Chapter A7: Entrainment Survival

Introduction

To calculate benefits associated with entrainment reduction, EPA used the assumption that all organisms passing through a facility's cooling water system would experience 100 percent mortality. This assumption was recommended in EPA's 1977 Guidance for Evaluating the Adverse Environmental Impact of Cooling Water Intake Structures on the Aquatic Environment: Section 316(b) P.L. 92-500 (U.S. EPA, 1977). This is also the basic assumption currently used in the permitting programs for section 316(b) in Arizona, California, Hawaii, Louisiana, Maine, Maryland, Massachusetts, Minnesota, Nevada, New Hampshire, Ohio and Rhode Island (personal communication, I. Chen, U.S. EPA Region 6, 2002; personal communication, P. Colarusso, U.S. EPA Region 1, 2002; personal communication, G. Kimball, 2002; personal communication, M. McCullough, Ohio EPA, 2002; McLean and Dieter, 2002; personal communication, R. Stuber, U.S. EPA Region 9, 2002).

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In comments on the Proposed Regulations to Establish Requirements for Cooling Water Intake Structures at Phase II Existing Facilities; Proposed Rule, a few stated that this assumption may be incorrect and cited studies in which entrainment survival has been demonstrated. These entrainment survival studies were conducted by facilities to demonstrate that some organisms may survive the passage through the cooling water intake structure, and thus the assumption of 100 percent mortality may not be justified at their site.

EPA obtained 37 entrainment survival studies conducted at 22 individual power producing facilities and conducted a detailed review. Twenty of these facilities are in-scope for the section 316(b) Phase II rule for existing facilities. These facilities represent 3.7 percent of all section 316(b) Phase II existing facilities. EPA also reviewed a report prepared for the Electric Power Research Institute (EPRI) (EA Engineering Science and Technology, 2000) which summarized the results of 36 entrainment studies, 31 of which were the same studies reviewed by EPA. The intent of EPA's review was to determine the soundness of the findings behind the entrainment survival studies and to evaluate whether the assumption of 100 percent entrainment mortality is appropriate for use in the national benefits assessment for the section 316(b) Phase II rule to compare to the costs of installing the best technology available for minimizing adverse environmental impact.

A7-1 The Causes of Entrainment Mortality

A7-1.1 Fragility of Entrained Organisms

Cooling water intake structures entrain many species of fish, shellfish, and macroinvertebrates. These species are most commonly entrained during their early life stages, as eggs, yolk-sac larvae (YSL), post yolk-sac larvae (PYSL), and juveniles, because of their small size and limited swimming ability. In addition to having limited or no mobility, these early life stages are very fragile and thus susceptible to injury and mortality from a wide range of factors (Marcy, 1975). For these reasons, entrained eggs and larvae experience high mortality rates as a result of entrainment. The three primary factors contributing to the mortality of organisms entrained in cooling water systems are thermal stress, mechanical stress, and chemical stress

(Marcy, 1975). The relative contribution of each of these factors to the rate of mortality of entrained organisms can vary among facilities, based on the nature of their design and operations as well as the sensitivity of the species entrained (Marcy, 1975; Beck and the Committee on Entrainment, 1978; Ulanowicz and Kinsman, 1978). These three primary factors are discussed in more detail below.

A7-1.2 Thermal Stress

Facilities use cooling water as a means of disposing of waste heat from facility operations. Thus, organisms present in the cooling water are exposed to rapid increases in temperatures above ambient conditions when passing through the cooling water system. This thermal shock causes mortality or sublethal effects that affect further growth and development of entrained eggs and larvae (Schubel *et al.*, 1978; Stauffer, 1980). The magnitude of thermal stress experienced by organisms passing through a facility's cooling system depends on facility-specific parameters such as intake temperature, maximum temperature, discharge temperature, duration of exposure to elevated temperatures through the facility and in the mixing zone of the discharge canal, the critical thermal maxima of the species, and delta T (ΔT, i.e., the difference between ambient water temperature and maximum water temperature within the cooling system) (Marcy, 1975; Schubel *et al.*, 1978). The extent of the effect of thermal stress can also vary among the species and life stages of entrained organisms (Schubel *et al.*, 1978; Stauffer, 1980).

A7-1.3 Mechanical Stress

Entrained organisms are also exposed to significant mechanical stress during passage through a cooling system, which also causes mortality. Types of mechanical stress include effects from turbulence, buffeting, velocity changes, pressure changes, and abrasion from contact with the interior surfaces of the cooling water intake structure (Marcy, 1973; Marcy *et al.*, 1978). The extent of the effect of mechanical stress depends on the design of the facility's cooling water intake structure and the capacity utilization of operation. Some studies have suggested that mechanical stress may be the dominant cause of entrainment mortality at many facilities (Marcy, 1973; Marcy *et al.*, 1978). For this reason, it has been suggested that the only effective method of minimizing adverse effects to entrained organisms is to reduce the intake of water (Marcy, 1975).

A7-1.4 Chemical Stress

Chemical biocides are occasionally used within cooling water intake structures to remove biofouling organisms. Chlorine is the active component of the most commonly used biocides (Morgan and Carpenter, 1978; Morgan, 1980). These biocides are used in concentrations sufficient to kill organisms fouling the cooling system structures, and thus cause mortality to the organisms entrained during biocide application. The extent of the effect of chemical stress depends on the concentration of biocide and the timing of its application. Eggs may be less susceptible to biocides than larvae (Lauer *et al.*, 1974; Morgan and Carpenter, 1978). Tolerance to biocides may also vary according to species. However, most species have been shown to be affected at low concentrations, < 0.5 ppm, of residual chlorine (Morgan and Carpenter, 1978).

A7-2 Factors Affecting the Determination of Entrainment Survival

There are many challenges that must be overcome in the design of a sampling program intended to accurately establish the magnitude of entrainment survival (Lauer *et al.*, 1974; Marcy, 1975; Coutant and Bevelhimer, 2001). Samples are almost certain not to be fully representative of the community of organisms experiencing entrainment. Some species are extremely fragile and disintegrate during collection or when preserved, and are thus not documented when samples are processed (Boreman and Goodyear, 1981). This is particularly true for the most fragile life stages, such as eggs and yolk-sac larvae of many species. All sampling devices are selective for a certain size range of organisms, so a number of sampling methods would have to be employed to accurately sample the broad size range of organisms subject to entrainment. The relative ability of different organisms to avoid sampling devices also determines abundance and species composition estimated from samples (Boreman and Goodyear, 1981). This avoidance ability varies with the size, motility, and condition of the organisms. If dead or dying organisms tend to settle out, then sampling will be selective for the live, healthy specimens (Marcy, 1975). If, on the other hand, the healthy, more motile specimens are able to avoid sampling gear, the sampling will tend to be selective for dead or stunned specimens. The patchy distribution of many species (Day *et al.*, 1989; Valiela, 1995) creates difficulties in developing precise estimates of organism densities (Boreman and Goodyear, 1981). The patchier the distribution, the greater the number of samples required to reduce the uncertainty associated with the density estimates to an acceptable level.

The factors just discussed affect the ability to accurately establish the type and abundance of organisms present at the intake and discharge of a cooling water system. A second suite of factors, superimposed on the first, affects the ability to estimate the percentages of those organisms that are alive and dead at those two locations. The greatest challenge to be overcome is posed by the fragility of the organisms being studied. The early life stages of most species are so fragile that they may experience substantial mortality simply due to being sampled, both from contact with the sampling gear and in being handled for subsequent evaluation. For example, Marcy (1973) reported on the effects of current velocity on percent mortality of ichthyoplankton taken in plankton nets, and found sampling mortality of 18 percent at velocities of 0.3 to 0.6 m/sec. The loss or damage of organisms beyond identification during plant passage causes overestimations of the true fraction of live organisms in the discharge samples, because the disintegrated organisms are extruded from the sampling device (Boreman and Goodyear, 1981).

The entrainment survival studies addressed in this review quantified survival by estimating the percentage of organisms categorized as alive, stunned, or dead present in samples collected at the intake and discharge locations of a facility. In the studies reviewed, a variety of methods were used to determine the physiological state of sampled organisms, ranging from placing the sampled organisms in various types of holding containers for observation to the use of devices specifically designed for assessment of larval survival, such as a larval table. A variety of criteria was also used in these studies to categorize the physiological status of the organisms, such as opacity as an indicator of a dead egg, and movement of a larva in response to being touched as an indicator of being alive or stunned. The lack of standardized procedures applied for assessing physiological condition in all of the studies reviewed made comparisons of the study findings difficult.

When quantifying entrainment survival, these studies used the estimates of the percentage dead from samples collected at the intake as controls to correct the samples at the discharge for mortality associated with natural causes and with sampling and handling stress. The use of intake samples as controls requires the assumption that sampling- and handling-induced mortality rates be the same at the intake and discharge, which, in turn, requires that sampling methods and conditions be nearly identical in both locations (Marcy, 1973). This requirement is difficult to meet at most facilities because of the differences in the physical structures and hydrodynamic conditions at intakes and discharges (e.g., frequently high velocity, turbulent flow at discharges versus lower velocity, laminar flows at intakes). In many cases, the location and design of the cooling water intake and discharge structures may preclude use of the same type of sampling gear in both locations. Another assumption implicit in this approach is that mortality due to entrainment is entirely independent of mortality due to sampling and handling and that there is no interaction between these stresses, an assumption that is acknowledged but never proven in the studies reviewed.

The percent alive in the intake control is frequently well below 100 percent because these fragile organisms experience substantial mortality from stresses caused by being collected. An additional factor contributing to the less than 100 percent alive in intake samples is that some dead organisms may be present in the water column being sampled because of natural mortality or recirculation of water discharged from the cooling system. In many studies, the survival in the intake sample is extremely low; for example, the intake survival for bay anchovy was 0 percent in studies conducted at Bowline (Ecological Analysts Inc., 1978a), Brayton Point (Lawler, Matusky & Skelly Engineers, 1999), and Indian Point (Ecological Analysts Inc., 1978c; EA Engineering Science and Technology, 1989). The studies reviewed corrected their discharge survival estimates to account for the control sample mortality by using the percent alive in the intake control samples in the following manner. First, the proportion initially alive at the intake (P_I) and discharge (P_D) samples was determined, for each species in most cases, using the following equation:

$$P_I \text{ or } P_D = \frac{\text{Number of alive and stunned organisms}}{\text{Total number of organisms collected}}$$

Using the intake proportion as the control, initial percent entrainment survival (S_I) was then calculated using the following equation:

$$S_I = \left[\frac{P_D}{P_I}\right] \times 100$$

When latent mortality was studied, a sample of the alive and stunned organisms from the initial entrainment survival determination was observed for a given period of time. The latent survival rate calculated is the proportion of those that remained alive after a given period of time from only those that survived initially and not the total number sampled. The latent percent survival (S_L) was determined using the following equation:

$$S_L = 100 \times \left[\frac{\dfrac{\#\ \text{of alive organisms after a given time from discharge samples}}{\#\ \text{of organisms initially sampled alive or stunned indischarge samples}}}{\dfrac{\#\ \text{of alive organisms after a given time from intake samples}}{\#\ \text{of organisms initially sampled alive or stunned in intake samples}}} \right]$$

Entrainment survival was then calculated by adjusting the initial entrainment survival with latent entrainment survival using the following equation:

$$\text{Entrainment Survival (\%)} = S_I \times S_L$$

A variation of this formula, specifically Abbott's formula, is used for acute toxicity testing in the Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms (U.S. EPA, 2002d; EPA-821-R-02-012) and in testing of pesticides and toxic substances in Product Performance Test Guidelines OPPTS 810.3500 Premises Treatments (U.S. EPA, 1998b; EPA-712-C-98-413), to adjust mortality for the possibility of natural deaths occurring during a test. This formula is intended to account for acceptable levels of unavoidable control mortality in the range of 5 to 10 percent (Newman, 1995). Abbott's formula is as follows:

$$\text{Corrected mortality} = 1 - \left[\frac{1 - \text{proportion dead in treatment}}{1 - \text{proportion dead in control}} \right]$$

This method of correcting for control mortality is often used in toxicological experiments in which organisms in concurrent control and experimental samples experience identical conditions except for the stressor that is the subject of study, and, as already noted, this method is applied when control mortalities, from stress due to holding or sampling and from natural causes, are generally low (less than 10 percent). In entrainment survival studies, sampling conditions at the intake and discharge are seldom identical. Also, the initial mortalities in the intake samples are often much higher than 5 or 10 percent and sometimes higher than the mortality in the discharge samples.

