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Vulnerability and Survival of Young Connecticut River Fish Entrained at a Nuclear Power Plant

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MARCY, B. C. JR. 1973. Vulnerability and survival of young Connecticut River fish entrained at a nuclear power plant. J. Fish. Res. Board Can. 30: 1195–1203.

Most of the young fish of nine species that were entrained in the condenser cooling-water system of the Connecticut Yankee nuclear power plant were dead by the time they reached the lower end of the plant's 1.83-km (1.14 mile) long discharge canal. Sampling during June and July, when 95% of the nonscreenable fish were abundant near the plant's intake, showed that approximately 80% of the mortality in the canal was caused by mechanical damage and 20% was attributed to heat shock and prolonged exposure to temperatures elevated above 28 C. There was no measurable mortality due to the injection of sodium hypochlorite into the system as a biocide. The number of nonscreenable living fish entrained at the intake averaged about 4% (range, 1.7–5.8%) of those passing by the plant under conditions of unidirectional net tidal flow.

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La plupart des jeunes de neuf espèces de poisson entraînés dans le système condensateur de l'eau de refroidissement de la centrale électronucléaire Connecticut Yankee sont morts au moment où ils atteignent l'extrémité inférieure du long (1.83 km ou 1.14 milles) canal de vidange de la centrale. L'échantillonnage en juin et juillet, alors que 95% des poissons non tamisables étaient abondants près de la prise d'eau de la centrale, démontre qu'environ 80% des mortalités dans le canal sont attribuables à des blessures et 20% au choc thermique et à l'exposition prolongée à des températures dépassant 28 C. L'introduction d'hypochlorite de sodium dans le système, comme biocide, ne semble pas causer de mortalités mesurables. Le nombre de poissons vivants non tamisables entraînés dans la prise d'eau est en moyenne d'environ 4% (intervalle de 1.7 à 5.8%) de ceux qui passent près de la centrale dans des conditions de flot net continu de marée.

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THE fate of young fish passing through condenser cooling-water systems of power plants has been a recent concern in environmental impact evaluations. Coutant (1970, 1971) has provided the most comprehensive review of entrainment studies. I gave a preliminary report (Marcy 1971) on the effects of different temperatures on the survival of entrained nonscreenable young fishes during June and July in the condenser cooling-water system of the Connecticut Yankee Atomic Power Company's plant at Haddam Neck, Conn. The present report describes a broader study of mechanical, biocidal, and thermal factors influencing the survival of fish during passage through the condenser and discharge canal system of the plant; it includes estimates of the percentages of nonscreenable living fish larvae passing by the plant that were entrained under conditions of unidirectional net tidal flow.

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Materials and Methods

The plant is an electric generating station located 26 km (16 miles) from the mouth of the Connecticut River (Fig. 1). It went into commercial operation in October 1967. At peak load it pumps approximately 25 m^3/sec (883 ft^3/sec) of water heated about 12.5 C above ambient water temperature. The plant uses approximately 6% of the average available river flow at the intake point during extreme low-flow conditions. Merriman (1971) has provided a more detailed description of the location and operation of the plant.

The river water that enters the cooling-water system passes through (1) an intake structure at a velocity of 0.3–0.6 m/sec, (2) a 1-cm mesh traveling screen, (3) a variable axial flow water pump of 352,000 liters/min capacity, (4) twin, single-pass, divided water boxes — in which the velocity may approach 2.4 m/sec, (5) two right-angle turns, and (6) two banks of 26,860 condenser tubes (2.3 cm ID × 236 cm long), in which the exchange of heat takes place. Total elapsed time was calculated as 93 sec. The heated water then passes over a weir and continues down a canal 18.3 m wide and 3 m deep at

