SURVIVAL OF ENTRAINED ICHTHYOPLANKTON AND MACROINVERTEBRATES AT HUDSON RIVER POWER PLANTS

Prepared for:

Central Hudson Gas & Electric Corporation

Consolidated Edison Company of New York, Inc.

Orange and Rockland Utilities, Inc.

Prepared by:

Ecological Analysts, Inc.
R.D. 2, Goshen Turnpike
Middletown, New York 10940

July 1977

CONTENTS

SUMMARY

This report represents an evaluation of entrainment survival potential at Hudson River power plants. Results of field and laboratory studies simulating the effects of entrainment of macroinvertebrates and young fish provide the means for predicting entrainment-induced mortality both from mechanical and thermal stresses at Hudson River power plants. Laboratory study results of thermal stress depict the specific response to entrainment. Direct measure of entrainment survival at the power plants has provided a means of verifying laboratory predicted responses including determination of background mechanical effect as well as thermal component.

Thermal bioassay laboratory studies on key representative species of macroinvertebrates and young fish indicate defined threshold temperature levels where mortality increases from 0 to 100 percent over a range of only a few degrees C. The specific threshold varies with the species as well as the age or life stage within the species. Acclimation temperature and duration of exposure also affect threshold levels. The potential mortality induced by the thermal component of the entrainment process is thus a function of the specific ambient temperature and plant operation characteristics when entrainment occurs.

Thermal tolerance of the organisms tested under conditions simulating entrainment at Hudson River power plants was generally high for total temperatures less than 33 C for summer ambient conditions. Thresholds were reached for the macroinvertebrates *Neomysis* at about 34 C, *Gammarus* at 37 C, and *Chaoborus* at about 40 C. For fish, including the striped bass, white perch, and Clupeidae, the larvae threshold is about 33 C.

Entrainment survival measured in field sampling at the power plants is generally consistent with thermal bioassay study results. Mortality observed below expected thermal threshold temperatures is probably attributable to mechanical effects. Reductions in survival observed below 30 C were generally from 0 to 30 percent which are consistent with levels which might be expected based on pressure studies. Observed survival declines rapidly at temperatures consistent with threshold temperatures observed in thermal bioassay studies for 30-40 minute exposures to heated water.

Based on the results of these studies it is apparent that in most cases entrainment mortality is limited to low levels (0-30 percent) of mechanical mortality when discharge temperatures are maintained below threshold levels. The significance and extent of potential entrainment mortality is thus a function of the extent of threshold conditions existing at each of the power plants during the entrainment season.

Entrainment survival potential of any particular organism at a power plant can be evaluated given the tolerance of the organism, its expected frequency of occurrence, the expected ambient temperature regime, and the expected plant time-temperature exposure. The predicted survival potential of striped bass at each of the power plants is presented in this report for various possible operating regimes. Results indicate that with maximum flow, and thus minimal total temperature, survival of striped bass larvae at the plants would be high (about 75 to 90 percent for the entrainment season).

CHAPTER 1: ENTRAINMENT SURVIVAL STUDIES AT HUDSON RIVER POWER PLANTS - 1972 TO 1976

1.1 INTRODUCTION

Early studies performed elsewhere on the effects of entrainment of fish (Marcy 1971, 1973) and invertebrates (Carpenter 1974) indicated high mortality due to mechanical and thermal stress. The mechanical stress can be caused by extremes in pressure (both high and low), shear forces, and abrasion. Thermal stress is caused by sudden increases in temperatures above ambient in the condenser cooling water system as well as by continued exposure until the cooling water is discharged and again returned to ambient conditions.

From 1972 to 1977 field studies were performed at five Hudson River power plants to determine the effect of entrainment on Hudson River biota. Studies were performed at the power plants under actual operating conditions during the entrainment seasons of the major fishes and macroinvertebrates. Laboratory thermal tolerance studies simulating potential time-temperature entrainment exposures at the plants were also performed on several of the most commonly entrained ichthyoplankton species. Pressure effect studies designed to simulate extremes in pressure exposures were performed on entrainable stages of striped bass. The results of these studies are summarized in this report.

1.2 THE POWER PLANTS

Entrainment studies were performed at six power plants located on the tidal portion of the lower Hudson River (Figure 1.2-1). All the plants are steam electric generating stations; four are oil fired and two are nuclear (specifications are presented in Table 1.2-1). Cooling water temperature

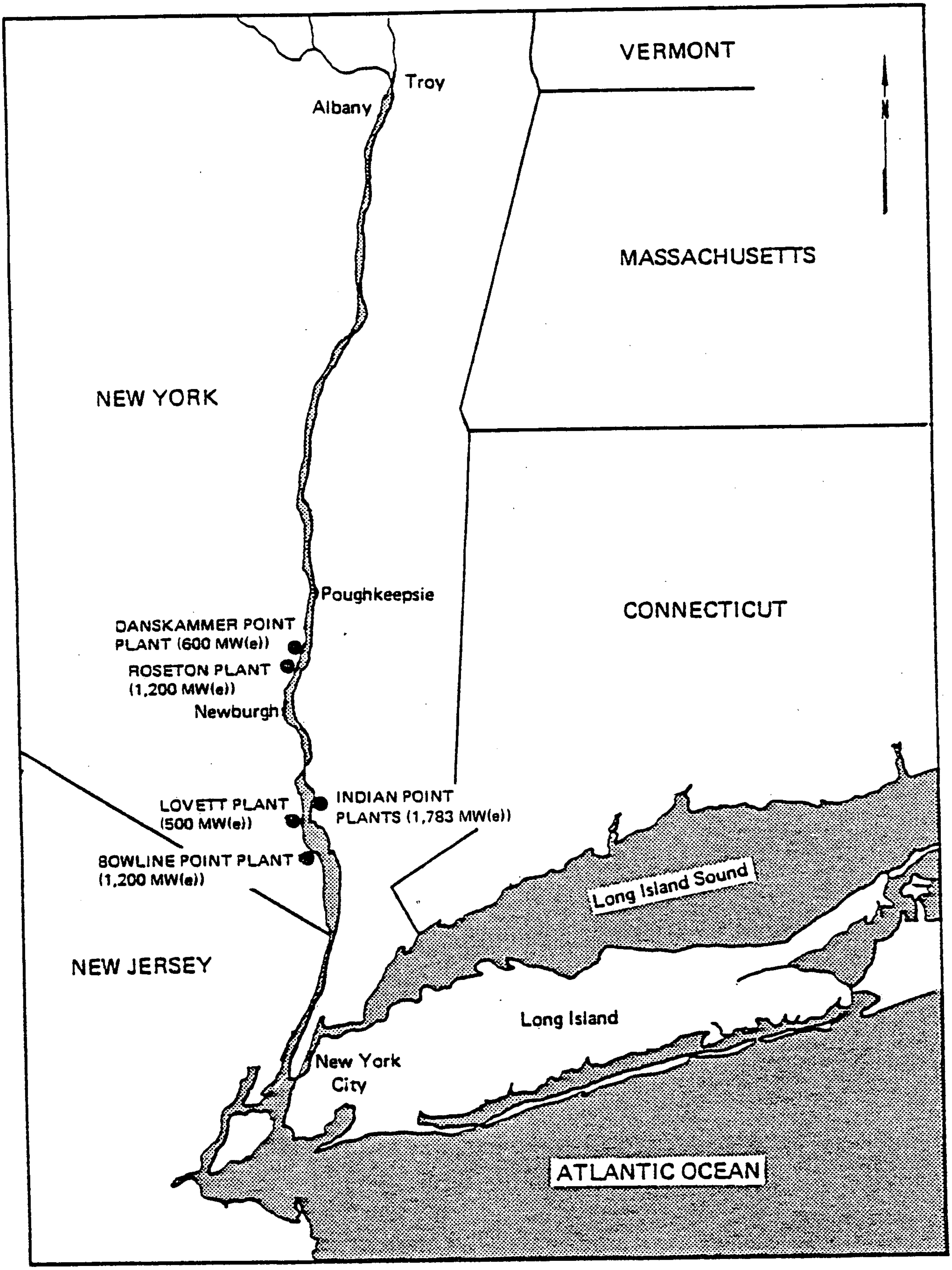

Figure 1.2-1. Location of steam electric generating stations along the Lower Hudson River Estuary (Scale = 1/1,267,200) at which entrainment survival studies were performed.

TABLE 1.2-1 SELECTED DATA ON THE SIX LOWER HUDSON RIVER POWER PLANTS

Power Plant	Type	Number of Units	Total MW(e)	Maximum Circulating Flow (m^3/min)	Temperature Rise (C)[a]	Exposure Time (min)[b]
Lovett[c]	Coal, oil	5	504	1,218	10.0-12.2	2.1
Bowline Point[c]	Oil	2	1,200	2,903	8.5	5.2
Danskammer Point[d]	Oil	4	495	2,078	7-10	1.3-6.9
Roseton[d]	Oil	2	1,200	2,426	9.0	3.4
Indian Point Unit II[e]	Nuclear	1	873	3,175	8.9	8.5-9.7
Indian Point Unit III[f]	Nuclear	1	910	3,175	9.7	5.2-5.6

(a) At full load and maximum circulating water flow.
(b) Estimated exposure time to delta-T at maximum circulating water flow.
(c) Orange and Rockland Utilities, Inc.
(d) Central Hudson Gas & Electric Corporation.
(e) Consolidated Edison Company of New York, Inc. - Unit II.
(f) Power Authority of the State of New York - Unit III. (Unit I is no longer in operation.)

Source: Consolidated Edison Corporation of New York, Inc. (1977), Orange and Rockland Utilities, Inc. (1977), Central Hudson Gas & Electric Corporation (1977).

rise within the plants varies with the generating load and amount of circulating water flow. Temperature rise at peak loads and full flows ranges from 7 to 12 C above ambient water temperature for periods of from 2 to 10 minutes.

1.3 FIELD ENTRAINMENT SURVIVAL STUDIES

Survival studies were performed at the Indian Point nuclear power plants from 1972 to 1975 by New York University and in 1977 by Ecological Analysts, Inc., and at the Roseton, Danskammer Point, Bowline Point, and Lovett plants during 1975, 1976, and 1977 by Ecological Analysts. The objective of the studies was to determine survival rates for macrozooplankton and ichthyoplankton that passed through the condenser cooling systems of the plants. The basic design of the studies entailed sampling at the intakes and discharges of the plants. Intake sampling served as a control representing the mortality induced by sampling and handling; discharge sampling represented mortality induced by sampling, handling, and the entrainment process, as well as any synergistic effects.

Entrainment survival sampling at Indian Point was performed from 1972 to 1975, during which time sampling was extended from one to two units when Unit II became operational. Sampling was usually conducted weekly or twice weekly from early May through July, encompassing the entrainment season of most of the ichthyoplankton species. Sampling was attempted once per month during the other months during most of the four years of sampling. Sampling was usually performed at night to coincide with higher abundances of organisms.

The sampling stations are depicted in Figure 1.3-1. Up to eight stations were sampled (four in intakes and four in discharges) when units were operating. Since the discharge is combined for all units, discharge sta-

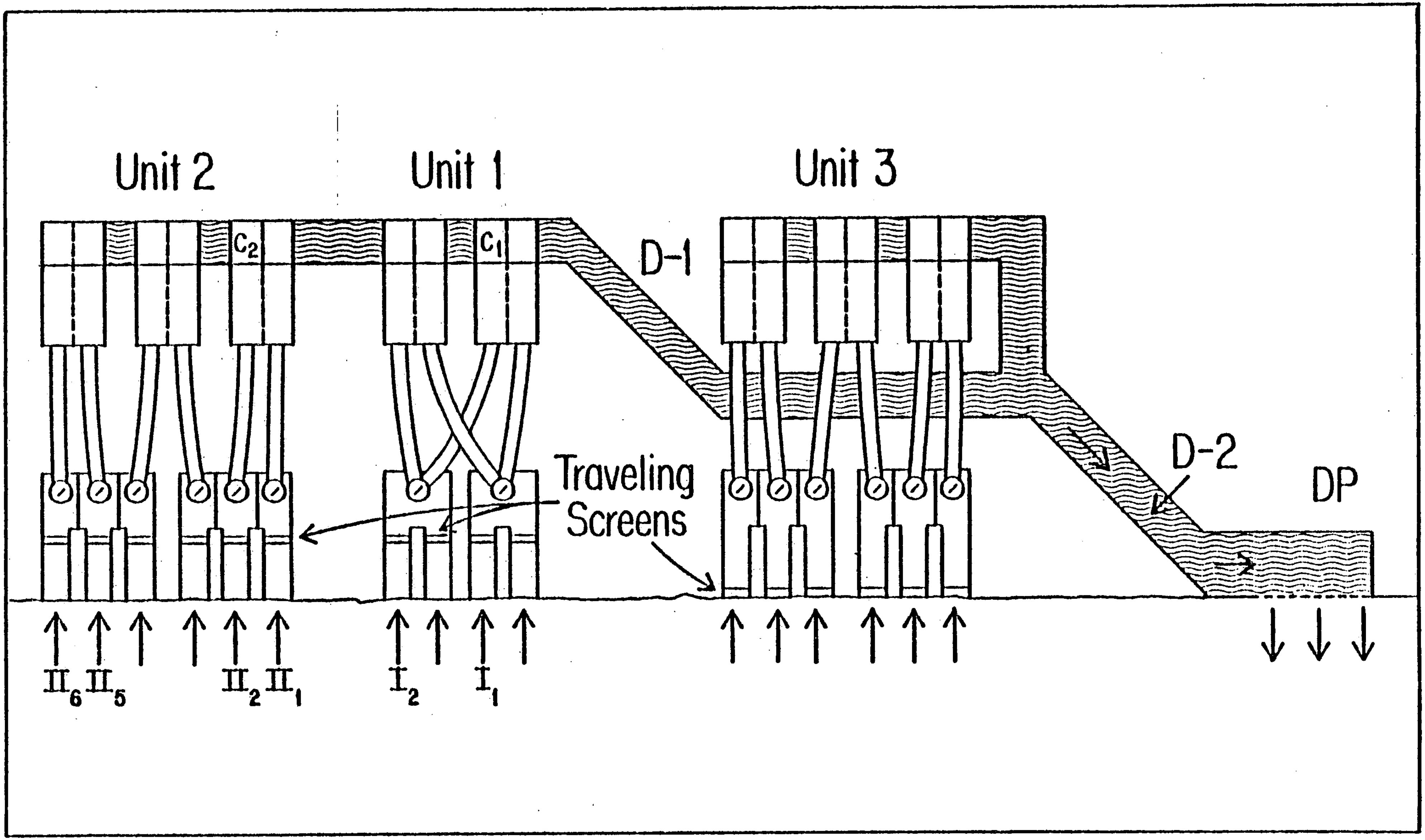

Figure 1.3-1. Schematic diagram of Indian Point cooling water system showing locations of sampling stations.

tions included water from all units (except when one unit was not operating). In 1972 only Unit I was operational. Intake sampling was performed only at Unit I in 1973, although Unit II circulators (pumps) were being tested and were contributing a greater proportion of the flow to the discharge canal.

In 1974 both Unit I and Unit II circulators were operating at near capacity and intake sampling was performed at both units; while in 1975 only Unit II was operational with intake sampling confined to that unit.

Nets of No. 0 mesh (571-μ) were rigged to sample at surface, middle, and bottom (Figure 1.3-2) at each of the sampling stations. One or two nets were sampled at each position for 5-minute periods as often as possible during a day's sampling period. The number of samples and frequency of sampling within a sampling period varied between the years.

In 1974, velocity reduction cones were placed on the openings of the nets in the dicharge canal to reduce approach velocity to a level similar to that of the intakes. This was deemed necessary because of the increased velocities in the discharge canal as Unit II became operational. Decreased survival in 1973 from the 1972 level was attributed to the higher approach velocities in the discharge canal from operation of Unit II circulators. Discharge port stations proved difficult to sample due to extremely high velocities despite velocity reduction cones; thus, results from these stations are not presented in this report.

Entrainment survival sampling was performed at the Roseton, Danskammer Point, Lovett, and Bowline Point power plants during 1975 and 1976. Ichthyoplankton entrainment survival sampling was performed from March through

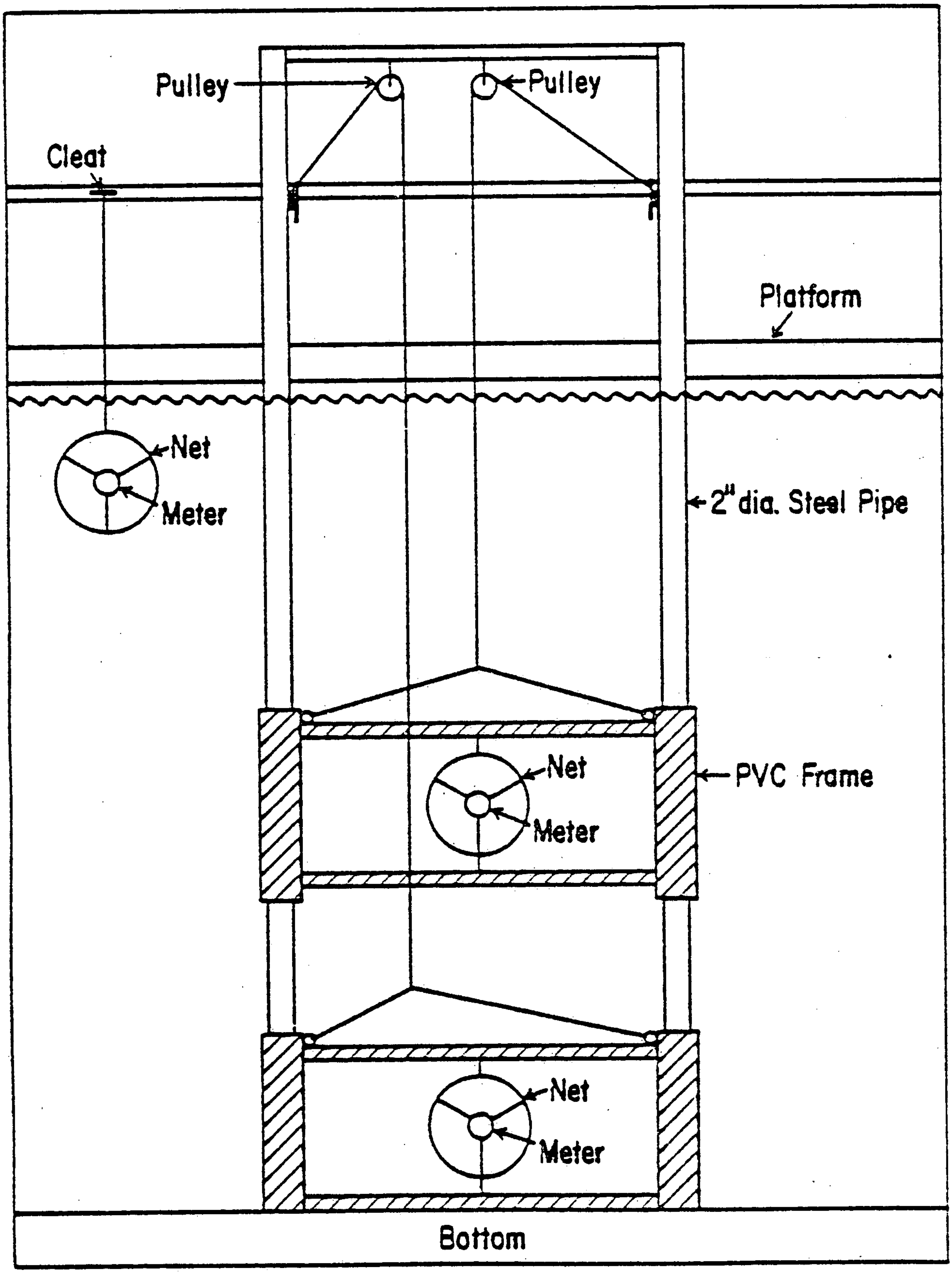

Figure 1.3-2. Sampling rig used to sample macrozooplankton and ichthyoplankton in the Indian Point cooling system (Lauer et al. 1974).

August during the peak of the entrainment season for clupeids (alewife, blueback herring, and American shad), striped bass, white perch, Atlantic tomcod, and bay anchovy. Macroinvertebrates were sampled continuously throughout the year on a twice-per-month, monthly, or seasonal basis depending on the plant and year. Sampling was generally performed in the late afternoon, evening, or nighttime hours with the intent of coinciding with peak abundance of organisms.

Sampling at the intakes and discharges of the plants was accomplished using high-volume, recessed-impeller pumps in conjunction with flow-reducing troughs called "larval tables" (Figure 1.3-3) modified from an original design described by McGroddy and Wyman (1977). Intake and discharge water was pumped into the larval tables during 15-minute periods at approximately 600-800 liters (about 150-200 gallons) per minute. Organisms and debris were diverted by fine mesh screening into the back of the table where they were retained in a collection basket. At the end of a 15-minute sampling period the pumping was terminated and the table drained through the collection basket. The tables were thoroughly washed down near the end of the draining period and after removal of the collection basket. Table washes were collected and preserved for subsequent examination to ensure that all organisms were being retained in the collection basket.

In 1977, the pump-larval table sampling system is again being employed at the Roseton, Bowline Point, and Lovett plants. The system is also being employed at Indian Point at the intakes of Unit I and Unit II and at two discharge stations (near D-2 and DP).

The method of processing samples was essentially identical at all the plants during all the sampling years. Intake and discharge samples were sorted

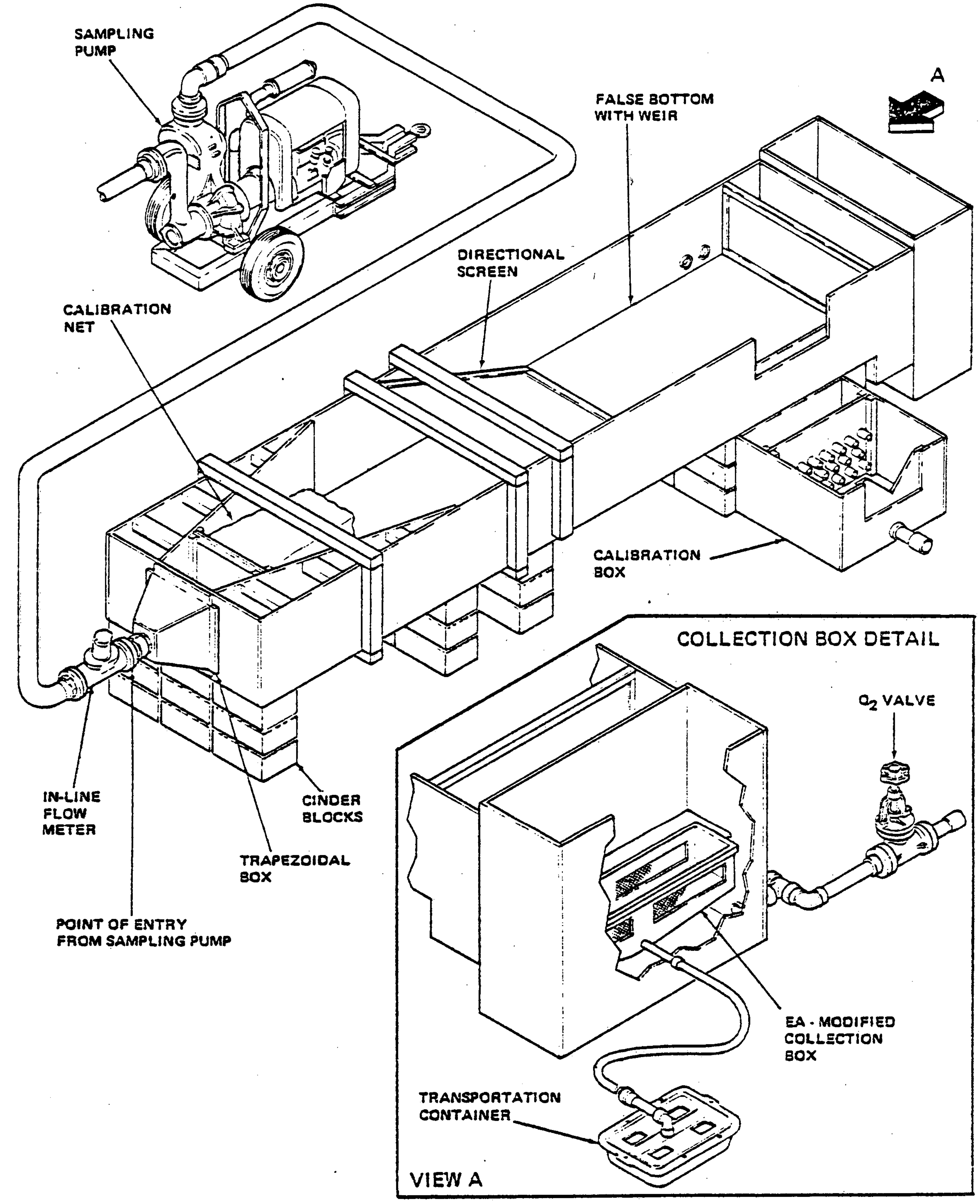

Figure 1.3-3. Design of the larval collection tables used in the Roseton plant entrainment survival studies during 1976.

simultaneously immediately after sample collection in an onsite laboratory. Organisms were sorted from a sorting tray with large-bore pipettes into the categories of live, stunned, or dead based on the following criteria:

Live: Swimming vigorously, no orientation problems, behavior normal.

Stunned: Swimming erratically, struggling, responsive to stimulus.

Dead: No life signs, no body or opercular movements, no response to probing.

Dead organisms were removed from the samples and stored in 10 percent formalin for later identification. Subsamples of live and stunned macrozooplankton and all live and stunned ichthyoplankton were held for latent effects observations in containers maintained in ambient water baths. Frequency and length of latent observation varied. Live macrozooplankton were usually subsampled for latent effects observations. All ichthyoplankton were generally held for latent observation. The latent observation period varied from three to five days.

The statistical test used for comparison of survival between control (intake) and treatment (discharge) groups is the binomial test for differences between two proportions (Freund 1967). The proportions measured in these studies were percent alive, stunned, and dead. The primary means of presenting these data in this report will be by total proportion alive (both live and stunned) under specified conditions. The specific test comparison is a comparison of the live proportion between intake and discharge stations.

The proportions alive at the intake and discharge immediately following sample collection were compared to determine the initial effects of the entrainment process. The proportion of those organisms collected alive at the two stations over a specified latent effects observation period was also compared.

The statistical significance of the difference in proportions at the intake and discharge was tested with the z statistic (Freund 1967):

$$z = \frac{P_i - P_d}{\sqrt{\frac{P_i(1 - P_i)}{N_i} + \frac{P_d(1 - P_d)}{N_d}}}$$

where

P_i = proportion surviving at intake

P_d = proportion surviving at discharge

N_i = number of organisms collected at the intake

N_d = number of organisms collected at the discharge.

