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John S. Howard
Director- FERC Hydro Compliance

VIA ELECTRONIC FILING

March 18, 2014

Kimberly D. Bose, Secretary
Federal Energy Regulatory Commission
888 First Street, N.E.
Washington, DC 20426

Re: Northfield Mountain Pumped Storage Project, FERC Project No. 2485
FERC Request for Northfield Mountain Pumped Storage Project, 1992 American Shad Study

Dear Secretary Bose:

As requested by the Federal Energy Regulatory Commission (FERC), attached is the following report that was referenced in FirstLight's Pre-Application Document for the Northfield Mountain (FERC No. 2485) and Turners Falls Projects (FERC No. 1889).

Lawler, Matusky and Skelly Engineers (LMS). 1993. Northfield Mountain Pumped-Storage Facility – 1992 American Shad Studies. February 1993. Northeast Utilities Service Company, Berlin, CT.

If you have any questions, or need additional information, please feel free to contact me.

Sincerely,

John Howard
FERC- Director Hydro Compliance

HYDNF ~~2014~~ 2007

Prepared for

NORTHEAST UTILITIES SERVICE COMPANY

Berlin, Connecticut

NORTHFIELD MOUNTAIN
PUMPED-STORAGE FACILITY
1992 AMERICAN SHAD STUDIES

DRAFT REPORT

February 1993

Northfield: FERC Project No. 2485

Prepared by

LAWLER, MATUSKY & SKELLY ENGINEERS
Environmental Science & Engineering Consultants
One Blue Hill Plaza
Pearl River, New York 10965

Project No. 298-011/012/013

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TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

In accordance with a Memorandum of Agreement between the Northeast Utilities Service Company (NUSCo) and the resource agencies responsible for the management of migratory fish on the Connecticut River, NUSCo conducted studies in 1992 to assess the impact of the Northfield Mountain Pumped-Storage Facility (NMPSF) on American shad. The objectives of this study were to estimate the number of juvenile shad entrained by the NMPSF to provide a basis for calculating the impact of the facility on the river's shad population.

The NMPSF system consists of a riverine intake, an underground powerhouse and control room, and an upper storage reservoir, located approximately 800 ft above, and 8000 ft east, of the river. The NMPSF has four units each having the capacity to pass up to 5000 cfs in the generation mode and up to 3600 cfs in the pumping mode depending upon the upper reservoir elevation.

The study plan involved sampling for shad ichthyoplankton in the NMPSF nearfield region, electrofishing for juvenile shad at 10 stations, two each in five strata encompassing the length of Turners Falls Pool, and entrainment net sampling in the upper reservoir. Eleven ichthyoplankton samples were taken from 21 May to 22 July (nine of them at night), 13 electrofishing surveys were conducted at night from 23 June to 20 October, and 23 entrainment samples were taken during the plant's pumping cycle from 9 August to 27 October. Thirteen net efficiency tests were run in conjunction with entrainment sampling.

Peak densities of shad ichthyoplankton (life stages combined) were collected on 18 June. No significant difference in shad ichthyoplankton densities was detected among sampling stations. By life stage, peak densities of eggs and yolk-sac larvae were collected on 11 June and on 18 June for post yolk-sac larvae. While the seasonal peaks in the various life stages followed an expected pattern of maturation, quantitatively, a much greater density of post yolk-sac larvae was observed compared to both eggs and yolk-sac larvae. This difference in density may have been due to sampling methodology and gear biases.

A significant difference in the Catch-Per-Unit-Effort (CPUE) of juvenile shad was detected among sampling strata; the greatest CPUE of shad occurred in the strata located farthest upstream of the plant. CPUE did not differ significantly among sample dates. Greatest shad growth in Turners Falls Pool occurred from June through August; shad lengths (TL) remained near 82 to 83 mm from mid-September through late October, due either to the cessation of the growing season or the influx of individuals from upstream areas.

A total of 331 shad were collected during the 80.19 hours and in the 8,204,756 m^3 of water sampled during the entrainment netting program. The net filtered between 6.46 and 13.92% of the plant flow during sampling. Greatest entrainment catch rates were recorded in mid-October and they generally corresponded to a period of rapidly decreasing water temperature, peaking near 14 to 15°C. The length of shad collected in the entrainment samples generally corresponded to the length of shad collected from Turners Falls Pool.

INTRODUCTION

The American shad (*Alosa sapidissima*) is an important anadromous species that uses the Connecticut River for reproduction and as a juvenile rearing habitat. In 1992, 721,359 adult shad were counted at Holyoke Dam and 60,089 of them migrated upstream of Turners Falls Dam. Juvenile American shad found in and above Turners Falls Pool may potentially be exposed, during either their development or out-migration, to the Northfield Mountain Pumped-Storage Facility (FERC Project: 2485) located 5.3 miles above Turners Falls Dam. The NMPSF pumps water from the Connecticut River to a storage reservoir and then generates electricity by releasing water from the reservoir. During the pumping phase, juvenile American shad may be carried with the water (i.e., entrained) into the upper reservoir. Assuming no survival nor return to the river, juvenile shad entrained are removed from the river population.

In September 1990 Northeast Utilities Service Company (NUSCo) entered into a Memorandum of Agreement (MOA) with the natural resource agencies having responsibility for the management of migratory fish in the Connecticut River. The MOA outlined a program to further improve downstream fish passage at the Holyoke and Turners Falls projects and investigate impact at the Northfield Project. In response to the MOA, NUSCo undertook studies at Northfield in 1991 and 1992 of juvenile Atlantic salmon (Harza 1992a; LMS 1992) and in 1991 of juvenile American shad (Harza 1992b). This report summarizes work completed in the second year (1992) of American shad studies.

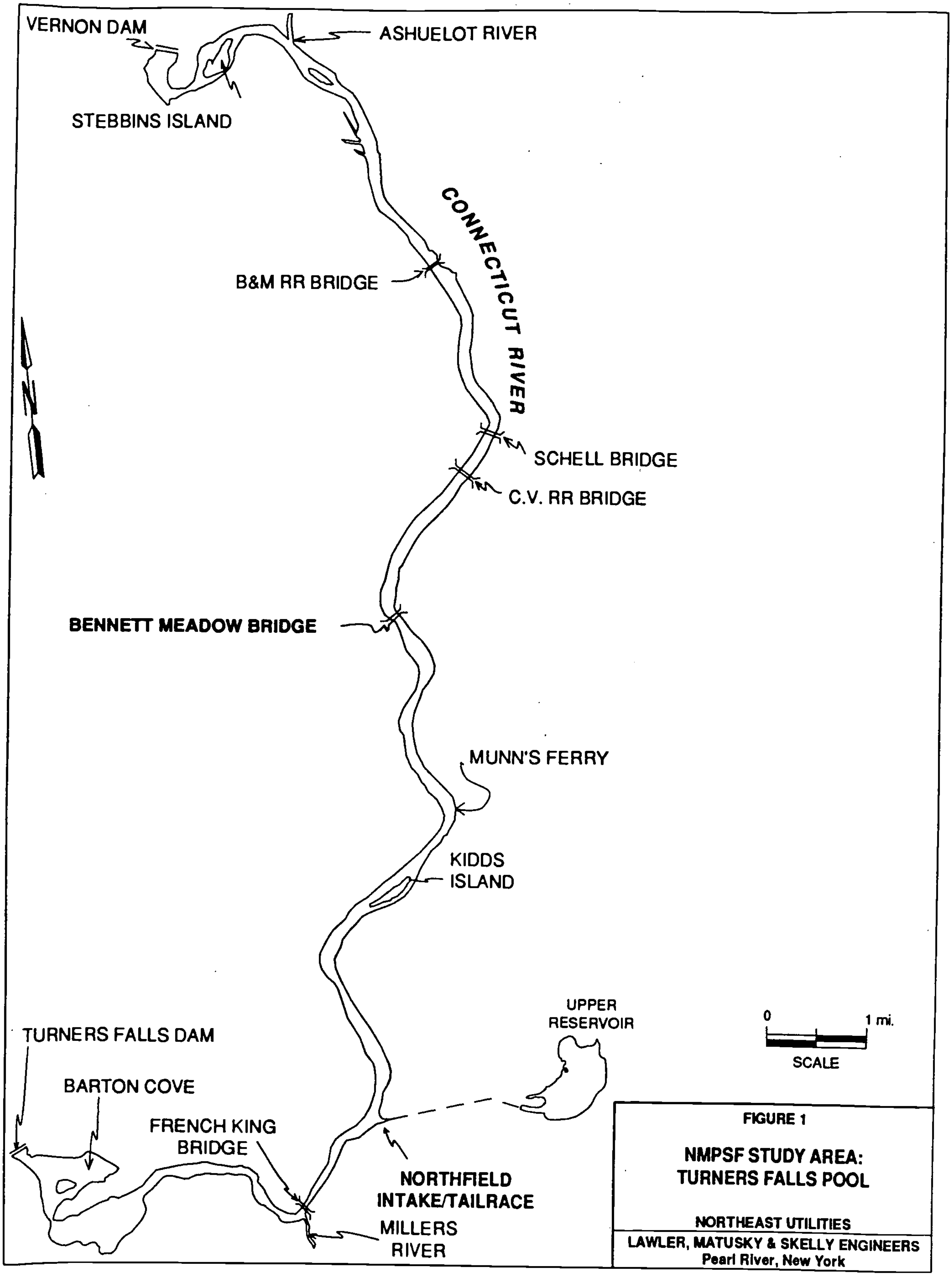
Previous studies of American shad in relation to the NMPSF involved an evaluation of the behavior of adult shad in relation to the operation of the NMPSF (Layzer 1974), documentation but not quantification of shad spawning in Turners Falls Pool (with some emphasis on the NMPSF nearfield area) (Layzer 1978), and an analysis of juvenile shad entrainment using radiotelemetry (Layzer 1978). The studies of adult shad behavior in relation to the NMPSF and the documentation of shad spawning were conducted prior to the expansion of the shad population to areas above Turners Falls Dam. They were of an exploratory nature and thus provided no quantitative information on shad ichthyoplankton densities in Turners Falls Pool or ichthyoplankton entrainment by the NMPSF. The radiotelemetry study of juvenile shad entrainment (Layzer 1978) was limited to the out-migration period and did not provide a quantitative measure of entrainment. Only 11 of the 86 tagged juvenile shad that were monitored near the plant were in the vicinity of the facility while it was pumping and none of them entered the intake.

Studies by NUSCo in 1991 (Harza 1992b) provided information on densities of American shad ichthyoplankton in the NMPSF nearfield region, the temporal and spatial distribution of juvenile shad in Turners Falls Pool, and juvenile shad entrainment. The basic sampling program was maintained in 1992. The most important difference was that the net collection of juvenile shad coupled with net efficiency tests rather than hydroacoustics were used to estimate the total number of juvenile shad entrained by the plant. Other modifications included: (1) shad ichthyoplankton were sampled at an additional three stations in the NMPSF nearfield area; (2) juvenile shad temporal and spatial distribution sampling was conducted at 10 stations (all sampling was performed by electrofishing); and (3) the entrainment sampling study period was extended and major changes were made to the sampling gear and methodology. The 1992 study plan, presented to the resource agencies in June, is appended to this report (Appendix B).

The objective of the 1992 study program was to assess impact of the operation of the NMPSF on American shad in the Connecticut River. This report presents the results of the river sampling for ichthyoplankton and juveniles, and the sampling of entrained juveniles at the NMPSF. The impact assessment will be presented in a separate report.

STUDY AREA AND PLANT OPERATION

The NMPSF is located approximately 5.3 miles upstream of Turners Falls Dam, which forms the Turners Falls Pool portion of the Connecticut River (**Figure 1**). The plant is operated by the Western Massachusetts Electric Company and includes a riverine intake area, an underground operational area that houses the turbines and control room, as well as a storage reservoir located 800 ft above, and 8000 ft east, of the river. The NMPSF has four units each having the capacity to pass up to 5000 cfs in the generation mode and up to 3600 cfs in the pumping mode depending upon the upper reservoir elevation. From one to four units are


VERNON DAM
ASHUELOT RIVER
STEBBINS ISLAND
CONNECTICUT RIVER
B&M RR BRIDGE
N
SCHELL BRIDGE
C.V. RR BRIDGE
BENNETT MEADOW BRIDGE
MUNN'S FERRY
KIDDS
ISLAND
UPPER
RESERVOIR
0
1 mi.
SCALE
TURNERS FALLS DAM
BARTON COVE
FRENCH KING
BRIDGE
NORTHFIELD
INTAKE/TAILRACE
MILLERS
RIVER
FIGURE 1
NMPSF STUDY AREA:
TURNERS FALLS POOL
NORTHEAST UTILITIES
LAWLER, MATUSKY & SKELLY ENGINEERS
Pearl River, New York

used during both the generating and pumping phases. Pumping begins at approximately 23:30 with one unit and can potentially increase incrementally to two, three, or four units by 02:00 and is generally completed by 07:00; however, no set operational schedule is followed.

METHODS

Ichthyoplankton

Eleven shad ichthyoplankton samples were taken from 21 May to 22 July. Sampling was focused on the NMPSF nearfield region and within that area, nine sampling stations were established, three each in three strata located north, south, and adjacent to the intake (**Figure 2**). For each sample, a 10 min oblique tow (beginning at the water surface) was made at each station. Tows were made over the stern into the river flow. One replicate sample was taken from each longitudinal strata per sample. The plankton tow net consisted of a 0.5 m square frame having 0.5 micron net mesh, supported by a benthic-sled device (**Figure 3**). A rigid plastic detachable cup was attached to the cod-end of the net to facilitate the retrieval of the sample. Recordings of a General Oceanics (model 2030) digital flowmeter attached across the face of the net frame provided the basis for the calculation of the volume sampled.

Sampling commenced at dark, which for the time of year occurred near 21:00. Two of the 11 samples were taken during the daytime following a nighttime sample to measure the diurnal variability in the density of shad ichthyoplankton. Ichthyoplankton and debris collected in the net were washed into its cod-end, collected, and immediately preserved in a 5% formalin solution.

Ichthyoplankton were sorted, stored, and later identified. Starting with the initial sorting of ichthyoplankton from debris, the sampling processing procedure followed a multi-tiered quality control approach to reduce the probability of missing organisms. During sorting, samples were checked twice, once each by two different individuals to reduce the influence of systematic personal biases from the sorting procedure. A final quality control procedure involved a check of a randomly chosen sample by a third individual.