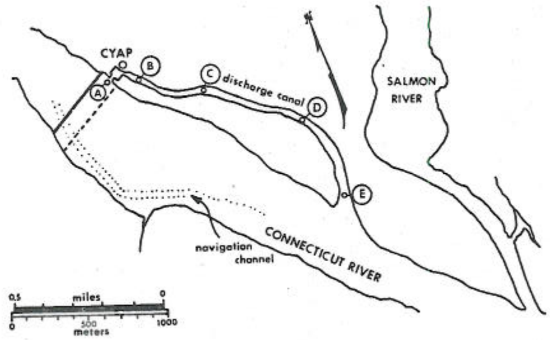

FIG. 1. Location of sampling stations A–E at the Connecticut Yankee Atomic Power Company (CYAP). The solid line across the river indicates the upstream (ebb tide) cross section sampled and the dashed line the downstream (slack tide) cross section.

an average velocity of 0.3–0.6 m/sec depending upon the stage of the tide. The water is returned to the river 1.83 km (1.14 miles) downstream of the plant. The drop in temperature between the upper and lower ends of the canal is approximately 1 C. An entrained organism is exposed to the elevated temperatures in the canal for 50–100 min.

For the collection of fish specimens, 0.5-m, # 2 mesh (0.39-mm), cone-shaped nylon plankton nets with # 313 TSK flowmeters at their centers were used. A 1-liter plastic container was attached to the codend of each net.

The field observation device used for maintaining water at ambient and at elevated temperatures during the counting of living and dead specimens has been described by Marcy (1971). Only those specimens that had begun to turn opaque were considered dead. All samples were preserved in 2% neutral formalin with rose bengal dye added to facilitate separation and counting in the laboratory.

As the river passes the plant, a proportion of its living nonscreenable young fish population is entrained at the intake. This percentage of young living fish entrained was calculated as follows. Between June 1 and July 25, 1972, 7 day and night series of samples were taken on a grid-cross section across the width (502 m) of the river and at each of the four intake bays. Each sampling of a cross section of the river was conducted 50 m upstream or downstream of the intake on ebb or slack tide, respectively (Fig. 1). Cross sections of the river were divided into nine stations, approximately 50 m apart. Two more stations were located in the shallows near the east shore. Five-minute stationary net collections were taken at 1, 3, and 5 m below the surface, or 0.5 m above the bottom if the depth of the river was less than 5 m. A 50-m line was stretched between two buoys anchored with 23-kg weights along a line of sight from the east to west shores. The cross section of the intake was sampled simultaneously by a second crew. Five-minute stationary net collections were made at 1 and 3 m below the surface and 1 m above the bottom in front of each of the 3.7-m wide intake bays in 0.3–0.6 m/sec water that was committed to the intake.

The number of larvae and early juvenile fish per cubic meter of water sampled was calculated for each sample. The number of living fish (those surviving natural or net caused mortality) collected in all the samples of each sampling day was estimated using the field observation device to count the number of living and dead fish in the samples from the middle of the river cross section at 1 and 3m below the surface and 0.5 m above the bottom. An estimate of the percentage of living fish was calculated from the combined samples from the three depths. This percentage was multiplied by the total number collected in the river and intake cross sections to estimate the total number of living fish in each cross section on each sampling day. The total number of cubic meters of water recorded on all net flowmeters in each cross section was divided into the total number of living fish collected by all nets to obtain the average number of living fish per m^3 in each cross section.

The percentages of nonscreenable living young fish entrained under conditions of unidirectional net tidal flow were calculated by the formula,

$$\frac{(N_i)\ (F_i)}{(N_r)\ (F_r)}(100) = \%$$

where N_i = average number of living fish per cubic meter in the intake cross section; F_i = flow rate into intake in m^3/sec; N_r = average number of living fish per cubic meter in the river cross section; and F_r = average net tidal flow rate (m^3/sec) in the river near the plant during each time period sampled.

The intake flow rate (F_i) was obtained from plant records and the net tidal flow rates (F_r) for the river were obtained from the U.S. Geological Survey, Hartford, Conn. These flow rates were from the Canal station (8 km upstream from the plant's intake) and were not considered to be significantly different from those in the plant site area (J. Stackpole personal communication). The methods used to calculate these flow rates have been described by Lai et al. (1971). The net tidal flow rates were unidirectional or downstream during the entire experiment. Percentage calculations using the above formula, therefore, relate only to a single tidal pass situation where larvae were assumed to pass by the plant only once. River net tidal flow rate records (F_r) were available for each 15 min during the plankton net sampling. All 15-min records were totaled for each plankton net sampling period and were divided by the total number of records to obtain an average river net tidal flow rate during each sampling time period.