In addition, the assumption that mortality due to entrainment is entirely independent of mortality due to sampling and handling with no interaction between these stresses is not true. The dead organisms observed in the intake samples comprise organisms that died before sampling from natural conditions, organisms that died from the stress of sampling and sorting, and possibly organisms that died from previous passages through the cooling water system at facilities where water is recirculated. The dead organisms observed in the discharge samples comprise organisms that died before passage through the facility from natural conditions, organisms that died from the stresses associated with entrainment as described above, and organisms that died from the stress of sampling and sorting. The fundamental difference between the extent of the effect of sampling stress in the intake and the discharge samples is that the discharge samples are exposed to sampling stress after they have been exposed to entrainment stress. Thus the most vulnerable organisms have already died because of entrainment and would not be alive at the time of sampling to die from that stress. By correcting discharge samples for sampling and natural deaths using the intake results, the assumption is made that the mortality in the discharge sample is the result of the same probability of death due to sampling as in the intake sample and only the additional mortality is due to the stress of entrainment. When intake survival (P_I) is less than discharge survival (P_D), the use of the equation for entrainment survival (S_I) results in a calculation of 100 percent survival even though the majority of organisms may be dead in both samples (EA Engineering Science and Technology, 2000). However, in the intake sample, much of the mortality may be due to sampling stress, whereas in the discharge sample, much of the mortality may be due to entrainment stress. Additionally, the initial survival estimates may be overestimations of survival due to the disintegration of entrained organisms and their subsequent extrusion through the sampling gear (Boreman and Goodyear, 1981). For all of the reasons described above, the applicability of this equation for determining entrainment survival by correcting discharge survival with intake survival is questionable. Also, the statistical attributes of these calculated mortality proportions are often not addressed. The higher and more variable the intake sample mortality percentages, the greater the degree of uncertainty that would be expected to be associated with the resultant entrainment survival estimates.

An additional factor that was not accounted for in all the studies reviewed was the fate of organisms discharged into receiving waters after passage through the cooling system. Latent mortality studies were intended to document delayed mortality of organisms that were lethally injured or stressed during entrainment but were not killed immediately. Some studies (e.g., Lauer *et al*, 1974) also reported that some fish larvae surviving entrainment behaved normally when maintained in laboratory conditions for extended periods of time, eating and growing normally. However, larvae that did not experience immediate mortality from lethal stresses were discharged into receiving waters under conditions substantially altered from the normal environment in which they were present before entrainment and under conditions very dissimilar to those experienced under laboratory conditions. Any naturally occurring vertical positioning of the organisms within the water column would be disrupted (Day *et al.*, 1989), and the turbulence and velocities present in discharge locations would be unlike the environmental conditions they experienced before entrainment. Under such altered conditions, their normal ability to feed or escape predation is compromised. In addition, thermal shock can disrupt further development of eggs and larvae even if they survive entrainment (Schubel *et al.*, 1978). The potential for such phenomena to occur and the magnitude the effect may have on any possible survival of entrained organisms would be nearly impossible to confirm or refute through field studies. However, were these phenomena to occur, they would result in mortalities beyond and in addition to the initial and latent mortalities that were calculated in the studies reviewed.

The factors discussed above served as the basis for EPA's review of the entrainment survival studies. Table A7-1 presents summary information collected directly from each of the original studies reviewed.

Table A7-1: Summary of Entrainment Survival Study Results

Facility	Sampling Period	Number of Samples and Days	Species	Number Sampled at Intake	Number Sampled at Discharge	Survival Study	Initial Discharge Survival	Latent Discharge Survival	Study Survival Estimate
Anclote	September - November 1985	120 samples 8 days	Fish larvae Amphipods Chaetognatha Crab larvae Caridean shrimp	109 5185 1549 3007 2728	474 4662 1927 6145 1766	initial and 24 hour latent	8 - 47% 29 - 58% 28 - 35% 74 - 80% 45 - 66%	- - - - -	27 - 62% 49 - 73% 67 - 72% 21 - 100% 64 - 81%
Bergum Power Station	April - June 1976	unknown # 6 days	smelt perches	unknown unknown	322 826	initial	10 - 28% 32 - 74%	- -	10-41% 39-82%
Bowline Point	June - July 1975	unknown # unknown days	striped bass white perch bay anchovy	141 122 2134	111 168 1317	initial and 96 hour latent	74% 68% 2%	23% 26% 0%	70% 100% 22%
Bowline Point	May - July 1976	unknown # 10 days	striped bass PYSL white perch PYSL bay anchovy PYSL herrings PYSL Atlantic tomcod PYSL	118 54 148 46 54	207 42 1120 83 17	initial and 96 hour latent	54% 33% 0% 20% 29%	23% 21% 0% 1% 12%	26 - 77% 13 - 84% – 0 - 80% 54%
Bowline Point	March - July 1977	736 samples 46 days	striped bass larvae white perch PYSL bay anchovy larvae herrings PYSL silverside PYSL	228 26 634 37 24	452 38 1524 22 56	initial and 96 hour latent	71 - 72% 34% 0 - 2% 23% 16%	55 - 66% 69% 0% 5% 0%	41 - 100% 16 - 62% – 51% –
Bowline Point	March - October 1978	609 samples 40 days	striped bass PYSL white perch PYSL bay anchovy PYSL herrings PYSL	646 190 325 271	792 301 763 51	initial and 96 hour latent	52 - 63% 19% 0 - 3% 23 - 63%	5 - 46% 0-5% 0% 0%	76 - 100% 52 - 68% – –
Bowline Point	May - June 1979	435 samples 19 days	striped bass PYSL white perch PYSL bay anchovy PYSL herrings PYSL	77 205 181 63	155 191 89 92	initial and 96 hour latent	35 - 41% 26 - 35% 0 - 4% 30 - 31%	8-20% 5-8% 0% 0-3%	24 - 42% 32% – 0 - 58%
Braidwood Nuclear	June - July 1988	68 samples 3 days	all species combined	191	103	initial	59%	-	100%
Brayton Point	April - August 1997 February - July 1998	6829 samples 41 days	winter flounder tautog windowpane flounder bay anchovy american sand lance	49 34 58 539 1091	965 401 58 15896 2941	initial and 96 hour latent	30 - 38% 4% 29 - 30% 0% 0%	- - - - -	90 - 100% 98 - 100% 65 - 67% 0% 100%
Cayuga Generating Plant	May - June 1979	80 samples 24 days	suckers carps and minnows perches	984 466 108	649 192 66	initial and 48 hour latent	75 - 92% 12 - 74 % 43 - 69%	93 - 98% 45 - 100% 44 - 61%	87 - 98% 25 - 86% 19 - 59%

Table A7-1: Summary of Entrainment Survival Study Results

Facility	Sampling Period	Number of Samples and Days	Species	Number Sampled at Intake	Number Sampled at Discharge	Survival Study	Initial Discharge Survival	Latent Discharge Survival	Study Survival Estimate
Connecticut Yankee	June - July 1970	102 samples 7 days	alewife blueback herring	unknown	unknown	initial	0-8%	-	0-25%
Connecticut Yankee	June - July, 1971 and 1972	30 samples 2 days	alewife blueback herring	273	795	initial	0 - 24%	-	0-26%
Contra Costa	April - July, 1976	unknown # 7 days	striped bass	637	329	initial	0 - 50%	-	0-95%
Danskammer Point Generating Station	May - November 1975	372 samples 29 days	striped bass PYSL white perch PYSL herrings PYSL	54 36 200	61 55 326	initial and 96 hour latent	39% 38% 20%	3% 4% 0%	95% 100% 80 - 87%
Fort Calhoun	October 1973 - June 1977	unknown # 89 days	Ephemeroptera Hydropsychidae Chironomidae	2221 3690 2646	2220 4964 2925	initial	18 - 32% 47 - 56% 43 - 66%	- - -	92% 92% 84%
Ginna Generating Station	June and August, 1980	255 samples 20 days	alewife larvae rainbow smelt larvae	54 31	95 17	initial and 48 hour latent	0% 0%	- -	- 0%
Indian Point	June and July, 1977	unknown # 7 days	striped bass PYSL white perch PYSL bay anchovy PYSL herrings PYSL	806 158 1254 100	518 67 704 65	initial and 96 hour latent	45 - 52% 15 - 43% 3 - 4% 10 - 11%	29 - 36% 15 - 30% 0% 0%	85 - 87% 73 - 89% 18 - 36% 40%
Indian Point	May - July, 1978	unknown # 22 days	striped bass PYSL white perch PYSL bay anchovy PYSL herrings PYSL	447 227 500 1046	1102 392 820 1104	initial and 96 hour latent	0 - 34% 0 - 37% 0% 0 - 8%	0-19% 6-15% 0% 0%	0 - 82% 0 - 58% 0% 0%
Indian Point Generating Station	March - August 1979	unknown # 40 days	Atlantic tomcod striped bass white perch herrings bay anchovy	266 127 195 254 457	212 153 147 186 485	initial and 96 hour latent	14 - 46% 62 - 77% 24 - 70% 28% 6%	15 - 75% 4 - 21% 18% 13% 4%	11 - 64% 59 - 75% 29 - 32% 22 - 31% 3 - 7%
Indian Point Generating Station	April - July 1980	unknown # 44 days	striped bass bay anchovy white perch	227 260 113	248 588 176	initial and 96 hour latent	50 - 81% 0 - 4% 0 - 90%	60-72% 0% 73%	55-81% 2-4% 50-90%
Indian Point Generating Station	May - June 1985	unknown # 49 days	bay anchovy PYSL	106	274	initial and 48 hour latent	6%	0%	0-24.3%
Indian Point Generating Station	June 1988	unknown # 13 days	striped bass larvae bay anchovy larvae	353 633	2710 7391	initial and 24 hour latent	62 - 68% 0 -2%	24 - 44% 0%	60-79% 0-25%
Indian River Power Plant	July 1975 - December 1976	46 samples 27 days	bay anchovy Atlantic croaker spot Atlantic menhaden Atlantic silverside	unknown	unknown	initial and 96 hour latent	unknown	unknown	0 - 100% 0 - 100% 25 - 100% 0 - 100% 0 - 100%
Muskingum River Plant	1979	no samples	none specified	0	0	none	intermediate to high potential	-	–
Northport Generating Station	April and July, 1980	162 samples 20 days	American sand lance winter flounder bay anchovy	29 13 7	782 17 11	initial and 48 hour latent	17% 35% 0%	2% 17% 0%	2% 10% –

Table A7-1: Summary of Entrainment Survival Study Results

Facility	Sampling Period	Number of Samples and Days	Species	Number Sampled at Intake	Number Sampled at Discharge	Survival Study	Initial Discharge Survival	Latent Discharge Survival	Study Survival Estimate
Oyster Creek Nuclear Generating Station	February - August 1985	28 samples 20 days	bay anchovy larvae winter flounder larvae	3396 3935	3474 2999	initial and 96 hour latent	0 - 71% 32 - 92%	0% 6 - 66%	0 - 68% 15 - 84%
Pittsburg Power Plant	April - July, 1976	unknown # 7 days	striped bass	196	266	initial	8 - 87%	-	12-94%
Port Jefferson	April 1978	94 samples 5 days	winter flounder sand lance fourbeard rockling American eel sculpin	36 249 216 107 22	26 191 144 96 17	initial and 96 hour latent	0 - 23% 12 - 40% 19 - 21% 94 - 96% 88%	50% 0 -10% - 71-96% -	65% 25 - 86% 73 - 100% 100% 75%
PG&E Potrero	January 1979	25 samples	Pacific herring	546	716	initial and 96 hour latent	16%	-	70%
Quad Cities Nuclear Station	June 1978	unknown # 5 days	freshwater drum minnows	378 278	916 307	initial and 24 hour latent	0 - 71% 2 - 75%	- -	2 - 62% 7 - 63%
Quad Cities Nuclear Station	April - June 1984	unknown # 8 days	freshwater drum carp buffalo	unknown unknown unknown	unknown unknown unknown	initial and 24 hour latent	unknown unknown unknown	- - -	63% 92 - 97% 94%
Roseton Generating Station	May - November 1975	672 samples 41 days	striped bass PYSL white perch PYSL herrings PYSL	100 77 471	172 97 833	initial and 96 hour latent	62% 29% 26%	6% 1% 0%	38% - -
Roseton Generating Station	June - July 1976	unknown # 27 days	striped bass PYSL white perch PYSL herring PYSL	93 401 1,054	80 349 645	initial and 96 hour latent	14 - 43% 6 - 42% 5 - 29%	- - 0%	19 - 58% 11 - 79% 10 - 59%
Roseton Generating Station	March May - July 1977	unknown # unknown days	striped bass PYSL white perch PYSL herring PYSL Atlantic tomcod YSL	427 251 880 1178	765 266 1344 1345	initial and 96 hour latent	3 - 29% 0 - 17% 0 - 5% 16%	18% 27% 0% 40%	6 - 58% 0 - 52% 0-19% 41%
Roseton Generating Station	March July - July 1978	256 samples 30 days	striped bass PYSL white perch PYSL herring PYSL Atlantic tomcod PYSL	123 395 1274 83	211 459 1089 153	initial and 96 hour latent	27 - 50% 0 - 35% 0 - 10% 33 - 45%	18% 10% 0% 36%	46% 56-96% 0% 39%
Roseton Generating Station	May - July 1980	1431 samples 42 days	striped bass PYSL white perch PYSL herring PYSL	245 194 812	425 366 1252	initial and 48 hour latent	46 - 61% 30 - 59% 7 - 31%	48 - 56% 27 - 62% 1 - 3%	88% 67% 23%
Salem Generating Station	1977-1982	640 samples, 38 days	spot herrings Atlantic croaker striped bass white perch bay anchovy weakfish	66 8 - - - - -	130 14 - - - - -	onsite and simulated studies	74.1 7.1 - - - - -	- 0 - - - - -	0 - 76% 2 - 74% 0 - 60% 32 - 46% 30 - 70% 2 - 3% 14 - 56%

A review of the data in Table A7-1 shows that the majority of the studies were conducted at facilities located in a limited geographical region of the country: 24 of the studies were conducted in the northeastern region of the United States. This may explain why these studies provide entrainment survival estimates for relatively few, only 24, species or families of fish. The majority of survival estimates in these studies were for striped bass, white perch, bay anchovy, and herrings. Also, the majority of these studies are over 20 years old, with 25 of the studies conducted in the 1970s. Thus, the results on species composition and abundance are not necessarily indicative of current conditions, with improved water quality due to the enactment of the Clean Water Act in 1972. Entrainment survival in these studies was also estimated with relatively short sampling periods, with the 15 studies using sampling periods of approximately two months long. Also, the sampling periods did not always correspond to peak egg and larval abundance in the waterbody. Twelve of these studies determined that sample sizes of fewer than 100 individuals for a particular species at the discharge station were sufficient to give an accurate estimation of entrainment survival. These small sample sizes are not be sufficient to provide accurate estimates of entrainment survival given that these facilities entrain organisms on the order of millions to billions per year. Also, small sample sizes in conjunction with the high variability of entrainment survival increase the uncertainty associated with these estimations. The small sample sizes allowed for limited study of latent survival, and no facility attempted to study latent physiological effects of entrainment on a species, such as the possible effects on growth rates, maturation, fertility, and vulnerability to natural mortality. The nature of the equation for entrainment survival results in estimates substantially higher than the proportion of survival in the discharge samples because of its use of a correction for mortality in the intake samples, which is often quite high. The fact that the existing studies are characterized by high uncertainty, high variability, and the potential for high bias (Boreman and Goodyear, 1981) complicates efforts to synthesize the various results in a manner that would provide useful generalizations of the results or application to other particular facilities. For these reasons, EPA believes that the reported results do not provide a clear indication as to the extent of entrainment survival significantly above 0 percent to be used as a defensible assumption to calculate benefits for this rule.