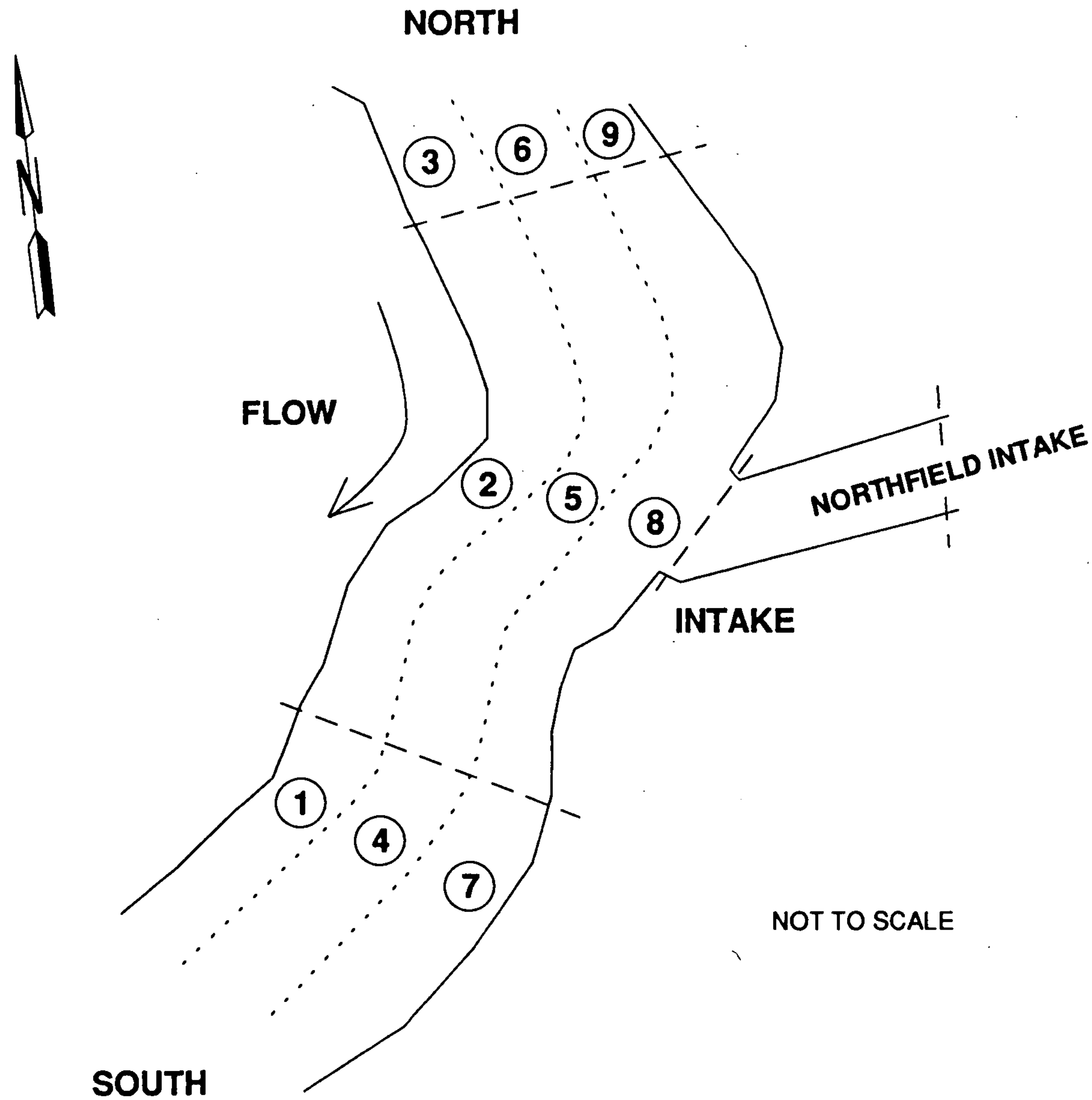


FIGURE 2
LOCATION OF ICHTHYOPLANKTON SAMPLING STATIONS: NMPSF NEARFIELD AREA
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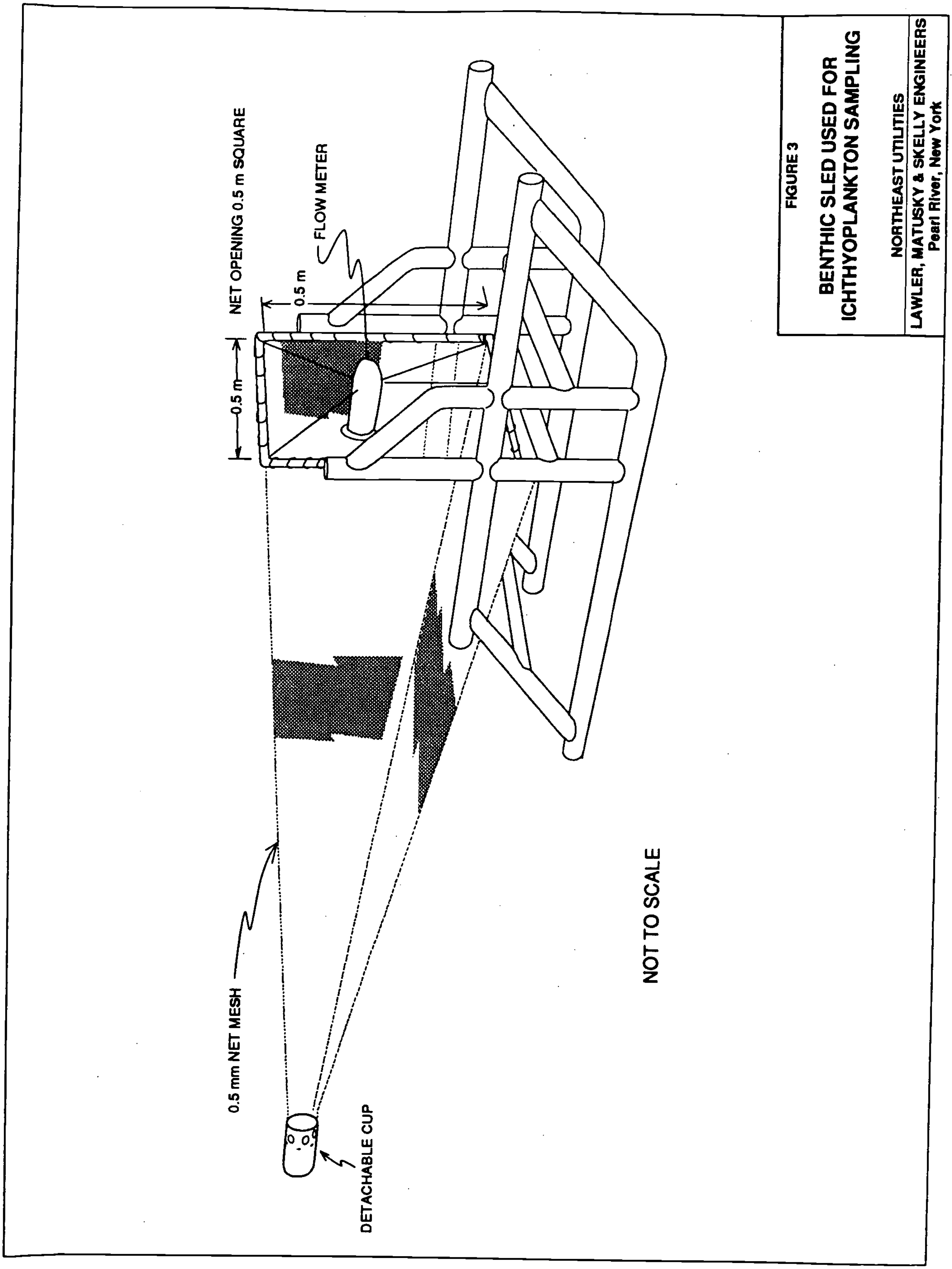

FIGURE 3

BENTHIC SLED USED FOR ICHTHYOPLANKTON SAMPLING

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Juvenile Shad Spatial and Temporal Distribution

The temporal and spatial distribution of juvenile shad in Turners Falls Pool was determined via boat-electrofishing at night. Thirteen electrofishing surveys were conducted from 23 June to 20 October. Samples were collected approximately bi-weekly from late June to late August and weekly from early September through late October. The purpose of intensifying the sampling effort beginning in September was to increase the chances of quantifying juvenile shad spatial and temporal distribution during the fall out-migration.

Turners Falls Pool was divided into five longitudinal strata; one stratum included the NMPSF nearfield region (**Figure 4**). Two sampling stations were established in each strata and samples were taken at these stations on each sampling event. The strata and stations used in 1992 were selected based on work conducted in 1991 (Harza 1992a). Twenty minute electrofishing runs were made in an upstream direction at each station. All fish collected were counted and the lengths of all American shad were recorded. All shad were either immediately released or preserved for other study tests. Catch-Per-Unit-Effort (CPUE) or the number of shad collected per minute of sampling was used to standardize the electrofishing catch data.

Entrainment Netting

Sampling

Twenty-three juvenile shad entrainment samples were taken from 9 August to 27 October. Sampling was conducted in the NMPSF upper reservoir with a 15 ft x 34 ft net frame, the area (47.36 m^2) of which represented approximately 11% of the area of the tunnel opening which carried flow into the reservoir. The frame was deployed from a 65 ton crane, which held the net in approximately the center of the pump-back outflow (**Figure 5**). The frame supported a single 80 ft long net having several sections of varied size mesh sizes aimed at dissipating the force of the flow. The bottom of the net frame was held in position by cables running through steel blocks attached to a concrete sill at the base of the outlet structure. The crane's main and auxiliary line was thus used to control the position of the net frame.