The null hypothesis of equal proportions ($P_i = P_d$) was tested against the alternative hypothesis, $P_i > P_d$, at an α level of 0.05. The one-sided alternative was chosen since only a reduction in discharge survival was expected and deemed of value in these studies.

Results of survival studies performed at Indian Point from 1972 to 1975 were generally complicated by variations in plant operation. Unit I operated consistently only in 1972. Unit II began testing in 1973; however, minimal heat load was generated. In the 1974 and 1975 entrainment seasons Unit II operated consistently at near normal or full load generation; however, variability existed in operation of Unit I and Unit III circulating water systems, which resulted in considerable variability in delta-T, transit time, intake and discharge canal velocities, and overall time-temperature exposure of organisms entrained.

Variations in the discharge canal velocities, in particular the existence of higher velocities than those at the intakes, have resulted in underestimates of survival despite the existence of velocity reduction cones on the sampling nets (NYU 1976).

Periods when minimal plant load occurred provide data as to mechanical effects of the plants. During higher load generation, data were obtained on response of organisms to thermal shock in addition to the mechanical effect due to entrainment.

Survival studies at the four fossil fuel steam generating stations were performed under lesser variations in plant operations. Operation was near normal during entrainment sampling seasons at each plant, except at Roseton and Bowline Point in 1975 when plant loading was low. Again, as in the case of Indian Point, data obtained in these studies provided information on the response of organisms to the thermal and mechanical stresses imposed during the entrainment process.

1.3.1 Macroinvertebrates

Survival of macroinvertebrates at the five plants as measured immediately upon collection (termed initial survival) is presented by plant in Tables 1.3-1 through 1.3-7. Latent survival (4-5 days) is presented by plant in Tables 1.3-8 and 1.3-9. The proportion surviving the intakes and discharges are presented by species under various intake and discharge temperature conditions. Significant differences between the intake and discharge proportion surviving are noted with an asterisk.

Survival of *Gammarus daiberi* was similar between intake and discharge at all plants for initial observations. Although statistically significant

TABLE 1.3-1 SURVIVAL OF MACROINVERTEBRATES AT THE UNIT I (STATIONS I-1 AND I-2) INTAKES AND DISCHARGE (STATIONS D-1 AND D-2) OF THE INDIAN POINT PLANT, 1972

Taxon	Station	Temperature (C)	Initial Proportion Surviving
Gammarus spp.	I	20-22	0.97
	D	20-22	0.99
	I	23-26	0.97
	D	28-31	0.95
	I	26-26	0.98
	D	32-33	0.96
Monoculodes edwardsi	I	6-15	0.95
	D	16-22	0.90
	I	21-24	0.95
	D	28-30	0.95
	I	25	0.97
	D	31-33	0.93
Neomysis americana	I	14-19	0.85
	D	20-26	0.77
	I	21-26	0.88
	D	28-31	0.82
	I	25-26	0.95
	D	32-33	0.61*

Note: * indicates significantly lower proportion surviving than intake.
Source: Adapted from Lauer et al. (1974).

TABLE 1.3-2 SURVIVAL OF MACROINVERTEBRATES AT THE UNIT I (STATIONS I-1 AND I-2) AND UNIT II (STATIONS II-2) INTAKES AND COMMON DISCHARGE (STATIONS D-1 AND D-2) OF THE INDIAN POINT PLANT, 1974

Taxon	Station	Temperature (C)	Initial Proportion Surviving
Gammarus spp.	I	13-18	0.98
	D	20-28	0.97
	I	21-25	0.96
	D	26-33	0.96
Monoculodes edwardsi	I	13-25	0.94
	D	19-33	0.92
Neomysis americana	I	13-26	0.84
	D	19-33	0.58*

Note: * indicates significantly lower proportion surviving than intake.
Source: Adapted from NYU (1976).

TABLE 1.3-3 SURVIVAL OF MACROINVERTEBRATES AT THE UNIT II (STATIONS II-2 AND II-5) INTAKES AND DISCHARGE (STATIONS D-1 AND D-2) OF THE INDIAN POINT PLANT, 1975

Taxon	Station	Temperature (C)	Initial Proportion Surviving
Gammarus sp.	I		0.96
	D	17-31	0.97
	I		0.95
	D	31-34	0.96
Monoculodes edwardsi	I		0.91
	D	21-33	0.90
Neomysis americana	I		0.94
	D	32-34	0.77*
Chaoborus punctipennis	I		0.96
	D	30-33	0.94

Note: * indicates significantly lower proportion surviving than intake.
Source: Adapted from NYU (1977).

TABLE 1.3-4 SURVIVAL OF MACROINVERTEBRATES AT THE INTAKE (I) AND DISCHARGE (D) AT THE ROSETON PLANT, 1975 AND 1976

Taxon	Station	Temperature (C)	Number of Organisms	Initial Proportion Surviving
Gammarus daiberi	I	4-7	267	0.98
	D	11-19	607	0.94
	I	12-17	1,694	0.98
	D	15-25	1,211	0.95*
	I	20-24	976	0.94
	D	26-29	1,209	0.91*
	I	25-26	945	0.95
	D	31-33	1,570	0.94
	I	25-26	309	0.92
	D	35-36	357	0.64*
Chaoborus punctipennis	I	12-15	57	0.97
	D	15-25	70	0.97
	I	20-24	529	0.95
	D	26-29	345	0.90
	I	25-26	4,247	0.98
	D	31-34	2,189	0.94*
	I	25-26	3,412	0.98
	D	35-36	1,980	0.92*

Note: * indicates significantly lower proportion surviving than intake.

TABLE 1.3-5 SURVIVAL OF MACROINVERTEBRATES AT THE INTAKE (I) AND DISCHARGE (D) AT THE BOWLINE POINT PLANT, 1975 AND 1976

Taxon	Station	Temperature (C)	Number of Organisms	Initial Proportion Surviving
Gammarus daiberi	I	3-20	694	0.92
	D	12-29	731	0.93
	I	24-26	1,630	0.99
	D	30-34	495	0.93*
	I	26-29	426	0.92
	D	35-37	168	0.90
Monoculodes edwardsi	I	5-20	442	0.88
	D	9-29	356	0.81
	I	26-29	236	0.71
	D	35-37	151	0.82
Chaoborus punctipennis	I	25-26	450	0.97
	D	30-34	314	0.95
	I	26-29	1,043	0.94
	D	35-37	582	0.92
Neomysis americana	I	19-21	101	0.90
	D	28-29	178	0.85
	I	24-25	142	0.82
	D	32-34	147	0.61*

Note: * indicates significantly lower proportion surviving than intake.

TABLE 1.3-6 SURVIVAL OF MACROINVERTEBRATES AT THE INTAKE (I) AND DISCHARGE (D) AT THE DANSKAMMER POINT PLANT, 1975

Taxon	Station	Temperature (C)	Number of Organisms	Initial Proportion Surviving
Gammarus daiberi	I	11-12	2,001	0.99
	D	18-22	405	0.87*
	I	22-26	4,531	0.96
	D	30-33	3,761	0.87*
Chaoborus punctipennis	I	20-23	532	0.94
	D	27-31	304	0.97
	I	25-26	4,004	0.98
	D	31-33	2,084	0.92*

Note: * indicates significantly lower proportion surviving than intake.

TABLE 1.3-7 SURVIVAL OF MACROINVERTEBRATES AT THE INTAKE (I) AND DISCHARGE (D) AT THE LOVETT PLANT, 1976

Taxon	Station	Temperature (C)	Number of Organisms	Initial Proportion Surviving
Gammarus daiberi	I	6-10	612	0.96
	D	14-20	781.	0.93
	I	26	990	0.996
	D	31	395	0.984
Monoculodes edwardsi	I	6-10	499	0.91
	D	14-20	463	0.65*
	I	26	365	1.00
	D	31	84	0.95
Chaoborus punctipennis	I	6	4,488	0.98
	D	14-15	2,404	0.97*
	I	26	4,464	0.98
	D	31	2,301	0.97*
Neomysis americana	I	26	282	0.93
	D	31	597	0.94

Note: * indicates significantly lower proportion surviving than intake.

TABLE 1.3-8 LATENT SURVIVAL OF MACROINVERTEBRATES (NOT INCLUDING *GAMMARUS DAIBERI*) COLLECTED IN ENTRAINMENT SURVIVAL STUDIES AT INTAKES AND DISCHARGES OF FIVE HUDSON RIVER STEAM GENERATING STATIONS

Plant	Year	Species	Station	Number	Proportion Surviving
Indian Point[a]	1974	*Neomysis americana*	I	102	0.76
			D	177	0.76
Roseton	1975 and 1976	*Chaoborus punctipennis*	I	728	0.45
			D	821	0.48
Danskammer Point	1975	*Chaoborus punctipennis*	I	617	0.56
			D	286	0.40*
Lovett	1976	*Chaoborus punctipennis*	I	81	0.56
			D	136	0.74
		Monoculodes edwardsi	I	85	0.81
			D	55	0.84
Bowline Point	1975 and 1976	*Chaoborus punctipennis*	I	422	0.54
			D	327	0.64
		Monoculodes edwardsi	I	212	0.53
			D	165	0.65
		Neomysis americana	I	78	0.45
			D	94	0.50

(a) 4-day latent holding period (NYU 1976)

Note: * indicates significantly lower proportion surviving than intake.

TABLE 1.3-9 LATENT SURVIVAL OF *GAMMARUS DAIBERI* COLLECTED IN ENTRAINMENT SURVIVAL STUDIES AT INTAKES AND DISCHARGES OF HUDSON RIVER POWER PLANTS

Plant	Season	Station	Temperature (C)	Number	Proportion Surviving
Indian Point	Spring	I	9-22	303	0.91
		D	21-23	510	0.92
Danskammer Point	Summer	I	22-26	291	0.92
		D	30-33	199	0.78*
	Fall	I	11-12	113	0.89
		D	18-22	94	0.77*
Lovett	Summer	I	26	31	0.84
		D	31	18	0.83
	Spring and fall	I	6-10	160	0.99
		D	14-20	322	0.90*
Bowline Point	Summer	I	25-26	157	0.81
		D	32-35	103	0.72*
	Spring and fall	I	3-20	234	0.76
		D	12-29	174	0.64*
Roseton	Summer	I	23-26	153	0.80
		D	31-36	229	0.52*
	Spring and fall	I	4-22	291	0.90
		D	11-26	271	0.78*

Note: * indicates significantly lower proportion surviving than intake.

reductions were detected in a few cases they were generally only a few percent with the exception of Danskammer Point (Table 1.3-6), where reductions were about 10 percent for all operating conditions studied, and Roseton (Table 1.3-4), where a reduction of 30 percent was observed at discharge temperatures of 35 to 36 C. Survival at Bowline Point under similar extreme discharge temperatures (35 to 37 C) was not significantly reduced (Table 1.3-5). These extremes were not observed at the other three plants.

Latent survival of Gammarus daiberi during the studies was consistently lower in the discharge collections (Table 1.3-9). Reductions were generally from 10 to 15 percent during spring and fall conditions, except at Indian Point where no difference was observed. Reductions during the summer period were similar, with the exception of Roseton where the reduction was 35 percent. These observed latent effects are at least partially attributable to the extended exposure time (30 to 60 minutes) to high discharge temperature during sampling as compared to that during actual entrainment (3 to 5 minutes). Ginn (1977) found a statistically significant latent effect on Gammarus at temperatures above 33.8 C for durations longer than 30 minutes.

Survival of Chaoborus punctipennis and Monoculodes edwardsi was similar for intake and discharge collection at both initial and latent observation. Data at each of the plants under the extremes of conditions indicated high initial survival in intake and discharge collections with one exception, where Monoculodes edwardsi initial survival at the Lovett plant was reduced 29 percent for spring and fall conditions (Table 1.3-7).

Survival of Neomysis americana at the Indian Point, Lovett, and Bowline Point plants was significantly reduced when discharge temperatures reached or exceeded 32 C. Initial survival was similar between intake and discharge collections when discharge temperatures were less than 32 C. Survival was reduced 20 to 30 percent for discharge temperatures between 32 and 34 C; no survival data were obtained for higher discharge temperatures. Latent survival (4 days) was not significantly reduced in discharges.

1.3.2 Ichthyoplankton

Survival of ichthyoplankton at the six plants as measured immediately upon collection (initial survival) is presented by plant in Tables 1.3-10 through 1.3-17. Latent survival (3 days) of those which initially survived is presented by plant in Table 1.3-18. The proportion surviving the discharges is presented by species and life stage under various conditions of discharge temperature. Intake survival has been lumped for all conditions, since the specific life stages of each species were usually collected over a narrow range of ambient temperatures. Levels of discharge temperatures were generated from changes in both ambient temperature and plant operation (either load or circulating water flow).

Survival of striped bass (*Morone saxatilis*) varied considerably between intake and discharge, depending on conditions existing at each of the plants. Data collected at Indian Point from 1972 to 1975 were the most variable due to extremes in plant operation, in particular, discharge canal flows generated from the operation of up to 16 circulating water pumps from the three units. Survival data collected with the sampling gear used at Indian Point (0.5-m plankton nets) proved to be directly related to water velocities at the mouth of the net (NYU 1976). Otherwise, survival at Indian Point and at the other four plants appeared to be primarily related to the discharge temperature, which varied considerably between years, within years,

TABLE 1.3-10 SURVIVAL OF LARVAL FISH AT THE UNIT I INTAKE (STATIONS I-1 AND I-2) AND DISCHARGE STATIONS (D-1 AND D-2) OF THE INDIAN POINT PLANT, 1972

Taxon	Station	Discharge Temperature (C)	Number of Fish	Initial Proportion Surviving
Morone (striped	I		657	0.64
bass & white	D	(No ΔT)	188	0.49*
perch, combined)	D	20.6-34.4[a]	211	0.52*
Atlantic tomcod	I	(No ΔT)	272	0.83
	D	(No ΔT)	180	0.77

(a) Only 14 percent of larvae collected in discharge were collected at temperatures from 31.1 C to 34.4 C; the remainder were collected at temperatures from 20.6 C to 26.1 C.

Note: * indicates significantly lower than intake proportion.

TABLE 1.3-11 SURVIVAL OF STRIPED BASS YOUNG AT THE UNIT I INTAKES (I-1 AND I-2) AND DISCHARGES (STATIONS D-1 AND D-2) OF THE INDIAN POINT PLANT, 1973

Life Stage	Station	Discharge Temperature (C)	Number of Fish	Initial Proportion Surviving
Eggs	I	(a)	946	0.60
	D	--	616	0.13*
Yolk-sac larvae	I	--	132	0.50
	D	--	99	0.18*
Larvae	I	--	849	0.45
	D	--	3,516	0.22*
Juveniles	I	--	153	0.77
	D	--	785	0.34*

(a) During 1973 delta-Ts were present in the discharge on only 3 of the 12 sampling days and ranged only from 3.2 to 6.4 C.

Note: * indicates significantly lower proportion surviving than intake.

TABLE 1.3-12 SURVIVAL OF STRIPED BASS YOUNG AT THE UNIT I (STATIONS I-1 AND I-2) AND UNIT II (STATIONS II-2) INTAKES AND COMMON DISCHARGE (STATIONS D-1 AND D-2) OF THE INDIAN POINT PLANT, 1974

Life Stage	Station	Discharge Temperature (C)[a]	Number of Fish	Initial Proportion Surviving
Eggs	I		968	0.51
	D	<30.0	227	0.26*
Yolk-sac larvae	I		196	0.35
	D	<30.0	39	0.05*
Larvae	I		654	0.41
	D	<30.0	403	0.16*
Juveniles	I		25	1.00
	D	<30.0	19	0.84

(a) Delta-Ts ranged from 5.4 C to 8.7 C; ambient temperatures were such that discharge temperatures during sampling remained below 30 C.

Note: * indicates significantly lower proportion surviving than intake.

TABLE 1.3-13 SURVIVAL OF STRIPED BASS YOUNG AT THE UNIT II (STATIONS II-2 AND II-5) INTAKES AND COMMON DISCHARGE (STATIONS D-1 AND D-2) OF THE INDIAN POINT PLANT, 1975

Life Stage	Station	Discharge Temperature (C)	Number of Fish	Initial Proportion Surviving
Eggs	I		1,115	0.48
	D	<28	273	0.23*
Yolk-sac larvae	I		110	0.21
	D	<28	24	0.00*
Larvae	I		1,390	0.57
	D	23-31	439	0.30
Juveniles	I		23	0.61
	D	33-34	8	0.13

Note: * indicates significantly lower proportion surviving than intake.

TABLE 1.3-14 SURVIVAL OF ICHTHYOPLANKTON AT THE INTAKE (I) AND DISCHARGE (D) OF THE LOVETT PLANT, 1976

Taxon	Life Stage	Station	Discharge Temperature (C)	Number of Fish	Initial Proportion Surviving
Striped bass	Yolk-sac larvae	I		25	0.80
		D	20.0-29.9	13	0.92
	Larvae	I		101	0.80
		D	23.0-29.9	87	0.53*
		D	30.0-32.9	47	0.43*
		D	33.0-35.9	10	0.40*
White perch	Larvae	I		42	0.57*
		D	17.0-29.9	42	0.29*
		D	30.0-32.9	34	0.35*
		D	33.0-35.9	7	0.29
Clupeidae (blueback herring and alewife)	Larvae	I		338	0.33
		D	19.0-29.9	396	0.33
		D	30.0-32.9	35	0.09*
		D	33.0-35.9	19	0.05*

Note: * indicates significantly lower proportion surviving than intake.

TABLE 1.3-15 SURVIVAL OF ICHTHYOPLANKTON AT THE INTAKE (I) AND DISCHARGE OF THE ROSETON PLANT, 1975 AND 1976

Taxon	Life Stage	Station	Discharge Temperature (C)	Number of Fish	Initial Proportion Surviving
Striped bass	Larvae	I		193	0.78
		D	19.0-29.9	181	0.60*
		D	30.0-32.9	25	0.48*
		D	33.0-35.9	46	0.07*
White perch	Larvae	I		478	0.56
		D	21.0-29.9	121	0.38*
		D	30.0-32.9	80	0.23*
		D	33.0-35.9	239	0.03*
Clupeidae (blueback herring and alewife)	Larvae	I		1,518	0.54
		D	19.0-29.9	871	0.30*
		D	30.0-32.9	425	0.07*
		D	33.0-35.9	174	0.01*
	Juvenile	I		498	0.64
		D	29.0-29.9	153	0.35*
		D	30.0-32.9	95	0.13*
		D	33.0-35.9	47	0.00*

Note: * indicates significantly lower proportion surviving than intake.

TABLE 1.3-16 SURVIVAL OF ICHTHYOPLANKTON AT THE INTAKE (I) AND DISCHARGE (D) OF THE DANSKAMMER POINT PLANT, 1975

Taxon	Life Stage	Station	Discharge Temperature (C)	Number of Fish	Initial Proportion Surviving
Striped bass	Larvae	I		54	0.41
		D	19.0-29.9	61	0.39
White perch	Larvae	I		36	0.33
		D	21.0-29.9	51	0.39
		D	30.0-32.9	4	0.25
Clupeidae (alewife and blueback herring	Larvae	I		200	0.36
		D	19.0-29.9	285	0.21*
		D	30.0-32.9	36	0.11*
		D	33.0-35.9	5	0.40
	Juveniles	I		33	0,27
		D	29.0-29.9	41	0.19
		D	30.0-32.9	24	0.25

Note: * indicates significantly lower proportion surviving than intake.

TABLE 1.3-17 SURVIVAL OF ICHTHYOPLANKTON AT THE INTAKE (I) AND DISCHARGE (D) OF THE BOWLINE POINT PLANT, 1975 AND 1976

Taxon	Life Stage	Station	Discharge Temperature (C)	Number of Fish	Initial Proportion Surviving
Striped bass	Larvae	I		259	0.81
		D	19.0-29.9	250	0.67*
		D	30.0-32.9	29	0.62*
		D	33.0-35.9	40	0.20*
	Juveniles	I		13	1.00
		D	24.0-29.9	12	1.00
		D	30.0-32.9	23	0.96
		D	33.0-34.9	10	0.80
White perch	Larvae	I		177	0.58
		D	21.0-29.9	176	0.68
		D	30.0-32.9	15	0.47
		D	33.0-35.9	18	0.01*
Clupeidae (alewife and blueback herring)	Larvae	I		70	0.39
		D	19.0-29.9	73	0.34
		D	30.0-32.9	6	0.17
		D	33.0-35.9	19	0.00*
Bay anchovy	Larvae	I		2,282	0.09
		D	24.0-29.9	161	0.07
		D	30.0-32.9	226	0.01*
		D	33.0-35.9	1,980	0.00*
	Juveniles	I		514	0.62
		D	23.0-29.9	42	0.74
		D	30.0-32.9	60	0.33*
		D	33.0-35.9	263	0.08*

Note: * indicates significantly lower than intake proportion.

TABLE 1.3-18 LATENT SURVIVAL (3 DAYS) OF STRIPED BASS LARVAE AND JUVENILES COLLECTED IN ENTRAINMENT SURVIVAL STUDIES AT INTAKES AND DISCHARGES OF FIVE HUDSON RIVER STEAM GENERATING STATIONS

			Larvae		Juveniles	
Plant	Year	Station	Number of Fish	Proportion Surviving	Number of Fish	Proportion Surviving
Indian Point	1973-1975[a]	I	1,334	0.32	63	0.81
		D	515	0.29	52	0.54*
Danskammer Point	1975	I	22	0.15		
		D	24	0.18		
Lovett	1976	I	80	0.46		
		D	70	0.35		
Bowline	1975 & 1976	I	210	0.50	13	0.92
		D	193	0.44	39	0.69*
Roseton	1975 & 1976	I	151	0.22		
		D	123	0.17		

(a) Adapted from NYU (1974, 1976, and 1977).

Note: * indicates significantly lower than intake proportion.

and between plants, due to variations in the temporal occurrence of the striped bass, ambient temperature, and plant operations.

Striped bass egg and yolk-sac larvae survival were obtained only for the Indian Point plant, where numbers collected were sufficient for comparison. Observed survival of eggs in the discharge canal at Indian Point was from 49 to 78 percent lower than that for the intake (Tables 1.3-11 to 1.3-13). Yolk-sac larvae survival reduction was substantially higher. For both egg and yolk-sac larvae collection periods discharge temperatures were below 30 C. Striped bass larvae survival at Indian Point varied from reductions of only about 20 percent in 1972 to as high as 61 percent in 1974 (Tables 1.3-10 to 1.3-13). Discharge temperatures varied little between and within years, thus, relative survival over a range of temperature conditions was not obtained. Discharge temperatures were less than 30 C for most of the sampling dates during all four years of sampling.

Striped bass larvae survival at three of the four other power plants was significantly lower in the discharge collections, with the degree of reduction being directly related to discharge temperature. At discharge temperatures less than 30 C, no significant reduction was observed at the Danskammer Point plant (Table 1.3-16), while reductions of 17, 23, and 34 percent were observed for the Bowline Point, Roseton, and Lovett plants, respectively. For discharge temperatures from 33 to 36 C, survival reductions observed were 50, 75, and 91 percent for the Lovett, Bowline Point, and Roseton plants, respectively. No data were obtained for discharge temperatures of 30 C or greater at the Danskammer Point plant.

Latent survival (3 days) of the striped bass larvae was not significantly different between intake and discharge at each of the five power plants (Table 1.3-18). Discharge survival levels, however, were about 10 to 20 percent lower than intake survival for four of the five plants.

Striped bass juvenile survival information was generally minimal due to low abundance in collections. One exception was the collections at Indian Point in 1973 (Table 1.3-11), when 938 juveniles were collected. A 55 percent reduction in survival for temperatures for the most part less than 30 C in the discharge was similar to that of larvae for that year. Minimal data collected at Bowline Point (Table 1.3-17) indicate high initial survival in discharge for juveniles. Corresponding data on latent effects (Table 1.3-18), however, indicate significant latent reductions of 37 percent and 25 percent for Indian Point and Bowline Point, respectively.

Survival of ichthyoplankton of other species of fish including white perch (Morone americana), alewife (Alosa pseudoharengus), blueback herring (Alosa estivalis), bay anchovy (Anchoa mitchilli), and Atlantic tomcod (Microgadus tomcod) was also related to magnitude of discharge temperature. White perch larvae, being of the same genus as the striped bass, responded similarly. For temperatures below 30 C, white perch larvae survival in the discharge collections was not significantly lower at Bowline Point (Table 1.3-17) or Danskammer Point (Table 1.3-16), while it was 32 percent and 49 percent lower at Roseton (Table 1.3-15) and Lovett (Table 1.3-14), respectively. At discharge temperatures from 33 to 36 C white perch larvae survival was reduced 95 percent and 99 percent at Roseton and Bowline Point, respectively. Latent survival of white perch larvae was not significantly reduced in the discharge collections (Table 1.3-19).

TABLE 1.3-19 LATENT SURVIVAL (4 DAYS) OF WHITE PERCH LARVAE COLLECTED IN ENTRAINMENT SURVIVAL STUDIES AT INTAKES AND DISCHARGES OF FOUR HUDSON RIVER STEAM GENERATING STATIONS

Plant	Year	Station	Number of Fish	Proportion Surviving
Bowline Point	1975 and 1976	I	101	0.37
		D	128	0.41
Roseton	1975 and 1976	I	268	0.03
		D	72	0.06

Survival of Clupeidae larvae collected in discharge samples appears similar to the Morone. Initial survival of larvae for discharge temperatures below 30 C was reduced 0, 13, 42, and 45 percent for Lovett, Bowline Point, Danskammer Point, and Roseton, respectively (Tables 1.3-14 to 1.3-17). Discharge temperatures above 35 C resulted in survival reductions of 98 and 100 percent for Roseton and Bowline Point, respectively. Latent mortality was generally 100 percent within the first day of observation for both intake and discharge groups, thus, existence or nonexistence of latent effects was not determined.

Clupeidae juveniles were similar in tolerance to larvae, based on data from Roseton (Table 1.3-15) and Danskammer Point (Table 1.3-16). Reduction in survival was 45, 80, and 100 percent for discharge temperatures below 30 C, from 30 to 33 C, and 33 to 35 C, respectively. As in the case of larvae, latent effects could not be determined due to poor survival in both intake and discharge groups.

Bay anchovy larvae and juvenile survival was observed at the Bowline Point plant. Poor initial survival limits the interpretation of larval data, although it is apparent that high mortality occurs at discharge temperatures in excess of 30 C (Table 1.3-17). Initial survival of bay anchovy juveniles was considerably higher than larvae, and results indicated no significant reduction in survival below 30 C and a significant reduction of 87 percent above 33 C.

Survival of Atlantic tomcod larvae, which occur during winter rather than spring and summer as do the other species, was not significantly reduced in discharge collections at Indian Point (Table 1.3-10) with no delta-T present.

The results of studies being performed at the power plants during 1977 will be compiled by late 1977. Preliminary initial survival data from field collection sheets, which do not include classification as to species or life stage, indicate survival patterns similar to previous years.

