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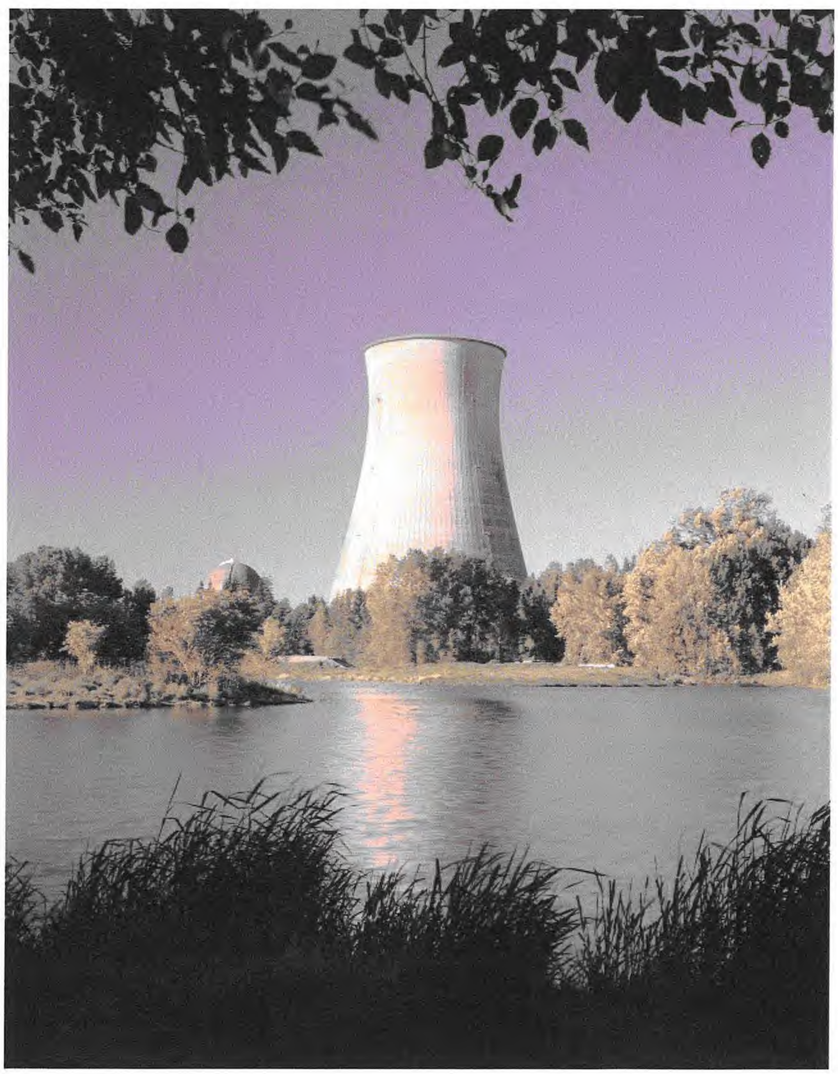
Review of Entrainment Survival Studies: 1970-2000

Technical Report



Review of Entrainment Survival Studies: 1970–2000

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Final Report, December 2000

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REPORT SUMMARY

This report summarizes the results of entrainment survival studies conducted at power stations over the last 30 years. It is the most comprehensive review to date and will be of value to utilities, industries, and government agencies involved in assessing potential environmental impacts of cooling water intake structures.

Background

The potential impacts of entraining aquatic organisms, particularly young fish and larger invertebrates, in power plant cooling-water streams received only limited attention prior to 1972. The passage of the Clean Water Act in 1972 heightened concern over the potential effects of cooling water intake structures (CWIS). Section 316(b) of the Act requires that the "design, location, construction and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impact." Subsequently, many utilities sponsored studies of the impacts of their CWIS on aquatic organisms. In that early period, the prevailing opinion was that most if not all entrained organisms were killed. However, in addition to quantifying the number of entrained organisms, some studies also measured survival rates of entrained organisms. Survival rates were shown to be notably high for some species, particularly following improvements in sampling gear and techniques through the 1970s. As a result of legal action in the early 1990s, the U.S. EPA entered into a consent decree with the Hudson Riverkeeper and a coalition of environmental groups and agreed to undertake a rulemaking to implement Section 316(b). This provided the impetus for a synthesis and review of existing data on entrainment survival.

Objectives

To review, organize, and summarize nearly 30 years of entrainment survival data collected at steam-electric power stations

To identify common factors affecting, or associated with, the entrainment survival phenomenon.

Approach

The project team identified and assembled copies of reports and publications describing entrainment survival studies, aided by an EPRI survey of utilities and resources in EPRI's library and databases. The team then carefully reviewed each available report and summarized it on a single page. They prepared various tabular and graphical displays to provide an overview of the entrainment experience and identified biological and plant-operating factors that influence entrainment survival.

Results

A total of 36 discrete entrainment survival studies were identified from 21 power stations. Most of the studies were done in the 1970s, with fewer in the 1980s and 1990s. The majority of the studies were done at estuarine sites in the northeast, primarily in the Hudson River. The remaining studies were done mainly in the Midwest, with a few in California and Florida. Entrainment survival of estuarine species was most commonly evaluated. Larvae of striped bass and white perch frequently exhibited a high rate of survival (>50 percent), but fragile species such as herring and anchovies had relatively low survival rates (~25 percent). Macroinvertebrates, which are important in the food chain, experienced very high survival, averaging in the 70 to 90 percent range. Key factors that influence the level of entrainment survival were identified as (1) the species entrained; (2) size of entrained fish larvae (larger larvae fare better); (3) biocide use at the power station; (4) mechanical effects such as abrasion and pressure changes; and (5) temperature of the discharge water. The latter was found to be particularly important, with a threshold of 30-32°C above which survival rapidly declines. Based on this review, it is recommended that assessment of CWIS impacts be based on the actual number of organisms experiencing entrainment mortality, and not the total number entrained.

EPRI Perspective

The information presented in this report will be a valuable resource for utilities and other CWIS owners, as well as resource agency and regulatory personnel, as the EPA 316(b)-rulemaking process evolves. The availability of the report will ensure that new generations of both CWIS owners and regulators will benefit from the intensive research and resulting large body of data accrued over the last 30 years. It will also serve as a resource for researchers designing future studies of entrainment survival.

Keywords

Section 316(b)
Entrainment
Entrainment survival
Cooling water intake structures (CWIS)
Impact Assessment

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EPRI and EA Engineering, Science & Technology, Inc. would also like to extend a special thanks to all the electric power companies that supplied the entrainment survival data presented in this report.

The report was prepared and edited by EA Engineering, Science, & Technology, Inc.

EXECUTIVE SUMMARY

This review of entrainment survival studies was undertaken to summarize a body of information that has accrued over the past nearly 30 years. The impetus for the review was the Section 316(b) rulemaking process mandated in a 1995 consent decree between the U.S. EPA and a coalition of environmental groups. The rulemaking is intended to implement Section 316(b) of the Clean Water Act, which requires that the "location, design, construction, and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impact." This report will be a valuable resource for both the U.S. EPA and industry in addressing one facet of Section 316(b), the entrainment of small aquatic organisms in cooling-water systems.

Following passage of the Clean Water Act in 1972, many utilities began to sponsor studies of the effects of their cooling water intake structures (CWIS) on the aquatic environment. Entrained aquatic organisms are pulled into power plant cooling systems and subjected to elevated temperatures, physical stresses, and potential chemical stresses from biocides as they transit pumps and condensers, and are discharged back to the receiving water. Limited studies and much conjecture in the early 1970s appeared to support a conclusion that virtually all entrained organisms were killed. Subsequent research began to contradict that conclusion as sampling techniques and gear were more and more refined through the 1970s.

This review was initiated by identifying and compiling study reports on entrainment survival. Most of these were unpublished reports sponsored by utilities. A few were found in peer-review publications or workshop proceedings. Thirty-six reports were identified covering 20 power plants in the U.S. and 1 in the Netherlands. The U.S. studies were concentrated in the northeast, and most of those were done at Hudson River power plants. More than 80 percent of the studies were carried out between 1972 and 1980, a period bracketed by passage of the Clean Water Act in 1972 and settlement of the Hudson River case in 1980. Approximately 50 different species or species groups were evaluated in these studies. Estuarine fish species such as striped bass, white perch, herring, and anchovies were most commonly studied. Entrainment survival data on estuarine macroinvertebrates such as amphipods and mysid shrimp were also common in the reports.

When available in the reviewed studies, data were compiled for both initial and extended survival. That is, the proportion of organisms found alive immediately after plant passage, and the proportion of initially-alive organisms that survived an extended holding period, most commonly 96 hours. Initial and extended survival were combined to estimate total entrainment survival, the best estimate of the total entrainment experience for a species. Some studies measured only initial survival.

The survival rates of entrained organisms varied considerably within and among species, and among power plants. The survival of young life stages of striped bass in approximately 60 individual tests ranged from 28 to 90 percent, with a mean of 61 percent. Tests of Atlantic tomcod and cyprinids (minnows) produced similar results, with means of 57 and 64 percent survival, respectively. Survival rates of young white perch, winter flounder, and freshwater drum were lower with means between 48 and 51 percent. At one power plant, survival of larval catostomids (suckers) was high (88 to 98 percent). Larval and juvenile spot survival was measured at two estuarine power plants and the mean survival rate was just over 75 percent. In contrast to these relatively high survival rates, larvae and juveniles of herring (alewife, blueback herring, and menhaden) and bay anchovy did not fare well in entrainment survival tests. Survival rates for these sensitive species ranged from near zero to 50 percent, with mean survival rates about 25 percent. Tests of estuarine macroinvertebrates had a mean survival rate of near 75 percent. Survival of entrained freshwater macroinvertebrates (drifting aquatic insects) was measured at one power station over a four-year period and ranged from about 84 to 93 percent.

Although survival rates were quite variable, even for the same species, it is clear that for most species survival can be quite high. The available data do not support the assumption that all entrained organisms are killed.

This review identified several factors that influence the rate of survival of entrained organisms. As noted above, survival is species specific. Under similar conditions, survival of striped bass is higher than survival of herring. The size of young fish entrained is an important factor noted in a number of studies. In one Hudson River study, survival of 3.0–5.9-mm entrained striped bass larvae was between 10 and 30 percent, and survival increased with growth to 65–90+ percent for larvae 12 mm or longer. The use of biocides to control condenser-tube fouling can substantially reduce survival of entrained organisms. Typically, biocide applications are intermittent and of short duration, and represent a negligible influence on overall entrainment survival at a power station. However, if a particular power station is permitted for frequent biocide use to control fouling, entrainment survival rates will be low. Mechanical effects such as abrasion, pressure changes, and shear forces were once thought to be the primary factor causing entrainment mortality. However, many later studies—including measurement of survival with circulating-water pumps running but no thermal addition—have shown that mechanical effects, although present, are not a major influence on entrainment survival. The one factor that has been most consistently reported as a major influence on entrainment survival rates is discharge temperature.

As would be expected, the influence of discharge temperature varies with species, but in all cases survival decreases as discharge temperature increases. When the entrainment survival data were segregated by discharge temperature range and plotted, the inverse relationship was clear. When discharge temperatures were less than 30°C, survival of striped bass and white perch young was between 60 and 70 percent. Between 30 and 33°C, striped bass survival remained at about 70 percent, but survival of white perch had decreased to below 50 percent. When discharge temperatures exceeded 33°C, survival of both species decreased to about 30 percent. Herring and anchovy exhibited a similar pattern, but started with lower survival at discharge temperatures less than 30°C, and ended with lower survival (near zero) at discharge temperatures greater than 33°C. Mysid shrimp had high survival rates (90 percent) at less than 30°C discharge temperature, but survival decreased to 30 percent and lower at discharge temperatures greater than 30°C. This field-based relationship of survival with discharge temperature has been corroborated by laboratory studies of thermal tolerance of young fish. Both indicate that there is a threshold between 30 and 33°C above which entrainment survival markedly decreases.

To illustrate the appropriate use of entrainment survival data, an entrainment survival model was described that integrates exposure, mortality, and involvement. Exposure (primarily temperature) and mortality (or survival) have been discussed above. Involvement refers to the seasonal and day-night occurrence and abundance of entrainable organisms. Entrainment survival data is one important component of this model, which must be integrated with other components to measure or model the population impacts of entrainment. Several examples were cited where investigators used this approach to estimate population impacts of entrainment. In these studies, it was recognized that entrainment survival can be substantial, and that survival rates must be incorporated into overall impact assessment, rather than assume 100 percent loss of entrained organisms.

The entrainment survival data can also be of value as a screening tool for addressing proposed new power plants or existing plants that have not had entrainment evaluations. When data from environmental surveys and plant-operating specifications are evaluated in light of the factors that affect entrainment survival, a qualitative estimate of entrainment effects is possible. There is the potential to move from a qualitative screening tool to a quantitative predictive model by applying appropriate statistical treatments to biological data and plant-operating specifications for proposed and existing plants.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1
INTRODUCTION

Section 316(b) of the Clean Water Act requires that the "location, design, construction, and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impact." Under an October 1995 consent decree, the U.S. Environmental Protection Agency (EPA) was directed to develop proposed regulations implementing Section 316(b) and to take final action on those regulations in accordance with a schedule established by the Court. All power plants and industrial facilities that withdraw cooling water from U.S. surface waters and have point source discharges will be subject to the new rule. In July 2000, the EPA published the proposed draft rule for new facilities. A separate draft rule for existing facilities currently is scheduled to be published in July 2001.

EPRI has initiated a number of projects to develop information that may be useful to EPA in its deliberations on the new rule for Section 316(b). This report presents the results of one of those projects: a distillation and summary of existing data on the survival of aquatic organisms entrained through power plant cooling systems.

In the context of Section 316(b), entrainment refers to the incorporation of small animals such as fish eggs and larvae and macroinvertebrates in the cooling water that is pulled into a power plant or other industrial facility. These floating or weakly-swimming organisms are carried with the cooling water into the intake, through the circulating-water pumps, then through the condensers, and ultimately, in once-through cooling systems, are discharged back to the receiving water body in heated effluent. The effect of this passage on the individual animals and their populations has been the subject of much research and debate. As discussed in the next section, much conjecture and some limited research in the 1960s and very early 1970s appeared to support the conclusion that virtually all entrained organisms were killed. Later studies, with more advanced sampling gear, demonstrated that a significant proportion of entrained animals survived. The key studies are reviewed in this report.

The objectives of this report are:

- Review, organize, and summarize nearly 30 years of entrainment survival data collected at steam-electric power plants; and
- Identify common factors affecting, or associated with, the entrainment survival phenomenon.

2
BACKGROUND

During the late 1960s and early 1970s, when concern about the possible impacts of cooling water intake structure (CWIS) entrainment began to heighten, the prevailing assumption was that virtually all entrained organisms were killed. In large part, this assumption was based on unsupported conjecture, as reviewed by EA (1979a), which then was perpetuated by secondary references (e.g., Marcy et al. 1978). Some early research (Marcy 1971, 1973) reported 100 percent mortality of entrained larval fish. Consequently, the assumption of 100 percent mortality was widely accepted. Jinks et al. (1981) acknowledged that, lacking hard data, the obvious intuitive conclusion reached in those early days was that "…most, if not all, of these apparently fragile organisms must certainly be killed." As a result of this assumption, most entrainment studies and resulting 316(b) demonstrations did not attempt to evaluate survival, and the assumption of 100 percent mortality was common. Attempts at modeling population impacts of entrainment typically included the assumption of 100 percent mortality, e.g., Hess et al. (1975) for winter flounder in Long Island Sound and Spigarelli et al. (1981) for alewife, rainbow smelt, and yellow perch in Lake Michigan. As this report will show, the opinion of 100 percent entrainment mortality began to change as more and more research began to document considerable survival of entrained organisms.

Muessig et al. (1988) reviewed the entrainment survival research from the Hudson River in the 1970s and included case history information for the Indian Point Generating Station. According to these authors, once it was known that some species and life stages had considerable entrainment survival probability, research focused on reducing sampling variability and bias. In particular, increasing sample sizes and/or the proportion of animals surviving intake sampling was important, as well as equalizing sampling stress between intake and discharge locations. The solution to these problems came with the evolution of the larva table. This is essentially a flume modified for the collection of planktonic organisms, developed by McGroddy and Wyman (1977) (Figure 2-1). Samples are introduced to the flume in a reduced-velocity environment that permits relatively gentle handling and collection. Originally, samples were pumped into the front of the table (pump/larva table, Figure 2-1). Subsequent, sequential improvements included use of recessed impeller pumps, moving the pump to the rear of the table so organisms did not have to pass through the pump, and removing the pump altogether. Muessig et al. (1988) reported marked increases in survival of striped bass larvae at the Indian Point Station as collection gear transitioned from *in situ* plankton nets to pump/larva tables to rear-draw or pumpless flumes.

Ultimately, due to extensive research at Hudson River power stations, the "preconceived ideas" referenced by Muessig et al. (1988) regarding 100 percent mortality began to dissipate. Englert and Boreman (1988), in discussing the historical evolution of Hudson River entrainment impact assessments produced by government and utility-consulting biologists, indicated that government biologist estimates of conditional entrainment mortality were initially about eight times higher than those of the utility-consulting biologists. Ultimately, the resource agency estimates of conditional entrainment mortality dropped to nearly the level of the utility scientists, a principal reason being the resource agency's "acceptance of estimates of through-plant mortality obtained from larva table data collected at the power plants." These authors further noted that "by reducing sampling mortality, the larva table demonstrated that a considerable percentage of the entrained organisms survived passage through the plant."

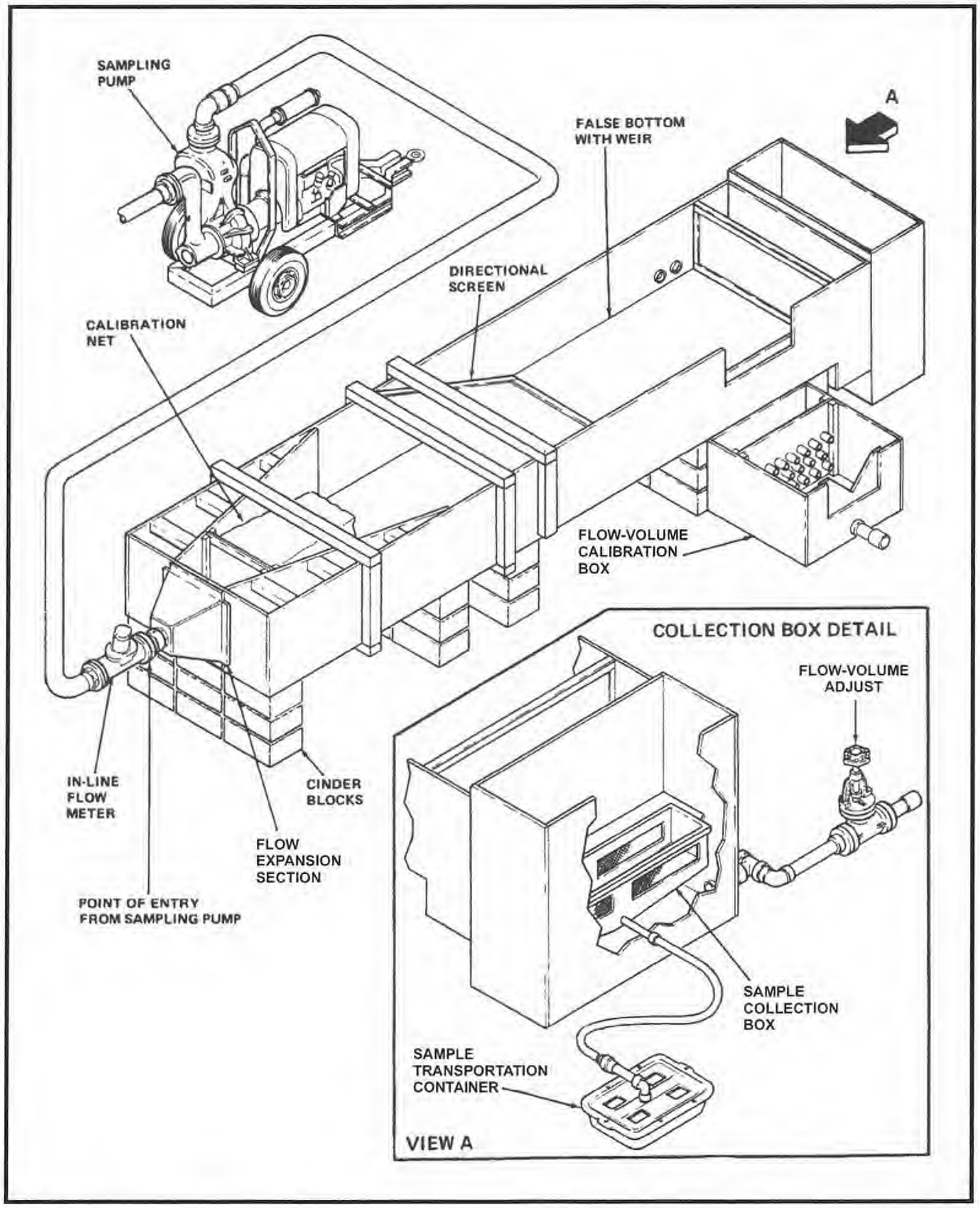

Figure 2-1
Design of the Larva Collection Table (from Mayhew et al. 2000).