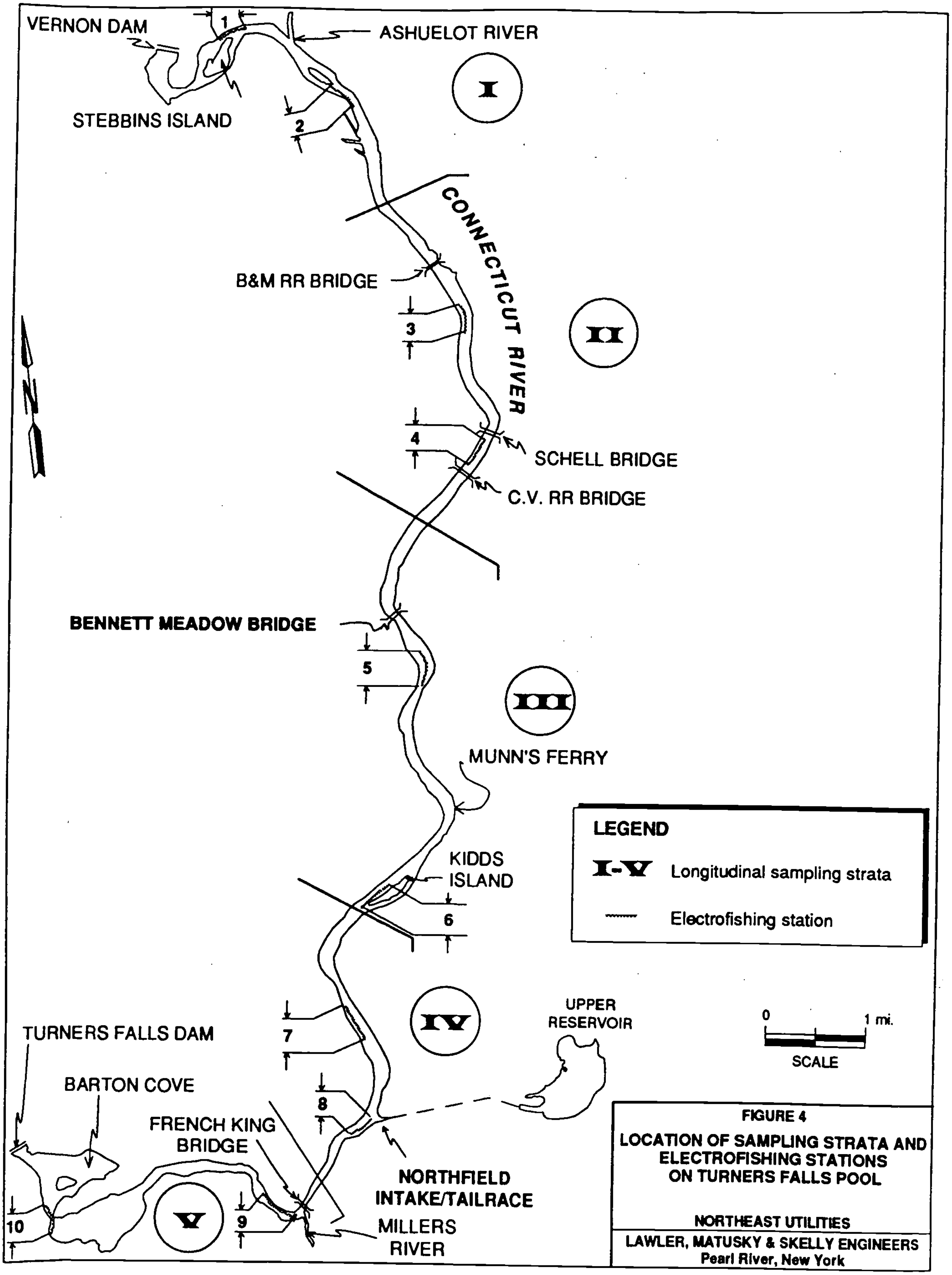

FIGURE 4
LOCATION OF SAMPLING STRATA AND ELECTROFISHING STATIONS ON TURNERS FALLS POOL

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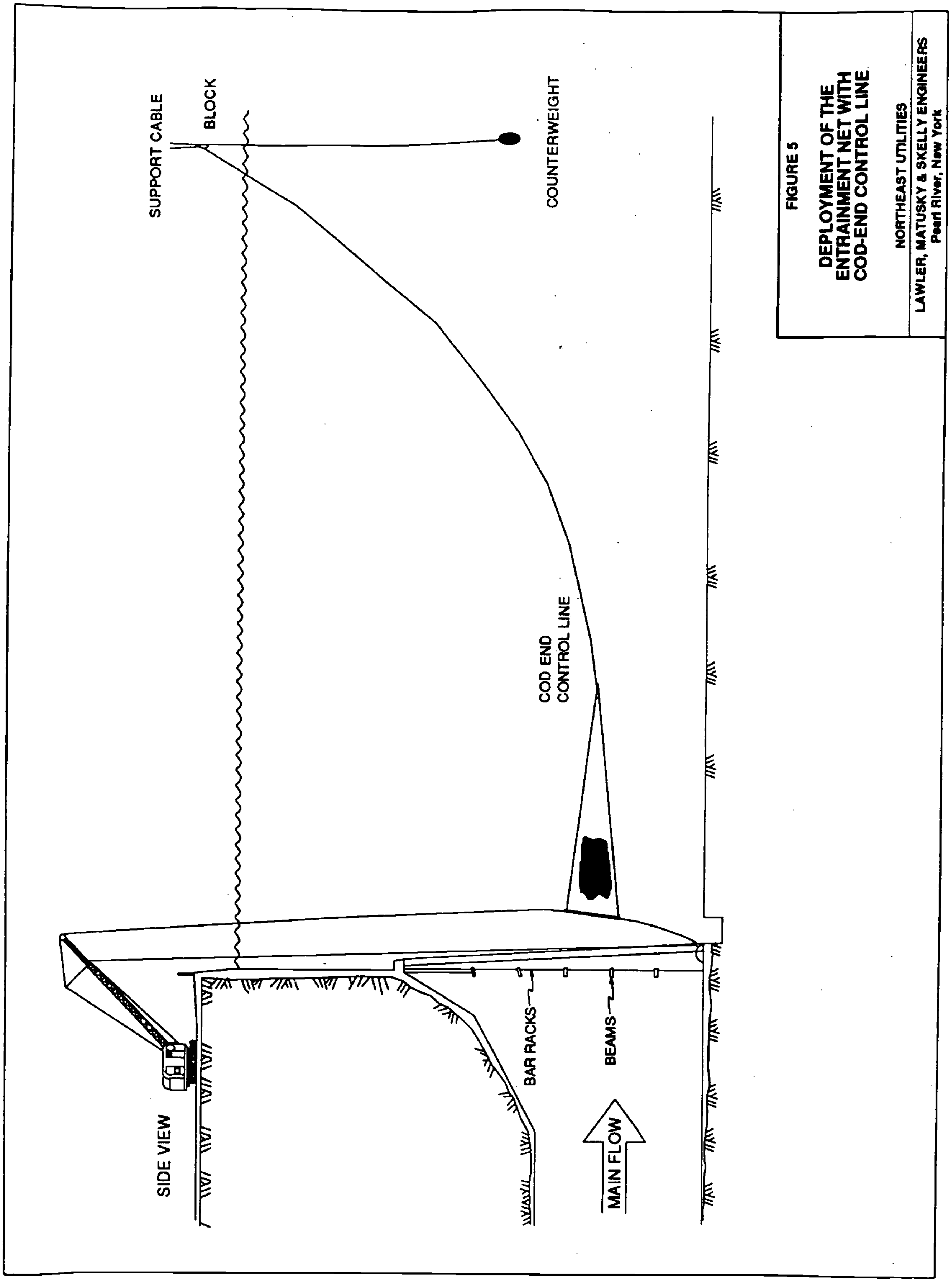

FIGURE 5
DEPLOYMENT OF THE ENTRAINMENT NET WITH COD-END CONTROL LINE
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A control line with a 150 lb counter weight supported by a block attached to a cross-reservoir cable, was attached to the cod-end of the net to stabilize the frame.

The original sampling plan called for the net frame to: (1) be deployed from a 40 ton crane; (2) support two 60 foot nets deployed side-by-side; (3) collect multiple samples during a pumping cycle; and (4) be held at several outlet elevations during the sampling period. However, the original gear and sampling plan needed to be modified, due to the turbulent forces encountered during sampling. Modifications to the gear included: (1) the use of a 65 ton crane to control the net frame and cables; (2) the placement of a bridle and swivel on the lower frame bar to prevent the support cables from twisting; (3) changing from a double to single net arrangement to reduce the effect of torsional forces on the net; and (4) the addition of a net cod-end control line to prevent the net frame from spinning. Operational changes included: (1) keeping the net at one elevation for the duration of the sampling period; (2) keeping the net away from the bottom of the outlet channel where turbulent forces were believed to be greatest; (3) taking one sample per pumping cycle; and (4) sampling with a maximum of 3 units pumping.

The net was deployed after pumping was initiated, which during most evenings occurred near 23:30 and was fished for up to 5.5 hours. On those occasions when the plant went from 3 to 4 pumps or in the latter part of the season when debris loads became excessive, samples were less than 2 hours in length.

Eight flow meters were mounted in the mouth of the net frame to measure the water volume sampled (**Figure 6**). Flow meters were read previous to the deployment of the net and immediately after the net was retrieved from its fishing position. To determine total flow on any given sampling occasion, meter total counts were related to the percent of the net area that each sampled, so that the contribution of each to the total would be appropriately represented.

Samples were collected by boat and sorted twice for quality assurance. The lengths of all shad that were intact upon collection were recorded. In most entrainment samples, shad heads or tails accompanied full bodied individuals in the entrainment net. The convention

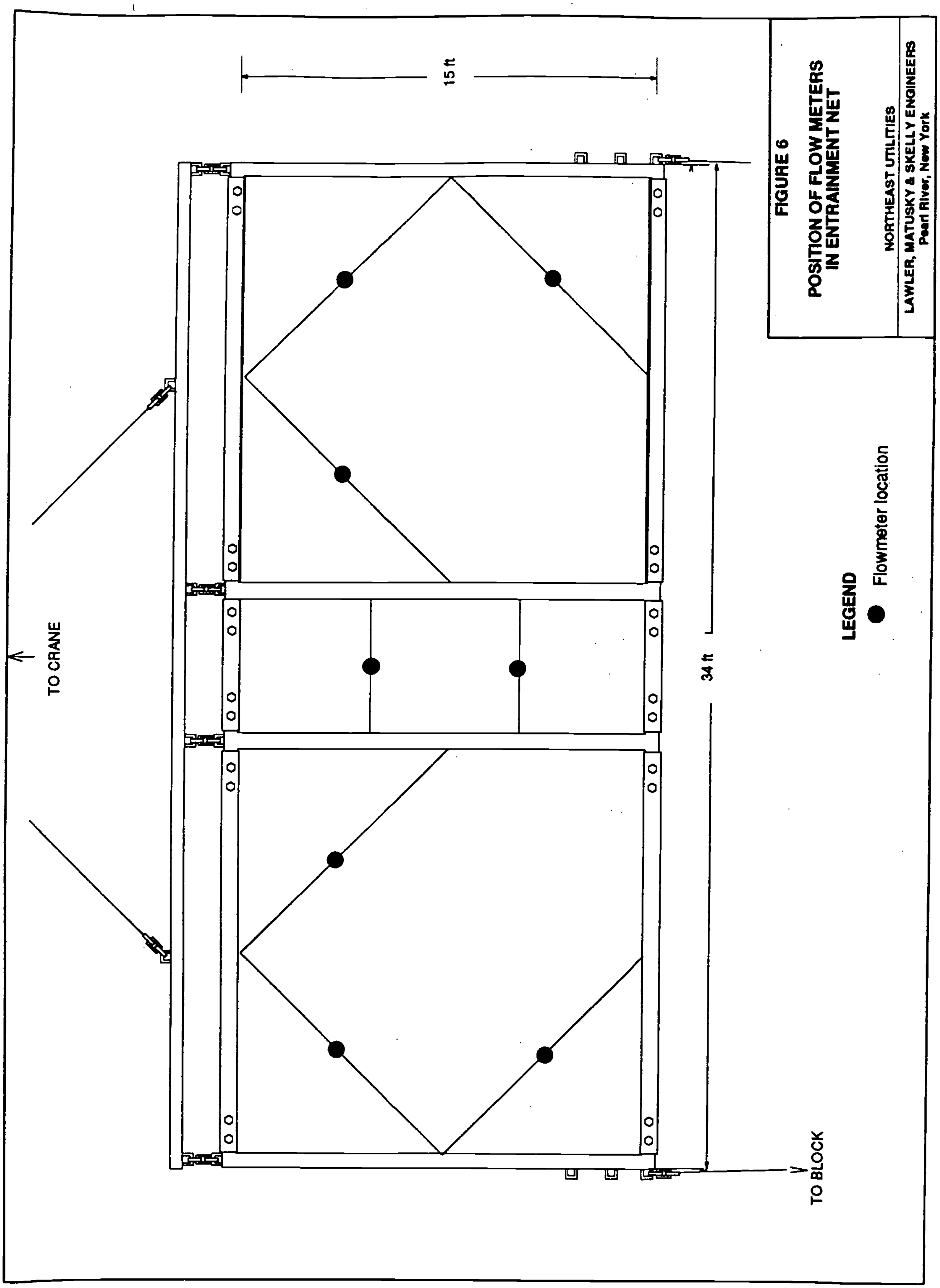

FIGURE 6
POSITION OF FLOW METERS IN ENTRAINMENT NET

NORTHEAST UTILITIES
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for including these individuals into the data base was to include heads, but not tails to avoid duplication in the total counts. Only the individual body parts that were conclusively identifiable as shad were included.

Net Efficiency Testing

Thirteen individual tests of net efficiency were made throughout the extent of the entrainment study program. Efficiency test fish were injected into the plant flow through a an existing service port in unit 2, located on the river side of the pump-turbine unit and between the surge chambers and the unit.

A steel tank, 24 in. in length by 12 in. in diameter, was attached to the service port by an 8 ft length of 2.5 in., high pressure hose (**Figure 7**). The head differential at the service port was such that 50 psi of water pressure existed at the injection location. A 1.5 in. diameter ball valve controlled water flow out of the service port. The efficiency test injection procedure involved filling the tank with water from the service port. Between 20 and 30 marked shad were counted into the tank; the number live and dead at the time of introduction was noted. The tank was then sealed and pressurized (150 psi) service air was introduced into the tank, simultaneous to the opening of the service port ball valve. The pressurization of the tank coupled with the opening of the service port ball valve, created a mass movement of water and fish into the plant flow. The injection of groups of 20 to 30 fish normally took less than 30 seconds. The injection procedure was repeated consecutively until all fish were injected. After injection, the service port valve was shut off simultaneously with the service air and the system was de-pressurized.

All efficiency test fish were marked with neutral red dye. Fish were introduced into the dye for 15 to 20 minutes (USFWS 1982) and oxygen was bubbled into the solution at a rate of 1 to 2 liters per minute. Normally, dissolved oxygen levels near 8 mg/L were maintained in the dye solution. Dead fish were given a ventral caudal fin clip just prior to injection, so that their recapture rates could be compared to those of live released fish. Shad used for efficiency testing were acquired from electrofishing surveys on Turners Falls Pool or from shad sampling at the Cabot Station at Turners Falls Dam.

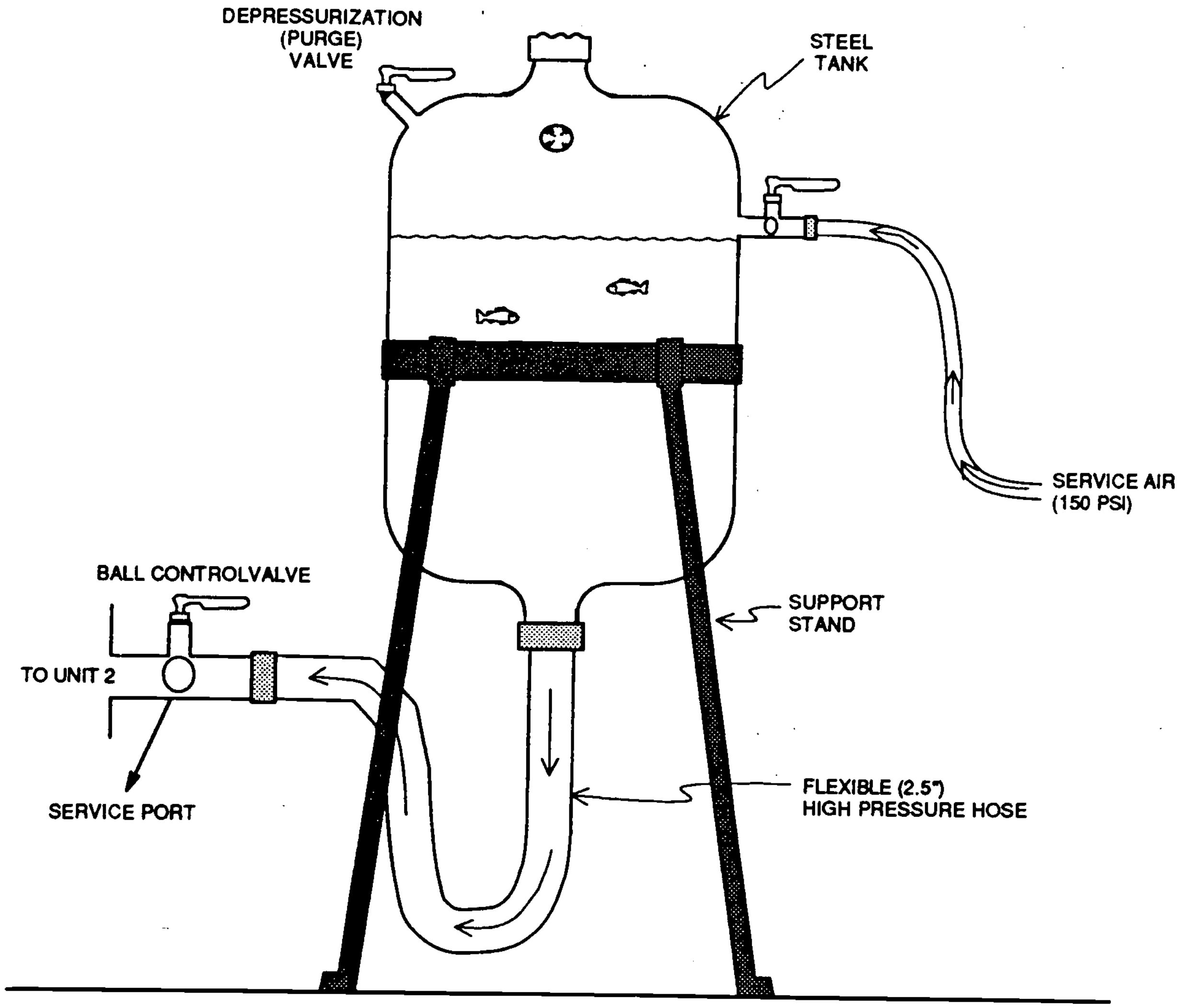

FIGURE 7

EFFICIENCY TEST
INJECTION TANK APPARATUS

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Estimate of Shad Entrainment

The entrainment of larval and juvenile shad was estimated on a weekly basis. For shad eggs and larvae, the total number entrained was estimated by multiplying the density (No. collected/1000 m^3 filtered) by the total volume of water pumped by the plant each week. The density of shad eggs and yolk-sac and post yolk-sac larvae was averaged by life stage over all 9 sampling stations (plus 3 replicates) for each sampling event, which generally corresponded to the weekly interval used for the calculation of entrainment.

