27.9/5.6	R	96	1
		L	99	0
15	27.9/5.6	R	79	2
		L	96	4
45	27.9/5.6	R	98	0
		L	84	4
90	27.9/5.6	R	92	13
		L	86	10
180	27.9/5.6	R	84	4
		L	99	15
3	30.7/8.4	R	87	6
		L	54	1
15	30.7/8.4	R	143	19
		L	92	7
45	30.7/8.4	R	108	0
		L	36	2
90	30.7/8.4	R	75	4
		L	86	9
180	30.7/8.4	R	80	14
		L	96	8
3	33.5/11.2	R	90	3
		L	87	2
15	33.5/11.2	R	77	2
		L	86	2
45	33.5/11.2	R	71	5
		L	106	5
90	33.5/11.2	R	105	11
		L	82	5
180	33.5/11.2	R	96	2
		L	96	6
3	36.3/14.0	R	58	0
		L	98	4
15	36.3/14.0	R	95	9
		L	90	57
45	36.3/14.0	R	84	27
		L	61	23
90	36.3/14.0	R	5	83
		L	6	88
180	36.3/14.0	R	9	98
Control	22.3/0	R	97	14
		L	106	10

Table 3

Exposure Times, Exposure Temperatures, ΔT's, Live/Dead Counts for Weakfish Larvae. (R denotes right side of hatching box, L denotes left side)

Weakfish Larvae

Spawning Ground Temperature: 22°C

Base Temperature used during Experiment: 22.5°C

Exposure Time (min)	Exposure Temperature /ΔT (°C)	side of hatching box	number live	number dead
3	25.3/2.8	R	315	7
		L	290	3
15	25.3/2.8	R	243	10
		L	x	x
45	25.3/2.8	R	138	9
		L	118	7
90	25.3/2.8	R	253	14
		L	241	10
180	25.3/2.8	R	234	4
		L	186	3
3	28.1/5.6	R	220	8
		L	352	9
15	28.1/5.6	R	130	29
		L	137	35
45	28.1/5.6	R	150	20
		L	134	12
90	28.1/5.6	R	159	4
		L	167	5
180	28.1/5.6	R	x	x
		L	x	x
3	30.9/8.4	R	81	10
		L	82	5
15	30.9/8.4	R	258	43
		L	227	37
45	30.9/8.4	R	112	8
		L	129	10
90	30.9/8.4	R	144	10
		L	176	12
180	30.9/8.4	R	111	11
		L	192	7
3	33.7/11.2	R	192	45
		L	174	51
15	33.7/11.2	R	167	33
		L	186	39
45	33.7/11.2	R	26	70
		L	37	71
90	33.7/11.2	R	52	99
		L	45	120
180	33.7/11.2	R	42	52
		L	49	54
3	36.5/14.0	R	118	24
		L	147	11
15	36.5/14.0	R	13	99
		L	26	97
45	36.5/14.0	R	4	112
		L	0	11
90	36.5/14.0	R	0	127
		L	1	84
180	36.5/14.0	R	0	110
		L	0	155
Control	22.5/0	R	255	8
		L	264	9

Table 4

Weakfish Egg Mortalities Corrected for Control

Weakfish Eggs

Time (min)	Exposure Temperature/ΔT (°C)				
	25.1/2.8	27.9/5.6	30.7/8.4	33.5/11.2	36.3/14.0
3R	0	0	0	0	0
3L	0	0	0	0	0
15R	0	0	1	0	0
15L	0	0	0	0	29
45R	0	0	0	0	15
45L	0	0	0	0	18
90R	0	2	0	0	94
90L	5	0	0	0	94
180R	0	0	4	0	91
180L	0	2	0	0	88

Control R: 13
Control L: 8

Table 5

Weakfish Larvae Mortalities Corrected for Control

Weakfish Larvae

Time (min)	Exposure Temperature/ΔT (°C) 25.3/2.8	28.1/5.6	30.9/8.4	33.7/11.2	36.5/14.0
3R	0	1	8	16	14
3L	0	0	3	20	4
15R	1	16	11	14	88
15L	x	20	11	14	78
45R	3	9	4	72	97
45L	3	5	4	65	100
90R	2	0	4	65	100
90L	1	0	3	72	99
180R	0	x	6	54	100
180L	0	x	1	51	100