As a result of legal action in the early 1990s, the U.S. EPA entered into a consent decree with the Hudson Riverkeeper and a coalition of environmental groups and agreed to undertake a rulemaking to implement Section 316(b). As the proposed rule for new sources is under review, and the proposed rule for existing sources is in preparation, EPRI intends to submit to the U.S. EPA updated information on a variety of pertinent subjects related to the rulemaking, including entrainment survival. The purpose of this report on entrainment survival is to ensure that the "hard-won knowledge of the past is not lost or ignored" by a new generation of regulators, and to suggest that the impact assessment process should begin by considering the "number of organisms that are actually killed by entrainment and not the total number entrained" (Mayhew et al. 2000).

Thirty-six entrainment survival studies conducted at 21 power stations are summarized in this report. As far as can be determined, this collection of entrainment survival studies represents most, and perhaps all, of the studies performed to assess entrainment survival of fish eggs/larvae and macroinvertebrates. As indicated in Figure 2-2, most of the studies were done during the period 1975 to 1980. This prominent grouping of studies was undoubtedly a result of Section 316(b) of the Federal Water Pollution Control Act (Clean Water Act) Amendments of 1972 and the settlement of the Hudson River power plant case in late 1980. Most of the entrainment survival studies were done in the northeastern U.S., primarily in the Hudson River (Figure 2-3). Smaller clusters of studies are evident in large, Midwestern rivers and in the San Francisco Bay/Delta area.

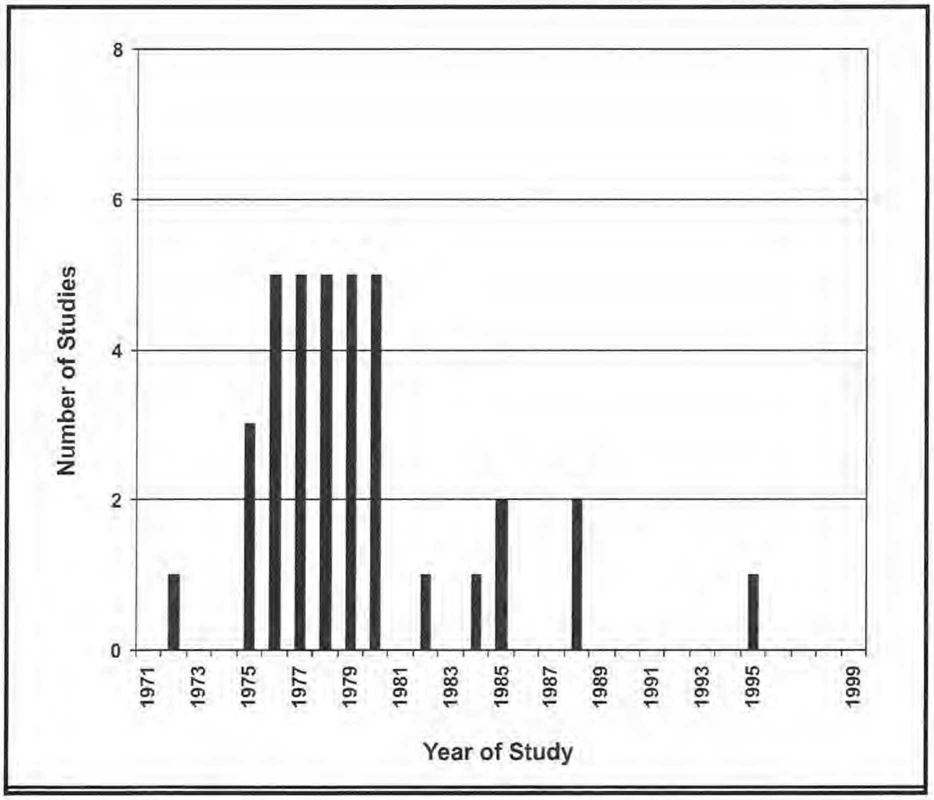

Figure 2-2
Chronological Distribution of Entrainment Survival Studies.

Since the late 1970s, several authors published reports that reviewed and synthesized information on entrainment. Some were general reviews of the effects of power plants on the environment, including entrainment. Examples include the extensive work of Langford (1983) who described the interaction of power plants and the environment from both a European and U.S. perspective. Also, Hocutt et al. (1980) evaluated the effects of power plants on the behavior of fish and shellfish. Schubel and Marcy (1978) published a detailed review of entrainment data, including survival, which had accrued over the first half of the 1970s. Jinks et al. (1981) described techniques for estimating entrainment survival, including laboratory simulation and thermal tolerance testing and *in situ* sampling of power plant discharges. These authors included a compilation of entrainment survival data from the 1970s. In a more focused review, Englert and Boreman (1988) detailed the evolution of entrainment impact assessments, including survival estimates, conducted on the Hudson River in the 1970s. In a recent review, Mayhew et al. (2000) reevaluated historical entrainment survival data from a limited number of estuarine power plants. The current review encompasses all historical and contemporary information on entrainment survival and represents the most comprehensive data available.

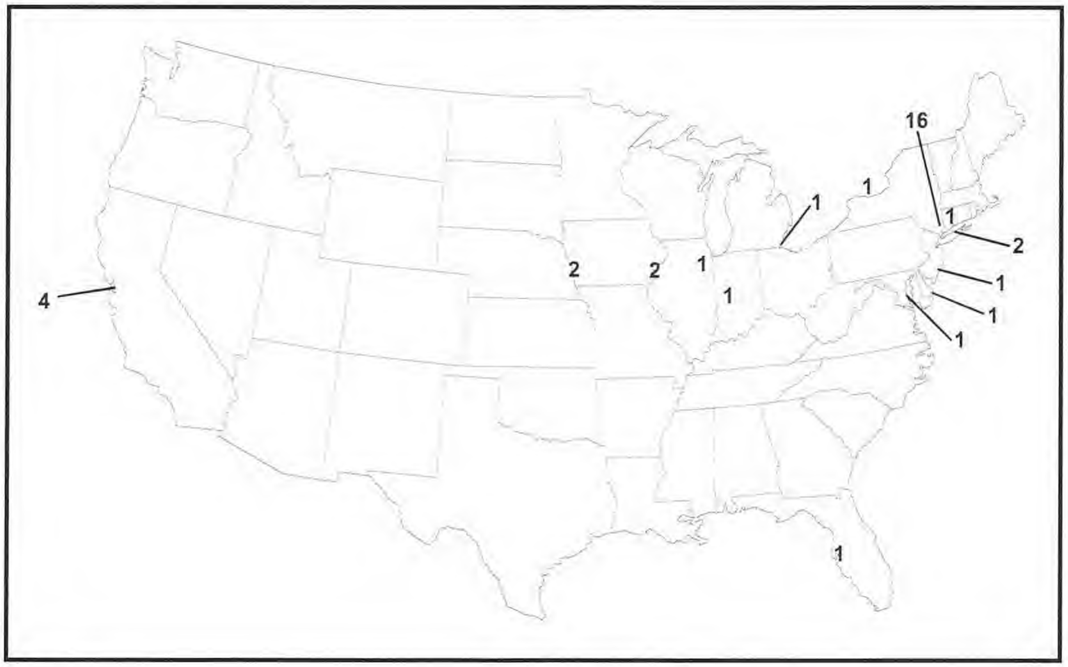

Figure 2-3
Location of Entrainment Survival Studies.

3
ENTRAINMENT SURVIVAL SUMMARIES

3.1 Information Sources

The primary source of information on entrainment survival was unpublished reports prepared for utilities. The majority of those used to prepare this report were accessed from the library of EA Engineering, Science, and Technology, Inc. (formerly Ecological Analysts, Inc.). To ensure that all pertinent reports were obtained and reviewed, EPRI resources, including library materials and internal databases were also utilized.

The search for entrainment survival information was augmented with a utility questionnaire circulated by EPRI. This questionnaire was developed jointly by Alden Research Laboratory, Inc., EA Engineering, Science, and Technology, Inc., and EPRI, and was circulated to EPRI utility members via E-mail. The questionnaire solicited several kinds of information, including the availability of entrainment survival reports.

For several of the entrainment survival studies summarized herein, the information sources were peer review journals or published workshop proceedings (e.g., Marcy 1973, Hadderingh 1978, Jensen 1978).

3.2 Approach

3.2.1 Entrainment Survival Test Methods

This section contains information that may be helpful to the reader in interpreting the various study summaries, and the syntheses provided in this report.

A "typical" entrainment survival study involved collecting samples from both the intake and discharge, ideally simultaneously, or with the discharge sample delayed by the amount of time it takes water to transit from the intake to the discharge sampling point. The purpose of the intake samples was to serve as a control to account for organisms already dead or those killed by the sampling process. Some studies, particularly earlier ones, used plankton nets placed in intake and discharge flows to collect the samples. Many later studies used the larva table, as described in Section 2. Upon collection, the samples were immediately sorted, and live and stunned organisms were separated from dead organisms. This information could then be used to calculate initial entrainment survival, which was the endpoint for some of the studies. That is, survival immediately after plant passage was used to estimate entrainment impacts.

To investigate the possibility of delayed mortality, many studies involved extended observations of organisms initially collected alive. These organisms were held in a laboratory setting and periodically observed for up to 96 hours. The data from these extended observations were then either examined separately, or incorporated with initial survival to calculate total entrainment survival. Some investigators tested intake and discharge extended (=latent) survival statistically, and if there was no difference, initial survival was used as an estimate of total entrainment survival.

Table 3-1 contains several examples of entrainment survival calculations encountered in the review of available studies. The first example is a simple calculation of initial survival, i.e., the survival evident immediately after plant passage. The proportions of larvae alive in both intake and discharge samples (P_I and P_D) are determined by dividing the live counts by the total number collected (live + dead). Entrainment survival is calculated by dividing the proportion live in the discharge (P_D) by the proportion live in the intake (P_I). The intake sample serves as an experimental control. It is assumed that the number of dead larvae in the intake sample—due either to natural causes, or sampling-gear damage, or both—is the same in the discharge sample. The entrainment survival calculation "corrects" for these "already dead" larvae, and assures that any mortality reflected in the estimate is due solely to the effects of entrainment passage.

The second example in Table 3-1 involves both initial and extended survival measurements of a relatively large number of macroinvertebrates. Initial survival is calculated just as in Example 1. A portion of the initially alive animals were stocked in a laboratory setting, and the number live and dead recorded at intervals up to 24 hours. At each extended observation interval, entrainment survival is calculated in a similar manner to initial survival. However, to estimate P_I and P_D, rather than dividing the number live by the total number collected (as with initial survival), the number alive at each extended observation interval is divided by the total number of live animals originally stocked in the laboratory. In this case, neither initial survival nor extended survival alone reflects the entire entrainment experience. Therefore, the conditional probability of surviving both initially and during the extended observation period is calculated by multiplying the initial entrainment survival proportion by the 24-hr entrainment survival proportion to obtain the estimate of total entrainment survival.

The third example in Table 3-1 also involves both initial and extended survival, but differs from Example 2 in that every initially living larva was accounted for and monitored through the extended observation period. Entrainment survival is calculated by dividing the number alive initially and at each extended observation interval by the total number originally collected. Because the number alive at each interval is divided by the total number originally collected (in both intake and discharge), initial survival is automatically integrated with extended survival. Thus, the entrainment survival value for the last extended observation (24-hr) is the estimate of total entrainment survival.

Table 3-1
Example Entrainment Survival Calculations

Example 1: Fish Larvae, Initial Survival

Sample Data:

Intake			Discharge			Entrainment Survival
No. Live	No. Dead	P_I	No. Live	No. Dead	P_D	(P_D/P_I)*100
400	100	0.80	325	175	0.65	81.3

Proportion live in intake sample (P_I)=number live/number live + dead= 0.80

Proportion live in discharge sample (P_D)=number live/number live + dead= 0.65

Entrainment (initial) survival is calculated as:

$(P_D/P_I)*100 = (0.65/0.80)*100 = 81.3\%$

This calculation corrects for any dead larvae in intake samples due to natural causes or from sampling damage.

Example 2: Macroinvertebrates, Extended Survival

Sample Data:

	Intake			Discharge			Entrainment Survival
	No. Live	No. Dead	P_I	No. Live	No. Dead	P_D	(P_D/P_I)*100
Initial	800	200	0.80	650	350	0.65	81.3

After the initial live-dead sorts are completed, subsets of live animals from both intake and discharge are selected for extended survival observations in the laboratory, with the following results:

0-hr	400	0	1.00	400	0	1.00	—
6-hr	380	20	0.95	368	32	0.92	96.8
12-hr	361	39	0.90	338	62	0.85	94.4
18-hr	343	57	0.86	297	103	0.74	86.0
24-hr	325	75	0.81	273	173	0.68	84.0

To integrate, or combine, initial survival with extended survival, the proportions are multiplied to calculate total entrainment survival:

0.813 (initial) X 0.84 (24-hr extended) = 0.683, or 68.3 % total entrainment survival

Example 3: Fish Larvae, Extended Survival

Sample Data:

	Intake			Discharge			Entrainment Survival
	No.Live	No. Dead	P_I	No. Live	No. Dead	P_D	(P_D/P_I)*100
Initial	400	100	0.80	325	175	0.65	81.3
6-hr	380	120	0.76	302	182	0.60	78.9
12-hr	361	139	0.72	217	283	0.43	59.7
18-hr	343	157	0.69	200	300	0.40	58.0
24-hr	326	174	0.65	175	325	0.35	53.8

In this example, every live larva from the intake and discharge was accounted for and tracked through the extended observation period. Consequently, total entrainment survival is not calculated as in Example 2. Rather, total entrainment survival is equal to the survival calculated for the last extended observation period (24-hr), or 53.8 %. If needed for comparative purposes, extended survival can be isolated by dividing the 24-hr by the initial survival (53.8/81.3)=0.662, or 66.2 %.

Example 4: Fish Eggs, Extended Survival

Sample Data:

	Intake	P_I	Discharge	P_D	Entrainment Survival (P_D/P_I)*100
Number eggs collected:	600		600		
Number eggs hatched by 96 hrs:	280	0.47	190	0.32	68.1

In this example, the initial viability (live/dead) of the eggs could not be determined. Consequently, the live-dead ratios at the intake and discharge were assumed to be the same. Calculation of total entrainment survival is the same as in Examples 1 and 3.

The fourth example in Table 3-1 involves fish eggs that could not be assigned as live or dead when initially collected. Survival was equated with hatching success, and the number that successfully hatched within the 96-hr extended observation period was divided by the total number originally collected to calculate P_I and P_D. Similar to Example 3, the entrainment survival calculation incorporates both initial and extended survival, and thus is an estimate of total entrainment survival. This procedure requires the assumption that the numbers of eggs already dead or killed by sampling are identical between intake and discharge.

3.2.2 Preparation of Summary Tables

Each available entrainment survival study report was reviewed and summarized. Many of the reports were voluminous, and heavy with detail, assumptions, and qualifications. The approach taken in this report was to reduce the information to the minimum essential elements to convey the essence of the study. One-page summaries were produced for each study. Each contains pertinent information on the power plant and operating characteristics, the receiving water body, sampling gear, entrainment survival data, pertinent qualifying remarks, and a complete citation for the study report. Examples of these one page summaries are provided in Tables 3-2 through 3-4.

These examples illustrate the range of information types available in study reports. Table 3-2 summarizes survival testing of striped bass larvae at Pittsburg Power Plant in California. In addition to data on the power plant, receiving-water body, and sampling gear, a matrix of the survival data is presented. In this case, and whenever the data were available, survival data were presented by discharge temperature ranges. As discussed later in this report, discharge temperature has a major influence on entrainment survival, so the temperature data were presented whenever readily available. The last column is the percent initial survival, that is, the proportion of striped bass larvae determined to be alive immediately after having passed through the cooling system. The "remarks" section contains observations on the data, either evident from this summary process, or provided by the authors.

Table 3-3 presents a simpler summary for an entrainment survival study at the Protrero Power Plant. This study was short-term, and focused on a single species. The survival results information was easily summarized in a brief text section. In this study, both initial and extended survival were measured, and used to calculate total entrainment survival.

A more extensive survival study is illustrated in Table 3-4 for the Bowline Point Generating Station on the Hudson River. In this study, the larvae of several species of fish were evaluated, as well as two types of macroinvertebrates. Both initial and extended survival were measured in this study. For this summary, initial and extended survival data were used to calculate total entrainment survival, as described in Section 3.2.1.

Summary tables for all studies reviewed are contained in Appendix A, Tables A-1 through A-36.

Table 3-2
Example Entrainment Survival Study Summary: Pittsburg Power Plant

ENTRAINMENT SURVIVAL STUDY SUMMARY SHEET

Power Station: Pittsburg Power Plant

Owner: Pacific Gas and Electric Company

Plant Capacity (MWe): 1,320

Report Reference: Stevens, D. and B. Finlayson. 1978. Mortality of Young Striped Bass Entrained at two Power Plants in the Sacramento-San Joaquin Delta, California, pp. 57-69 in: *Fourth National Workshop on Entrainment and Impingement* (L. Jensen, ed.). EA Communications, a Division of Ecological Analysts, Inc., Melville, NY.

Water Body: Suisun Bay, San Joaquin Delta, California

Sampling frequency/dates: Weekly during 28 April-10 July 1976

Cooling Water Flow (M^3/min.): 2,712

Sample Location(s): Condenser cooling-water intake and discharge

Sampling Gear: 0.75-m dia. conical plankton nets with 505-[mesh netting, fished from a boat at mid-depth

Type of Survival Test(s): Initial survival, striped bass larvae

Results Summary:

Period	Mean Length (mm)	Discharge Temperature (°C)	Number Tested (discharge)	Initial Survival (%)
25 May-4 June	12.8	27-29	36	20.5
25 May-4 June	12.8	30-32	29	53.8
5 June-8 July	21.6	27-29	47	93.5
5 June-8 July	21.6	30-32	45	90.3
5 June-8 July	21.6	33-35	55	33.3
5 June-8 July	21.6	36-37	54	11.8

Note: Survival calculated from author's data by dividing initial proportion alive in discharge samples by initial proportion alive in intake samples.

Remarks: Based on the 5 June-8 July data, survival clearly decreased with increasing discharge temperature. The generally lower survival during 25 May-4 June may have been related to the smaller size of the larvae during that period.

Table 3-3
Example Entrainment Survival Study Summary: Protrero Power Plant

ENTRAINMENT SURVIVAL STUDY SUMMARY SHEET

Power Station:	Protrero Power Plant
Owner:	Pacific Gas and Electric Company
Plant Capacity (MWe):	332
Report Reference:	Ecological Analysts, Inc. 1980. *Protrero Power Plant Cooling Water Intake Structures 316(b) Demonstration.* Prepared for [owner].
Water Body:	San Francisco Bay
Sampling frequency/dates:	Daily during 15–, 22–25, and 27 January 1979
Cooling Water Flow (M^3/min.):	1,008
Sample Location(s):	Condenser cooling-water intake and discharge (Unit 3)
Sampling Gear:	Recessed-impeller pump/larva table
Type of Survival Test(s):	Initial and latent (extended) 96-hr. tests
Results Summary:	Over a 10-day period, 546 Pacific herring larvae were collected at the intake and 716 at the discharge over a consistent 18-19°C discharge temperature range. Based on initial survival of 73.7%, and 96-hr extended survival of 94.9%, total entrainment survival was calculated as 70 percent.
Remarks:	Latent survival did not differ significantly between the intake and discharge, or among several length classes evaluated.

Table 3-4
Example Entrainment Survival Study Summary: Bowline Point Generating Station

ENTRAINMENT SURVIVAL STUDY SUMMARY SHEET

Power Station: Bowline Point Generating Station

Owner: Orange and Rockland Utilities, Inc.

Plant Capacity (MWe): 620

Report Reference: Ecological Analysts, Inc. 1979. *Bowline Point Generating Station Entrainment Abundance and Survival Studies: 1978 Annual Report.* Prepared for [owner].

Water Body: Hudson River

Sampling frequency/dates: 3 days per week during 13 March–6 October 1978

Cooling Water Flow (M^3/min.): 1,422

Sample Location(s): Condenser cooling-water intake and discharge

Sampling Gear: Pump/larva table

Type of Survival Test(s): Initial and latent (extended) and 96-hr. tests

Results Summary:

		No. Tested	Survival (%)		
Species	Life Stage	(discharge)	Initial	Extended	Total
Striped bass	YSL	82	100.0	84.1	84.1
Striped bass	PYSL	392	100.0	100.0	100.0
Striped bass	PYSL	24	100.0	100.0	100.0
White perch	PYSL	265	50.3	60.8	30.6
Atlantic tomcod	PYSL	54	100.0	100.0	100.0
Gammarus sp.	—	4,563	100.0	92.3	92.3
Neomysis americana	—	2,185	100.0	70.0	70.0

Note: YSL=yolk sac larvae; PYSL= post-yolk sac larvae

Remarks: Data are from three different discharges. Data from all discharge temperatures combined. Some of the white perch mortality was related to mechanical effects, i.e., the number of circulating-water pumps operating and whether throttled or full-flow modes were used.

3.3 Entrainment Survival Results

The data in Appendix A are from 36 reports covering 21 power plants. Approximately 50 different species and taxa groups are represented in the entrainment survival data. Over half of the study reports are for Hudson River power plants, and consequently, striped bass, white perch, clupeids (herring), and estuarine macroinvertebrates are most prominently represented.

