Thermal Resistance Characteristics of Early Life History Stages of Finfish from Long Island Waters

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ABSTRACT

Eggs and larvae of finfish from Long Island (New York) waters were subjected to elevated temperature shocks in a square wave exposure experimental design to determine their thermal resistance characteristics. Ten, fifty, and ninety percent mortality thermal resistance curves were drawn for egg and larval stages of weakfish *(Cynoscion regalis)*, striped searobin *(Prionotus evolans)*, and scup *(Stenotomus chrysops)*, and egg stages of summer flounder *(Paralichthys dentatus)* and blackfish *(Tautoga onitis)*. In general, thermal resistance was found to be related to acclimation (base) temperature prior to experimentation and age of the life history stage used. For each species, resistance to thermal stress increased with age and with increasing acclimation temperature. As the thermal stress increased, the variation of response of similarly acclimated organisms decreased.

INTRODUCTION

Although there is a large literature on the effects of temperature on organisms, relatively little of this information is of direct use in predicting the effects of the thermal stresses experienced by organisms entrained by power plants with once-through cooling systems, or in designing these systems to minimize total entrainment mortality. In most of the published laboratory studies of thermal tolerance, the organisms have been subjected to a constant temperature for all, or nearly all, of the experimental periods; in other studies organisms have been subjected to changing temperatures but at rates too slow for comparison to power plant exposures. In this study, data were obtained on the thermal tolerances of eggs and larvae of finfish from Long Island Sound, in a form appropriate for prediction of thermal effects of entrainment by power plants with once-through cooling. From these data, thermal resistance curves were generated for weakfish[1] *(Cynoscion regalis)*, scup *(Stenotomus chrysops)*, striped searobin *(Prionotus evolans)*, blackfish *(Tautoga onitis)*, and summer flounder *(Paralichthys dentatus)*.

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[1] In addition to this report, a separate report on weakfish eggs and larvae has been prepared (Greges and Schubel, 1979).

MATERIALS AND METHODS

Collection and Handling of Fish Eggs and Larvae

For each experiment, eggs were artificially fertilized onboard commercial fishing vessels in Long Island Sound or Great South Bay. Eggs were stripped from one to four ripe females into polyurethane buckets containing a small volume of seawater, and mixed with milt from two to four ripe males. Table 1 summarizes information pertaining to field conditions existing at spawning sites.

After swirling eggs in the milt-seawater mixture for one to ten minutes, buckets were filled with surface water from the collection site. The water was periodically changed during the time spent onboard the fishing vessel. To prevent temperature changes of eggs while on deck and during transportation, buckets were placed in insulated containers half-filled with seawater. Egg samples were continuously aerated by battery-powered air pumps,

Table 1

Information pertaining to field collection, culture, and experimental exposure of eggs and larvae.

	FIELD					CULTURE	EXPOSURE			
Species	Site Collected	Date Collected	Spawning Temperature (°C)	# of Females	# of Males	Culture Temperature (range in °C)	# of Experiment	Base Temperature (°C)	Life History Stage	Hours after Fertilization
Weakfish	Great South Bay	6/22/78	22.0	1	3	22.0 - 23.0	1	22.3	Tail-free embryo	12
							2	22.5	Yolk sac larvae	54
Striped Searobin	Long Island Sound	7/13/78	19.0	2	4	20.0 - 21.0	1	20.3	Early embryo	33
		7/25/78	21.8	3	4	21.7 - 22.5	2	21.7	Mid embryo	31
							3	21.7	Tail-free embryo	54
							4	21.9	Yolk sac larvae	78
Scup	Long Island Sound	6/07/78	13.0[a]	2	4	17.9 - 18.9	1	17.9	Blastula	10
		7/06/78	17.0	3	3	16.8 - 17.8	2	17.1	Early embryo	38
							3	16.8	Yolk sac larvae	83
Summer Flounder	Narragansett Bay, R.I.	10/21/78	17.0	1	2	16.0 - 17.0	1	16.0	Late embryo	65
Blackfish	Long Island Sound	6/20/78	15.0	3	4	15.0 - 16.0	1	15.0	Gastrula	17

[a]Bucket temperature increased 5°C during transportation; eggs were kept at 13.0°C for initial 8 hours.

and their temperature maintained by the addition of seawater when necessary. In this way, temperature was held to within ±1°C of the temperature of the water over the spawning grounds.

Upon arrival at the laboratory, eggs were transferred from the buckets to a constant temperature water bath system, Figure 1. This system consisted of four thirty gallon salt water aquaria contained in a plywood bath measuring eight feet by four feet by one and one-half feet. Aquaria contained filtered water from Flax Pond, a salt marsh near the University freely connected to Long Island Sound. The plywood bath contained fresh water which was continuously circulated around the aquaria. Water temperature of the fresh water contained in the plywood bath were maintained by a thermostatically-controlled refrigeration unit, and was monitored with a continuously recording thermometer. Water was circulated within the plywood bath by two industrial recirculating pumps. This system maintained temperatures within the salt water aquaria to within ± 0.5°C of the temperature at the collection site.

All exposure and holding waters, except for summer flounder, were collected from the main tidal creek of Flax Pond, a small 0.5 km^2 salt marsh located between Crane Neck and Old Field Point on the north shore of Long Island, New York. This intertidal marsh creek has an average salinity of 25‰, which is approximately equal to that of Long Island waters in this region (Woodwell and Pecan, 1973). Water used in the summer flounder experiment was obtained from the Atlantic Ocean; salinity was approximately 30‰.

Larvae were reared from eggs and maintained at the culture temperature until an experiment was run. Each batch of eggs or larvae, from a spawning constituted a sample. Live eggs, or larvae, were removed from a sample and transferred to compartmented holding boxes; approximately seventy-five to one hundred and twenty-five eggs, or larvae, were placed in each side.

Figure 1 illustrates the design of a holding box. Each box consisted of a PVC plastic frame divided into two compartments and covered with Nitex monofilament nylon cloth of 243 micrometer mesh. This design enabled duplicate experiments to be run concurrently. Individual subsamples within a holding box were exposed to the appropriate time-excess temperature history, and returned to the constant temperature bath. One holding box remained in the constant temperature bath throughout each experiment to serve as a control. Each seawater aquarium was continuously aerated.

Time-Temperature Exposures

Each holding box of eggs, or larvae, underwent a different time-excess temperature history which consisted of: 1) an initial acclimation period at the culture temperature, followed by 2) an abrupt rise in temperature (the excess temperature, ΔT) maintained for a specified time, and followed by 3) an immediate cooling back to the culture temperature in the constant temperature water bath.

Excess temperatures ranged from 2.5°C to 21.0°C above a specific base temperature which was the culture temperature. Exposure times ranged from 30 seconds to 360 minutes. The time-temperature combinations used were based on previous thermal tolerance data for eggs and larvae of a variety of species.

Temperature exposures were conducted in the following manner: 5 gallon, plastic lined styrofoam containers were filled with 3 to 4 gallons of filtered water from Flax Pond. Each container was brought to the desired exposure temperature with additions of hot or cold seawater. Holding boxes containing eggs, or larvae, were removed from the constant temperature bath and quickly immersed into the exposure containers for a specified amount of time. Hot or cold seawater was carefully mixed

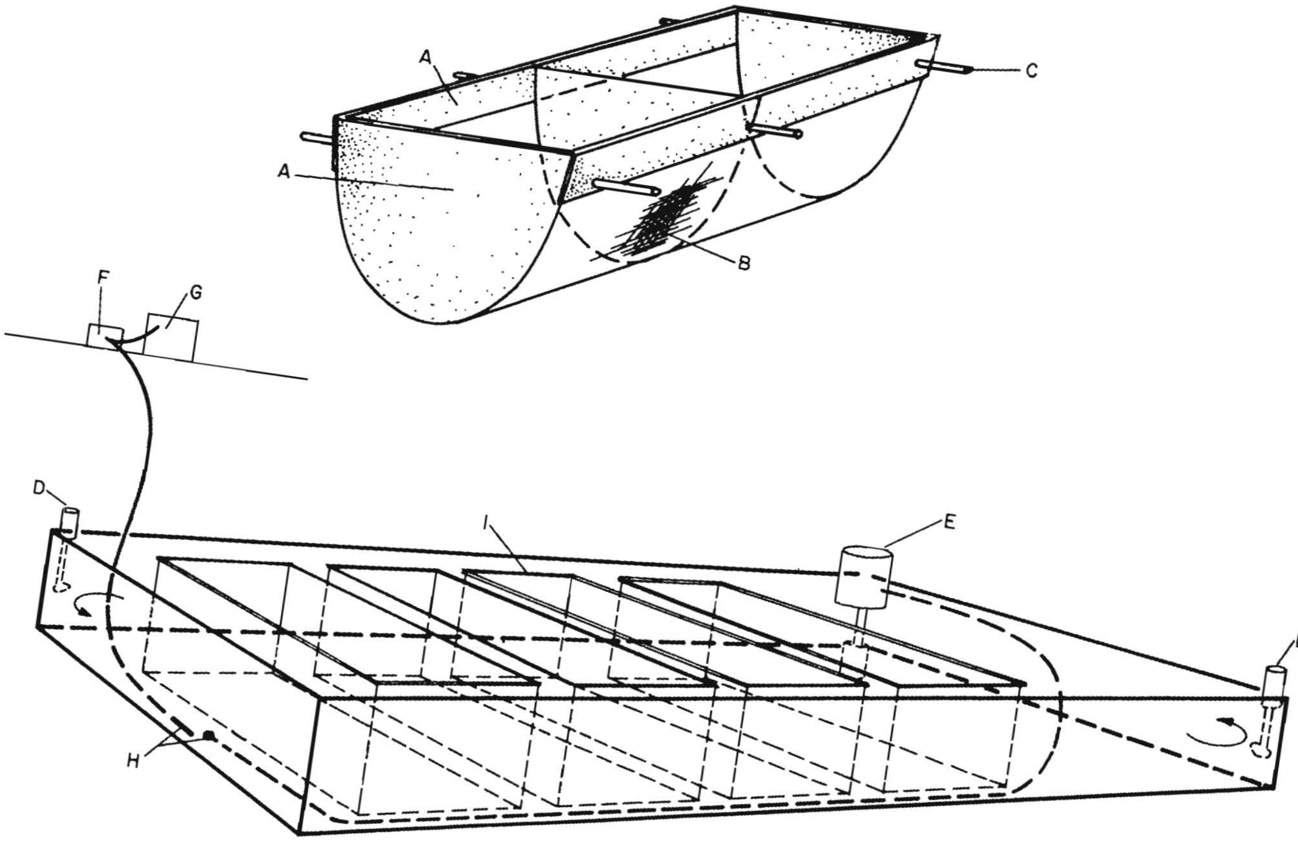

Figure 1. Sketch of hatching box and culture system.

A 1/8" PVC Sheet Stock
B 243 Micrometer Nylon Mesh Screen
C 1/8" PVC Mounting Pins for Floatation Attachment
D 1/20 HP Recirculating Pump
E 1/3 HP Water Chiller rated at 3950 BTU; equipped with 1°F differential thermostat
F Tele-thermometer
G Temperature Recorder
H Thermistor Probes
I Saltwater Aquarium

with water in the exposure tank in order to maintain a particular temperature. Figure 2 depicts a typical thermal history of a subsample of eggs, or larvae. The water in each exposure tank was aerated, and its temperature monitored throughout the experiment.

Data Presentation

Dead organisms were counted, removed, and preserved immediately after being returned to the culture bath after an exposure, and again 24 hours later when the experiment was terminated and all remaining organisms were preserved. The total number of organisms that died over the 24 hour period was recorded and the resulting percent mortalities calculated for each exposure. The following equation

$$\text{Corrected Percent Mortality} = 1 - \frac{\text{\% surviving an exposure}}{\text{\% surviving in control}}$$

was used to normalize all experimental exposure mortalities to the mortality of the control group.

Using isometric graph paper, time, temperature, and percent mortality were plotted on the three dimensional grid. The resulting surface conveys a general pattern of the lethal response of the organisms to thermal stress. Mortalities at experimental time-temperature points were also plotted at each exposure point, representing mortalities of replicate subsamples. The generation of 10%, 50%, and 90% mortality thermal resistance curves was attempted using several statistical computer techniques. Contouring the experimental data by eye, however, was found to give consistently the most reasonable fit to the data.

In a great many experiments the objective is not to determine the value of a parameter but to arrive at an idea of a reasonable functional relation for the variables involved. This study is of that class. There are three ways in which the function suggested by the data can be presented. The first, and least useful, is simply to tabulate the data since any table is a statement of a functional relation. The drawbacks with presentation by tabulation are that the nature of the function is hard to grasp and that the data values are subject to error. Tabular presentation, unless supplemented by other material, offers the reader no clue as to the investigator's appreciation of the measurement error.

The two other methods of presenting the function are graphical and curve fitting by least squares. Contrary to the commonly held uncritical opinion that the least squares method is always better, there are circumstances in which the graphical method is superior. It all depends on what further use is to be made of the function.

In the graphical method the measured points are plotted and the investigator, bringing to bear all his physical intuition and experience, fairs a curve through them. The sketched curve represents his best judgement of the function. From it values can be read off at need. The investigator expresses his sense of the error involved and his evaluation of it by drawing his curve wide of the measured points. It is often objected that the functions sketched are not repeatable; that they will vary widely from one investigator to another for the same set of points. This is not the case. Experience shows that curves sketched independently by several investigators, each experienced with the problem for which the data were taken, very, very seldom choose curves which differ from each other by more than the experimental error. Another objection frequently made is that functions presented graphically cannot be read to any required number of decimal places. This limitation is a virtue; not a vice. Reading functional values to 20 decimal places when the data from which

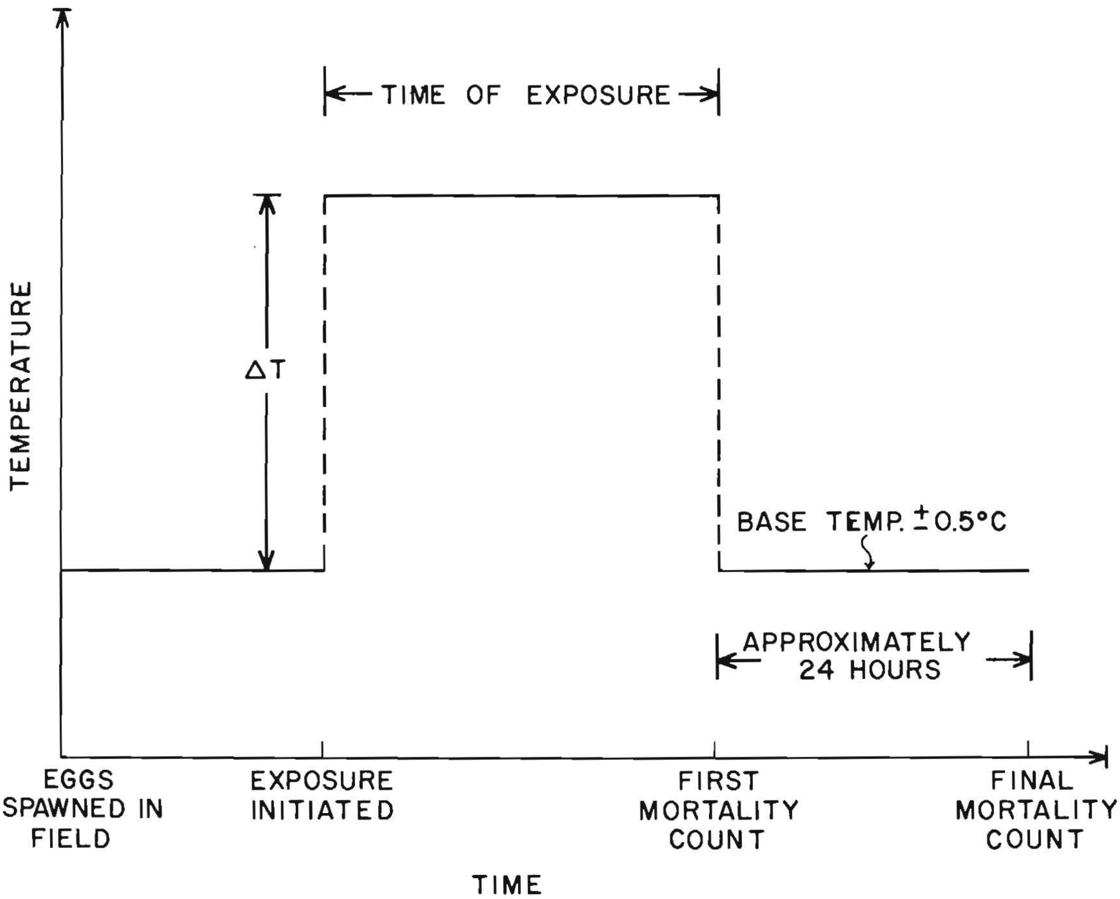

Figure 2. Graphical representation of a typical time-temperature exposure history of a sub-sample.

the function was derived are accurate to only 1 place is irresponsible and misleading. The graphical method almost automatically prevents this kind of nonsense. The one serious deficiency of the graphical method is that the function, not being expressed in analytic form, can not be incorporated easily in other studies which are in analytic form. If that is your objective, then least squares, which gives the function in analytic form, will be preferable. If your objective is to use the functional values directly, as is the case in this study, the graphical method is preferable.

The great virtue of the least-squares method is that it expresses the function in analytic form. It is sometimes accused of being "objective" which it most certainly is not. Subjectivity enters in the choice of the functional *form* to be fit. Admittedly, once the form has been chosen, the rest of the least-squares method is mechanical. But the choice of an appropriate form is just as much a high art as is the sketching of a curve in the graphical method. Few scientists are as adept at mathematics as they are at science. Their judgement of the real world is usually far more acute than is their knowledge of functional forms and their behavior. Further, least-squares is a linear method and the variety of functional forms suitable to it is severely restricted. Too often a query about why a particular form was chosen is answered with: "Because that's what Dr. Whosis used in his paper."

In short, neither the graphical method nor the least-squares method is universally superior. Which is preferable depends on the use that is to be made of the result. Personally, when the data are sparse and of low precision we prefer the graphical method since it permits much freer play for the experience, common sense, and physical intuition of the investigator (Blair Kinsman, personal communication).

RESULTS

Weakfish

Two experiments were run with weakfish ichthyoplankton; the first with eggs in the late tail-free stage, the second with larvae in the mid yolk sac absorption stage. Time-temperature histories, live/dead counts, percent mortalities, and base temperatures for these experiments are shown in Tables 2 and 3. Figures 3 and 4 show thermal response graphs. Thermal resistance curves for each experiment are shown in Figures 5 and 6.

Data for weakfish eggs in the late tail-free stage acclimated to a base temperature of 22.3°C showed:

(1) No mortalities above 5% for exposures to ΔT's from 2.8°C to 11.2°C for 3 to 180 min.

(2) No increase in mortality over controls for 3 min exposures to all ΔT's used.

(3) Mortalities of 15% and 18% from an exposure of 45 min at the highest ΔT (14.0°C). Doubling the exposure time to 90 min at the same ΔT resulted in an average mortality of 94%.

(4) An exposure time of 180 min to a ΔT of 14.0°C did not result in complete mortality of the eggs.

Data for weakfish larvae at mid yolk sac absorption acclimated to a base temperature of 22.3°C showed:

(1) A general increase in mortality with increasing ΔT for all exposure periods.

(2) No apparent change in mortality over the range of times tested for ΔT's of 2.8°C, 5.6°C, and 8.4°C.

(3) Near complete mortality for a 45 min exposure at a ΔT of 14.0°C.

Striped searobin

Four experiments were run with striped searobin ichthyoplankton; the first with

Table 2

Summary of weakfish tail free embryo egg data; base temperature, 22.3°C.

Exposure Time (min)	Exposure Temp. (ΔT) (°C)	# Live Side 1	# Dead Side 1	# Live Side 2	# Dead Side 2	% Mortality (control corrected) Side 1	% Mortality (control corrected) Side 2	Box Average
3	25.1 (2.8)	65	2	106	0	0	0	0
15	25.1 (2.8)	66	2	125	1	0	0	0
45	25.1 (2.8)	88	0	46	3	0	0	0
90	25.1 (2.8)	89	8	89	16	0	5	2
180	25.1 (2.8)	81	2	76	0	0	0	0
3	27.9 (5.6)	96	1	99	0	0	0	0
15	27.9 (5.6)	79	2	96	4	0	0	0
45	27.9 (5.6)	98	0	84	4	0	0	0
90	27.9 (5.6)	92	13	86	10	2	0	1
180	27.9 (5.6)	84	4	99	15	0	3	2
3	30.7 (8.4)	87	6	54	1	0	0	0
15	30.7 (8.4)	143	19	92	7	1	0	0
45	30.7 (8.4)	108	0	36	2	0	0	0
90	30.7 (8.4)	75	4	86	9	0	0	0
180	30.7 (8.4)	80	14	96	8	5	0	2
3	33.5 (11.2)	90	3	87	2	0	0	0
15	33.5 (11.2)	77	2	86	2	0	0	0
45	33.5 (11.2)	71	5	106	5	0	0	0
90	33.5 (11.2)	105	11	82	5	0	0	0
180	33.5 (11.2)	96	2	96	6	0	0	0
3	36.3 (14.0)	58	0	98	4	0	0	0
15	36.3 (14.0)	95	9	90	57	0	32	16
45	36.3 (14.0)	84	27	61	23	15	19	17
90	36.3 (14.0)	5	83	6	88	94	93	94
180	36.3 (14.0)	9	98	12	98	91	98	90
CONTROL		97	14	106	10	13	8	10

Table 3

Summary of weakfish mid yolk sac larvae data; base temperature 22.5°C.

Exposure Time (min)	Exposure Temp. (ΔT) (°C)	# Live Side 1	# Dead Side 1	# Live Side 2	# Dead Side 2	% Mortality (control corrected) Side 1	% Mortality (control corrected) Side 2	Box Average
3	25.3 (2.8)	315	7	290	3	0	0	0
15	25.3 (2.8)	243	10	-	-	1	-	1
45	25.3 (2.8)	138	9	118	7	3	3	3
90	25.3 (2.8)	253	14	241	10	2	1	2
180	25.3 (2.8)	234	4	186	3	0	0	0
3	28.1 (5.6)	220	8	352	9	0	0	0
15	28.1 (5.6)	130	29	137	35	16	18	17
45	28.1 (5.6)	150	20	134	12	9	5	7
90	28.1 (5.6)	159	4	167	5	0	0	0
180	28.1 (5.6)	-	-	-	-	-	-	-
3	30.9 (8.4)	81	10	82	5	8	3	6
15	30.9 (8.4)	258	43	227	37	12	11	12
45	30.9 (8.4)	112	8	129	10	4	4	4
90	30.9 (8.4)	144	10	176	12	4	3	4
180	30.9 (8.4)	111	11	192	7	6	0	3
3	33.7 (11.2)	192	45	174	51	16	20	18
15	33.7 (11.2)	167	33	186	39	14	15	15
45	33.7 (11.2)	26	70	37	71	72	65	68
90	33.7 (11.2)	52	99	45	120	65	72	68
180	33.7 (11.2)	42	52	49	54	54	51	52
3	36.5 (14.0)	118	24	147	11	14	4	9
15	36.5 (14.0)	13	99	26	97	88	78	83
45	36.5 (14.0)	4	112	0	11	96	100	98
90	36.5 (14.0)	0	127	1	84	100	99	100
180	36.5 (14.0)	0	110	0	155	100	100	100
CONTROL		255	8	264	9	3	3	3

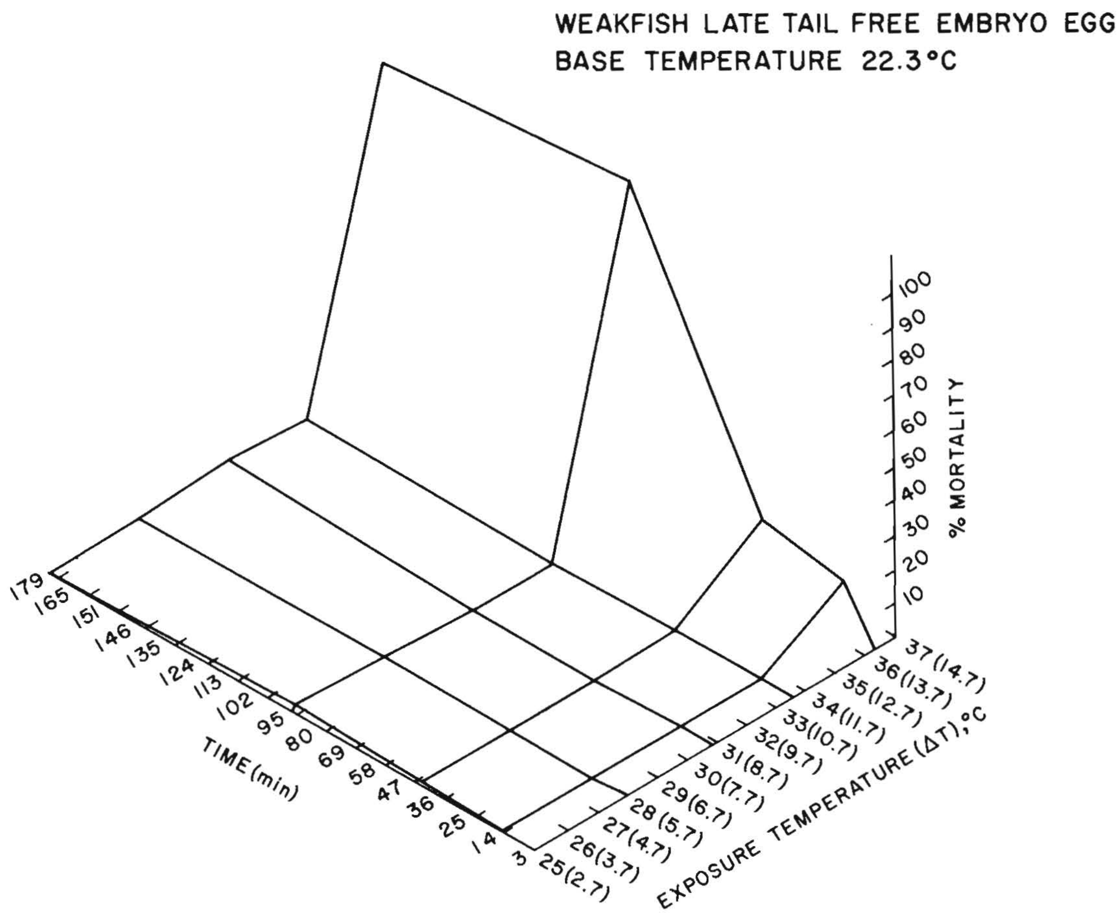

Figure 3. Response surface graph for weakfish late tail-free embryo eggs.