Control R: 3
Control L: 3

Figure 2

Response Surface Generated from Actual Data Points for Weakfish Eggs

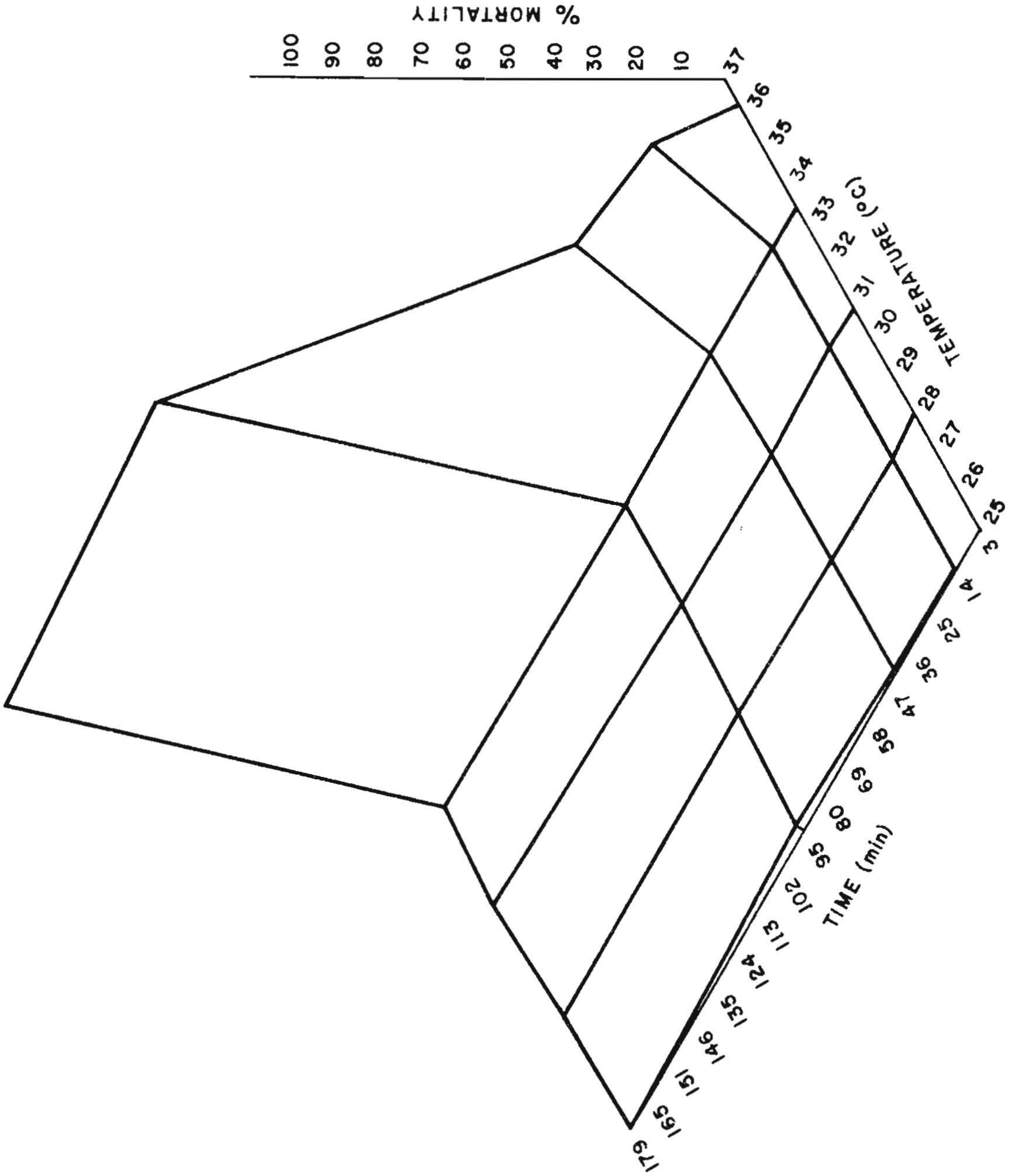

% MORTALITY
100
90
80
70
60
50
40
30
20
10
37
36
35
34
33
32
31
30
29
28
27
26
25
TEMPERATURE (oC)
3
14
25
36
47
58
69
80
95
102
113
124
135
146
151
165
179
TIME (min)