Winter 1977 survival data collected at Roseton and Bowline Point reflect survival potential of Atlantic tomcod larvae (Table 1.3-20). Survival reductions were greatest at minimal plant flows, especially at Roseton. Since time-temperature conditions were similar under the various pump modes, differences in reductions observed especially at Roseton are probably due to mechanical damage. Two-pump operation at Roseton results in minimal pressure (about atmospheric in condenser) compared to three- or four-pump operation (Central Hudson Gas and Electric Corporation 1977:Chapter 3).

Preliminary results of studies performed at the Indian Point plants during 1977 using the pump-larval table system indicate that survival potential at Indian Point is similar to the other plants. Survival of ichthyoplankton collected from June 1 to June 8 is shown in Table 1.3-21. Most of the organisms collected, based on observation during collection, were post-yolk-sac larvae *Morone* and *Clupeidae*. Survival was slightly depressed in the discharge stations. Discharge temperatures were 30 C or less during this period.

1.4 THERMAL EFFECTS LABORATORY STUDIES

Laboratory thermal effects studies designed to duplicate entrainment thermal time-temperature exposure were performed on invertebrate macrozooplankton and ichthyoplankton of the lower Hudson River during 1972 by New York University (Lauer et al. 1974) and in 1976 by Ecolcgical Analysts (1977). Studies in 1972 were designed to include laboratory bioassay testing of the

TABLE 1.3-20 SURVIVAL OF ATLANTIC TOMCOD AT THE INTAKE (I) AND DISCHARGE (D) OF THE ROSETON AND BOWLINE POINT PLANTS DURING THE WINTER OF 1977

Plant	Pump Mode	Station	Temperature (C)	Number of Fish	Initial Proportion Surviving
Roseton		I	0.6-5.5	1,033	0.32
	2 pumps[a]	D	≤10	116	0.20*
		D	>10	892	0.14*
	3 pumps	D	≤10	3	0.33
		D	>10	219	0.28
Bowline		I	3.0-5.5	397	0.80
	2 pumps[b] (throttled)	D	≤10	76	0.62*
		D	>10	246	0.68*
	2 pumps	D	≤10	41	0.78
		D	>10	62	0.68*
	3 pumps	D	≤10	29	0.69
		D	>10	33	0.85

(a) Roseton operates from two to four circulating water pumps.
(b) Bowline Point operates under three modes: two pumps throttled; two pumps unthrottled; and three pumps.

Note: * indicates significantly lower than intake proportion.

TABLE 1.3-21 SURVIVAL OF ICHTHYOPLANKTON AT THE INDIAN POINT PLANTS 1-8 JUNE, 1977

Station	Temperature (C)	Number of Fish	Initial Proportion Surviving
Unit 3 Intake	18-20	341	0.62
Unit 2 Intake	18-20	405	0.47
Unit 3 Discharge	28-30	295	0.38
Discharge Ports	28-30	302	0.41

time-dose responses to temperature elevation above ambient (delta-T) that would be representative of conditions at the Indian Point plant. The effort was devoted primarily to the eggs and larvae of striped bass and Atlantic tomcod and to *Gammarus* sp., *Neomysis americana*, and *Monoculodes edwardsi*. The fish eggs and larvae were obtained by artificial propagation; the macroinvertebrates were collected from the power plant intakes in 0.5-m No. 0 mesh plankton nets.

Temperature exposures were conducted by immersing test containers containing experimental organisms in thermal gradient constant-temperature water baths (Figure 1.4-1). Shock temperatures utilized in the tests varied over a wide range, generally covering the expected increase in ambient water temperatures due to the Indian Point nuclear power plant. Exposure periods included 5, 15, 30, 60, 120, and 720 minutes, varying somewhat between the species. Ambient (or acclimation) temperatures used were those that would normally be expected to occur in the Hudson River during the period of occurrence for the life stages of each species tested.

Macrozooplankton survival was determined at 1 hour and 24 hours after exposure periods. Ichthyoplankton survival was determined within 10 minutes after exposure period. Organisms were considered dead if they did not respond to probing or appeared discolored.

The general analytical approach taken in the analyses of these data was to present test data by test and acclimation temperatures and percent mortality. Tolerance limits (upper lethal, and 50 percent and 95 percent limits) were calculated by test temperature, duration, and acclimation temperature.

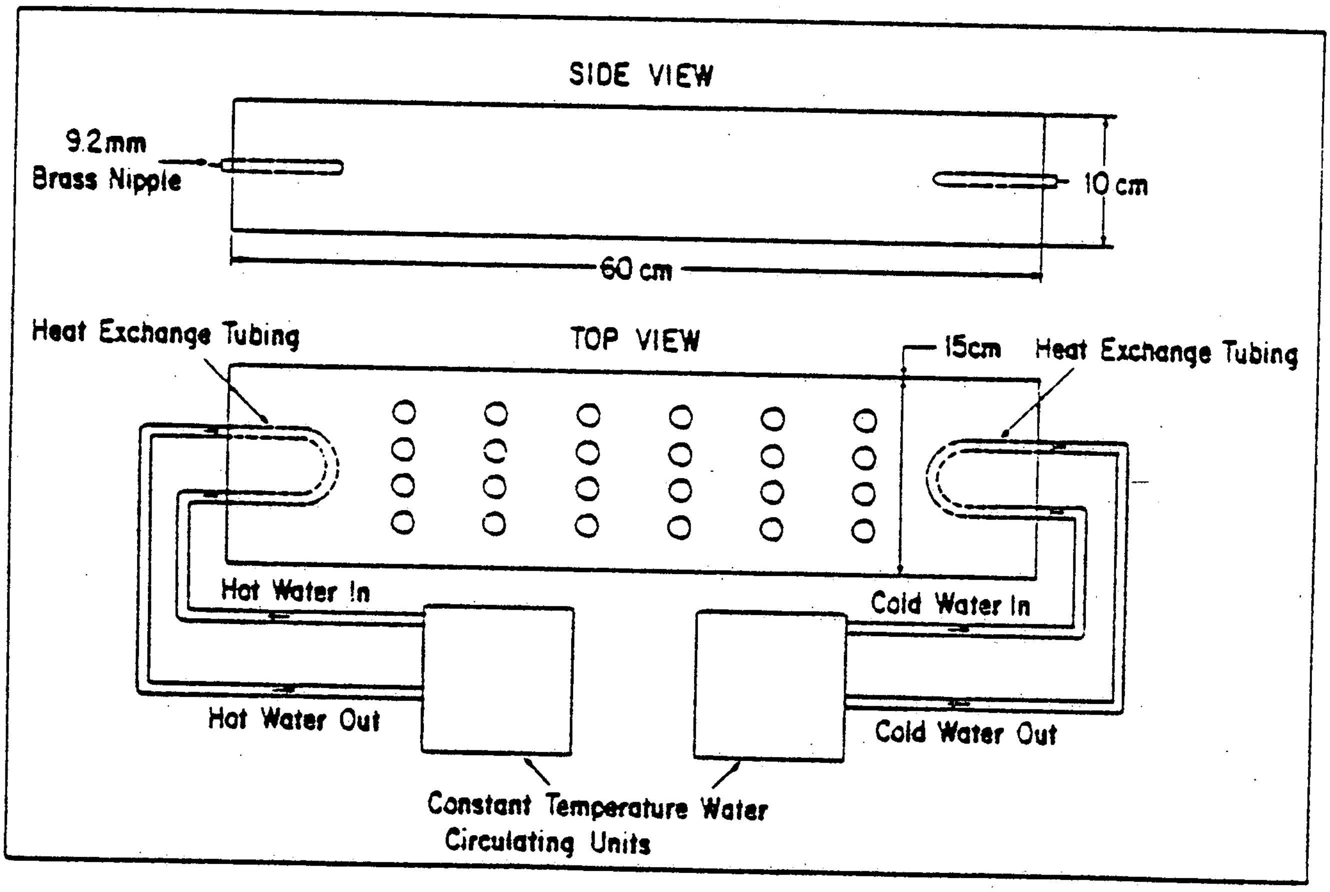

Figure 1.4-1. Sixty-centimeter thermal gradient block used to test temperature tolerance of various life history stages of fish (Lauer et al. 1974).

During 1976, thermal tolerance experiments were conducted with four species of macroinvertebrates and the larvae of six species of fish. The fish larvae tested included alewife, striped bass, white perch, yellow perch, white catfish, and brown bullhead. The four groups of invertebrates tested included Gammarus daiberi, Neomysis americana, Chaoborus punctipennis, and Crangon septemspinosa. The objective of the studies was to provide data on temperature tolerence at various acclimation (incubation) temperatures and durations of exposure. Detailed methodologies are presented in Chapter 2.

Thermal tolerance bioassay test data on macroinvertebrates and eggs, larvae, and juvenile fish collected in 1972 and 1976 provided information on survival relating to time-temperature exposures of the species tested. The test temperatures simulated the extremes which would be expected during entrainment at Hudson River steam generating plants.

The principal macroinvertebrate group studied was Gammarus sp. Survival of Gammarus sp. was a function of both acclimation temperature, test temperature, and duration of exposure (Figures 1.4-2, 1.4-3, and 1.4-4). At acclimation temperatures of 10 C or below, significant mortality was observed at delta-Ts greater than 20 C. For acclimation temperatures from 19 to 26 C, significant mortality was observed at 35 C or higher test temperatures. An increase in the duration of exposure from 5 to 60 minutes appeared to reduce tolerance (TL50) from 1 to 3 C.

Other macroinvertebrates studied included Chaoborus punctipennis, Neomysis americana, and Crangon septemspinosa. Chaoborus tested were extremely tolerant of heat shock with TL50s for 10- to 60-minute exposures near 40 C or higher (Figure 1.4-5); however, there was no apparent increase in tolerance with acclimation temperature in the range tested. Crangon and Neomysis

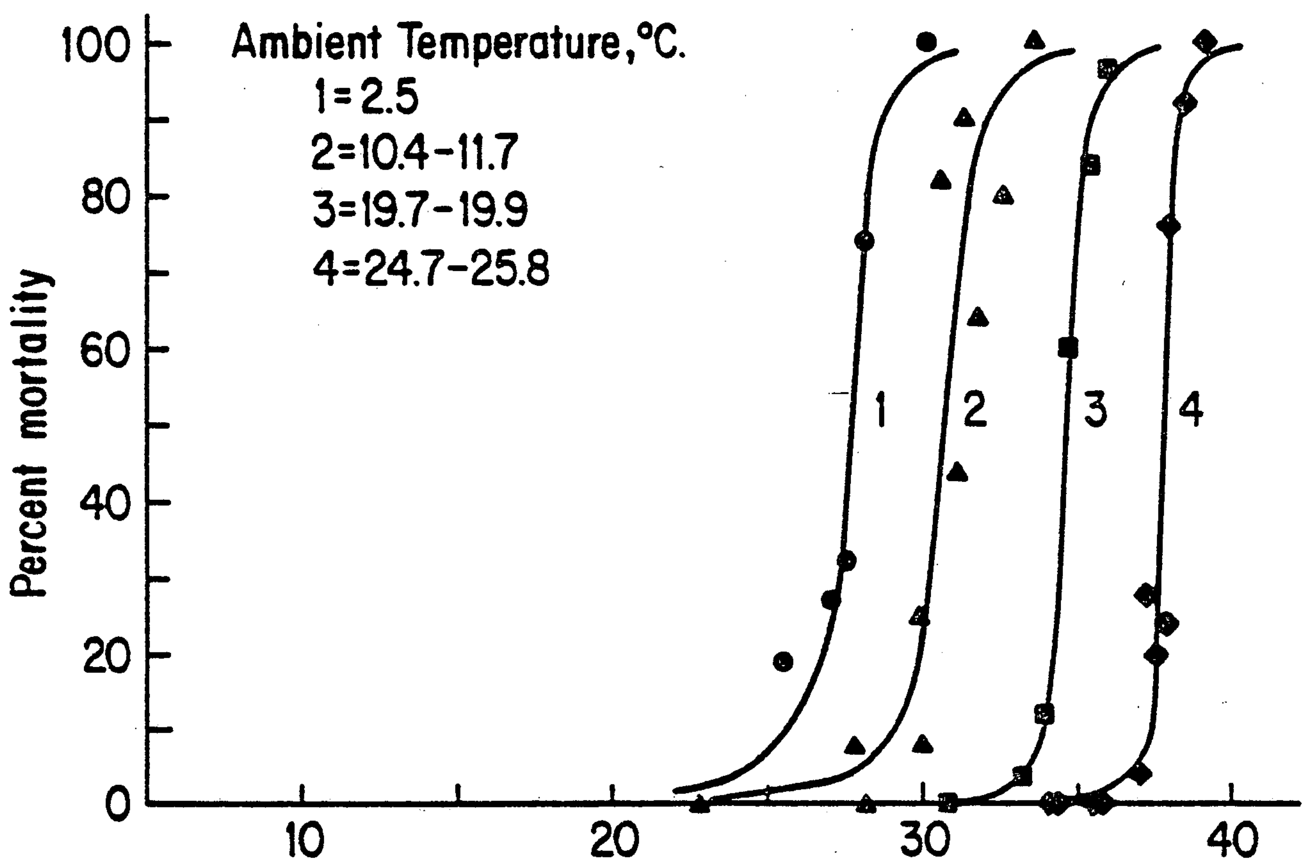

Figure 1.4-2. Temperature tolerance (30-minute exposure) of *Gammarus* sp. during ambient temperatures of 2.5 to 25.8 C (36.5 to 78.4 F) (Lauer et al. 1974).

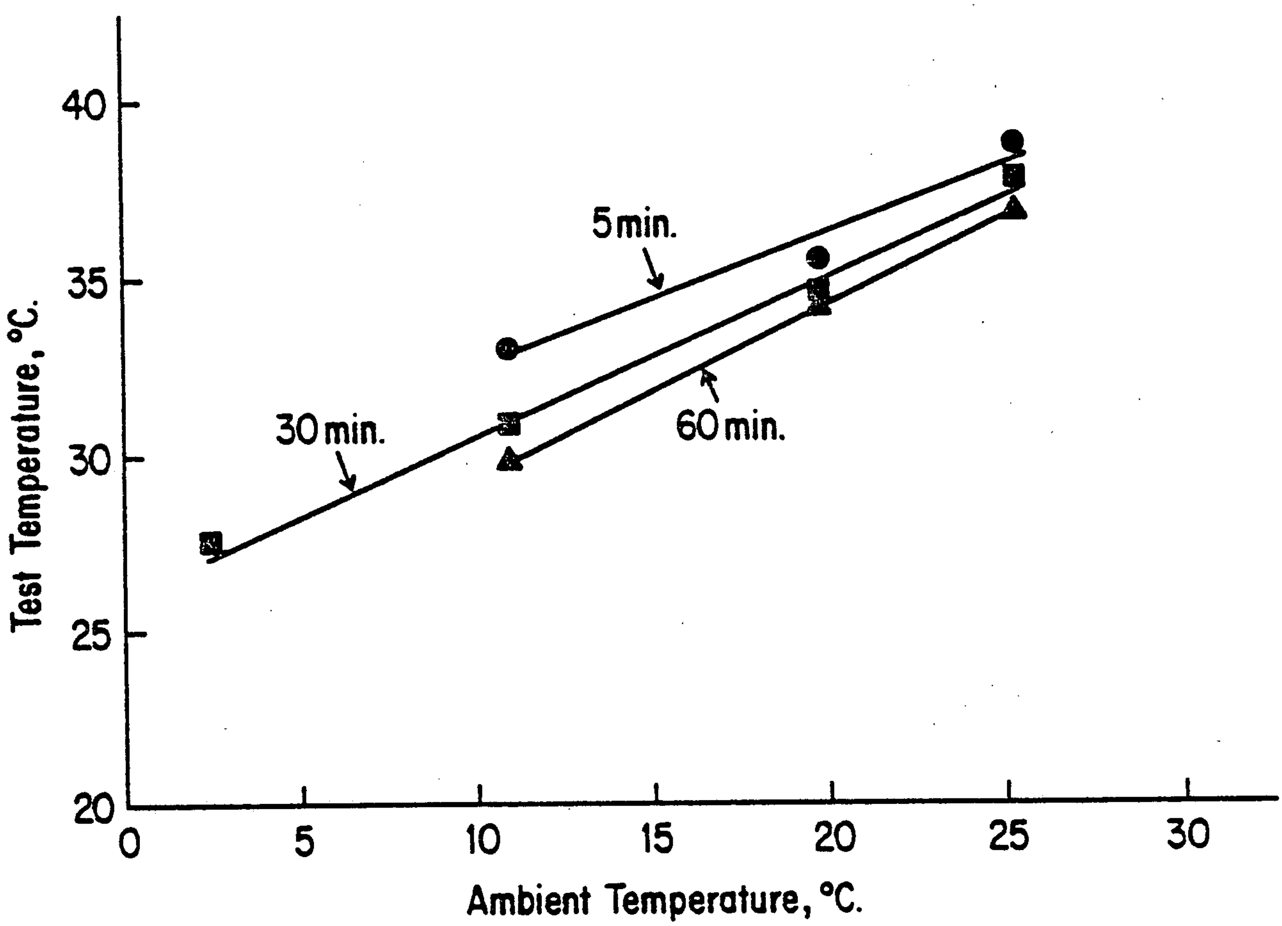

Figure 1.4-3. Upper 50 percent tolerance limits of *Gammarus* sp. (Lauer et al. 1974).

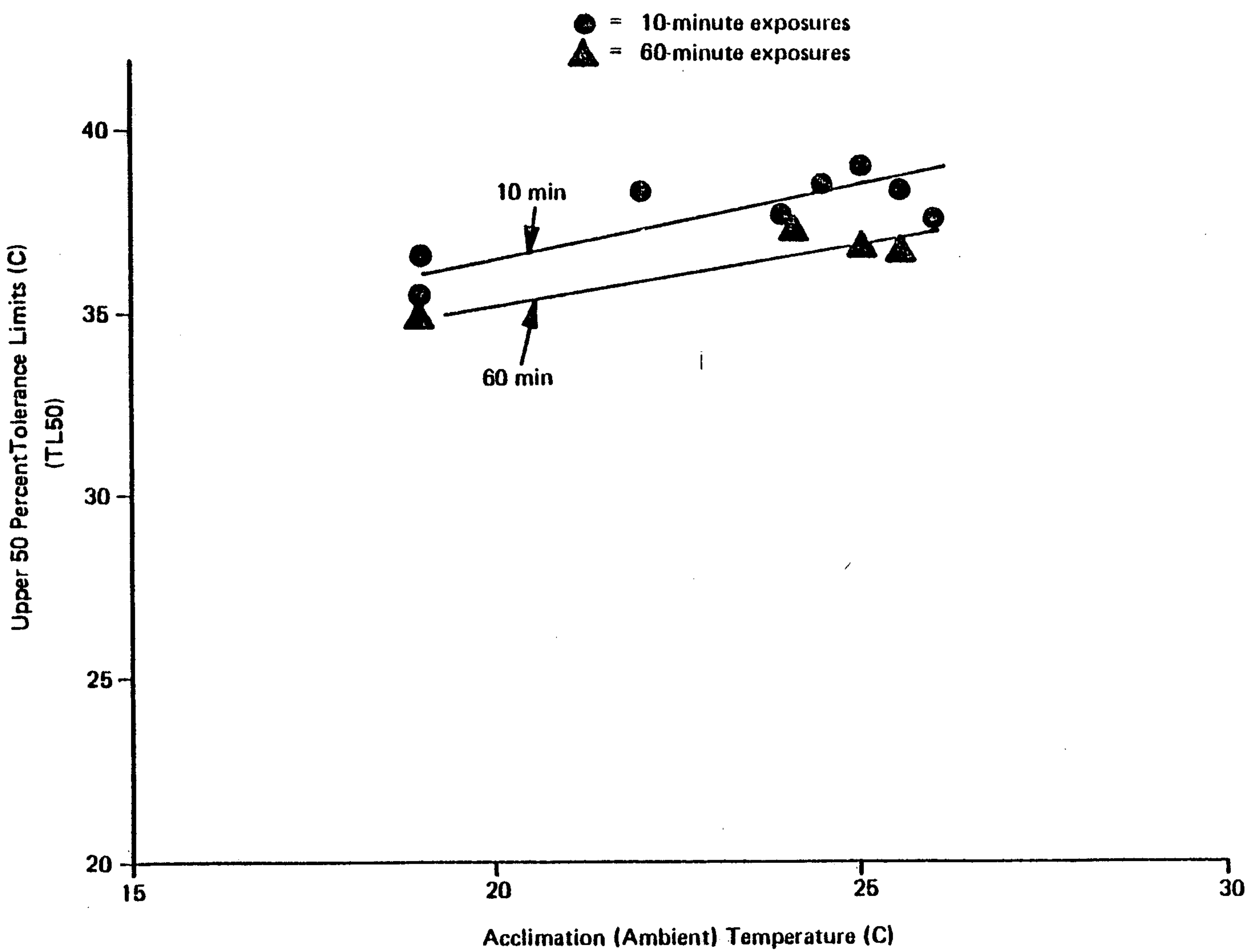

Figure 1.4-4. Upper 50 percent tolerance limits (TL50) of *Gammarus* sp. at various durations of exposure; data collected in 1976.

were the least heat shock tolerant, with TL50s from 31 to 34 C and 31 to 32 C, respectively, for exposures of 10 to 30 minutes (Table 1.4-1). For these species, as well as for the other invertebrate species tested, the TL5 was generally from 2 to 3 C below the TL50 level.

Heat shock tolerance data of young fish including alewife, white perch, striped bass, and Atlantic tomcod are presented in Figures 1.4-6 through 1.4-8. Alewife and white perch larvae (from 1 to 3 days of age) had similar tolerance for 10- to 30-minute exposures (Figures 1.4-6 and 1.4-7), with TL50s of about 34 to 37 C depending on duration of exposure and acclimation temperature. Tests of older larvae of these two species were not undertaken due to difficulty in holding. White perch tolerance was slightly lower (TL50 was 31 to 33 C) at lowest acclimation temperature (15 C).

Striped bass larvae tolerance was lower than the white perch and alewife (Figure 1.4-8). The TL50 for a 10-minute exposure was between 32 and 35 C; at a 60-minute exposure the TL50 was slightly less (30 to 33 C).

Striped bass egg tolerance appears to increase with development (Table 1.4-2). Tolerance for a 5-minute exposure ranged from a TL50 of 33.6 C for the blastula stage soon after fertilization to about 37 C for late embryos at hatching (36-48 hours).

Atlantic tomcod larvae that occur in the Hudson River during the winter at near freezing ambient temperatures generally can tolerate total temperatures of from 16 to 27 C depending on age and duration of exposure (Table 1.4-3). Larvae appear to tolerate at least a 12 C increase in temperature.

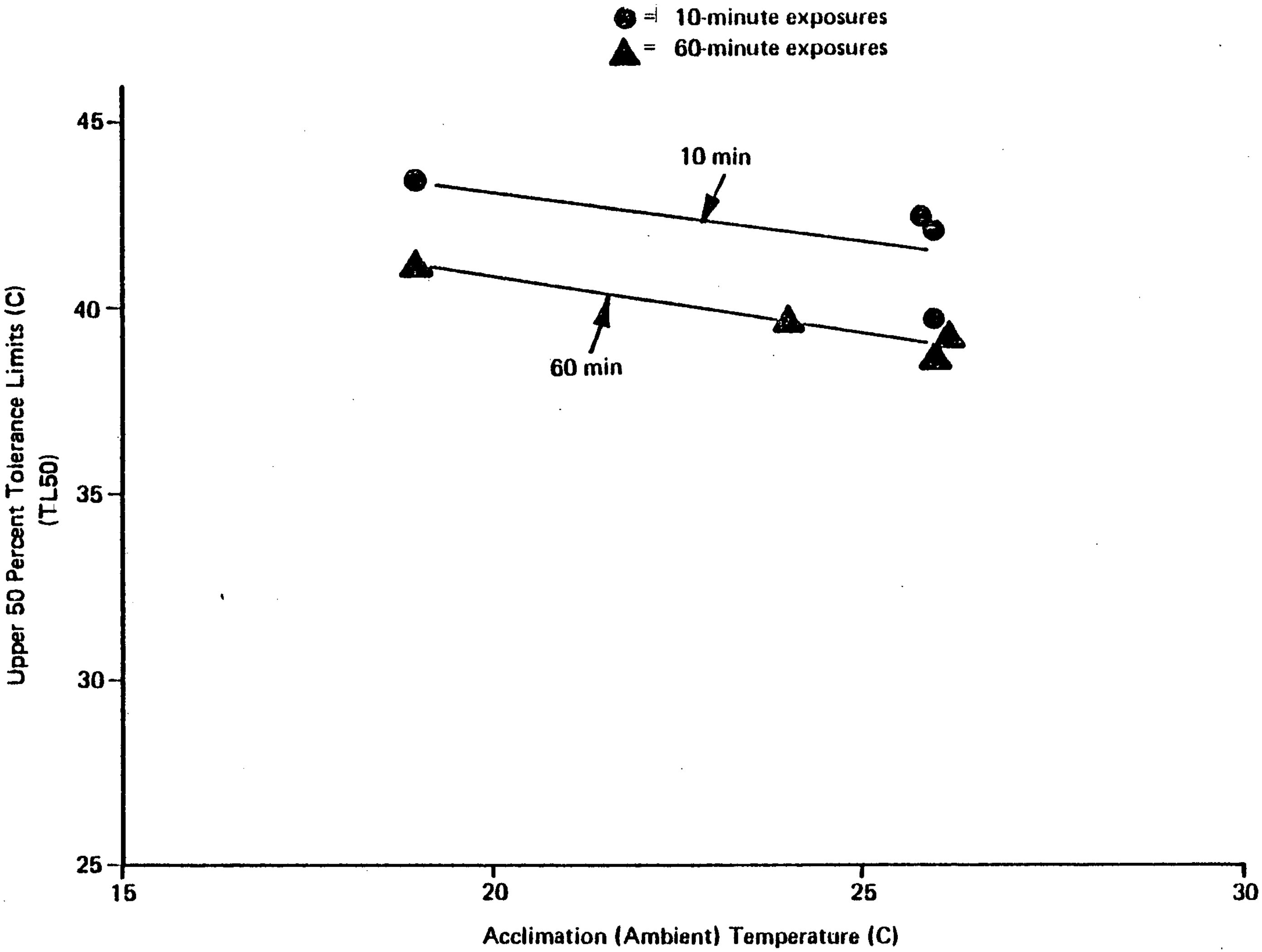

Figure 1.4-5. **Upper 50 percent tolerance limits (TL50) of *Chaoborus punctipennis* at various durations of exposure; data collected in 1976.**

TABLE 1.4-1 THERMAL TOLERANCE EXPERIMENTS WITH *NEOMYSIS AMERICANA* AND *CRANGON SEPTEMSPINOSA**

Acclimation Temperature (C)	Duration (min)	TL5 (C)	TL50 (C)	TL95 (C)
Neomysis americana				
24.5[a]	10	31.3	33.6	35.8
23.9[a]	10	32.9	34.3	35.8
	30	30.4	32.4	34.4
24.0[b]	10	28.6	31.9	35.2
	30	28.8	31.2	33.6
Crangon septemspinosa				
24.0[b]	10	30.3	32.3	34.2
	30	30.4	32.2	34.1
16.0[c]	(10 sec)	33.9	37.6	41.3
	10	27.1	30.1	33.2
	30	29.0	31.4	33.8
	60	28.6	30.7	32.9

(a) Collected at 1.5-ppt salinity; tests run at 3-ppt salinity.
(b) Collected at 2-to-5-ppt salinity; tests run at 3-ppt salinity.
(c) Collected at 6-to-8-ppt salinity; tests run at 3.8-ppt salinity.