A7-3 Detailed Analysis of Entrainment Survival Studies Reviewed

The summary tables at the end of this chapter provide detailed summary descriptions of each of the 37 studies reviewed. EPA reviewed these studies to determine if they were conducted in a manner that provides adequate representation of the current probability of entrainment survival at the facility. The criteria EPA used to evaluate the studies focused on three main themes: the sampling effort of the study, the operating conditions of the facility during the study, and the survival estimates determined as the result of the study. Specifically, EPA asked the following questions:

Sampling:

- When were samples collected?
- With what frequency were samples collected?
- Were samples collected when organisms were spawning, or at peak abundance?
- What time of day were samples collected?
- What was the number of replicates per sampling date?
- Were the intake and discharge samples collected at the same time so the results can be compared?
- How long was each sample collected?
- What method was used to collect samples?
- At what depth were samples collected?
- What was the location of the samples collected at the intake and discharge?
- Which water quality parameters were measured?
- Were dissolved organic carbon (DOC) and particulate organic carbon (POC) measured?
- What was the velocity at the intake and at the discharge?

Operating conditions during sampling:

- How many generating units at the facility were in operation?
- How many pumps at the facility were in operation?
- What was the intake temperature range, the discharge temperature range, and the ΔT range to which organisms were exposed?
- Were biocides in use?

Survival estimation:

- How many sampling events occurred?
- What was the total number of samples collected?
- What was the total number of organisms collected?
- How many organisms are entrained each year at this facility?
- Did the study take into account fragmented organisms?
- Were the number of organisms collected at the intake and at the discharge comparable?
- What were the most abundant species collected?
- Were stunned larvae included with live larvae in survival estimates?
- Did the facility omit dead and opaque organisms from the count of dead organisms?

- How was latent survival studied?
- Were data sampled from all times and operating conditions combined to determine entrainment survival?
- What were the controls for the study?
- What was the range of intake survival determined by the study?
- What was the range of discharge survival determined by the study?
- How was entrainment survival calculated?
- Were confidence intervals or standard errors calculated?
- Were significant differences tested between intake and discharge survival?
- Was entrainment survival calculated for species with low sample sizes, such as fewer than 100 organisms?
- Was egg survival studied?
- Was there any trend evident in larval survival?
- Were the raw data provided to verify results?
- What was the trend of survival with regard to temperature?
- What was the extent of mechanical mortality?
- What quality control procedures were used?
- Was the study peer reviewed?

A7-4 Discussion of Review Criteria

In this section, the criteria EPA used to review the entrainment survival studies are discussed in depth to give a better indication of the soundness of the science behind a facility's estimate of potential survival.

A7-4.1 Sampling Design and Method

These aspects of the sampling effort are relevant to whether the samples collected are representative of all organisms experiencing entrainment with regard to taxa and size classes, whether the estimates of densities and numbers are accurate and precise, and whether the survival estimates for the intake and discharge can be validly compared (Marcy, 1975; Boreman and Goodyear, 1981). Sampling should be carefully planned to minimize any potential bias (Marcy, 1975; Boreman and Goodyear, 1981). Studies should be conducted throughout the parts of the year when substantial numbers of organisms are entrained. Any possible survival may vary with factors that change seasonally, such as organism size and life stage and ambient water temperature. Most studies attempted to collect samples during times of peak abundance, although the sampling frequency may not have been sufficient to fully capture peak densities. Of those reviewed by EPA, six studies did not correspond with the timing of peak densities at that location.

Even if a study is limited to the early life stages of particular fish or shellfish, survival differences among sizes and life stages and seasonal or temperature-related changes in entrainment survival must be quantified. The timing of the sample collection for an entrainment survival study can influence results in a number of ways, such that results from studies collected during one period may not be representative of potential effects during other periods. For instance, samples collected when the intake temperatures are low or late in a spawning season when larvae are larger can produce estimates of entrainment survival that may be higher than at other times. Thus, studies need to be conducted throughout the entire spawning season to accurately characterize overall entrainment mortality if entrainment survival is found to vary with life stage or size of each species entrained. For the same reason, it may not be appropriate to develop average survival estimates from samples collected under different environmental conditions (in particular under different temperature regimes) and from only parts of a spawning period for a particular species. This was done in almost all the studies reviewed by EPA, which causes their results to be of questionable value. This also makes it difficult for EPA to synthesize the results of these studies into a meaningful average value of entrainment survival to be used in a national benefits assessment.

Many studies collected samples at night to ensure high numbers of organisms in their samples because larvae rise to the surface at night to feed and avoid predation (Marcy, 1975; Day *et al.*, 1989). This practice will bias results because the samples will contain a disproportionate number of live organisms than that which is actually present in the water column. There is evidence that dead organisms will sink to the bottom of the water column after entrainment (Marcy, 1975). Twenty-four studies indicated that most sampling took place at night. For many studies, the depth of sampling is not noted and thus it is unclear whether the samples were collected near the surface, at mid-depth, or near the bottom of the water column. Any potential for bias due to a higher percentage of alive organisms present near the surface could not be assessed.

The method of sampling should be selected to cause the least amount of mortality possible and the mesh size should be fine enough to capture disintegrated or fragmented organisms. Many studies sampled organisms using sampling instruments with mesh size greater than or equal to 500 μm. This may not be fine enough to capture disintegrated or fragmented organisms in the discharge. Attention should be given to the mesh size of sampling instruments to be sure that the targeted sample is not extruded through the mesh.

Intake and discharge sampling should be paired to be sure that the same population of organisms is sampled and subsequently compared. In 12 studies examined, it is unknown if the samples at the intake and discharge were paired. In some studies, samples were not collected at all locations during all sampling events. In other studies, twice as many samples were collected at the discharge than at the intake. Also, in many instances, the intake samples were collected at different generating units of the facility than the discharge samples. Average elapsed times for sample collection were given, and it is unclear if the same elapsed time was used at both locations to give an accurate depiction of organismal densities. The time elapsed during sample collection or the volume of water sampled should be identical in the paired intake and discharge samples to ensure valid comparisons of samples. It was not indicated in any of the studies reviewed whether the same volume of water was sampled in all the intake and discharge samples. If intake samples are to be compared to discharge samples, consistent sampling methods must be used at the two locations so that the samples contain the same density of organisms.

The location of the intake sampling is important because it may contain organisms that already died because of the changes in velocity near the intake. Two studies reviewed collected intake samples after the water had entered the cooling system. The location of the discharge sampling is also important. Samples collected from the end of the discharge canal may not contain organisms that died from passage through the facility because of the tendency of dead organisms to settle out of the water column in the discharge canal. Samples collected from the discharge pipe may not contain organisms that died from thermal effects of entrainment because the samples are collected before the full effects of thermal exposure were experienced. Fourteen studies reviewed collected discharge samples from the discharge pipe. It is also unknown if the samples collected in the discharge canal or from the receiving water contained organisms in the dilution water that bypassed the cooling water system. Five studies reviewed collected discharge samples in the receiving water downstream from the discharge canal, which can result in samples containing organisms that never passed through the cooling water system. The velocity at the intake and discharge should also be recorded to determine the potential to cause mortality. Fourteen of the studies noted the velocity at the intake, at the discharge, or both. For the ones that did not give both intake and discharge velocities, it is unknown whether the velocities at the two sampling sites were comparable, and thus whether the mortalities due to velocity-related sampling stress were comparable at the two locations.

Water chemistry conditions also need to be recorded to be sure conditions are similar at all sampling locations. Water quality parameters include measurements of dissolved oxygen, pH, and conductivity in the through-plant water, at the discharge point, and in the containers or impoundments in which the entrained organism are kept when determining latent mortality. Eighteen studies reviewed gave some indication that water quality parameters were measured. However, it is unclear whether measurements were collected at both the intake and the discharge, and only one study reviewed indicated that water quality parameters were measured in latent mortality studies (EA Engineering Science and Technology, 1986).

A7-4.2 Operating Conditions During Sampling

Mortality due to entrainment stress is affected by the operating characteristics of the power facility. The conditions under which the samples are collected are extremely important and, therefore, the results can be assumed to represent possible survival only when the facility is operating under those same conditions and at that time of year, and may not represent any potential for survival at all times. For example, results of studies conducted when the plant was not generating power (and thus not transferring heat to the cooling water) would not be applicable to impacts when it was in full operation. The magnitude of mechanical stress is dependent on the design of the facility's cooling water intake structure. The physical and operating conditions of the facility must be recorded to determine the effect on entrainment survival. The percentage of the maximum load at which the facility is operating must be recorded at the time of sampling to indicate the extent to which organisms are exposed to stress. The number of generating units was highly variable or unknown in many of the studies reviewed. Only one study indicated that the facility operated at peak load to maximize temperature stress during the time of sampling. Eight studies indicated that power was generated during only a portion of time in the sampling period. To fully account for the effects of mechanical stressors on entrainment survival, the study must reflect the speed and pressure changes within the condenser, the number of pumps in operation, the occurrence of abrasive surfaces, and the turbulence within the condenser. In addition, it is important to note the number and arrangement of generating units, parallel or in sequence, which may expose organisms to entrainment in multiple structures. Survival should be studied under the range of facility conditions that may influence survival, for example, intake flow or capacity utilization and ambient (intake) water temperature and ΔT.

The effect of temperature can be species-specific since different fishes have different critical thermal maxima. The maximum temperature to which organisms may be exposed while passing through the facility may cause instant death in some species but not others. To assess the effect of thermal stressors on entrainment survival, the study must determine the temperature regime of the facility. Specifically, the study must record the temperature at both the intake and the discharge point for each component of the facilities system: temperature changes within the system, including the inflow temperature; maximum temperature; ΔT; rate of temperature change; and the temperature of the water to which the organisms are discharged. It is also important to measure the duration of time an organism is entrained and thus exposed to the thermal conditions within the condenser and in the mixing zone of the discharge canal. This information was not provided in the studies reviewed by EPA. Also, in those studies that attempted to relate survival to temperature stress, too few samples were collected at different temperature ranges to give an adequate representation of survival in that range. The EPRI report sorted larval entrainment survival data by discharge temperature and concluded that survivability decreased as the discharge temperature increased (EA Engineering Science and Technology, 2000). The lowest probability of larval survival occurred at temperatures greater than 33 °C. In the studies reviewed by EPA, a noticeable decline in survival estimates occurred at discharge temperatures above 30 °C. The amount of time that a facility discharges water in different temperature ranges and survival estimates at that temperature range should be weighted when attempting to determine the survival estimate throughout the year, rather than using an average survival during the sampling period, which may not adequately reflect operating conditions throughout the year.

To properly account for chemical stressors, the timing, frequency, methods, concentrations, and duration of biocide use for the control of biofouling must be determined. The extent to which biocides are routinely used is unknown. The studies reviewed by EPA were all conducted at times when biocides were not in use because the biocide use would be expected to kill all organisms. Thus, the results of these studies do not account for biocide impacts and only reflect other times when biocides are not in use at the particular facility. A reduced survival estimate for the proportion of time when biocides were in use would have to be incorporated into any estimation of annual mean entrainment mortality value for a facility for that estimate to be valid.