Survival in the discharge canal in relation to heat was determined from plankton net collections of larvae and early juvenile fishes from June 30 to July 29, 1970 and June 2 and 24, 1971, at the plant's intake (A), below the outfall weir (B), and along the discharge canal at 457 m (C), 1200 m (D), and 1800 m (E) (Fig. 1). Triplicate 5-min stationary samples at the surface, middle, and bottom depths were taken successively at the five stations. The data from each of the three collections per station were combined for comparisons. Five-minute stationary net collections with the # 2 mesh held mortality due to combined netting and natural causes to 18%, for of the 4480 larvae and early juveniles collected near the plant's intake, 3664 were alive when captured.

The percentage survival at each discharge canal station was calculated by dividing the number of living fish per cubic meter counted at that station by the number of living fish per cubic meter counted at the intake for each sampling day. Survival was based on the number of living fish because sampling for dead fish in the canal often gave inconsistent results. For example, fewer dead fish were collected as the sampling approached the lower end of the canal, indicating a settling out process. Such inconsistency is probably due to the inherently variable nature of the fish distribution in the water column which is further influenced by turbulent mixing, organism mobility, and changes in the specific gravity of the water in the canal due to temperature changes.

The percentages of mortality caused by mechanical damage were estimated on June 27 and July 13, 1972 when all intake pumps were running at capacity with no addition of heat or hypochlorite. Five-min net collections were made at all canal stations immediately after the intake was sampled in cross section. The estimated percentage living at the intake was multiplied by the total number of fish collected in each intake cross section and divided by the total number of cubic meters sampled to obtain the number of living fish per cubic meter sampled at the intake.

The percentage of mortality due to the injection of sodium hypochlorite, while all intake pumps were running and no heat was added, was calculated from data collected on July 13 and 14, 1972. Sampling procedures and calculations were the same as described above for evaluations of mechanical damage. The biocide, sodium hypochlorite, containing approximately 13.5% by weight of available chlorine, is injected at a rate of 5 gal/min for 10 min into one intake bay at a time in front of each traveling screen, generally once per day. This "split stream" method gives maximum concentrations of residual chlorine of 2 ppm before reaching the condenser, 1 ppm at the condenser outlet, and <0.1 ppm at a point 45 m below the outfall weir (Anon. 1972).

Results

Entrained Species

Entrained species were alewives, *Alosa pseudoharengus*, blueback herring, *Alosa aestivalis*, white perch, *Morone americana*, carp, *Cyprinus carpio*, white catfish, *Ictalurus catus*, American eel, *Anguilla rostrata*, spottail shiner, *Notropis hudsonius*, johnny darter, *Etheostoma nigrum*, and American shad, *Alosa sapidissima*.

A total of 1068 and 10,271 larvae and juveniles were collected in 1971 and 1972, respectively. Of the 2681 larvae and juveniles that were sorted, identified, and measured during 1970, 97.5% were in the post yolk-sac larval stage (2.6-15.0 mm total length), and 2.5% were early juveniles (15.1–40.0 mm total length) (Table 1). Alewives and blueback herring made up 97.6% of the total catch and white perch 1.3%. The six other species were represented in quantities of less than 1%. Those fish surviving to various points in the discharge canal were alewives, blueback herring, and carp (Table 2). No living white perch larvae were observed after passage through the plant (station B). The only survivors taken in the canal after day 3 (canal temperature 37 C) were the two small American eels. It is not known whether they had come in through the intake or up the canal.

Table 1. Percentages of the total catches on the various sampling dates that were represented by the various species, and total lengths of the fish, June 30–July 29, 1970.