Note: * indicates data collected in 1976.

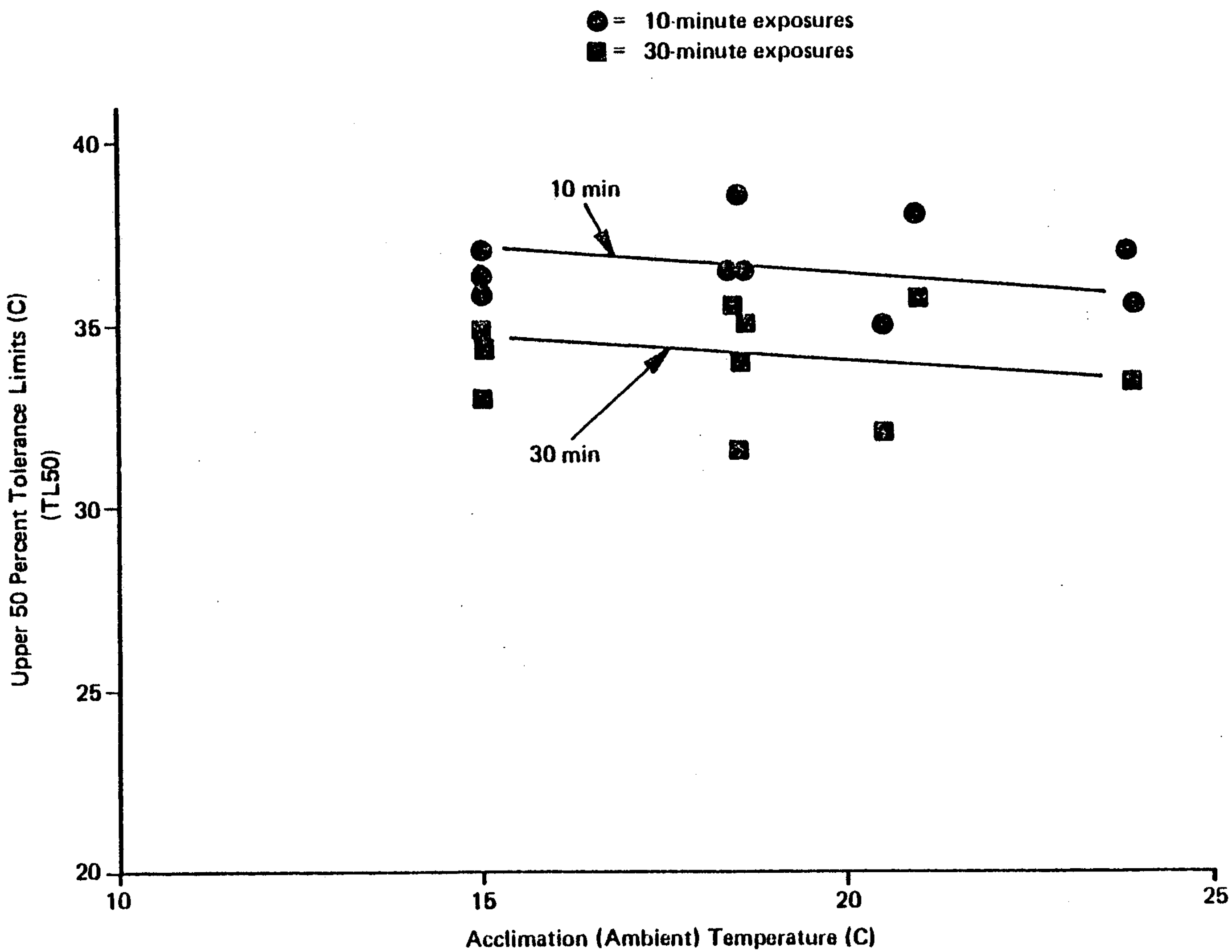

Figure 1.4-6. Upper 50 percent tolerance limits (TL50) of alewife larvae, 1-2 days old, at various durations of exposure; data collected in 1976.

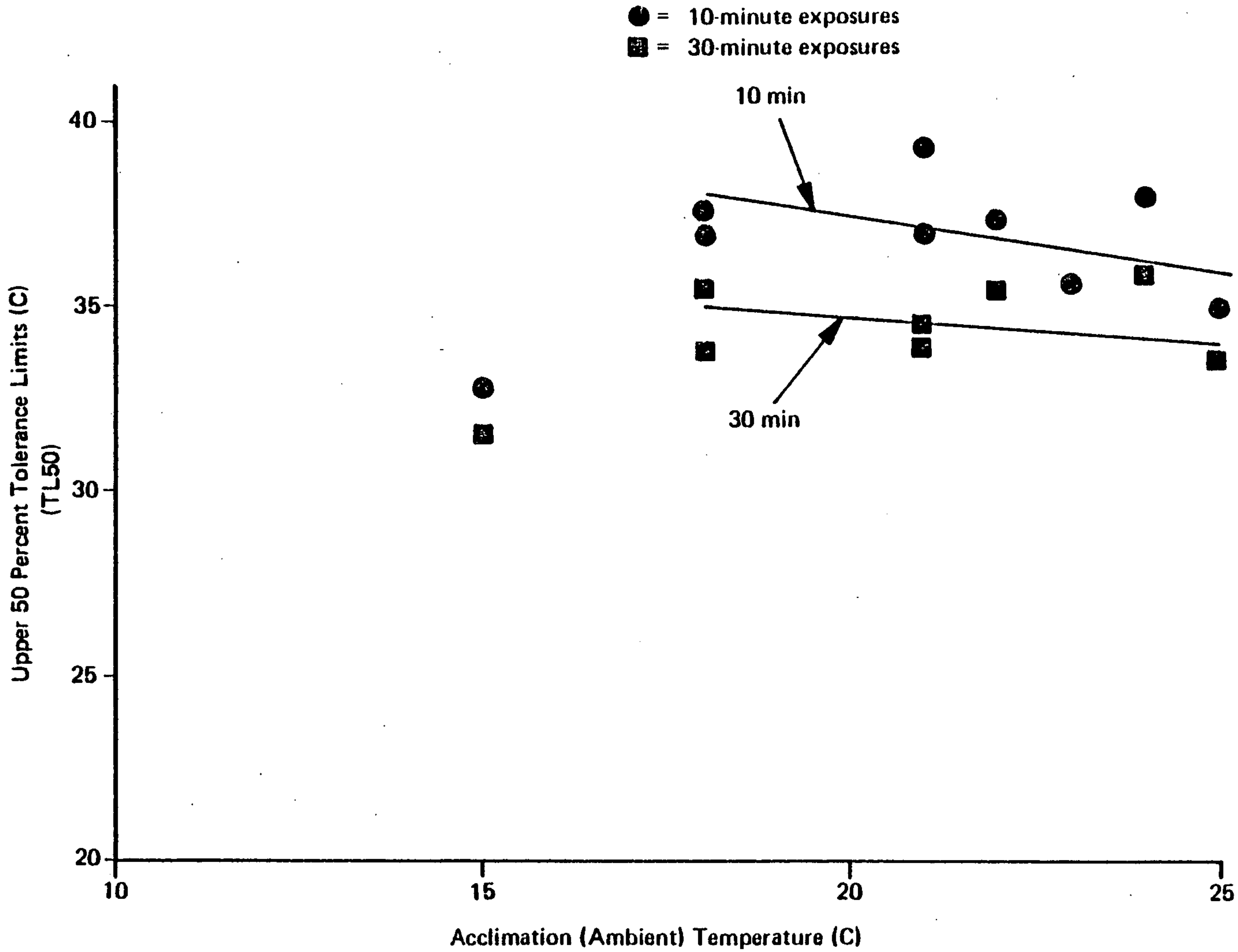

Figure 1.4-7. Upper 50 percent tolerance limits (TL50) of white perch larvae, 1-3 days old; data collected in 1976.

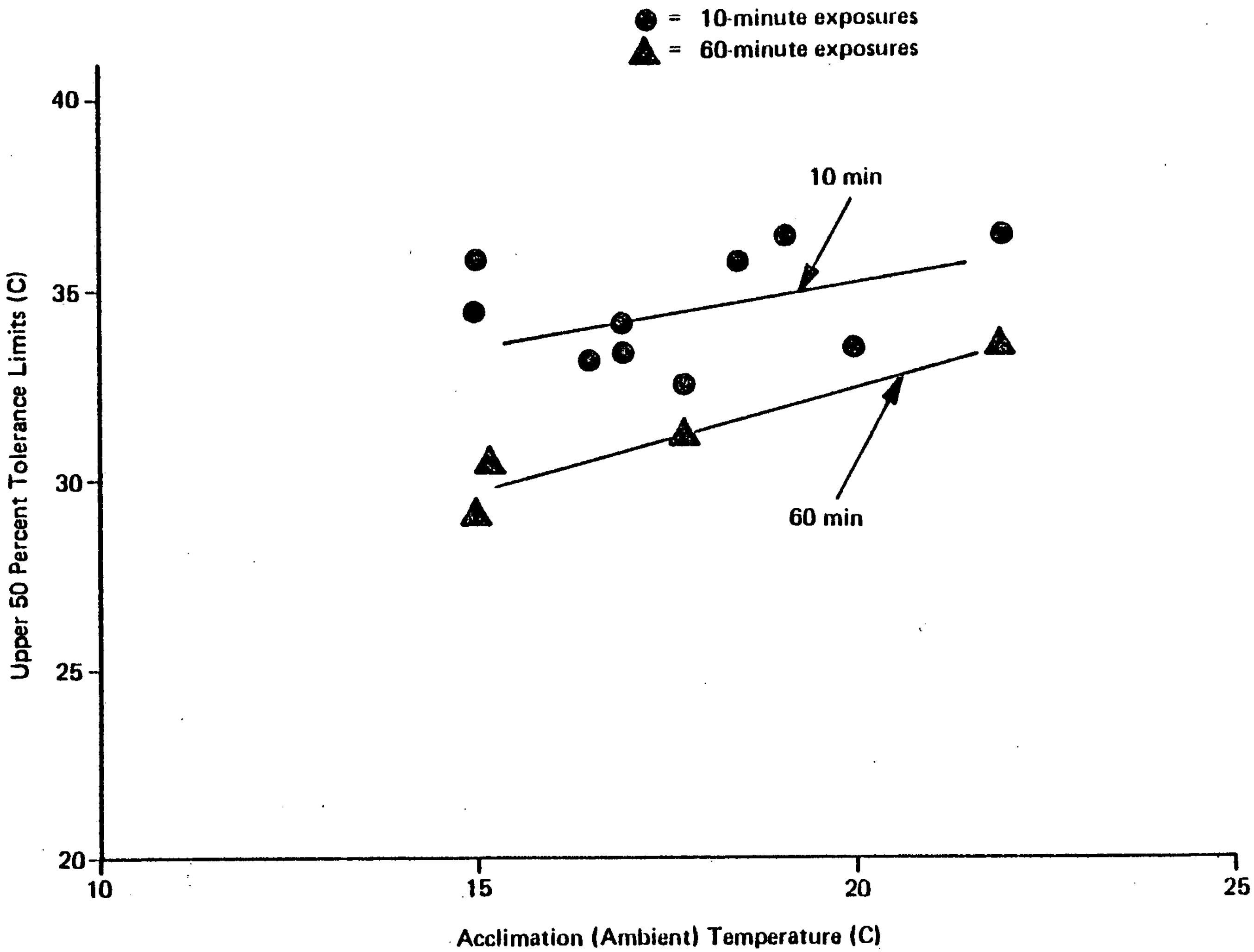

Figure 1.4-8. Upper 50 percent tolerance limits (TL50) of striped bass larvae, 2-35 days old; data collected in 1976 and 1977.

TABLE 1.4-2 THERMAL TOLERANCE (TL50) OF STRIPED BASS EGGS FOR 5-MINUTE EXPOSURE; DATA COLLECTED IN SPRING 1977

Development Stage	5-min TL50 (C)
Blastula	33.6
Gastrula	37.5
Early embryo	37.7
Middle embryo	38.5
Late embryo	37.0

TABLE 1.4-3 THERMAL TOLERANCE (TL50) OF ATLANTIC TOMCOD LARVAE REARED IN THE WINTER OF 1977

Age (days)	Acclimation Temp. (C)	Duration of Exposure (min)	TL50 (C)
0 - 1	2.0 - 4.9	10	26.2
		30	26.1
		60	24.9
		1,140	17.8
22 - 26	3.2 - 3.3	10	26.9
		30	25.3
		60	24.1
		1,140	16.1
29	3.3	10	27.1
		30	26.2

1.5 PRESSURE STUDIES

Pressure studies designed to simulate conditions at the proposed Cornwall Pumped Storage Hydroelectric Plant (New York University 1974, 1975) included simulations which are similar to some portions of the entrainment process at the Hudson River steam generating stations. A hypothetical representation of a time-pressure exposure at the steam power plants as expected for an entrained organism is presented in Figure 1.5-1. The primary pressure factors in the entrainment process are the sudden drop from atmospheric or greater pressure (to which an organism would be acclimated prior to entrainment) to subatmospheric or atmospheric pressures, and sudden increases and short duration (several minutes) exposures to pressures greater than atmospheric pressure.

Experiments were performed in 1974 and 1975 in a 227-liter programmable pressure chamber designed by the Consolidated Edison Company of New York, Inc. The chamber is equipped with a digital and analog programmer which sequentially opens and closes valves to regulate the pressure and rate of pressure change. Both positive and negative (subatmospheric) pressures can be created within the chamber. Some of the experiments presented herein were conducted in 1974 and were performed in a Parr pressure bomb.

Organisms tested included eggs, larvae, and juvenile striped bass and macroinvertebrates including *Gammarus* spp. and *Neomysis americana*. Striped bass were obtained from artificial propagation. The macroinvertebrates were obtained from intake net samples at the Indian Point plant or from the Hudson River.

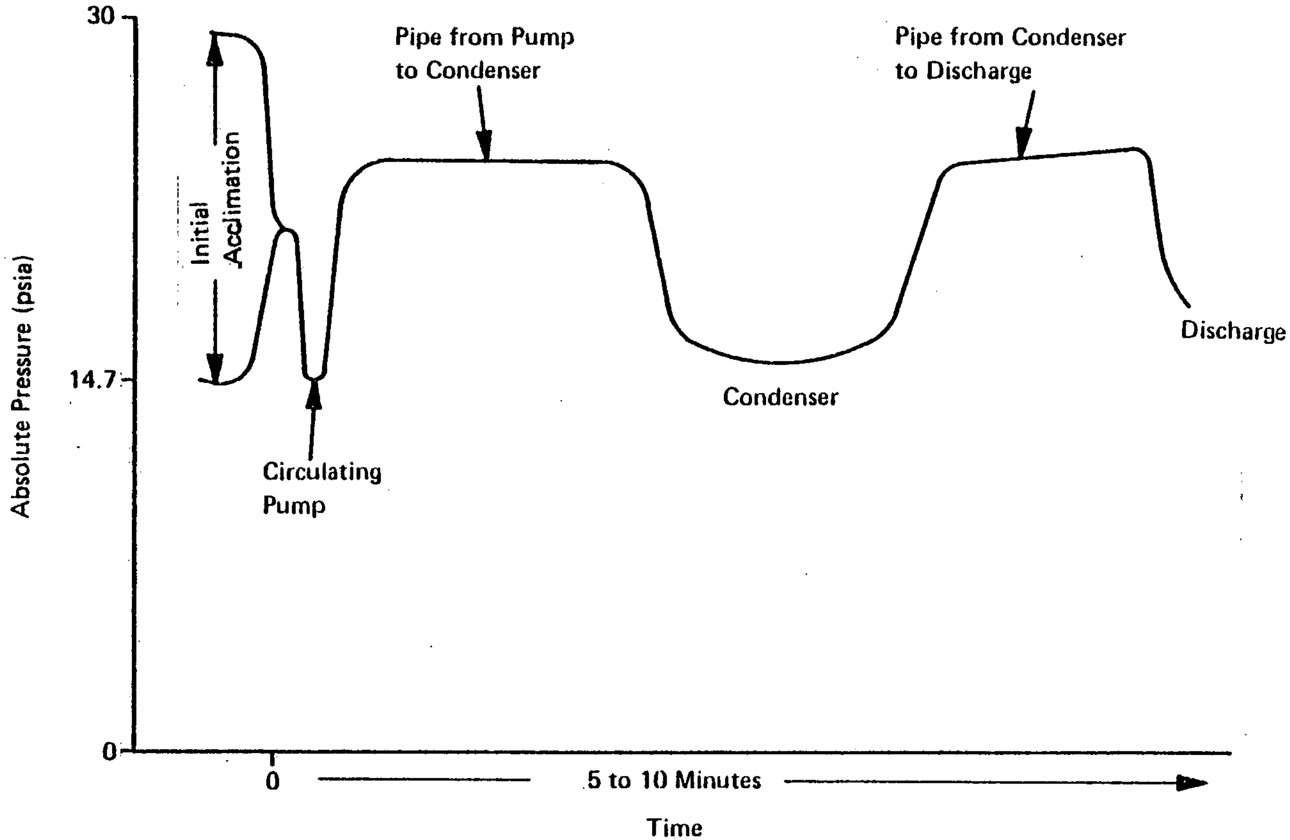

Figure 1.5-1. Hypothetical representation of time-pressure regime at a Hudson River steam generating station.

Experimental organisms were exposed to the pressure chamber and controls were maintained and handled in the same manner as experimental organisms, including counting and latent effects observations. Survival observations were made immediately after completion of the experiment and at 24-hour intervals through the fourth day.

The experiments simulating entrainment followed two general types of pressure exposures. In the first type, organisms acclimated to atmospheric pressure were exposed for varying periods to subatmospheric pressures or subsequent exposure to above atmospheric pressure. The second type simulates organisms acclimated to greater depths in the river, with subsequent exposure to subatmospheric or atmospheric pressure.

The pressure regimes tested in these studies generally were of greater extremes than those existing at the Hudson River plants. Subatmospheric pressures tested ranged from 1.5 to 2.9 psia, which are below the subatmospheric pressures expected at the Hudson River plants (4 to 5 psia). Maximum pressures tested ranged up to 510 psia, considerably above the pressures expected at the Hudson River (20 to 30 psia). Considerable difference in the time-pressure exposures and rates of pressure change also exists between the tests and the conditions expected at the power plants.

For striped bass eggs, larvae, and juveniles, a sudden pressure drop either from atmospheric pressure to subatmospheric pressure or from greater than atmospheric pressure to atmospheric pressure generally resulted in significantly reduced survival for test organisms compared to control organisms (Tables 1.5-1, 1.5-2, and 1.5-3). Striped bass juveniles acclimated to atmospheric pressure and exposed to a subatmospheric pressure of 1.7 psia (Table 1.5-1) appeared to be most significantly affected (a 71 percent reduction in survival immediately after exposure) with the effect appearing immediately.

The effect on larvae at the same conditions was less severe. Larvae subjected to less severe drops in pressure (Table 1.5-3) also were minimally affected although differences were significant two to four days following exposure. Juveniles acclimated to 30 psig and subsequently exposed to atmospheric pressure were not affected (Table 1.5-2); however, significant mortality (38 to 78 percent reduction in survival four days after exposure) was detected in the larvae.

Striped bass eggs survival was also reduced (from 10 to 30 percent) upon exposure to subatmospheric pressures (Table 1.5-3).

In the experiments where pressure drops were most severe (Tables 1.5-1 and 1.5-2), mortality in larvae and juveniles appeared immediately. It is most likely that this immediate reduction can be attributed to swim bladder damage or related damage to internal organs. The striped bass, being a physoclistic fish (having a closed swim or gas bladder), cannot regulate the internal pressure of its gas bladder fast enough to compensate for the rapid decline in pressures; thus, the bladder expands and may rupture or damage the internal organs.

Sudden increases in pressure (up to 250 psig in these tests for 15 minutes) above acclimation appear to have minimal effect on striped bass eggs and juveniles (Tables 1.5-4 and 1.5-5). A significant reduction (34 percent three days after exposure) was detected for larvae; however, the total pressure in the test (250 psig) was far above that which would be expected in the circulating water system at the Hudson River plants.

TABLE 1.5-1 SURVIVAL OF STRIPED BASS LARVAE AND JUVENILES ACCLIMATED TO ATMOSPHERIC PRESSURE AND EXPOSED TO SUBATMOSPHERIC PRESSURE (1.7 psia)

Life Stage	Treatment	N[a]	Hours After Exposure				
			0	24	48	72	96
Larvae[b]	Experimental	300	0.85*	0.74*	0.69*	0.65	0.60
	Control	300	0.98	0.85	0.74	0.67	0.60
Juveniles[c]	Experimental	100	0.29*	0.23*	0.23*	0.23*	0.23*
	Control	100	1.00	1.00	1.00	0.98	0.96

(a) N indicates number of organisms tested.
(b) Age 10-15 days.
(c) Age 46 days.

Note: * indicates significantly lower survival than control.
Source: Adapted from NYU (1975).

TABLE 1.5-2 SURVIVAL OF STRIPED BASS LARVAE AND JUVENILES ACCLIMATED TO 30 psig FOLLOWED BY AN INSTANTANEOUS RETURN TO ATMOSPHERIC PRESSURE

	Acclimation			Hours After Exposure				
Life Stage	Period	Treatment	N[a]	0	24	48	92	96
Larvae[b]	8 hours	Experimental	500	0.60*	0.52*	0.45*	0.41*	0.34*
		Control	500	0.88	0.78	0.69	0.62	0.55
Larvae[c]	24 hours	Experimental	50	0.22*	0.22*	0.22*	0.22*	0.22*
		Control	50	1.00	1.00	1.00	1.00	1.00
Juvenile[d]	24 hours	Experimental	50	1.00	1.00	0.98	0.92	0.84
		Control	50	1.00	1.00	1.00	0.98	0.82

(a) N indicates number of organisms tested.
(b) Age 11-16 days.
(c) Age 16 days.
(d) Age 74-84 days.

Note: * indicates significantly lower survival than control.
Source: Adapted from NYU (1975).

TABLE 1.5-3 SURVIVAL OF STRIPED BASS EGGS AND LARVAE ACCLIMATED AT ATMOSPHERIC PRESSURE AND EXPOSED TO PRESSURES LESS THAN ATMOSPHERIC

	Group 1 (Variable Exposure Time)					
Life Stage	Exposure (psia)	Exposure Time (sec)	Treatment	N[a]	Initial Proportion Surviving	Proportion Surviving 24 Hours
Egg[b]	6	10-15	Experimental	100	0.98	0.82*
			Control	100	0.96	0.92
Larvae[c]	6-10	3-10	Experimental	500	0.98	0.62*
			Control	500	0.99	0.70

	Group 2 (Instantaneous Exposure)			Hours After Exposure				
Life Stage	Exposure (psia)	Treatment	N	0	24	48	72	96
Eggs[d]	6	Experimental	100	1.00	0.95	0.64*	0.55*	0.52*
	9	Experimental	100	1.00	0.98	0.65*	0.54*	0.50*
		Control	100	1.00	0.99	0.83	0.74	0.71
Larvae[e]	6	Experimental	250	1.00	0.92	0.80*	0.67*	0.64*
		Experimental	250	1.00	0.93	0.80*	0.72*	0.68*
		Control	250	1.00	0.88	0.86	0.80	0.76

(a) N indicates number of organisms tested.
(b) Age 4-25 hours.
(c) Age 4-18 days.
(d) Age 12-24 hours.
(e) Age 1-4 days.

Note: * indicates significantly lower survival than control.
Source: Adapted from NYU (1974).

Experiment results on Gammarus spp. and Neomysis americana (Table 1.5-6) indicate they are tolerant to extremes in conditions. Acclimation to 30 psig and subsequent exposure to 1.5 psia for 15 seconds resulted in no reduced survival for Gammarus spp. Gammarus and Neomysis further exposed to 350-510 psia for 12 minutes were not significantly affected; although Gammarus survival was reduced about 10 percent four days after exposure.

1.6 DISCUSSION AND SUMMARY

Entrainment survival studies performed at the six Hudson River power plants indicate that entrainment mortality is minimal (0-30 percent) when discharge temperatures are maintained below lethal thermal thresholds. Survival measured at the plants during higher temperature conditions appears to coincide with that which would be expected based on laboratory thermal tolerance data. Survival at higher temperatures was consistent between plants as would be expected, since survival is directly related to thermal stress.

For most macroinvertebrates entrainment mortality was not observed except under extreme summer conditions (discharge temperatures of 35 C or higher). One exception was Neomysis americana for which reductions from 20 to 30 percent were observed at Indian Point and Bowline Point at discharge temperatures of 32 to 34 C. Laboratory studies also indicated similar patterns.

For ichthyoplankton high mortalities attributable to thermal stress were observed at the plants at temperatures above 30 C. Striped bass, white perch, and Clupeidae larvae generally exhibited this pattern. Laboratory thermal tolerance data on these larval fish generally indicated threshold thermal

TABLE 1.5-4 SURVIVAL OF STRIPED BASS EGGS AND LARVAE ACCLIMATED TO ATMOSPHERIC PRESSURE AND EXPOSED TO 250 psig FOR 15 MINUTES

Treatment	N(a)	Hours After Exposure 0	24	48	72	96
				Eggs(b)		
Experimental	100	1.00	0.96	0.77	0.75	0.75
Control	100	1.00	0.97	0.86	0.84	0.81
				Larvae(c)		
Experimental	150	1.00	0.91	0.69*	0.45*	no data
Control	150	1.00	0.97	0.86	0.68	

(a) N indicates number of organisms tested.
(b) Age 24-41 days.
(c) Age 1-4 days.

Note: * indicates significantly lower survival than controls.
Source: Adapted from NYU (1974).

TABLE 1.5-5 SURVIVAL OF STRIPED BASS JUVENILES (AGE: 62 DAYS) ACCLIMATED TO ATMOSPHERIC PRESSURE AND EXPOSED TO 350-510 psia FOR 12 MINUTES AND RETURNED TO ATMOSPHERIC PRESSURE

Treatment	N[(a)]	Hours After Exposure				
		0	24	48	72	96
Experimental	28	1.00	1.00	0.96	0.96	0.85
Control	28	1.00	1.00	1.00	1.00	0.96

(a) N indicates number of organisms tested.