Figure 3

Response Surface Generated from Actual Data Points for Weakfish Larvae

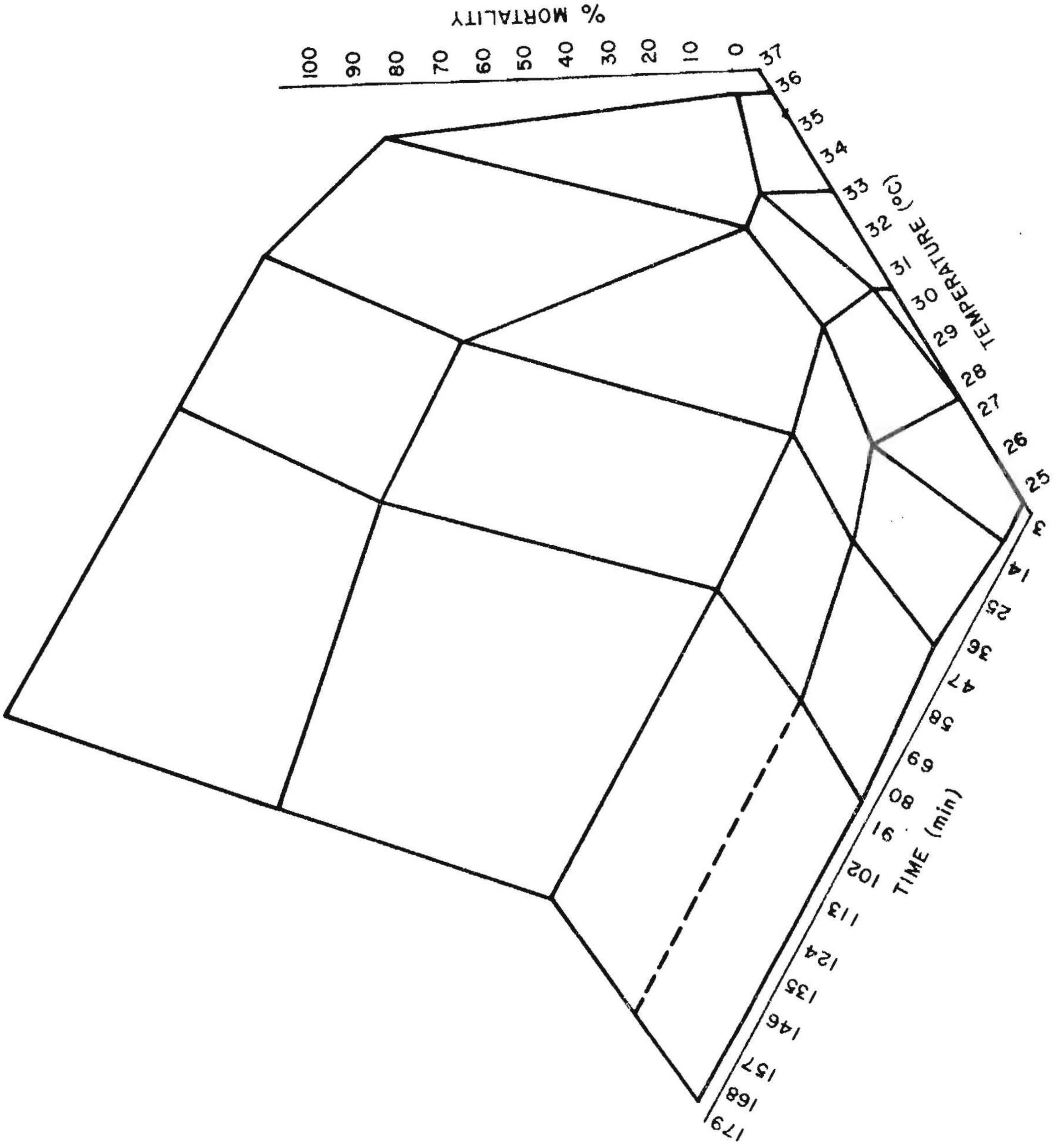

% MORTALITY
0
10
20
30
40
50
60
70
80
90
100
TEMPERATURE (°C)
37
36
35
34
33
32
31
30
29
28
27
26
25
TIME (min)
3
14
25
36
47
58
69
80
91
102
113
124
135
146
157
168
179

Figure 4

Thermal Resistance Curves for Weakfish Eggs Showing 10, 50, and 90% Mortality Curves