The key data from the Appendix A summaries were compiled in Table 3-5. The survival data are quite variable, as would be expected, because of different species, power plants (i.e. discharge temperatures, biocide use), habitats, temperature regimes, and sampling techniques. Nonetheless, some patterns can be seen in Table 3-5, such as decreasing survival with increasing discharge temperatures (discussed in next section), and generally lower survival of clupeids (i.e., herring) and anchovies. To further synthesize the entrainment survival data, Figure 3-1 was prepared for the more common species or taxa groups in the database. The variability in the combined data is obvious, but nonetheless, certain observations are apparent. Mean survival values from most species and taxa groups exceed 50 percent. Several taxa, i.e., freshwater (drifting) macroinvertebrates, the freshwater catostomids (suckers), and the estuarine/marine spot (croaker family) had means exceeding 75 percent entrainment survival. Estuarine macroinvertebrates also exhibited high entrainment survival, with a mean of 70 percent. Striped bass, white perch, and Atlantic tomcod, all important in the Hudson River, exceeded 50 percent mean entrainment survival. The clupeids and (bay) anchovy were notably low, with mean survival values around 25 percent. The latter species are relatively fragile, as evidenced by reported difficulties in sampling and handling intake samples at a number of power plants.

The fundamentally important conclusion that can be drawn from Table 3-5 and Figure 3-1 is that assuming 100 percent mortality or loss of entrained organisms cannot be supported by available data. Survival is often quite high, and assuming otherwise would lead to erroneous assessment of entrainment impacts.

One question that must be addressed concerns why survival may be high for a given species at one time, yet low at another time. While the studies reviewed show that many species are capable of high entrainment survival, the error bars in Figure 3-1 indicate that high survival is not always achieved. Factors affecting survival are discussed in Section 4.

Table 3-5
Compilation of Survival Data from Appendix A Summaries

Species/ Taxa	Life Stage	Plant	Year	Summary Table	Discharge Temperature (°C)	# Tested	Type Survival	% Survival
striped bass	larvae	Pittsburg	1976	A-26	27–29	36	Initial	20.5
striped bass	larvae	Pittsburg	1976	A-26	30–32	29	Initial	53.8
striped bass	larvae	Pittsburg	1976	A-26	27–29	47	Initial	93.5
striped bass	larvae	Pittsburg	1976	A-26	30–32	45	Initial	90.3
striped bass	larvae	Pittsburg	1976	A-26	33–35	55	Initial	33.3
striped bass	larvae	Pittsburg	1976	A-26	36–37	54	Initial	11.8
striped bass	larvae	Pittsburg	1978/79	A-27	<30	—	Total	60.8
striped bass	larvae	Pittsburg	1978/79	A-27	30.0–31.9	—	Total	42.4
striped bass	larvae	Pittsburg	1978/79	A-27	32.0–33.9	—	Total	19.1
striped bass	PYSL	Bowline Pt.	1975	A-3	—	111	Total	70.4
striped bass	PYSL	Bowline Pt.	1977	A-4	20.0–29.0	—	Initial	97.0
striped bass	PYSL	Bowline Pt.	1977	A-4	30.0–32.9	—	Initial	100.0
striped bass	PYSL	Bowline Pt.	1977	A-4	33.0–35.9	—	Initial	41.0
striped bass	juvenile	Bowline Pt.	1977	A-4	20.0–29.0	—	Initial	90.0
striped bass	juvenile	Bowline Pt.	1977	A-4	30.0–32.9	—	Initial	90.0
striped bass	juvenile	Bowline Pt.	1977	A-4	33.0–35.9	—	Initial	43.0
striped bass	YSL	Bowline Pt.	1978	A-5	—	82	Total	84.1
striped bass	PYSL	Bowline Pt.	1978	A-5	—	392	Total	100.0
striped bass	PYSL	Bowline Pt.	1978	A-5	—	24	Total	100.0
striped bass	PYSL	Bowline Pt.	1979	A-6	—	104	Total	41.9
striped bass	PYSL	Bowline Pt.	1979	A-6	—	51	Total	23.6
striped bass	PYSL	Roseton	1975	A-32	—	172	Total	37.5
striped bass	PYSL	Roseton	1976	A-33	24.0–30.5	23	Initial	58.0
striped bass	PYSL	Roseton	1976	A-33	30.6–37.0	57	Initial	18.9
striped bass	juvenile	Roseton	1976	A-33	30.6–37.0	10	Initial	80.0
striped bass	PYSL	Roseton	1977	A-34	24.0–29.9	400	Initial	58.0
striped bass	PYSL	Roseton	1977	A-34	30.0–32.9	325	Initial	32.0
striped bass	PYSL	Roseton	1977	A-34	33.0–36.0	40	Initial	6.0
striped bass	juvenile	Roseton	1977	A-34	24.0–29.0	12	Initial	100.0
striped bass	PYSL	Roseton	1978	A-35	—	211	Total	46.3
striped bass	YSL	Roseton	1980	A-36	—	—	Initial	87.8
striped bass	PYSL	Roseton	1980	A-36	—	—	Initial	88.2
striped bass	juvenile	Roseton	1980	A-36	—	—	Total	69.0
striped bass	larvae	Contra Costa	1976	A-11	19.0–29.0	73	Initial	95.0
striped bass	larvae	Contra Costa	1976	A-11	30.0–32.0	92	Initial	57.5
striped bass	larvae	Contra Costa	1976	A-11	33.0–34.0	12	Initial	0.0
striped bass	larvae	Contra Costa	1976	A-11	24.0–29.0	6	Initial	31.5
striped bass	larvae	Contra Costa	1976	A-11	30.0–32.0	95	Initial	88.9
striped bass	larvae	Contra Costa	1976	A-11	33.0–35.0	37	Initial	14.8
striped bass	larvae	Contra Costa	1976	A-11	36.0–38.0	14	Initial	25.9
striped bass	PYSL	Danskammer Pt.	1975	A-12	—	61	Initial	95.1
striped bass	YSL	Indian Pt.	1977	A-16	26.0–29.0	18	Initial	63.0
striped bass	PYSL	Indian Pt.	1977	A-16	26.0–29.0	221	Initial	85.0

Species/ Taxa	Life Stage	Plant	Year	Summary Table	Discharge Temperature (°C)	# Tested	Type Survival	% Survival
striped bass	PYSL	Indian Pt.	1977	A-16	30.0–32.9	19	Initial	87.0
striped bass	PYSL	Indian Pt.	1978	A-17	—	36	Total	0.0
striped bass	YSL	Indian Pt.	1978	A-17	—	39	Total	0.0
striped bass	PYSL	Indian Pt.	1978	A-17	—	46	Total	0.0
striped bass	PYSL	Indian Pt.	1978	A-17	—	237	Total	63.6
striped bass	PYSL	Indian Pt.	1978	A-17	—	232	Total	81.8
striped bass	eggs	Indian Pt.	1979	A-18	24.0–28.0	—	Total	73.6
striped bass	YSL	Indian Pt.	1979	A-18	<30.0	—	Initial	58.6
striped bass	YSL	Indian Pt.	1979	A-18	30.0–32.9	—	Initial	75.0
striped bass	PYSL	Indian Pt.	1979	A-18	<30.0	—	Initial	63.0
striped bass	PYSL	Indian Pt.	1979	A-18	30.0–32.9	—	Initial	70.1
striped bass	eggs	Indian Pt.	1980	A-19	24.0–31.0	147	Total	57.5
striped bass	YSL	Indian Pt.	1980	A-19	<29.0	21	Initial	66.7
striped bass	YSL	Indian Pt.	1980	A-19	30.0–32.0	16	Initial	56.2
striped bass	PYSL	Indian Pt.	1980	A-19	<29.0	31	Initial	74.2
striped bass	PYSL	Indian Pt.	1980	A-19	30.0–32.0	16	Initial	81.2
striped bass	PYSL	Indian Pt.	1980	A-19	>33.0	160	Initial	55.0
striped bass	YSL	Indian Pt.	1988	A-21	—	312	Total	60.0
striped bass	PYSL	Indian Pt.	1988	A-21	—	2,398	Total	79.0
white perch	PYSL	Bowline Pt.	1975	A-3	—	168	Total	100.0
white perch	PYSL	Bowline Pt.	1977	A-4	20.0–29.0	—	Initial	62.0
white perch	PYSL	Bowline Pt.	1977	A-4	30.0–32.9	—	Initial	16.0
white perch	PYSL	Bowline Pt.	1977	A-4	33.0–35.9	—	Initial	48.0
white perch	PYSL	Bowline Pt.	1978	A-5	—	265	Total	30.6
white perch	PYSL	Bowline Pt.	1979	A-6	—	112	Total	31.5
white perch	PYSL	Roseton	1975	A-32	—	97	Initial	40.8
white perch	PYSL	Roseton	1976	A-33	24.0–30.5	57	Initial	79.2
white perch	PYSL	Roseton	1976	A-33	30.6–37.0	292	Initial	11.3
white perch	juvenile	Roseton	1976	A-33	30.6–37.0	25	Initial	59.6
white perch	PYSL	Roseton	1977	A-34	24.0–29.0	155	Initial	52.0
white perch	PYSL	Roseton	1977	A-34	30.0–32.9	78	Initial	45.0
white perch	PYSL	Roseton	1977	A-34	33.0–36.0	33	Initial	0.0
white perch	PYSL	Roseton	1978	A-35	—	459	Total	55.8
white perch	PYSL	Roseton	1978	A-35	—	17	Total	96.0
white perch	juvenile	Roseton	1978	A-35	—	17	Total	55.1
white perch	PYSL	Roseton	1980	A-36	—	—	Initial	67.3
white perch	juvenile	Roseton	1980	A-36	—	—	Initial	100.0
white perch	PYSL	Danskammer Pt.	1975	A-12	—	55	Initial	100.0
white perch	PYSL	Indian Pt.	1977	A-16	26.0–29.9	32	Initial	73.0
white perch	PYSL	Indian Pt.	1977	A-15	30.0–32.9	12	Initial	89.0
white perch	PYSL	Indian Pt.	1978	A-17	—	35	Total	0.0
white perch	PYSL	Indian Pt.	1978	A-17	—	33	Total	0.0
white perch	PYSL	Indian Pt.	1978	A-17	—	64	Total	58.3
white perch	PYSL	Indian Pt.	1978	A-17	—	64	Total	25.0
white perch	PYSL	Indian Pt.	1979	A-18	<30.0	—	Initial	32.0
white perch	PYSL	Indian Pt.	1979	A-18	30.0–32.9	—	Initial	28.9

Species/ Taxa	Life Stage	Plant	Year	Summary Table	Discharge Temperature (°C)	# Tested	Type Survival	% Survival
white perch	PYSL	Indian Pt.	1980	A-19	<29.0	49	Initial	89.8
white perch	PYSL	Indian Pt.	1980	A-19	>33.0	117	Initial	49.6
white perch	PYSL	Indian Pt.	1988	A-21	—	341	Total	38.0
Morone sp.	PYSL	Bowline Pt.	1975	A-3	—	279	Total	100.0
white bass	postlarvae	Monroe	1982	A-23	—	28	Initial	92.9
clupeids	PYSL	Bowline Pt.	1977	A-4	20.0–29.9	—	Initial	51.0
clupeids	PYSL	Bowline Pt.	1979	A-6	—	52	Initial	57.7
clupeids	PYSL	Bowline Pt.	1979	A-6	—	40	Initial	57.8
clupeids	PYSL	Roseton	1975	A-32	—	833	Initial	40.0
clupeids	juvenile	Roseton	1975	A-32	—	243	Initial	44.8
clupeids	PYSL	Roseton	1976	A-33	24.0–30.5	167	Initial	59.2
clupeids	PYSL	Roseton	1976	A-33	30.6–37.0	478	Initial	10.2
clupeids	juvenile	Roseton	1976	A-33	24.0–37.0	57	Initial	16.2
clupeids	PYSL	Roseton	1977	A-34	24.0–29.9	874	Initial	19.0
clupeids	PYSL	Roseton	1977	A-34	30.0–32.9	389	Initial	11.0
clupeids	PYSL	Roseton	1977	A-34	33.0–36.0	81	Initial	0.0
clupeids	juvenile	Roseton	1977	A-34	24.0–29.9	14	Initial	24.0
clupeids	juvenile	Roseton	1977	A-34	30.0–32.9	22	Initial	0.0
clupeids	juvenile	Roseton	1977	A-34	33.0–36.0	51	Initial	0.0
clupeids	PYSL	Roseton	1978	A-35	—	1,089	Total	0.0
clupeids	PYSL	Roseton	1978	A-35	—	43	Total	0.0
clupeids	PYSL	Roseton	1980	A-36	—	—	Initial	22.7
clupeids	juvenile	Roseton	1980	A-36	—	—	Initial	0.0
clupeids	PYSL	Danskammer Pt.	1975	A-12	—	326	Initial	55.6
clupeids	juvenile	Danskammer Pt.	1975	A-12	—	65	Initial	81.5
clupeids	PYSL	Indian Pt.	1977	A-16	26.0–29.9	27	Initial	40.0
clupeids	PYSL	Indian Pt.	1978	A-17	—	192	Total	0.0
clupeids	PYSL	Indian Pt.	1978	A-17	—	145	Initial	14.3
clupeids	PYSL	Indian Pt.	1978	A-17	—	170	Initial	16.7
clupeids	PYSL	Indian Pt.	1978	A-17	—	92	Initial	16.7
clupeids	PYSL	Indian Pt.	1979	A-18	<30.0	—	Initial	30.5
clupeids	PYSL	Indian Pt.	1979	A-18	30.0–32.9	—	Initial	22.2
clupeids	PYSL	Indian Pt.	1980	A-19	<29.0	13	Initial	61.5
clupeids	PYSL	Indian Pt.	1988	A-21	—	195	Total	22.0
clupeids	larvae	Protrero	1979	A-29	18.0–19.0	716	Total	70.0
clupeids	PYSL	Conn. Yankee	1970–72	A-10	—	230	Initial	29.5
clupeids	PYSL	Conn. Yankee	1970–72	A-10	—	227	Initial	23.9
clupeids	PYSL	Conn. Yankee	1970–72	A-10	28.0–29.0	458	Initial	25.9
clupeids	PYSL	Conn. Yankee	1970–72	A-10	33.5	257	Initial	12.1
clupeids	PYSL	Conn. Yankee	1970–72	A-10	35.0	1,061	Initial	0.0
clupeids	eggs	Ginna	1980	A-15	—	—	Total	16.0
clupeids	prolarvae	Monroe	1982	A-23	—	184	Initial	1.2
clupeids	prolarvae	Monroe	1982	A-23	—	457	Total	15.3
clupeids	postlarvae	Monroe	1982	A-23	—	808	Total	37.9
clupeids	juvenile	Monroe	1982	A-23	—	18	Total	25.0
Atlantic menhaden	larvae/juvenile	Indian River	1975–76	A-22	<25.0	—	Total	96.8

Species/ Taxa	Life Stage	Plant	Year	Summary Table	Discharge Temperature (°C)	# Tested	Type Survival	% Survival
Atlantic menhaden	larvae/juvenile	Indian River	1975–76	A-22	25.0–30.0	—	Total	55.0
Atlantic menhaden	larvae/juvenile	Indian River	1975–76	A-22	30.0–35.0	—	Total	24.0
Atlantic menhaden	larvae/juvenile	Indian River	1975–76	A-22	>35.0	—	Total	0.0
Atlantic tomcod	YSL	Bowline Pt.	1977	A-4	5.5–13.9	—	Initial	84.0
Atlantic tomcod	YSL	Bowline Pt.	1977	A-4	14.0–17.9	—	Initial	85.0
Atlantic tomcod	PYSL	Bowline Pt.	1978	A-5	—	54	Total	100.0
Atlantic tomcod	YSL	Roseton	1977	A-34	7.0–17.0	1,345	Initial	41.0
Atlantic tomcod	YSL	Roseton	1978	A-35	—	13	Total	30.8
Atlantic tomcod	YSL	Roseton	1978	A-35	—	16	Total	66.7
Atlantic tomcod	PYSL	Roseton	1978	A-35	—	64	Total	38.9
Atlantic tomcod	larvae	Indian Pt.	1979	A-18	12.0–15.9	—	Initial	63.8
Atlantic tomcod	larvae	Indian Pt.	1979	A-18	16.0–17.9	—	Initial	51.8
Atlantic tomcod	larvae	Indian Pt.	1979	A-18	18.0–19.9	—	Initial	29.3
Atlantic tomcod	larvae	Indian Pt.	1979	A-18	20.0–21.9	—	Initial	11.4
Atlantic tomcod	PYSL	Indian Pt.	1980	A-19	<26.0	162	Initial	87.7
Atlantic tomcod	juvenile	Indian Pt.	1980	A-18	>27.0	25	Initial	48.0
Cyprinidae	PYSL	Roseton	1975	A-32	—	40	Total	100.0
Cyprinidae	PYSL	Roseton	1976	A-33	24.0–37.0	16	Initial	69.1
Cyprinidae	PYSL	Danskammer Pt.	1975	A-12	—	12	Total	34.8
Cyprinidae	larvae/juvenile	Quad Cities	1978	A-30	30.5–31.2	100	Initial	53.0
Cyprinidae	larvae/juvenile	Quad Cities	1978	A-30	32.5–33.0	34	Initial	62.8
Cyprinidae	larvae/juvenile	Quad Cities	1978	A-30	28.0–34.3	31	Initial	40.6
Cyprinidae	larvae/juvenile	Quad Cities	1978	A-29	38.0–39.0	142	Initial	7.3
Cyprinidae	larvae	Quad Cities	1984	A-31	30.0	60	Initial	97.1
Cyprinidae	larvae	Quad Cities	1984	A-31	33.5	36	Initial	91.9
Cyprinidae	YSL	Cayuga	1979	A-9	26.0–31.9	25	Initial	85.7
Cyprinidae	YSL	Cayuga	1979	A-9	32.0–36.0	70	Initial	25.4
Cyprinidae	PYSL	Cayuga	1979	A-9	26.0–31.9	60	Initial	85.1
Cyprinidae	PYSL	Cayuga	1979	A-9	32.0–36.0	37	Initial	73.5
Cyprinidae	PYSL	Monroe	1982	A-23	—	16	Total	75.0
tessellated darter	PYSL	Roseton	1975	A-32	—	46	Total	100.0
Percidae	YSL	Cayuga	1979	A-9	26.0–31.9	41	Initial	59.4
Percidae	YSL	Cayuga	1979	A-9	32.0–36.0	12	Initial	19.4
Percidae	larvae/juvenile	Bergum	1976	A-2	16.7–24.6	115	Initial	40.0
Percidae	larvae/juvenile	Bergum	1976	A-2	16.7–24.6	78	Initial	65.0
Percidae	larvae/juvenile	Bergum	1976	A-2	16.7–24.6	112	Initial	39.0
Percidae	larvae/juvenile	Bergum	1976	A-2	16.7–24.6	86	Initial	72.0
Percidae	larvae/juvenile	Bergum	1976	A-2	16.7–24.6	258	Initial	82.0
Percidae	larvae/juvenile	Bergum	1976	A-2	16.7–24.6	177	Total	69.0
yellow perch	prolarvae	Monroe	1982	A-23	—	550	Total	2.6
yellow perch	postlarvae	Monroe	1982	A-23	—	42	Initial	2.7
anchovy	PYSL	Danskammer Pt.	1975	A-12	—	11	Initial	27.3
anchovy	PYSL	Indian Pt.	1977	A-16	30.0–32.9	230	Initial	36.0
anchovy	PYSL	Indian Pt.	1977	A-16	33.0–33.9	91	Initial	18.0
anchovy	PYSL	Indian Pt.	1978	A-17	>32.9	222	Initial	0.0
anchovy	PYSL	Indian Pt.	1978	A-17	>32.9	188	Initial	0.0