Source: Adapted from NYU (1975).

TABLE 1.5-6 SURVIVAL OF *GAMMARUS* SPP. AND *NEOMYSIS AMERICANA* ACCLIMATED TO 30 psig FOR 24 HOURS, EXPOSED TO NEGATIVE PRESSURE TO 1.5 psia FOR 15 SECONDS, AND FURTHER EXPOSED TO 35-510 psia FOR 12 MINUTES

Organism	Exposure	Treatment	N(a)	Hours After Exposure				
				0	24	48	72	96
Gammarus spp.	Subatmospheric only	Experimental	100	0.95	0.92	0.83	0.80	0.75
		Control	100	0.97	0.94	0.86	0.82	0.76
	Subatmospheric + positive pressure	Experimental	100	0.97	0.88	0.84	0.77*	0.72*
		Control	100	0.97	0.93	0.90	0.87	0.83
Neomysis americana	Subatmospheric + positive pressure	Experimental	50	0.98	0.94	0.74	0.52	50
		Control	50	1.00	0.86	0.74	0.52	0.52

(a) N indicates number of organisms tested.

Source: Adapted from NYU (1975).

tolerance limits at about 32 C with 10-minute TL50s of 33 to 36 C. In some cases plant survival data resulted in a higher mortality than the thermal lab studies; this can be attributed to some extent to the increased duration of exposure to higher temperatures in the sampling process compared to actual entrainment exposure which was more accurately simulated in the lab studies.

Complications in the sampling process from 1972 to 1975 at Indian Point resulted in considerable difference in results compared with similar conditions at the other plants. Implementation of a common sampling program in 1977 has alleviated the approach velocity problem with nets at Indian Point. Preliminary review of the data indicates that the stress response due to entrainment at Indian Point is similar to the other plants.

REFERENCES: CHAPTER 1

Carpenter, E. J., B. B. Peck, and S. J. Anderson. 1974. Survival of copepods passing through a nuclear power plant in northeastern Long Island Sound. Mar. Biol. 24:49-55.

Central Hudson Gas & Electric Corporation. 1977. Roseton Generating Station: Near-Field Effects of Once-through Cooling System Operation on Hudson River Biota.

Consolidated Edison company of New York, Inc. 1977. Indian Point Nuclear Generating Station: Near-Field Effects of Once-through Cooling System Operation on Hudson River Biota.

Ecological Analysts, Inc. 1977. Second Progress Report on the Hudson River Thermal Effects Studies for Representative Species. Vol. 1. Prepared for Central Hudson Gas & Electric Corporation. Poughkeepsie, New York. (January).

Ecolological Analysts, Inc. 1976. Danskammer Point Generating Station Entrainment Survival and Abundance Studies. 1975 Annual Interpretive Report. Reanalyzed data supplement in preparation. Prepared for Central Hudson Gas & Electric Corporation.

Freund, J. E. 1967. Modern Elementary Statistics. 3rd edition. Prentice Hall, Englewood Cliffs, New Jersey.

Ginn, T. C. 1977. An ecological investigation of Hudson River macrozoo-plankton in the vicinity of a nuclear power plant. Ph.D. dissertation. New York University. March.

Lauer, G. J., W. T. Waller, D. W. Bath, W. Meeks, R. Heffner, T. Ginn, L. Zubarik, P. Bibko, and P. C. Storm. 1974. Entrainment studies on Hudson River organisms. In Proceedings of the Second Workshop on Entrainment and Intake Screening. L. D. Jensen (ed.). February 5-9, 1973. The Johns Hopkins University, Baltimore, Maryland. pp. 37-82.

Marcy, B. C., Jr. 1973. Vulnerability and survival of young Connecticut River fish entrained at a nuclear power plant. J. Fish. Res. Bd. Canada 30:1,195-1,203.

Marcy, B. C., Jr. 1971. Survival of young fishes in the discharge canal of a nuclear power plant. J. Fish. Res. Bd. Canada 28:1,057-1,060.

McGroddy, P. M. and R. L. Wyman. 1977. Efficiency of nets and a new device for sampling living fish larvae. J. Fish. Res. Bd. Canada 34:571-574.

New York University (NYU). 1976a. Hudson River Ecosystem Studies: Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary. Progress Report for 1974. Report to Consolidated Edison Company of New York, Inc.

New York University (NYU). 1976b. The Effects of Temperature and Chlorine on Entrained Hudson River Organisms. Progress Report for 1975. Report to the Consolidated Edison Company of New York, Inc.

New York University (NYU). 1976c. Mortality of Striped Bass Eggs and Larvae in Nets. Report to the Consolidated Edison Company of New York, Inc.

New York University (NYU). 1976d. Effects of Entrainment by the Indian Point Power Plant on Biota in the Hudson River Estuary. Addenda to the 1973 Report. Report to the Consolidated Edison Company of New York, Inc.

New York University (NYU). 1974. Effects of Entrainment by the Indian Point Power Plant on Hudson River Estuary Biota. Progress Report for 1973. Prepared for the Consolidated Edison Company of New York, Inc.

New York University (NYU). 1974. Effects of Entrainment by the Indian Point Power Plant on Hudson River Biota: A Progress Report for 1973 to the Consolidated Edison Company of New York, Inc.

New York University (NYU). 1973. Effects of Entrainment by the Indian Point Power Plant on Hudson River Biota: A Progress Report for 1971 and 1972 to the Consolidated Edison Company of New York, Inc.

Orange and Rockland Utilites, Inc. 1977. Bowline point Generating Station: Near-Field Effects of Once-through Cooling System Operation on Hudson River Biota.

CHAPTER 2: PREDICTION OF THE THERMAL COMPONENT OF ENTRAINMENT MORTALITY AT HUDSON RIVER POWER PLANTS FROM LABORATORY THERMAL TOLERANCE STUDIES OF LARVAL FISH AND MACROINVERTEBRATES

2.1 INTRODUCTION

The objective of this study was to provide a means by which the thermal component of the entrainment mortality of larval fish and macroinvertebrates could be predicted under all possible plant operating and thermal conditions. Laboratory thermal tolerance studies were designed to measure thermal mortality; given exposure duration, a function of plant circulation pumping rate; ambient water temperature, a function of the season of the year and climatic conditions; and plant discharge temperature, a function of plant generating load and pumping rate. Results of these studies were utilized to supplement and confirm observed entrainment mortality determined from intake-discharge experiments at each power plant site, and to identify that component of the observed mortality attributable to thermal stress.

2.2 METHODS AND MATERIALS

Larval fish were obtained by artificially fertilizing brood stock collected from the Hudson River. Eggs from each female were generally fertilized with sperm from 5 to 10 males. After fertilization was complete, the eggs of several females were thoroughly mixed together and equally divided among several flow-through incubation jars. The eggs were then incubated at ambient temperature and each of several constant temperatures above ambient. Incubation baths were provided with a continuous flow of flocculated, filtered Hudson River water, and water temperatures were maintained with thermistatic mixing valves.

Newly hatched larvae were removed from the incubation jars with pipettes and assigned in a stratified random fashion to a number of screen-walled test containers, and were maintained at incubation temperatures prior to testing. Approximately 15-20 larvae were placed in each container. Striped bass (*Morone saxatalis*) larvae were also reared at ambient temperatures for thermal tolerance testing at later life stages. These larvae were fed brine shrimp larvae (*Artemia salar*) every six hours.

Macrozooplankton was obtained from the Hudson River either from bottom trawl collections or from pumped samples drawn from the intake areas of the Roseton or Bowline Point generating stations. Organisms collected in freshwater were held in freshwater flow-through aquaria at ambient or collection temperatures prior to testing. Organisms collected in saltwater were acclimated for 12-36 hours to a test salinity, similar to that at the collection site prior to testing. Macrozooplankters were assigned to test containers in the same manner as were larval fish.

The thermal tolerance tests were conducted by removing the test container from the acclimation temperature bath and immediately immersing it in a constant temperature test bath for a predetermined time. Temperature equilibration was accelerated by flushing the containers with water of the test bath. Test temperatures included the ambient or acclimation temperature (control) plus several temperatures in the range of the upper lethal temperature of the species being tested. Exposure durations were 10, 30, and 60 minutes. Following exposure, the containers were returned to the ambient or acclimation temperature baths and flushed for rapid temperature equilibration. Each container was examined immediately, 1 hour, and 24 hours after the end of the exposure to determine the number of live and dead organisms.

Death was defined as a lack of response to probing and/or a cessation of heartbeat. The 24-hour observation was utilized in mortality calculations, except in cases of high control mortality, since it represented both initial and latent thermal effects.

Mortality was calculated using the following equation:

$$\text{Percentage Mortality} = \left(1 - \frac{P_E}{P_C}\right) \times \ 100\%$$

where

P_E = proportion of organisms surviving exposure to elevated temperature

P_C = proportion of organisms surviving exposure to control temperature.

The analysis of the thermal tolerance data obtained in these studies departed from typical dose-response methodologies, because of the objective of developing a multivariate model for the prediction of thermal mortality. Nonetheless, many elements of the classical methodologies were employed in the model. The basic function of the model was to predict mortality (response) given varying levels of dose (test temperature).

Since many dose-response relationships, when plotted graphically on arithmetic axes, assume an asymmetric sigmoid appearance (Finney 1971), the desirability of linearity mandates the transformation of variables into nonarithmetic units. The expression of dose in terms of logarithms (common or natural), and response in terms of probability units (probits) usually achieves that linearity. Thus, the first step in assembling the prediction model was the establishment of a linear dose-response relationship, as represented by the following equation:

$$\text{Mortality (probit)} = b_0 + b_1 \log \text{(test temperature)} \quad (2.1\text{-}1)$$

Actually, in this case, the log transformation of dose was not necessary since the range of temperatures examined in any test rarely spanned more than a few degrees, and the resultant difference between the log and arithmetic scales over this range was negligible.

Once the basic relationship between dose and response was established, the model was expanded to include terms relating response to exposure duration and acclimation temperature. Brett (1952) showed that the expression of exposure duration in terms of logarithms tended to linearize the relationship of duration to probit transformed mortality. Also, acclimation temperature has been shown to be linearly related to mortality (Ecological Analysts 1977a). Assuming independence of variables, log duration and acclimation temperature terms were added to the model, resulting in a multiple linear regression equation:

$$\text{Mortality} = b_0 + b_1 \underset{\text{(C)}}{\text{(test temp.)}} + b_2 \underset{\text{(min)}}{\text{(log duration)}} + b_3 \underset{\text{(C)}}{\text{(acclimation temp.)}} \quad (2.1\text{-}2)$$

2.3 RESULTS

During 1976, thermal tolerance experiments were conducted with the larval fishes striped bass (*Morone saxitilis*), white perch (*Morone americana*), and alewife (*Alosa pseudoharengus*); and the macroinvertebrates *Gammarus daiberi* (amphipod), *Neomysis americana* (mysid shrimp), and *Chaoborus punctipennis* (dipteran larva). A total of 81 tests were performed with larval fish, and 36 with macroinvertebrates over a range of exposure durations and acclimation temperatures representative of actual or expected plant operational and climatological conditions (Table 2.3-1). Detailed results of these studies were previously reported (Ecological Analysts 1977a).

Prior to assembling the multiple regression models, the upper temperature tolerance in terms of the mean TL50 (temperature causing 50 percent mortality) was examined (Table 2.3-2). For striped bass larvae, little difference in temperature tolerance with age was observed. Therefore, the multiple linear regression model was assembled grouping data obtained for striped bass larvae from 3-37 days old. Additional data are being collected in 1977 to further document the temperature tolerance of early yolk-sac stages. The temperature tolerance of the early yolk-sac stages of white perch and alewife was roughly comparable with that of the older striped bass stages. Although no data were collected on post-yolk-sac white perch or alewife, it is unlikely that their thermal tolerance will increase much with age, since their TL50 values for 1 to 3-day-old yolk-sac larvae ranged in the mid-30s C, near the upper lethal limits for any species or life stage examined.

Results of thermal tolerance multiple linear regression models are given in Tables 2.3-3 and 2.3-4, for larval fish and macroinvertebrates, respectively. In the case of larval fish, over 70 percent of the experimental variance was explained by the model, while over 80 percent was explained for the macroinvertebrates. In all cases, the regression slopes for duration and test temperatures were significantly different ($\alpha = 0.05$) from zero, and positively related to mortality as expected. However, the regression slope for acclimation temperature was neither significant in all cases, nor consistently negatively related to mortality as would have been expected.

TABLE 2.3-1 RANGE OF EXPERIMENTAL CONDITIONS EMPLOYED IN THERMAL TOLERANCE TESTS

Species	Acclimation Temperature (C)	Exposure Duration (min)	Age[a] (days)	Test Temperatures[b] (C)
Morone saxatilis	14.9-21.8	10-60	3-37	23.5-38.2
Morone americana	15.0-30.5	10-60	1-3	24.8-40.4
Alosa pseudoharengus	15.0-23.9	10-60	1-2	26.8-39.8
Chaoborus punctipennis	19.0-26.0	10-60	--	33.9-45.2
Gammarus daiberi	19.0-26.0	10-60	--	32.1-41.0
Neomysis americana	23.9-24.5	10-30	--	28.0-35.8

(a) Age applicable to fish larvae only.
(b) Range of test temperatures leading to mortalities falling on regression line--see illustration below:

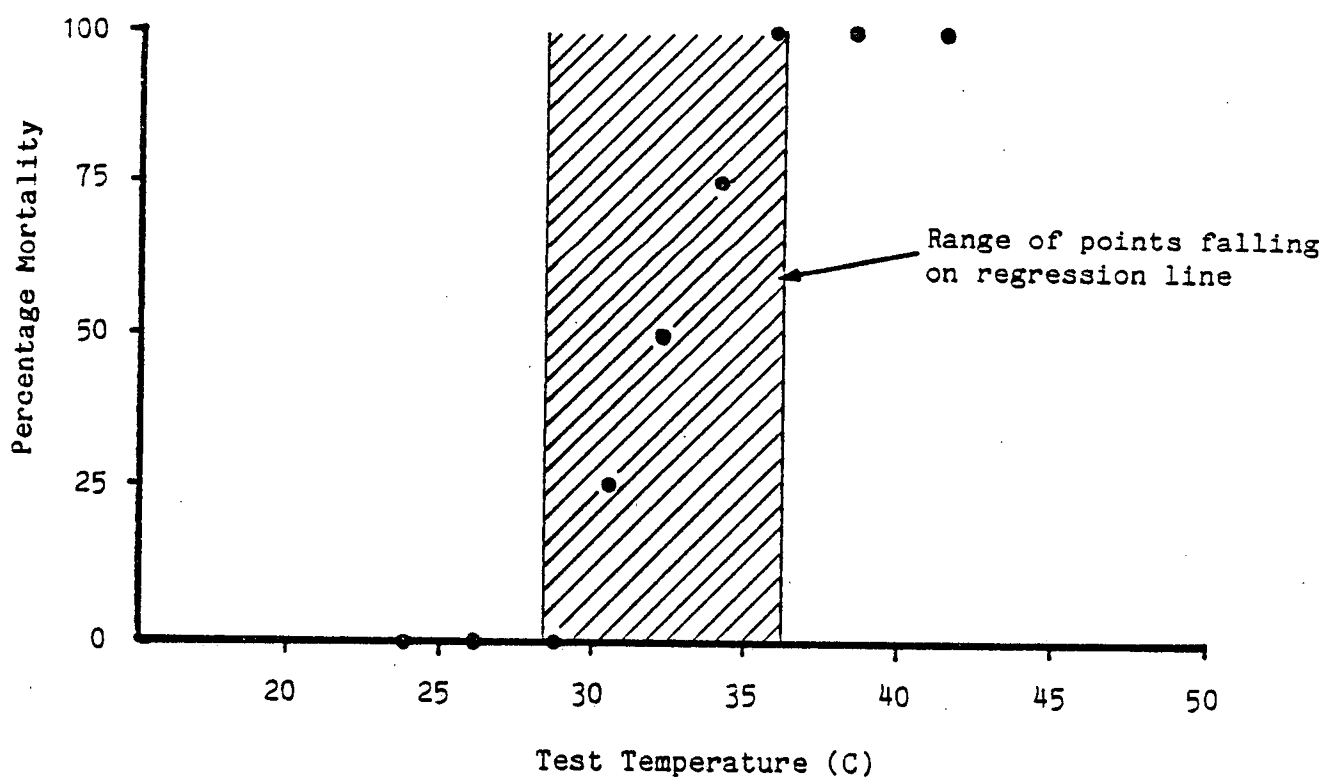

TABLE 2.3-2 MEAN TL50 VALUES OBTAINED OVER THE RANGE OF ACCLIMATION TEMPERATURES TESTED

Species	TL50 Values (C)					
	10-min Exposure		30-min Exposure		60-min Exposure	
	Mean	Range	Mean	Range	Mean	Range
Morone saxatilis	34.5	32.4-36.4	31.8	30.8-32.6	30.9	29.0-33.6
Morone americana	36.6	32.9-39.3	34.3	31.5-36.1	33.2	31.0-35.6
Alosa pseudoharengus	36.7	34.9-38.6	34.0	31.5-35.9	33.2	32.5-34.5
Chaoborus punctipennis	41.8	39.7-43.3	40.1	38.6-42.0	39.7	38.8-41.2
Gammarus daiberi	37.7	35.6-39.0	37.4	37.0-37.8	36.5	35.1-37.5
Neomysis americana	33.3	31.9-34.3	31.8	31.2-32.4		

Note: Dashes indicate only one TL50 value available.
Blanks indicate no data available.

TABLE 2.3-3 RESULTS OF MULTIPLE LINEAR REGRESSION MODELS PREDICTING THERMAL MORTALITY FOR LARVAL *MORONE SAXATILIS*, *MORONE AMERICANA*, AND *ALOSA PSEUDOHARENGUS*[(a)]

$$\text{Probit percentage mortality} = b_0 + b_1x_1 + b_2x_2 + b_3x_3$$

where

b_0 = Y intercept
x_1 = acclimation temperature (C)
x_2 = log exposure duration (min)
x_3 = test temperature (C)
b_i = regression coefficients.

Morone americana

R^2 = 0.69; standard error of regression = 1.692; $F_{(3,86)}$ = 26.06;*
b_0 = -18.92; standard error of b_0 = 3.091

i	b_i	Standard Error of b_i	Computed t-value
1	-0.1678	0.0524	-3.203*
2	2.665	0.6349	4.198*
3	0.6840	0.0777	8.801*

Morone saxatilis

R^2 = 0.73; standard error of regression = 1.678; $F_{(3,47)}$ = 18.31;*
b_0 = -17.32; standard error of b_0 = 3.611.

i	b_i	Standard Error of b_i	Computed t-value
1	-0.2009	0.1048	-1.918
2	3.0682	0.7919	3.875*
3	0.6593	0.0898	17.345*

Alosa pseudoharengus

R^2 = 0.77; standard error of regression = 1.347; $F_{(3,108)}$ = 51.31;*
b_0 = -19.01; standard error of b_0 = 2.277.

i	b_i	Standard Error of b_i	Computed t-value
1	0.0112	0.0403	0.2766
2	2.396	0.4486	5.342*
3	0.5976	0.0486	12.29*

(a) Source: Ecological Analysts (1977c).

Note: * indicates significant at $\alpha = 0.05$.

TABLE 2.3-4 RESULTS OF MULTIPLE LINEAR REGRESSION MODELS PREDICTING THERMAL MORTALITY FOR GAMMARUS DAIBERI, CHAOBORUS PUNCTIPENNIS, AND NEOMYSIS AMERICANA[a]

$$\text{Probit percentage mortality} = b_0 + b_1x_1 + b_2x_2 + b_3x_3$$

where

b_0 = Y intercept
x_1 = acclimation temperature (C)
x_2 = log exposure duration (min)
x_3 = test temperature (C)
b_i = regression coefficients.

Neomysis americana

R^2 = 0.81; standard error of regression = 1.459; $F_{(2,15)}$ = 14.53;*
b_0 = -26.02; standard error of b_0 = 5.742 (variable x_1 not included for N. americana, tested only at 23-35 C).

i	b_i	Standard Error of b_i	Computed t-value
2	3.481	1.491	2.334*
3	0.822	0.154	5.319*

Gammarus daiberi

R^2 = 0.87; standard error of regression = 1.22; $F_{(3,44)}$ = 47.32;*
b_0 = -32.15; standard error of b_0 = 3.554.

i	b_i	Standard Error of b_i	Computed t-value
1	-0.2165	0.0737	-2.939*
2	1.868	0.546	3.423*
3	1.071	0.090	11.853*

Chaoborus punctipennis

R^2 = 0.79; standard error of regression = 1.224; $F_{(3,42)}$ = 23.21;*
b_0 = -29.09; standard error of b_0 = 4.363.

i	b_i	Standard Error of b_i	Computed t-value
1	0.248	0.0688	3.609*
2	1.566	0.646	2.423*
3	0.636	0.0785	8.106*

(a) Source: Ecological Analysts (1977c).

Note: * indicates significant at $\alpha = 0.05$.

This may have been due to the small range of acclimation temperatures tested in most cases.

It is graphically impossible to portray multiple linear regression models generated in this study, since four dimensions are involved. However, by solving for a specific acclimation temperature and exposure duration, the graphic display is reduced to two dimensions. To demonstrate one use of the models, this was done for both the larval fish and macroinvertebrates for conditions typical of the peak entrainment season (Figures 2.3-1 and 2.3-2). The result is a sigmoid relationship between test temperature and mortality which would have been linearized had the mortality scale been expressed in probits. The effects of exposure duration on the thermal tolerance of striped bass larvae is shown in Figure 2.3-3. Increases in duration result in a lowering (shifting to the left) of the thermal response curve. Superimposed on each graph are empirical data points obtained in the thermal tolerance studies at conditions similar to those for which the predicted curves were generated. The goodness of fit of the actual data to the predicted thermal response curves indicates the utility of the model for predicting thermal tolerance under a variety of conditions.

2.4 DISCUSSION

The estimation of entrainment mortality has played an important role in the evaluation of entrainment impact at Hudson River power plants. Mortalities of entrained larval fish (*Morone* spp.) and macroinvertebrates have remained at low levels (less than 20 percent), except at maximum discharge temperatures (Ecological Analysts 1977b, 1977c). Two approaches to entrainment impact assessment have been developed, both based on the prediction of thermal

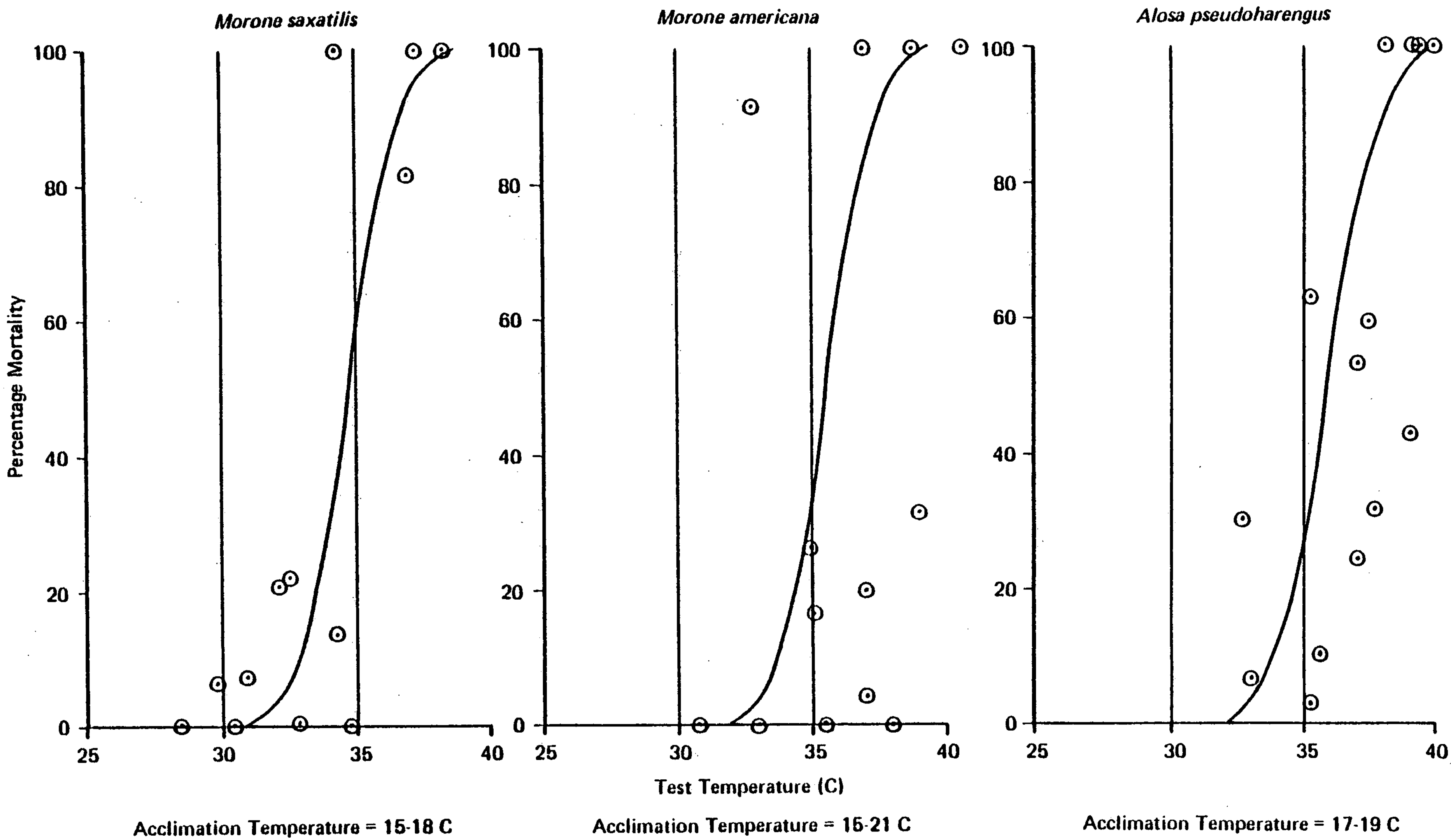

Figure 2.3-1. Predicted thermal mortality curves for three species of larval fish. Curves derived for exposure duration of 10 minutes and acclimation temperature of 18 C. Also shown are empirical data from laboratory thermal tolerance tests.