A7-4.3 Survival Estimates

Many of the entrainment survival studies reviewed did not account for the extent to which the fragile life stages are fragmented and disintegrated by both sampling and entrainment. Only six of the studies acknowledged that the entrainment survival estimates were indicative only of alive and stunned identifiable organisms out of all those sampled and enumerated that were at least 50 percent intact. In such circumstances, an important proportion of entrained dead (fragmented) organisms is omitted from the calculated estimate of survival. Entrainment survival studies should not limit their estimates of survival to include only those organisms that are either whole or 50 percent whole in the sample. For those studies that did not discuss the issue of fragmented organisms, it is unclear how the issue was treated. Several studies indicated that the majority of the sample was mangled or unidentifiable. There is potential for an extremely large number of dead organisms to be excluded from entrainment survival estimates because they are fragmented to the point of being unidentifiable. Studies should account for this fragmentation of organisms by measuring unidentifiable biomass in the samples from the intake and discharge stations. Without taking these organisms into account, entrainment survival estimates will be biased and the results will be higher than that which actually occurs. There are indications that the number of fragmented organisms, which are generally not included in survival estimates, may be high which results in an overestimation of entrainment survival if these fragmented organisms are more prevalent in the discharge. In the proceedings of a conference held in Providence, RI, on January 6, 1972, entitled *Pollution of the Interstate Waters of Mount Hope Bay and its Tributaries in the States of Massachusetts and Rhode Island*, the following regarding fragmentation was quoted "...in 1970 when we observed many small transparent larval menhaden in the intake. They were most readily noted by their black eyes. But in the effluent, all we found were eyes. They were torn to pieces" (U.S. EPA, 1972). Foam observed in the discharge (Thomas, 2002) may indicate that fragmentation is substantial. The data summary in Jinks *et al.* (1981) suggests that a substantial number of fish larvae may be fragmented by mechanical forces and become unrecognizable, contributing to a bias in estimates of survival. Ten of the studies reviewed by EPA reported finding fragmented organisms; others did not quantify evidence of disintegrated organisms. High rates of physical damage and abundant larval fish fragments were reported by Stevens and Finlayson (1978) at the Pittsburg and Contra Costa power plant discharges. Such losses can contribute to a bias (overestimation) of entrainment survival because the number of dead organisms are not properly enumerated. In addition, the low numbers of organisms sampled in the studies in relation to the high annual entrainment numbers give further indication that the sampling effort may not result in an adequate representation of the organisms entrained and therefore the survival estimates may not be representative of what occurs.

Including stunned larvae in the initial survival estimates also results in overestimations of survival, since the majority of these organisms died in the laboratory latent survival studies and even more will die in the natural conditions of the discharge canal because of predation or disrupted growth and development. Twenty-nine studies reviewed included stunned larvae in their initial survival estimates, and only a few of these indicated that this method will overestimate initial survival. The remainder of the studies reviewed did not discuss the treatment of stunned larvae. Many studies reviewed reported only initial acute mortality. Both initial mortality and extended or latent (96 hour) mortality should be studied and reported.

Dead and opaque organisms that may have died before entrainment should not be excluded from the enumeration of dead organisms. Several studies reviewed by EPA noted that dead organisms can turn opaque within an hour. This is the same amount of time that can elapse during sampling collection and sorting. Also, zero dead and opaque organisms were collected in the samples of one study when the facility was not generating power. Three studies omitted dead and opaque organisms from the dead classification used to estimate survival. This resulted in an elimination of up to 99 percent of the organisms in the samples of one study. Alternatively, one study counted only those organisms that were opaque as dead.

The study design should support unbiased estimation of survival, taking into account pertinent factors and the changing relative abundances of species and life stages. Because entrainment mortality changes with ambient and operating conditions, and because the numbers of various species and life stages entrained also change diurnally and seasonally, use of an average value for entrainment survival could be misleading. Organisms should be counted and sorted by species, life stage, and size. Entrainment survival should then be calculated separately for each life stage of each species. Entrainment survival estimates appears to vary markedly with fish larval size (EA Engineering Science and Technology, 1989); estimates of mortality are often higher for smaller larvae and lower for larger ones. Thus, survival measured for a heterogeneous mixture of sizes will apply only to that mixture under the same conditions, and cannot be used to accurately estimate survival for the species over the course of even part of a season. The approach of modeling survival in relation to size may be more promising (EA Engineering Science and Technology, 1989). The implication is that accurate assessment of entrainment survival requires frequent samples throughout a season, to reflect the changing size and species composition of the ichthyoplankton. In most of the studies all data from all samples collected under varied times and conditions were combined to give an average entrainment survival. However, bias could be introduced when a disproportionate number of samples are taken under a specific set of conditions that may not accurately reflect conditions throughout the year. Only 16 of the 37 studies reviewed estimated entrainment survival by sampling reported standard deviations or confidence intervals for the survival estimates. The apparent precision of estimates based on hundreds of organisms, and the estimates themselves, are deceptive. Such estimates are based on aggregated numbers that vary in size; however, larval fish survival is dependent on size (EA Engineering Science and Technology, 1989).

The volume of water sampled should always be reported with the number of organisms counted in the sampled volume. This allows estimates of the densities of organisms in the intake and the discharge water. Density estimates provide an important check on assumptions. When organism densities cannot be measured accurately, a useful check on disintegration of organisms that are never counted cannot be performed. Another check on loss of organisms by disintegration is a count of body parts, which was done in only one of the studies reviewed, but this will not account for organisms rendered unidentifiable or disintegrated. In some studies, the numbers of organisms in discharge samples were many times greater than the numbers of organisms in intake samples using the same sampling methods. In other studies, there were many times more organisms collected in the intake samples than in the discharge samples. Such large differences raise concerns about sampling methods and possible sources of bias that would need to be investigated.

Control samples taken to test the mortality associated with sampling gear should be taken as far away from the intake as possible. This will ensure that the rates of mortality determined will be solely from natural causes or sampling damage and not from potential damage due to increased velocity and turbulence near the intake. Sampling mortality should be reduced to the maximum extent possible, using modern sampling techniques (EA Engineering Science and Technology, 2000). When control survival is less than discharge survival, no attempts should be made to calculate entrainment survival; this would give an erroneous survival result of greater than 100 percent. That some studies reported entrainment survival estimates greater than 100 percent indicates that these studies' methods of calculating entrainment survival were flawed by methodological biases.

Calculating survival from the ratio of the fraction alive in discharge samples to the fraction alive in intake samples requires assumptions not supported by the same studies. These assumptions are that (1) no organisms are lost to counting by destruction in the cooling water system, in other words, the same density of organisms (dead or alive) is observed in the discharge as in the intake; and that (2) the sampling method causes the same rate of mortality in the discharge sample as in the intake sample. The first assumption is without doubt violated for many species and life stages. The second assumption is also questionable, because any organisms alive in the discharge have survived entrainment and may be more resistant to sampling-related mortality. Because the loss of organisms by disintegration is not measured, if a substantial number of organisms are destroyed and thus are not counted in the discharge, it is more likely that entrainment survival will be overestimated. The second assumption can be minimized if methods of sampling are used that reduce sampling mortality to a minimum (EA Engineering Science and Technology, 2000); such methods (e.g., rear-draw pumping methods, pumpless flume) were used in only 5 of the 37 studies reviewed. The formula commonly used (EA Engineering Science and Technology, 2000) to estimate entrainment survival, $S_I = P_{D\,/}\,P_I$, is appropriate in experimental situations in which the number of organisms at risk is verified to equal the number counted (alive and dead) at the end of the study. It can be applied in observational studies when it is known that the number at risk is conserved (i.e., no organisms are lost in sampling or destroyed so they cannot be counted). The biases that result from loss via sampling or destruction, and other causes, were illustrated by Boreman and Goodyear (1981). If Abbott's correction for control mortality is applied, it requires the assumption that sampling mortality rate is the same for the intake and discharge samples. This source of bias was also considered by Boreman and Goodyear (1981). Abbott's correction may contribute to overestimation of entrainment survival because it attributes to entrainment only that mortality in excess of the mortality attributed to sampling. This may overestimate entrainment survival for two reasons: it is likely that sampling mortality and entrainment mortality are not entirely additive, and, as noted above, it is quite possible that the sampling mortality rate is less in the discharge sample than in the intake sample used as the control.

A7-5 Applicability of Entrainment Survival Studies to Other Facilities

Because of many factors, any potential for entrainment survival is most likely facility-specific. Therefore, EPA does not suggest that entrainment survival estimates be applied to other facilities, as was done in the Muskingum River Plant study (Ecological Analysts Inc., 1979a). To correctly transfer the results, the physical attributes of facilities would need to be identical. Specifically, the facilities would need to have similar numbers of cooling water flow routes; similar lengths of flow routes in terms of time and linear distance; similar mechanical features in terms of abrasive surfaces, pressure changes, and turbulence; and similar number and types of pumps used. In addition, there would need to be similarity and constancy of the flow rates, transit times, thermal regimes, and biocide regimes. The ecological characteristics of the environment around the facility would also need to be similar in terms of ambient water temperature, dissolved oxygen level, and the species and life stage of organisms present. Similarities or differences in these aspects may profoundly affect the applicability of the study across facilities. The studies reviewed by EPA were unsuitable for developing unbiased estimates of entrainment survival over the pertinent courses of time (diel and seasonal) and the typical environmental and operating conditions at the facilities conducting the studies, and thus cannot be used to estimate entrainment survival at section 316(b) facilities nationwide.

A7-6 Conclusions

EPA's review of the 37 entrainment survival studies revealed a number of limitations that challenge their use in assessing the benefits of the section 316(b) Phase II Existing Facilities Rule. The primary issue with regard to these studies is whether their results can support a defensible estimate of survival substantially different from the value of 0 percent survival assumed by EPA in assessing benefits of the rule. Given that live organisms can be found in the discharge canals of many cooling water intake systems, it may be true that not all organisms are necessarily killed as they pass through the cooling systems of all facilities under all operating conditions. However, the results of the 37 studies, summarized in Table A7-1, suggest that the proportion alive in the samples is highly variable and unpredictable among species and among facilities. The studies document that some species (e.g., herrings, bay anchovy) are very sensitive to entrainment and experience 0 percent survival with calculated mortality rates of 100 percent at most facilities. Other species (e.g., striped bass) may be more resistant to entrainment effects. However, even for these apparently hardy species, some studies yielded ranges of entrainment survival estimates that included zero and latent survival values very close to zero. Multiple studies at the same facility (e.g., Bowline Point, Indian Point) yielded survival values for some species (e.g., striped bass) that varied substantially among years, most likely due to a combination of changes in environmental conditions, changes in plant operations, and changes in sampling and testing procedures. The studies indicate that any survival is dependent on temperature, but the effect may vary greatly depending on intake water temperature, plant design, fish species, and life stages. Few of the studies could conclusively document and quantify the specific stressors causing the observed mortalities, and no rigorous, validated method or model was put forward that would allow survival rates to be accurately predicted. Another major constraint on the use of these findings in this rulemaking process is that they cover very few species, and primarily in a single geographical region of the country, thus providing no basis for prediction or projection of effects to other species in other parts of the country. These studies as well as other literature also show that findings from one facility cannot be considered to be valid for another facility, since many site-specific and facility-specific factors may affect the magnitude of mortality that occurs. The current state of knowledge would not support predictions of entrainment survival for the range of species, life stages, regions, and facilities involved in EPA's benefits estimates.

The potential usefulness of the findings of the studies reviewed is further compromised by the numerous factors that can influence the representativeness, accuracy, and precision of the survival estimates presented, and that are often not rigorously accounted for in the studies reviewed. These factors are described in section A7-2, and some of the deficiencies of the studies with regard to these factors are elaborated in section A7-3. The most frequent and serious deficiencies noted (e.g., high control mortalities, omission of fragmented or unidentifiable organisms, and uncertainty regarding post-discharge survival) compromise the accuracy and precision of the survival estimates. In many of the studies reviewed, the precision of the survival estimates was not rigorously assessed, and thus the uncertainty associated with the estimates is not known. If the factors addressed in this review were taken into account in an entrainment survival study, EPA believes that the estimates of survival that would result would not be substantially different from zero.

EPA acknowledges that some of the studies performed at some facilities were designed in a more rigorous manner than others in order to minimize the influence of factors that could compromise findings (e.g., the use of a larval table for assessing physiological condition) and included comprehensive sampling in an attempt to enhance the accuracy and precision of the survival estimates. However, while such studies may have provided estimates for the facility studied under the environmental and operational conditions that occurred at the time the study was performed, these studies do not provide a basis for generalizing specific survival rates for all or even the same species at other facilities or at the same facility in other years. In addition, there exists the possibility of additional post-discharge (latent) mortality when entrained organisms are returned to the receiving water body. Overall, the unreliability, variability, and unpredictability of entrainment survival estimates evident from EPA's review of the entrainment survival studies support the use of the assumption of 0 percent survival in the benefits assessment because there is no clear indication of any defensible estimate of survival substantially different from 0 percent to use to calculate benefits for this rule.