Species/ Taxa	Life Stage	Plant	Year	Summary Table	Discharge Temperature (°C)	# Tested	Type Survival	% Survival
anchovy	PYSL	Indian Pt.	1979	A-18	<30.0	—	Initial	7.0
anchovy	PYSL	Indian Pt.	1979	A-18	30.0–32.9	—	Initial	2.8
anchovy	PYSL	Indian Pt.	1980	A-19	<29.0	24	Initial	4.0
anchovy	PYSL	Indian Pt.	1980	A-19	>33.0	556	Initial	1.6
anchovy	PYSL	Indian Pt.	1985	A-20	—	274	Initial	24.3
anchovy	PYSL	Indian Pt.	1988	A-21	—	6,929	Initial	25.0
anchovy	eggs	Oyster Creek	1984–85	A-25	<27.0	—	Total	82.5
anchovy	eggs	Oyster Creek	1984–85	A-25	32.0	—	Total	39.8
anchovy	eggs	Oyster Creek	1984–85	A-25	>33.0	—	Total	16.7
anchovy	larvae	Oyster Creek	1984–85	A-25	25.9–27.2	—	Initial	68.0
anchovy	larvae	Oyster Creek	1984–85	A-25	30.2–35.0	—	Initial	67.6
anchovy	larvae	Oyster Creek	1984–85	A-25	>35.0	—	Initial	0.1
anchovy	larvae/juvenile	Calvert Cliffs	1979	A-8	—	726	Total	5.4
anchovy	larvae/juvenile	Calvert Cliffs	1980	A-8	—	970	Total	2.9
anchovy	larvae/juvenile	Indian River	1975–76	A-22	<25.0	—	Total	79.0
anchovy	larvae/juvenile	Indian River	1975–76	A-22	25.0–30.0	—	Total	23.0
anchovy	larvae/juvenile	Indian River	1975–76	A-22	30.0–35.0	—	Total	0.0
anchovy	larvae/juvenile	Indian River	1975–76	A-22	>35.0	—	Total	0.0
freshwater drum	larvae/juvenile	Quad Cities	1978	A-30	30.5–31.2	134	Initial	61.9
freshwater drum	larvae/juvenile	Quad Cities	1978	A-30	32.5–33.0	254	Initial	30.4
freshwater drum	larvae/juvenile	Quad Cities	1978	A-30	28.0–34.0	354	Initial	31.7
freshwater drum	larvae/juvenile	Quad Cities	1978	A-30	38.0–39.0	174	Initial	2.4
freshwater drum	larvae	Quad Cities	1984	A-31	33.5	57	Initial	62.8
freshwater drum	larvae	Fort Calhoun	1977	A-13	29.0–37.0	—	Initial	19.3
freshwater drum	prolarvae	Monroe	1982	A-23	—	33	Initial	100.0
freshwater drum	postlarvae	Monroe	1982	A-23	—	32	Initial	93.8
buffalo sp.	larvae	Quad Cities	1984	A-31	30.0	40	Initial	93.9
Catostomidae	YSL	Cayuga	1979	A-9	26.0–31.9	131	Initial	88.1
Catostomidae	YSL	Cayuga	1979	A-9	32.0–36.0	175	Initial	86.6
Catostomidae	PYSL	Cayuga	1979	A-9	26.0–31.9	213	Initial	91.2
Catostomidae	PYSL	Cayuga	1979	A-9	32.0–36.0	130	Initial	98.4
winter flounder	larvae	Oyster Creek	1984–85	A-25	13.5–14.8	—	Total	83.5
winter flounder	larvae	Oyster Creek	1984–85	A-25	18.3–20.3	—	Total	14.8
winter flounder	PYSL	Port Jefferson	1978	A-28	—	23	Total	64.9
winter flounder	PYSL	Northport	1980	A-24	—	17	Total	9.6
sand lance	PYSL	Port Jefferson	1978	A-28	12.0–18.0	166	Total	24.5
sand lance	PYSL	Port Jefferson	1978	A-28	12.0–18.0	25	Total	85.5
sand lance	PYSL	Northport	1980	A-24	—	782	Total	1.8
sculpin	PYSL	Port Jefferson	1978	A-28	12.0–18.0	17	Total	75.0
American eel	juvenile	Port Jefferson	1978	A-28	12.0–18.0	71	Total	100.0
American eel	juvenile	Port Jefferson	1978	A-28	12.0–18.0	25	Total	100.0
fourbeard rockling	eggs	Port Jefferson	1978	A-28	12.0–18.0	102	Total	100.0
fourbeard rockling	eggs	Port Jefferson	1978	A-28	12.0–18.0	42	Total	73.1
Lepomis sp.	larvae	Braidwood	1988	A-7	—	75	Initial	100.0
naked goby	larvae	Calvert Cliffs	1979	A-8	—	1,112	Total	87.7
naked goby	larvae	Calvert Cliffs	1980	A-8	—	170	Total	98.0

Species/ Taxa	Life Stage	Plant	Year	Summary Table	Discharge Temperature (°C)	# Tested	Type Survival	% Survival
blenny	larvae	Calvert Cliffs	1979	A-8	—	148	Total	36.9
blenny	larvae	Calvert Cliffs	1980	A-8	—	37	Total	79.0
spot	juvenile	Calvert Cliffs	1979	A-8	—	51	Total	100.0
spot	juvenile	Calvert Cliffs	1980	A-8	—	108	Total	100.0
spot	larvae/juvenile	Indian River	1975–76	A-22	<25.0	—	Total	100.0
spot	larvae/juvenile	Indian River	1975–76	A-22	25.0–30.0	—	Total	81.0
spot	larvae/juvenile	Indian River	1975–76	A-22	30.0–35.0	—	Total	53.0
spot	larvae/juvenile	Indian River	1975–76	A-22	>35.0	—	Total	25.0
Atlantic croaker	larvae/juvenile	Indian River	1975–76	A-22	<25.0	—	Total	84.3
Atlantic croaker	larvae/juvenile	Indian River	1975–76	A-22	25.0–30.0	—	Total	34.0
Atlantic croaker	larvae/juvenile	Indian River	1975–76	A-22	30.0–35.0	—	Total	11.0
Atlantic croaker	larvae/juvenile	Indian River	1975–76	A-22	>35.0	—	Total	0.0
rainbow smelt	PYSL	Ginna	1980	A-15	—	—	Initial	0.0
smelt	larvae/juvenile	Bergum	1976	A-2	16.7–24.6	20	Initial	10.0
smelt	larvae/juvenile	Bergum	1976	A-2	16.7–24.6	47	Initial	17.0
smelt	larvae/juvenile	Bergum	1976	A-2	16.7–24.6	87	Initial	17.0
smelt	larvae/juvenile	Bergum	1976	A-2	16.7–24.6	32	Initial	41.0
smelt	larvae/juvenile	Bergum	1976	A-2	16.7–24.6	97	Initial	34.0
smelt	larvae/juvenile	Bergum	1976	A-2	16.7–24.6	39	Total	23.0
northern pipefish	juvenile	Northport	1980	A-24	—	24	Total	51.0
Atlantic silverside	larvae/juvenile	Indian River	1975–76	A-22	<25.0	—	Total	100.0
Atlantic silverside	larvae/juvenile	Indian River	1975–76	A-22	25.0–30.0	—	Total	100.0
Atlantic silverside	larvae/juvenile	Indian River	1975–76	A-22	30.0–35.0	—	Total	48.0
Atlantic silverside	larvae/juvenile	Indian River	1975–76	A-22	>35.0	—	Total	0.0
"fish larvae"	larvae	Anclote	1995	A-1	—	331	Total	27.2
"fish larvae"	larvae	Anclote	1995	A-1	—	143	Total	62.2
"fish juveniles"	juvenile	Anclote	1995	A-1	—	200	Total	64.0
"fish juveniles"*	juvenile	Anclote	1995	A-1	—	144	Total	69.6
Monoculodes edwardsi	—	Bowline Pt.	1975	A-3	—	—	Total	98.6
Gammarus daiberi	—	Bowline Pt.	1975	A-3	—	—	Total	94.8
Gammarus daiberi	—	Roseton	1975	A-32	—	—	Total	87.8
Gammarus daiberi	—	Roseton	1976	A-33	11.3–29.2	202	Total	76.7
Gammarus mucronatus	—	Calvert Cliffs	1978–80	A-8	—	231	Total	70.0
Corophium sp.	—	Calvert Cliffs	1978–80	A-8	—	3,363	Total	65.0
Gammarus sp.	—	Bowline Pt.	1978	A-5	—	4,563	Total	92.3
Gammaridean amphipods	—	Pittsburg	1978–79	A-27	<30.0	—	Total	99.6
Gammaridean amphipods	—	Pittsburg	1978–79	A-27	30.0–31.9	—	Total	100.0
Gammaridean amphipods	—	Pittsburg	1978–79	A-27	32.0–33.9	—	Total	41.3
Gammaridean amphipods	—	Pittsburg	1978–79	A-27	>33.9	—	Total	21.4
amphipods	—	Anclote	1995	A-1	—	2,632	Total	48.5
amphipods	—	Anclote	1995	A-1	—	2,030	Total	72.9
Edotea triloba	—	Bowline Pt.	1975	A-3	—	—	Total	100.0

Species/ Taxa	Life Stage	Plant	Year	Summary Table	Discharge Temperature (°C)	# Tested	Type Survival	% Survival
Neomysis americana	—	Bowline Pt.	1975	A-3	—	—	Initial	100.0
Neomysis americana	—	Bowline Pt.	1978	A-5	—	2,185	Total	70.0
Neomysis americana	—	Calvert Cliffs	1979–80	A-8	—	18,841	Total	79.0
Neomysis americana	—	Indian River	1975–76	A-22	<25.0	—	Total	93.5
Neomysis americana	—	Indian River	1975–76	A-22	25.0–30.0	—	Total	87.0
Neomysis americana	—	Indian River	1975–76	A-22	30.0–35.0	—	Total	37.0
Neomysis americana	—	Indian River	1975–76	A-22	>35.0	—	Total	28.0
Neomysis mercedis	—	Pittsburg	1978–79	A-27	<30.0	—	Total	89.8
Neomysis mercedis	—	Pittsburg	1978–79	A-27	30.0–31.9	—	Total	28.5
Neomysis mercedis	—	Pittsburg	1978–79	A-27	32.0–33.9	—	Total	0.0
Neomysis mercedis	—	Pittsburg	1978–79	A-27	>33.9	—	Total	0.0
Chaoborus punctipennis	—	Bowline Pt.	1975	A-3	—	—	Total	92.4
Chaoborus punctipennis	—	Roseton	1975	A-32	—	—	Total	98.1
Chaoborus punctipennis	—	Roseton	1976	A-33	<30.0	62	Total	86.1
Chaoborus punctipennis	—	Roseton	1976	A-33	>30.0	120	Total	96.1
Crangon septemspinosa	—	Indian River	1975–76	A-22	<25.0	—	Total	95.0
Crangon septemspinosa	—	Indian River	1975–76	A-22	25.0–30.0	—	Total	56.0
Crangon septemspinosa	—	Indian River	1975–76	A-22	30.0–35.0	—	Total	33.0
Crangon septemspinosa	—	Indian River	1975–76	A-22	>35.0	—	Total	9.0
Nereis succinea	—	Calvert Cliffs	1979–80	A-8	—	2,348	Total	89.0
Scolecolepides viridis	—	Calvert Cliffs	1979–80	A-8	—	2,650	Total	100.0
chaetognaths	—	Anclote	1995	A-1	—	495	Total	67.1
chaetognaths	—	Anclote	1995	A-1	—	1,432	Total	72.4
Caridean shrimp	—	Anclote	1995	A-1	—	1,026	Total	63.8
Caridean shrimp	—	Anclote	1995	A-1	—	740	Total	80.5
Penaeid shrimp	—	Anclote	1995	A-1	—	212	Total	66.0
Penaeid shrimp	—	Anclote	1995	A-1	—	202	Total	75.1
Ephemeroptera	—	Fort Calhoun	1973–77	A-14	up to 37.0 C	2,220	Initial	91.7
Hydropsychidae	—	Fort Calhoun	1973–77	A-14	up to 37.0 C	4,964	Initial	91.7
other Trichoptera	—	Fort Calhoun	1973–77	A-14	up to 37.0 C	872	Initial	92.5
Chrionomidae	—	Fort Calhoun	1973–77	A-14	up to 37.0 C	2,925	Initial	83.7
other Diptera	—	Fort Calhoun	1973–77	A-14	up to 37.0 C	380	Initial	87.1

Notes: * = all organisms below this point are macroinvertebrates
PYSL = post-yolk sac larvae
YSL = yolk sac larvae
— = data not available or readily extractable

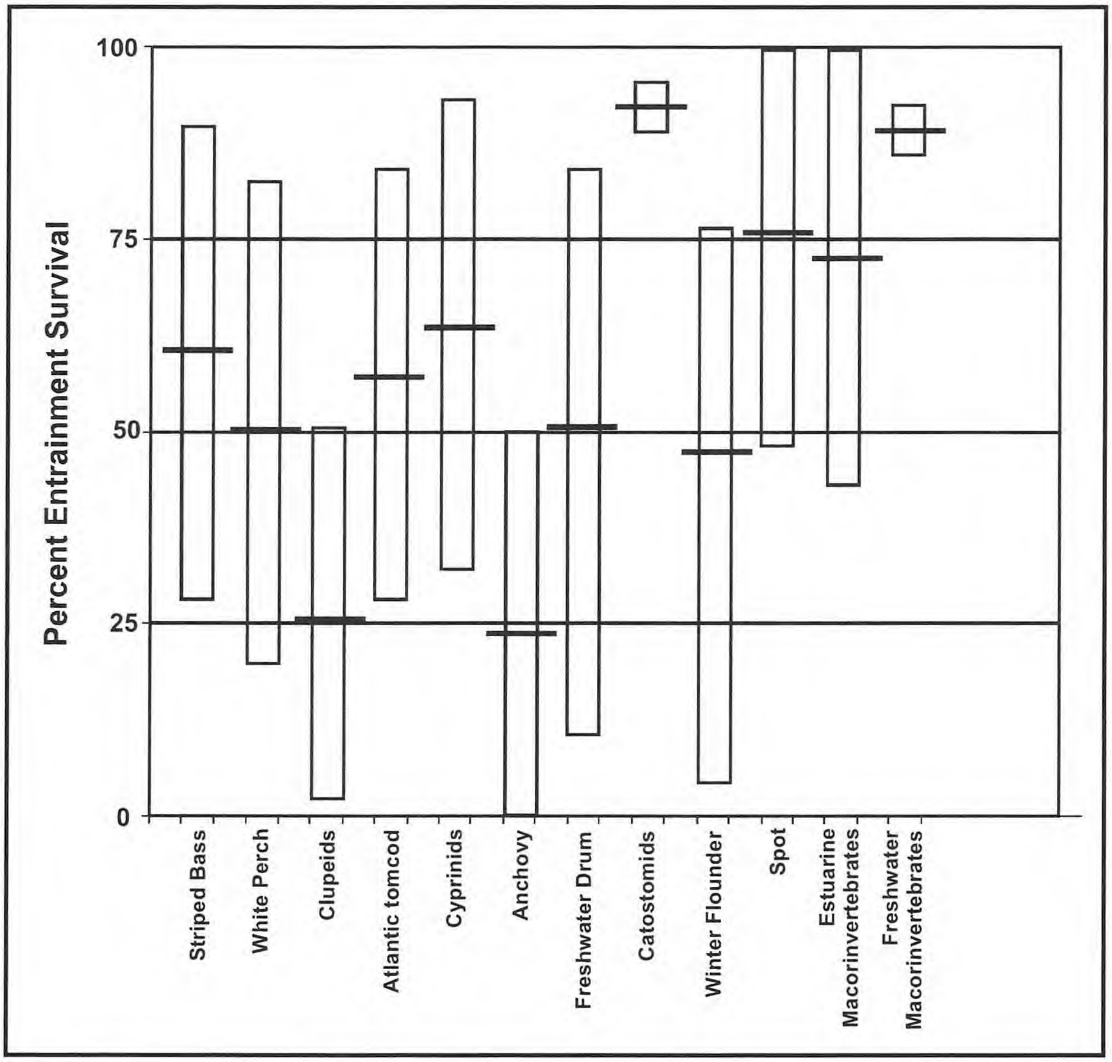

Figure 3-1
Survival Data (Mean 1 S.D.) for Key Species/Groups from Table 3-5.

4
FACTORS AFFECTING ENTRAINMENT SURVIVAL

4.1 Species Entrained

Key factors that influence the probability that an entrained organism will survive are illustrated in Figure 4-1. The first of these, "species entrained," has already been discussed to some extent in Section 3. Referring to Figure 3-1, it is clear that, with all other factors equal, the probability of survival of catostomids is markedly greater than that of anchovies. Similarly, striped bass exhibit higher survival than clupeids over all conditions. Figure 3-1 illustrates considerable variability within a species or group. Survival of a species may vary over a considerable range, depending on factors such as discharge temperature, but the range is unique to the species. Consequently, for a given set of conditions, probability of survival depends on which species is entrained. It is also clear from Figure 3-1 that except for clupeids and anchovy, average survival for all other species/taxa is ≥50 percent.

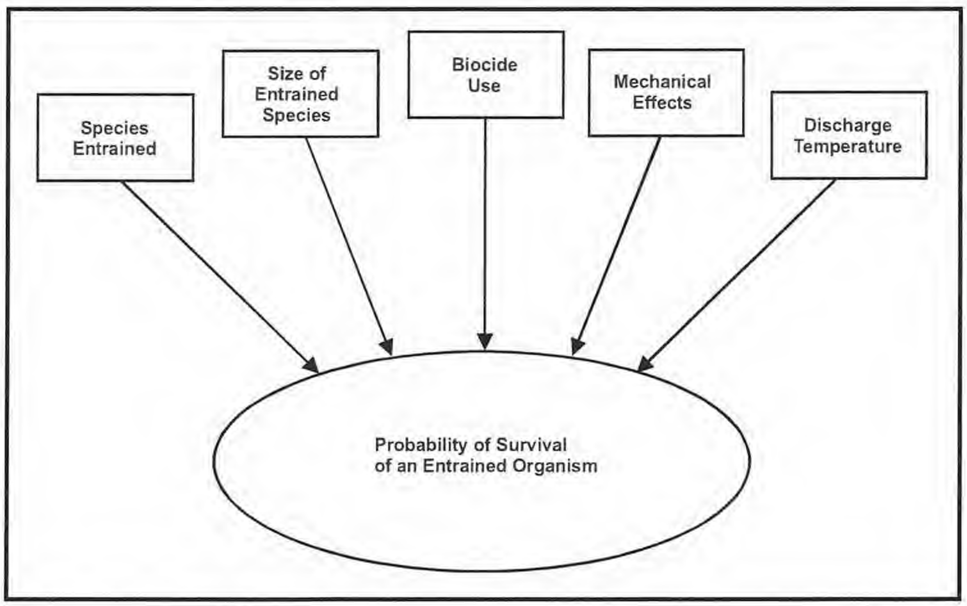

Figure 4-1
Factors Affecting Entrainment Survival.

4.2 Size of Entrained Species

A number of studies examined the effect of the size of entrained fish larvae on survival. Although some reports, such as for the Pittsburg and Protrero Power Plants in 1978–79 (Summary A-27 and A-29), reported no relationship between larval size and survival, a number of other studies did. A consistent relationship of increasing survival with increasing length of larval striped bass, white perch, and clupeids was shown at Hudson River power plants. This relationship is typified by the plot (Figure 4-2) of survival vs. length of striped bass larvae at the Roseton Generating Station (EA 1983) (Summary A-36). Data are illustrated for several different sampling gear at both intake and discharge locations. Similar relationships were noted for white perch. Cluepid survival also increased with increasing larval length, but exhibited an abrupt decrease in survival at about 24 mm at Roseton Generating Station and at 14 mm at Monroe Power Plant (EA 1982) (Summary A-23).

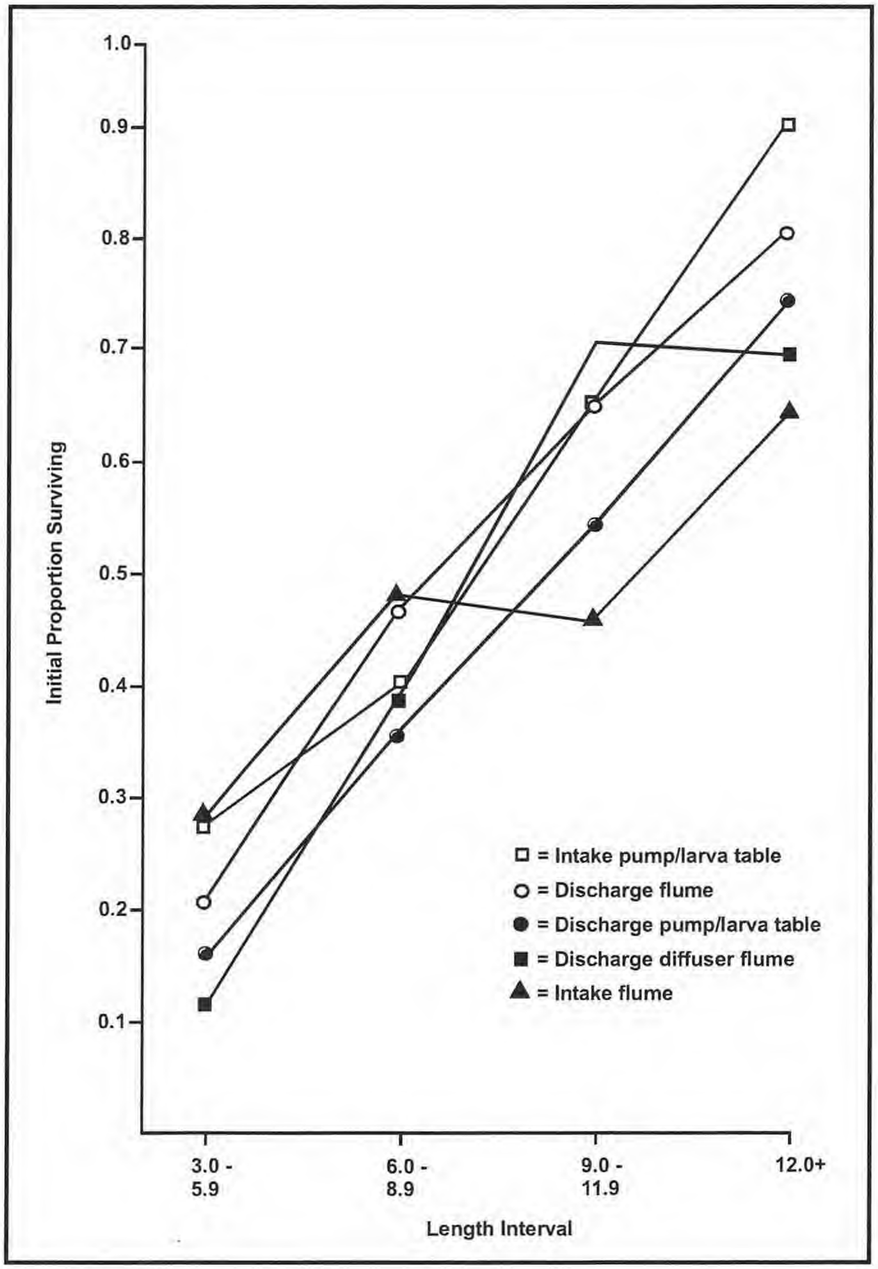

Figure 4-2
Initial Survival as a Function of Length for Striped Bass Collected at Five Stations During Entrainment Survival Sampling at the Roseton Generating Station, 26 May–31 July 1980. [From EA 1983]

Whereas increasing survival of larger, hardier specimens may seem intuitively obvious, there are implications for impact assessment. As indicated by EA (1981a), the high survival of the larger, late post-yolk sac larvae and juvenile striped bass occurs at the time that the year class strength is set in the Hudson River population. Thus, sensitivity to entrainment is the least during a critical biological period for the species. Impact assessment is discussed further in Section 5.