Date	No. collected	% of total catch	Mean length (*mm*)	Range
Alosa aestivalis and *Alosa pseudoharengus*				
June 30	239	91.6	7.8	4.7–14.0
July 2	134	92.4	6.5	4.0–11.5
6	833	99.4	5.9	3.6–11.3
8	1277	97.9	9.3	4.0–40.0
22	115	100.0	10.1	5.5–28.5
29	18	100.0	8.4	5.0–13.5
Morone americana				
June 30	21	8.0	3.1	2.0–03.9
July 2	9	6.2	3.5	3.2–03.7
6	5	0.6	3.0	2.8–03.3
Cyprinus carpio				
June 30	1	0.4	7.5	7.5
July 2	1	0.7	5.5	5.5
8	10	0.7	3.0	2.1–05.0
Ictalurus catus				
July 2	1	0.7	10.6	10.6
8	2	0.1	17.2	13.0–21.3
Anguilla rostrata				
July 8	2	0.1	100.7	100.5–100.8
Notropis hudsonius				
July 8	12	0.9	24.5	19.2–30.0
Etheostoma nigrum				
July 8	1	0.1	28.5	28.5
Alosa sapidissima				
July 8	1	0.1	16.0	16.0

TABLE 2. Percentages of larvae and early juveniles surviving at the various stations in the discharge canal, and environmental conditions, June 30-July 29, 1970, and June 2 and 24, 1971.

Station[a]		Time (*hr*) and power level (Mw_e)	Temp. (*C*)	No. living/m³	No. dead/m³	% survival/m³
June 30, 1970	A	0900–1200	22.2	1.74	0.91	65.5[b]
	B	300	28.2	0.60	2.54	34.5
	C		28.2	0.49	0.52	28.2
	E		28.2	0.13	0.24	07.5
June 2, 1971	A	1000–1535	16.0	0.06	0.00	100.0
	B	610	29.0	0.04	0.48	66.6
	C		29.0	0.02	0.42	33.3
	D		28.8	0.00	0.33	00.0
	E		28.6	0.00	0.29	00.0
July 2, 1970	A	1200–1600	22.0	0.54	0.30	64.8
	B	588	33.5	0.09	1.64	16.6
	C		33.5	0.10	1.22	18.5
	D		33.0	0.00	0.96	00.0
	E		33.0	0.00	0.82	00.0
June 24, 1971	A	1120–1535	26.0	3.92	2.23	63.7
	B	579	35.0	0.00	3.08	00.0
	C		35.0	0.00	2.45	00.0
	D		34.8	0.00	3.23	00.0
	E		34.2	0.00	0.89	00.0
July 6, 1970	A	1000–1500	23.9	1.89	0.90	67.7
	B	587	35.5	0.00	1.12	00.0
	C		35.2	0.00	0.97	00.0
	D		35.0	0.00	1.76	00.0
	E		35.4	0.00	0.55	00.0
July 8, 1970	A	1430–1800	29.0	0.92	0.14	86.8
	B	584	38.5	0.00	0.96	00.0
	C		38.0	0.00	0.78	00.0
	D		38.0	0.00	0.92	00.0
	E		37.8	0.00	0.26	00.0
July 8, 1970	A	2100–0130	25.0	0.48	0.49	49.5
	B	584	36.0	0.00	1.26	00.0
	C		36.0	0.00	0.74	00.0
	D		36.0	0.00	1.12	00.0
	E		36.0	0.00	0.43	00.0
July 9, 1970	A	0230–0630	25.5	1.41	0.86	62.1
	B	581	37.0	0.03	2.19	02.6
	C		37.0	0.00	0.97	00.0
	D		36.5	0.00	2.06	00.0
	E		36.5	0.00	1.19	00.0
July 22, 1970	A	1300–1600	26.1	0.32	0.89	28.8
	B	578	38.2	0.00	0.30	00.0
	E		38.0	0.00	0.00	00.0
July 29, 1970	A	0900–1100	30.0	0.04	0.00	100.0
	B	569	41.0	0.00	0.33	00.0

[a]Station A is plant intake; B is outfall weir; C is 457 m below weir; D is 1200 m below weir; E is 1800 m below weir (end of canal).

[b]Intake (control) percent surviving netting and natural mortality factors. Percent survival at stations B through E was calculated by dividing the number of living larvae per cubic meter at each canal station by the number of living larvae per cubic meter at the intake (control) station.