Summary Tables of Entrainment Survival Studies

Anclote Power Plant

Anclote River, FL

1985 Study

CCI Environmental Services, Inc., 1996

Sampling: Dates: Sept. 25 - 29, October 9 - 11, and November 1-2
Samples collection frequency: a few days per month
Times of peak abundance: autumn months when densities maybe not the highest
Time: mostly at night, some late afternoon to evening
Number of replicates: varied between 5 - 25 per month
Intake and discharge sampling: paired number, timing unknown
Elapsed collection time: 20 - 30 minutes
Method: 400 µm mesh net with 1 m diameter and 5 gallon plastic bucket with 500 µm mesh side panels
Depth: mid-depth and surface
Intake location: unknown
Discharge location: condenser discharge and point of discharge in canal
Water quality parameters measured: pH, DO, salinity
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: operated at peak load to maximize ΔT, 1 - 2 Units
Number of pumps in operation: varied due to sampling location, 0- 4 pumps
Temperature: Discharge temperature: 28.8 - 38.3 °C
ΔT average: 5.4 - 7.3 °C
Biocide use was not noted

Survival Estimation:
Number of sampling events: 8
Total number of samples collected: 120
Total number of organisms collected: 41,196
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: approx. equal
Most abundant species: not classified to species level
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars for 24 hours
In several replicates, more organisms were counted after 24 hours in jar
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 64% for Fish larvae
73% for Amphipoda
44% for Chaetognatha
72% for crab larvae
72% for Caridean shrimp
Initial discharge survival range: 8 - 47% for Fish larvae
29 - 58% for Amphipoda
28 - 35% for Chaetognatha
74 - 80% for crab larvae
45 - 66% for Caridean shrimp
Calculation of Entrainment Survival: Discharge survival / Intake survival
Mean survival for each replicate was reported as survival estimate per species
Confidence intervals (95%) and standard deviations were calculated
Significant differences were tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: none collected
Larval survival: decreased markedly within hours of collection
Raw data: were provided to verify results
Temperature effects: unknown
Mechanical effects: unknown
Quality control: QA/QC officer oversaw sorting and sample handling
Peer review: not mentioned, study was conducted for the facility

Bergum Power Station

Bergumermeer, Netherlands

1976 Study

Hadderingh, 1978

Sampling: Dates: April 27 - June 1
Samples collection frequency: approximately once per week
Times of peak abundance: coincided with abundance of larvae and juveniles
Time: unknown
Number of replicates: unknown
Intake and discharge sampling: unclear if paired sampling
Elapsed collection time: 3 minutes
Method: conical net with 0.5 mm mesh and 0.5 m diameter
Depth: unknown
Intake location: unknown
Discharge location: in outlet before weir
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: 40 cm/sec

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: Intake temperature: 10.8 - 21.6
Discharge temperature: 16.7 - 24.6 °C
ΔT ranged from 2.4 - 8.0 °C
Biocide use was not noted

Survival Estimation:
Number of sampling events: 6
Total number of samples collected: unknown
Total number of organisms collected: unknown at intake, 1148 at discharge
Number of organisms entrained per year: unknown
approximately 10 million organisms entrained per day in May
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: unknown
Most abundant species: smelt, perches
Stunned larvae: unknown if included in survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in floating buckets in the outlet canal for 24 hours
5 - 50% appeared to be dead in buckets floating in outlet canal
However, latent survival was not explicitly studied
Data: survival by sampling date and then averaged
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 54 - 100% for smelt
81 - 96% for perches
Initial discharge survival range: 10 - 28% for smelt
32 - 74% for perches
Calculation of Entrainment Survival: Discharge survival / Intake survival
Confidence intervals and standard deviations were not presented.
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: no eggs collected
Larval survival: increased in samples later in year, may be due to larger sized
Raw data: were not provided to verify results
Temperature effects: not discussed
Mechanical effects: not discussed
Quality control: not discussed
Peer review: work done for facility, published in Applied Limnology

Bowline Point Generating Station

Hudson River, NY

1975 Study

Ecological Analysts Inc., 1976a

Sampling: Dates: June 3 - July date unknown
Samples collection frequency: 1 - 4 times per week
Times of peak abundance: sampling intended to coincide with peak densities
Time: day or night
Number of replicates: unknown
Intake and discharge sampling: unknown if paired
Elapsed collection time: 15 minutes
Method: larval collection tables
Depth: unknown
Intake location: in front of intake
Discharge location: from standpipe connected to discharge pipe of Unit 2
Water quality parameters measured: conductivity, DO, pH
DOC and POC measured: no
Intake and discharge velocity: intake: 1.5 - 2 m/sec, discharge 2- 4.6 m/sec

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: ΔT range: 0.5 - 12.1 °C
Biocide use was not noted

Survival Estimation:
Number of sampling events: 37
Total number of samples collected: 400
Total number of organisms collected: 4643
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: no, more at intake
Higher percentage of larvae were collected at the discharge station in the later weeks of the collection period. Conversely, a higher percentage of larvae were collected at the intake at the beginning weeks of the collection period. This discrepancy in larval collection combined with higher survival rates later in the spawning season accounts for the bias which results in higher survival rates at the discharge station. The study acknowledges this bias and concludes that it is responsible for the higher discharge survival estimates
Most abundant species: striped bass, white perch and bay anchovy
Stunned larvae: included in initial survival proportion; most died within hours
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars for 96 hours
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 81% for striped bass
56% for white perch
9% for bay anchovy
Initial discharge survival range: 74% for striped bass
68% for white perch
2% for bay anchovy
Calculation of Entrainment Survival: Discharge survival / Intake survival
Confidence intervals (95%) were presented
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: no
Egg survival: not studied
Larval survival: decreased markedly within 3 hours of collection.
Raw data: were not provided to verify results
Temperature effects: too few samples collected to establish relationship
Mechanical effects: extent was not discussed
Quality control: color coded labeling, routine checks on sorting accuracy
Peer review: not mentioned, study was conducted for the facility

Bowline Point Generating Station

Hudson River, NY

1976 Study

Ecological Analysts Inc., 1977

Sampling: Dates: May 18 - July 26
Samples collection frequency: approx. 4 nights per week
Times of peak abundance: for all species except Atlantic tomcod
Time: at night
Number of replicates: stated average of 10 per sampling trip
Intake and discharge sampling: sorted simultaneously
Elapsed collection time: 15 minutes
Method: larval collection table with 4 inch diameter trash pump
Depth: unknown
Intake location: in front of Unit 1 trash racks
Discharge location: from standpipes of discharge at Units 1 or 2
Water quality parameters measured: conductivity, pH, and DO
DOC and POC measured: no
Intake and discharge velocity: intake: 0.11 - 3 m/sec, discharge: 3 - 4.6 m/sec

Operating Conditions During Sampling:
Number of units in operation: varied between 1 and 2
Number of pumps in operation: unknown
Temperature: discharge range: 29.0 - 35.9 °C
Biocide use was not noted

Survival Estimation:
Number of sampling events: 39
Total number of samples collected: 688
Total number of organisms collected: 2795
Number of organisms entrained per year: unknown
Fragmented organisms: only included in count if > 50% was present
Equal number of organisms collected at intake and discharge: no, very different
Most abundant species: striped bass, white perch , atlantic tomcod, bay anchovy, herrings
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars for 96 hours
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 81 - 90% for striped bass
62% for white perch
54 - 82% for Atlantic tomcod
7 - 53% for bay anchovy
35% for herrings
Initial discharge survival range: 0 - 54% for striped bass
0 - 33% for white perch
29 - 94% for Atlantic tomcod
0 - 10% for bay anchovy
20% for herrings
Calculation of Entrainment Survival: Discharge survival / intake survival
Confidence intervals (95%) were presented
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not studied
Larval survival: decreased markedly within 12 hours of collection.
Raw data: were not provided to verify results.
Temperature effects: trend of decreasing survival when temperatures > 30 °C
Mechanical effects: unknown extent
Quality control: color coded labels, immediate checks of sorted samples, SOPs
Peer review: not mentioned, study was conducted for the facility

Bowline Point Generating Station

Hudson River, NY

1977 Study

Ecological Analysts Inc., 1978a

Sampling: Dates: March 7 - July 15
Samples collection frequency: 5 nights per week
Times of peak abundance: covered of peak densities of most targeted species
Time: at night
Number of replicates: varied between 2 and 10 per site
Intake and discharge sampling: paired
Elapsed collection time: 15 minutes
Method: larval table with pump, 2 pumps at intake; 2 tables at discharge
ambient water injection system added to reduce prolonged temp. exposure
Depth: middle to bottom at intake, at standpipes for discharge
Intake location: in front of Unit 1 trash rack
Discharge location from standpipes of either Unit 1 or 2, depending on operation
Water quality parameters measured: conductivity, pH and DO
DOC and POC measured: no
Intake and discharge velocity: intake: 0.11- 2 m/sec; discharge 3 - 4.6 m/sec

Operating Conditions During Sampling:
Number of units in operation: varied between 1 and 2
Number of pumps in operation: 2 pumps throttled or 2 pumps full
Temperature: Intake range: 3.7 - 27 °C
ΔT range: not provided
Biocide use was not noted

Survival Estimation:
Number of sampling events: 46
Total number of samples collected: 736
Total number of organisms collected: 4071
Number of organisms entrained per year: unknown
Fragmented organisms: included in count if > 50% of organism was present
Equal number of organisms collected at intake and discharge: no, very different
Most abundant species: striped bass, white perch, bay anchovy,
herrings and silversides
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars for 96 hours
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 74% for striped bass
69% for white perch
0 - 16% for bay anchovy
54% for herrings
37% for silversides
Initial discharge survival range: 71 - 72% for striped bass
34% for white perch
0 - 2% for bay anchovy
23% for herrings
16% for silversides
Calculation of Entrainment Survival: Discharge survival / Intake survival
Standard errors were presented
Significant differences were tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not studied
Larval survival: survival increased with larval length
Raw data: were not provided to verify results.
Temperature effects: decreased survival > 33 °C
Mechanical effects: unknown
Quality control: color coded labels, checks of sorting efficiency
Peer review: not mentioned, study was conducted for the facility

Bowline Point Generating Station

Hudson River, NY

1978 Study

Ecological Analysts Inc., 1979b

Sampling: Dates: March 13 - October 16
Samples collection frequency: 1 - 5 times per week
Times of peak abundance: majority of samples in June and July
Time: at night
Number of replicates: varied between 1 - 10 per sampling date.
Intake and discharge sampling: mostly paired, not all sites sampled all dates
Elapsed collection time: 15 minutes
Method: pump/larval table combination; also floating larval table
Depth: at bottom for intake and unspecified for discharge
Intake location: in front of trash racks of Unit 1 or 2
Discharge location: at either Unit 1 or 2 in standpipes from discharge pipe
floating larval table used for sampling at point of discharge
Water quality parameters measured: salinity, pH, DO, conductivity
DOC and POC measured: no
Intake and discharge velocity: intake: 0.15 - 0.23 m/s

Operating Conditions During Sampling:
Number of units in operation: varied between 1 and 2
Number of pumps in operation: unknown
Temperature: unknown
Biocide use was not noted

Survival Estimation:
Number of sampling events: 40
Total number of samples collected:609
Total number of organisms collected: unknown
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: varied
Most abundant species: striped bass, bay anchovy, white perch and herrings
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in holding jars for 96 hours
Data: was summarized and averaged over the entire sampling period.
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 48 - 49% for striped bass
39% for white perch
4% for bay anchovy
19% for herrings
Initial discharge survival range: 51 - 63% for striped bass
19% for white perch
0% for bay anchovy
23% for herrings
Calculation of Entrainment Survival: Discharge survival / Intake survival
Standard error were presented
Significant differences were tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not studied
Larval survival: decreased markedly within 12 hours of collection
Survival increased with larval length
Raw data: were not provided to verify results
Temperature effects: no survival for YSL for any species at temps. > 30 °C
no survival for PYSL for any species at temps. > 33 °C
majority of samples collected at temperatures < 30 °C
Mechanical effects: recirculation of water occurs
Quality control: color coded labels, double checks, sorting efficiency checks
Peer review: not mentioned, study was conducted for the facility

Bowline Point Generating Station

Hudson River, NY

1979 Study

Ecological Analysts Inc., 1981a

Sampling: Dates: May 23 - June 27
Samples collection frequency: 3 - 5 days per week
Times of peak abundance: timed to coincide with peak densities
Time: 1400 to 2200 hours
Number of replicates: varied between 0 - 9 per sampling date, generally 7
Intake and discharge sampling: mostly paired, initiated simultaneously
Elapsed collection time: 15 minutes
Method: intake: floating larval table or rear draw sampling flume
discharge: pumpless plankton sampling flume or pumped larval table
Depth: intake: mid-depth (4.6 m)
discharge: 2 m below surface
Intake location: in front of trash racks
Discharge location: at standpipe and diffuser
Water quality parameters measured: conductivity, pH, DO
DOC and POC measured: no
Intake and discharge velocity: intake: 1.5 - 3.0 m/sec; discharge 3 - 4.6m/sec

Operating Conditions During Sampling:
Number of units in operation: varied, power generated on only 5 sampling dates
Number of pumps in operation: operated through sampling
Temperature: ΔT range: not provided
Biocide use was not noted