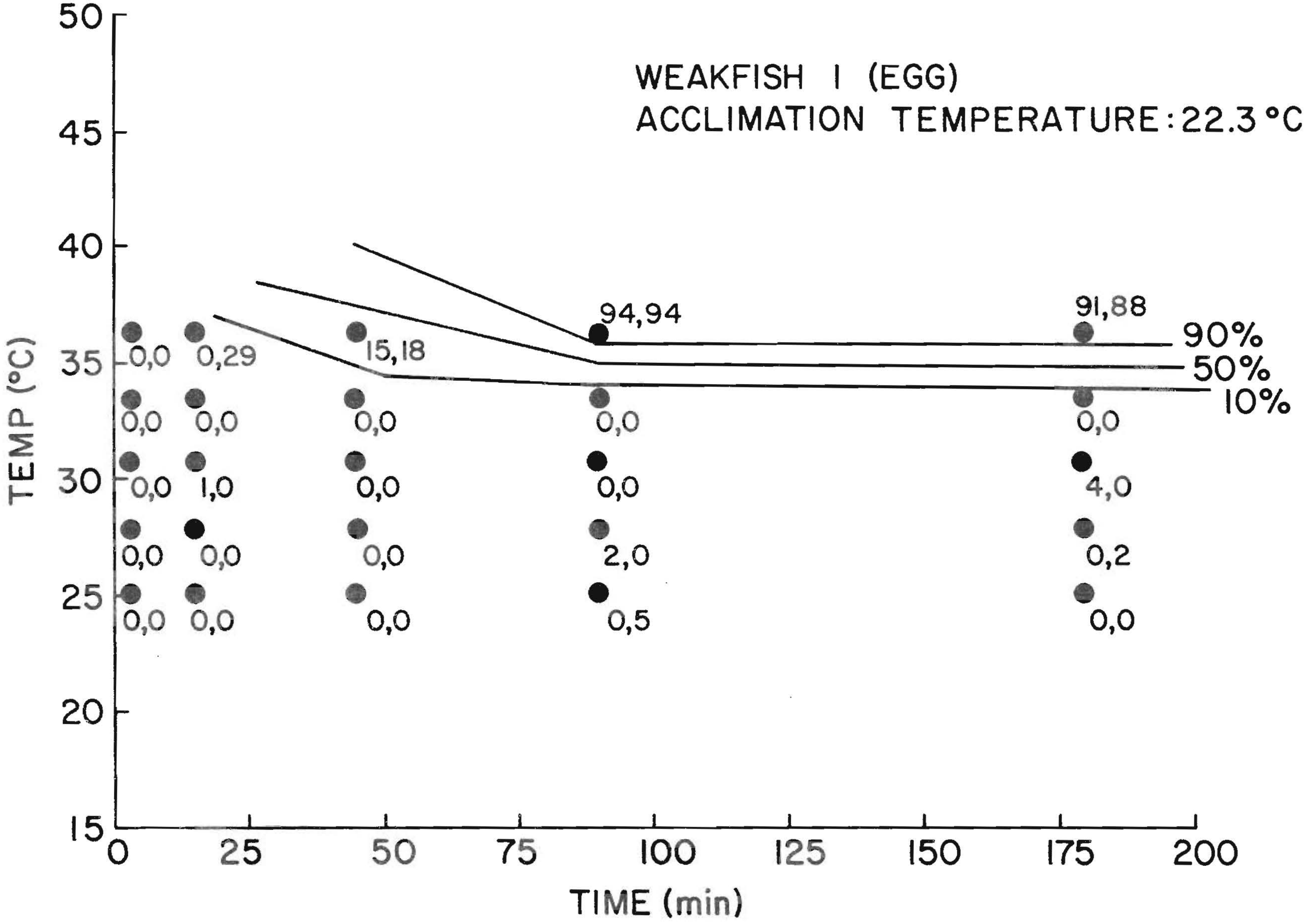
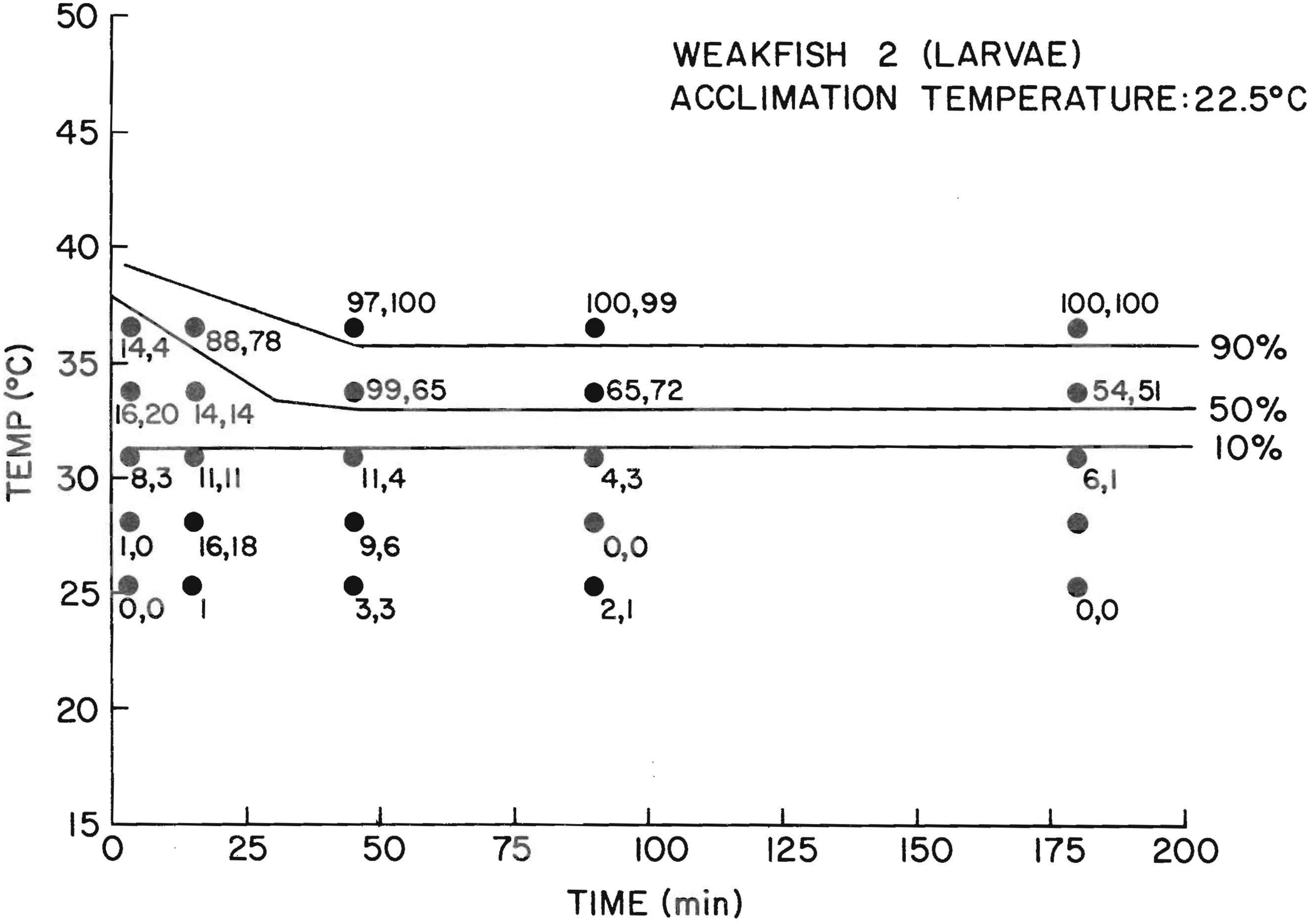