Percentage Entrained

Figure 2 shows both day and night and east–west distributions of young fish collected in two river cross sections. In all river cross sections, fish tended to be somewhat more abundant in the shallower areas near the east shore. Fish appeared to be more abundant near the bottom during the day and between midwater and surface at night, particularly in the intake cross section.

The percentage of nonscreenable young living fish entrained for the seven dates sampled ranged between 1.7 and 5.8%. The mean, as calculated in the sample computation (Table 3), was approximately 4.0% (95% confidence limits, 3.3–4.5%). The maximum percentage entrained (5.8%) occurred on a brief slack tide.

Mechanical Effects

Estimates of fish mortality due to mechanical damage during passage through the condenser cooling-water system ranged between 72 and 87%, averaging approximately 80% (Table 4). Mortality percentages were consistent (71–72%) on all dates except the June 27–28 night sample when the percentage reached 87%, probably as a result of a greater proportion of larger fish (20–40 mm total length) in the sample as compared to the majority of less than 15 mm in the other samples. Increased mechanical injury with increased size during condenser passage has been reported by Markowski (1962), Oglesby and Allee (1969), and Marcy (1971). The species, their life stages, and their sizes influence the percentage of mechanical damage. The high percentage of mechanical damage noted in the present study may have been largely influenced by the fact that 97.5% of the fish entrained were in the more critical post yolk-sac stages, and that the more fragile clupeids made up 97.6% of the total fish entrained.

Biocidal Effects

The range of mortality percentages during periods of hypochlorite injection were not measurably different from those calculated for mechanical damage (Table 4). The chlorination procedure at Connecticut Yankee is similar to that discussed by Draley (1972), where the addition of chlorine before the water reaches the condensers and the splitting of the coolant stream into parts (chlorination of one bay at a time) allows for its destructive removal by reaction with slower (organic) chlorine demand constituents when remixing occurs. Any small mortalities which might have been caused by injection of sodium hypochlorite in the present study probably went undetected because the samples taken involved only 25% of the total treated water volume and where residual chlorine was recorded at less than 0.1 ppm.