Survival Estimation:
Number of sampling events: 19
Total number of samples collected: 435
Total number of organisms collected:1212
Number of organisms entrained per year: estimated 1.5 million striped bass
2.7 million white perch
Fragmented organisms: included in count if 50%of organism was present
Equal number of organisms collected at intake and discharge: approx. equal
Most abundant species: white perch, bay anchovy, striped bass, herrings
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars for 96 hours.
Data: was summarized and averaged over the entire sampling period.
Controls: Survival in the intake samples was considered to be the control.
Initial intake survival range: 63 - 71% for striped bass
39 - 63% for white perch
4 - 14% for bay anchovy
56 - 61% for herrings
Initial discharge survival range: 35 - 41% for striped bass
26 - 35% for white perch
0 - 4% for bay anchovy
30 - 31% for herrings
Calculation of Entrainment Survival: Discharge survival / Intake survival
Standard errors were presented.
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: determined by translucency and hatching success
Larval survival: decreased markedly within 12 hours of collection.
Raw data: were not provided to verify results.
Temperature effects: little survival at discharge temperatures > 30 °C
Mechanical effects: due to no power generation on the majority of sampling dates, results give indication of extent of mechanical induced mortality
This study included analysis of diel patterns of ichthyoplankton abundance in comparison to diel patterns of plant generation. Facility tends to operate at 85 to 95 percent of capacity in the mid-afternoon hours which results in higher ΔT's and discharge temperatures. Facility tends to operate at minimum level, 20 to 30 percent capacity, in early morning when larval abundance is high and entrainment survival samples collected. Sample collection during the hours when the facility is operating at minimum levels of percent capacity, and at times with correspondingly lower ΔT's and discharge temperatures, may add bias to the results since more organisms will be exposed to lower levels of temperature stress. The peak abundance for each species is only slightly higher than abundance throughout the day. Thus, collectively, more organisms may be exposed to higher temperatures and have higher mortality rates but are not reflected in samples collected at night.
Quality control: color coded labels, check of sorting efficiency, SOPs
Peer review: not mentioned, study was conducted for the facility

Braidwood Nuclear Station

Kankakee River, IL

1988 Study

EA Science and Technology, 1990

Sampling: Dates: June 1 - July 5
Samples collection frequency: 3 samples taken in 35 days
Times of peak abundance: peak densities of eggs and larvae were found in May
Time: varied; day and night at intake, only day at discharge
Number of replicates: varied, 8 - 14 per sampling date
Intake and discharge sampling: more discharge replicates, not always same day
Elapsed collection time: 2 minutes
Method: plankton net with 1.0 m opening, net rinsed out in bucket
Depth: unknown
Intake location: in holding pond into which river water was pumped
Discharge location: downstream of outfall in discharge canal
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: 0.4 - 0.6 ft/sec

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: not given
Biocide use was not noted

Survival Estimation:
Number of sampling events: 3
Total number of samples collected: 62
Total number of organisms collected: 294
Samples, which were collected after peak densities, contained fewer and larger organism which may in turn have higher survival rates.
Number of organisms entrained per year: estimate 5.8 - 11.2 million eggs/larvae
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: more at intake
Most abundant species: minnows and sunfish
Stunned larvae: included in survival proportion
Dead and opaque organisms: were omitted from all calculations of survival
Thus 67% of those dead in the intake samples and 21% of those dead in the discharge samples were omitted from the survival proportions
Latent survival: not studied
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control.
Initial intake survival range: 60% for minnows (17% including dead-opaque)
78% for sunfish (54% including dead-opaque)
Initial discharge survival range: no minnows collected
80% for sunfish (76% including dead-opaque)
Calculation of Entrainment Survival: Discharge survival / Intake survival
Survival proportions calculated by dividing number of live larvae by number of live plus dead-transparent larvae
Confidence intervals / standard deviations: were not presented.
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: data not given
Larval survival: not studied
Raw data: were not provided to verify results.
Temperature effects: not studied
Mechanical effects: not studied
Quality control: not discussed
Peer review: not mentioned, study was conducted for the facility

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Brayton Point

Mount Hope Bay, MA

1997-1998 Study

Lawler Matusky & Skelly Engineers, 1999

Sampling: Dates: April 30 - August 27, 1997 and February 26 - July 29, 1998
Samples collection frequency: weekly
Times of peak abundance: not discussed specifically
Time: varied, day or night
Number of replicates: varied between 14 and 77
Intake and discharge sampling: not paired, 2 tables located in discharge canal
Elapsed collection time: 15 minutes
Method: pump/larval table combination
Depth: mid-depth for intake, 2 - 4 m below surface at discharge
Intake location: directly in front of Unit 3 intake screens
Discharge location: middle of discharge canal or from Unit 4 discharge pipe
Water quality parameters measured: conductance and salinity periodically
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: intake range: 4.5 - 28.0 °C
discharge range: 11 - 45 °C
ΔT data not provided
Biocide use: samples collected when not in use

Survival Estimation:
Number of sampling events: 41
Total number of samples collected: 2692 in 1997; 4137 in 1998
Total number of organisms collected: 2256 in intake; 27,574 in discharge
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal no. of organisms collected at intake and discharge: 4 - 79X more in discharge
Most abundant species: bay anchovy, American sand lance
Stunned larvae: assumed stunned larvae did not survive due to increased predation risk
Dead and opaque organisms: not discussed
Latent survival: observed in holding cups in aquarium racks for 96 hours
Data: was summarized and averaged with both sampling years combined
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 0% for American sand lance
4% for tautog
0% for bay anchovy
44 - 46% for windowpane flounder
32% for winter flounder
Initial discharge survival range: 0% for American sand lance
4% for tautog
0% for bay anchovy
29 - 30% for windowpane flounder
33 - 38% for winter flounder
Calculation of Entrainment Survival: discharge survival / intake survival
Standard errors were presented
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not studied
Larval survival: survival increased with larval length,
decreased markedly within 4 hours of holding in latent studies
Raw data: were provided by species and not by sample to verify results
Temperature effects: survival decrease markedly at temps > 20 °C
Mechanical effects: unknown extent
Quality control: continuous sampling plan which included reanalysis of samples
Peer review: not mentioned, study was conducted for the facility

Cayuga Generating Plant

Wabash River, IN

1979 Study

Ecological Analysts Inc., 1980a

Sampling: Dates: May 17 - 31 and June 8 - 22
Samples collection frequency: daily
Times of peak abundance: highest average densities sampled were June 8 - 10
Time: 1900 to 0300 hours
Number of replicates: varied between 0 - 6 per sampling date.
Intake and discharge sampling: simultaneous sampling, transit time = 36 mins
Elapsed collection time: 15 minutes
Method: pump / larval table collection system
Depth: intake: 2 and 5 m below surface, discharge: 3 - 4 m below surface
Intake location: in front of intake structure
Discharge location: where discharge of Units 1 and 2 enter canal
also cooling tower discharge in discharge canal
Water quality parameters measured: DO
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: varied, 2 - 4
Temperature: intake range: 17.6 - 24.3 °C
discharge range: 29.4 - 33.3 °C
ΔT ranged from 8.4 - 11.8 °C
Biocide use: occurs daily, but ceased at least 2 hours before sampling

Survival Estimation:
Number of sampling events: 24
Total number of samples collected: 80
Total number of organisms collected: 2556
Number of organisms entrained per year: unknown
Fragmented organisms: 13 - 14.6% were damaged
Equal number of organisms collected at intake and discharge: more at intake
Most abundant species: suckers, perches, carps, temperate basses
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: 48 hour observation in aerated glass jars of filtered river water
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 86 - 98% for suckers
28 - 92% for carps and minnows
50 - 86% for perches
Initial discharge survival range: 75 - 92% for suckers
12 - 74% for carps and minnows
43 - 69% for perches
Calculation of Entrainment Survival: Discharge survival/ Intake survival
Confidence intervals: were not presented; standard errors were calculated
standard error sometime as high as survival
Significant differences were tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not studied
Larval survival: latent effects were not seen until 48 hours after collection
Raw data: were provided to verify results
Temperature effects: lower survival for all species at temperatures above 30 ˚C
Mechanical effects: survival decreased when number of pumps increased
Quality control: sorting efficiency checks and color coded labels
Peer review: not mentioned, study was conducted for the facility

Connecticut Yankee Atomic Power Company

Connecticut River, CT

1970 Study

Marcy, 1971

Sampling: Dates: June 30 - July 29
Samples collection frequency: weekly
Times of peak abundance: sampling dates were estimated times of peak larvae
Time: varied throughout day to avoid biocide application
Number of replicates: sampled in triplicate, data from replicates combined
Intake and discharge sampling: samples taken successively
not all sites sampled on all dates
Elapsed collection time: 5 minutes
Method: conical nylon plankton net with 1 L plastic bucket attached to cod end
portable water table for maintaining temperature during counting
Depth: median depth at intake; surface, middle and bottom of discharge
because dead fish in canal may sink or float due to immobility or
changes in specific gravity of water, thus giving inconsistent results
Intake location: unknown
Discharge location: outfall weir and 3 location in discharge canal
Water quality parameters measured: DO
DOC and POC measured: no
Intake and discharge velocity: 1 - 2 ft/sec, may approach 8 ft/sec

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: Discharge temperature: 28.2 - 41 °C
ΔT ranged from 6 - 12.1 °C
Biocide use: sampling avoided daily application of 13% sodium hydrochlorite

Survival Estimation:
Number of sampling events: 7
Total number of samples collected: 102
Total number of organisms collected: 2681
Number of organisms entrained per year: unknown
Fragmented organisms: majority of dead fish were mangled
Equal number of organisms collected at intake and discharge: unknown
Most abundant species: alewife and blueback herring
Stunned larvae: not discussed
Dead and opaque organisms: not discussed
Latent survival: not studied
Data: all data for all species combined, survival calculated for each date
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 29 - 100% for all species combined
Initial discharge survival range: 0 - 7.5% for all species combined
Calculation of Entrainment Survival: number live per cubic meter in each
discharge sample/ number live per cubic meter in intake for each day
Confidence intervals and standard deviations: were not presented
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: July 29
Egg survival: not sampled
Larval survival: no organisms were found alive at end of discharge canal at
temperatures > 30 °C
Raw data: were not provided to verify results
Temperature effects: at discharge temp. > 33.5 °C, no living organisms sampled
Mechanical effects: not discussed
Quality control: not discussed
Peer review: published in notes of Journal Fisheries Research Board of Canada

Connecticut Yankee Atomic Power Company

Connecticut River, CT

1971 - 1972 Study

Marcy, 1973

Sampling: Dates: June 2 - 24, 1971 and June 27 - July 13, 1972 (mechanical only)
Samples collection frequency: approximately once per week
Times of peak abundance: unknown
Time: afternoons and evenings
Number of replicates: three at each station although at three different depths data were combined for each station
Intake and discharge sampling: collected successively at the 5 sites
Elapsed collection time: 5 minutes
Method: conical nylon plankton net with 0.39 mm mesh and 1L plastic bucket
Depth: surface, middle, and bottom
Intake location: unknown
Discharge location: below weir and 3 points along discharge canal
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: 0.3 - 0.6 m/sec, may approach 2.4 m/sec

Operating Conditions During Sampling:
Number of units in operation: unknown in 1971, no power generation in 1972
Number of pumps in operation: unknown
Temperature: Intake temperature: 16 - 26 °C (1971); 19.9 - 28 °C (1972)
Discharge temperature: 29 - 35 °C (1971 only)
ΔT ranged from 9-13 °C (1971 only)
Biocide use: 1972 study, chemical mortality indistinguishable from mechanical

Survival Estimation:
Number of sampling events: 2 (1971) and 7 (1972)
Total number of samples collected: 30 (1971) and 246 (1972)
often 2-3 times as many samples collected at discharge
Total number of organisms collected: 1068 (1971) and 10,271 (1972)
Number of organisms entrained per year: unknown,
estimated entrainment is 1.7 - 5.8% of nonscreenable fish which pass facility
Fragmented organisms: not discussed
Equal no. of organisms collected at intake and discharge: 4X more in discharge
lower numbers collected at end of canal may be due to dead fish settling out of water column
Most abundant species: alewife and blueback herring
Stunned larvae: were included as live unless they had begun to turn opaque
Dead and opaque organisms: only opaque organisms were counted as dead
Latent survival: not studied
Data: replicate data combined; survival calculated per sampling day
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 64 - 100% for all species sampled (1971)
Initial discharge survival range: 0% for all species sampled (1971)
Calculation of Entrainment Survival: number live per cubic meter in each discharge sample/ number live per cubic meter in intake for each day
Confidence intervals and standard deviations were not presented.
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: none sampled
Larval survival: no survival anywhere in discharge at temperatures > 29 °C
Raw data: were not provided to verify results
Temperature effects: organisms exposed to elevated temp. for 50 - 100 min
estimated as causing 20% of mortality
most fish are dead at the end of the 1.14 mile canal
Mechanical effects: 1972 study indicated that 72 - 87% is mechanical mortality
Quality control: not discussed
Peer review: published in Journal Fisheries Research Board of Canada

Contra Costa Power Plant

San Joaquin River, CA

1976 Study

Stevens and Finlayson, 1978

Sampling: Dates: April 28 - July 10
Samples collection frequency: once per week
Times of peak abundance: unknown
Time: varied, about 25% of all samples collected at night
Number of replicates: typically 3
Intake and discharge sampling: paired at closest time and temperature
Elapsed collection time: 1 - 2 minutes
Method: 505 micron mech conical nylon plankton net with 0.58 m plastic collecting tubes on cod end; towed net on boat at 0.6 ft/sec
Depth: mid-depth
Intake location: at intake for units 6 and 7
Discharge location: at discharge for units 1 - 5 and units 6-7
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: Intake temperature: 19 - 30 °C
Discharge temperature 19 - 38 °C
Biocide use was not noted