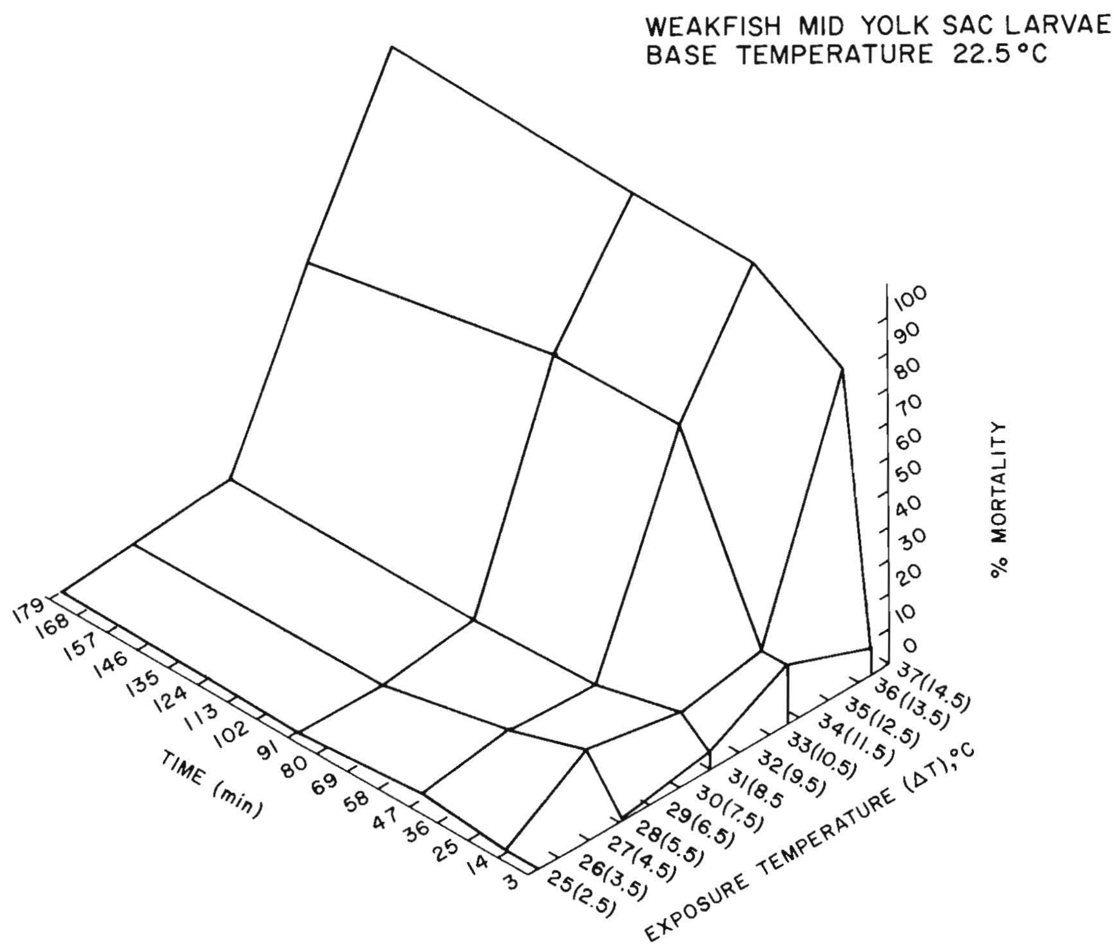

Figure 4. Response surface graph for weakfish mid yolk sac larvae.

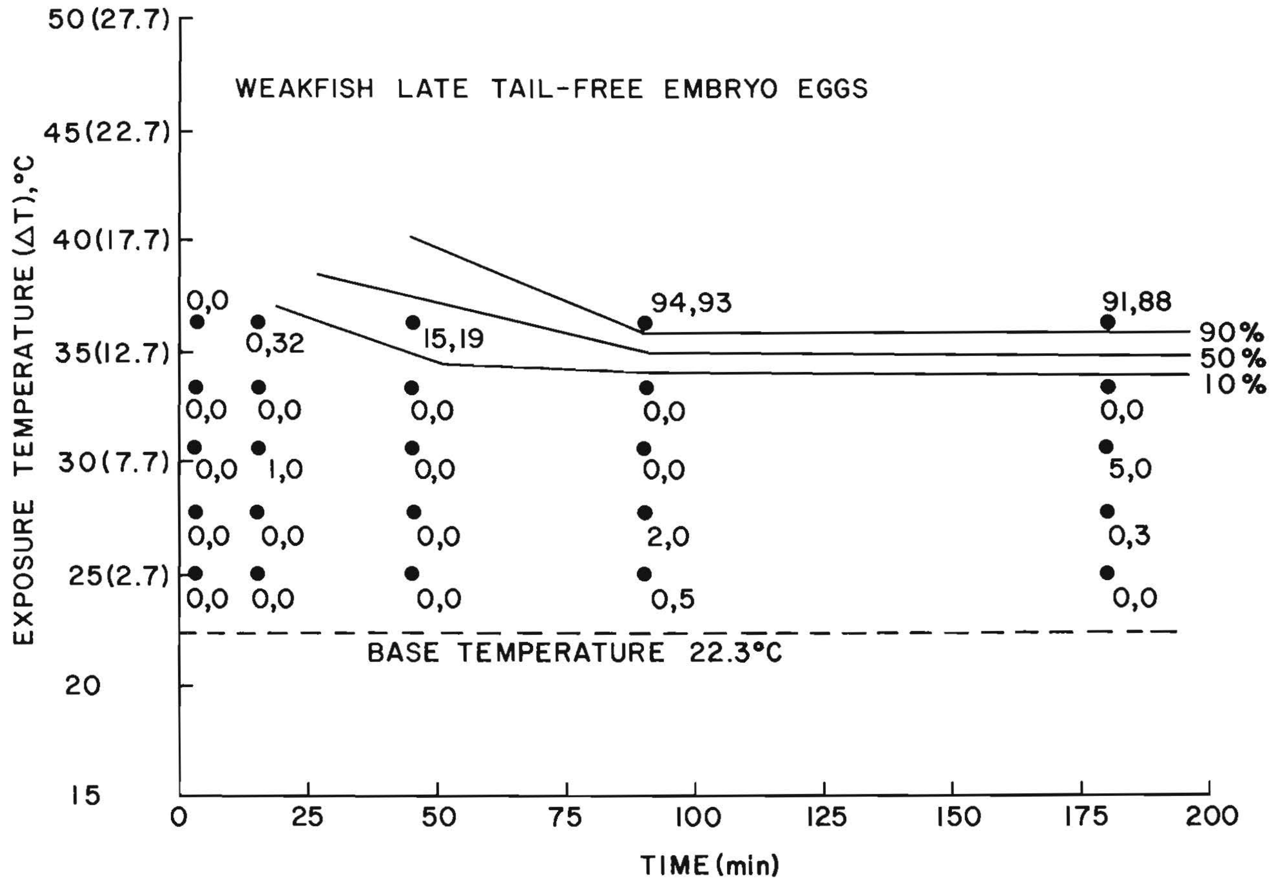

Figure 5. Thermal resistance curves (10, 50, and 90 % mortality) for weakfish late tail-free embryo eggs.

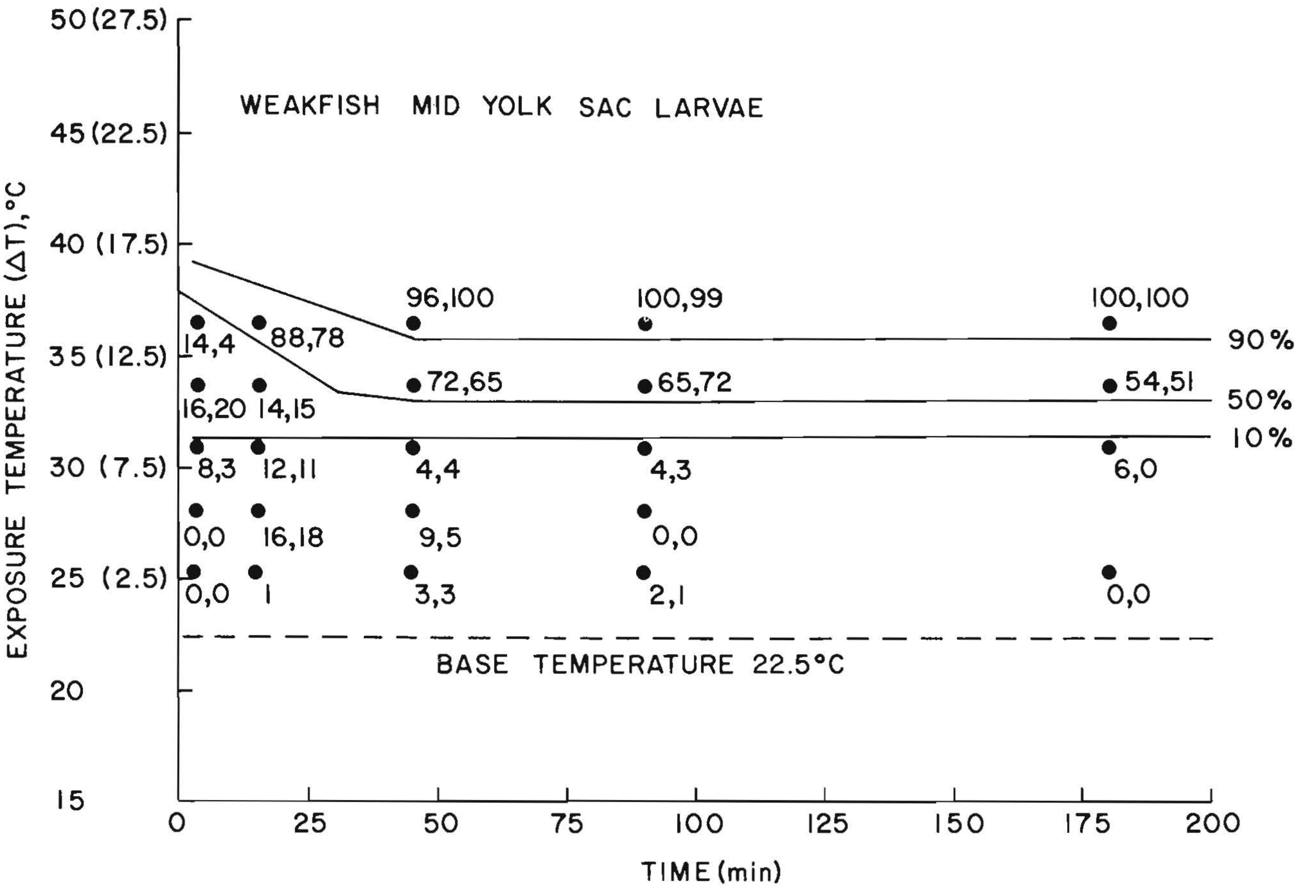

Figure 6. Thermal resistance curves (10, 50, and 90 % mortality) for weakfish mid yolk sac larvae.

eggs in the early embryo stage; the second with eggs in the mid embryo stage, the third with eggs in the tail-free embryo stage, and the fourth with larvae at mid yolk sac absorption. Time-temperature histories, live/dead counts, percent mortalities and base temperatures used in these experiments are shown in Tables 4, 5, 6, and 7. Figures 7, 8, 9, and 10 show thermal response surface graphs. Thermal resistance curves for each experiment are shown in Figures 11, 12, 13, and 14.

Data for striped searobin eggs at the early embryo stage acclimated to a base temperature of 20.3°C showed:

(1) At a ΔT of 3.2°C, low mortality occured at all time exposures.

(2) At ΔT's ranging from 6.4°C to 16.0°C, percent mortality increased with time for exposures from 3 to 180 min. Average mortalities for ΔT's of 6.4°C, 9.6°C, 12.8°C, and 16.0°C were 15.9%, 32.5%, 41.3%, and 72.9% respectively.

(3) An exposure time of 15 min at a ΔT of 16°C resulted in 52% mortality (average of both sides of the hatching box). Tripling the exposure time at the same ΔT resulted in 100% mortality.

Data for striped searobin eggs at the mid embryo stage acclimated to a base temperature of 21.7°C showed:

(1) At a ΔT of 3.0°C, low mortality occured at all time exposures.

(2) At ΔT's ranging from 6.0°C to 15.0°C, percent mortality increased with increasing exposure time for times from 1 to 360 min.

(3) Average mortalities for ΔT's of 6.0°C, 9.0°C, 12.0°C, and 15.0°C were 83.9%, 93.6%, 91.8%, and 95.5% respectively. An exposure time of 360 min at a ΔT of 9.0°C resulted in 100% mortality.

(4) At a ΔT of 6.0°C, all exposure times resulted in greater than 50% mortality of test organisms.

Data for striped searobin eggs in late tail-free embryo stage acclimated to 21.7°C showed:

(1) Less than 50% mortality for all exposure times at ΔT's ranging from 6.0°C to 12.0°C, and for the 1 and 15 min exposures at a ΔT of 15.0°C.

(2) A 45 min exposure at a ΔT of 15.0°C resulted in total mortality on one side of the hatching box and 97% mortality on the other; average mortality, 99%.

(3) Average mortalities for ΔT's of 6.0°C, 8.0°C, 10.0°C, 12.0°C, and 15.0°C were 3.2%, 9.6%, 19.4%, 27.3%, and 70.2% respectively.

Data for striped searobin larvae at mid yolk sac absorption acclimated to 21.9°C showed:

(1) Low mortality for all exposure times at ΔT's ranging from 6.0°C to 12.0°C, and for the 30 sec and 15 min exposures at a ΔT of 14.0°C.

(2) An exposure time of 45 min at a ΔT of 14.0°C resulted in 100% mortality of test organisms.

(3) Generally, percent mortality did not increase with increasing exposure time at ΔT's ranging from 6.0°C to 12.0°C.

(4) Average mortalities for ΔT's of 6.0°C, 8.0°C, 10.0°C, 12.0°C, and 14.0°C were 5.5%, 7.7%, 7.1%, 13.8%, and 68.6% respectively.

Scup

Three experiments were run with scup ichthyoplankton; the first with eggs in the blastula stage, the second with eggs in the early embryo stage, the third with larvae at mid yolk sac absorption. Time-temperature histories, live/dead counts, percent mortalities, and base temperatures are summarized in Tables 8, 9, and 10. Figures 15, 16, and 17 show thermal response surface graphs. Thermal resistance curves for each experiment are shown in Figures 18, 19, and 20.

Data for scup eggs in the blastula stage acclimated to a base temperature of 18.0°C showed:

(1) Highly variable mortalities at ΔT's ranging from 5.0°C to 13.0°C.

Table 4

Summary of striped searobin early embryo egg data; base temperature, 20.3°C.

Exposure Time (min)	Exposure Temp. (ΔT) (°C)	#Live Side 1	# Dead Side 1	# Live Side 2	# Dead Side 2	% Mortality (control corrected) Side 1	% Mortality (control corrected) Side 2	Box Average
3	23.5 (3.2)	87	9	82	9	5	6	6
15	23.5 (3.2)	102	2	101	2	0	0	0
45	23.5 (3.2)	93	3	95	0	0	0	0
90	23.5 (3.2)	96	2	93	3	0	0	0
180	23.5 (3.2)	96	5	88	6	1	2	2
3	26.7 (6.4)	86	14	72	13	10	11	11
15	26.7 (6.4)	90	12	86	9	8	5	7
45	26.7 (6.4)	79	29	65	32	24	30	27
90	26.7 (6.4)	77	32	81	20	26	16	21
180	26.7 (6.4)	83	19	88	19	15	14	15
3	29.9 (9.6)	92	11	97	8	7	4	6
15	29.9 (9.6)	65	35	63	39	32	36	34
45	29.9 (9.6)	65	51	61	54	42	45	44
90	29.9 (9.6)	60	38	61	39	36	36	36
180	29.9 (9.6)	65	38	49	59	34	53	44
3	33.1 (12.8)	88	16	98	13	12	8	10
15	33.1 (12.8)	75	52	67	54	38	42	40
45	33.1 (12.8)	43	54	52	61	54	52	53
90	33.1 (12.8)	28	67	30	70	69	69	69
180	33.1 (12.8)	38	77	34	61	66	63	65
3	36.3 (16.0)	83	14	79	18	11	15	13
15	36.3 (16.0)	46	56	45	49	53	50	52
45	36.3 (16.0)	0	95	0	111	100	100	100
90	36.3 (16.0)	0	95	0	112	100	100	100
180	36.3 (16.0)	0	99	0	102	100	100	100
CONTROL		94	3	102	6	3	6	5

Table 5

Summary of striped searobin mid embryo egg data; base temperature, 21.7°C.

Exposure Time (min)	Temp. (ΔT) (°C)	# Live Side 1	# Dead Side 1	# Live Side 2	# Dead Side 2	% Mortality (control corrected) Side 1	Side 2	Box Average
3	24.7 (3.0)	78	38	101	24	19	2	11
45	24.7 (3.0)	77	12	74	14	0	0	0
90	24.7 (3.0)	94	35	120	11	12	0	6
180	24.7 (3.0)	87	15	78	17	0	1	1
360	24.7 (3.0)	105	29	101	38	5	12	9
3	27.7 (6.0)	26	61	25	74	64	69	67
15	27.7 (6.0)	7	110	14	97	93	85	89
60	27.7 (6.0)	2	103	7	92	85	98	92
180	27.7 (6.0)	12	65	9	95	81	90	86
360	27.7 (6.0)	8	95	16	100	91	83	87
3	30.7 (9.0)	15	81	13	91	81	85	83
15	30.7 (9.0)	4	83	3	101	94	97	96
60	30.7 (9.0)	6	95	6	97	93	93	93
180	30.7 (9.0)	2	72	3	99	97	96	97
360	30.7 (9.0)	0	106	0	107	100	100	100
1	33.7 (12.0)	14	95	20	70	85	73	79
15	33.7 (12.0)	11	100	3	91	88	96	92
60	33.7 (12.0)	11	84	5	9	86	94	90
180	33.7 (12.0)	3	107	1	110	97	99	98
360	33.7 (12.0)	0	99	0	103	100	100	100
1	36.7 (15.0)	13	70	2	78	81	97	89
15	36.7 (15.0)	13	112	13	145	87	90	89
45	36.7 (15.0)	0	107	0	94	100	100	100
60	36.7 (15.0)	0	103	0	90	100	100	100
90	36.7 (15.0)	0	124	0	107	100	100	100
CONTROL		105	26	110	20	20	15	18

Table 6

Summary of striped searobin tail-free embryo egg data; base temperature, 21.7°C.

Exposure Time (min)	Exposure Temp. (ΔT) (°C)	# Live Side 1	# Dead Side 1	# Live Side 2	# Dead Side 2	% Mortality (control corrected) Side 1	% Mortality (control corrected) Side 2	Box Average
1	27.7 (6.0)	95	4	88	3	0	0	0
15	27.7 (6.0)	79	25	72	37	6	18	12
45	27.7 (6.0)	76	14	75	22	0	4	2
90	27.7 (6.0)	85	10	81	23	0	4	2
180	27.7 (6.0)	61	11	91	12	0	0	0
1	29.7 (8.0)	61	7	90	10	0	0	0
15	29.7 (8.0)	46	36	52	36	31	27	29
45	29.7 (8.0)	91	29	91	29	6	6	6
90	29.7 (8.0)	75	17	54	20	0	10	5
180	29.7 (8.0)	70	15	59	28	0	16	8
1	31.7 (10.0)	46	26	77	26	21	8	15
15	31.7 (10.0)	41	21	40	48	18	44	31
45	31.7 (10.0)	78	20	96	21	2	0	1
90	31.7 (10.0)	57	38	58	139	26	64	45
180	31.7 (10.0)	162	37	78	30	0	11	6
1	33.7 (12.0)	71	36	67	27	18	12	15
15	33.7 (12.0)	60	30	50	39	18	31	25
45	33.7 (12.0)	54	37	42	41	27	37	32
90	33.7 (12.0)	34	48	58	41	49	28	39
180	33.7 (12.0)	51	36	64	41	28	25	27
1	36.7 (15.0)	53	25	54	41	16	30	23
15	36.7 (15.0)	54	41	39	32	30	32	31
45	36.7 (15.0)	0	99	2	77	100	97	99
75	36.7 (15.0)	2	84	0	84	97	100	99
96	36.7 (15.0)	0	92	0	100	100	100	100
CONTROL		68	28	88	9	29	9	19

Table 7

Summary of striped searobin mid yolk sac larvae data; base temperature, 21.9°C.

Exposure Time (min)	Exposure Temp. (ΔT) (°C)	# Live Side 1	# Dead Side 1	# Live Side 2	# Dead Side 2	% Mortality (control corrected) Side 1	% Mortality (control corrected) Side 2	Box Average
3	27.9 (6.0)	76	2	65	1	2	1	2
15	27.9 (6.0)	55	4	87	2	6	2	4
45	27.9 (6.0)	97	6	81	4	5	4	5
90	27.9 (6.0)	74	4	93	5	5	5	5
180	27.9 (6.0)	80	19	112	8	19	6	13
3	29.9 (8.0)	103	5	128	2	4	1	3
15	29.9 (8.0)	133	9	128	7	6	5	6
45	29.9 (8.0)	95	5	88	6	5	6	6
90	29.9 (8.0)	47	4	60	5	7	7	7
180	29.9 (8.0)	62	21	105	14	25	11	18
1	31.9 (10.0)	90	4	88	1	4	1	3
15	31.9 (10.0)	103	13	89	17	11	16	19
45	31.9 (10.0)	66	1	60	7	1	10	6
90	31.9 (10.0)	90	5	91	10	5	10	8
180	31.9 (10.0)	49	5	63	3	9	4	7
30S	33.9 (12.0)	67	3	88	5	4	5	5
15	33.9 (12.0)	107	16	92	12	13	11	12
45	33.9 (12.0)	65	29	94	15	31	13	22
60	33.9 (12.0)	63	19	102	15	23	12	18
90	33.9 (12.0)	99	16	66	9	14	12	13
30S	35.9 (14.0)	92	7	116	10	7	8	8
15	35.9 (14.0)	43	24	33	18	36	35	36
45	35.9 (14.0)	0	100	0	100	100	100	100
60	35.9 (14.0)	0	85	0	70	100	100	100
90	35.9 (14.0)	0	100	0	100	100	100	100
CONTROL		115	0	119	1	0	1	1

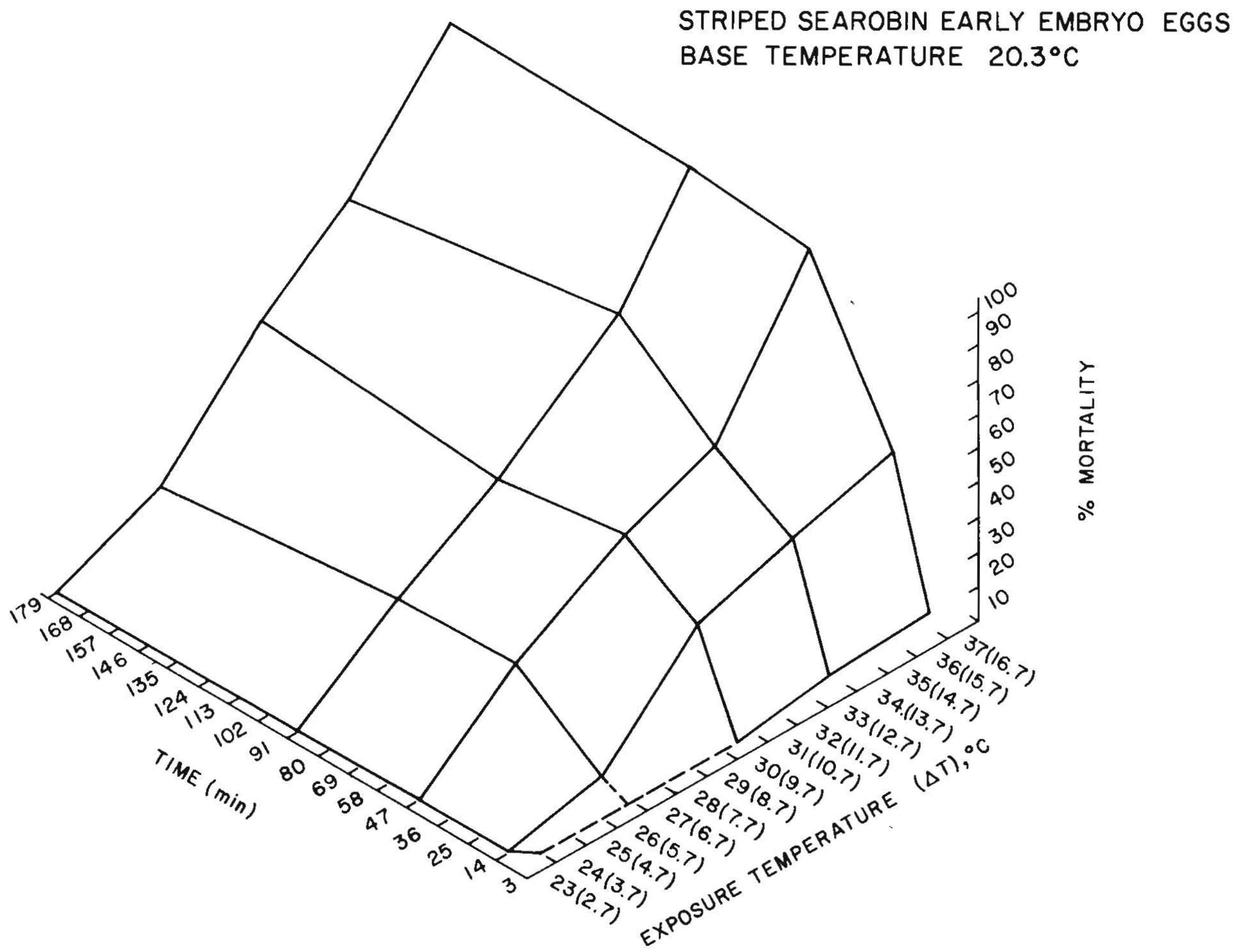

Figure 7. Response surface graph for striped searobin early embryo eggs.