The general methodology given by Casella et al. (1986) was used to estimate the number of juveniles entrained and to calculate 95% confidence limits for the estimate. The expanded catch by week was calculated with the following equation:

$$\bar{T} = \sum_{i=1}^{N} = \left(\frac{V_i}{Y_i}\right) X_i \qquad (1)$$

where:

$\hat{T}$ = total expanded catch

V_i = volume pumped in week *i*

γ_i = volume sampled in week *i*

X_i = number of juvenile shad collected in week *i*

The procedure and equations (Elliot 1971) used to calculate the variance for this estimate are provided in Appendix A.

The net efficiency adjustment was derived by dividing the total of the recaptures of marked fish by the sum of the expected recaptures. The sum of the expected recaptures was derived by summing the product of the number of fish released by the percentage of the plant flow that was filtered by the net during sampling over all efficiency tests. The net efficiency estimate was used to adjust the total estimated entrainment catch of juvenile shad and the associated 95% confidence limits.

RESULTS

Ichthyoplankton

Life Stages Combined

The highest shad ichthyoplankton densities were observed on 18 June (**Table 1**) and the effect of the sampling event on the density of shad ichthyoplankton was significant (ANOVA; $p < 0.05$). However, neither the effect of sampling station (ANOVA; $p > 0.05$), nor the interaction between the sampling event and station (ANOVA; $p > 0.05$) were significant. There was a significant difference (t-Test; $p < 0.05$) between the nighttime density of shad ichthyoplankton (80.36/1000 m^3) recorded on 30 June and the daytime (5.05/1000 m^3) density recorded on 1 July. The diurnal difference in density was less pronounced later in the season. The ichthyoplankton density recorded on the evening of 13 July (2.89/1000 m^3) was not significantly (t-Test; $p > 0.05$) different from the density (0.74/1000 m^3) recorded during the daytime on 14 July.

Sampling Stations Combined

The greatest densities of shad eggs and yolk-sac larvae were recorded on 11 June and on 18 June for post yolk-sac larvae; only one juvenile shad was collected in the ichthyoplankton program (**Table 2; Figure 8**). The seasonal distribution of the peak density of each life stage was generally consistent with the expected pattern of maturation of the juvenile shad. Quantitatively however, a relatively large number of post yolk-sac larvae were collected compared to shad eggs and yolk-sac larvae.

TABLE 1

DENSITIES (No./1000 m^3) OF AMERICAN SHAD ICHTHYOPLANKTON IN THE NMPSF NEARFIELD AREA OF THE CONNECTICUT RIVER IN 1992: LIFE STAGES COMBINED

STATION	SAMPLE DATE											MEAN
	21 MAY	28 MAY	4 JUN	11 JUN	18 JUN	24 JUN	30 JUN	1 JUL[a]	13 JUL	14 JUL[a]	22 JUL	
1	0.00	0.00	0.00	22.09	198.21	313.17	509.16	0.00	0.00	6.62	0.00	95.39
2	0.00	0.00	0.00	85.78	31.77	101.63	6.96	0.00	6.64	0.00	0.00	21.16
3	0.00	0.00	5.18	5.94	14.54	30.64	0.00	0.00	8.26	0.00	0.00	5.87
4	0.00	25.21	18.47	36.11	43.75	28.58	89.29	0.00	0.00	0.00	0.00	21.95
5	0.00	0.00	0.00	53.00	32.43	89.00	14.17	6.09	0.00	0.00	0.00	17.70
6	25.06	0.00	12.09	114.49	91.28	17.59	13.36	33.39	0.00	0.00	0.00	27.93
7	0.00	6.10	10.41	0.00	93.91	46.98	21.85	0.00	0.00	0.00	5.94	16.84
8	0.00	28.03	15.65	71.91	123.57	278.98	20.19	0.00	0.00	0.00	0.00	48.94
9	0.00	11.29	18.79	206.31	1063.03	93.46	48.27	5.98	11.11	0.00	0.00	132.57
Mean:	2.78	7.85	8.95	66.18	188.05	111.12	80.36	5.05	2.89	0.74	0.66	43.15
Total:	25.06	70.64	80.58	595.63	1692.48	1000.04	723.25	45.46	26.00	6.62	5.94	

[a]Daytime sample.

TABLE 2

TOTAL DENSITIES (No./1000 m^3) OF AMERICAN SHAD ICHTHYOPLANKTON IN THE NMPSF NEARFIELD AREA OF THE CONNECTICUT RIVER IN 1992: SAMPLING STATIONS COMBINED

SAMPLE DATE	LIFE STAGE		
	EGG	YOLK-SAC	POST YOLK-SAC
21 May	0.00	25.06	0.00
28 May	42.53	22.51	5.61
4 Jun	51.38	29.20	0.00
11 Jun	116.74	414.43	64.46
18 Jun	40.63	99.31	1552.54
24 Jun	15.08	15.17	969.79
30 Jun	0.00	0.00	723.25
1 Jul	0.00	0.00	39.37
13 Jul	0.00	0.00	26.00
14 Jul	0.00	0.00	6.62
22 Jul	0.00	0.00	5.94
Mean:	24.21	55.06	308.51
Total:	266.36	605.68	3393.59

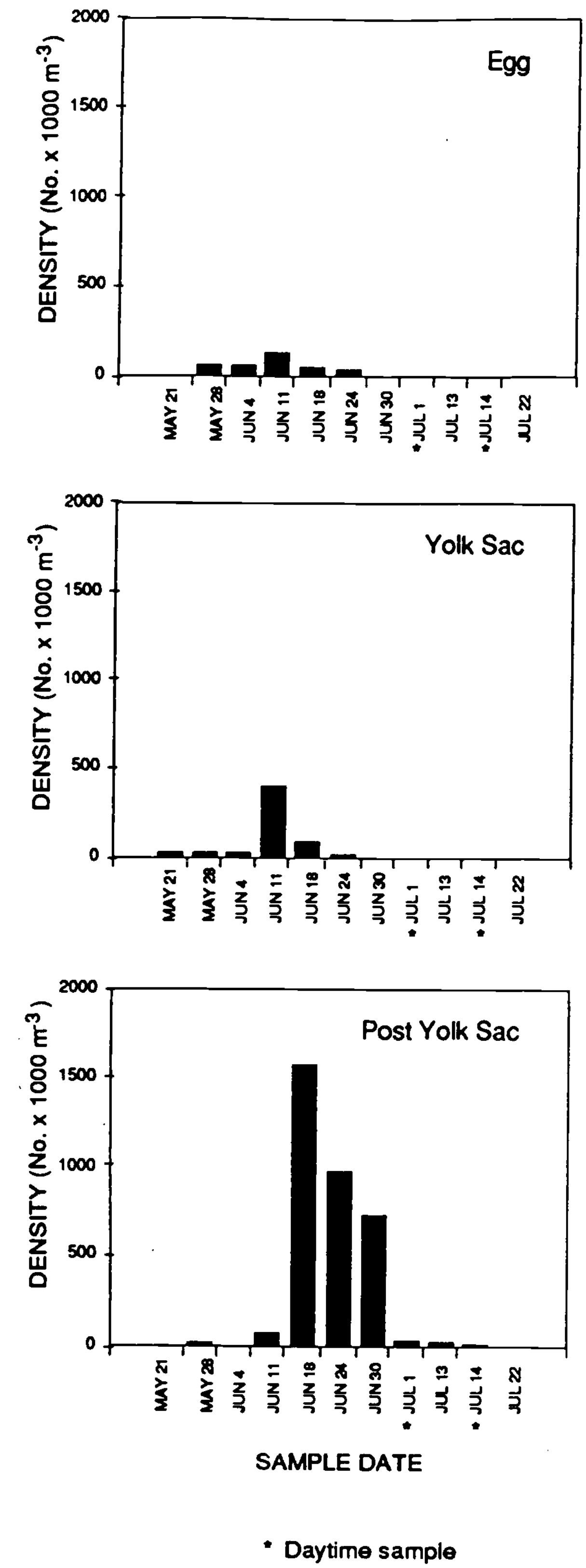

FIGURE 8

DENSITIES OF AMERICAN SHAD ICHTHYOPLANKTON BY SAMPLE DATE

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Juvenile Shad Spatial and Temporal Distribution

The mean CPUE of juvenile shad by strata ranged from 1.53 in strata V to 6.86 in strata I (**Table 3**). A significant difference in CPUE among strata was detected (ANOVA; $p < 0.05$) (See **Table 3** for pairwise comparisons.) The CPUE for juvenile shad peaked at 8.47 on 8 September. No distinct seasonal pattern in juvenile shad abundance was observed; CPUE did not differ significantly (ANOVA; $p > 0.05$) among sample dates. Shad growth in Turners Falls Pool was greatest from late July to early September (**Figure 9**). The mean length (TL) of shad remained near 82-83 mm from late September through the end of the sampling program, possibly due both to the cessation of the growing season and the influx of fish from upriver areas.

Entrainment Netting

Sampling

Three-hundred-thirty-one shad were collected during the 80.19 hours and in the 8,204,756 m^3 of water sampled during the entrainment netting program (**Table 4**). The net filtered between 6.46 and 13.92% of the plant flow during sampling (mean = 11.69%). Greatest entrainment catch rates were recorded in mid-October and they generally correspond to a period of rapidly decreasing water temperature, peaking near 14 to 15°C (**Figure 10**). The length of shad collected in the entrainment samples generally corresponded to the length of shad collected from Turners Falls Pool (**Figure 9**).

Net Efficiency Testing

A total of 3187 marked shad was injected into unit 2 for efficiency tests and 262 or 8.22% were recovered in the entrainment net (**Table 5**). The recovery rate by sample date ranged from 3.54% to 15.52%. There was no significant difference (χ^2-Test; $p > 0.05$) in the recovery rate of dead (8.39%) and live (6.77%) fish (**Table 6**). Some of the marked (i.e., dyed) fish collected were missing their tails; thus their release group could not be determined.

TABLE 3

ELECTROFISHING CATCH-PER-UNIT-EFFORT (CPUE)
FOR JUVENILE AMERICAN SHAD IN TURNERS FALLS POOL OF THE CONNECTICUT RIVER IN 1992

SAMPLE DATE	STRATA					MEAN	TOTAL
	I	II	III	IV	V		
22 Jun	0.50	0.10	0.00	0.05	0.00	0.13	0.65
6 Jul	12.22	3.49	0.00	0.00	0.00	3.14	15.70
19 Jul	12.95	5.64	3.05	0.55	2.04	4.85	24.23
2 Aug	8.30	1.95	9.70	0.20	2.70	4.57	22.85
17 Aug	5.20	5.40	0.09	7.05	0.50	3.65	18.24
1 Sep	11.82	4.00	7.58	5.97	2.25	6.32	31.62
8 Sep	13.50	4.30	14.35	9.30	0.90	8.47	42.35
14 Sep	3.15	1.35	1.55	1.80	1.56	1.88	9.40
22 Sep	3.70	5.25	9.40	4.04	2.60	5.00	24.99
29 Sep	1.45	5.95	0.20	3.35	2.50	2.69	13.44
7 Oct	3.15	3.64	7.66	1.85	3.05	3.87	19.35
13 Oct	8.65	1.70	3.80	2.10	1.35	3.52	17.60
18 Oct	4.65	1.40	1.85	0.60	0.45	1.79	8.95
Mean[a]:	6.86[x]	3.40[y]	4.56[xy]	2.84[y]	1.53[y]		
Total:	89.23	44.17	59.23	36.86	19.89		

[a]Means sharing a common letter are not significantly different.

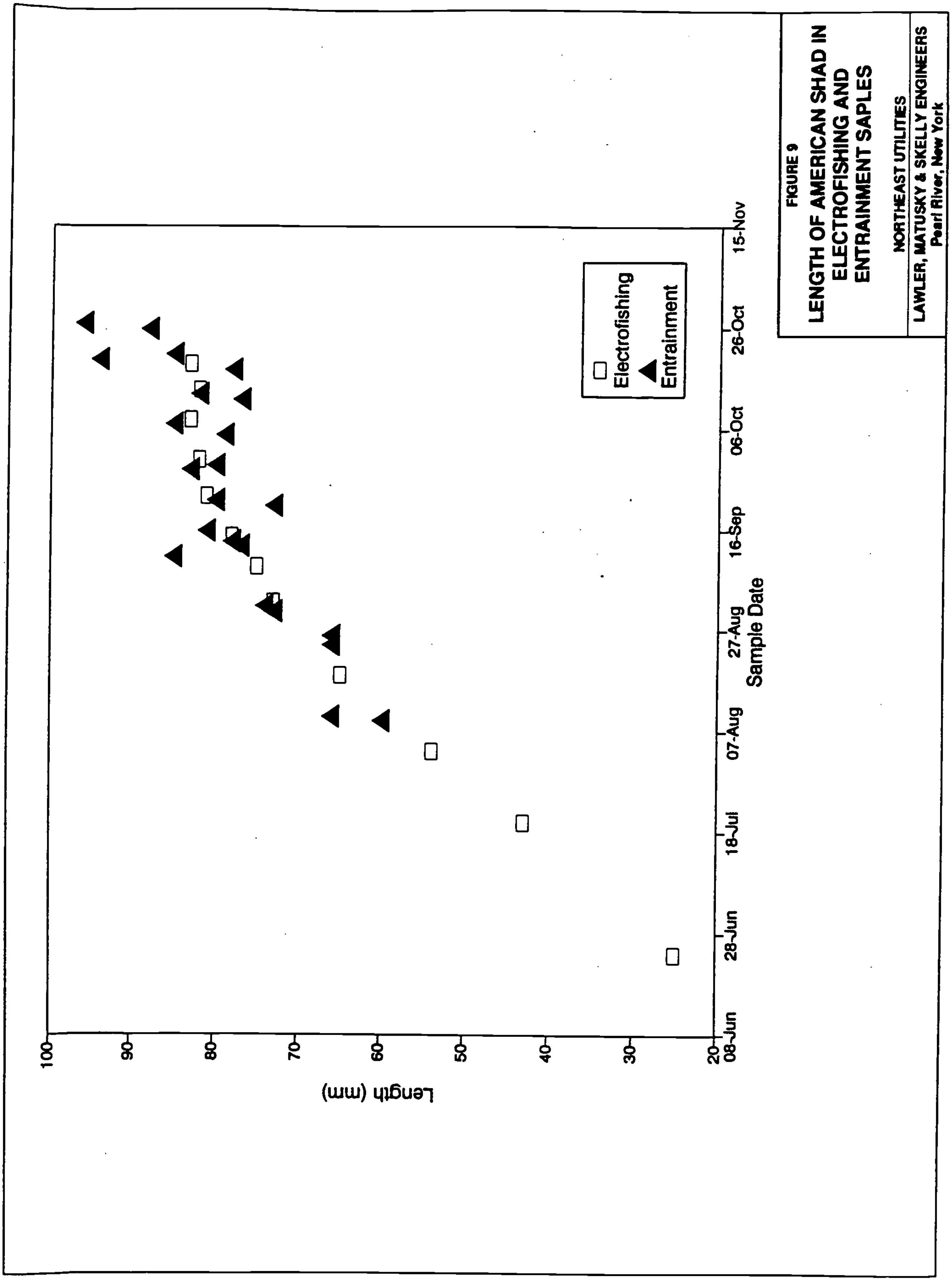
FIGURE 9
LENGTH OF AMERICAN SHAD IN ELECTROFISHING AND ENTRAINMENT SAPLES
NORTHEAST UTILITIES
LAWLER, MATUSKY & SKELLY ENGINEERS
Pearl River, New York
Length (mm)
100
90
80
70
60
50
40
30
20
Sample Date
08-Jun
28-Jun
18-Jul
07-Aug
27-Aug
16-Sep
06-Oct
26-Oct
15-Nov
Electrofishing
Entrainment