4.3 Biocide Use

The use of chemical biocides such as chlorine can affect survival of entrained organisms. EA (1982) reported lower survival of clupeid and yellow perch larvae at the Monroe Power Plant (A-23) when residual chlorine concentrations in cooling water were $\geq$0.1 mg/L. Although chemical stressors are commonly listed as one of three factors influencing entrainment survival (Schubel and Marcy 1978; Muessig et al. 1988; Mayhew et al. 2000), they are seldom implicated as having a marked impact on overall entrainment survival. Biocide treatments typically are intermittent and of short duration. Marcy (1973) reported chlorination at the Connecticut Yankee Station of 10 minutes per unit per day. A similar schedule was reported for the Monroe Power Plant (EA 1982). Muessig et al. (1988) stated that "biocides generally are not used to control fouling organisms in the cooling systems of Hudson River power plants during the period when entrainable fish are abundant." Therefore, although survival can be significantly reduced during biocide application, the very short duration of, and sometimes absence of application of biocides indicate that biocides represent a negligible influence on overall entrainment survival for many power plants. However, there are some generating units permitted for continuous biocide application, and in these cases entrainment survival would be negligible.

4.4 Mechanical Effects

Mechanical effects on organisms transiting cooling-water pumps and condensers include shear and buffeting from turbulent flow, rapid acceleration and deceleration, pressure increases and drops, and abrasion from contact with screens, pump impellers, and condenser tubes (Kedl and Coutant 1976; Marcy et al. 1978). Largely due to the work of Marcy (1971, 1973), early investigators thought that mechanical damage was the greatest contributor to entrainment-passage mortality. Marcy attributed 80 percent of entrainment mortality at the Connecticut Yankee Station to mechanical damage (A-10). Subsequent laboratory-simulation studies, reviewed by Jinks et al. (1981), began to generate contrary conclusions regarding mechanical damage. Studies at New York University demonstrated little mortality of striped bass eggs and larvae from pressure changes typical of power-plant cooling systems. Kedl and Coutant (1976) tested striped bass and bluegill larvae in a condenser-tube simulator and reported mortalities immediately after passage of <5 percent. Cada et al. (1981) also conducted simulation studies where the effects of pipe and condenser passage and pump passage could be assessed separately. With the exception of carp, they reported very low mortality of bluegill larvae and juveniles of channel catfish, mosquitofish, and largemouth bass due to either pipe/condenser or pump passage.

Whereas the simulation studies provided valuable information on mechanical effects, and suggested a greater resiliency of young fish to mechanical stresses than previously thought, they were limited by their artifciality. By the late 1970s and early 1980s, a number of entrainment-survival studies had been completed at existing power plants that permitted more realistic assessments of mechanical effects of entrainment. The most consistent observation from these studies was that survival decreased with increasing discharge temperatures. Based on field observations, and also laboratory thermal tolerance studies (EA 1978a), discharge temperatures below 30°C were considered to have little or no effect on survival. Consequently, any mortality measured when discharge temperatures were <30°C was ascribed to mechanical damage—assuming thermal and mechanical stresses were independent.

On occasion, there were opportunities to measure entrainment survival when generating units were off, but circulating-water pumps were running, i.e., there was no thermal addition. For example, two such studies were done at the Bowline Point plant in 1978 and 1979 (EA 1979b, 1981a) (A-5, A-6). In 1978, initial entrainment survival with no thermal addition was measured at 90 and 95 percent for post-yolk sac larval white perch and striped bass, respectively. Consequently, mortality due to mechanical effects was negligible. Similar studies at Bowline Point in 1979 showed lower survival. Initial entrainment survival was 56–60, 43.3–94.1, and 30–57.7, depending on discharge sampling location, for striped bass, white perch, and clupeids, respectively. Twenty-four hour extended survival was lower than initial survival for all taxa. Mechanical effects were obviously more prominent in 1979. The authors attributed this to the smaller size of the larvae entrained in 1979 relative to 1978.

Jinks et al. (1981) reviewed a number of entrainment-survival studies done largely in the absence of thermal effects. Of 40 survival estimates reported to include no thermal influence, 33 were greater than 50 percent survival and 21 were 75 percent survival or higher. Consequently, the corresponding mechanical contribution to mortality was usually less that 50 percent, and frequently less than 25 percent.

In summary, although there often is a mechanical component of entrainment mortality, it is typically a much less important determinant of entrainment survival than thermal stress from high discharge temperatures, as discussed below.

4.5 Discharge-Temperature Effects

The above-mentioned relationship of entrainment survival to discharge temperature is illustrated in Figure 4-3. The plotted data are mean survival values in each temperature range based on the data in Table 3-5. The data clearly corroborate the results of laboratory thermal-tolerance studies (e.g., EA 1978a) that identified upper thermal tolerance thresholds between 30 and 32°C for common Hudson River species. Based on Figure 4-3, striped bass appear to be more resistant to temperatures in the threshold region, but survival drops markedly at discharge temperatures above 33°C.

Figure 4-3 also illustrates the effect of species on entrainment survival, discussed above in Subsection 4.1. Under the best of circumstances, i.e., with discharge temperatures less than 30°C, survival recorded for the relatively delicate clupeids and anchovies is notably lower than that of striped bass, white perch, or mysid shrimp.

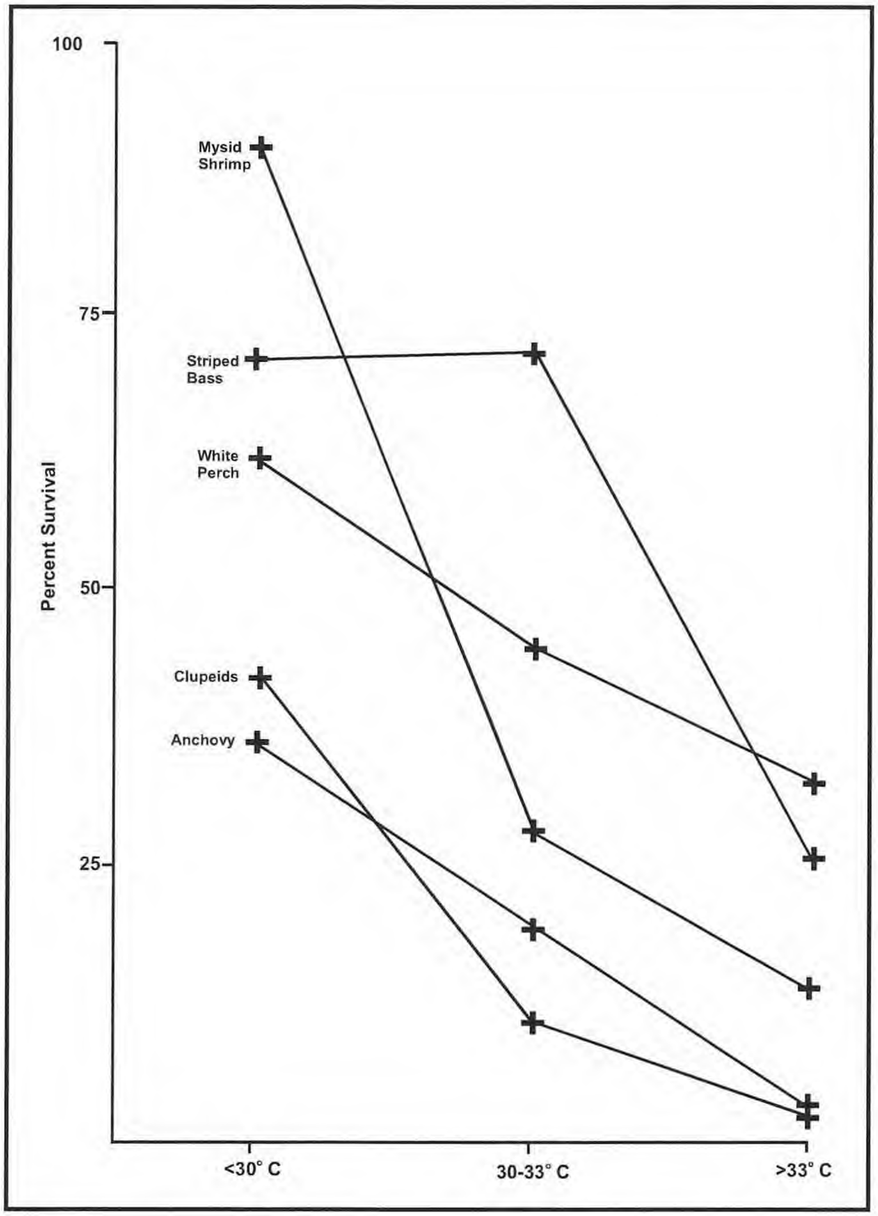

Figure 4-3
Effect of Discharge Temperature on Entrainment Survival.

Discharge temperature and the other factors that affect entrainment survival have been thus far discussed in a largely experimental context. That is, a certain set of circumstances were encountered in a given study, e.g., discharge temperatures >33°C and availability of white perch post-yolk sac larvae in entrainment samples. Samples were taken, survival was measured, and the results reported. These data alone are insufficient for impact assessment. Temperatures will change within and among years, spawning location and timing will vary, and other factors will vary among power plants and years. The implications of this are discussed in Section 5.0.

5
APPLICATION OF ENTRAINMENT SURVIVAL DATA

5.1 Existing Facilities

Jinks et al. (1978) described a predictive model for assessing entrainment survival of Hudson River striped bass. Their model (Figure 5-1) incorporated three key components: (1) exposure, (2) mortality, and (3) involvement. Exposure was in terms of thermal conditions, i.e., if a larva was entrained, what temperature would it be subjected to and for how long? The mortality component consisted of mechanical and thermal effects. All of the forgoing discussions in the present document have dealt with the first two model components, i.e., what is the discharge temperature and what is the measured or predicted probability of survival (or mortality)? Knowing what the discharge temperature is and, consequently, the probability of entrainment survival, is not enough to predict the environmental impact of entrainment. That is where the third component of the model, "involvement," applies. This is where the seasonal and diel occurrence and abundance of entrainable organisms is integrated with the exposure and survival/mortality estimates to predict the overall survival or loss of entrained organisms in a season.

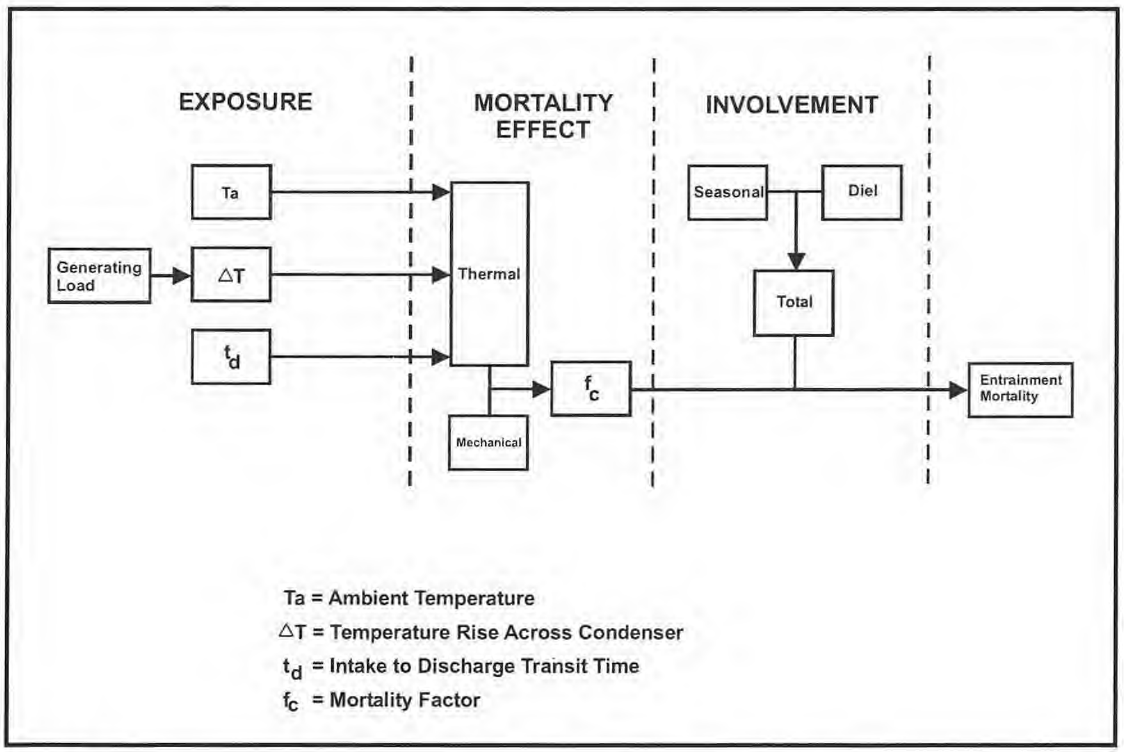

Figure 5-1
Predictive Model for Entrainment Mortality (from Jinks et al. 1978).

Seasonal occurrence and abundance of entrainable forms, and the timing thereof, varies depending on a number of factors such as ambient water temperature and salinity. It can happen, as at the Roseton Generating Station on the Hudson River in 1975 (A-32), that the entrainment season, or period of occurrence of entrainable striped bass and white perch, was largely over before the discharge temperature exceeded 30°C (EA 1978b). EA (1981a), in their discussion of entrainment abundance and survival at the Bowline Point Station on the Hudson River, indicated that "the peak period for the most abundant species and life stages typically occurs well before the discharge temperatures reach the lab predicted TL50s (median tolerance limit) for these taxa." The effect of seasonal variation in environmental conditions was reflected in the survival of striped bass and white perch larvae at Indian Point Station in 1977 and 1978 (EA 1979c) (A-16, A-17). The lower survival measured in 1978 was attributed to higher discharge temperatures (30–32.9°C) compared to 1977 (<30°C). Diel generating cycles at some plants can also influence entrainment survival. Jinks et al. (1978) pointed out that at the Roseton Station, minimal entrainment of striped bass larvae occurs in the afternoon when generating load (and consequently discharge temperature-related mortality factors) is highest. The highest entrainment is in the early morning hours when mortality factors are lowest.

The integration of exposure, mortality, and involvement has been done at a number of power plants to estimate actual entrainment losses on a seasonal and annual basis. Based on a two-year study at the Indian River Power Plant (EA 1978c) (A-22), the overall percentage of entrained organisms that survived entrainment during the study period ranged from less than 10 percent for bay anchovy to >70 percent for Atlantic croaker, 50 percent for Atlantic silverside, and >90 percent for Atlantic menhaden and spot. Corresponding estimates for the sand shrimp *Crangon septemspinosa* and mysid *Neomysis americana* were nearly 60 and 90 percent, respectively.

EA (1981b) utilized measured survival data for *Neomysis mercedis* and striped bass larvae to underpin extensive impact modeling at the Pittsburg Power Plant (A-27). Conditional mortality rates (the fractional reduction in year-class strength due to entrainment) were calculated for both taxa, and equivalent adult loss estimates were made for striped bass. Similar impact assessment modeling was conducted for the Protrero Power Plant (EA 1980) based on the entrainment survival data in Table A-29 of this document. For the Oyster Creek Nuclear Generating Station, EA (1986) used the entrainment survival data in Table A-25 (this document), in conjunction with 5 prior years of entrainment abundance and discharge temperature data, to estimate annual survival of winter flounder and bay anchovy in those prior years.

Much of the entrainment survival data for Hudson River power plants in Appendix A were employed by EPA consultants in conducting impact-assessment modeling in support of the 1977–1980 power plant adjudicatory hearings. Boreman and Goodyear (1988) summarized estimates of entrainment mortality presented to the EPA in 1979. These authors used the empirical transport model (ETM) to generate estimates of conditional entrainment mortality, the fractional reduction in year-class strength due to entrainment (assuming other sources of mortality are density-independent). The "f-factors" used by Boreman and Goodyear represented mortality due to plant passage as determined via (1) in-plant sampling with nets and larva tables (data summarized in this document) and (2) regression-model estimates of mortality based on laboratory thermal-tolerance studies. This analysis highlighted the importance of unbiased entrainment survival estimates; the conditional mortality rate is particular sensitive to the survival data.

The above synopsis of the use and application of entrainment survival data establishes the importance of such data in power plant impact analysis. Although EPA consultants initially were reluctant to accept the entrainment survival estimates (and resulting f-factors) generated by utility consultants on the Hudson River (Englert and Boreman 1988), the data eventually were accepted, largely due to improvements in entrainment-survival sampling techniques described by Muessig et al. (1988).

It must be emphasized that the measurement of entrainment abundance and survival does not constitute impact assessment. These are only interim steps in a process that culminates with a determination of whether or not entrainment causes adverse environmental impact. Entrainment abundance and survival data must be put in context with the species population in the waterbody. In all of the studies examined for purposes of this analysis, the assessment of entrainment survival has been part of a process the goal of which is to determine the risk to the *population*—not individuals within the population. There are many methods available with which to address population risks, as described in EPRI (1999).

5.2 Proposed Facilities

Whereas the entrainment data gathered for individual plants can and have been used in assessing impacts of entrainment at existing facilities, the accumulated 30-year database could also be of value as an environmental screening tool for proposed new facilities and for existing facilities where such studies have not been performed. Typically, environmental data are compiled during the plant siting process, and these data could be screened against the entrainment survival database to provide a qualitative prediction of the potential for entrainment impacts at the new facility. By reviewing the pre-operational environmental data and proposed plant-operating specifications in light of the factors that affect entrainment survival (Figure 4-1, this document), a qualitative estimate of potential entrainment impacts could be made. The pre-operational environmental data would provide answers to the questions:

- What species of ichthyoplankton and macroinvertebrates are common in the receiving waters?
- What are the size and densities of entrainable forms?

Plant-design specifications would answer:

- What type, frequency, and concentration of biocide, if any, are proposed?
- What type of circulating-water pumps is in the design?
- What are anticipated cooling-water flow rates?
- What is the design temperature rise across the condenser(s)?

When these questions are answered and related to the information in the entrainment survival database, the nature of potential future entrainment impacts could be evaluated. Ideally, the entrainment database could be consulted in the design phase to identify operating specifications such as cooling-water flow and predicted discharge temperatures that would minimize entrainment effects.

There is the potential, perhaps in a future project, to move from a qualitative screening tool to a quantitative predictive model. By merging the survival data and associated specific plant-operating characteristics from existing studies, and applying appropriate statistical treatments, an effective predictive model could result. This would allow assessment of entrainment effects not only for proposed facilities, but also for existing facilities that have not had prior entrainment evaluations.

6
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A
ENTRAINMENT SURVIVAL SUMMARY SHEETS

Table A-1
Entrainment Survival Study Summary, Anclote Power Plant, 1995

Power Plant: Anclote Power Plant

Owner: Florida Power Corporation

Plant Capacity (MWe): 1,112

Report Reference: CCI Environmental Services, Inc. 1996. *Zooplankton Entrainment Survival Study, Anclote Power Plant, Pasco County, Florida.* CCI, Palmetto, FL. Prepared for [owner].

Water Body: Anclote River, FL

Sampling frequency/dates: Daily during 25–29 Sept., 9–11 Oct., and 1–2 Nov. 1995

Cooling Water Flow (M^3/min.): Not provided in report

Sample Location(s): Intake canal; condenser discharge flume; discharge canal point-of-discharge

Sampling Gear: 1.0-m diameter conical plankton net with 400 µ-mesh netting

deployed from a boat

Type of Survival Test(s): Initial and extended 96-hr. tests

Results Summary:

	Total Entrainment Survival					
			Condenser Discharge		Point-of-Discharge	
Species Group	Intake % Survival	Number Tested	% Survival	Number Tested	% Survival	Number Tested
Fish larvae	64.1	109	27.2	331	62.2	143
Fish juveniles	78.3	140	64.0	200	69.6	144
Amphipods	72.9	5,185	48.5	2,632	72.9	2,030
Chaetognaths	44.0	1,549	67.1	495	72.4	1,432
Caridean shrimp	72.4	2,728	63.8	1,026	80.5	740
Penaeid shrimp	77.3	58	66.0	212	75.1	202

Remarks: Condenser samples included only organisms entrained through condensers. Point-of-Discharge samples included either condenser-entrained samples only, or if the dilution pumps were on, a mixture of condenser and dilution-pump entrained organisms. Total entrainment survival was based on initial and extended survival, corrected for control (intake) survival. Grand average calculations (above) were not done separately for initial and extended survival data. There was a trend of higher mortality at higher condenser discharge temperatures. The data suggested that dilution-pump entrainment was less stressful than condenser entrainment.