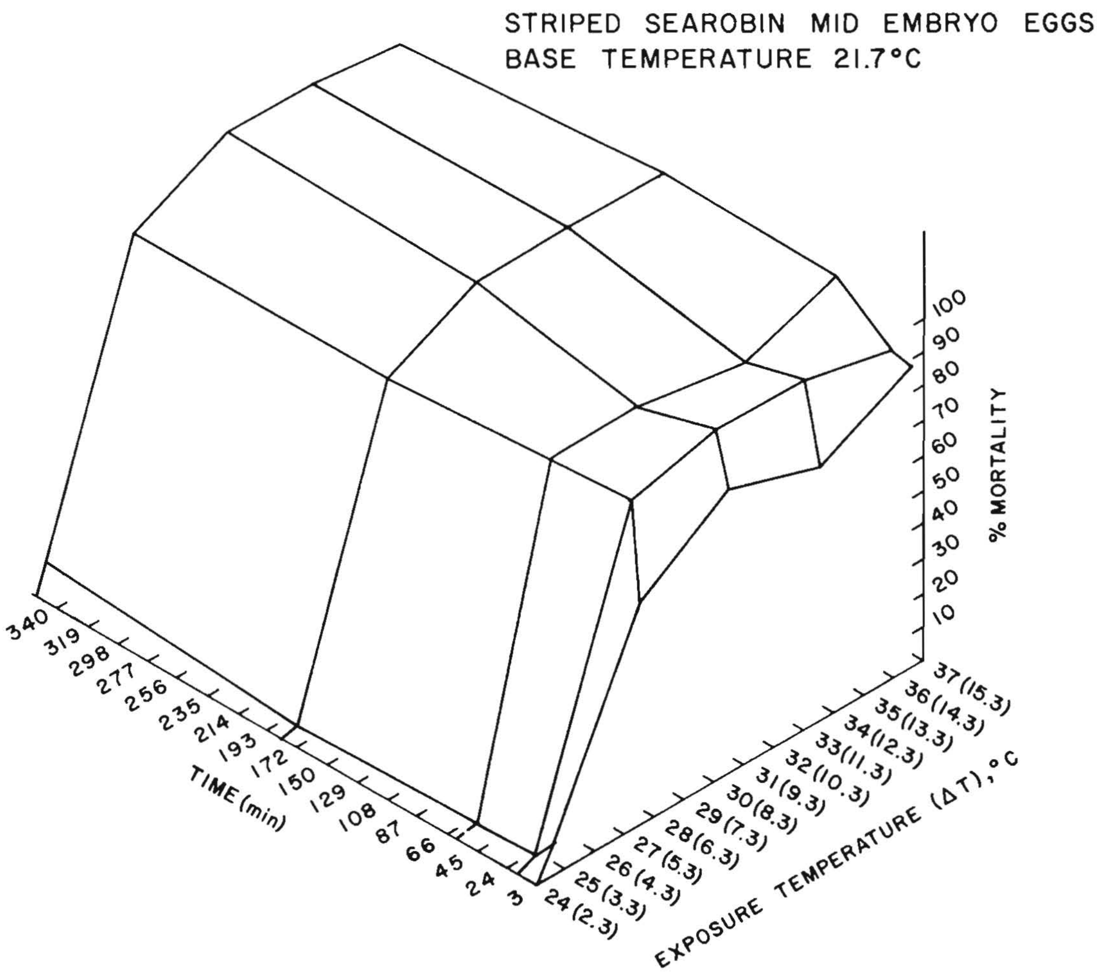

Figure 8. Response surface graph for striped searobin mid embryo eggs.

STRIPED SEAROBIN LATE TAIL-FREE EMBRYO EGGS
BASE TEMPERATURE 21.7°C

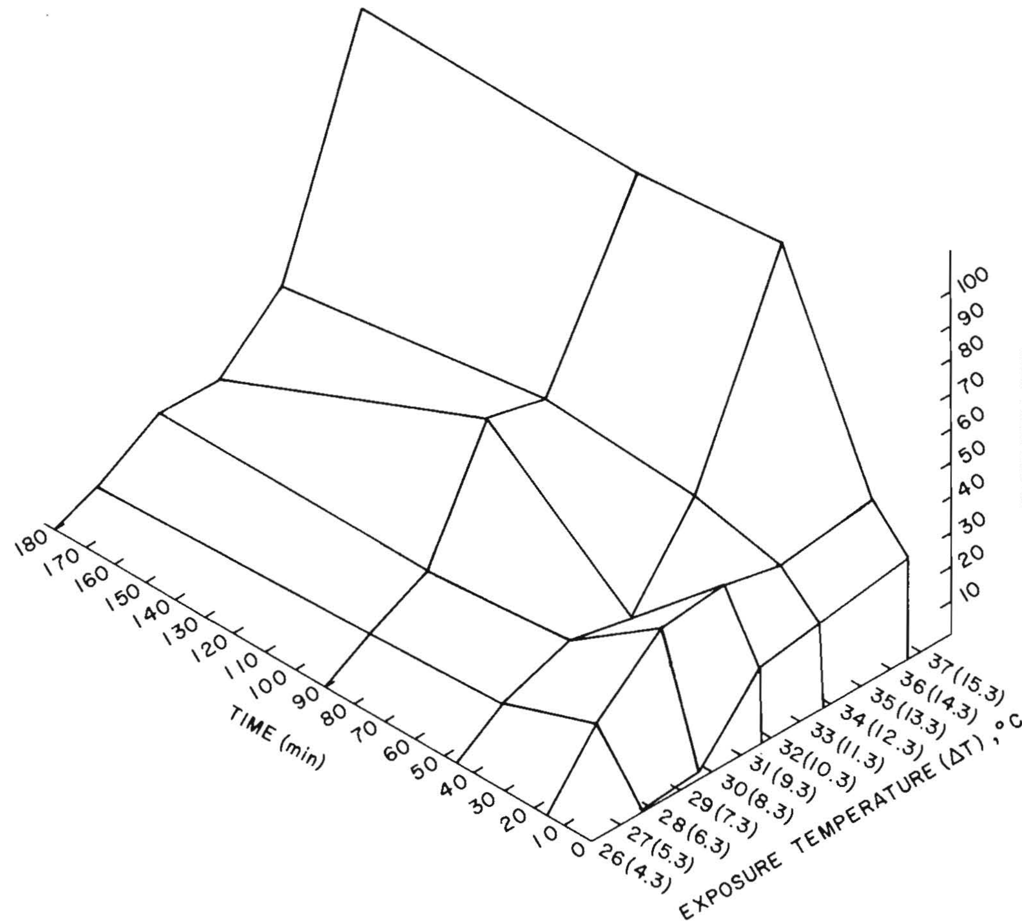

Figure 9. Response surface graph for striped searobin late tail-free embryo eggs.

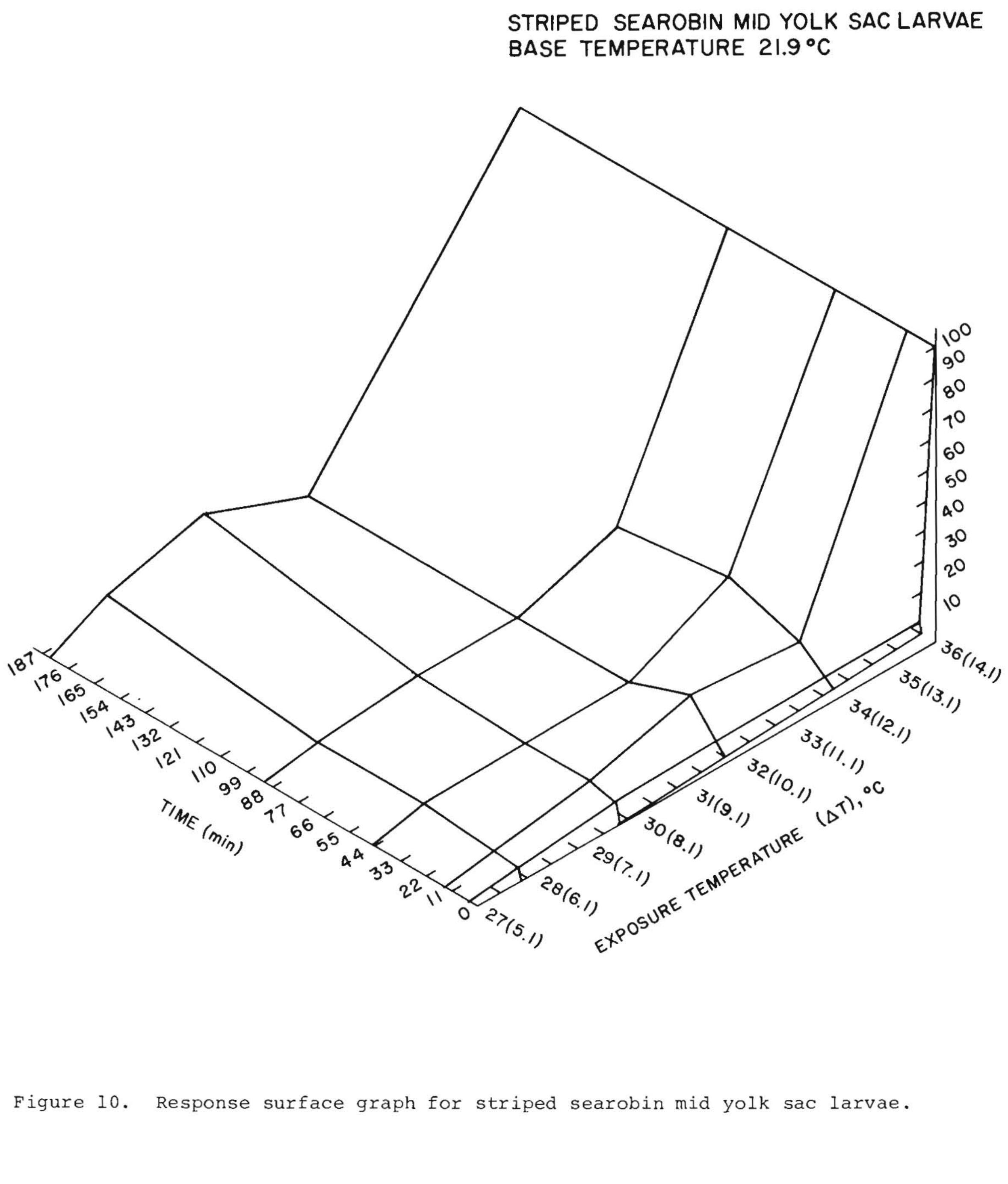

Figure 10. Response surface graph for striped searobin mid yolk sac larvae.

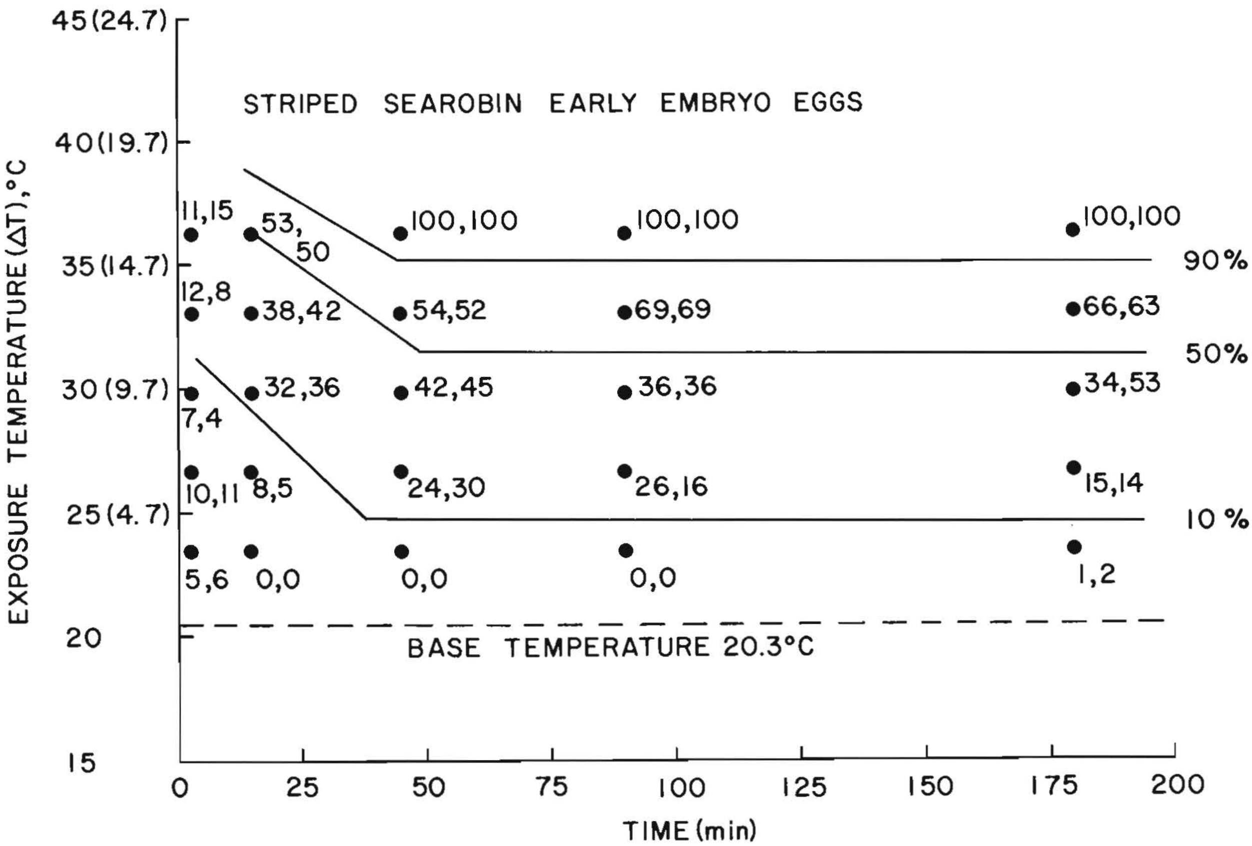

Figure 11. Thermal resistance curves (10, 50, and 90 % mortality) for striped searobin early embryo eggs.

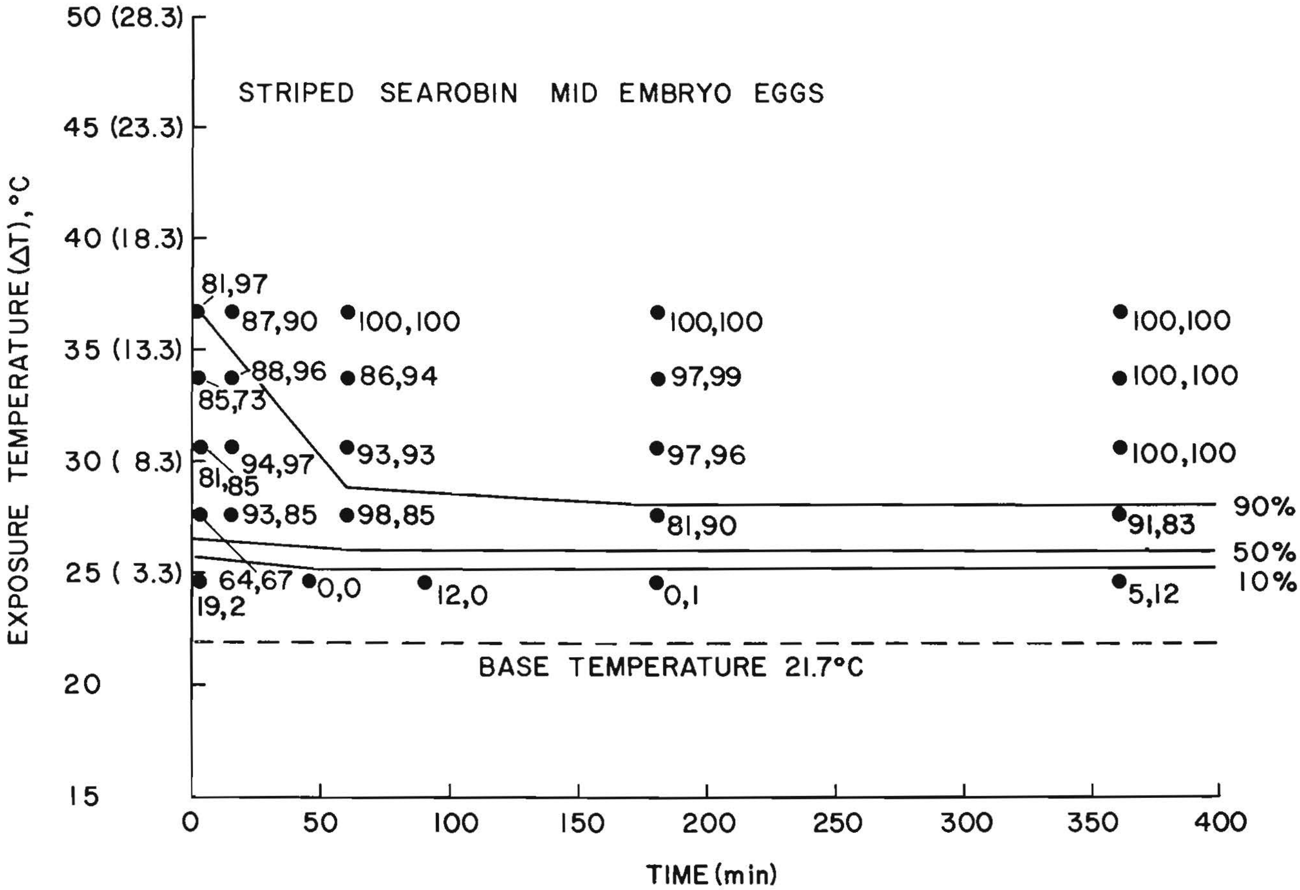

Figure 12. Thermal resistance curves (10, 50, and 90 % mortality) for striped searobin mid embryo eggs.

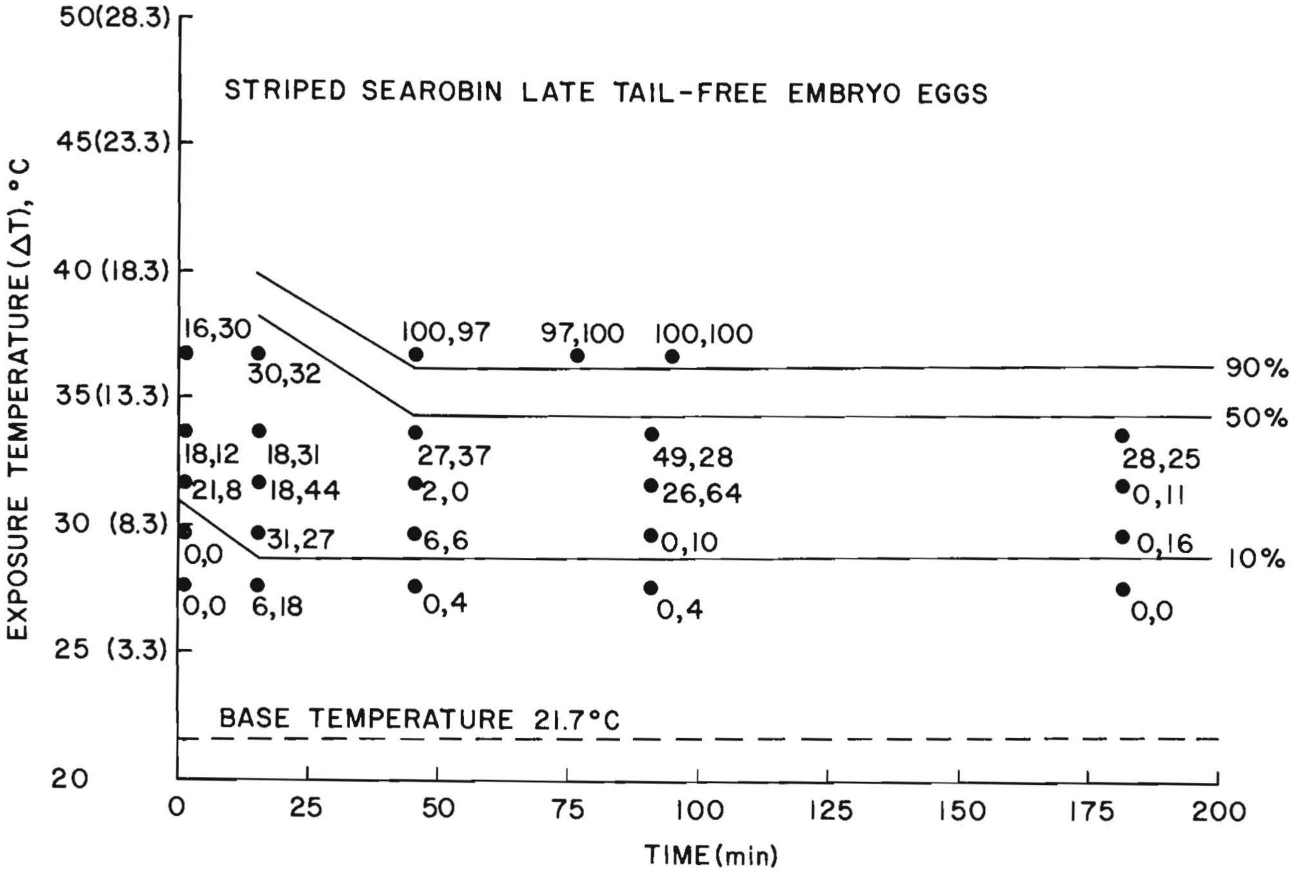

Figure 13. Thermal resistance curves (10, 50, and 90 % mortality) for striped searobin late tail-free embryo eggs.