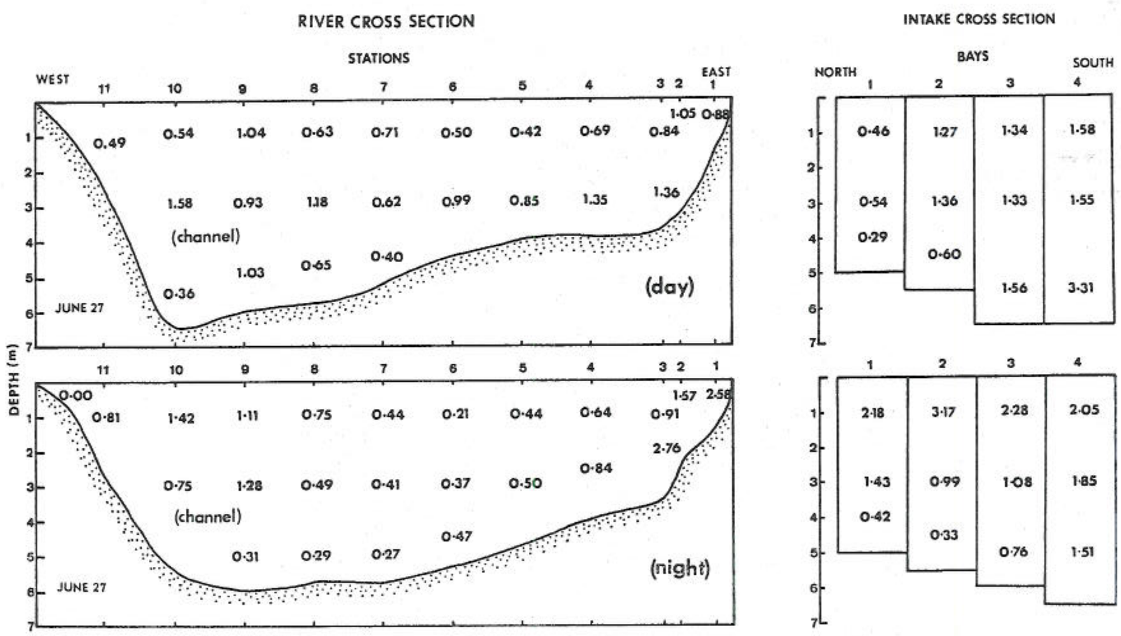

Fig. 2. Day and night intake and river cross sections showing the number of fish larvae collected per cubic meter of water sampled at each station and depth, June 27, 1972.

TABLE 3. Entrainment of young fish and environmental conditions, June 1–July 25, 1972. N_i and N_r represent total number of living larvae divided by the total number of cubic meters of water sampled in the intake and river cross sections, respectively; F_i is flow rate into intake (m^3/sec); F_r is average net tidal flow rate (m^3/sec) in river near the power plant from 93[a] 15-min records during all sampling time periods. Number of samples in parentheses.

				Cross section													
				Intake						River							
Date	Time (*hr*)	Tide	Temp. (*C*)	No. collected	No./m^3	% living	No. living	N_i	F_i	No. collected	No./m^3	% living	No. living	N_r	F_r	% living entrained	Confidence limits (95%)
June 1	1111–1342	Ebb	19.9	247(12)	0.33	85.4	211	0.28	25.00	804(21)	0.66	85.4	686	0.56	743.49	1.68	0.91–2.45
June 8	1053–1310	Ebb	19.0	1650(12)	2.25	83.9	1384	1.88	25.00	2782(23)	1.84	83.9	2334	1.54	741.15	4.11	2.79–5.43
June 27	0933–1300	Ebb	20.5	464(12)	1.07	73.9	343	0.79	25.00	960(23)	0.84	73.9	709	0.62	1052.92	3.02	2.34–3.70
June 27	2055–2356	Ebb	21.5	713(12)	1.47	100.0	713	1.47	25.00	1069(24)	0.78	100.0	1069	0.78	1076.43	4.38	2.78–5.98
July 13	0946–1343	Slack	26.0	298(12)	0.62	50.0	149	0.31	25.00	243(24)	0.38	50.0	122	0.19	704.12	5.79	3.99–7.60
July 13–14	2126–0100	Ebb	25.5	357(12)	0.60	100.0	357	0.60	25.00	562(23)	0.56	100.0	562	0.56	778.82	3.44	2.20–4.67
July 25	1400–1715	Ebb	28.0	24(12)	0.06	60.0	14	0.04	25.00	98(24)	0.06	60.0	59	0.04	561.22	4.45	1.90–7.00
			Total	3753(84)	–	–	3171	–	–	6518(162)	–	–	5541	–	–	3.91[a]	3.34–4.48

[a]Sample percent computation for all seven dates combined:

$$\frac{(N_i)\ (F_i)}{(N_r)\ (F_r)}\ (100) = \frac{(.8258)\ (25.00)}{(.6551)(805.11)}\ (100) = 3.91\%$$

TABLE 4. Larval and early juvenile mortality in the entire discharge canal due to mechanical, biocide, and heat damage, and environmental conditions during June and July, 1970–72. Number of samples in parentheses.