TABLE 4

ENTRAINMENT SAMPLING PROGRAM SUMMARY FOR JUVENILE AMERICAN SHAD

SAMPLE DATE	MAXIMUM No. OF PUMPS SAMPLED	SAMPLE DURATION (HRS)	VOLUME PUMPED (m^3)	VOLUME SAMPLED THROUGH NET (m^3)	PERCENT FLOW SAMPLED	CATCH	No. CAUGHT/HR	No. CAUGHT/m^3
9 Aug	3	1.65	1,181,098	132,569	11.22	1	0.61	7.54e-06
10 Aug	2	5.20	3,473,029	358,778	10.33	7	1.35	1.95e-05
23 Aug	3	5.37	4,891,421	650,798	13.30	21	3.91	3.23e-05
26 Aug[a]	3	1.23	766,601	101,791	13.28	2	1.63	1.96e-05
31 Aug	3	5.17	4,760,729	658,030	13.82	9	1.74	1.37e-05
1 Sep	3	5.68	5,130,723	663,393	12.93	5	0.88	7.54e-06
11 Sep	2	4.93	3,390,287	449,461	13.26	4	0.81	8.90e-06
13 Sep	3	5.30	4,593,641	639,541	13.92	22	4.15	3.44e-05
14 Sep	3	5.53	5,602,838	684,567	12.22	10	1.81	1.46e-05
16 Sep	3	5.67	6,016,137	639,238	10.63	13	2.29	2.03e-05
21 Sep[a]	3	1.27	1,007,755	117,709	11.68	7	5.51	5.95e-05
22 Sep	3	4.58	4,513,139	505,921	11.21	13	2.84	2.57e-05
28 Sep	3	3.58	3,109,963	275,023	8.84	8	2.23	2.91e-05
29 Sep[a]	3	1.33	2,045,386	132,117	6.46	13	9.77	9.84e-05
5 Oct	3	4.97	4,523,290	566,921	12.53	32	6.44	5.64e-05
7 Oct[a]	3	2.08	1,596,988	200,829	12.58	33	15.87	1.64e-04
12 Oct[a]	3	1.10	888,016	105,468	11.88	18	16.36	1.71e-04
13 Oct[a]	3	1.63	1,255,503	140,763	11.21	10	6.13	7.10e-05
18 Oct	3	4.03	3,518,297	427,264	12.14	59	14.64	1.38e-04
20 Oct	2	3.03	1,950,879	216,716	11.11	10	3.30	4.61e-05
21 Oct[a]	3	1.35	1,009,989	115,368	11.42	13	9.63	1.13e-04
26 Oct	2	2.93	1,904,853	225,799	11.85	11	3.75	4.87e-05
27 Oct	2	2.58	1,795,963	196,692	10.95	10	3.88	5.08e-05
Total:		80.19	68,926,524	8,204,756		331		
Mean:		3.49	2,996,805	356,729	11.69	14	5.20	5.43e-05

[a]Sampling terminated due to 4 units pumping.

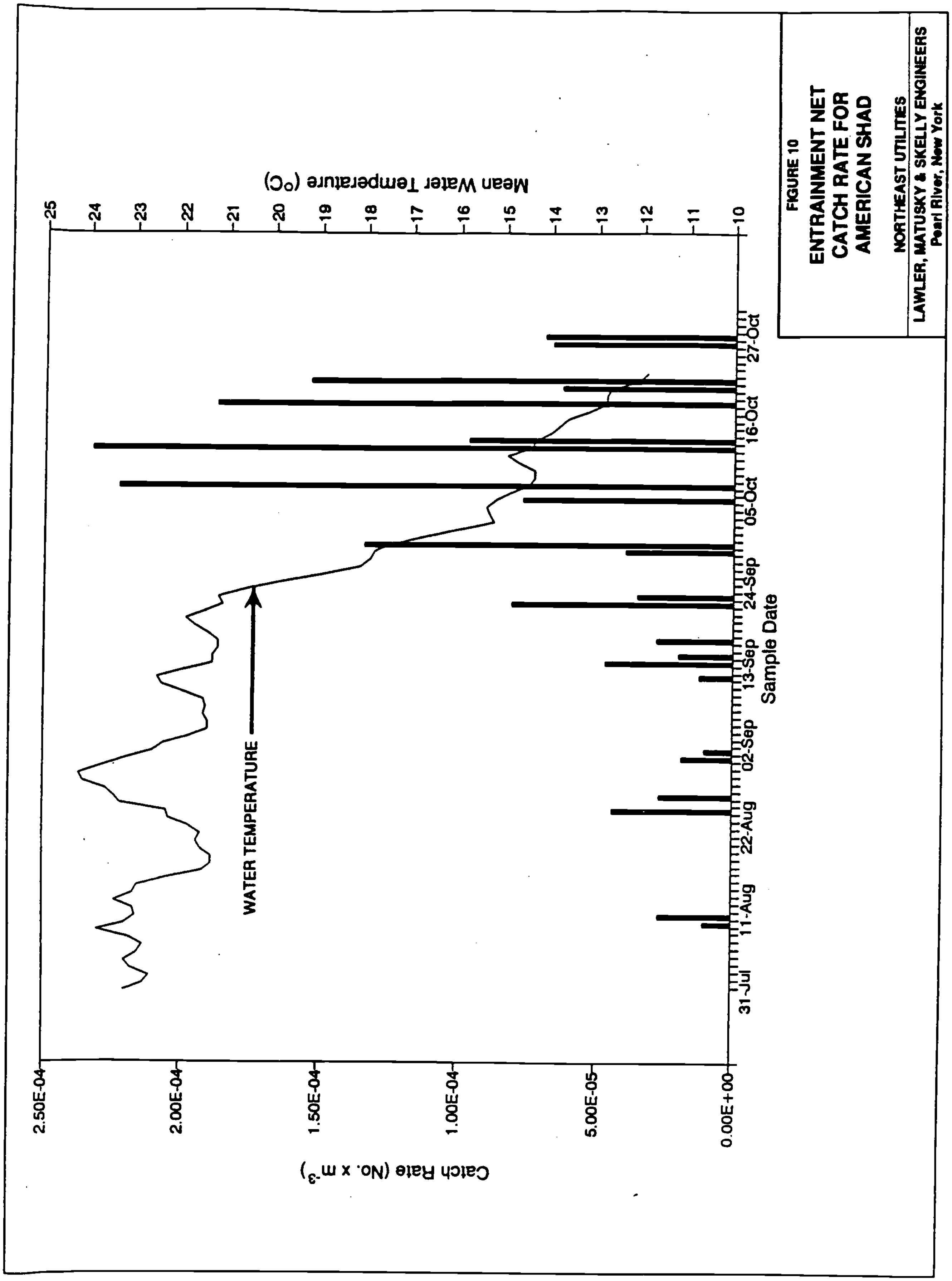
FIGURE 10
ENTRAINMENT NET CATCH RATE FOR AMERICAN SHAD
NORTHEAST UTILITIES
LAWLER, MATUSKY & SKELLY ENGINEERS
Pearl River, New York
Mean Water Temperature (°C)
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
Catch Rate (No. x m-3)
2.50E-04
2.00E-04
1.50E-04
1.00E-04
5.00E-05
0.00E+00
Sample Date
31-Jul
11-Aug
22-Aug
02-Sep
13-Sep
24-Sep
05-Oct
16-Oct
27-Oct
WATER TEMPERATURE

TABLE 5

ENTRAINMENT NET EFFICIENCY TESTING RECOVERY DATA: RELEASE GROUPS COMBINED

DATE	No. RELEASED	No. RECOVERED	PERCENT RECOVERED
14 Sep	367	15	4.09
16 Sep	172	11	6.40
22 Sep	120	16	13.33
28 Sep	198	7	3.54
29 Sep	174	27	15.52
07 Oct	188	12	6.38
12 Oct	185	28	15.14
13 Oct	147	11	7.48
18 Oct	524	51	9.73
20 Oct	500	42	8.40
21 Oct	140	11	7.86
26 Oct	163	15	9.20
27 Oct	309	16	5.18
Total:	3187	262	
Percent Recovered:			8.22

TABLE 6

RECOVERY RATE SUMMARY BY RELEASE GROUP

	RELEASE GROUP		
	DEAD	**LIVE**	**UNKNOWN[a]**
No. RELEASED:	2,360	827	0
No. RECOVERED:	198	56	8
PERCENT RECOVERED[b]:	8.39	6.77	

[a]Release group could not be determined.
[b]No significant difference ($p > 0.05$) in the recovery rate of dead and live released fish.

Estimate of Shad Entrainment

Ichthyoplankton Program (eggs and yolk-sac and post yolk-sac larvae)

The estimated number of shad ichthyoplankton entrained summed by week was 1,175,900 for eggs (**Table 7a**), 2,744,000 for yolk-sac larvae (**Table 7b**), and 10,525,600 for post yolk-sac larvae (**Table 7c**).

Entrainment Netting Program

The total estimated entrainment including late summer pre-migratory and fall migratory juvenile shad was 37,260 including the 73.65% (**Table 8**) adjustment for net efficiency (**Table 9**).

DISCUSSION

The estimation of shad ichthyoplankton entrainment assumes one way movement (i.e., only movement into the plant) and passiveness on the part of the ichthyoplankton. Some shad ichthyoplankton pumped to the upper reservoir may survive and return alive to the river during generation. For some types of turbines, entrainment mortality for ichthyoplankton may be as low as 5% (Cada 1991), which would be a major consideration in the plant's impact. The assumed passiveness of the later stages such as the post yolk-sac larvae and early juvenile stages of the shad ichthyoplankton is also questionable. The more advanced stages such as the post yolk-sac larvae may exhibit avoidance behavior of the intake or the ability to resist the pump-up flow.

While the seasonal distribution of peaks in egg, yolk-sac, and post yolk-sac larvae generally agreed with expectations in the pattern of development of larval shad, markedly greater densities of post yolk-sac larvae shad were collected than of eggs or yolk-sac larvae. This difference was probably the result of gear selectivity. The sampling gear for example, may have been more effective at catching post yolk-sac larvae than either eggs or yolk-sac larvae. Shad eggs are known to be heavier than water (Chittenden 1969), thus a concentration of eggs in the lower water column may reduce their susceptibility to the sampling gear compared

TABLE 7(a)

ESTIMATED TOTAL ENTRAINMENT OF AMERICAN SHAD EGGS FROM THE CONNECTICUT RIVER IN 1992

WEEK	START DATE	VOLUME PUMPED (m^3)	MEAN DENSITY (No./1000 m^3)	*SE*	*N*	95% LOWER LIMIT	95% UPPER LIMIT	No. ENTRAINED
5	1 May	55,408,126	ND	ND	ND	ND	ND	ND
6	8 May	56,396,819	ND	ND	ND	ND	ND	ND
7	15 May	50,164,176	0.00	0.00	12	0.00	0.00	0
8	22 May	64,134,021	3.54	2.22	12	-1.33	8.42	227,200
9	1 Jun	45,828,176	4.28	1.46	12	1.08	7.49	196,200
10	8 Jun	56,874,346	9.73	6.95	12	-5.57	25.03	553,300
11	15 Jun	49,839,359	3.39	2.86	24	-2.53	9.68	168,700
12	22 Jun	48,563,437	0.63	0.63	12	-0.75	2.01	30,500
13	1 Jul	55,115,704	0.00	0.00	12	0.00	0.00	0
14	8 Jul	48,277,860	0.00	0.00	24	0.00	0.00	0
15	15 Jul	40,548,705	ND	ND	ND	ND	ND	ND
16	22 Jul	53,339,849	0.00	0.00	12	0.00	0.00	0
17	1 Aug	46,782,741	ND	ND	ND	ND	ND	ND
Total:								1,175,900

ND = No data collected.

TABLE 7(b)

ESTIMATED TOTAL ENTRAINMENT OF AMERICAN SHAD YOLK-SAC LARVAE FROM THE CONNECTICUT RIVER IN 1992

WEEK	START DATE	VOLUME PUMPED (m^3)	MEAN DENSITY (No./1000 m^3)	*SE*	*N*	95% LOWER LIMIT	95% UPPER LIMIT	No. ENTRAINED
5	1 May	55,408,126	ND	ND	ND	ND	ND	ND
6	8 May	56,396,819	ND	ND	ND	ND	ND	ND
7	15 May	50,164,176	2.10	1.54	12	-1.29	5.49	105,300
8	22 May	64,134,021	1.88	1.26	12	-0.91	4.66	120,300
9	1 Jun	45,828,176	2.43	0.87	12	0.51	4.36	111,500
10	8 Jun	56,874,346	34.54	15.83	12	-0.30	69.37	1,964,300
11	15 Jun	49,839,359	8.28	2.59	24	2.92	13.97	412,400
12	22 Jun	48,563,437	0.63	0.44	12	-0.34	1.60	30,200
13	1 Jul	55,115,704	0.00	0.00	12	0.00	0.00	0
14	8 Jul	48,277,860	0.00	0.00	24	0.00	0.00	0
15	15 Jul	40,548,705	ND	ND	ND	ND	ND	ND
16	22 Jul	53,339,849	0.00	0.00	12	0.00	0.00	0
17	1 Aug	46,782,741	ND	ND	ND	ND	ND	ND
Total:								2,744,000

ND = No data collected.