Table A-2
Entrainment Survival Study Summary, Bergum Power Station, 1976

Power Plant: Bergum Power Station

Owner: Not reported

Plant Capacity (MWe): 640

Report Reference: Hadderingh, R.H. 1978. Mortality of young fish in the cooling water system of Bergum power station. *Proceedings International Association of Theoretical and Applied Limnology* 20:347–352.

Water Body: Bergumereer (Netherlands lake)

Sampling frequency/dates: 6 days during 27 April–1 June 1976

Cooling Water Flow (M^3/min.): 1,667

Sample Location(s): Condenser cooling-water intake and discharge

Sampling Gear: 0.5-m diameter conical plankton net with 500 μ-mesh netting

Type of Survival Test(s): Initial and (limited) 24-hr. extended survival (see remarks)

Results Summary:

Species	Date	Life Stage	Number Tested Discharge	Initial Survival (%)	Extended Survival (%)	Total Entrainment Survival (%)
Smelt[a]	27–Apr	larvae/juveniles	20	10	nd	10
Smelt	3–May	larvae/juveniles	47	17	nd	17
Smelt	10–May	larvae/juveniles	87	17	nd	17
Smelt	25–May	larvae/juveniles	32	41	nd	41
Smelt	31–May	larvae/juveniles	97	34	nd	34
Smelt	1–Jun	larvae/juveniles	39	46	50[c]	23
Percidae[b]	27–Apr	larvae/juveniles	115	40	nd	40
Percidae	3–May	larvae/juveniles	78	65	nd	65
Percidae	10–May	larvae/juveniles	112	39	nd	39
Percidae	25–May	larvae/juveniles	86	72	nd	72
Percidae	31–May	larvae/juveniles	258	82	nd	82
Percidae	1–Jun	larvae/juveniles	177	73	95[c]	69

[a]*Osmerus eperlanus* [b]*Stizostedion lucioperca, Perca fluviatilis, and Gymnocephalus cernua*

[c]discharge extended survival apparently not corrected for intake extended survival; nd=not determined

Remarks: Survival increased with increasing size of larvae/juveniles as season progressed. Discharge temperatures ranged from 16.7 to 24.6°C over the study period.

Table A-3
Entrainment Survival Study Summary, Bowline Point Generating Station, 1975

Power Plant: Bowline Point Generating Station

Owner: Orange and Rockland Utilities, Inc.

Plant Capacity (MWe): 1,240 (Units 1&2 combined)

Report Reference: Ecological Analysts, Inc. 1976. *Bowline Point Generating Station Entrainment Survival and Abundance Studies, 1975 Annual Report.* Prepared for [owner].

Water Body: Hudson River

Sampling frequency/dates: 4 days per week during 3-23 June and then 1-2 days per week through July 1975

Cooling Water Flow (M^3/min.): 2,904 (Units 1&2 combined)

Sample Location(s): Condenser cooling-water Intake/Discharge

Sampling Gear: Pump/larva table

Type of Survival Test(s): Initial and extended 96-Hour Tests

Results Summary:

Species	Life Stage	Number Tested (Discharge)	Initial Survival (%)	Extended (96 hr) Survival (%)	Total Entrainment Survival (%)
Striped Bass	PYSL	111	91.4	77.0	70.4
White Perch	PYSL	168	100.0	100.0	100.0
Morone Spp.	PYSL	279	100.0	100.0	100.0
Monoculodes edwardsi	—	—	98.6	100.0	98.6
Gammarus daiberi	—	—	100.0	94.8	94.8
Edotea triloba	—	—	100.0	100.0	100.0
Neomysis americana	—	—	100.0	(a)	(a)
Chaoborus punctipennis	—	—	92.4	100.0	92.4

Note: PYSL= post yolk sac larvae. Macroinvertebrate counts not provided.

(a)Extended survival zero at 96 hrs. for both intake and discharge; regression slopes did not differ, so likely sampling/holding effects. Actual total entrainment survival was probably quite high.

Remarks: The mortality rate of the entrained organisms appears not to be significantly different than the mortality rate of the control (intake) organisms. An increase in mortality rate resulting from entrainment through the power plant was therefore not distinguishable from the mortality rate caused by the collection, handling, and holding procedures. Data are insufficient to allow interpretation of temperature effects with any reasonable degree of confidence.

Table A-4
Entrainment Survival Study Summary, Bowline Point Generating Station, 1977

Power Plant: Bowline Point Generating Station

Owner: Orange and Rockland Utilities, Inc.

Plant Capacity (MWe): 1,200 (Units 1&2 combined)

Report Reference: Ecological Analysts, Inc. 1978. *Bowline Point Generating Station Entrainment Survival, 1977 Annual Interpretive Report.* Prepared for [owner].

Water Body: Hudson River

Sampling frequency/dates: 5 days per week during 3 June-15 July 1977

Cooling Water Flow (M^3/min.): 2,904 (Units 1&2 combined)

Sample Location(s): Condenser cooling-water Intake/Discharge

Sampling Gear: Pump/larva table

Type of Survival Test(s): Initial and extended 96-Hour Tests

Results Summary:

Species	Life Stage	Discharge Temperature (°C)	Initial Entrainment Survival (%)
Striped Bass	PYSL	20.0–29.9	97
Striped Bass	PYSL	30.0–32.9	100
Striped Bass	PYSL	33.0–35.9	41
Striped Bass	Juvenile	20.0–29.9	90
Striped Bass	Juvenile	30.0–32.9	90
Striped Bass	Juvenile	33.0–35.9	43
White Perch	PYSL	20.0–29.9	62
White Perch	PYSL	30.0–32.9	16
White Perch	PYSL	33.0–35.9	48
Clupeids	PYSL	20.0–29.9	51
Atlantic Tomcod	YSL	5.5–13.9	84
Atlantic Tomcod	YSL	14.0–17.9	85

Note: YSL= yolk sac larvae; PYSL= post-yolk sac larvae

Remarks: For most taxa where at least 10 specimens were tested, extended survival was very high, between 95 and 100%; therefore, initial survival data were used as the best estimate of total entrainment survival. No significant effects of thermal exposure on survival were observed at discharge temperatures up to 33°C. Decreased survival was noted above 33°C for striped bass and white perch. Entrainment survival data taken from table 4-19 in report. The rapid mortality of bay anchovy following collection at both intake and discharge made quantification of total entrainment effects difficult.

Table A-5
Entrainment Survival Study Summary, Bowline Point Generating Station, 1978

Power Plant: Bowline Point Generating Station

Owner: Orange and Rockland Utilities, Inc.

Plant Capacity (MWe): 620

Report Reference: Ecological Analysts, Inc. 1979. *Bowline Point Generating Station Entrainment Abundance and Survival Studies: 1978 Annual Report.* Prepared for [owner].

Water Body: Hudson River

Sampling frequency/dates: 3-5 days per week during 13 March–16 October 1978

Cooling Water Flow (M^3/min.): 1,422

Sample Location(s): Condenser cooling-water intake and discharge

Sampling Gear: Pump/larva table

Type of Survival Test(s): Initial and extended 96-hr. tests

Results Summary:

			Survival (%)		
Species	Life Stage	No. Tested (discharge)	Initial	Extended	Total
Striped bass	YSL	82	100.0	72.0	72.0
Striped bass	PYSL	392	100.0	100.0	100.0
Striped bass	PYSL	24	100.0	100.0	100.0
White perch	PYSL	265	50.3	61.3	30.8
Atlantic tomcod	PYSL	54	100.0	99.0	99.0
Gammarus sp.	—	4,563	100.0	92.3	92.3
Neomysis americana	—	2,185	100.0	70.0	70.0

Remarks: Data are from three different discharges. Data from all discharge temperatures combined. Some of the white perch and Atlantic tomcod mortality was related to mechanical effects, i.e., the number of circulating-water pumps operating and whether throttled or full-flow modes were used.

Table A-6
Entrainment Survival Study Summary, Bowline Point Generating Station, 1979

Power Plant: Bowline Point Generating Station

Owner: Orange and Rockland Utilities, Inc.

Plant Capacity (MWe): 620

Report Reference: Ecological Analysts, Inc. 1980. *Bowline Point Generating Station Entrainment Abundance and Survival Studies: 1979 Annual Report with Overview of 1975-1979 Studies.* Prepared for [owner].

Water Body: Hudson River

Sampling frequency/dates: 3-5 days per week during 23 May–27 June 1979

Cooling Water Flow (M^3/min.): 1,422

Sample Location(s): Condenser cooling-water intake and discharge

Sampling Gear: Pump/larva table, rear-draw plankton flume, and pumpless plankton flume

Type of Survival Test(s): Initial and extended 96-hr. tests

Results Summary:

			Survival (%)		
Species	Life Stage	Number Tested (discharge)	Initial	Extended	Total
Striped bass(a)	PYSL	104	60.0	69.8	41.9
Striped bass(b)	PYSL	51	56.0	42.1	23.6
White perch(a)	PYSL	112	43.3	72.7	31.5
Clupeids(a)	PYSL	52	57.7	(c)	(c)
Clupeids(b)	PYSL	40	57.8	(c)	(c)

Note: PYSL=post-yolk sac larvae; (a)=intake and discharge standpipe sampled with pump/larva table;
(b)=intake and diffuser discharge sampled with rear-draw flume and pumpless flume, respectively;
(c)=24-hr survival zero or nearly so in both intake and discharge samples.

Remarks: Although 96-hr extended observations were carried out, all extended effects appeared by 24 hours, therefore extended survival was based on the 24-hr observations. Some indication of decreasing survival with higher discharge temperatures was indicated, however few data were recorded for discharge temperatures greater than 30°C. Survival of striped bass and white perch increased with size.

Table A-7
Entrainment Survival Study Summary, Braidwood Nuclear Station, 1988

Power Plant:	Braidwood Nuclear Station
Owner:	Commonwealth Edison Company
Plant Capacity (MWe):	2,240
Report Reference:	EA Science and Technology, Inc. 1990. *Results of Entrainment and Impingement Studies Conducted at the Braidwood Nuclear Station and the Adjacent Kankakee River.* Prepared for [owner].
Water Body:	Kankakee River, Illinois
Sampling frequency/dates:	1, 7, and 21 June 1988
Cooling Water Flow (M^3/min.):	189 (makeup water)
Sample Location(s):	Condenser cooling-water intake and discharge
Sampling Gear:	1-m dia. conical plankton net
Type of Survival Test(s):	Initial
Results Summary:	Only *Lepomis* sp. larvae were collected in sufficient numbers at the discharge to determine initial survival (all dates combined). Sixty of 75 specimens collected at the discharge were alive, therefore the survival proportion was calculated as 80 percent. The corresponding value for the intake was 78 percent. Correcting the discharge survival for the control (intake) survival (80/78) yields an (initial) entrainment survival value of 102.6%, set to the maximum possible value of 100%.

Table A-8
Entrainment Survival Study Summary, Calvert Cliffs Nuclear Power Plant, 1978–1980

Power Plant: Calvert Cliffs Nuclear Power Plant

Owner: Baltimore Gas & Electric Company

Plant Capacity (MWe): >1,000

Report Reference: Ecological Analysts, Inc. 1981. *Entrainment Abundance and Viability Studies, Calvert Cliffs Nuclear Power Plant, Final Report 1978-1980.* Prepared for [owner].

Water Body: Chesapeake Bay

Sampling frequency/dates: Once per month during fall and winter and weekly during spring and summer, April 1978–September 1980

Cooling Water Flow (M^3/min.): ~9,000

Sample Location(s): Condenser cooling-water intake and discharge

Sampling Gear: Pump/larva table

Type of Survival Test(s): Initial and extended 48 and 88-hr. periods

Results Summary:

Species	Life Stage	Number Tested	Study Year	Survival (%) Initial	Survival (%) Extended	Survival (%) Total
Bay anchovy	Larvae/juveniles	726	1979	35.1	15.4	5.4
Bay anchovy	Larvae/juveniles	970	1980	28.0	10.4	2.9
Naked goby	Larvae	1,112	1979	73.1	(a)	87.7
Naked goby	Larvae	170	1980	100.0	98.0	98.0
Blenny	Larvae	148	1979	72.0	51.3	36.9
Blenny	Larvae	37	1980	81.1	97.4	79.0
Spot	Juveniles	51	1979	84.9	(a)	100.0
Spot	Juveniles	108	1980	100.0	100.0	100.0
Neomysis americana	—	18,841	1979/1980	NA	NA	79.0
Corophium sp.	—	3,363	1979/1980	NA	NA	65.0
Gammarus mucronatus	—	231	1979/1980	NA	NA	70.0
Nereis succinea	—	2,348	1979/1980	NA	NA	89.0
Scolecolepides viridis	—	2,650	1979/1980	NA	NA	100.0

NA=not available;
(a)=cannot calculate

Remarks: For a given test of fish larvae/juveniles, initial and total survival were integrated in the same continuous set of observations, i.e., extended survival was not isolated from initial survival. For the above table, extended survival was calculated by dividing total by initial survival.

Table A-9
Entrainment Survival Study Summary, Cayuga Generating Plant, 1979

Power Plant: Cayuga Generating Plant

Owner: Public Service of Indiana (Cinergy Corp.)

Plant Capacity (MWe): 1,000

Report Reference: Ecological Analysts, Inc. 1980. *Entrainment Survival Studies at the Cayuga Generating Plant 1979.* Prepared for [owner].

Water Body: Wabash River, Indiana

Sampling frequency/dates: Daily during 17-31 May and 8-22 June 1979

Cooling Water Flow (M^3/min.): 2,014

Sample Location(s): Condenser cooling-water intake and discharge

Sampling Gear: Pump/larva table

Type of Survival Test(s): Initial and extended 48-hr. tests

Results Summary:

Taxon	Life Stage	Number Tested (Discharge)	Discharge Temperature (°C)	Total Entrainment Survival (%)
Catastomidae	YSL	131	26.0-31.9	88.1
Catastomidae	YSL	175	32.0-36.0	86.6
Catastomidae	YSL	306	All temps.	87.2
Catastomidae	PYSL	213	26.0-31.9	91.2
Catastomidae	PYSL	130	32.0-36.0	98.4
Catastomidae	PYSL	343	All temps.	93.9
Cyprinidae	YSL	25	26.0-31.9	85.7
Cyprinidae	YSL	70	32.0-36.0	25.4
Cyprinidae	YSL	95	All temps.	41.3
Cyprinidae	PYSL	60	26.0-31.9	85.1
Cyprinidae	PYSL	37	32.0-36.0	73.5
Cyprinidae	PYSL	97	All temps.	80.6
Percidae	YSL	41	26.0-31.9	59.4
Percidae	YSL	12	32.0-36.0	19.4
Percidae	YSL	53	All temps.	50.4

Note: YSL=yolk sac larvae; PSYL=post-yolk sac larvae

Remarks: Because extended (48-hr) survival differed little between intake and discharge samples, initial entrainment survival (discharge survival/intake survival) was used as estimate of total entrainment survival. Effects of circulating-water pump operation also were evaluated. At lower discharge temperatures, survival decreased as the number of operating pumps increased. At higher discharge temperatures, survival generally increased as the number of pumps operating increased. Collection of larvae from the trimming (cooling tower) discharge revealed high incidence of damaged specimens and very low survival (<1.0%).

Table A-10
Entrainment Survival Study Summary, Connecticut Yankee Atomic Power Plant, 1970, 1971 and 1972

Power Plant:	Connecticut Yankee Atomic Power Plant
Owner:	Connecticut Yankee Atomic Power Company
Plant Capacity (MWe):	600
Report Reference:	Marcy, B.C., Jr. 1971. Survival of young fish in the discharge canal of a nuclear power plant. *J. Fish. Res. Bd. Canada* 28:1057-1060. Mrcy, B.C., Jr. 1973. Vulnerability and survival of young Connecticut River fish entrained at a nuclear power plant. *J. Fish. Res. Bd. Canada* 30:1195-1203.
Water Body:	Connecticut River
Sampling frequency/dates:	30 June-29 July 1970 (6 days); June 1971 (2 days); June-July 1972 (4 days)
Cooling Water Flow (M^3/min.):	1,500
Sample Location(s):	Intake; discharge canal
Sampling Gear:	0.5-m diameter conical plankton net with 390 -mesh netting
Type of Survival Test(s):	Initial survival

Results Summary:

Date	Number Tested (discharge)	Condition	Initial Survival (%)
June-July 1972	230	Mechanical (no heat)	13.2–29.5
13-14 July 1972	227	Biocide (no heat)	19.2–23.9
30 June 1970; 2 June 1971	458	Discharge temp.=28–29°C	24.1–25.9
2 July 1970	257	Discharge temp.=33.5°C	12.1
6 July 1970 and 24 June 1971	1,061	Discharge temp.=35.0°C	0

Remarks: Nearly 98% of larvae tested were post-yolk sac larvae of clupeids (alewife and blueback herring). Discharge collections were made at four points throughout the 1.4 mile long discharge canal. Because dead larvae were not reliably collected in the discharge (attributed to settling), initial survival was calculated by dividing the density (no./M^3) of larvae in discharge samples by the density in intake samples. Based on results, author attributed 80% of entrainment mortality to mechanical effects.

Table A-11
Entrainment Survival Study Summary, Contra Costa Power Plant, 1976

Power Plant:	Contra Costa Power Plant
Owner:	Pacific Gas and Electric Company
Plant Capacity (MWe):	1,260
Report Reference:	Stevens, D. and B. Finlayson. 1978. Mortality of Young Striped Bass Entrained at two Power Plants in the Sacramento-San Joaquin Delta, California, pp. 57-69 in: *Fourth National Workshop on Entrainment and Impingement* (L. Jensen, ed.). EA Communications, a Division of Ecological Analysts, Inc., Melville, NY.
Water Body:	San Joaquin River, California
Sampling frequency/dates:	Weekly during 28 April-10 July 1976
Cooling Water Flow (M^3/min.):	2,718
Sample Location(s):	Units 1-5 and 6-7 discharges, and Units 6-7 intake
Sampling Gear:	0.75-m dia. conical plankton nets with 505-µ mesh netting, fished from a boat at mid-depth
Type of Survival Test(s):	Initial survival, striped bass larvae

Results Summary:

Period	Mean Length (mm)	Discharge Temperature (°C)	Number Tested (discharge)	Initial Survival (%)
1-10 June	9.0	19-29	73	95.0
1-10 June	9.0	30-32	92	57.5
1-10 June	9.0	33-34	12	0.0
14 June-9 July	16.0	24-29	6	31.5
14 June-9 July	16.0	30-32	95	88.9
14 June-9 July	16.0	33-35	37	14.8
14 June-9 July	16.0	36-38	14	25.9

Note: Survival calculated from author's data by dividing initial proportion alive in discharge samples by initial proportion alive in intake samples.

Remarks: Survival decreased with increasing discharge temperature. The threshold for increasing mortality was in the 30-32°C range.

Table A-12
Entrainment Survival Study Summary, Danskammer Point Generating Station, 1975

Power Plant: Danskammer Point Generating Station

Owner: Central Hudson Gas & Electric Corporation

Plant Capacity (MWe): 1,200

Report Reference: Ecological Analysts, Inc. 1976. *Danskammer Point Generating Station Impingement and Entrainment Survival Studies, 1975 Annual Report.* Prepared for [owner].

Water Body: Hudson River

Sampling frequency/dates: 4 days per week during 9 June-7 July and 2 days per week otherwise, 29 May-18 November 1975

Cooling Water Flow (M^3/min.): Not provided in report

Sample Location(s): Condenser cooling-water intake and discharge

Sampling Gear: Recessed impeller pump/larva table

Type of Survival Test(s): Initial and extended 96-hr. tests

Results Summary:

Species	Life Stage	Number Tested (discharge)	Initial Survival (%)	Extended Survival (%)	Total Entrainment Survival (%)
Striped Bass	PYSL	61	95.1	(a)	(a)
Clupeids	PYSL	326	55.6	(a)	(a)
Clupeids	Juveniles	65	81.5	(a)	(a)
White perch	PYSL	55	100.0	(a)	(a)
Cyprinidae	PYSL	12	52.4	100.0	34.8
Bay anchovy	PYSL	11	27.3	(a)	(a)

Note: PYSL = post-yolk sac larvae (a) =poor to no extended survival in either intake or discharge.

Remarks: Data based on Table 4.3-2 from report.