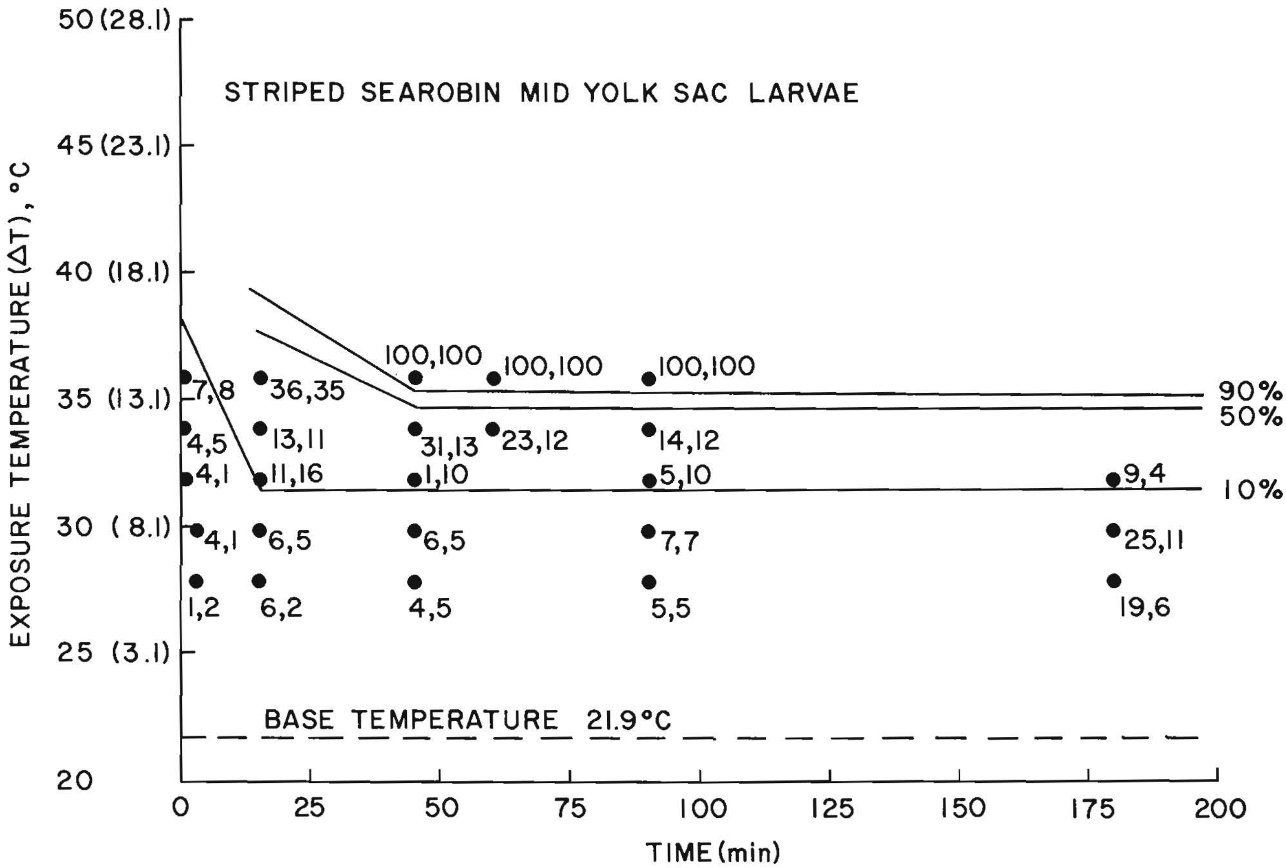

Figure 14. Thermal resistance curves (10, 50, and 90 % mortality) for striped searobin mid yolk sac larvae.

Table 8

Summary of scup blastula egg data; base temperature, 17.9°C.

Exposure Time (min)	Exposure Temp. (ΔT) (°C)	# Live Side 1	# Dead Side 1	# Live Side 2	# Dead Side 2	% Mortality (control corrected) Side 1	% Mortality (control corrected) Side 2	Box Average
3	22.9 (5.0)	56	37	59	33	32	27	30
15	22.9 (5.0)	-	-	-	-	-	-	-
45	22.9 (5.0)	41	29	79	19	34	9	22
90	22.9 (5.0)	75	24	76	30	14	19	17
3	25.9 (8.0)	86	43	73	79	25	46	36
15	25.9 (8.0)	-	-	77	28	-	17	17
45	25.9 (8.0)	49	59	-	-	49	-	49
90	25.9 (8.0)	95	10	81	12	0	1	1
3	28.9 (11.0)	76	15	86	11	5	0	5
15	28.9 (11.0)	68	36	58	40	26	33	30
45	28.9 (11.0)	-	-	-	-	-	-	-
90	28.9 (11.0)	51	52	35	62	44	59	52
3	30.9 (13.0)	52	48	42	60	41	53	47
15	30.9 (13.0)	17	73	24	84	79	75	77
45	30.9 (13.0)	150	102	69	97	33	53	43
90	30.9 (13.0)	5	98	5	103	95	95	95
3	34.9 (17.0)	1	97	1	95	99	99	99
15	34.9 (17.0)	0	99	0	95	100	100	100
45	34.9 (17.0)	0	102	0	111	100	100	100
90	34.9 (17.0)	0	98	0	92	100	100	100
CONTROL		93	10	88	14	10	14	12

Table 9

Summary of scup early embryo egg data; base temperature, 17.1°C.

Exposure Time (min)	Exposure Temp. (ΔT) (°C)	# Live Side 1	# Dead Side 1	# Live Side 2	# Dead Side 2	% Mortality (control corrected) Side 1	% Mortality (control corrected) Side 2	Box Average
3	19.6 (2.5)	87	22	86	9	20	9	15
15	19.6 (2.5)	85	18	93	0	17	0	9
45	19.6 (2.5)	79	9	90	10	10	10	10
90	19.6 (2.5)	84	15	79	21	15	21	18
180	19.6 (2.5)	95	8	71	18	7	20	14
3	23.6 (6.5)	86	8	65	30	8	31	20
15	23.6 (6.5)	70	16	88	11	18	11	15
45	23.6 (6.5)	72	16	85	11	18	11	15
90	23.6 (6.5)	85	14	95	8	14	7	11
180	23.6 (6.5)	71	19	89	11	21	11	16
3	27.6 (10.5)	88	1	86	1	1	1	1
15	27.6 (10.5)	75	24	66	31	24	32	28
45	27.6 (10.5)	58	26	57	46	31	44	38
90	27.6 (10.5)	57	43	58	41	43	41	42
180	27.6 (10.5)	62	42	51	40	40	44	42
3	31.6 (14.5)	77	25	77	25	24	24	24
15	31.6 (14.5)	1	98	7	94	99	93	96
45	31.6 (14.5)	0	94	5	91	100	95	98
90	31.6 (14.5)	1	104	1	98	99	99	99
180	31.6 (14.5)	0	114	0	105	100	100	100
3	35.6 (18.5)	10	89	14	84	90	86	88
15	35.6 (18.5)	0	97	2	99	100	98	99
45	35.6 (18.5)	0	94	0	92	100	100	100
90	35.6 (18.5)	0	105	0	93	100	100	100
180	35.6 (18.5)	0	94	0	94	100	100	100
CONTROL		96	0	96	1	0	1	1

Table 10

Summary of scup mid yolk sac larvae data; base temperature, 16.8°C.

Exposure Time (min)	Exposure Temp. (ΔT) (°C)	# Live Side 1	# Dead Side 1	# Live Side 2	# Dead Side 2	% Mortality (control corrected) Side 1	% Mortality (control corrected) Side 2	Box Average
3	19.3 (2.5)	37	4	46	12	5	16	11
15	19.3 (2.5)	26	25	28	25	46	44	45
45	19.3 (2.5)	14	33	23	28	69	52	61
90	19.3 (2.5)	18	30	24	25	60	48	54
180	19.3 (2.5)	14	37	25	14	71	32	52
3	23.3 (6.5)	32	2	33	12	1	23	12
15	23.3 (6.5)	25	28	27	21	50	41	46
45	23.3 (6.5)	35	17	34	14	29	25	27
90	23.3 (6.5)	30	18	30	16	34	31	33
180	23.3 (6.5)	32	15	28	23	28	42	35
3	27.3 (10.5)	31	14	48	14	27	18	23
15	27.3 (10.5)	40	9	47	6	14	6	10
45	27.3 (10.5)	33	14	33	13	26	24	25
90	27.3 (10.5)	32	12	44	13	23	18	21
180	27.3 (10.5)	37	13	40	11	22	17	20
3	31.3 (14.5)	25	10	48	12	25	15	20
15	31.3 (14.5)	54	10	45	11	11	15	13
45	31.3 (14.5)	33	25	27	24	40	44	42
90	31.3 (14.5)	39	13	20	28	21	56	39
180	31.3 (14.5)	30	15	26	19	30	39	35
3	35.3 (18.5)	34	13	46	6	24	7	16
15	35.3 (18.5)	7	42	10	34	85	76	81
45	35.3 (18.5)	0	38	0	43	100	100	100
90	35.3 (18.5)	0	52	0	51	100	100	100
180	35.3 (18.5)	0	40	0	46	100	100	100
CONTROL		-	-	35	2	-	5	5

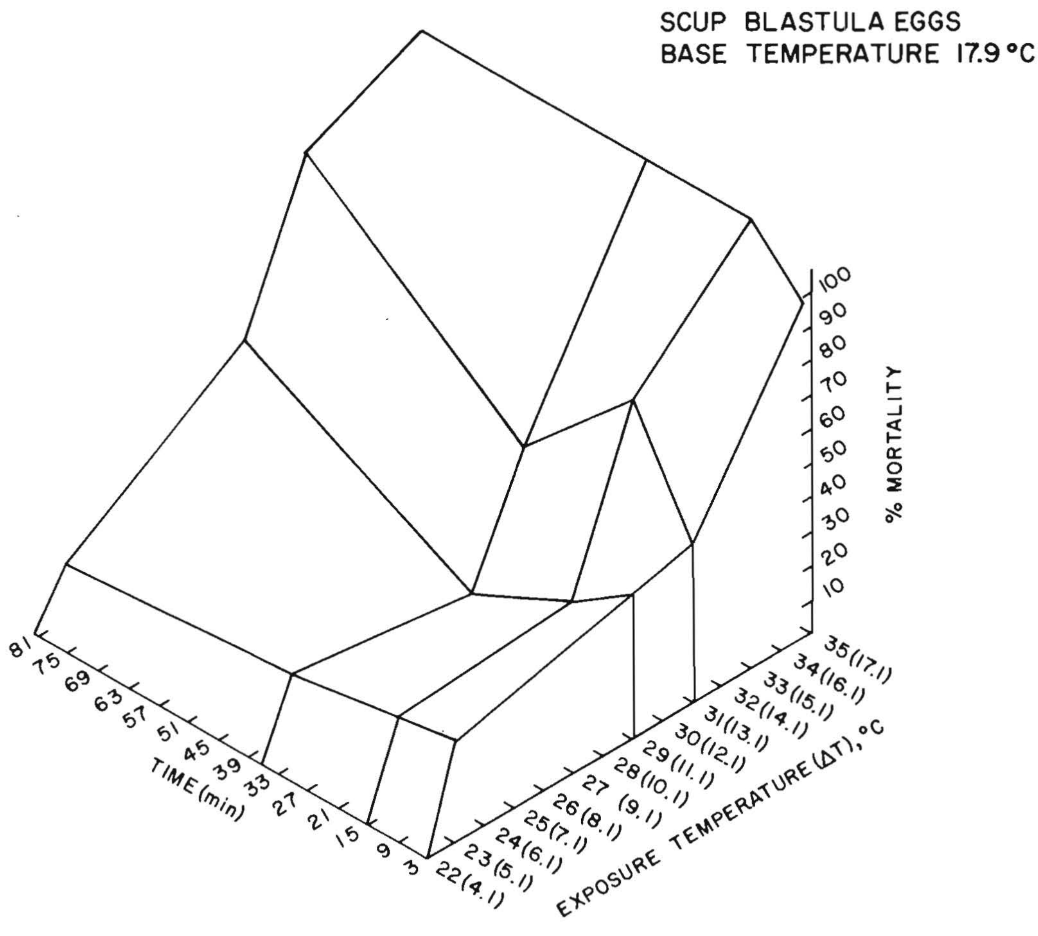

Figure 15. Response surface graph for scup blastula eggs.

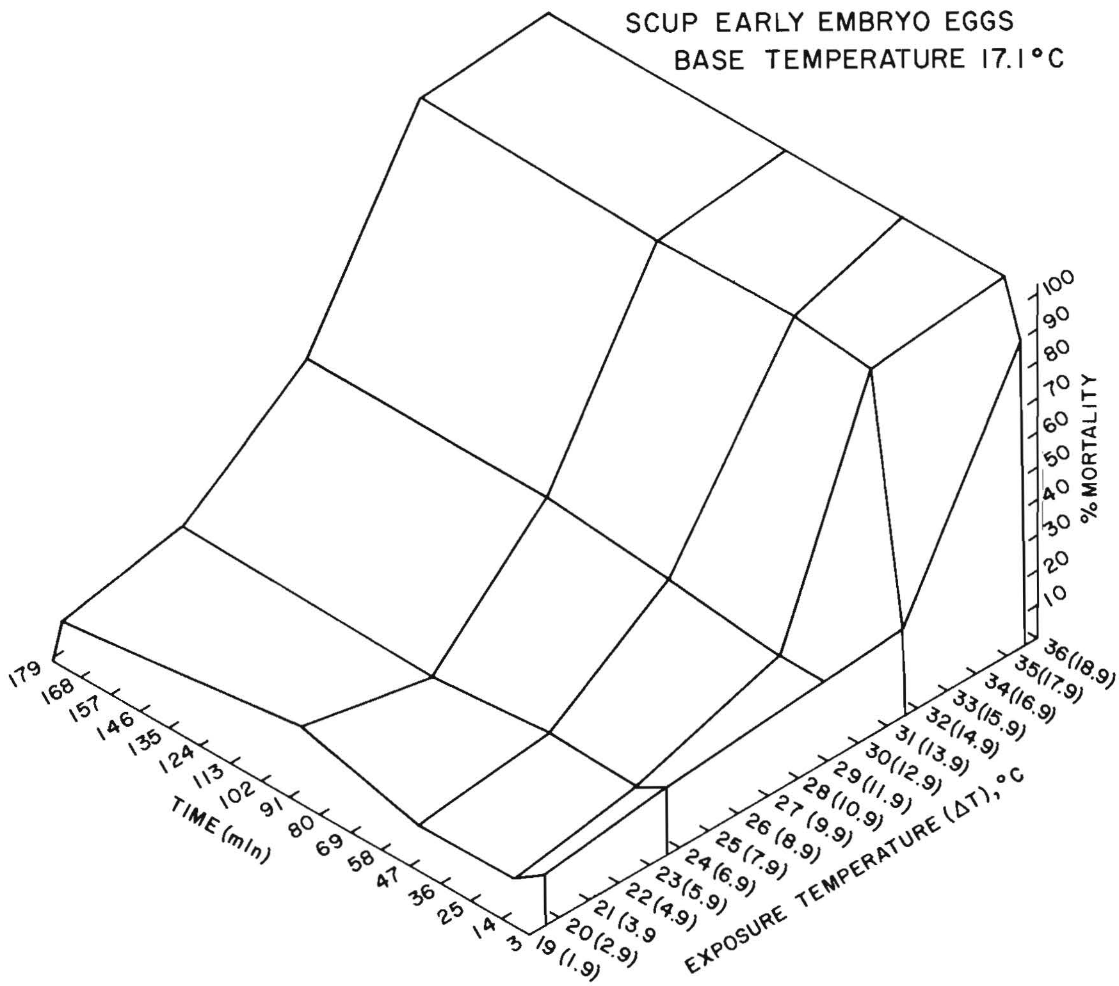

Figure 16. Response surface graph for scup early embryo eggs.

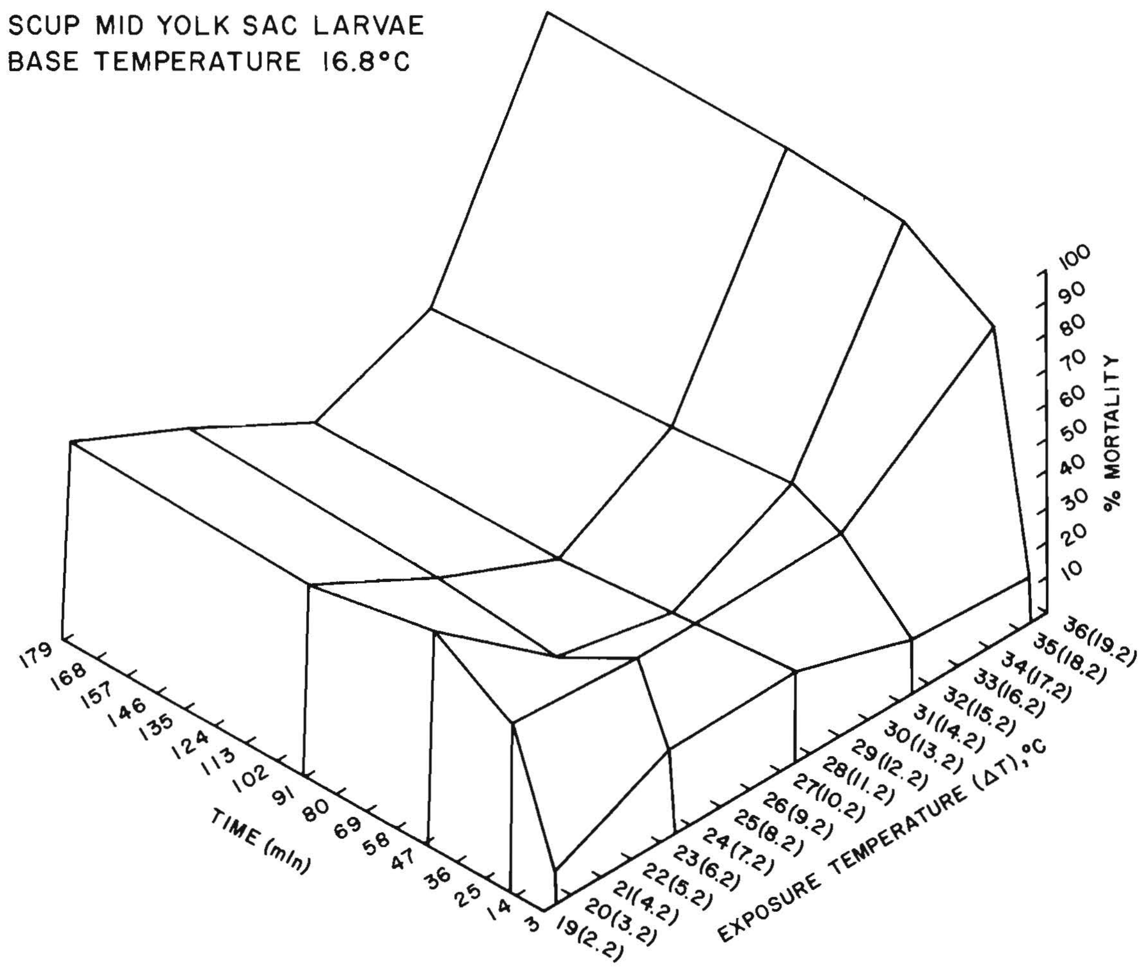

Figure 17. Response surface graph for scup mid yolk sac larvae.

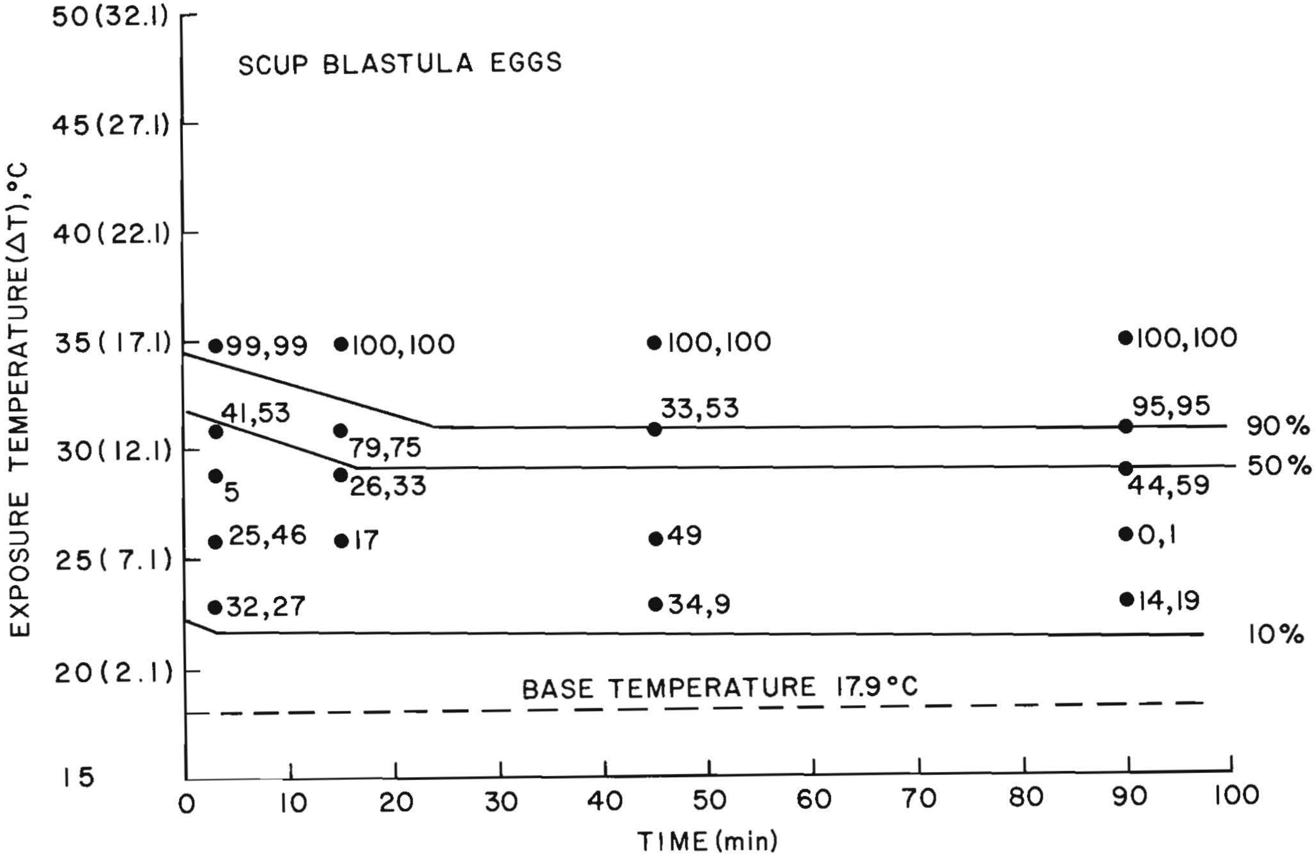

Figure 18. Thermal resistance curves (10, 50, and 90 % mortality) for scup blastula eggs.

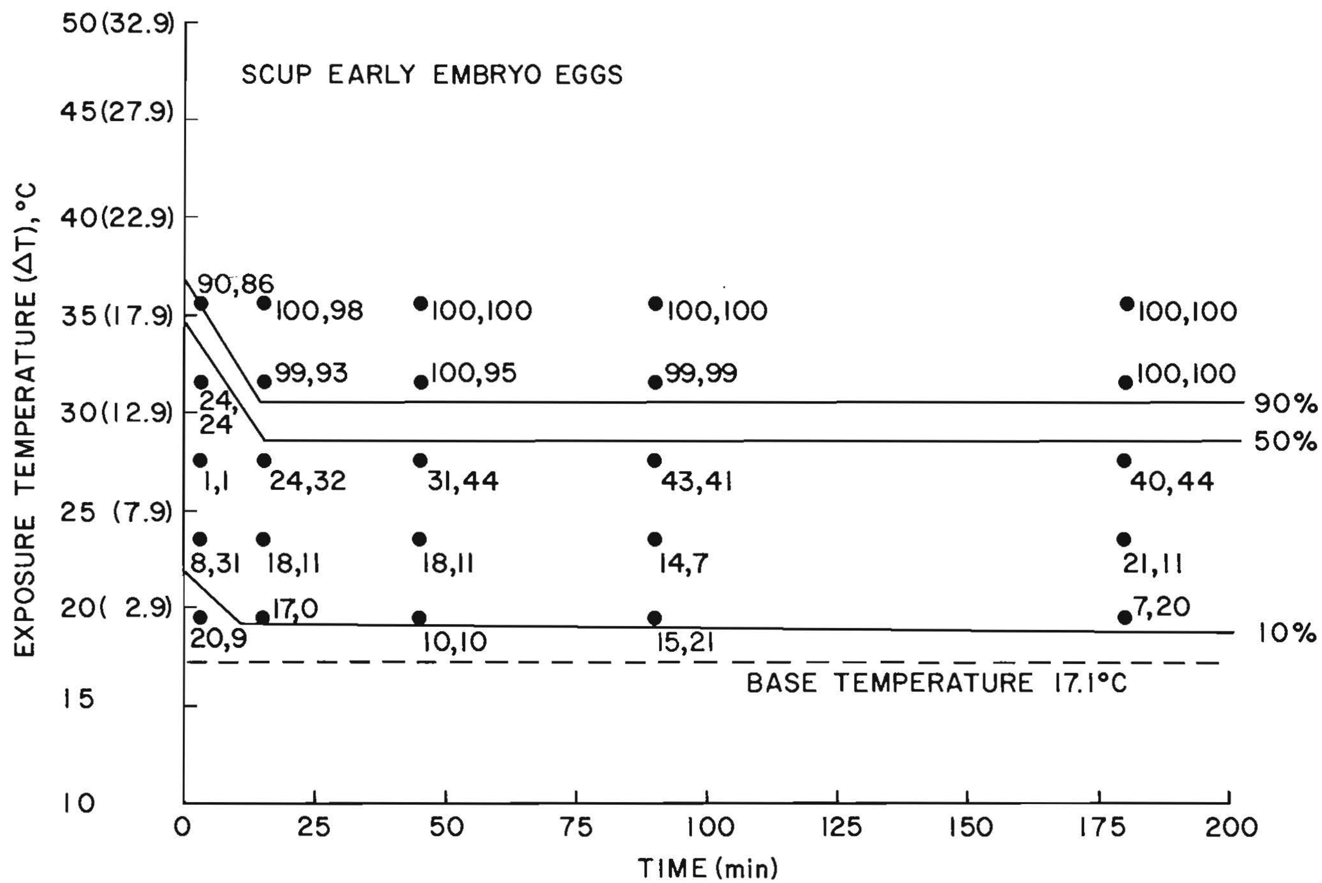

Figure 19. Thermal resistance curves (10, 50, and 90 % mortality) for scup early embryo eggs.