TABLE 7(c)

ESTIMATED TOTAL ENTRAINMENT OF AMERICAN SHAD POST YOLK-SAC LARVAE FROM THE CONNECTICUT RIVER IN 1992

WEEK	START DATE	VOLUME PUMPED (m^3)	MEAN DENSITY (No./1000 m^3)	*SE*	*N*	95% LOWER LIMIT	95% UPPER LIMIT	No. ENTRAINED
5	1 May	55,408,126	ND	ND	ND	ND	ND	ND
6	8 May	56,396,819	ND	ND	ND	ND	ND	ND
7	15 May	50,164,176	0.00	0.00	12	0.00	0.00	0
8	22 May	64,134,021	0.47	0.47	12	-0.56	1.50	30,000
9	1 Jun	45,828,176	0.00	0.00	12	0.00	0.00	0
10	8 Jun	56,874,346	5.37	3.30	12	-1.90	12.64	305,500
11	15 Jun	49,839,359	129.38	86.30	24	-49.17	319.31	6,448,100
12	22 Jun	48,563,437	70.54	24.95	12	15.64	125.45	3,425,800
13	1 Jul	55,115,704	3.28	2.78	12	-2.84	9.40	180,800
14	8 Jul	48,277,860	1.36	0.65	24	0.01	2.80	65,600
15	15 Jul	40,548,705	1.07[a]	0.64	ND	ND	ND	43,400
16	22 Jul	53,339,849	0.50	0.50	12	-0.59	1.58	26,400
17	1 Aug	46,782,741	ND	ND	ND	ND	ND	ND
Total:								10,525,600

[a]Estimated mean from the previous and subsequent week.
ND = No data collected.

TABLE 8

ENTRAINMENT NET EFFICIENCY CALCULATION

SAMPLE DATE	VOLUME PUMPED (m^3)	VOLUME SAMPLED THROUGH NET (m^3)	PERCENT VOLUME SAMPLED	No. FISH RELEASED	EXPECTED No. RECOVERED	NET CATCH
14 Sep	5,602,838	684,567	12.22	367	45	15
16 Sep	6,016,137	639,238	10.63	172	18	11
22 Sep	4,513,139	505,921	11.21	120	13	16
28 Sep	3,109,963	275,023	8.84	198	18	7
29 Sep	2,045,386	132,117	6.46	174	11	27
7 Oct	1,596,988	200,829	12.58	188	24	12
12 Oct	888,016	105,468	11.88	185	22	28
13 Oct	1,255,503	140,763	11.21	147	16	11
18 Oct	3,518,297	427,264	12.14	524	64	51
20 Oct	1,950,879	216,716	11.11	500	56	42
21 Oct	1,009,989	115,368	11.42	140	16	11
26 Oct	1,904,853	225,799	11.85	163	19	15
27 Oct	1,795,963	196,692	10.95	309	34	16
Total:					356	262
Percent:						73.65

TABLE 9

ESTIMATED NUMBER OF JUVENILE SHAD ENTRAINED FROM THE CONNECTICUT RIVER IN 1992: ENTRAINMENT NET SAMPLING

WEEK	START DATE	PLANT VOLUME PUMPED (m^3)	VOLUME SAMPLED THROUGH NET (m^3)	PLANT VOLUME (m^3)/ NET VOLUME (m^3)	CATCH	EXPANDED CATCH	
18 & 19	8 Aug	90,554,304	491,347	184.3	8	1,474	
20	22 Aug	74,213,920	1,410,619	52.6	32	1,684	
21	1 Sep	48,784,305	663,393	53.6	5	368	
22	8 Sep	40,135,410	1,773,569	22.6	36	815	
23	15 Sep	46,649,835	756,947	61.7	20	1,233	
24	22 Sep	54,998,106	913,061	60.2	34	2,048	
25	1 Oct	57,435,837	767,750	74.8	65	4,863	
26	8 Oct	62,688,226	246,231	254.6	28	7,129	
27	15 Oct	44,129,471	759,348	58.1	82	4,765	
28	22 Oct	61,645,394	422,491	145.9	21	3,064	
	Total:	581,234,808	8,204,756		331	27,442	
	Variance $(S^2)^a$ =						7.681e + 07
	Standard Error (SE) =						8.764e + 03
	Total Unadjusted Catch:					27,442	± 8,764
	Total Catch Adjusted for Net Efficiency (73.65%):					37,260	± 11,900

[a]See Appendix A for the procedure and equations used to determine the variance for the total entrainment estimate.

to larvae. The distribution of early life stages may also contribute to the observed differences in densities. Larvae may move at a different rate in the river currents than eggs so that densities at a given location could be a function of upstream spawning activities and river flow conditions.

A similar pattern in the distribution of juvenile shad observed in this study was found in 1991 (Harza 1992b). Based on CPUE data from both years, juvenile shad were more abundant in regions upstream of Kidds Island (see **Figure 1**) and the region immediate to the NMPSF riverine intake seemed not to be an important area for shad. Generally, fewer shad ichthyoplankton were collected in the NMPSF nearfield region in 1991 (Harza 1992b) than in 1992. Differences in sampling methodology between years may account for the observed differences in shad ichthyoplankton numbers.

The consistency of the net efficiency recovery results and the fact that a substantial portion of the plant flow was filtered on each sampling occasion indicates that the sampling methodology provided a reliable estimate of entrainment. The overall mean of the volume of plant flow filtered (11.69%) was very close to the percentage of the outlet area occupied by the net frame (11%), which suggests that the net was fishing effectively. Considering the size of the outlet structure and the shear volume of water pumped, a relatively small (73.65%) adjustment of the total catch for net efficiency was required.

While there was considerable variability in the weekly entrainment net catch rate, the peak catch rate corresponded with the expected seasonal peak of shad migration. The increase in the entrainment net catch rate corresponded to a period of rapidly decreasing water temperature and, in fact, peaked at a water temperature (14 to 15°C) at which shad migrations in the Connecticut River have been observed to peak (O'Leary and Kynard 1986). A very similar entrainment catch rate pattern was observed in 1991 (Harza 1992b). In 1991, upper reservoir entrainment net catch rates peaked during the first week of October at a water temperature of 15°C (Harza 1992b). In both years, catches declined to early September levels in late October possibly due to the fact that the bulk of the shad had already passed the plant.

Juvenile American shad were observed in the upper reservoir during entrainment sampling and it is possible that the entrainment samples included some shad which were resident in the upper reservoir. However, this effect was believed to have been minor. The entrainment net was always set after the plant began pumping, thus some degree of flushing of fish from the outlet area could be expected. Moreover, it would have been difficult for shad resident in the upper reservoir to have entered the sample after the net was set due to the velocities (on the order of 2 to 3 m/s) observed during multiple unit pumping. Shad are also surface oriented during the times (approximately 23:30 to 05:00) that entrainment samples were taken, which would tend to keep them away from the net which was fishing at depth.

CONCLUSIONS

1. The estimated total number of juveniles entrained from the entrainment netting program, was 37,260 including a 73.65% adjustment for net efficiency.

2. Both the consistency of the net efficiency recovery results and the fact that a significant portion of the plant flow was filtered on each sampling occasion support the reliability of the total entrainment estimate for juvenile shad.

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APPENDIX A

Calculation of the Variance for the Estimate of the Total Number of Juvenile Shad Entrained (Table 9)

Total entrainment and its variance of the number of juvenile shad entrained as reported in **Table 9** was calculated using the following equations (Casella et al. 1986):

$$\bar{T} = \sum_{i=1}^{N} = \left(\frac{V_i}{Y_i}\right) X_i \qquad (1)$$

$$Var(T) = \sum_{i=1}^{N} = \left(\frac{V_i^2}{Y_i^2}\right)\left(\frac{X_i^2 + \hat{c}^2 X_i^2}{(1+\hat{c}^2)}\right) \qquad \textbf{(A-1)}$$

where:

$\bar{T}$ = expanded catch (by week) during week *i*

V_i = volume pumped during week *i*

Y_i = volume sampled during week *i*

X_i = number of juvenile shad collected during week *i*

$\hat{c}^2$ = contagion coefficient

Values for the variables in the above equation except for the contagion coefficient ($\hat{c}^2$) were directly measured and are provided in **Table 9**. The contagion coefficient is a measure of the relationship between the mean and the variance. (See Elliot (1971) for a detailed discussion of contagious distributions.) The contagion coefficient ($\hat{c}^2$) or the reciprocal of the exponential product (k) of the negative binomial distribution (1/k) (Casella et al. 1986), provides a measure of the "excess variance or clumping of the individuals in a population" or sample (Elliot 1971). Following Elliot (1971), the negative binomial distribution can be used to fit "patchy" or "clumpy" patterns of data (i.e., where the population variance is equal to or greater than the arithmetic mean).

To estimate k the following relationships were used (Elliot 1971):

$$k=\frac{x'}{y'}$$

where:

$$x'=\bar{x}^2-\frac{s^2}{n}$$

$$y'=s^2-\bar{x}$$

and:

$\bar{x}$ = sample mean
s^2 = sample variance

From the juvenile shad entrainment data (**Table 4**), a mean entrainment catch rate (i.e., No. fish/m^3) ($\bar{x}$) and associated variance (s^2) estimate was derived by week from the two to three entrainment samples taken per week (n) (**Table A-1**).

The weekly estimates of k were then examined to determine if they could be pooled into a single value. This was done by plotting the reciprocal of k (i.e., 1/k) against the mean catch rate ($\bar{x}$) (**Figure A-1**). This plot reveled no relationship between these two variables (**Figure A-1**). Therefore, k can be considered a constant (k_c) equalling (**Table A-1**):

$$k_c=\frac{\sum x'}{\sum y'}=\frac{-1.29e-04}{-2.30e-04}=0.5634$$

The contagion coefficient or reciprocal of k_c equals 1.78. This value was used in equation A-1 to derive the variance associated with the estimate of the total number of juvenile shad entrained reported in **Table 9**.

TABLE A-1

ENTRAINMEMT CATCH RATE DATA FOR THE CALCULATION OF THE "k" STATISTIC

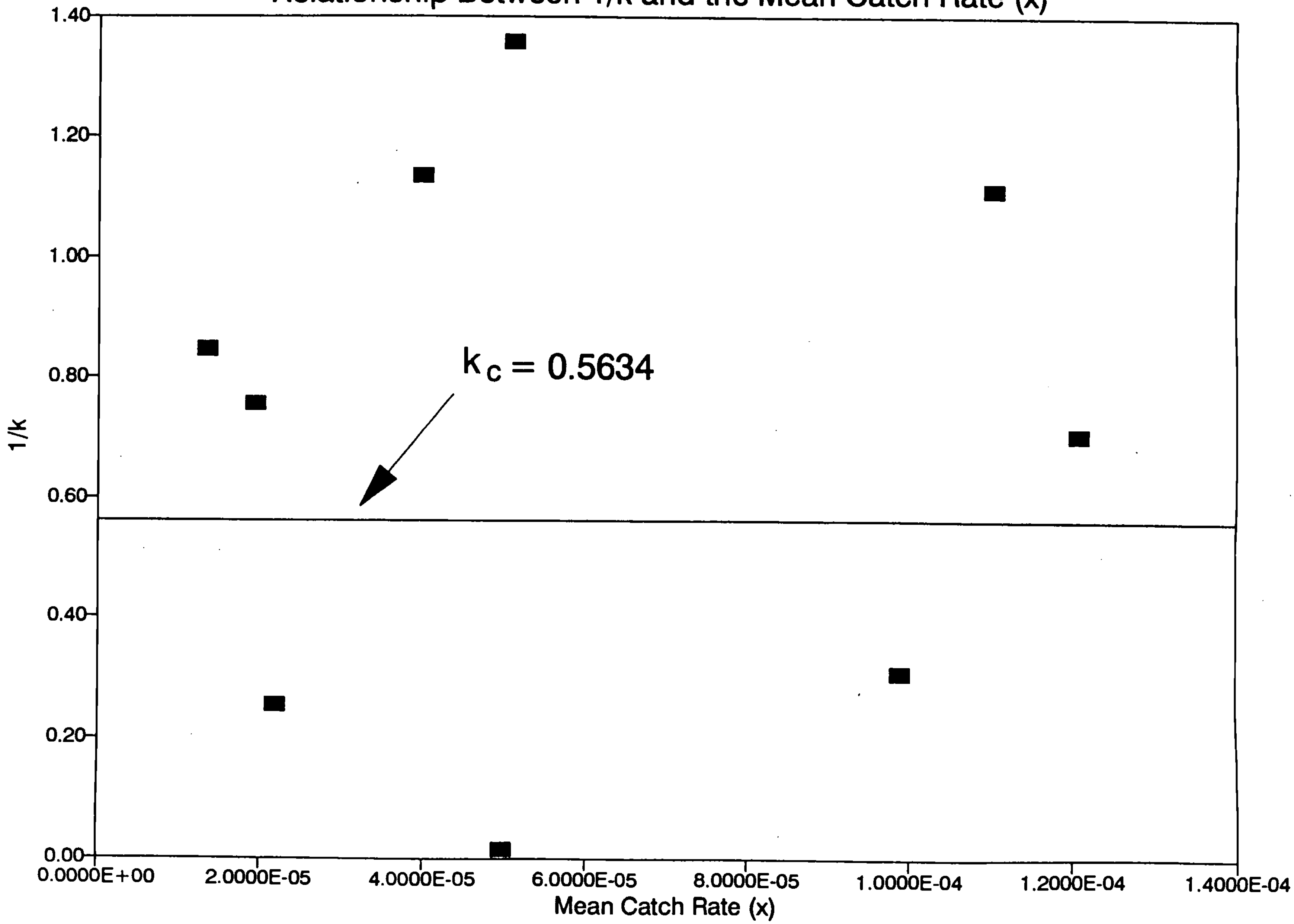
WEEK	START DATE	MEAN WEEKLY CATCH RATE (No. Caught/m³) ($\bar{x}$)	VARIANCE (S^2)	NUMBER OF SAMPLES TAKEN (n)	x'	y'	1/k	k
18&19	08-Aug	1.3520e-05	8.50e-06	2	-4.25e-06	-5.02e-06	0.846577	1.181227
20	22-Aug	2.1860e-05	9.50e-06	3	-3.17e-06	-1.24e-05	0.256164	3.903747
21[a]	01-Sep	7.5370e-06		1				
22	08-Sep	1.9300e-05	1.34e-05	3	-4.47e-06	-5.90e-06	0.756999	1.321006
23	15-Sep	3.9900e-05	2.77e-05	2	-1.38e-05	-1.22e-05	1.135115	0.880968
24	22-Sep	5.1060e-05	4.10e-05	3	-1.36e-05	-1.01e-05	1.358256	0.736238
25	01-Oct	1.1030e-04	7.61e-05	2	-3.80e-05	-3.42e-05	1.112217	0.899105
26	08-Oct	1.2080e-04	7.07e-05	2	-3.53e-05	-5.01e-05	0.705298	1.417841
27	15-Oct	9.8970e-05	4.57e-05	3	-1.58e-05	-5.14e-05	0.307432	3.252749
28	22-Oct	4.9770e-05	1.50e-05	2	-7.48e-07	-4.83e-05	0.015486	64.57327
Total:				23	-1.29e-04	-2.30e-04		

$$k_c = \frac{\sum x'}{\sum y'} = \frac{-1.29e-04}{-2.30e-04} = 0.5634$$

[a]One sample taken; variance not calculated.