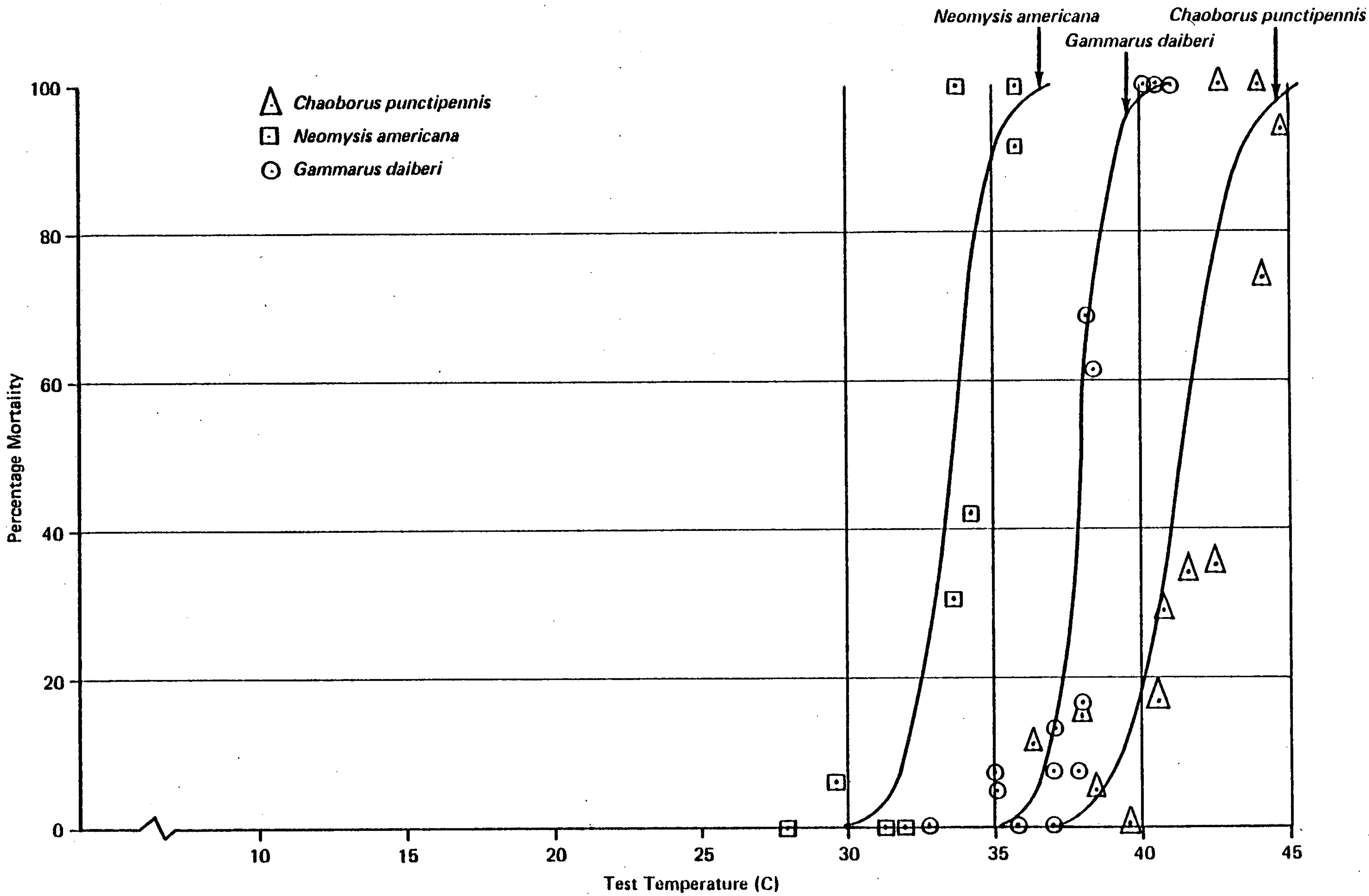

Figure 2.3-2. Predicted thermal mortality curves for three species of macrozooplankton. Curves derived for exposure duration of 10 minutes and acclimation temperature of 25 C. Also shown are empirical data from laboratory thermal tolerance tests where duration = 10 minutes and acclimation temperature = 24-26 C.

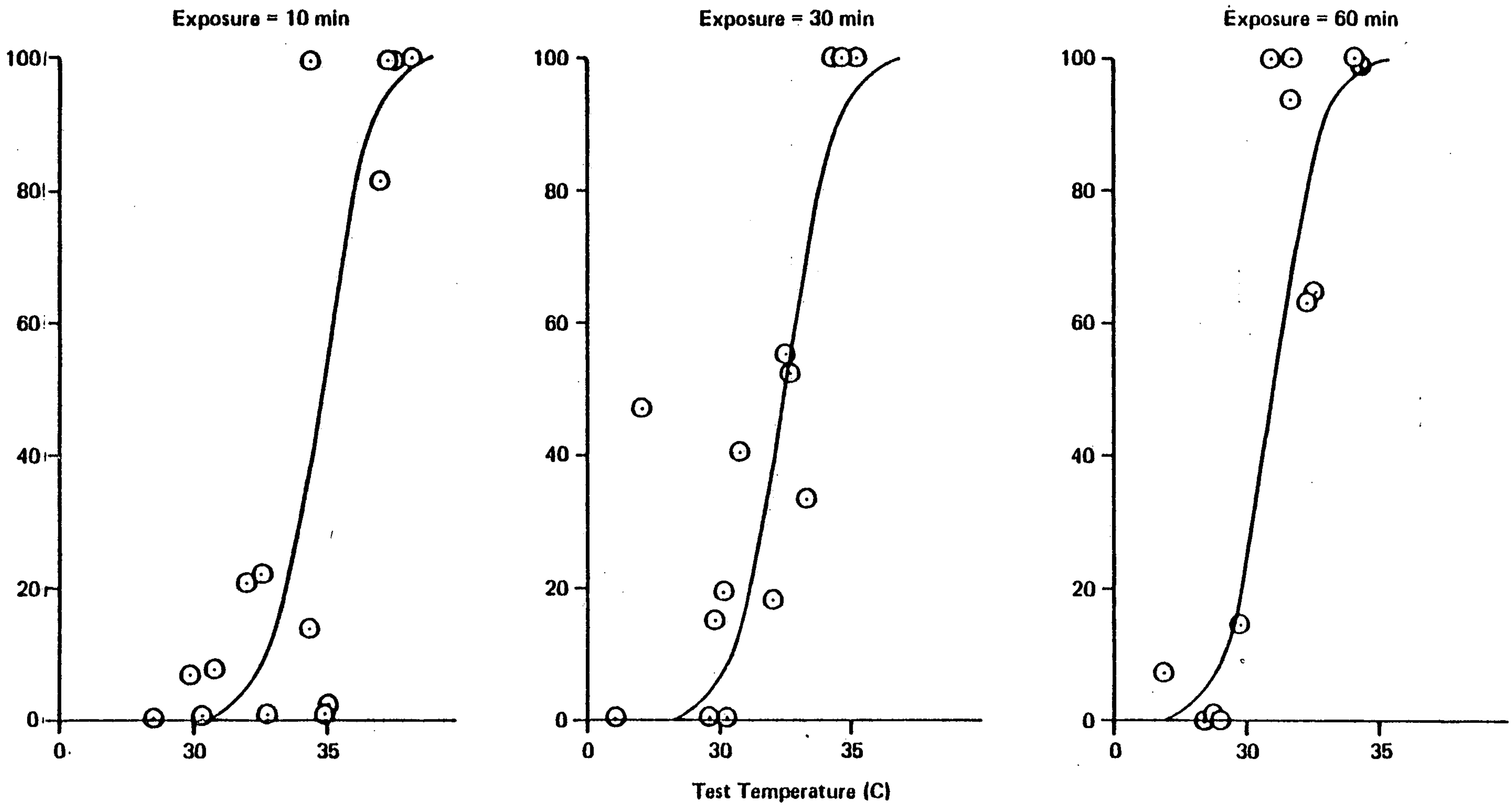

Figure 2.3-3. **Predicted thermal mortality curves for striped bass larvae. Curves derived for exposure durations of 10, 30, and 60 minutes and an acclimation temperature of 18 C. Also shown are empirical data from laboratory thermal tolerance tests.**

mortality using the thermal tolerance models described above. The approaches vary in the ensuing paragraphs.

The first approach, employed in the analysis of macrozooplankton entrainment impact, utilized the thermal tolerance model to both predict and confirm the critical plant discharge temperatures above which substantial thermal mortality is likely to occur. These critical temperatures, known as thermal thresholds, were derived from the solutions of the thermal tolerance model shown in Figure 2.3-2. The 10-minute exposure duration was selected to conservatively represent typical entrainment exposure durations (from condenser to discharge), and the acclimation temperature of 25 C was selected to represent the approximate midsummer maximum river ambient temperature. Under these conditions, thermal thresholds for Neomysis americana, Gammarus daiberi, and Chaoborus punctipennis were 32, 37 and 40 C, respectively. Figures 2.4-1, 2.4-2, and 2.4-3 show actual entrainment mortality data obtained for each of the three species at Hudson River power plants plotted versus discharge temperature. Superimposed are the predicted mortality curves from Figure 2.3-2. Actual entrainment mortalities of G. daiberi and N. americana remained at low levels until discharge temperatures reached the predicted thresholds. Since the threshold for C. punctipennis was never reached, mortalities remained at low levels over the entire range of discharge temperatures examined.

Confirming the thermal thresholds obtained in this study, Lauer et al. (1974) found TL5 values (temperatures causing 5 percent mortality) of 38.0 and 32.5 C, for Gammarus sp. and N. americana, respectively, based on 5-minute exposures. These are slightly higher than the respective 10-minute thresholds obtained in this study, the difference being due to the shorter test

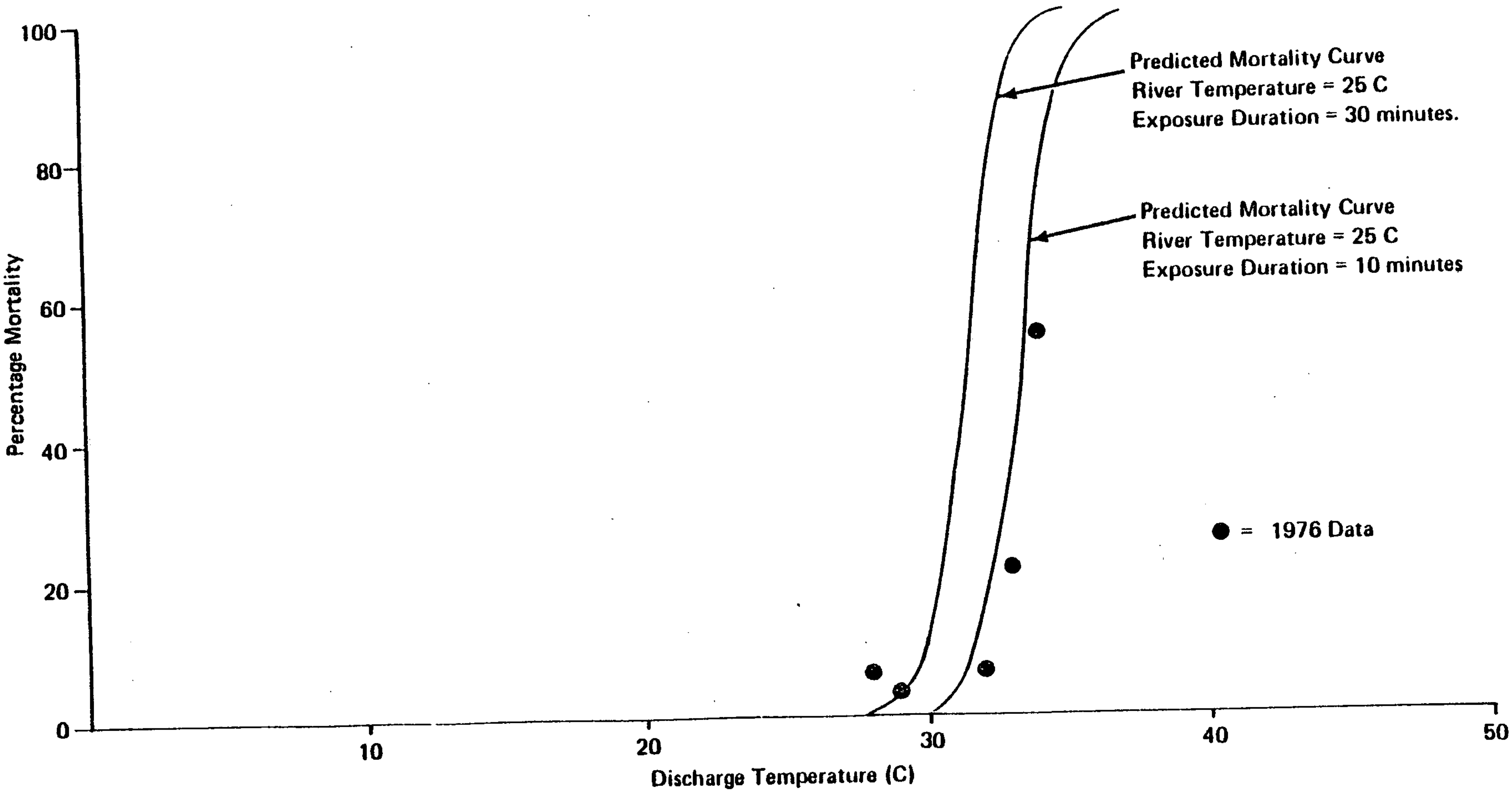

Figure 2.4-1. Empirical and predicted initial entrainment mortality in relation to discharge temperature for *Neomysis americana*. Predicted line from data reported by Ecological Analysts (1977C). Empirical data from Bowline Point plant (1976).

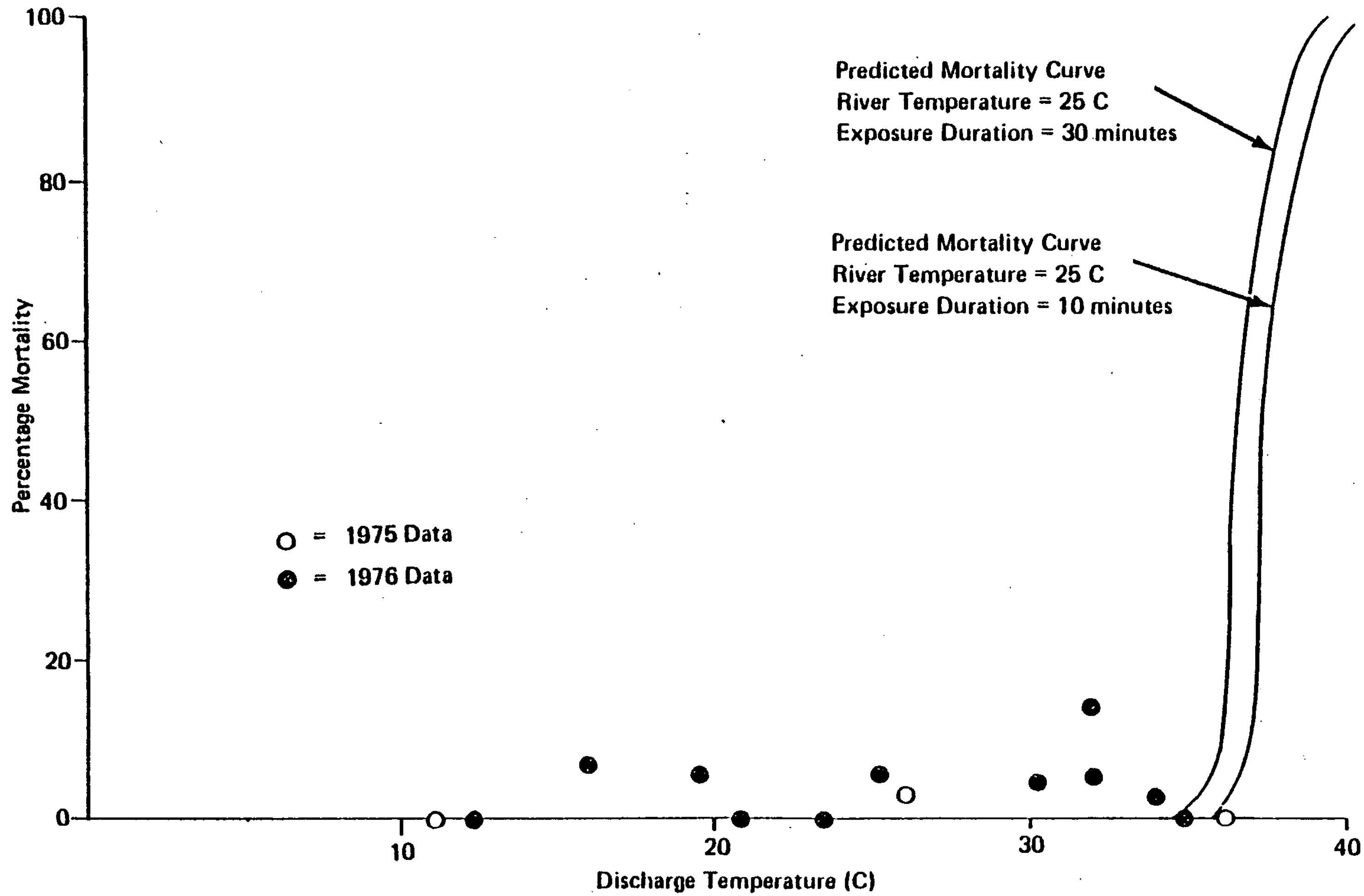

Figure 2.4-2. **Empirical and predicted initial entrainment mortality in relation to discharge temperature for *Gammarus daiberi*. Predicted line from data reported by Ecological Analysts (1977C). Empirical data from Roseton plant (1975-1976).**

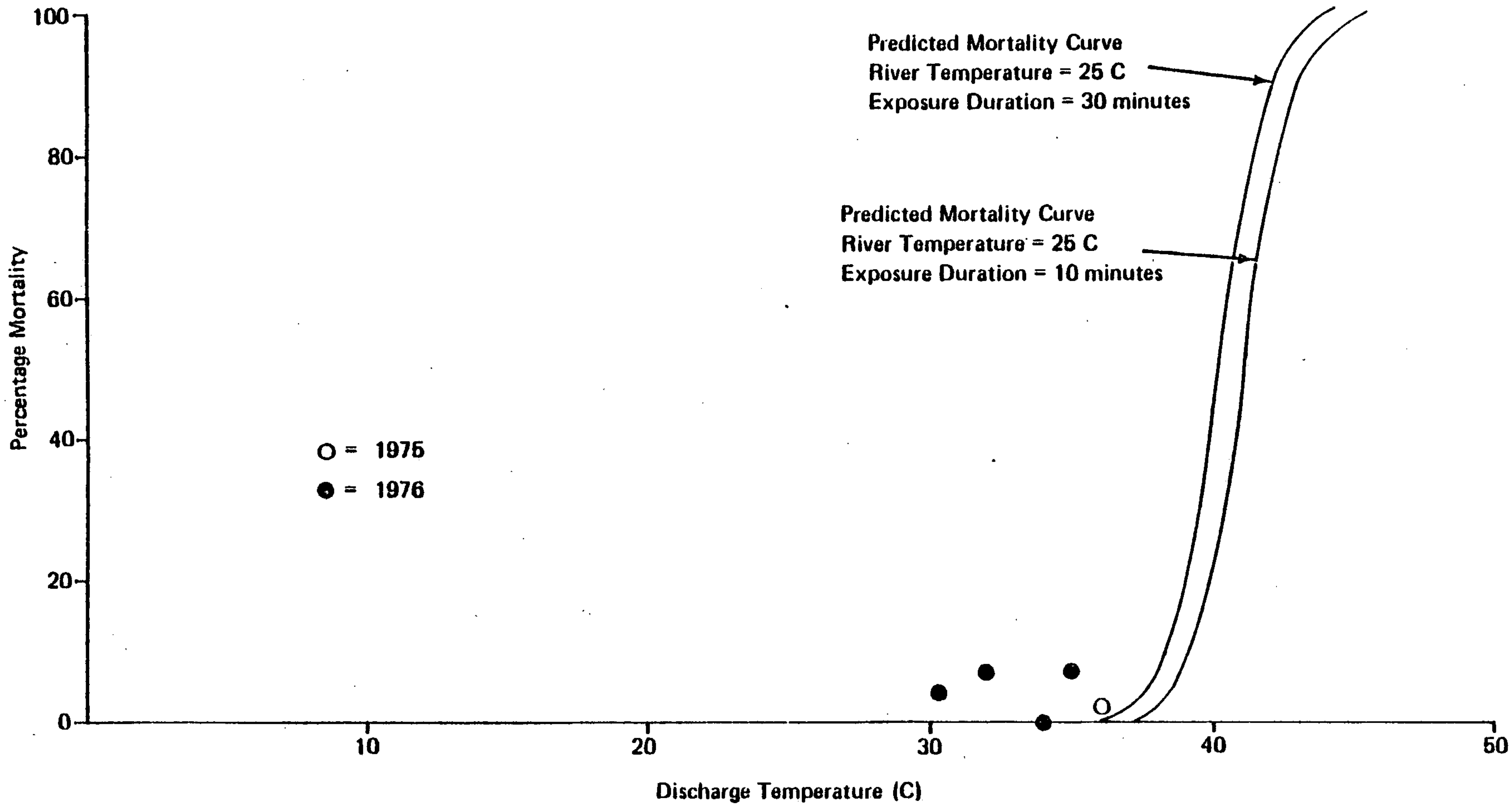

Figure 2.4-3. Empirical and predicted initial entrainment mortality in relation to discharge temperature for *Chaoborus punctipennis*. Predicted line from data reported by Ecological Analysts (1977C). Empirical data from Roseton (1975-76).

duration employed by Lauer et al. (1974). The similarity of the thresholds predicted by the two studies supports the validity and accuracy of prediction of the thermal tolerance models employed in this study.

A second approach to entrainment impact assessment was employed to estimate entrainment cropping--a function of both entrainment mortality and the probability of entrainment (see Chapter 3). This approach utilized the thermal tolerance models generated for larval striped bass to estimate entrainment mortality, given ambient river temperature, plant delta-T or discharge temperature, and transit time from condenser to discharge. Seasonal and diel variations in ambient temperature, plant generating load, and plant pumping rate were considered in order to provide estimates of the independent variables of the thermal tolerance model at any hour of any day during the entrainment season. The predicted mortalities were then combined with seasonal and diel distributions of entrainment abundance (in proportion to total entrainment) to provide an estimate of the proportion of the total number of entrained organisms that were killed. These proportions provided an estimate of cropping for each power plant.

2.5 SUMMARY

1. Thermal tolerance studies were performed with larval fish and macroinvertebrates under varying conditions of acclimation temperature, exposure duration, and test temperature.
2. Multiple linear regression models were developed to predict thermal mortality, given levels of the three variables mentioned above.
3. The models were an essential element in the analysis of entrainment impact at Hudson River power plants.

REFERENCES: CHAPTER 2

Brett, J. R. 1952. Temperature tolerance in young Pacific salmon, genus *Onchorhynchus*. J. Fish. Res. Bd. Canada 9:265-323.

Ecological Analysts, Inc. 1976a. Bowline Point Generating Station Entrainment Survival and Abundance Studies: 1975 Annual Interpretive Report. Prepared for Orange and Rockland Utilites Inc. Spring Valley, N.Y.

Ecological Analysts, Inc. 1976b. Roseton Generating Station Entrainment Survival and Abundance Studies: 1975 Annual Report. Prepared for Central Hudson Gas & Electric Corp. Poughkeepsie, N.Y.

Ecological Analysts, Inc. 1977a. Hudson River Thermal Effects Studies for Representative Species. Data collected for Central Hudson Gas & Electric Corporation. Poughkeepsie, New York.

Ecological Analysts, Inc. 1977b. Bowline Point Generating Station. Data collected for Orange and Rockland Utilities, Inc.

Ecological Analysts, Inc. 1977c. Roseton Generating Station. Data collected for Central Hudson Gas & Electric Corp.

Finney, D. J. 1971. Probit Analysis. 3rd Edition. Cambridge University Press. New York, N.Y. 333 pp.

Lauer, G. J., W. T. Waller, D. W. Bath, W. Meeks, R. Heffner, T. Ginn, L. Zubarik, P. Bibko, and P. C. Storm. 1974. Entrainment studies on Hudson River organisms. *In* Proceedings of the Second Workshop on Entrainment and Intake Screening. L. D. Jensen (ed.) February 5-9, 1973. The Johns Hopkins University, Baltimore, Maryland.

CHAPTER 3: PREDICTIVE ASSESSMENT OF ENTRAINMENT SURVIVAL

3.1 INTRODUCTION

Mortality of ichthyoplankton entrained at the Hudson River power plants is a function of a variety of factors that primarily relate to the thermal exposure which these organisms receive. Three key factors are the circulating water temperature rise (delta-T) produced by the plant, the ambient water temperature at the time of entrainment, and the duration of exposure to the heated water (transit time).

Temporal variations may occur in many of the factors that control thermal exposure. For example, generating load may fluctuate during a 24-hour period due to diel cycles in the demand for electricity, and ambient water temperature is dependent on season of the year. Entrainment mortality will therefore vary according to season and time of day, and the specific time at which entrainment occurs becomes an important consideration in the assessment of power plant cropping.

An empirical computer model was developed to account for the important factors controlling exposure of organisms during entrainment. The model integrates plant, field, and laboratory information to predict the probable entrainment mortality at the Roseton, Bowline Point, and Indian Point plants. Three main objectives were established:

1. Estimate the entrainment mortality likely to occur on any day and hour, given the fact that an organism is entrained (mortality factors).

2. Combine the probability of entrainment occurring on any day and hour with the estimates of resulting mortality to calculate the proportion of entrained organisms that would be cropped (entrainment mortality).
3. Provide the temporal distribution of cropping and examine the effect of cooling water flow on the magnitude of cropping by entrainment.

3.2 MODEL DESCRIPTION

The entrainment mortality model has three major divisions that characterize, respectively, the exposure of the organisms given the fact that entrainment occurs, the effect of such exposure, and the probability of entrainment occurring (involvement). Each of these divisions consists of several components (Figure 3.2-1).

3.2.1 Organism Exposure

The thermal exposure of entrained organisms is a function of four components: ambient water temperature, delta-T, transit time from condensers to discharge, and thermal recirculation. The cumulative distributions of historical daily ambient temperature at the sites* have been used as a model for predicting the probability of obtaining a given water temperature in future years. For example, the 90th percentile of daily ambient water temperatures obtained from these distributions is assumed to be the temperature that would not be exceeded in 90 of the next 100 years. The analysis

* A 26-year record of mean daily water temperature at Poughkeepsie was used to generate a cumulative distribution of ambient temperature. Poughkeepsie temperature has been converted to plant site temperature by regression of the plant intake temperatures on the Poughkeepsie data.