WEAKFISH I (EGG)
ACCLIMATION TEMPERATURE: 22.3 °C
TEMP (°C)
50
45
40
35
30
25
20
15
TIME (min)
0
25
50
75
100
125
150
175
200
90%
50%
10%
94,94
91,88
0,0
0,29
15,18
0,0
0,0
0,0
0,0
0,0
0,0
1,0
0,0
0,0
4,0
0,0
0,0
0,0
2,0
0,2
0,0
0,0
0,0
0,5
0,0

Figure 5

Thermal Resistance Curves for Weakfish Larvae Showing 10, 50, and 90% Mortality Curves


WEAKFISH 2 (LARVAE)
ACCLIMATION TEMPERATURE:22.5°C
TEMP (°C)
50
45
40
35
30
25
20
15
TIME (min)
0
25
50
75
100
125
150
175
200
90%
50%
10%
14,4
88,78
97,100
100,99
100,100
16,20
14,14
99,65
65,72
54,51
8,3
11,11
11,4
4,3
6,1
1,0
16,18
9,6
0,0
0,0
1
3,3
2,1
0,0

DISCUSSION

Tolerances of Eggs and Larvae

The mortality data indicate that weakfish eggs at the late tail free stage acclimated to 22.3°C are highly resistant to ΔT's up to 11.2°C for time exposures up to 180 minutes. The eggs showed essentially no mortality for the time-excess temperature exposure histories in this range. Mortalities greater than 30% did not arise until eggs were exposed to a ΔT of 14°C for 90 minutes, when 94% mortalities occurred.

It has been well documented (Frank, 1973; Hopkins and Dean, 1975; Lauer, et.al, 1974; Koo, et.al, in prep.) that the ability of eggs to withstand thermal stress is dependent on their stage of development. In general, the later the developmental stage, the greater the tolerance to a particular ΔT, and hence, to a particular maximum temperature. The stage of the eggs during this experiment was quite advanced: 94% of those organisms counted as "live" had hatched 24 hours after exposure. Although no information exists for other weakfish stages it can be reasonably assumed that late tail free eggs would exhibit different tolerances to thermal stress than would eggs in an earlier stage of development. Judging from the work of other investigators with different species, earlier stages would probably show less tolerance to equivalent thermal exposures.

Larvae at late yolk sac absorption which were exposed to the same ΔT's as the eggs, were found to be less tolerant. Significant mortalities were observed at a ΔT of 11.2°C for a time exposure of 45 minutes (72% and 64% mortalities occurred at this exposure). Larvae exhibited 100% mortality when exposed to a ΔT of 14.0°C for 45 minutes; mortalities of eggs at an equivalent exposure ranged from only 15% to 18%. Since experimental base temperatures were practically identical (22.3°C for eggs, 22.5°C for larvae) the mortality results indicate that weakfish eggs at the late tail free stage show a greater tolerance to thermal stress than do larvae at late yolk sac absorption.

This is not unusual. Lauer, et.al (1974) have shown that newly hatched larvae of striped bass (Morone saxatilis) are more sensitive to thermal stress than late stage eggs. In their research, larvae acclimated to a base temperature of 19.6°C were tolerant only to a ΔT of 3.3°C for 60 minutes, while eggs could withstand exposures to a ΔT of 14.2°C for the same time. Lauer further noted that older larvae were increasingly less sensitive to thermal shock than younger larval stages.

The fact that thermal tolerances change with different life stages is one of several factors to consider when interpreting thermal resistance data. The ambient temperature of the water in which eggs and larvae are acclimated plays a pivotal role in thermal tolerance estimates. It has been generally established that with increasing acclimation temperature, an organism's tolerance to an elevated temperature will increase (up to some limit) while its tolerance to a particular ΔT will decrease. For example, individuals A of a species, acclimated to 10°C may be able to withstand an exposure temperature of 28°C (ΔT of 18°C) for one hour, while individuals B of the same species acclimated to 20°C can withstand the same exposure temperature of 28°C for three hours. If B individuals, however, were to experience the same ΔT as A individuals (18°C) they would be exposed to a maximum temperature of 38°C. Tolerances to a temperature of this magnitude would be quite low.

Genetic differences in parents could also effect responses to thermal stress. Schubel (1974) has shown that significant differences in hatching success occur in exposed eggs of different females fertilized by different males.