		Intake						Discharge canal					
Date	Time (*hr*)	Power level (Mw_e)	River temp. (*C*)	No. collected	No. living	m^3 sampled	No. living/m^3	Canal temp.	No. collected	No. living	m^3 sampled	No. living/m^3	% mortality
Mechanical (no heat)													
June 27, 1972	1130–1430	0	20.5	464(12)	343	432.75	.7929	20.5	53(4)	42	192.19	.2185	72.4[a]
June 27–28, 1972	1040–1300	0	21.5	713(12)	713	486.22	1.4664	21.5	34(4)	31	160.50	.1931	86.8
July 13, 1972	1500–1840	0	26.0	298(12)	149	477.26	.3122	26.0	67(4)	29	318.46	.0910	70.9
July 14, 1972	0210–0320	0	25.5	357(12)	357	592.29	.6027	25.5	76(4)	40	255.21	.1776	70.5
Biocide (no heat)													
July 13, 1972	1700–1830	0	26.0	298(12)	238	477.26	.4995	26.0	127(4)	50	418.49	.1194	76.1
July 14, 1972	0340–0510	0	25.5	357(12)	357	592.29	.6027	25.5	100(4)	42	361.88	.1160	80.8
Heat (28–29 C)													
June 30, 1970	0900–1200	300	22.2	32(3)	21	12.10	1.7355	28.2	311(9)	74	164.69	.4493	74.1
June 2, 1971	1000–1530	610	16.0	3(3)	3	53.92	.0556	29.0	147(12)	5	371.04	.0134	75.9
Heat (33.5 C)													
July 2, 1970	1200–1600	588	22.0	14(4)	9	19.96	.4509	33.5	257(15)	12	219.17	.0547	87.9
Heat (35.0 C)													
July 6, 1970	1000–1500	587	23.9	258(6)	175	92.17	1.8986	35.0	413(15)	0	379.12	.0000	100.0
June 24, 1971	1120–1535	579	26.0	270(3)	172	43.90	3.9179	35.0	648(12)	0	254.37	.0000	100.0

[a]Total percentage mortality in the discharge canal as calculated by dividing the total number of living larvae per cubic meter in the discharge canal (Stations B–E) by the total number of living larvae per cubic meter at the intake (A).

THERMAL EFFECTS

When heat was added to the cooling system and the discharge temperature was between 28 and 29 C, no fish survived passage to the end of the canal on June 2, 1971, while 7.5% survived on June 30, 1970 (Table 2). Although canal temperatures were similar on both dates, no fish survived to the end of the canal on June 2, 1971 because of increased heat shock caused by a greater difference between ambient and canal temperatures (ΔT) and a lower acclimation (ambient) temperature.

The survival rate of fish on June 30, 1970 immediately after passing through the plant (station B), was 34.5%, and this percentage continued to drop to 7.5% at the end of the discharge canal. The survival rate on July 2, 1970 at station B dropped to 16.6% as the power level and ΔT doubled. When the plant was at full power and canal temperatures were above 28 C no living fish were taken at the end of the canal. At canal temperatures between 29 and 33.5 C, no living fish survived passage to station D. When the canal temperature rose above 35.0 C, 100% mortality occurred during passage through the plant. It was estimated that approximately 20% of the total mortality which occurred in the canal was caused by heat shock and prolonged exposure to temperatures elevated above 28 C (Table 2 and 3).

Of the 81,875 fish larvae representing 16 species collected in 690 tows in the Connecticut River between 11.3 and 85.3 km, 95% were present during an 11-degree (19–29 C) temperature spread (Marcy unpublished 1965–69 data). If the plant operated continuously at full power at a Δ T of 12.5 C, then it would follow that discharge-canal temperatures would remain above the upper natural temperatures encountered by the young of most species during at least 95% of their seasonal occurrence. However, during normal operation the power level often fluctuates causing a corresponding change in the Δ T. Discharge-canal temperatures were recorded daily during June and July of 1968 and 1969 when 95% of the nonscreenable larvae were abundant in the intake area (Marcy 1971). Discharge-canal temperatures remained above 28 C during 44 and 56 days (June and July) in 1968 and 1969, respectively.

Discussion and Conclusions

This study shows that most fish larvae and early juveniles that went through the plant were dead by the time they reached the end of the discharge canal. Sampling during June and July, when 95% of the nonscreenable fish were abundant near the intake, showed that approximately 80% of the total mortality in the canal was caused by mechanical damage and 20% was attributed to heat shock and prolonged exposure to temperatures elevated above 28 C. There was no measurable mortality due to injection of sodium hypochlorite as a biocide. The number of nonscreenable young living fish entrained at the intake averaged about 4% (range, 1.7–5.8%) of those passing by the plant under conditions of unidirectional net tidal flow.