Figure A-1

Relationship Between 1/k and the Mean Catch Rate (x)



NORTHEAST UTILITIES SERVICE COMPANY

NORTHFIELD PROJECT

1992 STUDY PLAN FOR THE IMPACT OF PROJECT OPERATION ON AMERICAN SHAD

June 1992

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AMERICAN SHAD STUDY PLAN

1.0 INTRODUCTION

The objective of the 1992 juvenile shad study program is to assess the impact of the operation of the Northfield Mountain Pumped Storage Facility (NMPSF) on American shad in the Connecticut River. In order to make an esimate of the impact of plant operations on a fish population, one can examine the consequences of past operations or use mathematical models of the fish population, in combination with a direct measurement of plant effects, to estimate impact. For NMPSF, there are no definitive long-term records of shad population monitoring data that can isolate the effects of the plant. Absent this information, mathematical models are the only alternative.

Applications of mathematical models to fish populations typically address two levels of impact. The first, which will be referred to as short-term impacts, quantifies the effects on a population during a single year and in the absence of any ability of the population to compensate for the number lost at the plant. The second, referred to as long-term impacts, examines the effect of annual losses, at the short-term impact rate, on future levels of the population.

The proposed field study is designed to collect the information necessary to compute the short-term impact. Once the short-term loss rate is computed, this information is used to compute the long-term impact. In a study program which utilizes a relatively complex model to estimate impact, it is important to develop the models for computing impact first, so that the data collection can be designed to meet the model's needs. This plan of study first describes the methods used to compute the short-term and long-term impact measures so that areas of critical data needs can be identified. The field sampling program designed to obtain this information is described in a subsequent section.

The following sections provide a verbal description of the models and the selection of various components of the model. In reality, the model is a series of equations which mathematically describe the relationships between the model components. The mathematical representations of the models are presented in Appendix 1. To illustrate the basic modelling approach the components of the overall impact equation are presented in textual and symbolic form.

2.0 ASSESSMENT METHODOLOGY

2.1 Short-term Impact Assessment

The measure of short-term impact is the percentage of the population lost due to one year's operation of NMPSF. In the Connecticut River, only those juvenile American shad that reside in Turner's Falls Pool or migrate past NMPSF are potentially susceptible to being entrained into the NMPSF intake flow. Eggs, larvae and juveniles produced in the Turner's Falls pool during spring are susceptible to entrainment until the juveniles undertake their seaward migration in the fall. Juveniles produced upstream of the Vernon Dam are susceptible to entrainment as they migrate past NMPSF during their fall seaward migration. The percentage of the shad population lost due to entrainment may, therefore, be expressed as:

Impact = 1 - (1-proportional reduction of Turners Falls Pool population due to entrainment of resident juveniles) (1-proportional reduction of emigrating population from upstream of Turner's Falls Pool)

$$I = 1 - (1-E_r) \quad (1-E_m)$$

The values of the proportional reduction in resident juveniles (E_r) and proportional reduction in emigrating juveniles (E_m) can be estimated with a model based on standard fisheries management statistics. One such statistic is the conditional mortality rate (CMR or **m**), which represents the mortality due to a particular source of exploitation in the absence of all other sources of mortality (Ricker 1975). Considering NMPSF as the exploitation source of interest, the CMR provides an estimate percentage reduction in population size due to NMPSF operations relative to the population size without NMPSF operating in the absence of all other sources of mortality. Simplistically, the model traces the population decline over time, both with and without the NMPSF induced mortality. The CMR or percentage reduction is computed as the difference between the population size with and without

NMPSF divided by the population without. This process is illustrated in **Figure 2-1** and the computational details are described in **Appendix 1**.

Mathematically, the calculation of the conditional mortality rate for NMPSF requires three basic input parameters:

- The natural mortality rate during the entrainment period. This describes the rate of population decline without NMPSF.
- The number of individuals entrained during each time step. This is used to compute the NMPSF exploitation rate. Together with the natural mortality rate, these two values describe the rate of population decline with NMPSF.
- The number of individuals alive at the beginning of the impact period. This is used to convert the relative rates of decline to actual numbers of individuals.

The following paragraphs describe in greater detail how the values for each of these inputs will be obtained.

Natural Mortality Rate

The model to be used to estimate the effects of NMPSF on American shad requires an estimate of the daily natural mortality rate, i.e., mortality from all sources except those attributable to NMPSF. This information will be obtained from published literature. Crecco et al. (1983) and Crecco and Savoy (1985), among others, reported natural mortality rates for Connecticut River shad. The former found mortality rates of 19.8 to 25.6% per day for first feeding larvae, 4.4 to 8.7% per day for larvae approaching metamorphosis, and 1.8 to 2.0% per day for juveniles.

A check on the natural mortality values will be made from the data collected using the programs described in Sections 3.1 and 3.2. The average rate of decrease in the natural logarithms of the population abundance over time will yield the total (including NMPSF impact) mortality rate.

Number Entrained

The number of American shad, eggs, larvae, and juveniles entrained on any given day will be estimated from a series of field studies conducted at or near NMPSF. An ichthyoplankton sampling program in the river will be used for eggs and larvae while a netting program in the upper reservoir will be used for the juvenile life stage.

The number of eggs and larvae will be estimated by using 0.5-m ichthyoplankton nets with 500 μ mesh to measure the average concentration of these life stages in the river waters potentially withdrawn by NMPSF. Details of this program are described in Section 3.1. The average concentration in the river water potentially withdrawn by NMPSF will be multiplied by the plant intake volume to estimate the number entrained during each day.

The number of juvenile American shad entrained at NMPSF will be estimated using two 15 × 15 ft nets mounted at the discharge into the upper reservoir. Details of this program are described in Section 3.3. The average concentration during the sampling periods will be extrapolated to the period of operation by multiplying the average hourly concentration by the number of operating hours per day.

Starting Population Size

Because American shad spawn in Turner's Falls Pool it is expected that the first life stage susceptible to entrainment at NMPSF will be the egg stage. Therefore, the starting population size necessary for the calculation of the conditional mortality rate will be the number of eggs produced in Turner's Pool. However, due to the fact that juveniles from eggs spawned upstream of Vernon Dam are susceptible to entrainment during their downstream migration, the egg production in the upstream portions of the river must also be estimated.

There are several ways to estimate the number of eggs present at the beginning of the impact period. If emigration, mortality, recruitment and sampling errors can be considered negligible, the population size at any given time can be obtained from the ichthyoplankton study described in Section 3.1. Assuming a homogenous distribution throughout the pool, the total egg production for Turner's Pool may be estimated by multiplying the average concentration of eggs in the nearfield samples by the volume of the pool. However, due to the fact that samples will be collected only in the immediate vicinity of NMPSF, the estimate based on these samples may be biased. A second, and likely more accurate estimate, may be obtained by multiplying the number of spawning females by the average number of eggs produced per female shad. These methods will provide two independent estimates of the initial population size. If the two estimates are widely apart the estimate based on the number of spawning females will be used.

Information on the adult shad entering the pools will be obtained through government agencies, academic institutions, and published literature. Various fisheries agencies, cooperating through the Connecticut River Atlantic Salmon Commission (CRASC), Shad Subgroup, monitor the annual shad run. The results of the 1980 through 1991 counts are shown in **Figure 2-2**. Additionally, the State of Connecticut Department of Environmental Protection collects and analyzes data on the Connecticut River shad run. P. Minta, V. Crecco, T. Savoy, and others have published numerous papers on aspects of growth, survival, and reproduction of American shad.

2.2 Long-term Impact Assessment

Once the conditional mortality rate on a given year class is calculated, the next step is to translate those losses to a long-term effect, i.e., the effect of year-after-year losses (exploitation) on the population. It is widely documented that fish populations can, by a process known as compensation, withstand some level of exploitation without any adverse effects. In general, "compensation" refers to the tendency for populations to increase survival, growth, and birth rates in response to declining population numbers. McFadden (1977) summarized the findings of many studies where compensation was involved and demonstrated that fish populations could often withstand exploitation rates as high as 25-75%.

Compensatory mechanisms have been incorporated into a class of fisheries management models known as stock-recruitment models. These models generally partition the predicted number of young produced (recruits) from a given parental stock into density dependent (compensatory) and density independent (non-compensatory) components. The density dependent components frequently include such factors as competition, cannibalism, and predation while the density independent components often include such factors as flow, temperature, tides, currents, and salinity.

Walburg (1963), Marcy (1976), and Leggett (1976, 1977) pioneered the work on stock-recruitment models for Connecticut River shad. Leggett (1977) found three density-dependent factors (the number of eggs spawned, the growth rate, and the number of spawners) and two density-independent factors (water temperature and discharge flow) to be important in predicting the number of recruits. More recently, Crecco and Savoy (1984) extended these investigations and found that mean river discharge, water temperature, and total monthly precipitation were significantly correlated with the June year-class strength (the period of peak larvae emergence). Lorda and Crecco (1987) further investigated density dependent and independent effects on year-class strength and found a statistically significant relationship between parental stock size (above and below Holyoke Dam) and June river flow.

Given a stock-recruitment model, such as that developed by Lorda and Crecco (1987) and the conditional mortality rate attributable to NMPSF, it is possible to compute the long-term effect on the Connecticut River shad population. McFadden and Lawler (1977) demonstrated how the density independent component of the a stock-recruitment model can be modified to include the additional mortality associated with the imposition of a conditional mortality rate. Details of the method are provided in **Appendix A1** (Eq. 11).

2.3 Summary of Assessment Methodology

An overview of the impact assessment approach for American shad is as follows:

- ***Eggs and Larvae***

  - Estimate concentration (No./m^3) entrained based on nearfield sampling with ichthyoplankton nets near the intake.

  - Calculate losses due to entrainment based on plant flow and nearfield concentration.

  - Estimate initial population size (i.e., number of viable eggs produced in Turners Falls Pool) based on number of adults present.

  - Compute population size at weekly intervals based on initial population size and survival rates from the literature.

  - Use number entrained, initial population size, and natural mortality rates to compute the conditional mortality rate.

- ***Juveniles in Turners Falls Pool Prior to Emigration***

  - Estimate concentration of entrained organisms based on upper reservoir net sampling.

  - Calculate losses due to entrainment based on product of plant flow and entrainment concentration and assuming 100% mortality.

  - Compute population size at weekly intervals based on larval abundance computed above and survival rates from the literature.

  - Use number entrained, initial population size, and natural mortality rates to compute the conditional mortality rate.

- ***Emigrating Juveniles From Turners Falls, Vernon, and Bellows Falls Pools***

  - Estimate concentration of entrained organisms based on net sampling in the upper reservoir.

  - Calculate number of juveniles lost to entrainment based on concentration estimate from netting and plant flow.

  - Compute population size at beginning of emigration period for juveniles in Turners Falls Pool.

  - Compute population size for juveniles emigrating from Vernon and Bellows Falls Pool based on time at which emigration starts, the number of spawning adults in these pools, and the natural survival rates from literature.

- Combine populations from Turners Falls, Vernon, and Bellows Falls Pools along with natural mortality rates and estimates of entrainment losses to compute the conditional mortality rate.

Once the conditional mortality rates are computed, they will be incorporated into the stock-recruitment model to estimate the long-term reduction in equilibrium population size. An example of the assessment methodologies, using data from the Delaware River, are shown in **Appendix 2**.

3.0 FIELD STUDIES

The purpose of the field studies is to provide site-specific data on various life stages of shad in order to estimate densities in Turners Falls Pool and entrainment rate at Northfield Mountain. These studies will provide life stage specific data for the population models.

3.1 NEARFIELD SPATIAL AND TEMPORAL DISTRIBUTION OF CLUPEID EGGS AND LARVAE

The purpose of this sampling program is to describe the spatial and temporal distribution of the eggs and larvae of clupeids in the vicinity of the intake at Northfield Mountain. These data will be used in conjunction with river flow and plant pumping rates to estimate the number of early life stages entrained.

Sampling will be conducted with a sled-mounted 0.5-m ichthyoplankton net with 500 μ mesh (**Figure 3-1**). The net will be towed for 10 min for each sample. Each sample will be collected with an oblique tow starting at the surface and ending at the bottom. Each net will have a calibrated General Oceanics (GO) or TSK flowmeter to measure the volume sampled. A measurement of dissolved oxygen (DO) and temperature will be made at mid-depth in each stratum during each sampling occasion.

Sampling will take place 11 times between mid-May and mid-July. Nine sampling occasions will be at night and two will be during the day. The river segment within a half mile (±0.5) of the intake will be divided into three longitudinal and three horizontal segments, creating nine strata.

CONNECTICUT RIVER		
1	2	3
4	5	6
7	8	9

-0.5 mile +0.5 mile

A randomly placed sample will be taken from each of the nine strata and a replicate from each of the longitudinal segments on each sampling occasion. This program will produce 12 samples per occasion and a program total of 132 samples. Each sample will be concentrated and preserved in 5% buffered formalin and stained with Rose Bengal to aid in sorting. The laboratory analysis will differentiate among the clupeid early life stages to provide a separate count for American shad and blueback herring.

3.2 SPATIAL AND TEMPORAL DISTRIBUTION OF JUVENILE SHAD IN TURNERS FALLS POOL

The purpose of this program is to describe the general distribution of juvenile shad in Turners Falls pool. This program will provide data on the relative abundance of juveniles at selected locations during the summer and the early fall migratory period.