Survival Estimation:
Number of sampling events: 6
Total number of samples collected: unknown
Total number of organisms collected: 966 (1606 at north shore control)
Number of organisms entrained per year: unknown
Fragmented organisms: enumerated in one replicate tow
higher proportion of unidentifiable fragments in discharge
Equal number of organisms collected at intake and discharge: more at intake
Most abundant species: striped bass
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: not studied
Data: was summarized by mean larval length
Controls: survival in the intake samples was considered to be the control
additional control on north shore to determine background mortality
control site at north shore away from intake had lower mortality rates
Initial intake survival range: 33-90% for striped bass
recirculated water may be cause of some intake mortality
Initial discharge survival range: 0 - 50% for striped bass
Calculation of Entrainment Survival: paired discharge survival divided by paired intake survival
Confidence intervals and standard deviations were not presented.
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not studied
Larval survival: increased survival with greater larval length
Raw data: were not provided to verify results
Temperature effects: mortality increased with increase in discharge temperature
higher mortality with discharge temp. > 31 and ΔT > 7 °C
linear regression showed that half died at temps >33.3 °C
0% survival at temperatures of 38 °C
Mechanical effects: stated not as much of an effects as temperature
Quality control: not discussed
Peer review: study conducted by California Fish and Game with funds provided by facility

Danskammer Point Generating Station

Hudson River, NY

1975 Study

Ecological Analysts, Inc. 1976b

Sampling: Dates: May 29 - November 18
Samples collection frequency: varied from once every 2 weeks to 4 times per week
Times of peak abundance: increased frequency during spawning
Time: varied, generally overnight
Number of replicates: varied, ranged from 1 to 12
Intake and discharge sampling: usually paired
Elapsed collection time: unknown
Method: pump/larval table
Depth: mid-depth for intake, unspecified for discharge
Intake location: in canal in front of traveling screens
Discharge location: outlet of Unit 3 to Hudson River
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: varied between 1 and 2
Temperature: Intake temperature range: 21 - 26 °C
Discharge temperature range: not provided
ΔT ranged from 0 - 10 °C
Biocide use not used during sampling; noted that chlorination will reduce survival

Survival Estimation:
Number of sampling events: 29
Total number of samples collected: 372
Total number of organisms collected: 1655
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal no. of organisms collected at intake / discharge: up to 2X more in discharge
Most abundant species: herrings, striped bass and white perch
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars for 96 hours
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 0 - 50% for striped bass
33 - 100% for white perch
63 - 100% for herrings
Initial discharge survival range: 0 - 39% for striped bass
38 - 80% for white perch
20 - 22% for herrings
Calculation of Entrainment Survival: Discharge survival / Intake survival
Confidence intervals and standard deviations: were not presented.
Significant differences were tested between the intake and discharge survival
Significantly lower survival in discharge: herring PYSL
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: none collected
Larval survival: decreased markedly within 3 hours of collection.
Raw data: were not provided to verify results
Temperature effects: significantly lower survival when ΔT > 10 °C and discharge temperature >30 °C
Mechanical effects: not discussed
Quality control: samples double checked and data entry monitored
Peer review: not mentioned, study was conducted for the facility

Fort Calhoun Nuclear Station

Missouri River, NE

1973-1977 study

Carter, 1978

Sampling: Dates: October 1973 - June 1977
Samples collection frequency: 5 - 24 times per year
Times of peak abundance: same frequency all year round
Time: unknown
Number of replicates: unknown
Intake and discharge sampling: unknown if timing was paired
Elapsed collection time: unknown
Method: plankton net with 571 μm mesh and 0.75 m diameter
Depth: unknown
Intake location: in river near intake
Discharge location: near discharge in river immediately downstream of intake
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: varied, 25-97% of full power or shut down
Number of pumps in operation: unknown
Temperature: Discharge temperature: 27.0 - 36.9 °C during summer samples
ΔT ranged from 0.6 - 13.5 °C
Biocide use: unspecified number of samples collected during chlorination

Survival Estimation:
Number of sampling events: 89 (16 when facility was shut down)
Total number of samples collected: unknown
Total number of organisms collected: 24,535 macroinvertebrates
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: no, varied
Most abundant species: Ephemeroptera, Hydropsychidae, Chironomidae
Stunned larvae: macroinvertebrates studied
Dead and opaque organisms: not discussed
Latent survival: not studied
Data: was summarized and averaged over entire sampling period
Controls: Survival in the intake samples was considered to be the control
Initial intake survival range: 12 - 26% for Ephemeroptera
42 - 51% for Hydropsychidae
35 - 60% for Chironomidae
Initial discharge survival range: 18 - 32% for Ephemeroptera
47 - 56% for Hydropsychidae
43 - 66% for Chironomidae
Calculation of Entrainment Survival: Average differential mortality
Confidence intervals / standard deviations: were calculated but not presented
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not collected
Larval survival: macroinvertebrates only were studied
Raw data: were not provided to verify results
Temperature effects: discussed but data not presented
Mechanical effects: studied during 16 dates when facility was shut down
Quality control: unknown
Peer review: not mentioned, study was conducted for the facility

Ginna Generating Station

Lake Ontario, NY

1980 Study

Ecological Analysts Inc., 1981c

Sampling: Dates: June 11 - 24 and August 8 - 21
Samples collection frequency: 5 times per week
Times of peak abundance: to coincide with peak densities of targeted species
Time: late afternoon or early evening
Number of replicates: unknown
Intake and discharge sampling: simultaneous sampling at both sites
Elapsed collection time: 15 minutes
Method: Intake: pump to floating rear-draw sampling flume
Discharge: floating rear-draw pumpless plankton sampling flume
Also used ambient water injection to reduce exposure to high temps.
Depth: unknown
Intake location: at screenhouse intake after flow through 3,100 ft intake tunnel
Discharge location: discharge canal
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: Discharge range: 18.5 - 34.4 °C
ΔT ranged from 8 - 10 °C
Biocide use: sampled 4 hours after routine injections

Survival Estimation:
Number of sampling events: 20
Total number of samples collected: 255
Total number of organisms collected: 664
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: varied
Most abundant species: alewife
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars of filtered water for 48 hours
Data: was summarized and averaged over the sampling month
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 16.3% for alewife eggs
39% for alewife larvae
58-71% for rainbow smelt
Initial discharge survival range: 62.5% for alewife eggs; 16% hatching success
0% for Alewife larvae
0% for rainbow smelt
Calculation of Entrainment Survival: Discharge survival/Intake survival
In June, only one larvae was found alive int the discharge samples
Standard errors were presented
Significant differences were tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Too few of many species were collected at the two sites (only 1 or 2 per site) to provide any reliable estimate of entrainment survival
Egg survival: determined by translucency and hatching success
Raw data: were provided to verify results
Temperature effects: none survived at any temperature
Mechanical effects: none survived at any temperature
Quality control: SOPs, color coded labels, sorting efficiency checks
Peer review: not mentioned, study was conducted for the facility

Indian Point Generating Station

Hudson River, NY

1977 Study

Ecological Analysts Inc., 1978c

Sampling: Dates: Jun 1 - July 15
Samples collection frequency: twice per week
Times of peak abundance: expected to coincide with peak densities
Time: 1800 - 0200 hours
Number of replicates: varied between 5 - 7 per sampling date.
Intake and discharge sampling:
Elapsed collection time: 15 minutes
Method: pump/larval table with ambient water injection to reduce temp. stress
Depth: unknown
Intake location: at intake of Units 2 and 3
Discharge location: discharge for Unit 3 and discharge common to all Units
Water quality parameters measured: DO, pH and conductivity
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: varied between 2 and 3, outage at Unit 2 from 7/4
Number of pumps in operation:6, at or near full capacity
Temperature: Intake range: 18.8 - 26.4 °C
Discharge range: 22.7 - 34.9 °C
ΔT during study not provided
Biocide use: unknown

Survival Estimation:
Number of sampling events: 7
Total number of samples collected: unknown
Total number of organisms collected: 4097
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed specifically, however, there were 115 Morone spp. organisms which could not be further identified to the species level and there were 55 organisms which were mutilated to the point of being unidentifiable to even the family level of organization. Entrainment survival may have been even lower if these mutilated samples were included in the assessment.
Equal number of organisms collected at intake and discharge: more at intake
Most abundant species: striped bass, white perch, bay anchovy and herrings
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: in aerated holding container in ambient water bath for 96 hours
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 0 - 11% for bay anchovy
60 - 77% striped bass
66% for white perch
36% for herrings
Initial discharge survival range: 3% for bay anchovy
29 - 45% for striped bass
15% for white perch
11% for herrings
Calculation of Entrainment Survival: Discharge survival / Intake survival
Standard errors were presented
Significant differences were tested between the intake and discharge survival
Significantly lower survival in discharge: striped bass YSL and PYSL
white perch PYSL
bay anchovy PYSL
herring PYSL
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not studied
Raw data: were not provided to verify results
Temperature effects: no determination that temperature had a significant effect
Mechanical effects: unknown
Quality control: color coded labels and immediate checks of sorted samples
Peer review: not mentioned, study was conducted for the facility

Indian Point Generating Station

Hudson River, NY

1978 Study

Ecological Analysts Inc., 1979c

Sampling: Dates: May 1 - July 12
Samples collection frequency: 2 consecutive days per week
Times of peak abundance: coincided with spawning of targeted species
Time: 1800 - 0200 hours
Number of replicates: approximately 6 per date
Intake and discharge sampling: simultaneous
Elapsed collection time: 15 minutes
Method: pump/ larval table with ambient water injection
Depth: 1 - 3 m below surface, approximately mid-depth
Intake location: Unit 2 and 3 intake
Discharge location: Unit 2 and 3 discharge, discharge point common to all units
Water quality parameters measured: conductivity, pH and DO
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: varied between 1 and 2
Number of pumps in operation: varied between 5 - 11, near full capacity
Temperature: Intake range: 11.2 - 24.3 °C
Discharge range: 19 - 36 °C
ΔT ranged from 9 - 12 °C
Biocide use was not noted

Survival Estimation:
Number of sampling events: 22
Total number of samples collected: unknown
Total number of organisms collected: 4496
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: more at discharge
Most abundant species: striped bass, white perch, bay anchovy and herrings
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars for 96 hours
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 26 - 48% for striped bass
15 -48% for white perch
18% for herring
2% for bay anchovy
Initial discharge survival range: 0 - 34% for striped bass
0 - 37% for white perch
0 - 8% for herring
0% for bay anchovy
Calculation of Entrainment Survival: Discharge survival/ Intake survival
Standard errors were presented
Significant differences were tested between the intake and discharge survival
Significantly lower survival at discharge: striped bass YSL, PYSL and juveniles
white perch PYSL
herring PYSL
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: none were alive in either the intake or discharge samples
Larval survival: decreased markedly within 24 hours of collection.
Raw data: were not provided to verify results
Temperature effects: at temps. > 30 °C, no striped bass or white perch survived
also 0% survived when both Unit 2 and 3 were running
Mechanical effects: not discussed
Quality control: sorting efficiency checks, color coded labeling, SOPs
Peer review: not mentioned, study was conducted for the facility

Indian Point Generating Station

Hudson River, NY

1979 Study

Ecological Analysts Inc., 1981d

Sampling: Dates: March 12 -22 and April 30 - August 14
Samples collection frequency: March: 4 times per week,
rest was 2 consecutive days per week
Times of peak abundance: coincided with spawning of targeted species
Time: 1700 to 0200
Number of replicates: unknown
Intake and discharge sampling: simultaneous sampling
Elapsed collection time: 15 minutes
Method: March sampling: two pump/larval table combination
April- August sampling: rear-draw plankton sampling flume at intake
pumpless plankton sampling flume at discharge
Depth: mid-depth for intake, 1 - 5 m below surface for discharge
Intake location: of Units 2 and 3
Discharge location: in discharge canal for Unit 3 and at end of canal
Water quality parameters measured: conductivity, pH and DO
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: one unit not operating March 20 - 26
only one continuously April - August
Number of pumps in operation: varied between 5 and 12
Temperature: Discharge range: 12.0 - 21.9 °C in March; 24 - 32.9 °C
ΔT data not provided
Biocide use was not noted

Survival Estimation:
Number of sampling events: 8 in March; 32 in April - August
Total number of samples collected: unknown
Total number of organisms collected: 478 in March; 2362 April-August
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: varied
Most abundant species: Atlantic tomcod, striped bass, white perch, herring, bay anchovy
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars with filtered water for 96 hours
Data: sorted by discharge temperature in March; combined all April - August
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 43 - 68% for Atlantic tomcod
39 - 56% for striped bass
13 - 33% for white perch
23% for herrings
10% for bay anchovy
Initial discharge survival range: 14 - 46% for Atlantic tomcod
62 - 77% for striped bass
24 - 70% for white perch
28% for herrings
6% for bay anchovies
Calculation of Entrainment Survival: For the fish larvae samples, a difference in stress associated with the different sampling techniques at the intake and discharge was given as the reason why discharge survival was higher than intake survival for each taxa sampled. Thus, entrainment survival was not calculated.
Standard errors were presented
Significant differences were tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: determined by translucency and hatching success;
33% hatched in discharge samples; 44% in intake samples
Larval survival: decreased markedly within 3 hours of collection.
Raw data: were not provided to verify results.
Temperature effects: no white perch or striped bass survival at temps. > 33 °C
Mechanical effects: unknown extent
Quality control: sorting efficiency checks, color coded labels and SOPs
Peer review: not mentioned, study was conducted for the facility