Little information is presently available in the literature on the entrainment of young fish at power stations. Both Kerr (1953) and Markowski (1962) showed no harmful effects on fish passed through condensers. In both studies, discharge temperatures were no greater than 28 C and total exposure time was less than 4 min. Carlson and McCann (1969) estimated that 4% of the eggs and 12.2% of the larvae of striped bass, *Morone saxatilis*, were subject to withdrawal from a river cross section near the intake of a pump storage plant.

It would seem impossible to effectively screen small fish larvae; thus, Kerr (1953) found that impingement of striped bass eggs and larvae on fine mesh screening for even a short time was fatal.

Any estimate of the effect of mortality from entrainment on the total fish population has to take into account the natural mortalities during specific life stages of each individual species. Entrainment mortality adds to the total rate of natural mortality. Natural mortality is high in prolific species. For example, Leggett (1969) estimated a 0.001% survival rate from egg to adult stages for the American shad in the Connecticut River, and Kissil (1969) reported a 0.0014% freshwater survival from eggs to emigrating juveniles for an anadromous alewife population in Connecticut. Until natural mortality information is available on the life stages of the various species encountered in this study and more is known of the carrying capacity of the system, a precise evaluation of the 4% entrainment impact on the ultimate population of adults is not possible. Such an evaluation would also require a knowledge of what proportion of the entire population of each species in the lower Connecticut River is in the vicinity of the Connecticut Yankee plant at stages that are subject to the 4% entrainment.

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ANON. 1972. Nonradioactive chemicals and elements, p. 76–77. *In* Connecticut Yankee Atomic Power Company, Haddam Neck plant, environmental report to A. E. C., operating license stage. Docket No. 50–213, Sec. 5.4.4.

CARLSON, F. T., AND J. A. MCCANN. 1969. Hudson River fisheries investigations (1965–1968). Report to Consolidated Edison Co., New York by the Hudson River Policy Committee. 80 p.

COUTANT, C. C. 1970. Biological aspects of thermal pollution I. Entrainment and discharge canal effects. CRC Crit. Rev. Environ. Control, Nov. 1970: 341–381.

1971. Effects on organisms of entrainment in cooling water: steps toward predictability. Nucl. Saf. 12: 600–607.

DRALEY, J. E. 1972. The treatment of cooling waters with chlorine. Argonne Nat. Lab., Argonne, Ill., Environ. Proj. No. ANL/ES-12. 11 p.

KERR, J. E. 1953. Studies on fish preservation at Contra Costa steam plant of the Pacific Gas and Electric Company. Calif. Dep. Fish Game Fish Bull. 92: 66 p.

KISSIL, G. 1969. Contributions to the life history of the alewife, *Alosa pseudoharengus*, in Connecticut. Ph.D. Thesis. Univ. of Connecticut, Storrs, Conn. 111 p.

LAI, C., F. H. RUGGLES JR., AND L. A. WEISS. 1971. Evaluation of flow in tidal reaches of the Connecticut River by mathematical model. U.S. Dep. Int., Geol. Surv., Hartford, Conn. 40 p.

LEGGETT, W. C. 1969. Studies on the reproductive biology of the American shad (*Alosa sapidissima*, Wilson). A comparison of populations from four rivers of the Atlantic seaboard. Ph.D. Thesis. McGill Univ, Montreal, Que. 125 p.

MARCY, B. C. JR. 1971. Survival of young fish in the discharge canal of a nuclear power plant. J. Fish. Res. Board Can. 28: 1057–1060.

MARKOWSKI, S. 1962. Faunistic and ecological investigations in Cavendish Dock, Barrow-in-Furness. J. Anim. Ecol. 31: 43–51.

MERRIMAN, D. 1971. Does industrial calefaction jeopardize the ecosystem of a long tidal river?, p. 507–533. *In* Environmental aspects of nuclear power stations. Proc. Ser. Int. At. Energy Agency Symp., Vienna.

OGLESBY, R. T., AND D. J. ALLEE. 1969. Ecology of Cayuga Lake and the proposed Bell station (nuclear powered). Water Res. Mar. Sci. Cent. Cornell Univ., Ithaca, N.Y. No. 27: 315–328.