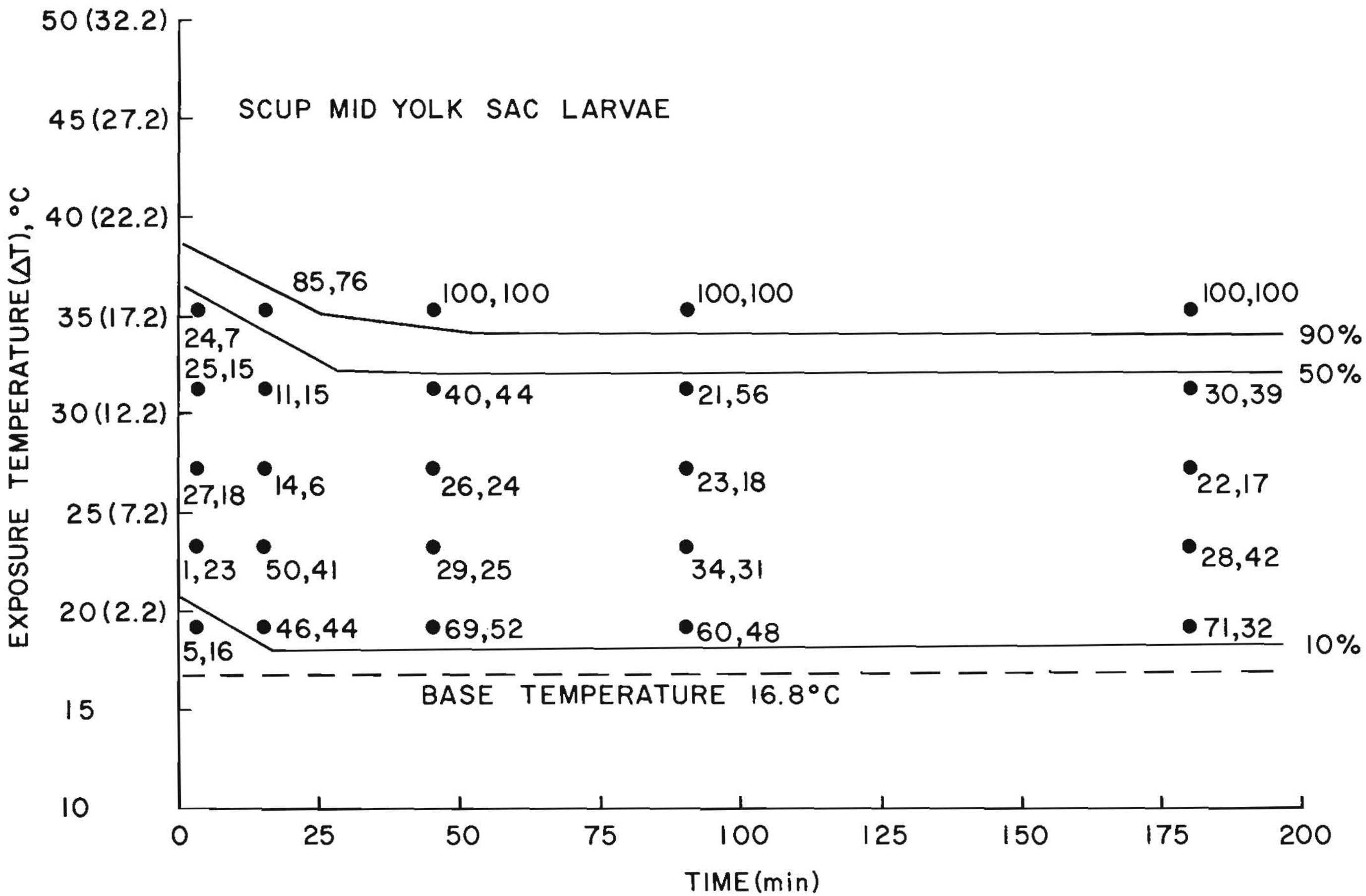

Figure 20. Thermal resistance curves (10, 50, and 90 % mortality) for scup mid yolk sac larvae.

(2) High mortality at all exposure times at a ΔT of 17.0°C.

(3) Average percent mortality at ΔT's of 5.0°C, 8.0°C, 11.0°C, 13.0°C, and 17.0°C were 32.0%, 23.0%, 24.3%, 65.5%, and 99.8% respectively.

Data for scup eggs in the mid embryo stage acclimated to a base temperature of 17.1°C showed:

(1) Less than 50% mortality for all time exposures at ΔT's ranging from 2.5°C to 10.5°C.

(2) With the exception of the three minute time exposure at a ΔT of 14.5°C, mortalities were characteristically high at exposure times ranging from 3 to 180 min for ΔT's of 14.5°C and 18.5°C.

(3) At ΔT's of 2.5°C and 6.5°C, percent mortality did not increase with increasing exposure time. At ΔT's of 10.5°C, 14.5°C, and 18.5°C, percent mortality increased with increasing time of exposure.

(4) Average percent mortality at ΔT's of 2.5°C, 6.5°C, 10.5°C, 14.5°C, and 18.5°C were 12.9%, 15.0%, 30.1%, 83.3%, and 97.4% respectively.

Data for scup larvae at mid yolk sac absorption acclimated to a base temperature of 17.0°C showed:

(1) Intermediate mortalities (11-61%) for exposure times of 3 to 180 min at ΔT's of 2.5°C, 6.5°C, 10.5°C and 14.5°C.

(2) At a ΔT of 18.5°C, percent mortality increased from 16% to 100% when exposure time increased from 3 to 45 min.

(3) Average percent mortality at ΔT's of 2.5°C, 6.5°C, 10.5°C, 14.5°C, and 18.5°C were 44.3%, 30.4%, 19.5%, 29.6%, and 79.2% respectively.

Summer Flounder

One experiment was run with summer flounder ichthyoplankton. This experiment used eggs in the late embryo stage. Time-temperature histories, live/dead counts percent mortalities, and base temperature are summarized in Table 11. Figure 21 shows the thermal response surface graph. 10%, 50%, and 90% mortality thermal resistance curves are shown in Figure 22.

Data for summer flounder eggs at the late embryo stage acclimated to 16.0°C showed:

(1) Generally, low mortalities at all exposure times for ΔT's of 7.0°C, 10.0°C, 13.0°C, and 16.0°C, and for the 3 and 15 min exposures at the 19.0°C ΔT.

(2) No increase in mortality with increasing exposure time at ΔT's of 7.0°C and 10.0°C. At ΔT's of 13.0°C, 16.0°C, and 19.0°C, increasing time of exposure resulted in increasing percent mortality.

(3) An exposure time of 90 minutes at a ΔT of 19.0°C resulted in 100% mortality.

(4) Average percent mortalities for ΔT's of 7.0°C, 10.0°C, 13.0°C, 16.0°C, and 19.0°C were 0.2%, 1.6%, 6.2%, 5.8%, and 48.2% respectively.

Blackfish

One experiment was run with blackfish ichthyoplankton. This experiment used blackfish eggs in the gastrula stage. Time-temperature histories, live/dead counts, percent mortalities, and base temperatures used in this experiment are summarized in Table 12. Figure 23 shows the thermal response surface graph. 10%, 50%, and 90% mortality thermal resistance curves for this experiment are shown in Figure 24.

Data for blackfish eggs in the gastrula stage acclimated to a base temperature of 15.0°C showed:

(1) Generally, high mortality at all time-temperature histories used.

(2) No marked increase in mortality with increasing exposure time for any one ΔT. Percent mortality did increase with increasing ΔT.

(3) A 180 minute exposure at a ΔT of 17.0°C resulted in 100% mortality.

(4) Average mortality at ΔT's of 5.0°C, 9.0°C, 13.0°C, 17.0°C, and 21.0°C,

Table 11

Summary of summer flounder late embryo egg data; base temperature 16.0°C.

Exposure Time (min)	Exposure Temp. (ΔT) (°C)	# Live Side 1	# Dead Side 1	% Mortality (control corrected)
3	23.0 (7.0)	59	2	1
15	23.0 (7.0)	107	2	0
45	23.0 (7.0)	52	0	0
90	23.0 (7.0)	63	1	0
180	23.0 (7.0)	77	0	0
3	26.0 (10.0)	81	2	0
15	26.0 (10.0)	69	0	0
45	26.0 (10.0)	115	0	0
90	26.0 (10.0)	118	4	1
180	26.0 (10.0)	94	9	7
3	29.0 (13.0)	87	3	1
15	29.0 (13.0)	83	1	0
45	29.0 (13.0)	69	2	1
90	29.0 (13.0)	50	6	9
180	29.0 (13.0)	96	27	20
3	32.0 (16.0)	52	0	0
15	32.0 (16.0)	69	0	0
45	32.0 (16.0)	62	2	1
90	32.0 (16.0)	45	6	10
180	32.0 (16.0)	100	24	18
3	35.0 (19.0)	109	8	5
15	35.0 (19.0)	69	3	2
45	35.0 (19.0)	22	12	34
90	35.0 (19.0)	0	60	100
180	35.0 (19.0)	0	68	100
CONTROL		99	2	2

was 52.8%, 40.9%, 70.1%, 77.1%, and 95.4% respectively.

DISCUSSION

General trends in thermal tolerances of fish eggs and larvae

Schubel *et al.*, 1978 reviewed the literature concerning laboratory exposure of eggs and larvae of a variety of fishes to time-excess temperature histories characteristic of those experienced by organisms entrained by power plants with once-through cooling systems. Their summary shows thermal tolerance of fish eggs and larvae to be related to:

(1) Stage of development. The more advanced the stage of development, the greater its thermal resistance.

(2) Acclimation temperature. The higher the acclimation temperature, the greater the resistance to a net temperature.

(3) Genetic factors. Identical life history stages at the same acclimation temperature, but originating from different parent fish may differ in their thermal resistance characteristics.

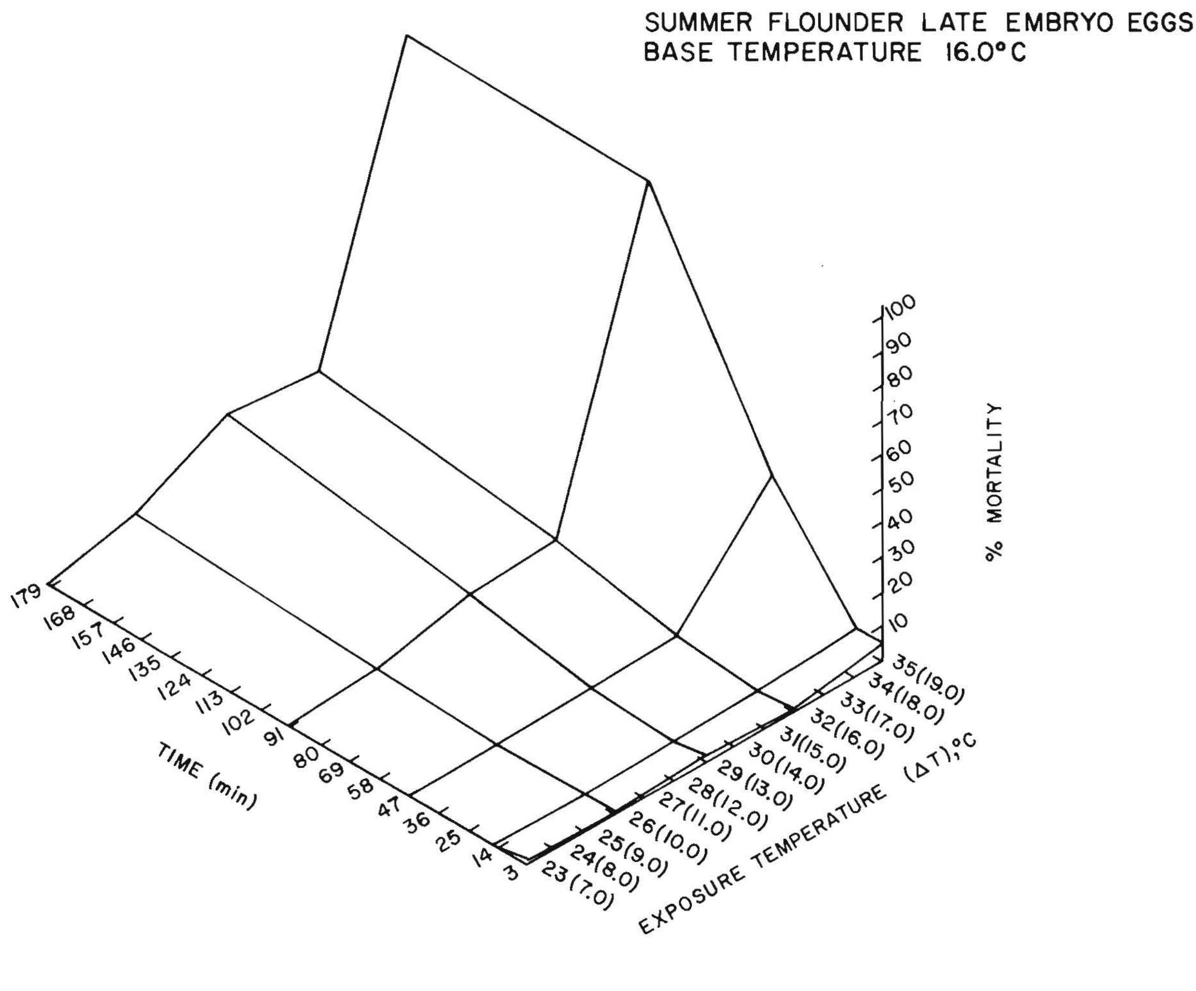

Figure 21. Response surface graph for summer flounder late embryo eggs.

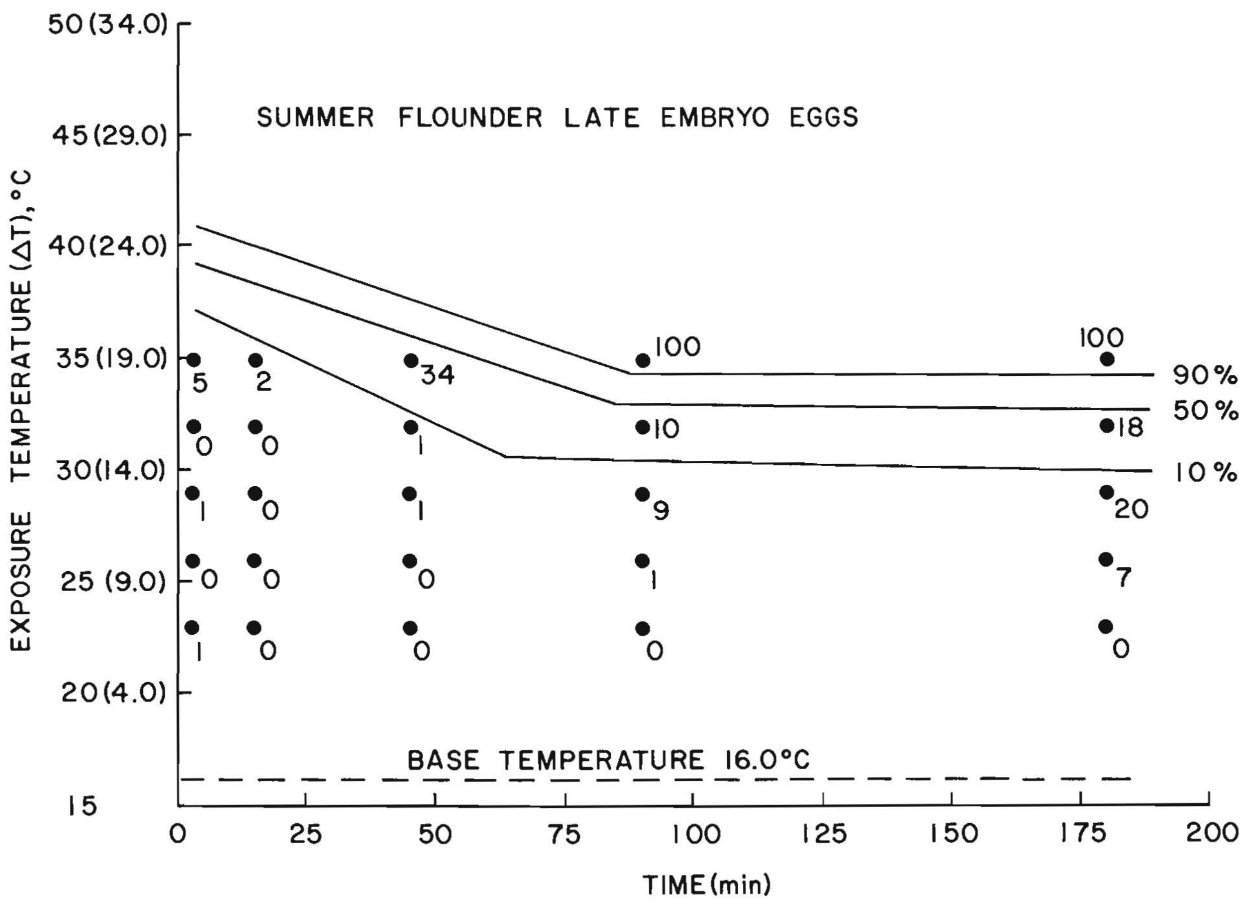

Figure 22. Thermal resistance curves (10, 50, and 90 % mortality) for summer flounder late embryo eggs.

Table 12

Summary of blackfish gastrula egg data; base temperature, 15.0°C.

Exposure Time (min)	Exposure Temp. (ΔT) (°C)	# Live Side 1	# Dead Side 1	# Live Side 2	# Dead Side 2	% Mortality (control corrected) Side 1	% Mortality (control corrected) Side 2	Box Average
3	20.5 (5.0)	7	60	13	131	83	85	84
18	20.5 (5.0)	42	63	45	56	35	27	31
95	20.5 (5.0)	17	109	44	131	78	59	69
180	20.5 (5.0)	17	149	36	232	83	78	81
3	24.0 (9.0)	69	32	51	42	0	10	5
15	24.0 (9.0)	26	141	26	127	75	72	74
45	24.0 (9.0)	49	36	18	63	6	64	35
90	24.0 (9.0)	42	50	32	76	25	52	39
180	24.0 (9.0)	28	92	35	66	62	43	53
3	28.0 (13.0)	20	100	35	118	73	63	68
15	28.0 (13.0)	36	54	92	56	35	38	37
45	28.0 (13.0)	9	64	8	67	80	83	82
90	28.0 (13.0)	12	89	5	81	81	91	86
180	28.0 (13.0)	15	84	10	82	75	82	79
3	32.0 (17.0)	35	57	47	46	38	17	28
15	32.0 (17.0)	8	93	13	79	87	77	82
45	32.0 (17.0)	6	40	9	77	79	83	81
90	32.0 (17.0)	10	172	1	171	91	99	95
180	32.0 (17.0)	0	82	0	81	100	100	100
3	36.0 (21.0)	14	88	15	88	78	76	77
17	36.0 (21.0)	0	76	0	114	100	100	100
46	36.0 (21.0)	0	95	0	100	100	100	100
90	36.0 (21.0)	0	104	0	102	100	100	100
180	36.0 (21.0)	0	111	0	106	100	100	100
CONTROL		56	29	59	46	34	44	39

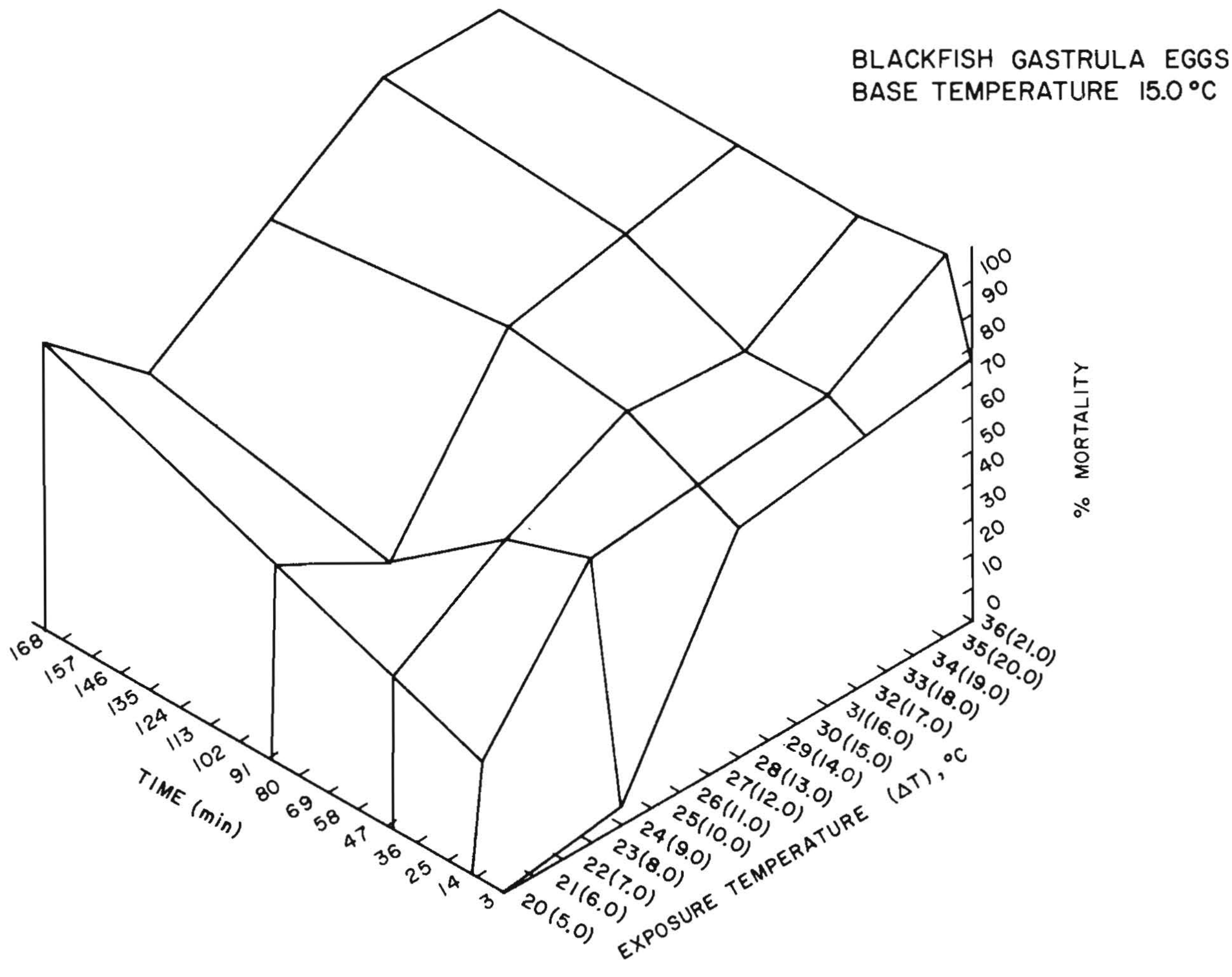

Figure 23. Response surface graph for blackfish gastrula eggs.

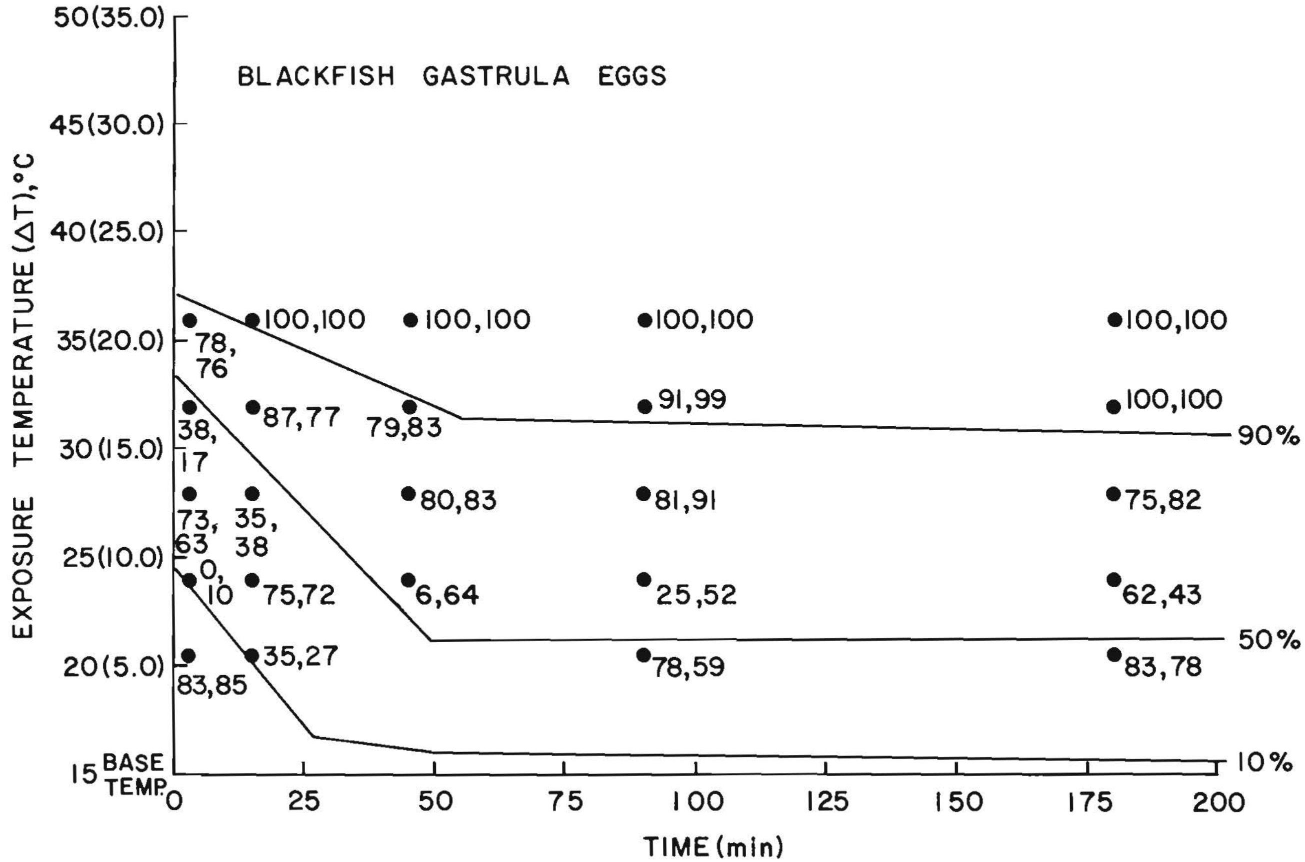

Figure 24. Thermal resistance curves (10, 50, and 90 % mortality) for blackfish gastrula eggs.