Sampling will be conducted with a boat-mounted electrofishing unit operating in a pulsed DC mode. The primary unit will be a 7.5 GPP Electrofisher, with a 3.5 GPP Electrofisher as a backup unit. These units are interchangeable on LMS' 17-ft Polarcraft electrofishing boat. The boat is equipped with two bow-mounted anode arrays and two cathode droppers along the sides. The boat is rigged with high-intensity lights for night sampling. A three-man crew will be used, with one person operating the boat and two people collecting fish. Fish will be held in the boat's live box for processing in the field. This equipment was recently successful in capturing small alewife in a riverine situation.

Electrofisher settings will be made at the time of each survey based on measurements of conductivity, water temperature, and size of fish. The settings (voltage, pulse width, and pulse frequency) will remain the same during each survey, but may change over the course of the program. Prior to the initial survey there will be a series of trial runs to test the equipment and standardize the sampling procedures.

Electrofishing was selected for this study because concentration data for shad are not needed to describe distribution through time. Trawling was previously unsuccessful in capturing juvenile shad in Turners Falls pool and is a more time consuming and potentially a more trouble-prone method of sampling in a river. Because juvenile shad are near the surface at night, they are susceptible to electrofishing gear. A standardized electrofishing program is an efficient sampling approach that provides relative abundance data that can show changing spatial distribution through time. Seining was not proposed because this technique is restricted to the shoreline and only in suitable locations, which may not fit the needs of a distributional study.

The Connecticut River between Vernon and Turners Falls will be divided into five strata. One stratum, one mile in total length, will be centered in front of the NMPSF intakes. The remaining strata will encompass the remainder of the pool: two strata upriver and two strata downriver from NMPSF. Additionally, the pool will be stratified into shoreline and channel habitats. The exact boundaries of the strata will be determined after an inspection of the pool and its habitats.

Biweekly sampling will be conducted from late June through August, weekly sampling from September through early October. Sampling will be conducted at night, with two 20-min samples taken from each stratum. This sampling design will produce a total of 200 samples.

As fish are collected they will be placed in the boat's live well. At the end of each sampling run the fish will be processed in the field. The shad will be counted and up to 100 individuals will be measured for total length. Any salmon collected will be counted and measured. DO and temperature will be measured at mid-depth at each stratum.

3.3 ENTRAINMENT SAMPLING

LMS believes that sampling with large nets in the upper reservoir is the best approach to obtain an estimate of entrainment rate for juvenile shad. Large net openings and a large filtering area (length of net) are needed to maximize sampling efficiency. Gear avoidance by fish is determined to a great extent by the interplay of behavior and swimming ability. Detection of the net through visual senses or lateral line sensors can result in an avoidance response. A large net opening and large filtering capacity reduces the probability that a fish will see the net or feel the pressure wave created by the net's resistance in the flow. The large opening also diminishes the chance that a fish can make an avoidance response before it is carried deep into the net.

Entrainment sampling will be conducted in the upper reservoir during pumping using a 30 by 15 ft steel frame capable of holding two 15 by 15 by 60 ft long tailrace nets (**Figure 3-2**). Two mesh sizes, 0.25 and 0.5 in. square mesh, will be used during the season to accommodate the increasing size of the shad. The paired nets will provide two replicate samples for each deployment. The frame will be set with the nets in a side-by-side configuration. Four calibrated GO velocity meters (seven digit) will be installed in each quadrant of each net to measure the flow sampled.

The entrainment net frame will be deployed with a crane having a boom of at least 80 ft (**Figure 3-3**). Spreader bars and cable rope legs will be used to suspend the frame from the crane. Cables (0.375 in.) will be attached to the bottom corners of the frame and will extend through blocks on the bottom and return to the crane. The net frame will be lowered with the crane while the winches take up slack in the bottom cables. Tension will be maintained on all of the cables to hold the net at a selected depth during sampling. At the end of the sampling interval, the crane will lift the net to the surface while the winches pay out slack. Between sampling periods the net frame will be held with the crane above the water and tension will be maintained on the bottom cables so they are not carried against the bar racks by the generating flow.

Entrainment sampling will be conducted biweekly from mid-June through August with 0.25-in. mesh and weekly from September through early October with 0.5-in. mesh. Sampling will take place on Sunday and Monday nights during each sampling episode. Net sets will be of 2-hr duration to increase the likelihood of capturing sufficient numbers of fish for statistical analysis. There will be two net sets per night on Mondays and three sets per night on Sundays. The depth of each sample will be randomized to ensure coverage of the entire flow during the program. This design will produce a total of 55 samples.

The net frame will be lifted just above the water surface at the end of each sampling interval to retrieve the fish and read the GO meters. A two-man crew in a boat will shake down the nets to concentrate the fish in the cod end. The crew will remove the fish and place them in a bucket of water and record the GO meter readings.

The fish will be counted by species and all shad and salmon will be measured for length. Observations on the condition of the fish will be recorded. Dead shad and salmon will be saved (frozen) and other dead fish will be discarded. Live fish will be analyzed and released. In addition to the data on fish, the field data sheets will contain information on the time, duration, and conditions of sampling and plant operating conditions during the sample interval. Any unusual factors that could influence sampling efficiency will be noted.

3.4 COLLECTION EFFICIENCY TESTS

These tests will be used to estimate the efficiency of the sampling nets for juvenile shad in the upper reservoir. The estimates of collection efficiency will be used to adjust the estimates of total juvenile shad entrainment derived from the upper reservoir net collections.

A release of marked juvenile shad will be made four times during the upper reservoir sampling program (late June through early October) at the stilling well of a selected pump/turbine unit at the beginning of the pumping cycle after the collection nets are set. The test fish will be acquired in the river using electrofishing or seines. The electrofishing program for juvenile shad distribution will provide information on the best locations for collecting shad. The test fish will be batch marked with a stain to minimize damage and stress due to handling during marking.

At least 100 juvenile shad will be released during each test. There will be two releases during the premigration period and two during outmigration. The fish collected during each test will be checked for the marking stain and all specimens will be identified and counted. The GO velocity meters will be read to provide an estimate of the volume sampled.

TABLE A2-1

DELAWARE RIVER AMERICAN SHAD POPULATION DYNAMICS

Ova Production

AGE	MEAN AGE CLASS COMPOSITION	MEAN % FEMALE	NUMBER OF PAWNING FEMALES[a]	MEAN SIZE AT SPAWNING	STANDARD DEVIATION OF MEAN SPAWNING SIZE	MEAN INDIVIDUAL FECUNDITY[b]	NUMBER OF EGGS PRODUCED (BILLIONS)
1	0	0	0	208.4	9.3	0	
2	0.25	0	0	322.2	14.3	0	
3	6.82	0	0	404.6	18.0	0	
4	40.56	16.50	14,118	464.4	20.6	288,852	4.07802
5	38.26	69.74	56,287	507.0	22.5	359,595	20.24051
6	12.33	97.46	25,349	539.1	23.9	416,736	10.56385
7	1.67	100.0	3,523	561.8	24.9	461,190	1.62477
8	0.1	100.0	211	578.3	25.7	495,201	0.10449
Total			99,488				36.61163

[a]Based on mean population size of 210,950.

[b]Method of Pitcher and MacDonald (1973).

APPENDIX A

A1 - MATHEMATICAL MODELS

A2 - DELAWARE RIVER EXAMPLE

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APPENDIX A1

MATHEMATICAL MODELS

APPENDIX A2

DELAWARE RIVER EXAMPLE

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MATHEMATICAL MODELS

It is often desirable to express short-term impacts as a proportional reduction in the population size relative to what it would have been without the impact. The standard fisheries management statistic, the conditional mortality rate (**m**), embodies this concept. Following Ricker (1975), the conditional mortality rate is defined as

$$m = 1 - e^{-Ft} \qquad (1)$$

where,

F = instantaneous fishing (or exploitation) mortality rate
t = time

It can be seen from the following that **m** is equal to the proportional reduction in the population subject to exploitation relative to that without exploitation.

The population size at any given time (N_t) can be expressed as

$$N_t = N_0 \, e^{-Zt} \qquad (2)$$

where,

N_0 = initial population size
Z = instantaneous total mortality rate

The instantaneous total mortality rate (**Z**) can be subdivided into its component parts as,

$$Z = F + M \qquad (3)$$

where,

M = instantaneous natural mortality rate

Therefore, the proportional reduction or impact (I) in population size with exploitation (N_{with}) relative to what it would have been without exploitation ($N_{without}$) is,

$$I = 1 - \left(\frac{N_{with}}{N_{without}} \right) = 1 - \left(\frac{N_0 \ e^{-Ft+Mt}}{N_0 \ e^{-Mt}} \right) \quad (4)$$

By simplification, **Equation (4)**, reduces to,

$$I = m = 1 - e^{-Ft} \quad (5)$$

There are several ways in which the instantaneous fishing (exploitation) mortality, **F**, can be calculated. However, one of the most useful methods for assessing entrainment effects for a Type II fishery, i.e., one where natural mortality occurs along with the exploitation, can be derived from Ricker's (1975) equation:

$$C = \frac{NFA}{Z} \quad (6)$$

where,

C = catch (number) lost to entrainment
N = number in population at start of exploitation phase
A = total mortality rate = $1 - e^{-Z}$

By substitution and rearrangement, **Equation (6)** can be expressed as,

$$F = (F+M) \ \frac{C/N_0}{1 - e^{-F+M}} \quad (7)$$

Because **Equation (7)** has no closed form solution, F is found by iterative substitution into,

$$0 = N_0 \frac{F}{F+M} (1-e^{-F+M}) - C \qquad (8)$$

If entrainment rates vary over time, as expected, then **Equation (8)** is further modified to solve for **m** over small time steps, e.g., hourly, daily, weekly, or monthly. The conditional mortality rates from these small time steps are combined using:

$$m_T = 1-\prod_{i=1}^{K} (1-m_i) \qquad (9)$$

where,

K = number of time steps

Long-term impacts are often expressed as reductions to the equilibrium population through the use of stock-recruitment models. Although several different forms are available, the most commonly used models are based on the Ricker model:

$$R = \alpha\ P\ e^{-\beta P} \qquad (10)$$

where,

R = number of mature recruits
P = parental stock size
α = model coefficient, often termed the intrinsic population growth rate or compensatory reserve
ß = model coefficients, often termed the density dependent mortality rate

If NMPSF impacts are to be incorporated into density-dependent models, McFadden and Lawler (1977) have shown that the fractional reduction in an equilibrium population (**p**) that would result from the imposition of a conditional mortality (**m**) can be computed as:

$$p = 1 - \frac{\ln(\alpha(1-m))}{\ln\alpha} \qquad (11)$$

DELAWARE RIVER EXAMPLE

The following example demonstrates the calculations necessary to assess the impact of NMPSF on Connecticut River American shad using data acquired to assess the effects of a power plant on American shad in the Delaware River.

In the Delaware River during 1963-1979, the mark-recapture program conducted by Delaware Basin Fish and Wildlife Management Cooperative (DBFWMC) estimated the average spawning population size of American shad at 210,950 adults. The major steps used to compute the number of subsequent progeny at any given time are outlined below. Most of the life history parameters were obtained from published literature.

(1) Egg production was calculated as 36 billion (**Table A2-1, Figure A2-1**).

(2) Spawning begins June 1.

(3) Egg retention 6.75%, 34 billion eggs released.

(4) Incubation @14°C is 9 days with hatching success of 88%, 30 billion larvae are hatched (**Figure A2-2**).

(5) Mortality (Z_d) through 28 day larval stage is 0.15245, 421 million juveniles are produced.

(6) Fall juvenile migration/overwintering completed by June (328 days) with Z_d of 0.01351, 5 million enter sea.

(7) After 4-5 years at sea, adults return to spawn. Annual Z is 1.2859.

(8) The expected return is given in the following table and in **Figure A2-3**.

Age	Years at Sea	Expected Return	Observed Return
4	3	105,686	85,561
5	4	29,212	80,710
6	5	8,074	26,010
7	6	2,232	3,523
8	7	619	211

The conditional mortality rate was then calculated using the methods outlined in **Appendix A1 (Table A2-2)**.

TABLE A2-2
AMERICAN SHAD CONDITIONAL MORTALITY RATE

Period	Month	Initial Population	Number Killed	Daily Z	Conditional Mortality
1	OCT	33250000	438	0.0135	0.00002
2	NOV	21879602	3579	0.0135	0.00020
3	DEC	14593187	2360	0.0135	0.00020
4	JAN	9602800	0	0.0135	0.00000
5	FEB	6318961	0	0.0135	0.00000
6	MAR	4315356	3456	0.0135	0.00098
7	APR	2839647	1319	0.0135	0.00569
8	MAY	1893979	1962	0.0135	0.00127
9	JUN	1246301	0	0.0035	0.00000
10	JUL	1122075	0	0.0035	0.00000
11	AUG	1006702	47	0.0035	0.00005
12	SEP	903192	0	0.0035	0.00000
13	OCT	813166	27	0.0035	0.00004
14	NOV	729555	363	0.0035	0.00052
15	DEC	656836	55	0.0035	0.00009
16	JAN	589300	0	0.0035	0.00000
17	FEB	528707	0	0.0035	0.00000
18	MAR	478933	128	0.0035	0.00028
19	APR	429688	775	0.0035	0.00190
20	MAY	386859	207	0.0035	0.00056
Conditional Mortality Over Period					0.01174

A Ricker stock-recruitment model was derived from commercial landings data from the Lewis Fishery, DE over the period 1925-1980. The proxy method, assuming lag periods of 3,4,5, and 6 years, was used to estimate the number of progeny. The best fit model was based on 1955-1980 data with a five year lag between progeny and parents, α = 6.1945, ß = 0.1240 (r^2 = 0.4988) (**Figure A2-4**) No adjustments were made for environmental factors in this application. Additionally, a single spawn model was used because most Delaware shad die after a single spawning, i.e., repeat spawning is only less than 10%.

Therefore, given a conditional mortality rate of 1.17%, a density independent coefficient (α) of 6.194 and substituting into the following equation,

$$p = 1 - \frac{\ln(\alpha(1-m))}{\ln\alpha} = 1 - \frac{\ln(6.1945(1-.01174))}{\ln(6.1945)} = 0.00647 \qquad (12)$$

yields a reduction of 0.647%. For an equilibrium population of 210,950 spawners, a long-term reduction of 0.647% represents approximately 1366 individuals.

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