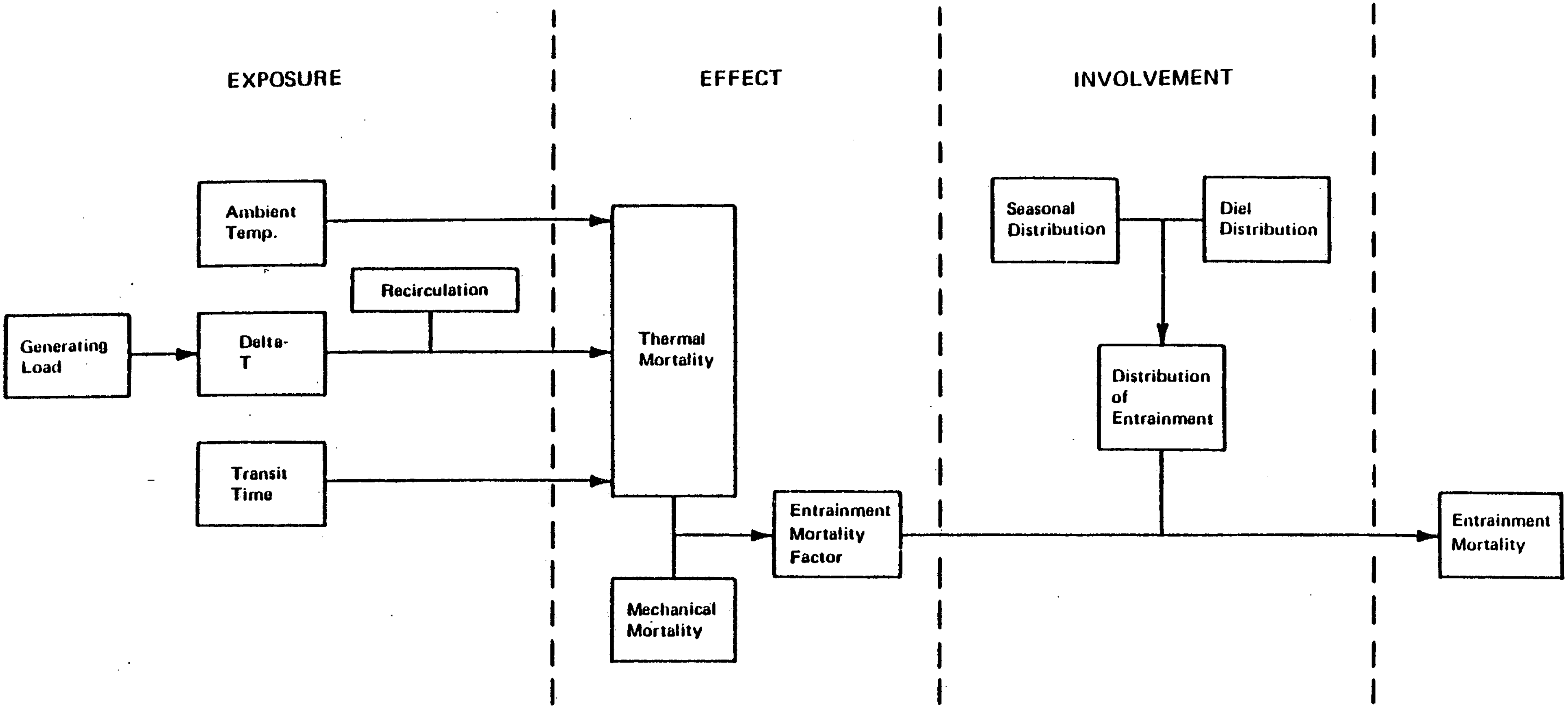

Figure 3.2-1. Schematic representation of the predictive model for entrainment mortality.

for the Bowline Point and Indian Point plants includes mean thermal recirculation since mean daily intake temperatures at these plants were used in constructing the distributions. The analysis for the Roseton plant used minimum daily temperatures upstream of the plant (at Danskammer Point), and therefore should reflect ambient temperature alone.

The rise in cooling water temperature across the plant (delta-T) is directly proportional to the plant generating load (megawatts) and inversely proportioned to the cooling water flow. The equations used to calculate delta-T were of the form:

$$\text{Delta-T (F)} = \frac{A \cdot \text{Plant capacity factor (\%)} + B}{\text{Flow rate (gal/hr)} \cdot 8.346 \text{ lb/gal}} \times 10^9 \qquad (3.2\text{-}1)$$

where plant capacity factor = net generating output/dependable maximum net generation.

The coefficients A and B have been calculated from plant engineering specifications provided by the utilities (Orange and Rockland Utilities, Inc. 1977:Chapter 2; Central Hudson Gas & Electric Corporation 1977:Chapter 2; Consolidated Edison Company of New York, Inc. 1977:Chapter 2). The cooling water temperature rise calculated for each plant at 100 percent generating capacity is shown in Table 3.2-1 as a function of the number of circulating pumps in operation.

During normal operation, generating load is expected to fluctuate over a 24-hour day according to electrical demand at the Bowline and Roseton sites. Representative diel cycles of generation during spring and summer show that maximum and minimum plant loads occur during mid-afternoon and early morning hours, respectively. The plants generally begin to reduce load between 2200

TABLE 3.2-1 RISE IN COOLING WATER TEMPERATURE AT HUDSON RIVER POWER PLANTS OPERATING AT FULL CAPACITY

Plant	Number of Pumps	ΔT (C)
Roseton[a]	2	15.3
	3	11.4
	4	10.0
Bowline[b]	2 (throttled)	11.9
	2	10.1
	3	8.5
Indian Point[c]	4	13.2
	5	10.6
	6	8.9

(a) Units 1 and 2 operating.
(b) Either unit.
(c) Units 2 and 3 operating.

and 0100 hours during these seasons. The historical generation data at these two plants were used to generate a cumulative distribution of load by hour of the day for each month (Orange and Rockland Utilities, Inc. 1977: Chapter 2; Central Hudson Gas & Electric Corporation 1977:Chapter 2). Examples of distributions obtained for peak load and minimum load hours are shown in Figure 3.2-2. The data are believed to be representative of future levels of plant operation, and have accordingly been used in Equation 3.2-1 to estimate the probable delta-T that would occur at the plants for each month and hour of the day.

The transit time is the duration for which the organisms are exposed to the heated water and is an important factor affecting the magnitude of the thermal component of mortality resulting from the entrainment process. The transit time from condenser inlet to discharge of the cooling water is inversely proportional to coolant flow and is generally between 3 and 10 minutes at the Hudson River power plants (Table 3.2-2).

3.2.2 Effect of Exposure

The biological effect of entrainment exposure was measured in terms of survival of the organisms passing through the circulating water system. The probability of entrainment survival was described by:

$$P_e = P_t \times P_m \qquad (3.2\text{-}2)$$

where

P_e = probability of surviving entrainment

P_t = probability of surviving thermal effects

P_m = probability of surviving mechanical effects.

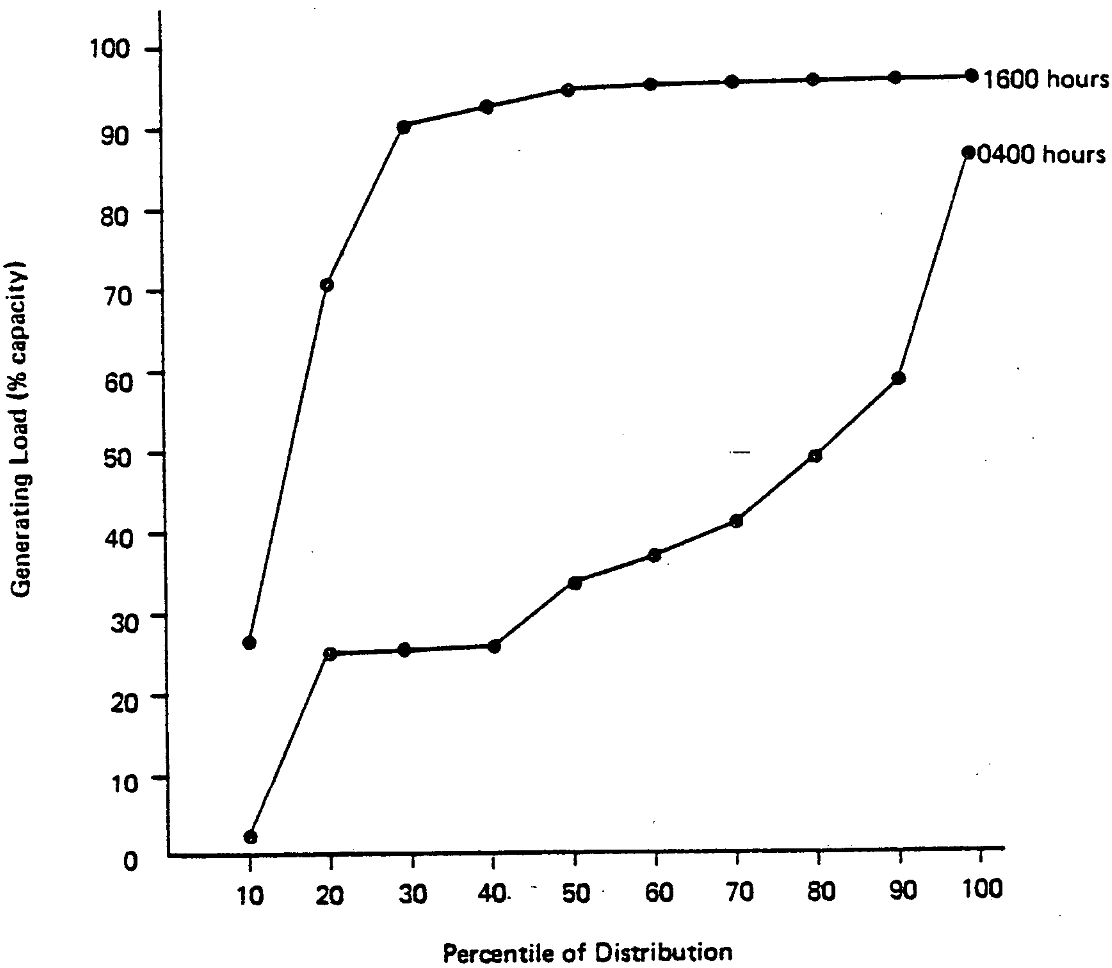

Figure 3.2-2. Cumulative distribution of generating load at the Roseton plant Unit 1, during June 1976.

TABLE 3.2-2 DURATION OF EXPOSURE TO HEATED WATER IN THE CIRCULATING WATER SYSTEMS AT HUDSON RIVER POWER PLANTS

Plant	Number of Pumps	Mode	Exposure Time (min)
Roseton[(a)]	2	Full	5.3
	3	Full	4.1
	4	Full	3.5
Bowline Point[(b)]	2	Throttled	7.4
	2	Full	6.4
	3	Full	5.3
Indian Point[(c)]	4	Full	14.1
	5	Full	10.1
	6	Full	8.2
Indian Point[(d)]	4	Full	7.0
	5	Full	5.2
	6	Full	4.1

(a) Units 1 and 2 operating.
(b) Applies to either unit.
(c) Unit 2 with Unit 3 operating at an identical flow.
(d) Unit 3 with Unit 2 operating at an identical flow.

Entrainment survival is simply the ratio of the proportion of organisms surviving in samples collected from the intake and discharge of the circulating water systems of these plants ($P_e = P_D/P_I$). The field data have been used to estimate the survival of entrained ichthyoplankton in the absence of thermal stress by setting P_m equal to the entrainment survival observed for larvae collected at discharge temperatures below their upper thermal tolerance.* Values of P_m used in model calculations are specific for each power plant and are summarized in Table 3.2-3. Values for mechanical survival of larvae at the Roseton and Bowline Point plants are based upon 1975 and 1976 field collections. The value for the Indian Point plant is based upon Unit 2 data for 1973 for intake and discharge samples collected at similar water velocities (Consolidated Edison Company of New York, Inc. 1977:Section 9.2). Survival of juvenile striped bass from mechanical effects was estimated from discharge collections under low temperature conditions at each plant. Yolk-sac larvae survival was assumed to be equal to post-yolk-sac survival since there appears to be no biological reason for lesser susceptibility to stresses encountered in the circulating water system, and since experimental testing with hatchery-reared fish has shown them to have equal resistance to collection stress (Ecological Analysts 1976a, 1977a).

Laboratory studies of the thermal tolerance of Hudson River fish larvae have shown that mortality depends primarily on the total temperature of exposure, and to a lesser extent on acclimation temperature and the duration of exposure (Ecological Analysts 1977b). Regression models of the form:

---

* Laboratory thermal tolerance studies of Hudson River fish larvae (Ecological Analysts 1977d) indicate that no significant thermal mortality occurs at temperatures below 30 C at exposure times of 40 minutes. P_m was estimated from the entrained survival observed in the field at total discharge temperature of <26 C for larvae and <30 C for juveniles.

TABLE 3.2-3 MECHANICAL SURVIVAL OF STRIPED BASS

Plant	Life Stage	Proportion Surviving
Bowline Point	Yolk-sac larvae	0.85
	Larvae	0.85
	Juveniles	0.89
Roseton	Yolk-sac larvae	0.77
	Larvae	0.77
	Juveniles	0.89
Indian Point	Yolk-sac larvae	0.85
	Larvae	0.85
	Juveniles	0.89

$$M_t = b_o + b_1(T_a) + b_2(\log t_d) + b_3(T_e) \qquad (3.2\text{-}3)$$

where

M_t = thermal mortality (probits)

T_a = ambient temperature (C)

t_d = exposure duration (min)

T_e = exposure temperature (C)

b_0, b_1, b_2, b_3 = regression coefficients

have been developed from the laboratory data to predict the thermal mortality of fish larvae (see Chapter 2). Regression coefficients determined from the laboratory data are shown below.

Species	b_0	b_1	b_2	b_3	r^2
Striped bass	-17.324	-0.201	3.068	0.659	0.73

The probability of surviving thermal stress (P_t) during entrainment was calculated as a function of discharge temperature for striped bass larvae collected at Hudson River power plants* by use of Equation 3.2-2. The results compare well to the thermal mortality ($1 - P_t$) predicted by the regression model at acclimation temperatures and exposure duration similar to those occurring in the field (Figure 3.2-3). The thermal laboratory information has the advantage of incorporating the duration of thermal exposure, an important factor determining thermal mortality which was not investigated in field studies.

---

* Bowline Point, Roseton, Lovett, and Danskammer Point plants.

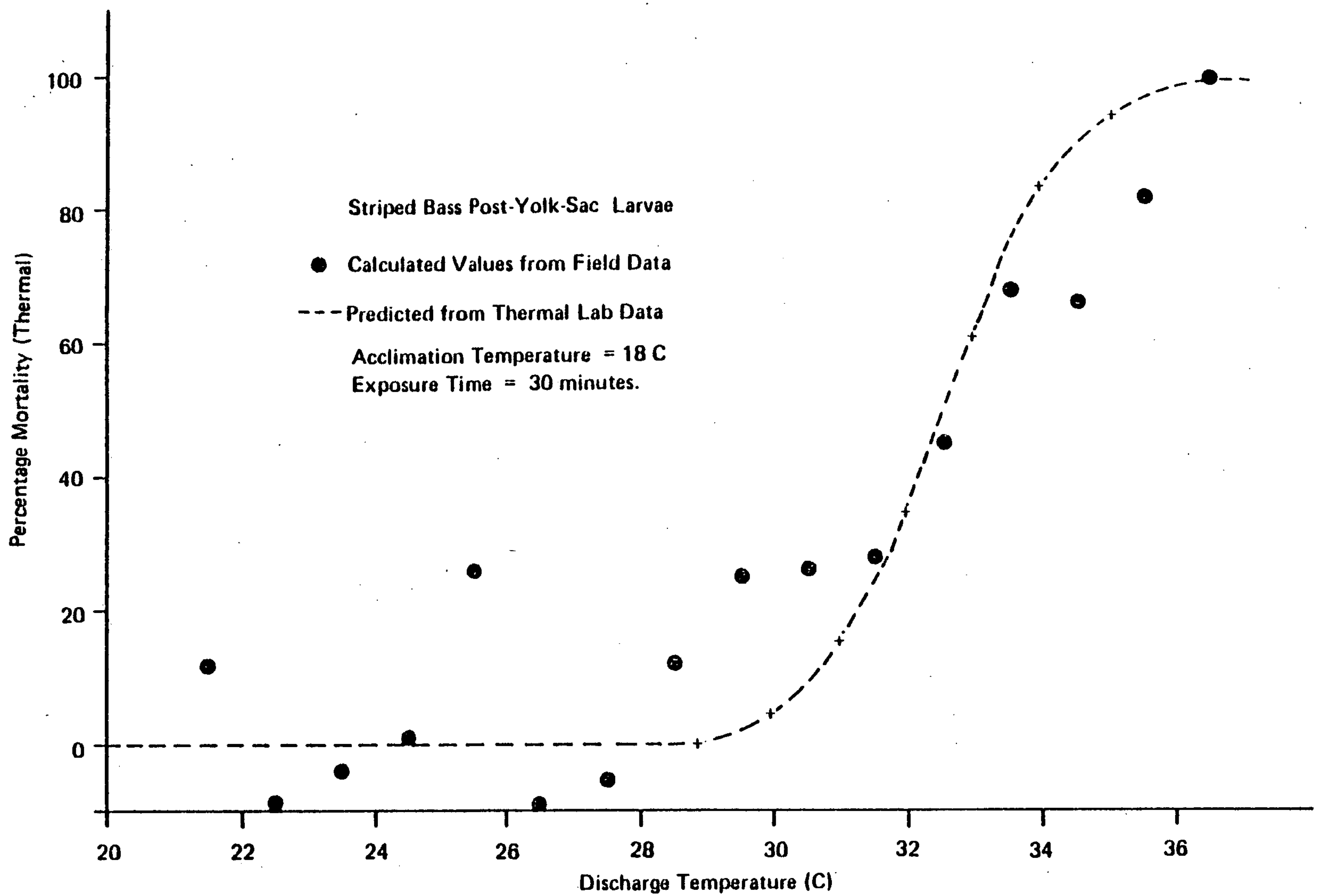

Figure 3.2-3. Comparison of thermal mortality observed at Hudson River power plants (Bowline Point plant, Roseton plant, Lovett plant, and Danskammer Point plant) with mortality predicted from thermal laboratory results.

The thermal laboratory data based regression coefficients have been used in the entrainment mortality model to predict the thermal effect on larvae and juveniles, although the field data suggest that the thermal tolerance of juvenile *Morone* may be slightly higher than that of larvae.

3.2.3 Involvement

Seasonal occurrence of entrainment at the Hudson River plants will vary depending upon spawning habits of the species, salinity, water temperature, and other factors. The average proportion of the annual entrainment of striped bass occurring during each week of the year was estimated from densities reported in studies conducted by LMS, TI, NYU, and Ecological Analysts at the Hudson River plants over the last 3-7 years (Tables 3.2-4 through 3.2-6). Peak entrainment of yolk-sac larvae at all the plants occurs in late May and early June, just after the main spawning season. Post-yolk-sac larvae are entrained in largest numbers from early to late June, whereas the juveniles are not seen at the plants in significant numbers until early July. The data from which these average distributions were obtained are presented in Appendix A of Volume II of this report.

Diel changes in the susceptibility of ichthyoplankton to entrainment have also been observed (Ecological Analysts 1977c). Higher nighttime entrainment may be due to increased activity and movement up into the water column or toward the shoals in search of food. Diel entrainment cycles should therefore become more pronounced as the larvae increase in size and become progressively less planktonic. This pattern has been observed in studies conducted by Ecological Analysts at the Roseton plant. The proportion of post-yolk-sac *Morone* entrained is 2-3 times higher between 2000 and 1000

TABLE 3.2-4 SEASONAL DISTRIBUTION OF LARVAE AND JUVENILE STRIPED BASS ENTRAINED AT THE ROSETON PLANT

Proportion of Annual Entrainment Occurring on Each Day											
Yolk-sac Larvae				Post-yolk-sac Larvae				Juveniles			
MAY	JUN	JUL	AUG	MAY	JUN	JUL	AUG	MAY	JUN	JUL	AUG
0.005	0.040	0.000	0.000	0.000	0.031	0.005	0.000	0.000	0.000	0.044	0.005
0.005	0.040	0.000	0.000	0.000	0.031	0.005	0.000	0.000	0.000	0.044	0.005
0.005	0.040	0.000	0.000	0.000	0.031	0.005	0.000	0.000	0.000	0.044	0.005
0.005	0.040	0.000	0.000	0.000	0.031	0.005	0.000	0.000	0.000	0.044	0.005
0.005	0.040	0.000	0.000	0.000	0.031	0.005	0.000	0.000	0.000	0.044	0.005
0.005	0.040	0.000	0.000	0.000	0.031	0.005	0.000	0.000	0.000	0.044	0.005
0.005	0.040	0.000	0.000	0.000	0.031	0.005	0.000	0.000	0.000	0.044	0.005
0.005	0.040	0.000	0.000	0.000	0.031	0.005	0.000	0.000	0.000	0.044	0.005
0.000	0.005	0.000	0.000	0.000	0.024	0.001	0.000	0.000	0.004	0.027	0.000
0.000	0.005	0.000	0.000	0.000	0.024	0.001	0.000	0.000	0.004	0.027	0.000
0.000	0.005	0.000	0.000	0.000	0.024	0.001	0.000	0.000	0.004	0.027	0.000
0.000	0.005	0.000	0.000	0.000	0.024	0.001	0.000	0.000	0.004	0.027	0.000
0.000	0.005	0.000	0.000	0.000	0.024	0.001	0.000	0.000	0.004	0.027	0.000
0.000	0.005	0.000	0.000	0.000	0.024	0.001	0.000	0.000	0.004	0.027	0.000
0.000	0.005	0.000	0.000	0.000	0.024	0.001	0.000	0.000	0.004	0.027	0.000
0.000	0.005	0.000	0.000	0.000	0.024	0.001	0.000	0.000	0.004	0.027	0.000
0.006	0.000	0.000	0.000	0.001	0.036	0.001	0.000	0.000	0.001	0.027	0.000
0.006	0.000	0.000	0.000	0.001	0.036	0.001	0.000	0.000	0.001	0.027	0.000
0.006	0.000	0.000	0.000	0.001	0.036	0.001	0.000	0.000	0.001	0.027	0.000
0.006	0.000	0.000	0.000	0.001	0.036	0.001	0.000	0.000	0.001	0.027	0.000
0.006	0.000	0.000	0.000	0.001	0.036	0.001	0.000	0.000	0.001	0.027	0.000
0.006	0.000	0.000	0.000	0.001	0.036	0.001	0.000	0.000	0.001	0.027	0.000
0.006	0.000	0.000	0.000	0.001	0.036	0.001	0.000	0.000	0.001	0.027	0.000
0.006	0.000	0.000	0.000	0.001	0.017	0.001	0.000	0.000	0.007	0.027	0.000
0.079	0.000	0.000	0.000	0.017	0.017	0.000	0.000	0.000	0.007	0.013	0.000
0.079	0.000	0.000	0.000	0.017	0.017	0.000	0.000	0.000	0.007	0.013	0.000
0.079	0.000	0.000	0.000	0.017	0.017	0.000	0.000	0.000	0.007	0.013	0.000
0.079	0.000	0.000	0.000	0.017	0.017	0.000	0.000	0.000	0.007	0.013	0.000
0.079	0.000	0.000	0.000	0.017	0.017	0.000	0.000	0.000	0.007	0.013	0.000
0.079	0.000	0.000	0.000	0.017	0.017	0.000	0.000	0.000	0.007	0.013	0.000
0.079		0.000	0.000	0.017		0.000	0.000	0.000		0.013	0.000

TABLE 3.2-5 SEASONAL DISTRIBUTION OF LARVAL AND JUVENILE STRIPED BASS AT THE BOWLINE POINT PLANT

	Proportion of Annual Entrainment Occurring on Each Day											
	Yolk-sac Larvae				Post-yolk-sac Larvae				Juveniles			
Day	MAY	JUN	JUL	AUG	MAY	JUN	JUL	AUG	MAY	JUN	JUL	AUG
1	0.016	0.020	0.000	0.000	0.000	0.015	0.006	0.000	0.000	0.000	0.032	0.009
2	0.016	0.020	0.000	0.000	0.000	0.015	0.006	0.000	0.000	0.000	0.032	0.009
3	0.016	0.020	0.000	0.000	0.000	0.015	0.006	0.000	0.000	0.000	0.032	0.009
4	0.016	0.020	0.000	0.000	0.000	0.015	0.006	0.000	0.000	0.000	0.032	0.009
5	0.016	0.020	0.000	0.000	0.000	0.015	0.006	0.000	0.000	0.000	0.032	0.009
6	0.016	0.020	0.000	0.000	0.000	0.015	0.006	0.000	0.000	0.000	0.032	0.009
7	0.016	0.020	0.000	0.000	0.000	0.015	0.006	0.000	0.000	0.000	0.032	0.009
8	0.016	0.020	0.000	0.000	0.000	0.015	0.006	0.000	0.000	0.000	0.032	0.009
9	0.026	0.002	0.000	0.000	0.000	0.029	0.009	0.000	0.000	0.000	0.019	0.000
10	0.026	0.002	0.000	0.000	0.000	0.029	0.009	0.000	0.000	0.000	0.019	0.000
11	0.026	0.002	0.000	0.000	0.000	0.029	0.009	0.000	0.000	0.000	0.019	0.000
12	0.026	0.002	0.000	0.000	0.000	0.029	0.009	0.000	0.000	0.000	0.019	0.000
13	0.026	0.002	0.000	0.000	0.000	0.029	0.009	0.000	0.000	0.000	0.019	0.000
14	0.026	0.002	0.000	0.000	0.000	0.029	0.009	0.000	0.000	0.000	0.019	0.000
15	0.026	0.002	0.000	0.000	0.000	0.029	0.009	0.000	0.000	0.000	0.019	0.000
16	0.026	0.002	0.000	0.000	0.000	0.029	0.009	0.000	0.000	0.000	0.019	0.000
17	0.023	0.010	0.000	0.000	0.000	0.036	0.000	0.000	0.000	0.000	0.015	0.000
18	0.023	0.010	0.000	0.000	0.000	0.036	0.000	0.000	0.000	0.000	0.015	0.000
19	0.023	0.010	0.000	0.000	0.000	0.036	0.000	0.000	0.000	0.000	0.015	0.000
20	0.023	0.010	0.000	0.000	0.000	0.036	0.000	0.000	0.000	0.000	0.015	0.000
21	0.023	0.010	0.000	0.000	0.000	0.036	0.000	0.000	0.000	0.000	0.015	0.000
22	0.023	0.010	0.000	0.000	0.000	0.036	0.000	0.000	0.000	0.000	0.015	0.000
23	0.023	0.010	0.000	0.000	0.000	0.036	0.000	0.000	0.000	0.000	0.015	0.000
24	0.023	0.000	0.000	0.000	0.000	0.034	0.000	0.000	0.000	0.004	0.015	0.000
25	0.033	0.000	0.000	0.000	0.004	0.034	0.000	0.000	0.000	0.004	0.053	0.000
26	0.033	0.000	0.000	0.000	0.004	0.034	0.000	0.000	0.000	0.004	0.053	0.000
27	0.033	0.000	0.000	0.000	0.004	0.034	0.000	0.000	0.000	0.004	0.053	0.000
28	0.033	0.000	0.000	0.000	0.004	0.034	0.000	0.000	0.000	0.004	0.053	0.000
29	0.033	0.000	0.000	0.000	0.004	0.034	0.000	0.000	0.000	0.004	0.053	0.000
30	0.033	0.000	0.000	0.000	0.004	0.034	0.000	0.000	0.000	0.004	0.053	0.000
31	0.033		0.000	0.000	0.004		0.000	0.000	0.000		0.053	0.000