Information pertaining to life history stages, acclimation temperatures, and number of males and females used in our experiments is summarized in Table 1.

Criterion for death and allowance for sub-lethal effects

In experiments investigating lethal effects of elevated temperatures on fish eggs and larvae, the decision to pronounce an egg or larva dead is a critical one. When fish eggs are the experimental subjects, the decision is not difficult. Upon death, the chorion, or outer egg membrane loses its physical and chemical integrity, and no longer is capable of protecting the embryo from its external environment. Also, after death the embryo does not retain its natural immunity to bacterial attack, which subsequently breaks down yolk and other organic matter, forming an opaque sphere which acts as a convienient indicator of death. In addition to rapid death, eggs may suffer more subtle damage as a result of elevated temperature shock, which may not be noticable until a later date. These effects may or may not result in death of the egg or resulting larva.

The decision to pronounce a larva dead is not as clear. It has been our experience and the experience of others (Coutant and Dean, 1972; Coutant, 1973; Koo and Johnston, 1978) that fish larvae under elevated temperature stresses may undergo a series of morphological and behavioral abnormalities which may or may not lead to eventual death. Morphological abnormalities are in the form of bent tails and curved spines. Behavioral abnormalities include disorientation, or cessation of, or sporadic, swimming. Upon immersion in water of elevated temperature, larvae may stop swimming only to regain their swimming ability at a later time. The percentage of these larvae that will fall prey to factors of mortality in nature is not known.

We have found that there are two characteristics of eggs and larvae exposed to elevated temperatures which invariably lead to death. They are:

(1) an opaque coloring of the anterior portion of the embryo or larva, and

(2) cessation of heartbeat.

These two characteristics were our basis for pronouncing organisms dead. In each experiment there also existed a certain percentage of individuals that suffered so severe an abnormality that they surely would not have survived in nature. In order to allow for this percentage, a 2°C "correction factor" (Environmental Protection Agency, 1973) has been listed in parenthesis next to the observed experimental temperatures in the graphs of thermal resistance that follow.

Thermal resistance curves

A thermal resistance curve is a curve on a graph of temperature versus time, deliniating the mortality response (as a percentage) of organisms exposed to different time-temperature combinations. Most thermal resistance curves can be divided into two sections (Figure 25). The first section consists of a line of negative slope. Mortalities at the time-temperature combinations represented by this portion of the curve will be a function of exposure times and temperatures. The second portion of the curve is a line which is theoretically horizontal to the time (or x) axis. Mortalities at the time-temperature combinations represented by this portion of the curve are independent of exposure time and will depend solely on the excess temperature. Time-temperature exposures to the left and below the curve will produce percent mortalities less than the percent mortality represented by the curve. Exposures above and to the right of the curve will produce percent mortalities greater than the percent mortality represented by the curve.

An abrupt slope change occurs on the thermal resistance curve where the two sec-

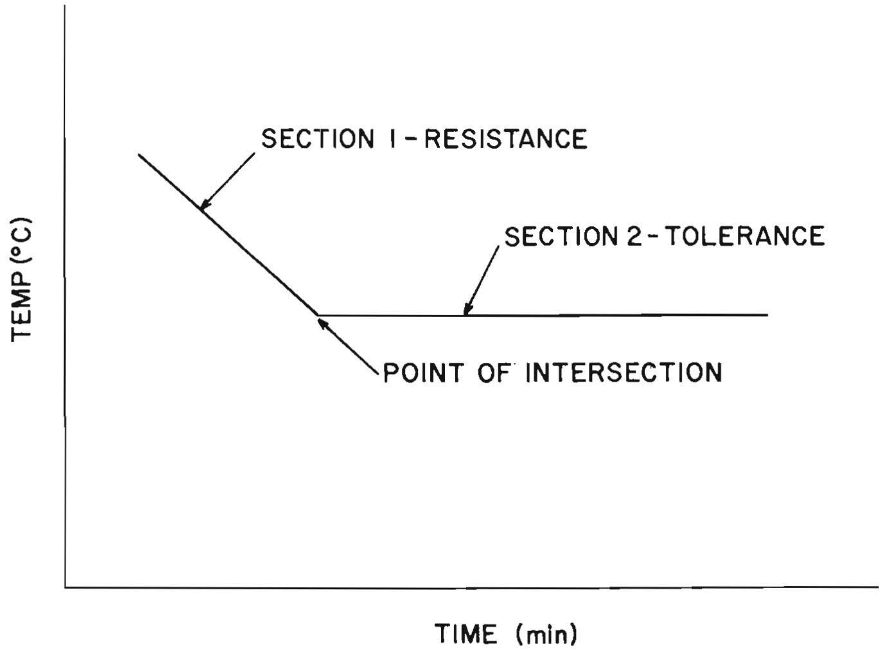

Figure 25. A model thermal resistance curve.

tions 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 duration of time with no change in mortality rate, they are said to have reached their incipient lethal temperature for that particular percent mortality level. The point of intersection signifies three things:

(1) The corresponding y-coordinate represents the incipient lethal temperature for that particular mortality level,

(2) The corresponding x-coordinate represents the time at which the incipient lethal temperature is reached, and

(3) The transition from resistance to tolerance has been completed.

Time of transition from resistance to tolerance is an important characteristic of a life history stage, for it will signify what time of exposure to an elevated temperature the organisms become tolerant to thermal stress and suffer no additional mortality with increasing exposure time. This transition time is particulary important when evaluating the thermal component of entrainment mortality when it occurs within the entrainment time of power plant cooling systems. Typical entrainment times of power plants with once-through cooling systems range from 4 minutes to 2 hours, with the majority of plants having entrainment times from 10 to 15 minutes (H.H. Carter and D.W. Pritchard, personal communication).

Weakfish

Weakfish range from Nova Scotia to the east coast of Florida, and are especially abundant from North Carolina northward. Weakfish spawn throughout the New York region in larger bays (Nichols and Breder, 1926) and in Long Island Sound (Wheatland, 1956; Richards, 1959). The spawning season extends from early May in Florida to September in Nova Scotia. Peak spawning in New York waters occurs in June, near the bottom, usually at night. Fertilized eggs have been found in temperatures ranging from 15.6°C to 23.9°C. Newly fertilized eggs are buoyant and readily float to the surface, however, as development progresses the specific gravity increases causing them to sink to the bottom before hatching. For this reason, late stage weakfish eggs may be less entrainable into power plant cooling systems than earlier stage eggs, or larvae. Weakfish eggs hatch in 38 hours at 20.5°C.

Table 13 lists incipient lethal temperature for 10%, 50%, and 90% mortality levels, and times at which they are reached for weakfish late tail-free embryo eggs and larvae at mid yolk sac absorption. The incipient lethal temperatures for eggs acclimated to 22.3°C were 34.0°C, 35.2°C, and 36.0°C for 10%, 50%, and 90% mortality respectively. All three incipient lethal temperatures were reached at 90 minutes of exposure. Weakfish eggs appear to be highly resistant to the thermal stresses used in our experiment, experiencing 10% mortality or less for exposures up to 34°C for 90 minutes. An increase in 1.2°C for this same exposure time resulted in 50% mortality. Another increase of 0.8°C resulted in 90% mortality. The incipient lethal temperatures for 10% and 90% mortality vary by only 2°C, signifying sudden onset of high percent mortality. This sudden onset of high percent mortality was previously shown in the response surface graph for weakfish eggs (Figure 3).

The incipient lethal temperatures for weakfish larvae at mid yolk sac absorption acclimated to 22.5°C are 31.3°C for 10% mortality, 33.0°C for 50% mortality, and 35.5°C for 90% mortality. The incipient lethal temperatures for 10% and 90% mortality of larvae are separated by 5°C, signifying a slightly more gradual onset of mortality than was seen for weakfish eggs. Low mortalities (box avg. less than 20%) of larvae were observed up to and including the 15 minute exposure at 33.7°C. The 45 minute exposure at 33.7°C resulted in approximately 70% mortality. The 45 minute exposure at 36.5°C resulted in near 100% mortality.

Late stage weakfish eggs are more resistant to thermal stress than early stage weakfish larvae. The same relationship has been observed by another investigator (Lauer *et al.*, 1974) working with striped bass eggs and larvae. At each mortality level in our experiments, late stage eggs reached incipient lethal temperature at greater temperatures and longer times than larvae. It should be emphasized that eggs used in this experiment were late stage eggs and, therefore it would be expected that they would show a greater thermal resistance than earlier stage eggs acclimated to similar temperature.

Striped Searobin

Striped searobin are distributed from the lower Bay of Fundy to the east coast of Florida. No description of the development of eggs and larvae of this species appears in the literature. We have found that the time schedule of development and appearance of morphological characteristics closely resembles that of northern searobin (*Prionotus carolinus*). Spawning of striped searobin occurs from May to early August in the New York region, with peak spawning activity in early July (Nichols and Breder, 1926). Eggs of the striped searobin are buoyant throughout their developmental period, which lasts about 3 days at 22°C.

Table 13 lists the incipient lethal temperature for 10%, 50%, and 90% mortality levels and the times at which they are reached for striped searobin eggs and larvae. These values are for early embryo eggs acclimated to 20.3°C, 24.6°C, 31.5°C, and 35.3°C, each in 45 minutes; for mid embryo eggs acclimated to 21.7°C, 25.1°C, 26.0°C, and 29.0°C, at 45 minutes, 60 minutes, and 60 minutes; for late tail-free embryo eggs acclimated to 21.7°C, 28.9°C, 34.4°C, and 36.1°C, at 15 minutes, 45 minutes and 45 minutes; and for mid yolk sac larvae acclimated to 21.9°C, 31.5°C, 34.8°C,

Table 13

Species, stage tested, base temperature, percent mortality, incipient lethal temperature, and time to incipient lethal temperature for early life history stages of finfish used in these experiments. Subtract 2°C from incipient lethal temperature values to account for sub-lethal effects.

Species	Life History Stage	Base Temperature	% Mortality	Incipient lethal temperature (ΔT)	Time to incipient lethal temperature
Weakfish	late tail-free embryo eggs	22.3	10	34.0 (11.7)	90
			50	35.2 (12.9)	90
			90	36.0 (13.7)	90
	mid yolk sac larvae	22.5	10	31.3 (8.8)	1
			50	33.0 (10.5)	30
			90	35.5 (13.0)	45
Striped searobin	early embryo eggs	20.3	10	24.6 (4.3)	45
			50	31.5 (11.2)	45
			90	35.3 (15.0)	45
	mid embryo eggs	21.7	10	25.1 (3.4)	45
			50	26.0 (4.3)	60
			90	29.0 (7.3)	60
	late tail-free embryo eggs	21.7	10	28.9 (7.2)	15
			50	34.4 (12.7)	45
			90	36.1 (14.4)	45
	mid yolk sac larvae	21.9	10	31.5 (9.6)	15
			50	34.8 (12.9)	45
			90	35.7 (13.8)	45
Scup	blastula eggs	18.0	10	22.0 (4.0)	3
			50	29.3 (11.3)	16
			90	31.3 (13.3)	24
	mid embryo eggs	17.1	10	19.2 (2.1)	11
			50	28.6 (11.5)	15
			90	30.6 (13.5)	15
	mid yolk sac larvae	17.0	10	18.3 (1.3)	16
			50	32.2 (15.2)	25
			90	34.4 (17.4)	50
Summer flounder	late embryo eggs	16.0	10	31.0 (15.0)	71
			50	33.5 (17.5)	85
			90	34.8 (18.8)	88
Blackfish	gastrula eggs	15.0	10	16.8 (1.8)	26
			50	21.3 (6.3)	50
			90	31.4 (16.4)	55

and 35.7°C, in 15 minutes, 45 minutes, and 45 minutes. Response surface graphs for striped searobin experiments indicate gradual onset of mortality of all life history stages in response to increasing exposure times and temperatures.

Eggs used in the early embryo experiment were from a separate sample than eggs and larvae used in the remaining experiments, which were from the same sample and base temperature. Differences in thermal resistance of mid embryo eggs, late tail-free embryo eggs, and mid yolk sac larvae were due to age of the organisms, since acclimation temperature and genetic pools were similar for all three experiments. These data show that the incipient lethal temperature for a given mortality increased with increasing age of the life history stage exposed. At all mortality levels, incipient lethal temperatures of mid embryo eggs were less than values for the same mortality rate of late tail-free embryo eggs and mid yolk sac larvae, which exhibited similar thermal resistance. Also, times at which incipient lethal temperatures were reached decreased with increasing age. These trends indicate that not only are older life history stages more resistant to elevated temperatures, but also, they make the transition from resistance to tolerance in a shorter time. The implication of this pattern of transition points is that while mortality of late tail-free embryo eggs and mid yolk sac larvae becomes constant at 10% after 15 minutes exposure at 28.9°C and 31.5°C respectively, mid embryo eggs continue to suffer increasing mortality with increasing time of exposure, because the latter has not yet made the transition from resistance to tolerance. For striped searobin, all the life history stages tested had transition times within the 4 minute to 2 hour range of entrainment times, and two stages had transition times within the 10 to 15 minute range.

Scup

Scup are distributed from Nova Scotia to the east coast of Florida. Spawning activity of scup in the New York region occurs in June and July (Nichols and Breder, 1926) with peak activity in mid June. Incubation time to hatching is approximately 40 hours at 22°C. Eggs are spawned at depths ranging from shallow, near shore waters to moderately deep waters in Long Island Sound. Scup eggs are not often found until bottom water temperatures have reached 11°C (Wheatland, 1956). Eggs are buoyant throughout their developmental period, and therefor, will encounter a thermal gradient while rising to the surface. Wheatland (1956) estimates this gradient to range from 3°C to 5°C in the areas where scup spawn in Long Island Sound. Eggs used in these experiements were collected from deep water spawning populations. Since eggs were artificially spawned in the presence of surface water, a slight temperature shock (approximately 4°C) was experienced when spawned. All experiments with early life history stages of scup assume acclimation to surface water temperatures. Eggs used in these experiments hatched in 60 hours at 17°C.

Table 13 lists the incipient lethal temperature for 10%, 50%, and 90% mortality levels and the times at which they were reached for scup blastula and early embryo eggs, and mid yolk sac larvae. These values were for blastula eggs acclimated to 18.0°C, 22.0°C, 29.3°C, and 31.3°C at 3 minutes, 16 minutes, and 24 minutes; for mid embryo eggs acclimated to 17.1°C, 19.2°C, 28.6°C, and 30.6°C at 11 minutes, 15 minutes, and 15 minutes; for mid yolk sac larvae acclimated to 17.0°C, 18.3°C, 32.2°C, and 34.4°C at 16 minutes, 25 minutes and 50 minutes. The response surface graph for blastula eggs reveals generally high mortality at most exposures. Response surface graphs of early embryo eggs and mid yolk sac larvae indicate gradual onset of mortality with increasing time and temperature of exposure. Eggs used in the blastula experiment were from a separate sample than eggs and larvae used in the remaining two scup experiments, which came from the same sample. At the 50% and 90% mortality levels, scup early embryo eggs and mid yolk sac larvae show a trend of increasing incipient lethal temperature with increasing age.

Summer Flounder

Summer flounder are distributed from Maine to Florida. Spawning of summer flounder occurs offshore in water from 20 to 48 meters deep. Spawning temperatures range from 12°C to 19°C. Eggs are buoyant throughout their developmental period, and encounter thermal gradients as they rise after being spawned in nature. Eggs used in this experiment were obtained from a hatchery and were not exposed to a thermal stress when spawned. Incubation of summer flounder eggs covers 72 hours at 17.5°C.

Table 13 lists time to, and the incipient lethal temperature for 10%, 50%, and 90% mortality levels for summer flounder eggs in the late embryo stage acclimated to 16.0°C. These values were 31.0°C, 33.5°C, and 34.8°C at 71 minutes, 85 minutes, and 88 minutes respectively. Summer flounder eggs were highly resistant to the thermal stresses used in these experiments. Less than 25% mortality was found at all but three exposures. A 15 minute exposure at a 19.0°C ΔT resulted in 3% mortality. Increasing the exposure time to 45 and 90 minutes at the same ΔT caused 34% and 100% mortality respectively. Sudden onset of mortality can also be seen in the response surface graph, and is similar to the response characteristics of weakfish eggs and larvae. Incipient lethal temperatures for 10% mortality differ from that for 50% mortality by 2.5°C, and the 50% mortality value differs from 90% by 1.3°C.

Blackfish

Blackfish are distributed from New Brunswick, Canada to South Carolina. Principle spawning activities in New York waters takes place in June and July. Eggs are buoyant, and remain so throughout the incubation period which lasts 42 hours at 20°C. Fertilized eggs have been found throughout Long Island Sound during summer months.

Table 13 lists the incipient lethal temperature for 10%, 50%, and 90% mortality levels and the times at which each is reached for blackfish eggs. These values were 16.8°C, 21.3°C, and 31.4°C at 26 minutes, 50 minutes and 55 minutes respectively. High mortalities were found at the majority of the time-temperature exposures, indicating low thermal resistance of this early life history stage.

All species

10%, 50% and 90% mortality thermal resistance curves for all species studied are compiled in Figures 26, 27, and 28. Resistance curves having similar acclimation temperatures are comparable, since resistance to thermal stress is a function of acclimation temperature (Brett, 1952). Acclimation temperatures used in these experiments ranged from 15°C to 22.3°C, and are composed of two groups, namely those from 15°C to 18°C, and those from 20.3°C to 22.3°C. By assuming that species within each of these groups are similarly acclimated, comparisons of the thermal resistance characteristics of species and stages of development can be made. The most appropriate portion of the resistance curve to use for comparison is that portion occuring befor 50 minutes, since this time frame encompasses the majority of entrainment times.

Blackfish, scup, and summer flounder compose the group whose acclimation temperatures range from 15°C to 18°C. The 10%,

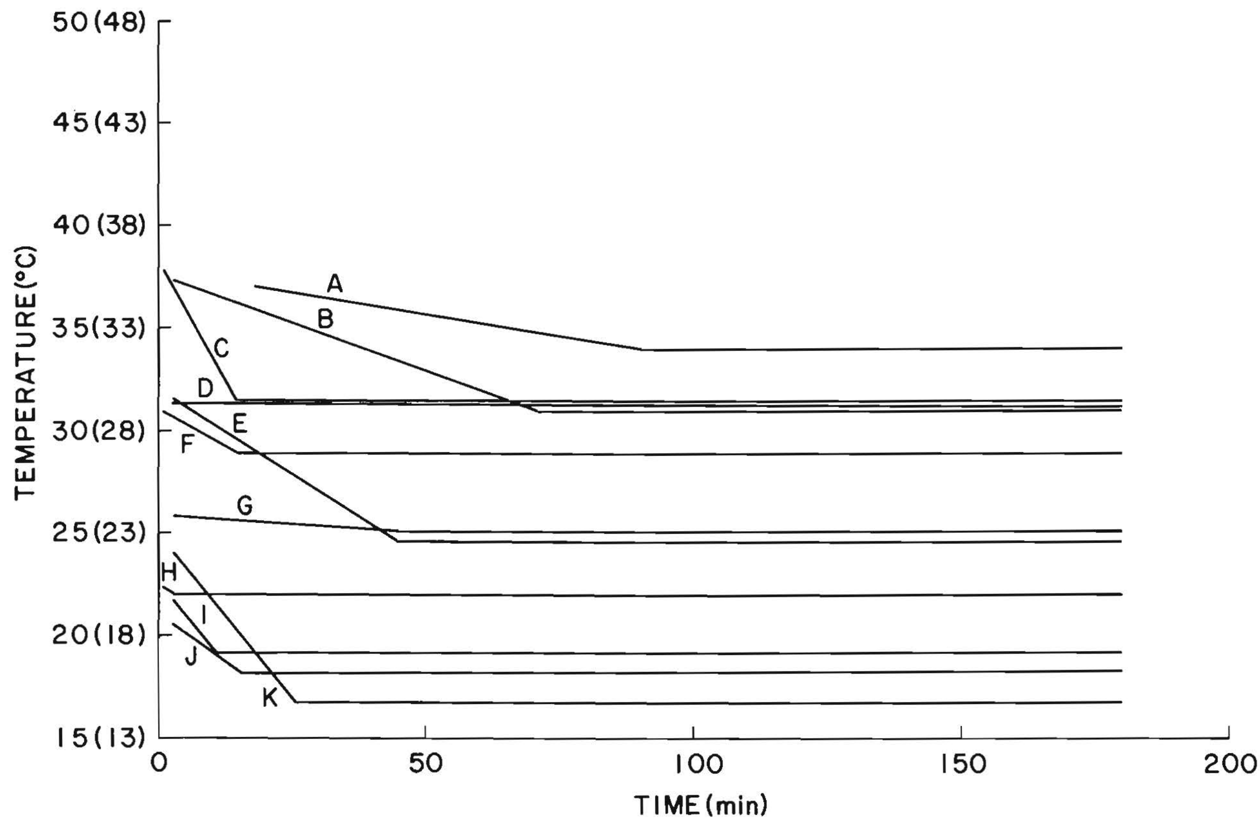

Figure 26. Graph of 10 percent mortality thermal resistance curves for all species studied. Numbers in parenthesis indicate temperature values which take into account sub-lethal effects.

A Weakfish Tail-Free Embryo Eggs
B Summer Flounder Late Embryo Eggs
C Striped Searobin Mid Yolksac Larvae
D Weakfish Mid Yolksac Larvae
E Striped Searobin Early Embryo Eggs
F Striped Searobin Tail-Free Embryo Eggs
G Striped Searobin Mid Embryo Eggs
H Scup Blastula Eggs
I Scup Mid Embryo Eggs
J Scup Mid Yolksac Larvae
K Blackfish Gastrula Eggs

50%, and 90% mortality resistance curves are complied in Figures 29, 30, and 31. The orders of relative resistance of developmental stages of each species are listed in Table 14. At all mortality levels tested, summer flounder eggs were the most resistant to thermal stress. At the 10% mortality level, the resistance characteristics of summer flounder late embryo eggs far exceeds that of any developmental stage of the other species within the acclimation temperature group. At 10% mortality, the order of resistance (from most to least resistant) was summer flounder late embryo eggs, scup blastula eggs, scup mid embryo eggs, scup larvae, and blackfish gastrula eggs; at 50% mortality the order was summer flounder late embryo eggs, scup larvae, scup mid embryo eggs, scup blastula eggs, and blackfish eggs; at 90% mortality the order is summer flounder late embryo eggs, scup larvae, scup blastula eggs, blackfish gastrula eggs, scup mid embryo eggs.

The second acclimation temperature

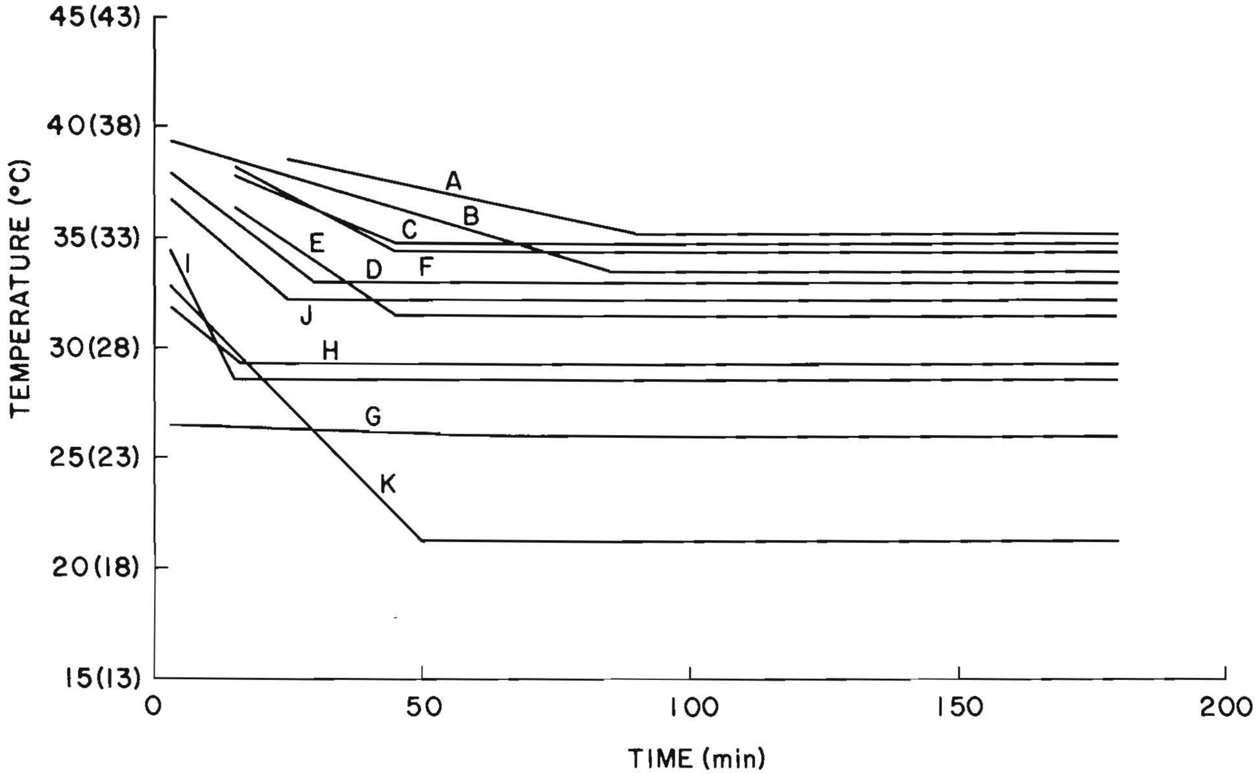

Figure 27. Graph of 50 percent mortality thermal resistance curves for all species studied. Numbers in parenthesis indicate temperature values which take into account sub-lethal effects.