Table A-13
Entrainment Survival Study Summary, Fort Calhoun Nuclear Station, 1977

Power Plant:	Fort Calhoun Nuclear Station
Owner:	Omaha Public Power District
Plant Capacity (MWe):	481
Report Reference:	King, R. 1978. Entrainment of Missouri River Fish Larvae through Fort Calhoun Station, pp. 45-56 in: *Fourth National Workshop on Entrainment and Impingement* (L. Jensen, ed.). EA Communications, a Division of Ecological Analysts, Inc., Melville, NY.
Water Body:	Missouri River
Sampling frequency/dates:	Weekly during 1 June-13 July 1977
Cooling Water Flow (M^3/min.):	1,363
Sample Location(s):	Condenser cooling-water intake and discharge
Sampling Gear:	0.75-m dia. conical plankton nets with 571-µ mesh netting, affixed to a boat (intake) and to a frame at end of discharge tunnel
Type of Survival Test(s):	Initial survival
Results Summary:	Over 7 weekly sampling dates, initial survival of freshwater drum ranged from 5.8 to 40.5% (unweighted mean=19.3%). Corresponding survival data for "total larvae" (primarily freshwater drum, Catostomidae, and gizzard shad) were 8.4 to 80.6% (unweighted mean=32.6%). Intake survival averaged 6.2-times greater than discharge survival.
Remarks:	Sampling was done in 1974-1976 also, but those data are not presented here because "prior to 1977, intake mortalities were generally similar to or greater than mortalities recorded from the discharge…" Size-related mortality was not evident. Discharge temperatures ranged from 29 to 37°C.

Table A-14
Entrainment Survival Study Summary, Fort Calhoun Nuclear Station, 1973–1977

Power Plant:	Fort Calhoun Nuclear Station
Owner:	Omaha Public Power District
Plant Capacity (MWe):	481
Report Reference:	Carter, S. 1978. Macroinvertebrate Entrainment Study at Fort Calhoun Station, pp. 155-169 in: *Fourth National Workshop on Entrainment and Impingement* (L. Jensen, ed.). EA Communications, a Division of Ecological Analysts, Inc., Melville, NY.
Water Body:	Missouri River
Sampling frequency/dates:	2 times per month during October 1973-June 1977
Cooling Water Flow (M^3/min.):	1,363
Sample Location(s):	Condenser cooling-water intake and discharge
Sampling Gear:	0.75-m dia. conical plankton nets with 571-µ mesh netting, affixed to a boat
Type of Survival Test(s):	Initial survival

Results Summary:

Macroinvertebrate Group	Number Tested (discharge)	Initial Survival (%)
Ephemeroptera	2,220	91.7
Hydropsychidae	4,964	91.7
Other Trichoptera	872	92.5
Chironomidae	2,925	83.7
Other Diptera	380	87.1

Note: Initial survival calculated from the author's data by converting mortality proportions to survival proportions and dividing discharge survival by intake survival.

Remarks: Thermal tolerance limits of most macroinvertebrates were apparently not exceeded during study (discharge temperatures up to 37°C).

Table A-15
Entrainment Survival Study Summary, Ginna Generating Station, 1980

Power Plant:	Ginna Generating Station
Owner:	Rochester Gas & Electric Corporation
Plant Capacity (MWe):	517
Report Reference:	Ecological Analysts, Inc. 1981. *Entrainment Survival Studies.* Prepared for Empire State Electric Energy Research Corporation (ESEERCO).
Water Body:	Lake Ontario
Sampling frequency/dates:	10 days during 11-24 June and 10 days during 8-21 August 1980
Cooling Water Flow (M^3/min.):	1,514
Sample Location(s):	Condenser cooling-water intake and discharge
Sampling Gear:	Recessed-impeller pump/larva table; floating rear-draw larva flume
Type of Survival Test(s):	Initial and extended 96-hr. tests
Results Summary:	Rainbow smelt PYSL initial entrainment survival was zero. Initial survival of alewife eggs from the discharge was 62.5 percent. Extended survival of alewife eggs from the discharge was 19.4 percent after 4 days, and 16 percent after 8 days.

Remarks: Weather and physical nature of intake and discharge presented sampling difficulties that may have affected results. Intake survival of alewife eggs was poor, 16.3 percent initial, and 8.2 percent extended. Sampling was directed more at gear development that actual determination of entrainment survival.

Table A-16
Entrainment Survival Study Summary, Indian Point Generating Station, 1977

Power Plant: Indian Point Generating Station

Owner: Consolidated Edison Company of New York, Inc.
Power Authority of the State of New York

Plant Capacity (MWe): 1,838 (Units 2 and 3 combined)

Report Reference: Ecological Analysts, Inc. *Indian Point Generating Station Entrainment Survival and Related Studies, 1977 Annual Report*. Prepared for [owner].

Water Body: Hudson River

Sampling frequency/dates: 2 days per week during 1 June-15 July 1977

Cooling Water Flow (M^3/min.): 6,588 (Units 2 and 3 combined)

Sample Location(s): Unit 2 and 3 intake; Unit 3 discharge, Combined discharge

Sampling Gear: Pump/larva table

Type of Test(s): Initial and extended 96-hr. tests

Results Summary:

Species	Life Stage	Number Tested (Disch.)	Discharge Temperature (°C)	Initial Entrainment Survival (%)
Striped bass	YSL	18	26.0–29.9	63
Striped bass	PYSL	221	26.0–29.9	85
Striped bass	PYSL	19	30.0–32.9	87
White perch	PYSL	32	26.0–29.9	73
White perch	PYSL	12	30.0–32.9	89
Bay anchovy	PYSL	230	30.0–32.9	36
Bay anchovy	PYSL	91	33.0–33.9	18
Clupeids	PYSL	27	26.0–29.9	40

Note: YSL=yolk sac larvae; PYSL=post-yolk sac larvae.

Remarks: The entrainment survival was taken from table 4-10 in report. Because extended survival of striped bass and white perch was similar between intake and discharge samples, initial survival was judged to be best estimate of total entrainment survival. Initial survival also was used for bay anchovy and clupeids because of die offs in the extended tests of both intake and discharge samples.

Table A-17
Entrainment Survival Study Summary, Indian Point Generating Station, 1978

Power Plant: Indian Point Generating Station

Owner: Consolidated Edison Company of New York, Inc.
Power Authority of the State of New York

Plant Capacity (MWe): 1,838 (Units 2 and 3 combined)

Report Reference: Ecological Analysts, Inc. 1979 *Indian Point Generating Station Entrainment Survival and Related Studies, 1978 Annual Report.* Prepared for [owner].

Water Body: Hudson River

Sampling frequency/dates: 2 days per week during 1 May-12 July 1978

Cooling Water Flow (M^3/min.): 6,586 (Units 2 and 3 combined)

Sample Location(s): Unit 2 and 3 intake; Unit 2 and 3 discharge, Combined discharge

Sampling Gear: Pump/larva table

Type of Test(s): Initial and extended 96-hr. tests

Results Summary:

Species	Life Stage	Number Tested (Discharge)	Initial Survival (%)	Extended Survival (%)	Total Entrainment Survival (%)
Striped bass(a)	PSYL	36	13.0	0.0	0.0
White perch(a)	PSYL	35	0.0	na	0.0
Clupeids(a)	PSYL	192	13.3	0.0	0.0
Striped bass(b)	YSL	39	0.0	na	0.0
Striped bass(b)	PSYL	46	0.0	na	0.0
White perch(b)	PSYL	33	0.0	na	0.0
Clupeids(b)	PSYL	145	14.3	no test	—
Striped bass(c)	PSYL	237	58.3	100.0	63.6
Striped bass(c)	PSYL	232	68.8	100.0	81.8
White perch(c)	PSYL	64	70.8	82.3	58.3
White perch(c)	PSYL	64	58.3	42.9	25.0
Clupeids(c)	PSYL	170	16.7	(d)	—
Clupeids(c)	PSYL	92	16.7	(d)	—
Anchovies(c)	PSYL	222	0.0	na	0.0
Anchovies(c)	PSYL	188	0.0	na	0.0

Note: YSL=yolk sac larvae, PYSL=post-yolk sac larvae; (a)=Unit 3 intake and discharge sampling, 1 May-7 June; (b)=sampling at combined Unit 2 and 3 intakes, and the combined discharge of Units 2 and 3, 30 May-7 June; (c)=sampling at Unit 2 intake and discharge, 12-June-12 July; (d)=no extended survival at either intake or discharge; na=not applicable

Remarks: With the exceptions of anchovies (>32.9°C), most collections were made when discharge temperatures were 30-32.9°C. Reason for marked differences in survival between early and later studies unknown.

Table A-18
Entrainment Survival Study Summary, Indian Point Generating Station, 1979

Power Plant: Indian Point Generating Station

Owner: Consolidated Edison Company of New York, Inc.
Power Authority of the State of New York

Plant Capacity (MWe): 1,838 (Units 2 and 3 combined)

Report Reference: Ecological Analysts, Inc. 1981. *Indian Point Generating Station Entrainment Survival and Related Studies, 1979 Annual Report.* Prepared for [owner].

Water Body: Hudson River

Sampling frequency/dates: Daily during 12-15 and 19-22 March 1979; twice per week during 30 April-14 August 1979

Cooling Water Flow (M^3/min.): 6,400 (Units 2 and 3 combined)

Sample Location(s): Unit 2 and 3 intake; discharge

Sampling Gear: Pump/larva table (March Atlantic tomcod sampling); during April–August sampling, a rear-draw plankton flume was used at the Unit 3 intake, and a floating, pumpless plankton flume at the discharge

Type of Survival Test(s): Initial and extended 96-hr. tests

Results Summary:

Species	Life Stage	Discharge Temperature (°C)	Initial Entrainment Survival (%)
Atlantic tomcod	Larvae	12.0–15.9	63.8
Atlantic tomcod	Larvae	16.0–17.9	51.8
Atlantic tomcod	Larvae	18.0–19.9	29.3
Atlantic tomcod	Larvae	20.0–21.9	11.4
Striped bass	Eggs	24.0–28.0	73.6
Striped bass	YSL	<30.0	58.6
Striped bass	YSL	30.0–32.9	75.0
Striped bass	PYSL	<30.0	63.0
Striped bass	PYSL	30.0–32.9	70.1
White perch	PYSL	<30.0	32.0
White perch	PYSL	30.0–32.9	28.9
Clupeids	PYSL	<30.0	30.5
Clupeids	PYSL	30.0–32.9	22.2
Anchovies	PYSL	<30.0	7.0
Anchovies	PYSL	30.0–32.9	2.8

Note: YSL=yolk sac larvae; PYSL=post-yolk sac larvae

Remarks: Except for tomcod (intake corrected initial survival) and striped bass eggs (total entrainment survival), entrainment survival based on initial discharge survival (uncorrected for intake survival) as conservative estimate—due to differential sampling stress between rear-draw and pumpless flume.

Table A-19
Entrainment Survival Study Summary, Indian Point Generating Station, 1980

Power Plant: Indian Point Generating Station

Owner: Consolidated Edison Company of New York, Inc.
Power Authority of the State of New York

Plant Capacity (MWe): 1,838 (Units 2 and 3 combined)

Report Reference: Ecological Analysts, Inc. 1982. *Indian Point Generating Station Entrainment Survival and Related Studies, 1980 Annual Report.* Prepared for [owner].

Water Body: Hudson River

Sampling frequency/dates: 4 days per week during 30 April–10 July 1980

Cooling Water Flow (M^3/min.): 6,400 (Units 2 and 3 combined)

Sample Location(s): Unit 3 intake; discharge

Sampling Gear: Rear-draw plankton sampling flume (intake)
Pumpless plankton sampling flume (discharge)

Type of Survival Test(s): Initial and extended 96-hr. tests

Results Summary:

Species	Life Stage	Number Tested (discharge)	Discharge Temperature (°C)	Initial Survival (%)
Atlantic tomcod	PYSL	162	<26	87.7
Atlantic tomcod	Juvenile	25	>27	48.0
Striped bass	Eggs	147	24–31	57.5(a)
Striped bass	YSL	21	<29	66.7
Striped bass	YSL	16	30–32	56.2
Striped bass	PSYL	31	<29	74.2
Striped bass	PSYL	16	30–32	81.2
Striped bass	PSYL	160	>33	55.0
White perch	PSYL	49	<29	89.8
White perch	PSYL	117	>33	49.6
Clupeids	PSYL	13	<29	61.5
Anchovies	PSYL	24	<29	4.0
Anchovies	PSYL	556	>33	1.6

Note: YSL=yolk sac larvae; PSYL=post-yolk sac larvae; (a)=96-hr extended survival based on hatching success

Remarks: Extended survival at the discharge (not available by temperature category) was 95-100% of intake survival for most species; therefore initial survival was judged an appropriate estimate of total entrainment survival. For the tomcod, extended survival at the discharge (55.8%) was lower than at the intake (80%), suggesting an extended effect of entrainment. Overall results gave higher survival than previous studies at Indian Point, attributable to advances in sampling gear development.

Table A-20
Entrainment Survival Study Summary, Indian Point Generating Station, 1985

Power Plant:	Indian Point Generating Station
Owner:	Consolidated Edison Company of New York, Inc. Power Authority of the State of New York Jointly funded by: Central Hudson Gas and Electric Corp. Niagara Mohawk Power Corporation Orange and Rockland Utilities, Inc.
Plant Capacity (MWe):	1,838 (Units 2 and 3 combined)
Report Reference:	EA Science and Technology 1986, *Indian Point Generating Station Entrainment Survival Study 1985 Annual Report,* Prepared for [owner].
Water Body:	Hudson River
Sampling frequency/dates:	Daily during 27 May-29 June 1985
Cooling Water Flow (M^3/min.):	6,360 (Units 2 and 3 combined)
Sample Location(s):	Unit 2 intake, unit 2 discharge
Sampling Gear:	Net/Barrel Sampler
Type of Test(s):	Initial
Results Summary:	Sample sizes were adequate only for calculation of entrainment survival for post-yolk sac larval bay anchovy. Based on collection of 106 larvae from the intake, and 274 larvae from the discharge, initial survival was calculated as 24.3 %. Neither intake nor discharge specimens survived the 48-hr extended survival period, therefore, total entrainment survival could not be calculated. The best case estimate would be 24.3%, but it was very likely lower, possibly approaching zero. Discharge temperatures during the study period ranged from 26.6 to 30.3°C.

Table A-21
Entrainment Survival Study Summary, Indian Point Generating Station, 1988

Power Plant: Indian Point Generating Station

Owner: Consolidated Edison Company of New York, Inc.
Power Authority of the State of New York

Plant Capacity (MWe): 1,838 (Units 2 and 3 combined)

Report Reference: Ecological Analysts, Inc. *Indian Point Generating Station 1988 Entrainment Survival Study*. Prepared for [owner].

Water Body: Hudson River

Sampling frequency/dates: 3 days per week during 23 May-30 June 1988

Cooling Water Flow (M^3/min.): 6,360 (Units 2 and 3 combined)

Sample Location(s): Unit 3 intake, Combined unit 2 & 3 discharge

Sampling Gear: Rear-draw sampling flumes

Type of Test(s): Initial and extended 24-hr. tests

Results Summary:

Species	Life Stage	Number Tested Discharge	Initial Survival (%)	Extended Survival (%)	Total Entrainment Survival (%)
Bay anchovy	PYSL	6,929	25.0	(a)	(a)
Striped bass	YSL	312	72.0	83.3	60.0
Striped bass	PYSL	2,398	76.0	100.0	79.0
White perch	PYSL	341	45.0	84.4	38.0
Alosa spp.	PYSL	195	53.0	41.5	22.0

Note: YSL=yolk sac larva; PYSL=post-yolk sac larvae; (a)=no survival after 24 hours in either intake or discharge samples.

Remarks: The entrainment survival data were taken from table 4-6 in report. Extended survival was not calculated separately. For both the intake and discharge, the number surviving after 24 hrs was divided by the total number collected, thus automatically integrating initial and extended survival. The resulting discharge value was divided by the intake value to calculate total entrainment survival. For this summary, extended survival was calculated by dividing total entrainment (24-hr) survival by initial survival.

Table A-22
Entrainment Survival Study Summary, Indian River Power Plant, 1975–1976

Power Plant: Indian River Power Plant

Owner: Delmarva Power & Light Co. (now Conectiv)

Plant Capacity (MWe): 758

Report Reference: Ecological Analysts, Inc. 1978. *Impact of the Cooling Water Intake at the Indian River Power Plant: a § 316(b) Evaluation.* Prepared for [owner].

Water Body: Indian River Estuary, Delaware

Sampling frequency/dates: 1-2 days per month during 21 July 1975-13 December 1976

Cooling Water Flow (M^3/min.): 989

Sample Location(s): Condenser cooling-water intake and discharge

Sampling Gear: 0.5-m diameter conical plankton net with 0.5mm mesh

Type of Survival Test(s): Initial and extended 96-hr. tests

Results Summary:

Total Entrainment Survival (%) by Discharge Temperature Range

		Discharge Temperature (°C)			
Species	Life Stage	≤25	25-30	30-35	≥35
Bay anchovy	entrainable*	50.0–100.0	23.0	0.0	0.0
Atlantic croaker	entrainable*	57.0–100.0	34.0	11.0	0.0
Spot	entrainable*	100.0	81.0	53.0	25.0
Atlantic menhaden	entrainable*	87.0–100.0	55.0	24.0	0.0
Atlantic silverside	entrainable*	100.0	100.0	48.0	0.0
Neomysis americana	entrainable	90.0–97.0	87.0	37.0	28.0
Crangon septemspinosa	entrainable	80.0–100.0	56.0	33.0	9.0

*primarily larvae; some juveniles

Remarks: Bay anchovy data beset by significant mortality in control samples. Survival in temperature ranges determined by linear regression.

Table A-23
Entrainment Survival Study Summary, Monroe Power Plant, 1982

Power Plant: Monroe Power Plant

Owner: The Detroit Edison Company

Plant Capacity (MWe): 3,000

Report Reference: Ecological Analysts, Inc. 1982. *Entrainment Survival Studies at the Monroe Power Plant 1982.* Prepared for [owner].

Water Body: Raisin River, Western Lake Erie

Sampling frequency/dates: 4 days per week during the first 8 weeks, and 2 days per week during the last 2 weeks, 4-14 May and 24 May-8 July 1982

Cooling Water Flow (M^3/min.): 5,302

Sample Location(s): Condenser cooling-water intake and discharge

Sampling Gear: Rear-draw larva table (Barrel Sampler)

Type of Survival Test(s): Initial and extended 48-hr. tests

Results Summary:

Taxon	Life Stage	Number Tested (discharge)	Total* Entrainment Survival (%)
Clupeidae	Prolarvae	184	1.2(a)
Clupeidae	Prolarvae	457	15.3(b)
Clupeidae	Postlarvae	808	37.9(b)
Clupeidae	Juveniles	18	25(b)
Cyprinidae	Postlarvae	16	75(c)
White bass	Postlarvae	28	92.9(a)
Yellow perch	Prolarvae	550	2.6(b)
Yellow perch	Postlarvae	42	2.7(a)
Freshwater drum	Prolarvae	33	100(a)
Freshwater drum	Postlarvae	32	93.8(a)

*Total Entrainment Survival based on comparison of extended survival between intake and discharge, i.e.: (a)=initial survival; (b)=3-hr extended survival; (c)=24-hr extended survival.

Remarks: Daily discharge temperatures were primarily between 29 and 31°C. Survival of yellow perch and clupeids decreased with increasing discharge temperature. Younger clupeids (prolarvae) had lower survival. Total residual chlorine at ≥ 0.1 mg/L reduced survival of clupeid and yellow perch larvae. The number of circulating-water pumps operating did not affect survival.

Table A-24
Entrainment Survival Study Summary, Northport Generating Station, 1980

Power Plant: Northport Generating Station

Owner: Long Island Lighting Company

Plant Capacity (MWe): 1,500

Report Reference: Ecological Analysts, Inc. 1981. *Entrainment Survival Studies.* Prepared for Empire State Electric Energy Research Corporation (ESEERCO).

Water Body: Long Island Sound

Sampling frequency/dates: 10 days during 10-22 April and 10 days during 10-23 July 1980

Cooling Water Flow (M^3/min.): 3,465

Sample Location(s): Condenser cooling-water intake and discharge

Sampling Gear: Floating rear-draw larva flume

Type of Survival Test(s): Initial and extended 48-hr. tests

Results Summary:

Taxon	Life Stage	Number Tested (discharge)	Survival (%) Initial	Survival (%) Extended	Survival (%) Total
American sand lance	PYSL	782	25.3	7.1	1.8
Winter flounder	PSYL	17	41.7	23.0	9.6
Northern pipefish	Juvenile	24	55.0	92.6	51.0

Note:PYSL=post yolk-sac larvae

Remarks: American sand lance PYSL collected at the discharge were significantly larger than those collected at the intake, possibly due to vertical stratification of different larval sizes in the intake.