Thermal Resistance Curves

In order to predict the thermal effects of power plants, thermal data must be in an appropriate form. The most suitable data are those which can be used to construct thermal resistance curves. The criteria for appropriate data for evaluation of power plant effects include: 1) that exposure to an excess temperature (ΔT) be applied instantaneously so that no thermal adaptation can occur, 2) that mortalities are reported as functions of both temperatures and exposure times, 3) that mortalities are reported within a range of exposure times of from a few minutes up to about two hours, and 4) experimental organisms are of a size small enough to be unable to avoid the thermal influences of an operating power plant (Carter, et.al, 1977). All of these standards were met during this research.

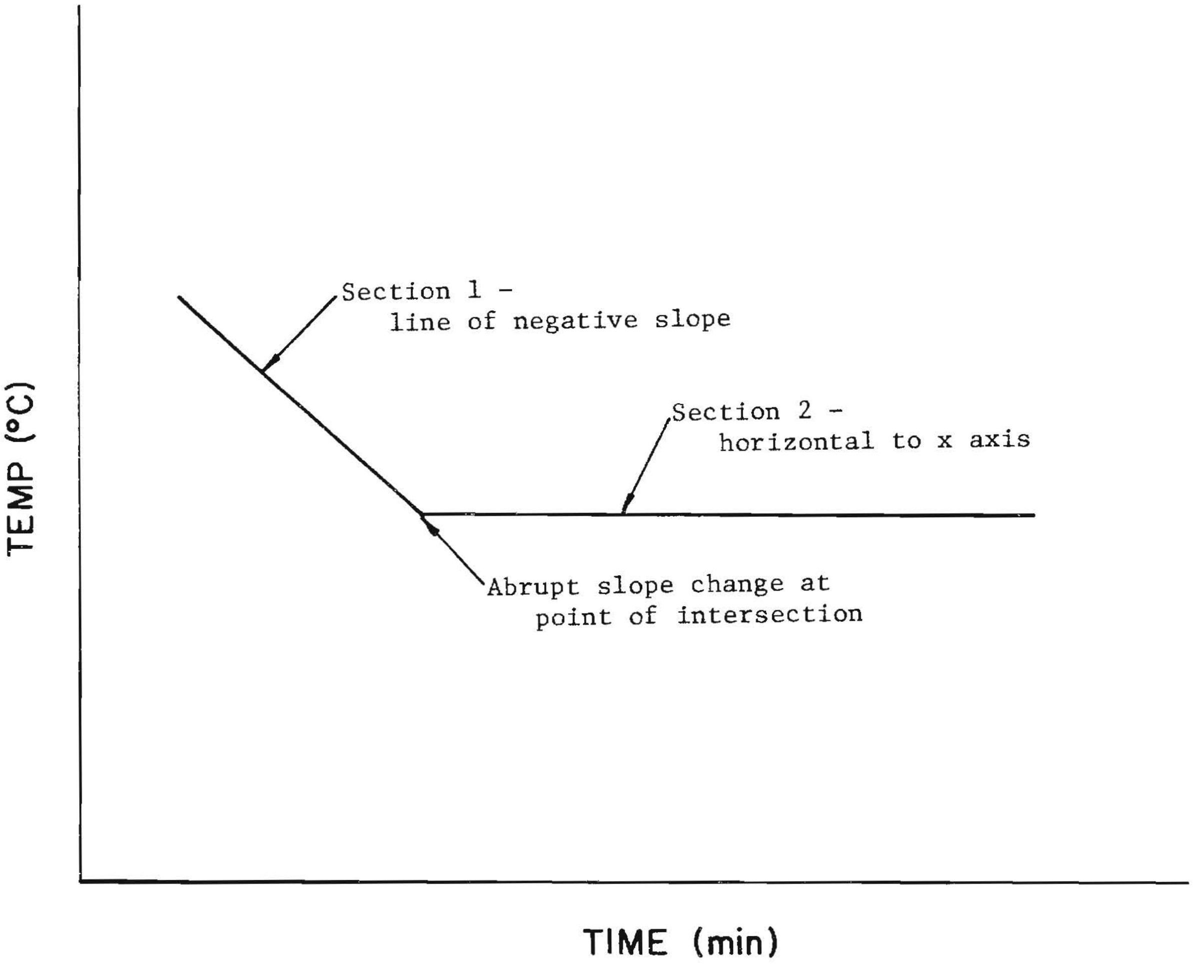
The thermal resistance curves presented in this research were contoured by eye rather than with the aid of analytical curve fitting by least square computations. Curves were sketched independently by the author and three investigators familiar with this project; in all cases the curves did not differ from each other by more than the experimental error. When deciding on the method to use to interpret this data, consideration was given to the type of data generated and to the uses that are to be made of the results. When the objective of a study is to use the information directly, and when the data are sparse and of high variability (as was the case in this study) the graphical method is preferred over the analytical, since it permits much freer play for the experience, common sense, and physical intuition of the investigator.