A Weakfish Tail-Free Embryo Eggs
B Summer Flounder Late Embryo Eggs
C Striped Searobin Mid Yolksac Larvae
D Weakfish Mid Yolksac Larvae
E Striped Searobin Early Embryo Eggs
F Striped Searobin Tail-Free Embryo Eggs
G Striped Searobin Mid Embryo Eggs
H Scup Blastula Eggs
I Scup Mid Embryo Eggs
J Scup Mid Yolksac Larvae
K Blackfish Gastrula Eggs

group (20.3° to 22.3°C) is composed of egg and larval stages of weakfish and striped searobin. The resistance curves for this acclimation group are compiled in Figures 32, 33, and 34. Table 14 summarizes the relative resistance of each life history stage tested. The order of relative resistance at 10% mortality was weakfish late tail-free embryo eggs, striped searobin larvae, weakfish larvae, striped searobin late tail-free embryo eggs, and striped searobin mid embryo eggs - striped searobin early embryo eggs; at 50% the order is weakfish late tail-free embryo eggs, striped searobin larvae - striped searobin late tail-free embryo eggs, weakfish larvae, striped searobin early embryo eggs, striped searobin mid embryo eggs; at 90% the order is weakfish eggs, striped searobin late tail-free embryo eggs, striped searobin larvae, weakfish larvae, striped searobin early embryo eggs, and striped searobin mid embryo eggs.

Experiments from both groups of acclimation temperatures show that the

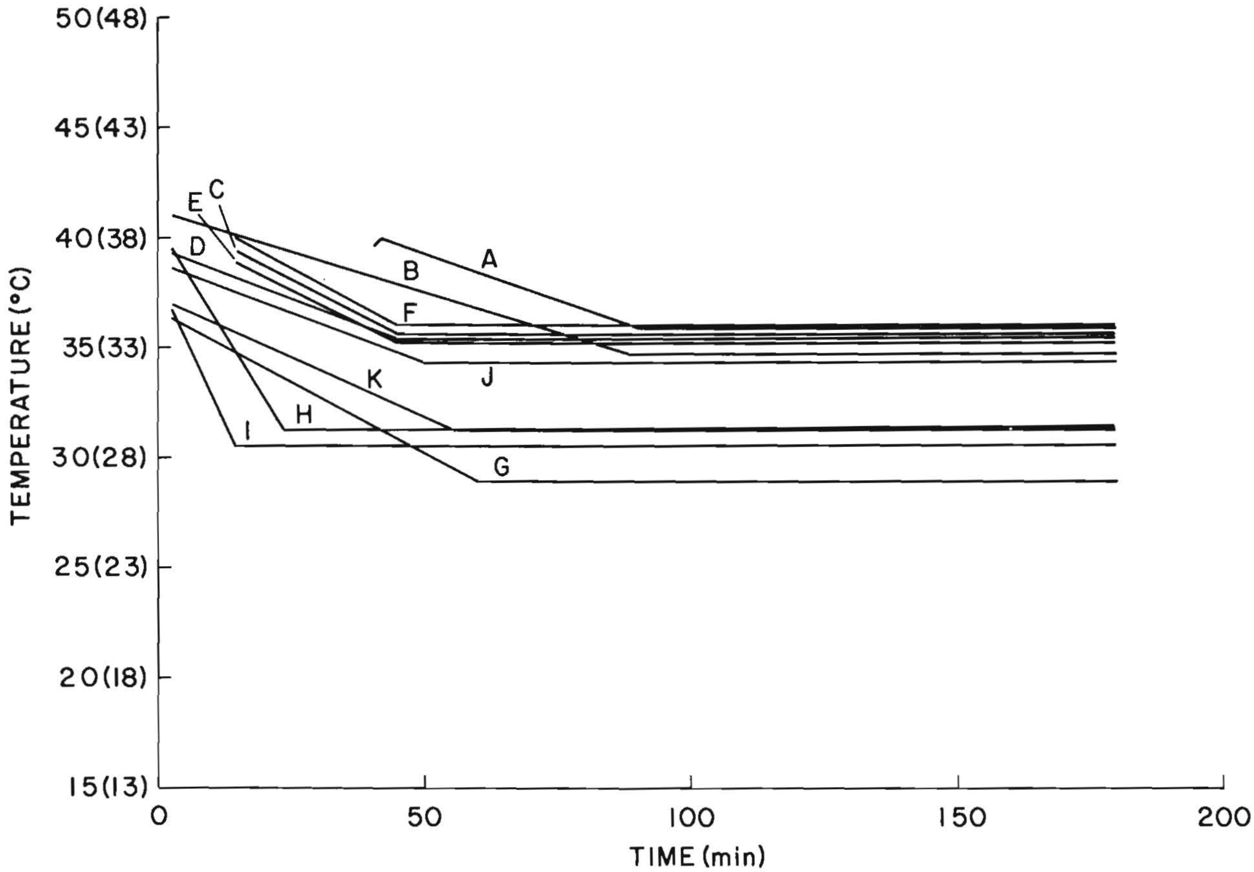

Figure 28. Graph of 90 percent mortality thermal resistance curves for all species studied. Numbers in parenthesis indicate temperature values which take into account sub-lethal effects.

A Weakfish Tail-Free Embryo Eggs
B Summer Flounder Late Embryo Eggs
C Striped Searobin Mid Yolksac Larvae
D Weakfish Mid Yolksac Larvae
E Striped Searobin Early Embryo Eggs
F Striped Searobin Tail-Free Embryo Eggs
G Striped Searobin Mid Embryo Eggs
H Scup Blastula Eggs
I Scup Mid Embryo Eggs
J Scup Mid Yolksac Larvae
K Blackfish Gastrula Eggs

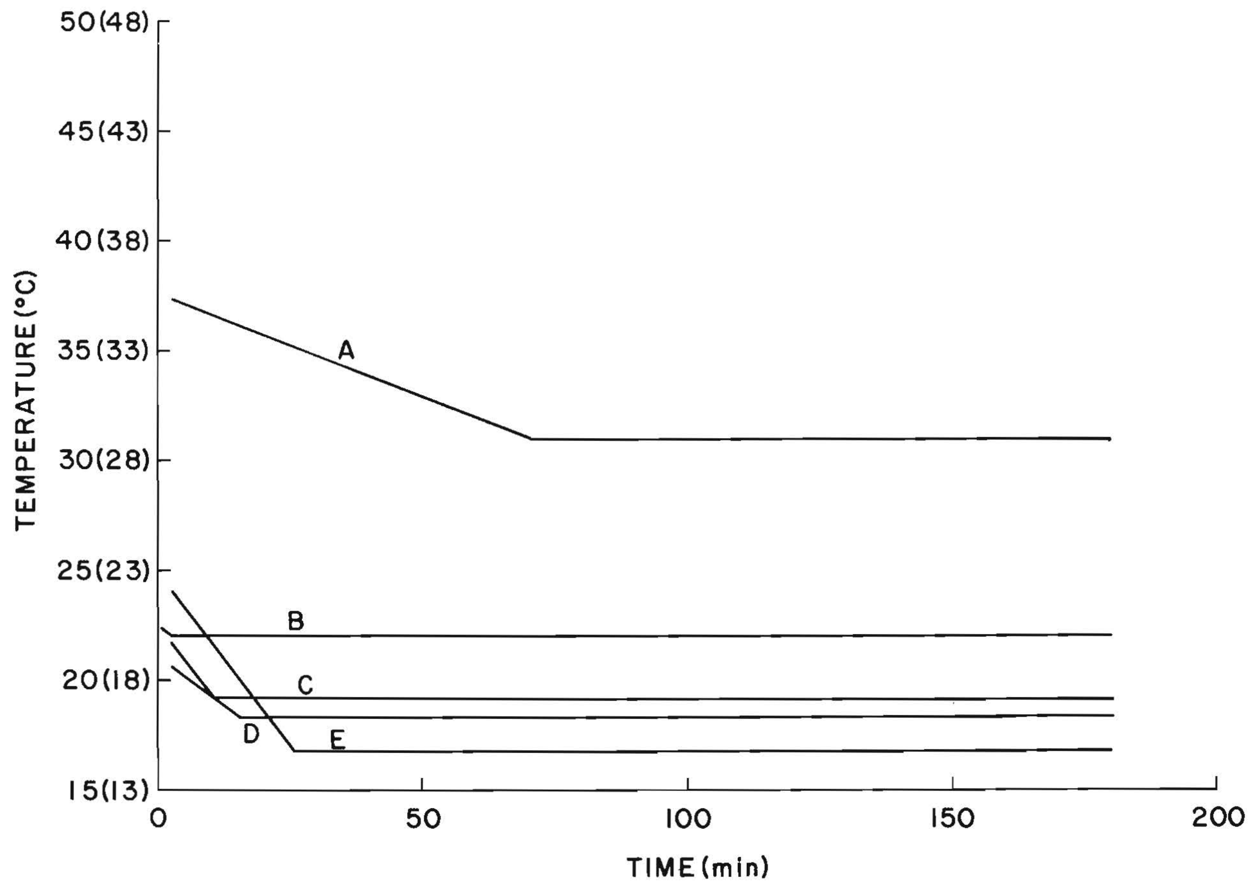

Figure 29. Graph of 10 percent mortality thermal resistance curves for 15-18°C acclimation group. Numbers in parenthesis indicate temperature values which take into account sub-lethal effects.

A Summer Flounder Late Embryo Eggs
B Scup Blastula Eggs
C Scup Mid Embryo Eggs
D Scup Mid Yolksac Larvae
E Blackfish Gastrula Eggs

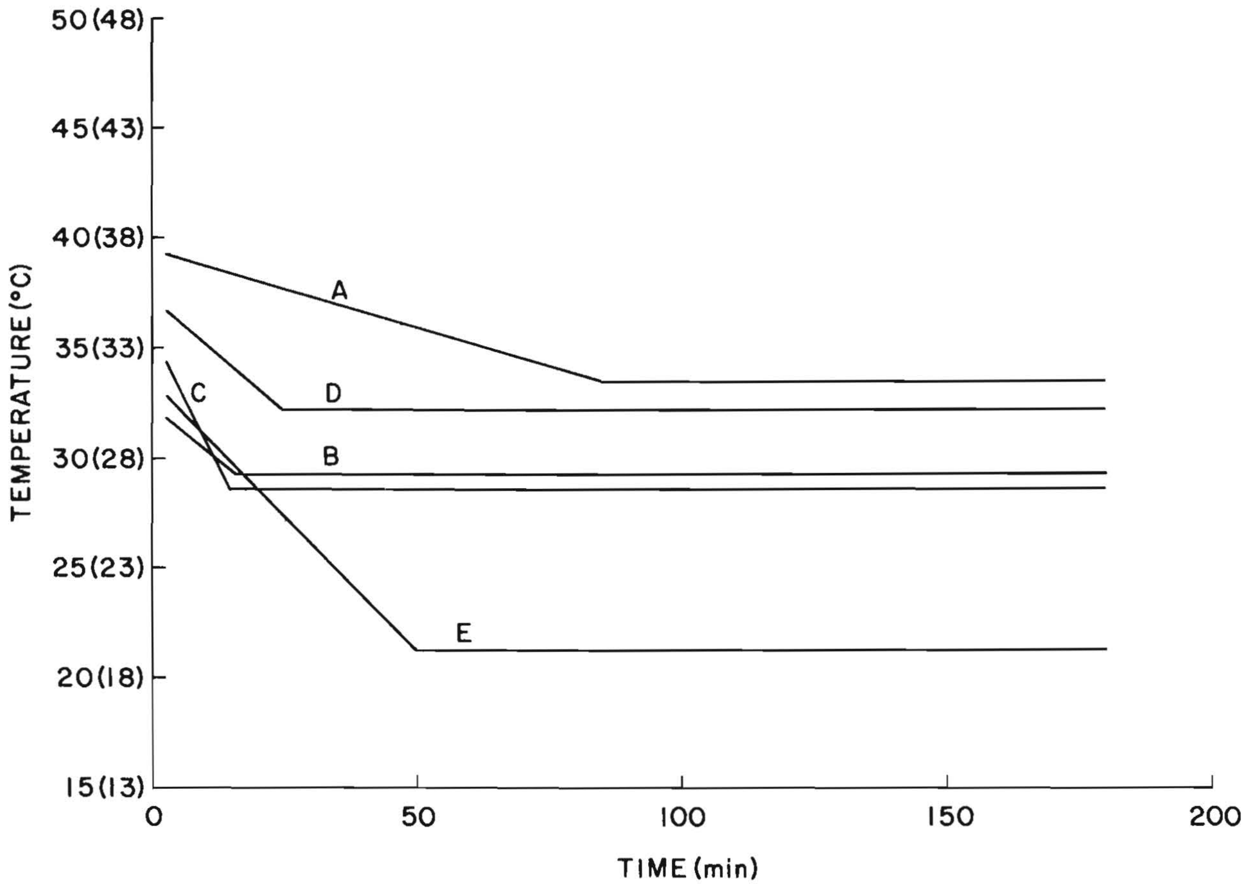

Figure 30. Graph of 50 percent mortality thermal resistance curves for 15-18°C acclimation group. Numbers in parenthesis indicate temperature values which take into account sub-lethal effects.

A Summer Flounder Late Embryo Eggs
B Scup Blastula Eggs
C Scup Mid Embryo Eggs
D Scup Mid Yolksac Larvae
E Blackfish Gastrula Eggs

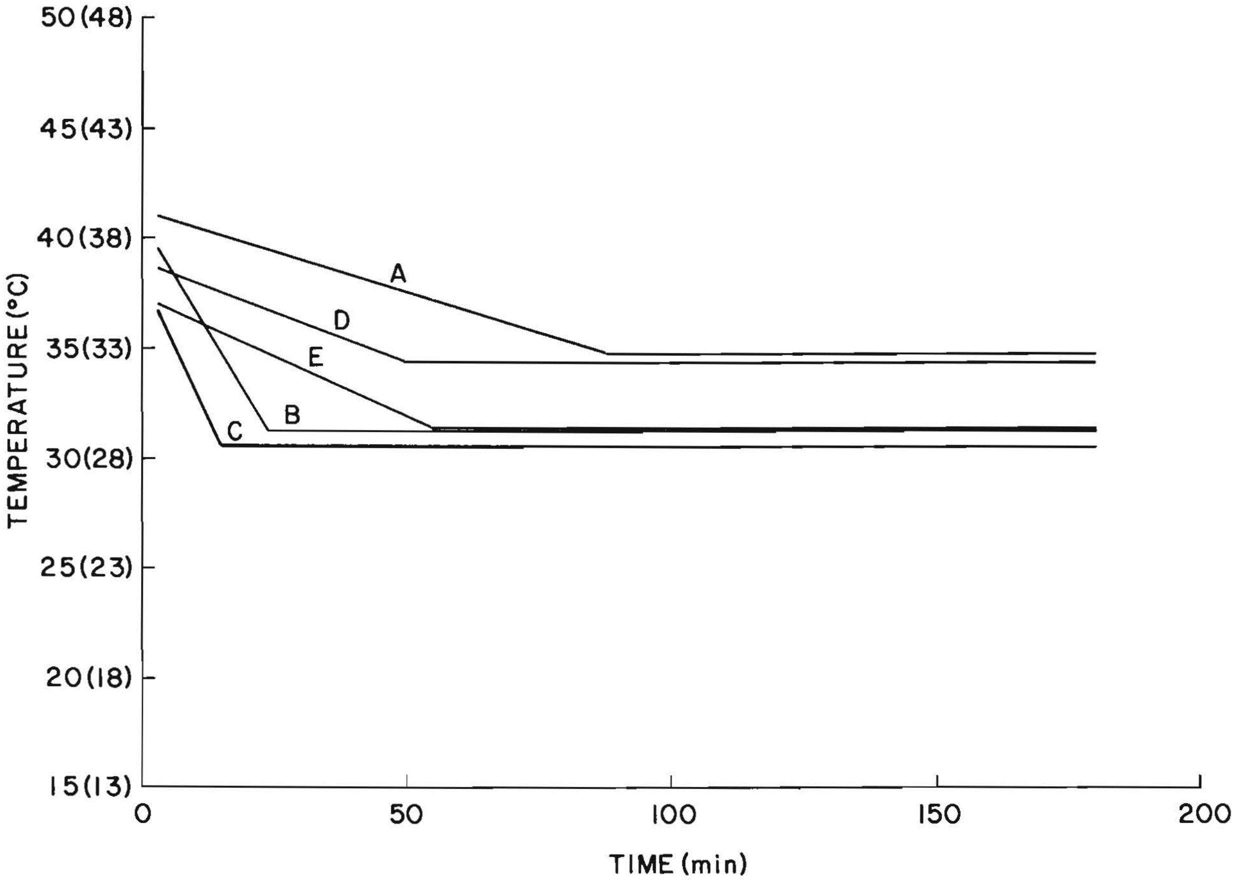

Figure 31. Graph of 90 percent mortality thermal resistance curves for 15-18°C acclimation group. Numbers in parenthesis indicate temperature values which take into account sub-lethal effects.

A Summer Flounder Late Embryo Eggs
B Scup Blastula Eggs
C Scup Mid Embryo Eggs
D Scup Mid Yolksac Larvae
E Blackfish Gastrula Eggs

Table 14

Order of resistance (from most to least resistant) at 10%, 50%, and 90% mortality levels of early life history stages of species acclimated to between 15°C and 18°C, and 20.3°C and 22.3°C.

15°C - 18°C	20.3°C - 22.3°C
10%	
Summer flounder late embryo eggs	Weakfish late tail-free embryo eggs
Scup blastula eggs	Striped searobin larvae
Scup larvae; Scup mid embryo eggs	Weakfish larvae
Blackfish gastrula eggs	Striped searobin late tail-free embryo eggs
	Striped searobin mid embryo eggs; Striped searobin early embryo eggs
50%	
Summer flounder late embryo eggs	Weakfish late tail-free embryo eggs
Scup larvae	Striped searobin larvae; late tail-free embryo eggs
Scup mid embryo eggs	Weakfish larvae
Scup blastula eggs	Striped searobin early embryo eggs
Blackfish gastrula eggs	Striped searobin mid embryo eggs
90%	
Summer flounder late embryo eggs	Weakfish late tail-free embryo eggs
Scup larvae	Striped searobin late tail-free embryo eggs
Scup blastula eggs;	Striped searobin larvae
Blackfish gastrula eggs	Weakfish larvae
Scup mid embryo eggs	Striped searobin early embryo eggs
	Striped searobin mid embryo eggs

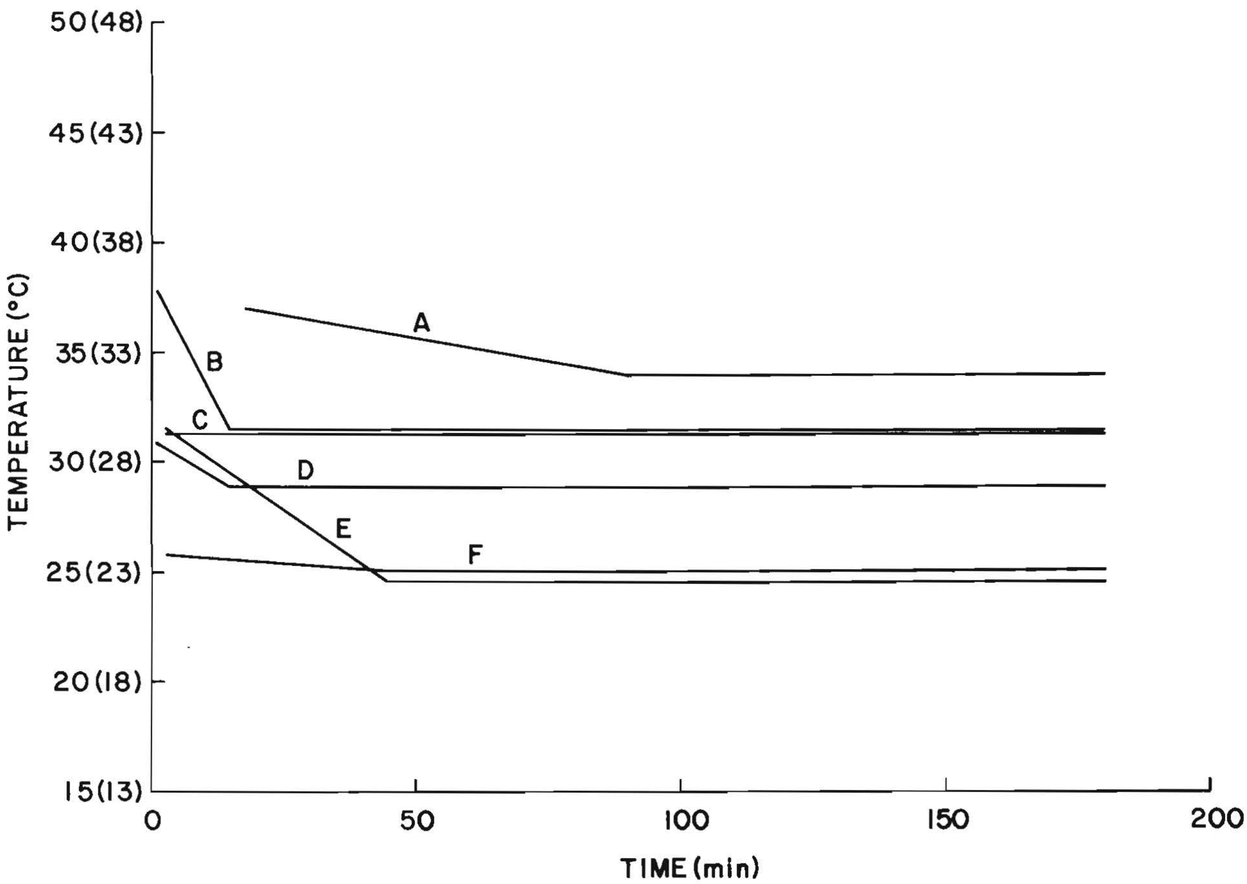

Figure 32. Graph of 10 percent mortality thermal resistance curves for 20.3-22.3°C acclimation group. Numbers in parenthesis indicate temperature values which take into account sub-lethal effects.