TABLE 3.2-6 SEASONAL DISTRIBUTION OF LARVAL AND JUVENILE STRIPED BASS ENTRAINED AT THE INDIAN POINT PLANT

	Proportion of Annual Entrainment Occurring on Each Day											
	Yolk-sac Larvae				Post-yolk-sac Larvae				Juveniles			
Day	MAY	JUN	JUL	AUG	MAY	JUN	JUL	AUG	MAY	JUN	JUL	AUG
1	0.006	0.036	0.000	0.000	0.000	0.021	0.015	0.000	0.000	0.000	0.029	0.021
2	0.006	0.036	0.000	0.000	0.000	0.021	0.015	0.000	0.000	0.000	0.029	0.021
3	0.006	0.036	0.000	0.000	0.000	0.021	0.015	0.000	0.000	0.000	0.029	0.021
4	0.006	0.036	0.000	0.000	0.000	0.021	0.015	0.000	0.000	0.000	0.029	0.021
5	0.006	0.036	0.000	0.000	0.000	0.021	0.015	0.000	0.000	0.000	0.029	0.021
6	0.006	0.036	0.000	0.000	0.000	0.021	0.015	0.000	0.000	0.000	0.029	0.021
7	0.006	0.036	0.000	0.000	0.000	0.021	0.015	0.000	0.000	0.000	0.029	0.021
8	0.006	0.036	0.000	0.000	0.000	0.021	0.015	0.000	0.000	0.000	0.029	0.021
9	0.002	0.019	0.000	0.000	0.000	0.031	0.006	0.000	0.000	0.000	0.025	0.006
10	0.002	0.019	0.000	0.000	0.000	0.031	0.006	0.000	0.000	0.000	0.025	0.006
11	0.002	0.019	0.000	0.000	0.000	0.031	0.006	0.000	0.000	0.000	0.025	0.006
12	0.002	0.019	0.000	0.000	0.000	0.031	0.006	0.000	0.000	0.000	0.025	0.006
13	0.002	0.019	0.000	0.000	0.000	0.031	0.006	0.000	0.000	0.000	0.025	0.006
14	0.002	0.019	0.000	0.000	0.000	0.031	0.006	0.000	0.000	0.000	0.025	0.006
15	0.002	0.019	0.000	0.000	0.000	0.031	0.006	0.000	0.000	0.000	0.025	0.006
16	0.002	0.019	0.000	0.000	0.000	0.031	0.006	0.000	0.000	0.000	0.025	0.006
17	0.026	0.009	0.000	0.000	0.001	0.031	0.002	0.000	0.000	0.000	0.014	0.000
18	0.026	0.009	0.000	0.000	0.001	0.031	0.002	0.000	0.000	0.000	0.014	0.000
19	0.026	0.009	0.000	0.000	0.001	0.031	0.002	0.000	0.000	0.000	0.014	0.000
20	0.026	0.009	0.000	0.000	0.001	0.031	0.002	0.000	0.000	0.000	0.014	0.000
21	0.026	0.009	0.000	0.000	0.001	0.031	0.002	0.000	0.000	0.000	0.014	0.000
22	0.026	0.009	0.000	0.000	0.001	0.031	0.002	0.000	0.000	0.000	0.014	0.000
23	0.026	0.009	0.000	0.000	0.001	0.031	0.002	0.000	0.000	0.000	0.014	0.000
24	0.026	0.000	0.000	0.000	0.001	0.019	0.002	0.000	0.000	0.009	0.014	0.000
25	0.027	0.000	0.000	0.000	0.006	0.019	0.001	0.000	0.000	0.009	0.026	0.000
26	0.027	0.000	0.000	0.000	0.006	0.019	0.001	0.000	0.000	0.009	0.026	0.000
27	0.027	0.000	0.000	0.000	0.006	0.019	0.001	0.000	0.000	0.009	0.026	0.000
28	0.027	0.000	0.000	0.000	0.006	0.019	0.001	0.000	0.000	0.009	0.026	0.000
29	0.027	0.000	0.000	0.000	0.006	0.019	0.001	0.000	0.000	0.009	0.026	0.000
30	0.027	0.000	0.000	0.000	0.006	0.019	0.001	0.000	0.000	0.009	0.026	0.000
31	0.027		0.000	0.000	0.006		0.001	0.000	0.000		0.026	0.000

hours than during mid-afternoon (Figure 3.2-4). For juveniles the cycle becomes more pronounced, with nighttime entrainment being 5-10 times higher than in the day and with a narrow peak between 2000 and 0500 hours. The Roseton data have been used for all plants as the best available estimate of the diel cycle of entrainment for Morone larvae and juveniles. Entrainment of yolk-sac larvae was assumed to be constant over a 24-hour cycle since available data are insufficient to determine diel distributions and pronounced cycles are not anticipated for these very young fish.

Seasonal and diel distributions of entrainment abundance (in proportion to total entrainment) and mortality are combined to provide an estimate of the proportion of the total number of entrained organisms that are cropped. These proportions provide an estimate of the probable entrainment mortality or cropping by the plant.

$$P_c(t) = f_c(t) \times f_e(t)$$

where

P_c = proportion of the total number of entrained organisms killed (entrainment mortality)

f_c = mortality factor

f_e = proportion of total entrainment occurring

t = time (day of year and hour of day).

By normalizing entrainment mortality estimates for circulating water flow (since the number of organisms entrained is presumably proportional to water withdrawal), relative cropping indices are obtained which provide a basis for comparing relative impact obtained under the different circulating pump operations possible at each plant.

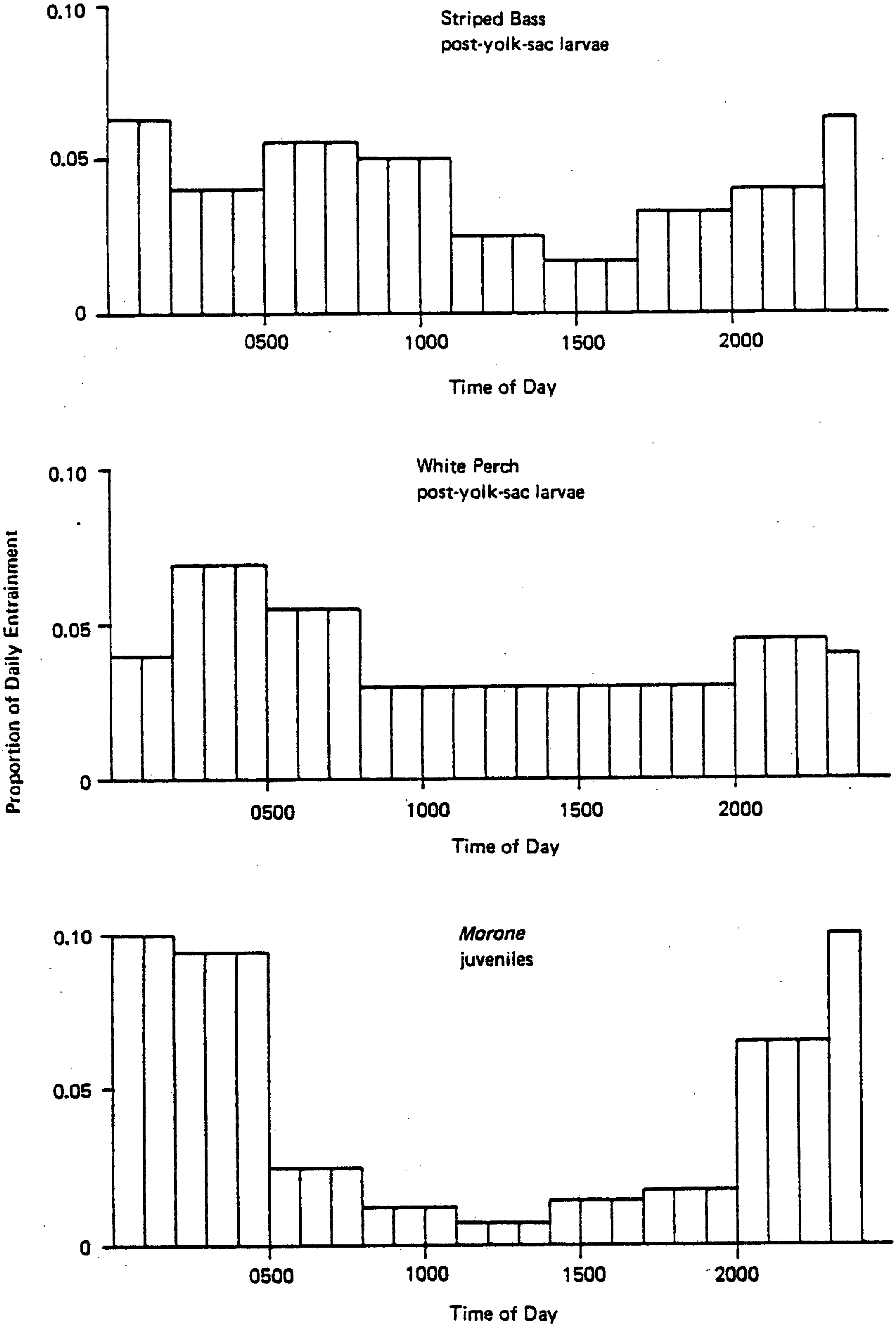

Figure 3.2-4. Diel distribution of entrainment at the Roseton plant during 1976.

3.3 MODEL PREDICTIONS

Predictive assessments of entrainment mortality of striped bass larvae and juveniles were made for the Roseton, Bowline Point, and Indian Point plants. Relevant ambient and operating conditions used in the baseline case assessments are shown in Table 3.3-1. Intake temperature at all plants was assumed to be at the 90th percentile (i.e., the numerical values would only be exceeded about 10 percent of the time). Generating load at the Roseton and Bowline Point plants also represented the 90th percentile of occurrence and was selected from the year during which generating performance of the plants was high (Bowline Point Unit 2 - 1975, Roseton Unit 2 - 1976). Indian Point calculations were made for Unit 2 under 100 percent capacity operation at all times since this plant has been designated a baseload generating station. Thermal recirculation was incorporated directly in the intake temperature analysis for Bowline Point and Indian Point, and no additional thermal recirculation was considered in the baseline cases for these plants. A mean thermal recirculation of 10 percent was used for the Roseton analysis. The above conditions provide a very conservative analysis of the thermal exposure of striped bass young.

Three types of analyses were performed: (1) entrainment mortality factors (f_c) were predicted as a function of time and circulating water flow; (2) entrainment mortality was estimated from the mortality factor estimates and the time distribution of entrainment; and (3) the entrainment mortality estimates were used to calculate the seasonal circulating pump operating scheme which would provide minimum entrainment impact on the striped bass.

TABLE 3.3-1 AMBIENT AND PLANT OPERATING CONDITIONS USED IN THE BASELINE CASES FOR PREDICTIVE ASSESSMENT OF ENTRAINMENT MORTALITY

Bowline Point

Intake Temperature: 90th percentile
Generating Load: Unit 2 1975; 90th percentile
Pump conditions: 2 (throttled), 2, 3
Units: Applicable to either unit.

Roseton

Ambient Temperature: 90th percentile
Generating Load: Unit 2 1976; 90th percentile
Pump conditions: 2, 3, 4
Thermal Recirculation: 10%
Units: Units 1 and 2 operating identically.

Indian Point

Intake Temperature: 90th percentile
Generating Load: 100% of capacity
Pump Conditions: 4, 5, 6
Units: Units 2 and 3 operating identically.

The complete set of predictions for all three plants is presented in Appendix B of Volume II, along with the relevant ambient and plant exposure information used in the calculations. Summarization of the results and analysis of trends is provided in the following sections of this chapter.

3.3.1 Entrainment Mortality Factors

In general, entrainment mortality factors are low (10-30 percent) during May under all operating pump modes at all plants. Under low coolant flow conditions, total thermal exposure begins to exceed the tolerance of the species in the latter half of May at the Roseton and Indian Point plants and by mid-June at the Bowline Point plant due to increasing ambient water temperature, and results in a gradual increase in mortality to peak levels (60-100 percent) in late July. The seasonal and diel trends in mortality factors with low cooling water flow are illustrated for the Bowline Point case in Figure 3.3-1. This seasonal trend could presumably result in different levels of cropping from year to year depending upon the time of spawning in the Hudson. For example, when the major period of entrainment of striped bass post-yolk-sac larvae occurs early in the year (first week in June) as it did in 1975, the risk of mortality from thermal effects will be much lower than a late peak larval entrainment (i.e., late June, early July) as that of 1976.

Diel cycles in generating load at the plant result in a maximum heat rejection to the cooling water during mid-afternoon hours and a minimum in the early morning. Entrainment mortality therefore fluctuates over the 24-hour cycle in response to the changes in heat stress of the organisms. The diel cycle in the magnitude of the mortality estimates becomes prominent when thermal stress contributes significantly to the total entrainment

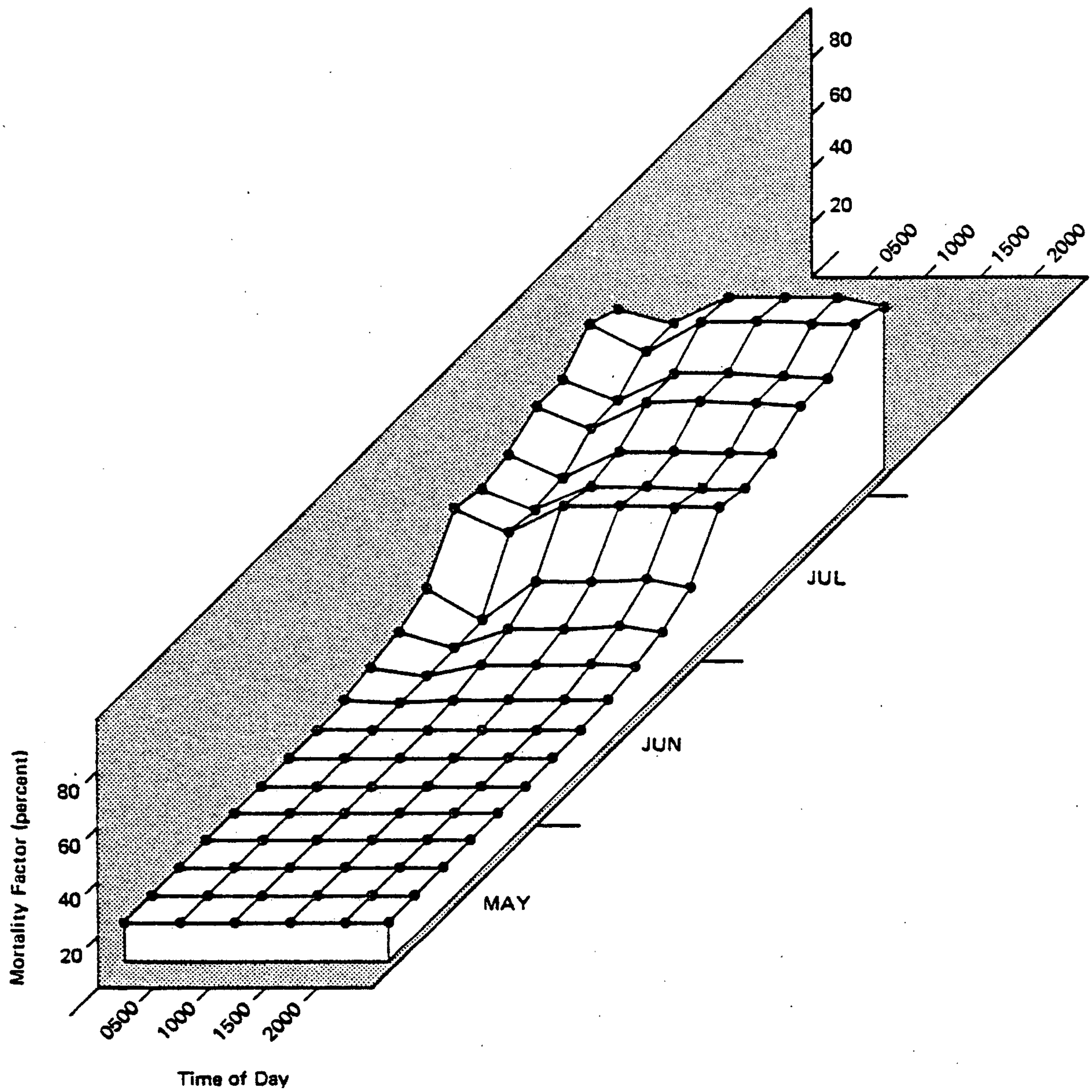

Figure 3.3-1. Seasonal and diel trends in predicted mortality factors for striped bass post-yolk-sac larvae with two pumps (throttled) at the Bowline Point plant (90th percentile ambient temperature, 90th percentile generating load).

mortality. This occurs mainly when circulating water flow at the plants is low and ambient temperatures are high, as in the latter half of June and July (Figure 3.3-1). Under these conditions, organisms entrained during the early morning hours will normally receive lower thermal exposures and survive the entrainment experience better than those entrained in the afternoon or early evening.

Thermal mortality is significantly reduced by increasing the flow of coolant. For example, mortality factors estimated for July at the Bowline Point plant range from 30-65 percent under low-flow conditions (2 pumps, throttled), but are only about 15 percent when coolant flow is high (3 pumps). Large reductions are also observed in the estimated mortality factor at the Roseton and Indian Point plants as coolant flow is increased (Table 3.3-2). The results indicate that thermal effects of entrainment on the early life stages of striped bass could be mitigated by increasing the flow of condenser cooling water. Manipulation of circulating system operation appears to be a feasible method for minimizing the impact of entrainment on striped bass. However, the effect of reducing thermal stress must be weighed against the increase in number of organisms entrained with higher circulating water flows. The problem is discussed further in Subsection 3.3.3.

3.3.2 Entrainment Mortality (Cropping)

The predicted entrainment mortality factors are an estimate of the effect to be expected if entrainment of striped bass occurs on any given date and time. The actual proportion of entrained organisms cropped by the plants depends upon the time distribution of entrainment, and the model incorporates this distribution in the analysis as previously described. Table 3.3-3 summarizes the estimated annual proportion of entrained yolk-sac

TABLE 3.3-2 APPROXIMATE RANGES OF MORTALITY FACTORS (PERCENT) FOR STRIPED BASS POST-YOLK-SAC LARVAE PREDICTED FOR JULY AT THE HUDSON RIVER POWER PLANTS

Plant	Coolant Flow Low[(a)]	Coolant Flow Intermediate[(b)]	Coolant Flow High[(c)]
Bowline Point	30-65	15-30	15
Roseton	50-100	25-75	25-40
Indian Point	85-95	25-55	15-25

(a) Bowline Point - 2 pumps (throttled)
Roseton - 2 pumps
Indian Point - 4 pumps
(b) Bowline Point - 2 pumps (full)
Roseton - 3 pumps
Indian Point - 5 pumps
(c) Bowline Point - 3 pumps
Roseton - 4 pumps
Indian Point - 6 pumps

TABLE 3.3-3 PREDICTED ANNUAL ENTRAINMENT MORTALITY OF STRIPED BASS AT HUDSON RIVER PLANTS

Plant	No. of Pumps	Annual Proportion Cropped		
		Yolk-sac Larvae	Larvae	Juveniles
Bowline Point	2 (throttled)	0.15	0.21	0.44
	2	0.15	0.15	0.17
	3	0.15	0.15	0.11
Indian Point	4	0.25	0.56	0.93
	5	0.15	0.20	0.37
	6	0.15	0.16	0.13
Roseton	2	0.46	0.56	0.83
	3	0.23	0.25	0.33
	4	0.23	0.23	0.16

larvae, post-yolk-sac larvae, and juveniles cropped by each plant for the various possible cooling water flows.

The total annual entrainment mortality increases progressively with life stage at the lower coolant flows as a result of increasing thermal stress, since the larger fish are entrained later in the season when ambient temperatures are high. Annual mortality is reduced at all plants by increasing circulating water flow, and cropping at the highest flows results mainly from nonthermal effects. Survival is improved most dramatically for striped bass juveniles by increased circulating water flow. Predicted cropping of juveniles ranges from 44 to 93 percent at the different plants under low-flow conditions, but annual mortality estimates are reduced to 11-16 percent for operation at the highest circulating water flows.

The extent of cropping by the plant may depend critically upon the relationship between diel cycles in entrainment mortality factors and entrainment abundance. For example, the relationship for striped bass juveniles at the Roseton plant shows that minimal numbers of organisms are entrained in the afternoon when mortality factors are highest, and that much of the peak entrainment occurs during the early morning hours (0100-0400), when generating load and mortality are at their lowest levels (Figure 3.3-2).

3.3.3 Cropping Indices and Optimum Circulating System Operation

Cropping indices* generated by the model provide a relative basis for comparing the magnitude of cropping resulting at each of the circulating water

---

* Cropping index = Entrainment Mortality x $\frac{Q_i}{Q_{min}}$
where Q_i = circulating water flow with pump mode i; Q_{min} = practical circulating water flow.

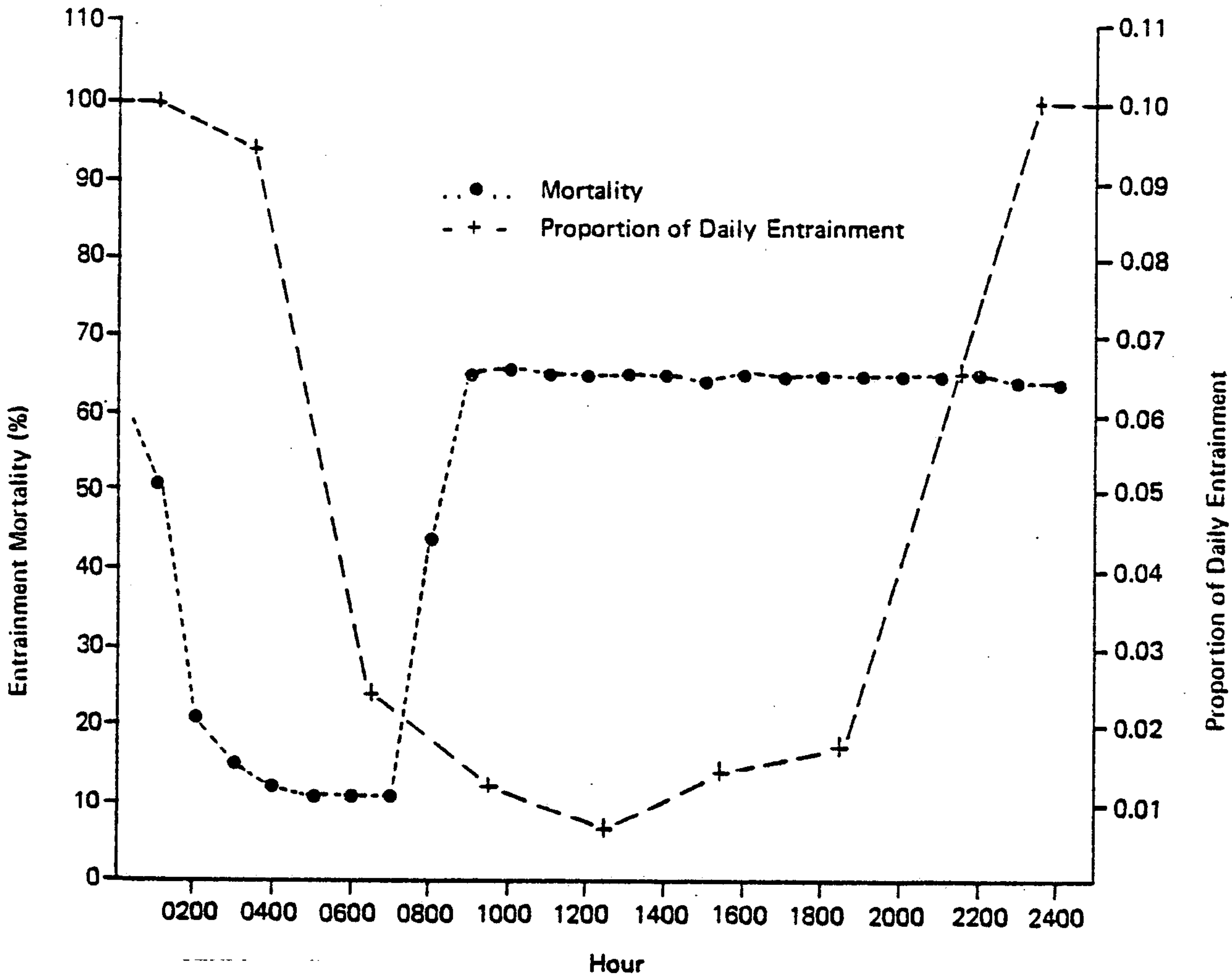

Figure 3.3-2. Diel cycle of entrainment mortality factors (21 July) and entrainment abundance of striped bass juveniles at the Roseton plant.

flows that can be implemented by the power plant. The magnitude of the cropping index for each day and hour was compared for the three possible circulating water flows at each plant to determine the schedule of pump operation that would provide the minimum cropping of striped bass due to entrainment at the plant. In general, the desirable operation is to increase flow when discharge temperature at low coolant flow begins to exceed the upper thermal tolerance of the organisms. At other times, low flow is preferable since it minimizes the number of organisms entrained. At Bowline Point, for example, the calculations indicate that minimum entrainment impact on striped bass young would result from operation of 2 pumps (throttled) during the early part of the entrainment season (May and early June), 2 pumps (unthrottled) in late June, and 3 pumps in July.

REFERENCES: CHAPTER 3

Central Hudson Gas & Electric Corporation. 1977. Roseton Generating Station: Near-Field Effects of Once-Through Cooling System Operation on Hudson River Biota.

Consolidated Edison Company of New York, Inc. 1977. Indian Point Nuclear Generating Station: Near-Field Effects of Once-Through Cooling System Operation on Hudson River Biota.

Ecological Analysts, Inc. 1977a. Bowline Point Generating Station. Data collected for Orange and Rockland Utilities, Inc.

Ecological Analysts, Inc. 1977b. Hudson River Thermal Effects Studies for Representative Important Species. Second Progress Report. Vol. 1.

Ecological Analysts, Inc. 1977c. Roseton Generating Station. Data collected for Central Hudson Gas & Electric Corp.

Ecological Analysts, Inc. 1976a. Entrainment Survival and Abundance Studies at the Bowline Point Generating Station. 1975 Annual Interpretive Report.

Orange and Rookland Utilities, Inc. 1977. Bowline Point Generating Station: Near-Field Effects of Once-Through Cooling System Operation on Hudson River Biota.