Most thermal resistance curves can be divided into two sections (Fig. 6). Section 1 consists of a line of negative slope; mortalities in this area will be a function of both exposure times and temperatures. Section 2 is a line which is approximately horizontal to the x axis. Mortalities here are independent of the exposure time and will depend solely on the excess temperature above base temperature.

An abrupt slope change occurs on the thermal resistance curve where sections 1 and 2 intersect. Any increase in exposure time for the temperature designated at this point will not change the mortality rate. When organisms can be held at a certain temperature for an indefinite amount of time with no change in their mortality rate, those organisms are said to have reached their incipient lethal temperature for that particular percent mortality.

Figure 6

Typical Thermal Resistance Curve


Section 1 -
line of negative slope
Section 2 -
horizontal to x axis
Abrupt slope change at
point of intersection
TEMP (°C)
TIME (min)

The point at the abrupt slope change signifies three things:

1) The y coordinate represents the incipient lethal temperature (LT) for that particular mortality level;
2) The x coordinate represents the time at which the incipient lethal temperature is reached;
3) The transition from resistance to tolerance has been completed.

Table 2 lists the incipient lethal temperatures for 10, 50, and 90% mortalities and the times at which they are reached for weakfish late tail free eggs and larvae at the late yolk sac absorption stage.

The resistance curves for weakfish eggs show that the incipient lethal temperatures for 10, 50, and 90% mortality levels vary by only about 2°C. Late tail free eggs appear to be highly tolerant, experiencing 10% mortality or lower for exposures of up to 34°C for 90 minutes. An increase in temperature of only 1.2°C however, for this same exposure time will cause 50% mortality. Another increase of only .8°C at 90 minutes results in 90% mortality. This suddenness of high mortality was previously shown in the response surface graph for weakfish eggs (fig. 2). The incipient lethal temperatures for larvae for 10 to 90% mortality levels are separated by about 5°C. The larval response surface graph (fig. 3) also shows this sudden mortality phenomena.

Although mortalities increase significantly within a small temperature range, the data demonstrate that thermal stress is a dose response. A dose response, defined as "a response that is a function of the strength of the stimulus and the duration of its application", is usually associated with patterns of chemical toxicity and the

Table 6

Incipient Lethal Temperature Data for Weakfish Eggs and Larvae

	Percent Mortality	Incipient Lethal Temperature (°C)	Exposure Time at which Incipient Lethal Temperature is reached (min)
Weakfish Eggs	10	34.0	90
	50	35.2	90
	90	36.0	90
Weakfish Larvae	10	31.3	1
	50	33.0	30
	90	36.0	45

actions of pharmaceuticals. In thermal death, dose is a function of temperature and length of exposure time.

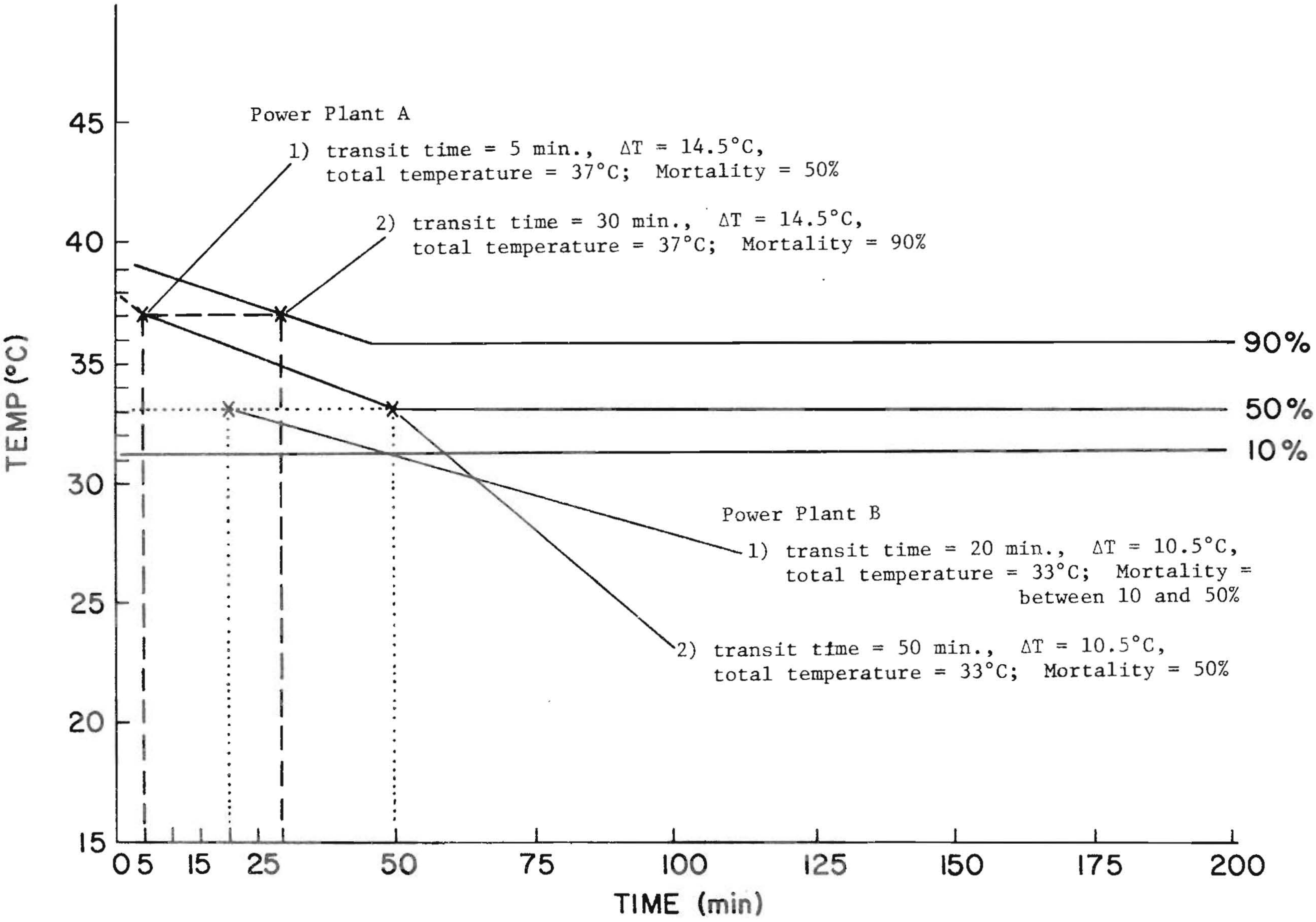
A thermal resistance curve can provide the framework for assessing and predicting the thermal effects on a particular entrainable organism for any power plant using a once through cooling system. Using the data for weakfish larvae, we will consider how it may be used to predict mortalities due to the thermal component of entrainment for two hypothetical power plants with different operating methods.