A Weakfish Tail-Free Embryo Eggs
B Striped Searobin Mid Yolksac Larvae
C Weakfish Mid Yolksac Larvae
D Striped Searobin Late Tail-Free Embryo Eggs
E Striped Searobin Early Embryo Eggs
F Striped Searobin Mid Embryo Eggs

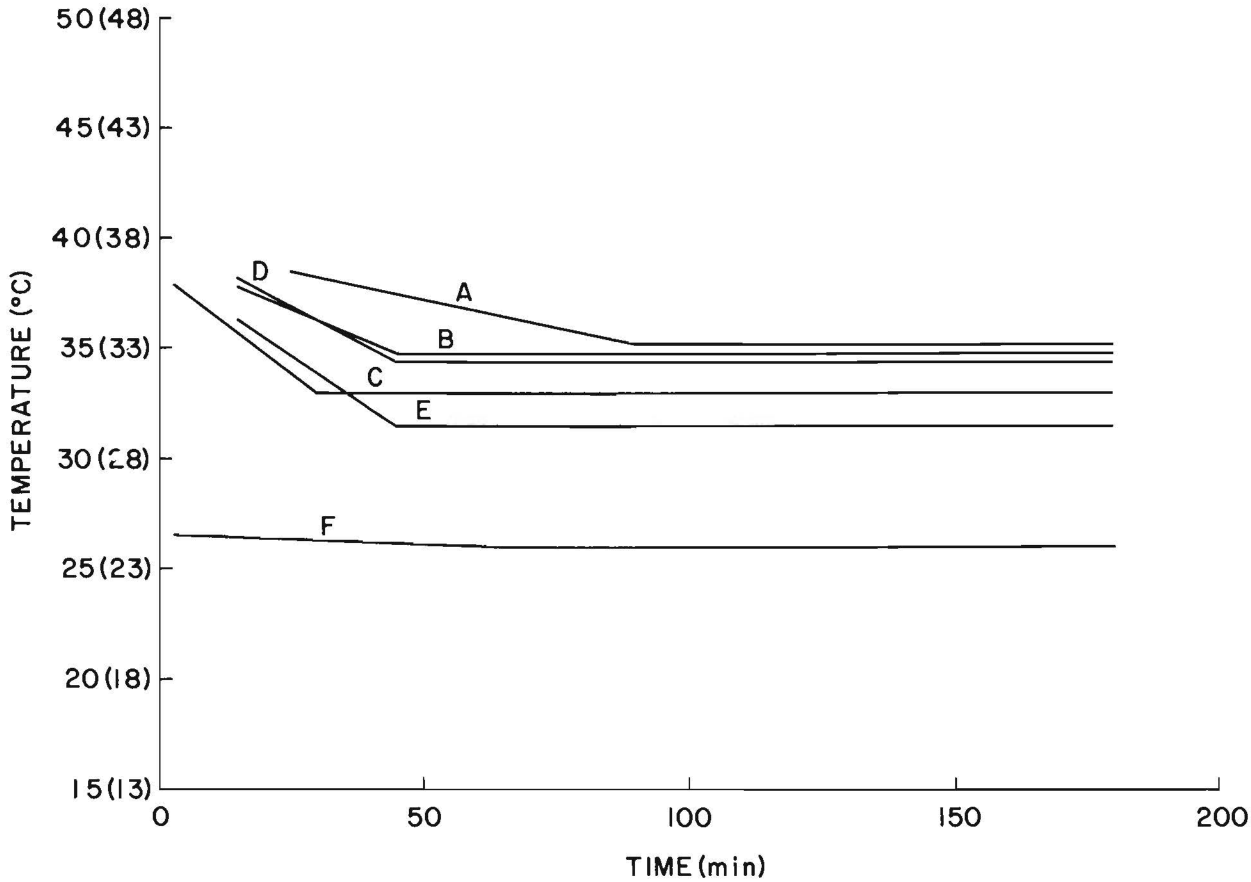

Figure 33. Graph of 50 percent mortality thermal resistance curves for 20.3-22.3°C acclimation group. Numbers in parenthesis indicate temperature values which take into account sub-lethal effects.

A Weakfish Tail-Free Embryo Eggs
B Striped Searobin Mid Yolksac Larvae
C Weakfish Mid Yolksac Larvae
D Striped Searobin Late Tail-Free Embryo Eggs
E Striped Searobin Early Embryo Eggs
F Striped Searobin Mid Embryo Eggs

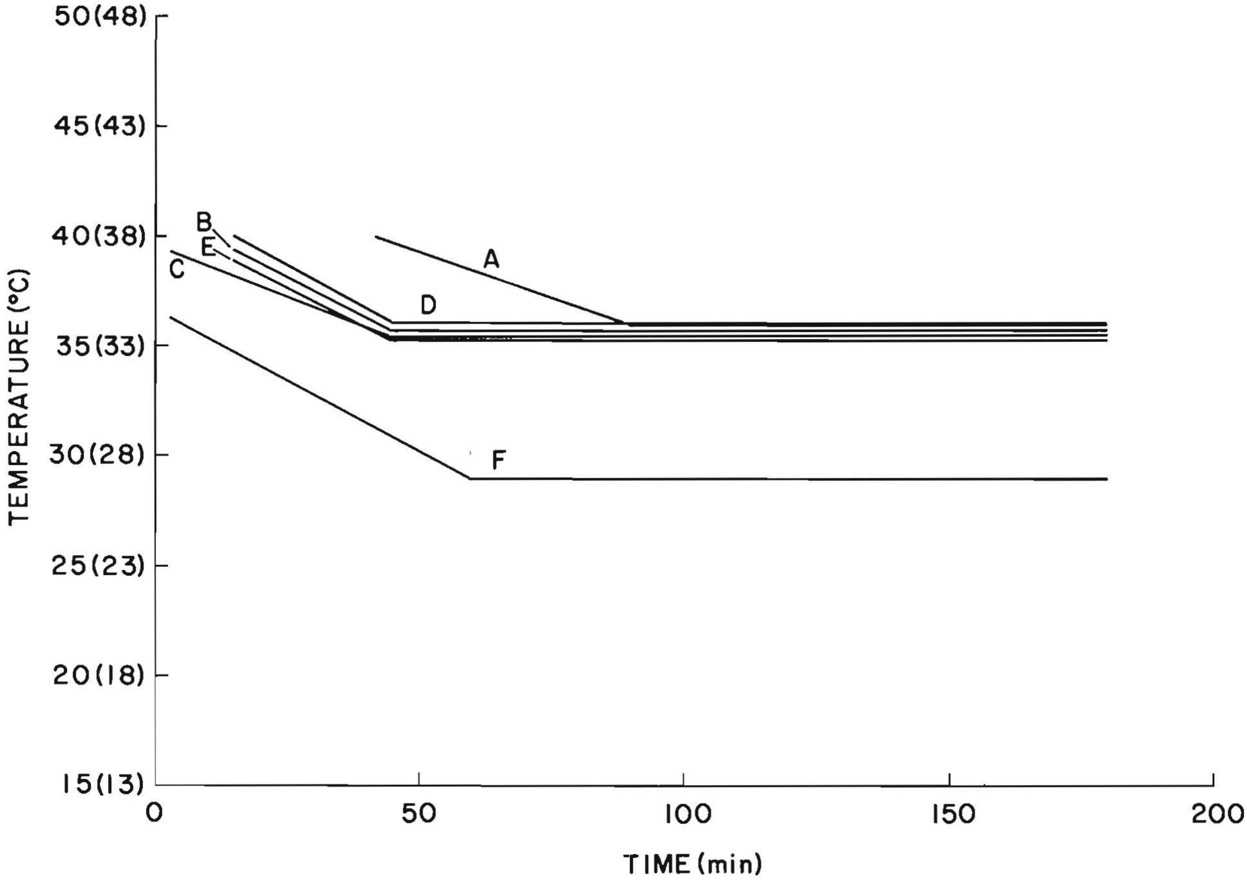

Figure 34. Graph of 90 percent mortality thermal resistance curves for 20.3-22.3°C acclimation group. Numbers in parenthesis indicate temperature values which take into account sub-lethal effects.

A Weakfish Tail-Free Embryo Eggs
B Striped Searobin Mid Yolksac Larvae
C Weakfish Mid Yolksac Larvae
D Striped Searobin Late Tail-Free Embryo Eggs
E Striped Searobin Early Embryo Eggs
F Striped Searobin Mid Embryo Eggs

distance between resistance curves decreases as the percent mortality increases. The resistance curves indicating 90% mortality are more closely spaced than those indicating 10% mortality, and 50% mortality. The same trend is seen when comparing curve spacing between the 50% and 10% mortality levels. This indicates that as the strength of the temperature stimulus increases, the variation of responses by similarly acclimated organisms decreases.

The resistance curves also show that the greater the acclimation temperature, the greater is the resistance to a given thermal stress. The 20.3°C to 22.3°C acclimated group consistently exhibited a greater resistance to temperature stress than the lower acclimated group. Two reasons may account for this difference. One is that the species composing the group acclimated to high temperature may be genetically more resistant. Two is that the greater acclimation temperature enables the group to tolerate a higher thermal stress.

Application of a thermal response model

A steam electric power plant consists of a heat source, boiler, turbine, generator, and a condenser system. Steam from the boiler drives the turbine which spins the generator producing electricity. After passing through the turbine, steam must be condensed and returned to the boiler. The most economical way of achieving this is a once-through cooling system which passes water from the environment through the steam condenser system and discharges it back into the environment at an elevated temperature. In 1973, 61% of the 808 operating steam electric power plants had once-through cooling systems (Schubel and Marcy, 1978).

Fish eggs and larvae may be drawn into the cooling water intake of a power plant, passed through the condensers and discharged back into the environment; or they may be entrained into the discharge plume along with the diluting water without having passed through the plant. The organisms that pass through the plant are subjected initially to a very rapid rise in temperature. They are exposed to maximum excess temperature during passage through the plant and to the point of discharge, where organisms are rapidly cooled to ambient temperature, or gradually cooled while they are carried along in a discharge plume. The rate of cooling will depend primarily on the design and placement of the discharge structure. The most rapid dilution of heated effluent, and therefor the most rapid reduction in temperature is achieved with a multi-port diffuser, which discharge water through a large number of small ports. Knowledge of the thermal resistance characteristics of entrained organisms enables an assessment of the thermal component of entrainment mortality at power plants having a multi-port diffuser discharge design.

Mortality Assessment

Graphs of thermal resistance curves can be used directly to assess the thermal component of entrainment mortality at power plants having a multi-port diffuser design. Consider a power plant with a once-through cooling system having a 15 minute transit time, a ΔT of 10°C, and discharging water through a multi-port diffuser. Figures 35, 36, and 37 graphically illustrate 10%, 50%, and 90% thermal resistance curves and corresponding exposure points as a result of cooling system entrainment. Lethal and sub-lethal effects are evaluated at each mortality level, and a point mortality estimate was made by linear interpolation. This information is summarized in Table 15. In order to locate the exposure point corresponding to a particular curve, the excess temperature (10°C) was added to the appropriate base temperature (rounded to the nearest degree) to obtain the exposure temperature (y-axis value). A fixed 15

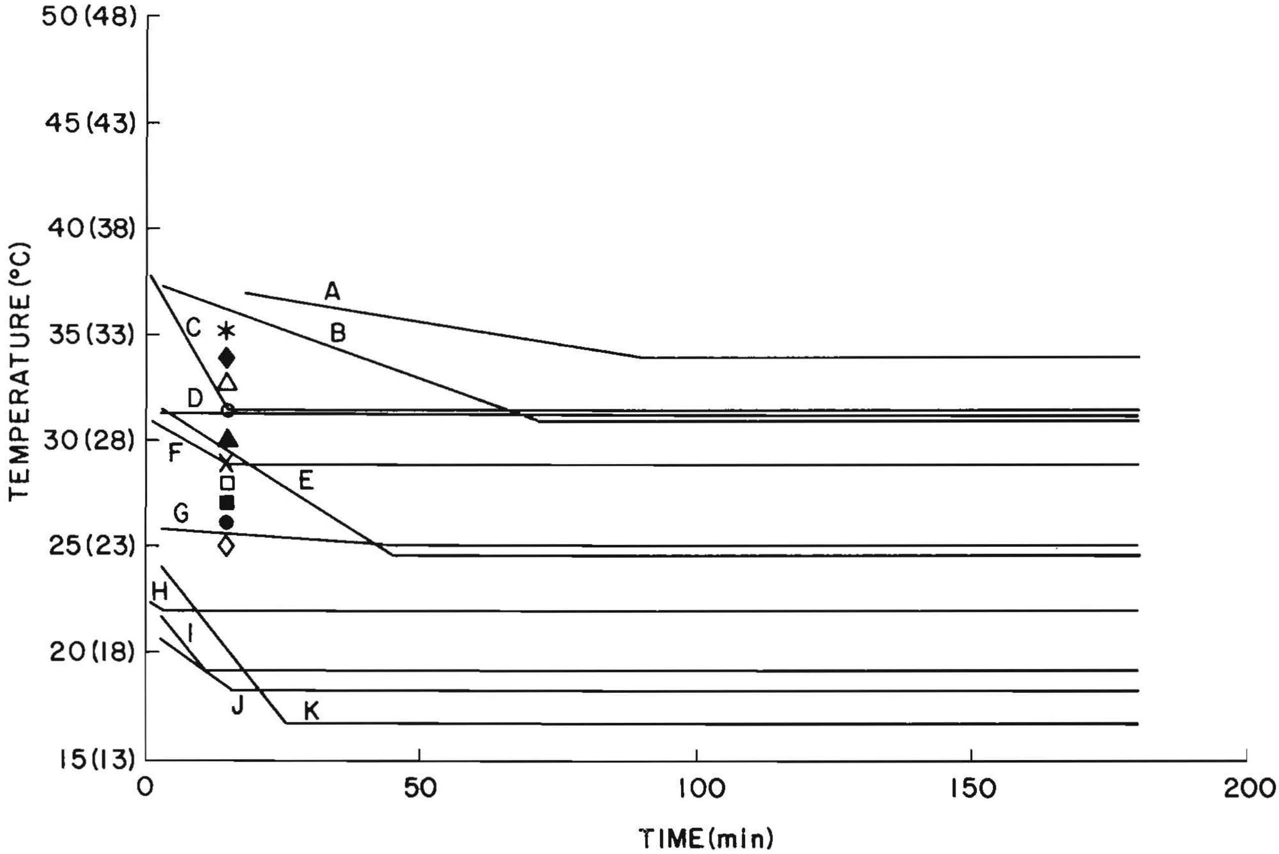

Figure 35. Graph of 10 percent mortality thermal resistance curves for all species studied. Numbers in parenthesis indicate temperature values which take into account sub-lethal effects.

	Life History Stage	Base Temp.(C)	(Lethal) Symbol	(Sub-lethal) Symbol
A	Weakfish Tail-Free Embryo Eggs	22.0	○	◆
B	Summer Flounder Late Embryo Eggs	16.0	●	□
C	Striped Searobin Mid Yolksac Larvae	22.0	○	◆
D	Weakfish Mid Yolksac Larvae	23.0	△	✱
E	Striped Searobin Early Embryo Eggs	20.0	▲	△
F	Striped Searobin Tail-Free Embryo Eggs	22.0	○	◆
G	Striped Searobin Mid Embryo Eggs	22.0	○	◆
H	Scup Blastula Eggs	18.0	□	▲
I	Scup Mid Embryo Eggs	17.0	■	×
J	Scup Mid Yolksac Larvae	17.0	■	×
K	Blackfish Gastrula Eggs	15.0	◇	■

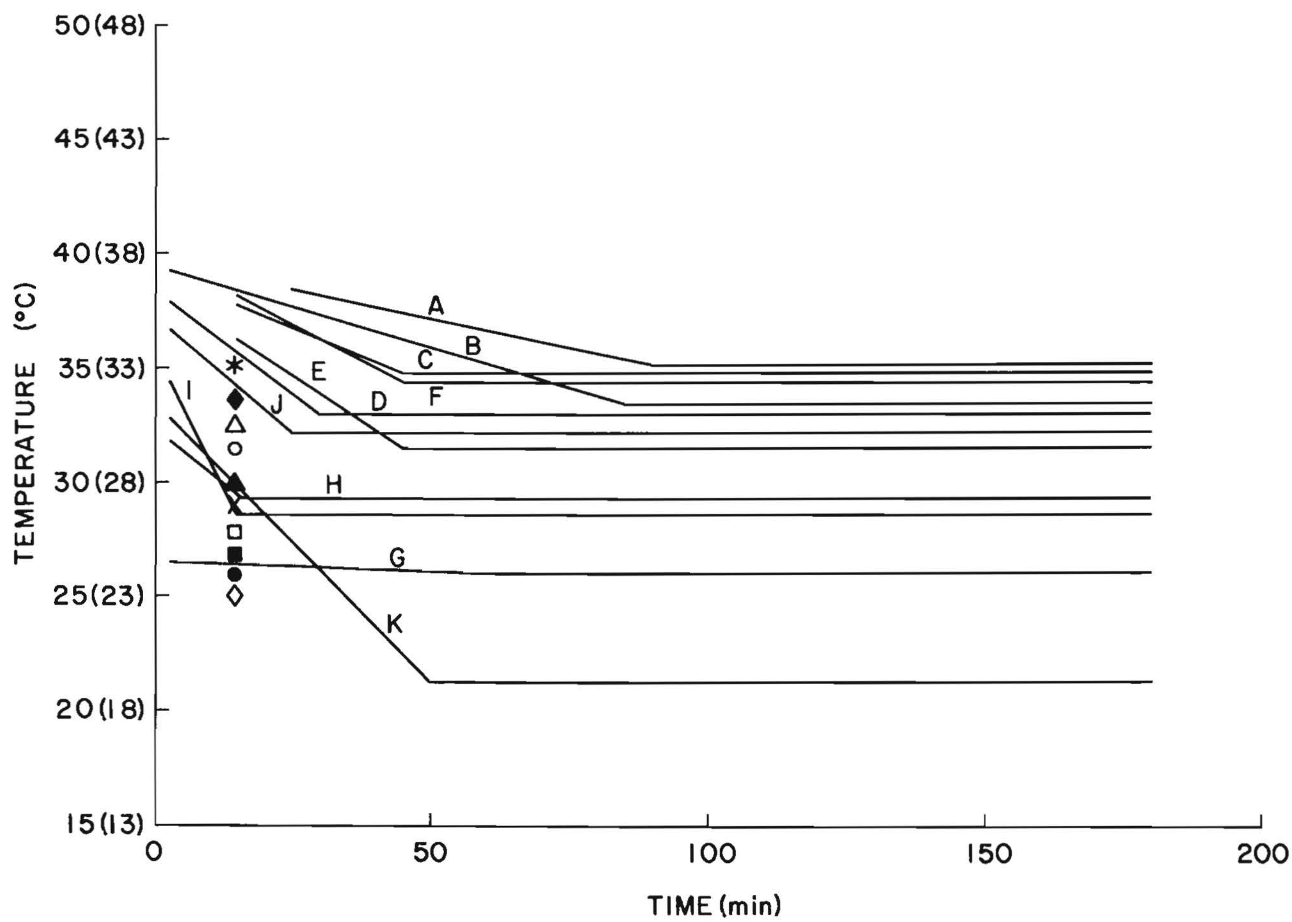

Figure 36. Graph of 50 percent mortality thermal resistance curves for all species studied. Numbers in parenthesis indicate temperature values which take into account sub-lethal effects.

	Life History Stage	Base Temp. (C)	(Lethal) Symbol	(Sub-lethal) Symbol
A	Weakfish Tail-Free Embryo Eggs	22.0	○	◆
B	Summer Flounder Late Embryo Eggs	16.0	●	□
C	Striped Searobin Mid Yolksac Larvae	22.0	○	◆
D	Weakfish Mid Yolksac Larvae	23.0	△	✳
E	Striped Searobin Early Embryo Eggs	20.0	▲	△
F	Striped Searobin Tail-Free Embryo Eggs	22.0	○	◆
G	Striped Searobin Mid Embryo Eggs	22.0	○	◆
H	Scup Blastula Eggs	18.0	□	▲
I	Scup Mid Embryo Eggs	17.0	■	×
J	Scup Mid Yolksac Larvae	17.0	■	×
K	Blackfish Gastrula Eggs	15.0	◇	■

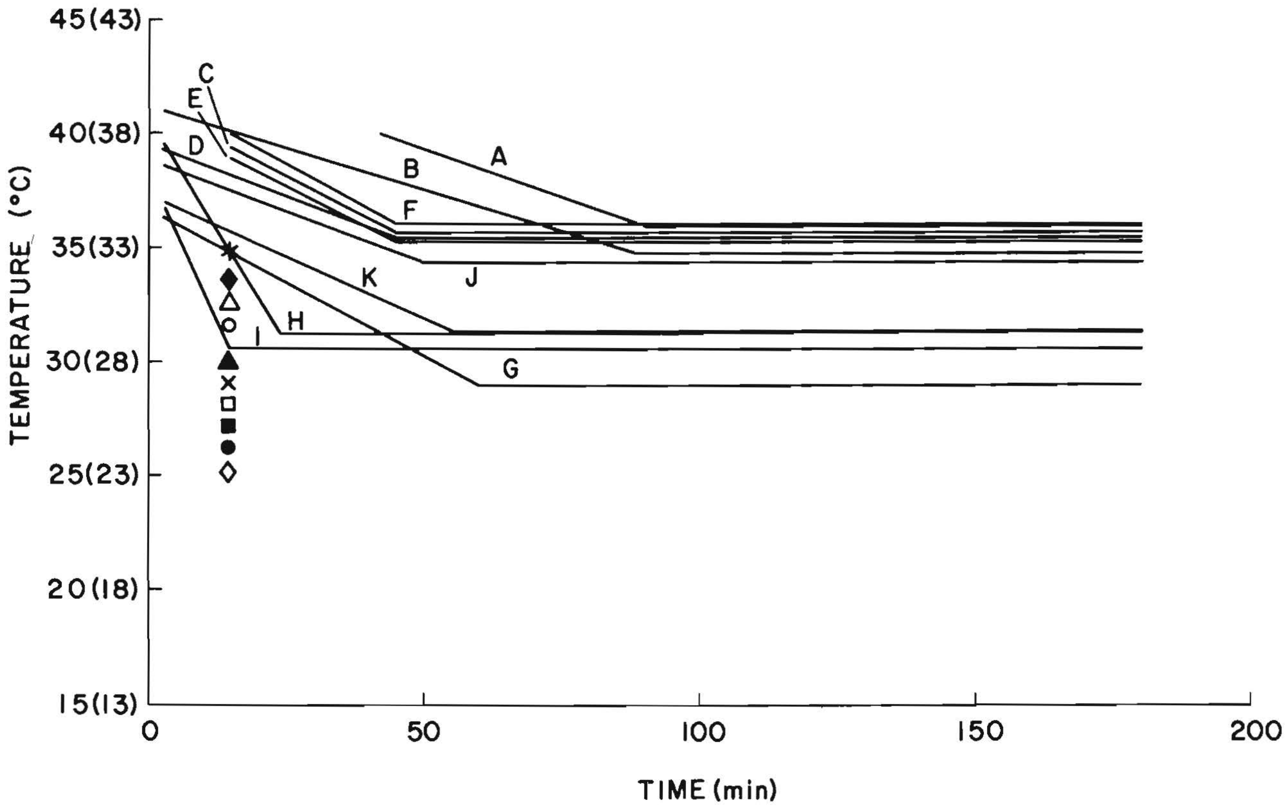

Figure 37. Graph of 90 percent mortality thermal resistance curves for all species studied. Numbers in parenthesis indicate temperature values which take into account sub-lethal effects.

	Life History Stage	Base Temp. (C)	(Lethal) Symbol	(Sub-lethal) Symbol
A	Weakfish Tail-Free Embryo Eggs	22.0	○	◆
B	Summer Flounder Late Embryo Eggs	16.0	●	□
C	Striped Searobin Mid Yolksac Larvae	22.0	○	◆
D	Weakfish Mid Yolksac Larvae	23.0	△	✱
E	Striped Searobin Early Embryo Larvae	20.0	▲	△
F	Striped Searobin Tail-Free Embryo Eggs	22.0	○	◆
G	Striped Searobin Mid Embryo Eggs	22.0	○	◆
H	Scup Blastula Eggs	18.0	□	▲
I	Scup Mid Embryo Eggs	17.0	■	×
J	Scup Mid Yolksac Larvae	17.0	■	×
K	Blackfish Gastrula Eggs	15.0	◇	■

minute transit time was used (x-axis value). Symbols representing the power plant exposure point corresponding to each resistance curve are listed in the figure captions.

Table 15 shows mortality to be largely a function of age of the life history stage considered. Late stage eggs and early stage larvae exhibit the lowest mortality response. Incorporating a 2°C correction factor for sub-lethal effects results in substantially higher mortalities. Differences between lethal and sub-lethal mortality values ranged from 1 to 29 percent, and averaged 13%. The unusually high mortality estimate for striped searobin mid embryo eggs can not be explained at this time. This value seems unreasonably high when compared with results from the other 10 experiments.

Table 15

Thermally induced percent mortality (range and value estimate, lethal and sub-lethal) of early life history stages of finfish, as a result of entrainment into the once-through cooling system of a power plant with a 15 minute transit time, operating at a ΔT of 10°C, and utilizing a multi-port diffuser discharge.

			LETHAL		SUB-LETHAL	
Life History Stage	Base Temperature (°C)	ΔT (°C)	Range (%)	Linear Interpolated Value (%)	Range (%)	Linear Interpolated Value (%)
A - Weakfish tail-free embryo eggs	22	10	<10	8	<10	9
B - Summer Flounder late embryo eggs	16	10	<10	5	<10	8
C - Striped Searobin mid yolk sac larvae	22	10	10	10	10-50	25
D - Weakfish mid yolk sac larvae	23	10	10-50	20	10-50	48
E - Striped Searobin early embryo eggs	20	10	10-50	11	10-50	30
F - Striped Searobin tail-free embryo eggs	22	10	10-50	15	10-50	35
G - Striped Searobin mid embryo eggs	22	10	50-90	75	50-90	85
H - Scup blastula eggs	18	10	10-50	40	50-90	52
I - Scup mid embryo eggs	17	10	10-50	40	50-90	52
J - Scup mid yolk sac larvae	17	10	10-50	30	10-50	39
K - Blackfish gastrula eggs	15	10	10-50	35	10-50	40

SUMMARY

Organisms entrained into once-through cooling systems of power plants undergo thermal, physical, and periodic chemical stresses. These stresses act synergistically to produce the pattern of mortality seen at any one point in time. Under a given set of conditions it is possible that one stress may predominate as the cause of mortality, only to decrease in importance as conditions change. This paper evaluates the thermal component of entrainment mortality by producing information on the thermal resistance characteristics of early life history stages of finfish from Long Island waters, and applies this information to a thermal response model.

Thermal resistance of fish eggs and larvae was found to be related to:

(1) the age of the developmental stage, and

(2) the temperature to which the organisms were acclimated.

As the strength of a temperature stimulus increased, the variation in responses of similarly acclimated organisms decreased.

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