Table A-25
Entrainment Survival Study Summary, Oyster Creek Nuclear Generating Station, 1984–1985

Power Plant:	Oyster Creek Nuclear Generating Station
Owner:	GPU Nuclear Corporation
Plant Capacity (MWe):	630
Report Reference:	EA Engineering, Science, and Technology, Inc. 1986. *Entrainment and Impingement Studies at Oyster Creek Nuclear Generating Station 1984-1985.* Prepared for [owner].
Water Body:	Barnegat Bay, New Jersey
Sampling frequency/dates:	Weekly during February-March and May-August 1985
Cooling Water Flow (M^3/min.):	Not provided in report
Sample Location(s):	Condenser cooling-water intake and discharge
Sampling Gear:	Rear-draw plankton sampling flume (barrel sampler)
Type of Survival Test(s):	Initial and extended 96-hr. tests

Results Summary:

Species	Life Stage	Number Tested (discharge)	Discharge Temperature(°C)	Survival (%) Initial	Survival (%) Extended	Survival (%) Total
Bay anchovy	Eggs	*	<27	81.2	97.1	82.5
Bay anchovy	Eggs	*	32	50.6	78.7	39.8
Bay anchovy	Eggs	*	>33	42.7	31.3	16.7
Bay anchovy	Larvae	**	25.9–27.2	68.0	—	—
Bay anchovy	Larvae	**	30.2-35.0	67.6	—	—
Bay anchovy	Larvae	**	>35	0.1	—	—
Winter flounder	Larvae	***	13.5–14.8	93.9	88.7	83.5
Winter flounder	Larvae	***	18.3–20.3	66.5	19.7	14.8

Note: *=10,007, **=3,474, and ***=1,906 over all temperature ranges.

Remarks: Bay anchovy larvae data were initial survival only. Virtually all specimens held for 96 hours died. Holding system problems were implicated. Survival of all taxa decreased with increasing discharge temperature. The relationship of winter flounder larvae survival and delta-T was highly significant. Data in above table are arithmetic means of survival data within temperature groups.

Table A-26
Entrainment Survival Study Summary, Pittsburg Power Plant, 1976

Power Plant: Pittsburg Power Plant

Owner: Pacific Gas and Electric Company

Plant Capacity (MWe): 1,320

Report Reference: Stevens, D. and B. Finlayson. 1978. Mortality of Young Striped Bass Entrained at two Power Plants in the Sacramento-San Joaquin Delta, California, pp. 57-69 in: *Fourth National Workshop on Entrainment and Impingement* (L. Jensen, ed.). EA Communications, a Division of Ecological Analysts, Inc., Melville, NY.

Water Body: Suisun Bay, San Joaquin Delta, California

Sampling frequency/dates: Weekly during 28 April–10 July 1976

Cooling Water Flow (M^3/min.): 2,712

Sample Location(s): Condenser cooling-water intake and discharge

Sampling Gear: 0.75-m dia. conical plankton nets with 505-µ mesh netting, fished from a boat at mid-depth

Type of Survival Test(s): Initial survival, striped bass larvae

Results Summary:

Period	Mean Length (mm)	Discharge Temperature (°C)	Number Tested (discharge)	Initial Survival (%)
25 May-4 June	12.8	27–29	36	20.5
25 May-4 June	12.8	30–32	29	53.8
5 June-8 July	21.6	27–29	47	93.5
5 June-8 July	21.6	30–32	45	90.3
5 June-8 July	21.6	33–35	55	33.3
5 June-8 July	21.6	36–37	54	11.8

Note: Survival calculated from author's data by dividing initial proportion alive in discharge samples by initial proportion alive in intake samples.

Remarks: Based on the 5 June-8 July data, survival clearly decreased with increasing discharge temperature. The generally lower survival during 15 May–4 June may have been related to the smaller size of the larvae during that period.

Table A-27
Entrainment Survival Study Summary, Pittsburg Power Plant, 1978–1979

Power Plant:	Pittsburg Power Plant
Owner:	Pacific Gas and Electric Company
Plant Capacity (MWe):	1,320
Report Reference:	Ecological Analysts, Inc. 1981. *Pittsburg Power Plant Cooling Water Intake Structures 316(b) Demonstration.* Prepared for [owner].
Water Body:	Suisun Bay, San Joaquin Delta, California
Sampling frequency/dates:	Daily during May-July 1978 and May-June 1979 (striped bass) and July 1978-April 1979 (*Neomysis mercedis* and amphipods)
Cooling Water Flow (M^3/min.):	2,712
Sample Location(s):	Condenser cooling-water intake and discharge, Units 5 & 6
Sampling Gear:	Recessed-impeller pump/larva table
Type of Survival Test(s):	Initial and extended 96*-hr. tests

Results Summary:

Species	Discharge Temperature (°C)	Total Entrainment Survival (%)
Striped bass larvae	<30	60.8
Striped bass larvae	30.0–31.9	42.4
Striped bass larvae	32.0–33.9	19.1
Neomysis mercedis	<30	89.8
Neomysis mercedis	30.0–31.9	28.5
Neomysis mercedis	32.0–33.9	0.0
Neomysis mercedis	≥34	0.0
Gammaridean amphipods	<30	99.6
Gammaridean amphipods	30.0–31.9	100.0
Gammaridean amphipods	32.0–33.9	41.3
Gammaridean amphipods	≥34	21.4

Remarks: Total entrainment survival estimates based on 12-hr. extended observations; beyond 12 hours, mortality did not differ between intake and discharge*. Initial and extended survival estimates not broken out separately. Mortality of striped bass larvae varied among length groups with no apparent trends, and was greater during recirculation (data include both recirculation and non-recirculation samples.

Table A-28
Entrainment Survival Study Summary, Port Jefferson Generating Station, 1978

Power Plant: Port Jefferson Generating Station

Owner: Long Island Lighting Company

Plant Capacity (MWe): 490 (Units1, 2, 3, and 4 combined)

Report Reference: Ecological Analysts, Inc. Port Jefferson Generating Station Entrainment Survival Study, Prepared for [owner].

Water Body: Port Jefferson Harbor, Long Island Sound

Sampling frequency/dates: Daily during 21-26 April 1978

Sample Location(s): Cooling Water Unit 4 Intake/ Unit 3 & 4 combined Discharge

Sampling Gear: Pump/Larval table

Type of Test(s): Initial and extended 96-hr. tests

Results Summary:

Species	Life Stage	Number Tested (discharge)	Initial Survival (%)	Extended Survival (%)	Total Entrainment Survival (%)
Winter flounder	PYSL	23	100.0	64.9	64.9
Sand lance	PYSL	166	27.0(a)	90.9	24.5
Sand lance	PYSL	25	93.0	90.9	85.5(c)
Sculpin	PYSL	17	100.0	75.0	75.0
American eel	Juveniles	71	100.0(a)	100.0	100.0
American eel	Juveniles	25	100.0	100.0	100.0(c)
Fourbeard rockling	Eggs	102	(b)	100.0	100.0
Fourbeard rockling	Eggs	42	(b)	73.1	73.1(c)

Note: PYSL=post-yolk sac larvae; (a)=Intake samples taken at pump heads of 18-19 ft. were not used in the calculation of survival; (b)=equal initial live-dead ratios were assumed between intake and discharge since egg viability could not be determined until several days after collection; (c)=samples collected with Homelite pump; all others collected with Marlow submersible pump.

Remarks: The entrainment survival data was taken from Tables 2 and 4 in report. Intake temperatures ranged from 7-9°C and discharge temperatures ranged from 12-18°C.

Table A-29
Entrainment Survival Study Summary, Protrero Power Plant, 1979

Power Plant:	Protrero Power Plant
Owner:	Pacific Gas and Electric Company
Plant Capacity (MWe):	332
Report Reference:	Ecological Analysts, Inc. 1980. *Protrero Power Plant Cooling Water Intake Structures 316(b) Demonstration.* Prepared for [owner].
Water Body:	San Francisco Bay
Sampling frequency/dates:	Daily during 15–20, 22–25, and 27 January 1979
Cooling Water Flow (M^3/min.):	1,008
Sample Location(s):	Condenser cooling-water intake and discharge (Unit 3)
Sampling Gear:	Recessed-impeller pump/larva table
Type of Survival Test(s):	Initial and extended 96-hr. tests
Results Summary:	Over a 10-day period, 546 Pacific herring larvae were collected at the intake and 716 at the discharge over a consistent 18–19°C discharge temperature range. Based on initial survival of 73.7%, and 96-hr extended survival of 94.9%, total entrainment survival was calculated as 70 percent.

Remarks: Extended survival did not differ significantly between the intake and discharge, or among several length classes evaluated.

Table A-30
Entrainment Survival Study Summary, Quad Cities Station, 1978

Power Plant: Quad Cities Station

Owner: Commonwealth Edison Company

Plant Capacity (MWe): 1,242

Report Reference: Hazelton Environmental Sciences, Inc. 1978. *The Survival of Entrained Ichthyoplankton at Quad-Cities Station 1978.* Prepared for [owner].

Water Body: Mississippi River, Illinois

Sampling frequency/dates: Daily during 19–23 and 26-28 June 1978

Cooling Water Flow (M^3/min.): 3,793

Sample Location(s): Condenser cooling-water intake and discharge

Sampling Gear: 0.75-m dia. conical plankton net towed from boat (No. 0 mesh)

Type of Survival Test(s): Initial

Results Summary:

Species	Life Stage	Number Tested (discharge)	Discharge Temperature (°C)	Initial Survival (%)
Freshwater drum	Larvae/Juveniles	134	30.5–31.2	61.9
Freshwater drum	Larvae/Juveniles	254	32.5–33.0	30.4
Freshwater drum	Larvae/Juveniles	354	28.0–34.0	31.7
Freshwater drum	Larvae/Juveniles	174	38.0–39.0	2.4
Cyprinidae (non-carp)	Larvae/Juveniles	100	30.5–31.2	53
Cyprinidae (non-carp)	Larvae/Juveniles	34	32.5–33.0	62.8
Cyprinidae (non-carp)	Larvae/Juveniles	31	28.0–34.0	40.6
Cyprinidae (non-carp)	Larvae/Juveniles	142	38.0–39.0	7.3

Remarks: Above survival data based on including both opaque and transparent larvae in the "dead" category. Removing opaque (presumably dead prior to sampling) from analysis increased survival estimates. Extended (24-hr.) survival was observed for 226 "total ichthyoplankton" from the intake and 64 from the discharge at two temperature ranges. Extended survival was 45.5% at 28.0–33.0°C-discharge temperature, and 5.0% at discharge temperature of 38.0–39.0°C.

Table A-31
Entrainment Survival Study Summary, Quad Cities Station, 1984

Power Plant:	Quad Cities Station
Owner:	Commonwealth Edison Company
Plant Capacity (MWe):	1,242
Report Reference:	Lawler, Matusky & Skelly Engineers, Inc. 1985. *Quad-Cities Aquatic Program, 1984 Annual Report.* Prepared for [owner].
Water Body:	Mississippi River, Illinois
Sampling frequency/dates:	Weekly during 25 April-27 June 1984
Cooling Water Flow (M^3/min.):	3,793
Sample Location(s):	Condenser cooling-water intake and discharge
Sampling Gear:	0.75-m dia. conical plankton net towed from boat (No. 0 mesh)
Type of Survival Test(s):	Initial

Results Summary:

Species	Life Stage	Number Tested (discharge)	Discharge Temperature (°C)	Initial Survival (%)
Buffalo sp.	Larvae	40	30	93.9
Carp	Larvae	60	30	97.1
Carp	Larvae	36	33.5	91.9
Freshwater drum	Larvae	57	33.5	62.8

Remarks: Dead larvae that were opaque were not counted in this analysis. They were presumed to have been dead prior to collection. Overall, 3,967 larvae were collected in intake and discharge combined, and 2,979 of these, or 75.1 % were "dead opaque." The initial survival of 93.9 % for Buffalo sp. was calculated as a weighted mean for two sampling dates from this study.

Table A-32
Entrainment Survival Study Summary, Roseton Generating Station, 1975

Power Plant:	Roseton Generating Station
Owner:	Central Hudson Gas & Electric Corporation
Plant Capacity (MWe):	1,200
Report Reference:	Ecological Analysts, Inc. 1976. *Roseton Generating Station Impingement and Entrainment Survival Studies, Annual Report.* Prepared for [owner].
Water Body:	Hudson River
Sampling frequency/dates:	4 days per week during29 May-7 July and 2 days per week during 8 July-18 November 1975
Cooling Water Flow (M^3/min.):	2,460
Sample Location(s):	Condenser cooling-water intake and discharge
Sampling Gear:	Recessed impeller pump/larva table
Type of Survival Test(s):	Initial and extended 96-hr. tests
Results Summary:	

Species	Life Stage	Number Tested (discharge)	Initial Survival (%)	Extended Survival (%)	Total Entrainment Survival (%)
Striped Bass	PYSL	172	75.6	49.6	37.5
Clupeids	PYSL	833	40.0	(a)	(a)
Clupeids	Juveniles	243	44.8	(a)	(a)
White perch	PYSL	97	40.8	(a)	(a)
Cyprinidae	PYSL	40	100.0	100.0	100.0
Tessellated darter	PYSL	46	100.0	100.0	100.0
Gammarus daiberi	—	not provided	99.0	88.6	87.8
Chaoborus punctipennis	—	not provided	98.1	100.0	98.1

Note: PYSL = post-yolk sac larvae (a)=zero extended survival in both intake and discharge samples, suggesting sampling stress.

Table A-33
Entrainment Survival Study Summary, Roseton Generating Station, 1976

Power Plant: Roseton Generating Station

Owner: Central Hudson Gas & Electric Corporation

Plant Capacity (MWe): 1,200

Report Reference: Ecological Analysts, Inc. 1978. *Roseton Generating Station Entrainment Survival Studies, 1976 Annual Report.* Prepared for [owner].

Water Body: Hudson River

Sampling frequency/dates: 4 days per week during mid-June through July 1976

Cooling Water Flow (M^3/min.): 2,426

Sample Location(s): Condenser cooling-water intake and discharge

Sampling Gear: Recessed impeller pump/larva table

Type of Survival Test(s): Initial and extended 96-hr. tests

Results Summary:

Species	Life Stage	No. Tested (discharge)	Discharge Temperature (°C)	Survival (%) Initial	Survival (%) Extended	Survival (%) Total
Striped bass	PYSL	23	24.0–30.5	58	—	—
Striped bass	PYSL	57	30.6–37.0	18.9	—	—
Striped bass	Juveniles	10	30.6–37.0	80	—	—
White perch	PYSL	57	24.0–30.5	79.2	—	—
White perch	PYSL	292	30.6–37.0	11.3	—	—
White perch	Juveniles	25	30.6–37.0	59.6	—	—
Clupeids	PYSL	167	24.0–30.5	59.2	—	—
Clupeids	PYSL	478	30.6–37.0	10.2	—	—
Clupeids	Juveniles	57	24.0–37.0	16.2	—	—
Cyprininds	PYSL	16	24.0–37.0	69.1	—	—
Gammarus daiberi (1975)	—	167	<30.0	92.0–96.6	81.9–100.0	75.3–99.6
Gammarus daiberi (1975)	—	477	>30.0	68.3–99.0	55.8–90.6	38.1–90.6
Gammarus daiberi (1976)	—	202	11.3–29.2	87.8–91.3	73.4–97.5	64.4–89.0
Chaoborus punctipennis (1975)	—	162	<30.0	96.6–97.4	92.3–100.0	89.2–97.4
Chaoborus punctipennis (1975)	—	477	>30.0	83.8–98.6	69.8–100.0	58.5–98.6
Chaoborus punctipennis (1976)	—	62	<30.0	90.0–97.0	83.4–100.0	75.1–97.0
Chaoborus punctipennis (1976)	—	120	>30.0	95.6–96.5	100.0–100.0	95.6–96.5

Note: PYSL= post-yolk sac larvae.

Remarks: Because of smaller sample sizes, extended survival was calculated on pooled data for striped bass and white perch (*Morone* sp.) for PYSL and juveniles, and also for clupeids. Extended survival was similar (and low--<20%) at intake and discharge for *Morone* sp., similar and relatively high for *Morone* juveniles, and zero at both intake and discharge for clupeids.

Table A-34
Entrainment Survival Study Summary, Roseton Generating Station, 1977

Power Plant: Roseton Generating Station

Owner: Central Hudson Gas & Electric Corporation

Plant Capacity (MWe): 1,200

Report Reference: Ecological Analysts, Inc. 1978. *Roseton Generating Station Entrainment Survival Studies, 1977 Annual Report.* Prepared for [owner].

Water Body: Hudson River

Sampling frequency/dates: 4 days per week during 3-17 March and 31 May-14 July 1977

Cooling Water Flow (M^3/min.): 2,426

Sample Location(s): Condenser cooling-water intake and discharge

Sampling Gear: Recessed impeller pump/larva table

Type of Survival Test(s): Initial and extended 24 and 96-hr. tests

Results Summary:

Species	Life Stage	Number Tested (discharge)	Discharge Temperature (°C)	Initial Survival (%)
Striped bass	PYSL	400	24.0–29.9	58
Striped bass	PYSL	325	30.0–32.9	32
Striped bass	PYSL	40	33.0–36.0	6
Striped bass	Juveniles	12	24.0–29.9	100
White perch	PYSL	155	24.0–29.9	52
White perch	PYSL	78	30.0–32.9	45
White perch	PYSL	33	33.0–36.0	0
Clupeids	PYSL	874	24.0–29.9	19
Clupeids	PYSL	389	30.0–32.9	11
Clupeids	PYSL	81	33.0–36.0	0
Clupeids	Juveniles	14	24.0–29.9	24
Clupeids	Juveniles	22	30.0–32.9	0
Clupeids	Juveniles	51	33.0–36.0	0
Atlantic tomcod	YSL	1,345	7.0–17.0	41

Note: YSL=yolk sac larvae; PYSL=post-yolk sac larvae

Remarks: Initial survival estimates were compared to discharge temperature, and found to decrease with increasing temperature. Extended survival did not differ between intake and discharge for white perch and clupeids. However, intake/discharge differences in extended survival for striped bass larvae and juveniles, and Atlantic tomcod larvae were significant. Consequently, total entrainment survival of these taxa would be somewhat less than reflected in the initial survival estimates. Survival increased with an increase in the number of circulating-water pumps operating. Survival of striped bass, white perch, and clupeids increased with increasing larval lengths.

Table A-35
Entrainment Survival Study Summary, Roseton Generating Station, 1978

Power Plant: Roseton Generating Station

Owner: Central Hudson Gas & Electric Corporation

Plant Capacity (MWe): 1,200

Report Reference: Ecological Analysts, Inc. 1980. *Roseton Generating Station Entrainment Survival Studies, 1978 Annual Report.* Prepared for [owner].

Water Body: Hudson River

Sampling frequency/dates: 4 days per week during 13-23 March and 6 June-13 July 1978

Cooling Water Flow (M^3/min.): 2,426

Sample Location(s): Condenser cooling-water intake and discharge

Sampling Gear: Recessed impeller pump/larva table

Type of Survival Test(s): Initial and extended 24 and 96-hr. tests

Results Summary:

Species	Life Stage	Number Tested (Disch.)	Survival (%) Initial	Survival (%) Extended	Survival (%) Total
Striped bass	PYSL	211	46.3	100.0	46.3(a)
White perch	PYSL	459	58.1	96.0	55.8(a)
White perch	PYSL	17	100.0	96.0	96.0(b)
White perch	Juveniles	17	88.3	62.4	55.1(b)
Clupeids	PYSL	1,089	21.0	0.0	0.0(a)
Clupeids	PYSL	43	17.8	0.0	0.0(b)
Atlantic tomcod	YSL	13	30.8	100.0	30.8(a)
Atlantic tomcod	YSL	16	66.7	100.0	66.7(b)
Atlantic tomcod	PYSL	64	38.9	100.0	38.9(a)

Note: PYSL=post-yolk sac larvae: (a)=one unit, 2-pump operation, (b)=two unit, 3-pump operation.

Remarks: The entrainment data showed that survival increased with increase in fish length and decreased with increase in discharge temperature exposure.

Table A-36
Entrainment Survival Study Summary, Roseton Generating Station, 1980

Power Plant:	Roseton Generating Station
Owner:	Central Hudson Gas & Electric Corporation
Plant Capacity (MWe):	1,200
Report Reference:	Ecological Analysts, Inc. 1983. *Roseton Generating Station Entrainment Survival Studies, 1980 Annual Report.* Prepared for [owner].
Water Body:	Hudson River
Sampling frequency/dates:	4 days per week during 26 May–31 July 1980
Cooling Water Flow (M^3/min.):	2,460
Sample Location(s):	Condenser cooling-water intake and discharge
Sampling Gear:	Recessed impeller pump/larva table and Plankton Flume
Type of Survival Test(s):	Initial and extended 48-hr. tests

Results Summary:

Species	Life Stage	Entrainment Survival (%) (a)
Striped Bass	YSL	87.8
Striped Bass	PYSL	88.2
Striped Bass	Juveniles	70.6
White perch	PYSL	67.3
White perch	Juveniles	100.0
Clupeids	PYSL	22.7
Clupeids	Juveniles	0.0

Note: YSL = yolk sac larvae; PYSL = post-yolk sac larvae (a) = Data are initial survival because either extended survival did not differ significantly between intake and discharge (striped bass juveniles and white perch PYSL), or was higher in the discharge samples (clupeids and striped bass YSL/PYSL). Extended survival not reported for white perch juveniles. Data from pump/larva table only.

Remarks: Results indicate that initial survival was generally higher for the plankton (pumpless) flume which may be related to the lack of pump-induced stress with the flume or higher flow rates associated with pump collection. However, entrainment survival estimates could not be based on the flume because of problems sampling the intake. Survival increased with length of striped bass and white perch larvae. With the exception of striped bass juveniles, initial survival was judged the best estimate of total entrainment survival. Data taken from table 4-4 in the report.

Target:
Section 316(a) and (b) Fish Protection Issues

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