Power plant A has a five minute transit time through the plant with a ΔT of 14.5°C across the condensers. A multi-port diffuser apparatus is used to discharge cooling water, making return to ambient temperature almost instantaneous (ambient temperature = 22°C). A ΔT of 14.5°C would subject organisms to a temperature of 37°C during their plant entrainment. The thermal resistance curve indicates that for this species, 50% of the organisms will survive this exposure (Fig. 7). A longer exposure time of 30 minutes would lead to 90% mortality.

Power plant B has a twenty minute transit time and operates at a ΔT of 10.5°C. Again, assuming an ambient temperature of 22.5°C and instantaneous cooling the graph predicts that between 10 and 50% of the organisms will die. If the transit time in the plant is increased to 45 minutes, 50% mortality of the entrained population can be expected. Any transit time beyond 50 minutes will still result in 50% mortality, indicating that this temperature (33°C) is the incipient lethal temperature for the 50% mortality level.

Figure 7

Hypothetical Time-Temperature Exposures for Weakfish Larvae Acclimated to 22°C


Power Plant A
1) transit time = 5 min., ΔT = 14.5°C, total temperature = 37°C; Mortality = 50%
2) transit time = 30 min., ΔT = 14.5°C, total temperature = 37°C; Mortality = 90%
Power Plant B
1) transit time = 20 min., ΔT = 10.5°C, total temperature = 33°C; Mortality = between 10 and 50%
2) transit time = 50 min., ΔT = 10.5°C, total temperature = 33°C; Mortality = 50%
90%
50%
10%
TEMP (°C)
45
40
35
30
25
20
15
TIME (min)
0
5
15
25
50
75
100
125
150
175
200

The average ΔT across the condensers in power plants using a once through cooling system in the U.S. is 11°C (Schubel, 1977). Weakfish eggs and larvae used during this experiment were collected from fish spawning in 22°C water. If these organisms were to be entrained in a power plant using once through cooling with this average ΔT, they would be subjected to a temperature of 33°C. One may predict from the resistance curves that 22°C acclimated eggs are well within a safe exposure, even if their entrainment continues for two hours (up to 10% of the eggs will suffer mortality). Entrained larvae, however, would experience much greater mortality: for entrainment times up to 30 minutes, mortalities would range from 10 to 50%; between 30 and 50 minutes, the curve predicts close to 50% mortality. Beyond 50 minutes, mortalities would remain at 50% (LT_{50} occurs at 33°C).

Caution should be taken in indiscriminately using these data as predictors of power plant mortalities. This analysis considers only the effects of thermal stresses and does not consider the effects of chemical biocides nor of mechanical abrasion and impact. Synergistic effects among the three stresses, particularly those between thermal and mechanical shocks, are also important consequences of once through cooling which have not been treated in this discussion.

The data presented in this research allows a predictive evaluation to be made of the thermal component of entrainment for two planktonic stages of weakfish. Further experimentation with ichthyoplankton that are 1) acclimated to different temperatures and 2) at different stages of development would help to strengthen the usefulness of the thermal resistance curve. This work represents the first step towards reliable assessment of power plant cooling water effects on an important food fish in New York State.

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