Indian Point Generating Station

Hudson River, NY

1980 Study

Ecological Analysts Inc., 1982b

Sampling: Dates: April 30 - July 10
Samples collection frequency: 4 consecutive nights per week
Times of peak abundance: coincided with primary spawning of target species
Time: 1600 - 0200 hours
Number of replicates: unknown
Intake and discharge sampling: initiated simultaneously
Elapsed collection time: 15 minutes
Method: intake: rear-draw plankton sampling flume mounted on raft
discharge: pumpless plankton sampling flume mounted on raft
Depth: unknown
Intake location: Unit 3 intake
Discharge location: discharge port number 1
Water quality parameters measured: conductivity, DO, pH
DOC and POC measured: no
Intake and discharge velocity: intake: 0.3 m/sec; discharge 3 m/sec

Operating Conditions During Sampling:
Number of units in operation: varied between 1 and 2, Unit 2 offline June 4-11
Number of pumps in operation: varied between 5 and 11
Temperature: intake range: 11.3 - 25.1 °C
discharge range: 23 - 31 °C
ΔT data not presented
Biocide use was not noted

Survival Estimation:
Number of sampling events: 44
Total number of samples collected: unknown
Total number of organisms collected: 2355
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: more at discharge
Most abundant species: striped bass, white perch, bay anchovies
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars for 96 hours
Data: combined by discharge temperature
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 95% for striped bass
93% for white perch
32% for bay anchovies
40% recirculation can occur so intake mortality may include organisms which were dead due to a previous passage through the facility
Initial discharge survival range: 50-81% for striped bass
0-90% for white perch
0-4% for bay anchovy
Calculation of Entrainment Survival: Discharge survival / intake survival
Confidence intervals / standard deviations: were not presented.
Significant differences were tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: hatching success: 82% in intake, 47% in discharge
Larval survival: decreased markedly within 3 hours of collection.
Raw data: were not provided to verify results
Temperature effects: little survival at discharge temps > 33 °C
Mechanical effects: unknown
Quality control: sorting efficiency checks, color coded labels and SOPs
Peer review: not mentioned, study was conducted for the facility

Indian Point Generating Station

Hudson River, NY

1985 Study

EA Science and Technology, 1986

Sampling: Dates: May 27 - June 29
Samples collection frequency: daily
Times of peak abundance: sampling did not occur during time of peak densities
Time: daytime, switched to nighttime after June 11 due to low sample sizes
Number of replicates: unknown
Intake and discharge sampling: simultaneous sampling
Elapsed collection time: 13 - 15 minutes (200 m^3)
Method: barrel sampler with 2 coaxial cylinders with 505 μm mesh
one sampler at intake; 2 at discharge
Depth: unknown
Intake location: in front of Unit 2 intake
Discharge location: in discharge canal downstream from Unit 2 discharge
Water quality parameters measured: salinity, DO, pH and conductivity
DOC and POC measured: no
Intake and discharge velocity: discharge: 2.8 - 10 ft/sec

Operating Conditions During Sampling:
Number of units in operation: varied between 1 and 2
Number of pumps in operation: unknown
Temperature: Intake range: 20.3 - 22.9 °C
Discharge range: 26.6 - 30.3 °C
ΔT range: 4.6 - 8.5 °C
Biocide use: residual chlorine not measured

Survival Estimation:
Number of sampling events: 49
Total number of samples collected: unknown
Total number of organisms collected: 457
Cited low efficiency of sampling gear as part of reason for low numbers of organisms sampled
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal no. of organisms collected at intake and discharge: 3X more at discharge
Most abundant species: bay anchovy
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars for 48 hours
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 23% for bay anchovy
Initial discharge survival range: 6% for bay anchovy
Calculation of Entrainment Survival: Discharge survival / Intake survival
Confidence intervals (95%) were presented
No calculations of significance due to small sample size
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: none collected
Larval survival: decreased markedly within 3 hours of collection.
Raw data: were not provided to verify results
Temperature effects: unknown, too narrow of temperature range sampled
Mechanical effects: New dual-speed pumps installed in Unit 2 in 1984, study was conducted to determine whether extent of mechanical mortality differed from previous studies.
Quality control: SOPs, reanalysis of samples, double keypunch of all data
Peer review: not mentioned, study was conducted for the facility

Indian Point Generating Station

Hudson River, NY

1988 Study

EA Engineering Science and Technology, 1989

Sampling: Dates: June 8 - June 30
Samples collection frequency: unclear
Times of peak abundance: sampling not at peak densities for targeted species
Time: afternoon and evening hours
Number of replicates: varied, unknown number per day
Intake and discharge sampling: simultaneous with twice as many at discharge
Elapsed collection time: 15 minutes
Method: rear-draw sampling flumes, 1 at intake and 2 at discharge
Depth: unknown at intake, surface at bottom at discharge
Intake location: on raft in front of Intake 35
Discharge location: downstream from flow of Units 2 and 3
Water quality parameters measured: salinity, DO, pH
DOC and POC measured: no
Intake and discharge velocity: discharge 2.2 - 10.0 ft/sec

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: Intake range: 20.3 - 23.8 °C
ΔT range: not provided
Biocide use: residual chlorine not monitored

Survival Estimation:
Number of sampling events: 13
Total number of samples collected: unknown
Total number of organisms collected: 12,333
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: 10X more in discharge
Most abundant species: bay anchovy, striped bass, white perch
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars for 24 hours
Data: was summarized and averaged over the entire sampling period; discharge survival estimates include data from direct release studies and combined surface and bottom samples
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 0 - 8% for bay anchovy
86 - 90% for striped bass
Initial discharge survival range: 0 - 2% for bay anchovy
62 - 68% for striped bass
Calculation of Entrainment Survival: discharge survival / intake survival
Standard errors were presented
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: none survived in intake and discharge samples
Larval survival: decreased markedly within hours of collection
Raw data: were not provided to verify results
Temperature effects: undetermined effect; too narrow range tested
Mechanical effects: study was conducted to determine the effect of the installation of dual speed circulating water pumps in Unit 2 in 1984 and variable speed pumps in Unit 3 in 1985; mechanical effects were determined to be main cause of mortality when discharge temperatures are < 32 °C
Quality control: SOPs, sampling stress evaluation, reanalysis of samples, double keypunch data
Peer review: not mentioned, study was conducted for the facility

Indian River Power Plant

Indian River Estuary

1975 - 1976 Study

Ecological Analysts Inc., 1978b

Sampling: Dates: July 2, 1975 - December 13, 1976
Samples collection frequency: once or twice monthly
Times of peak abundance: samples not taken frequently enough to detect
Time: mostly at night
Number of replicates: varied
Intake and discharge sampling: not paired
discharge samples not always collected
Elapsed collection time: approximately 5 minutes or until sufficient # collected
Method: 0.5 m diameter plankton sled with 505 μm net
rinsed in 10L of water of unspecified origin
Depth: unknown
Intake location: from foot bridge over intake canal
Discharge location: in discharge canal under roadway bridge
Water quality parameters measured: unknown
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: Intake range: -0.2 - 29.2
Discharge range: 5.4 - 39° C
ΔT ranged from 5.2 - 9.0 °C
Biocide use was not noted

Survival Estimation:
Number of sampling events: 27
Total number of samples collected: 25 intake and 21 discharge
Total number of organisms collected: unknown
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: unknown
Most abundant species: bay anchovy, Atlantic croaker, spot, weakfish,
Atlantic menhaden and Atlantic silversides
Stunned larvae: not discussed
Dead and opaque organisms: not discussed
Latent survival: in holding containers in ambient water baths for 96 hours
Data: sorted based on discharge temperature
Controls: survival in the intake samples was considered to be the control.
Initial intake survival range: not provided
Initial discharge survival range: not provided
Calculation of Entrainment Survival: not all were counted for most abundant species, a random sample was used instead
Confidence intervals / standard deviations: were not presented.
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms: unknown
Egg survival: were alive in either the intake or discharge samples.
Larval survival: unclear trend
Raw data: in Appendix B not available to EPA
Temperature effects: all species had lower survival at discharge temps > 20 ˚C.
only Spot survived above 35 °C though linear regression
Mechanical effects: unknown, however dye studies performed at this facility and recirculation of discharge water has been shown to occur. The extent to which organisms are entrained repeatedly and the effect this has on the number of organisms that were shown to have died through natural causes or from sampling is not known. Thus some intake mortality may be due to the organism's previous passage through the facility.
Quality control: unknown
Peer review: not mentioned, study was conducted for the facility

Muskingum River Plant

Muskingum River, OH

Literature Review

Ecological Analysts Inc., 1979a

Sampling: no on site sampling conducted

Operating Conditions During Sampling:
no sampling conducted

Survival Estimation:
analyzed pressure regimes in circulating water system
measured discharge temperature and ΔT at the facility
determined that pressure regimes were similar to facilities with entrainment survival studies
determined that low survival occurs at $\Delta T > 7.8$ °C which occurs for a small portion of entrainment season
reviewed documentation of survival at other steam electric stations
concluded that potential of survival at this facility was intermediate to high
Peer review: literature review prepared for facility

Northport Generating Station

Long Island Sound, NY

1980 Study

Ecological Analysts Inc., 1981c

Sampling: Dates: April 10 - 22 and July 10 - 23
Samples collection frequency: 5 nights per week
Times of peak abundance: attempted to coincide with peak abundance
Time: 1700 - 0100 hours
Number of replicates: unknown
Intake and discharge sampling: simultaneous
Elapsed collection time: 15 minutes
Method: floating rear-draw sampling flume with 505 μm mesh screens with ambient water injection system
Depth: intake: 2-8 m below surface; discharge: 1.5 m
Intake location: immediately in front of Unit 2 or 3 trash racks
Discharge location: immediately in front of Unit 2 or 3 seal well
Water quality parameters measured: DO, pH, conductivity
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: Discharge range: 15.9 - 35 °C, ave 19.9 in April and 33.6 in July
ΔT ranged from 8.6 - 15.0 °C
Biocide use was not noted

Survival Estimation:
Number of sampling events: 20
Total number of samples collected: 162
Total number of organisms collected: 884 in April and 76 in July
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: more at discharge
Most abundant species: American sand lance, winter flounder, northern pipefish
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated jars of filtered ambient water for 48 hours
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 66% for American sand lance
85% for winter flounder
28% for bay anchovy
Initial discharge survival range: 17% for American sand lance
35% for winter flounder
0% for bay anchovy
Calculation of Entrainment Survival: discharge survival / intake survival
Stated that survival estimate based on 4 assumptions: that the survival at the discharge is the product of the probabilities of surviving entrainment and sampling, that the survival at the intake is the probability of surviving sampling, that at the discharge there is no interaction between the two stresses, and each life stage consists of a homogenous population in which all individuals have the same probability of surviving to the next life stage
Standard errors were presented
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: none collected
Larval survival: decreased markedly within 6 hours of collection.
American sand lance significantly larger in intake sample
Raw data: were provided to verify results
Temperature effects: not studied
Mechanical effects: not studied
Quality control: SOPs, color coded labels, sorting efficiency checks
Peer review: not mentioned, study was conducted for the facility

Oyster Creek Nuclear Generating Station

Barnegat Bay, NJ

1985 Study

EA Engineering Science and Technology, 1986

Sampling: Dates: February - August
Samples collection frequency: unknown
Times of peak abundance: smaller samples collected during peak densities
Time: unknown
Number of replicates: unknown
Intake and discharge sampling: discharge collected 2 minutes after intake
Elapsed collection time: approximately 10 minutes
Method: barrel sampler with 2 nested cylindrical tanks with 331 mm mesh
Depth: unknown
Intake location: northernmost intake groin west of recirculation tunnel
Discharge location: easternmost condenser discharge point
Water quality parameters measured: DO, salinity and pH in latent studies
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: Discharge range: 13.5 - 39.3 °C
ΔT ranged from -0.2 - 12.1 °C
Biocide use: chlorine concentration was measured, but not detected

Survival Estimation:
Number of sampling events: 20
Total number of samples collected: 13 for bay anchovy eggs, 10 for bay anchovy larvae and 5 for winter flounder
Total number of organisms collected: 60,274
Number of organisms entrained per year: 619 million to 15.4 billion
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: no
Most abundant species: bay anchovy and winter flounder
Stunned larvae: included in initial survival proportion; as well as damaged
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars in water baths for 96 hours
Data: grouped by 3 day long sampling events
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 38 - 91% for bay anchovy larvae
77 - 96% for winter flounder larvae
Initial discharge survival range: 0 - 71% for bay anchovy larvae
32 - 92% for winter flounder larvae
Calculation of Entrainment Survival: Discharge survival / Intake survival
Confidence intervals / standard deviations: were not presented
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: no
Egg survival: based on translucency and hatching success
Larval survival: decreased markedly within 3 hours of collection
Raw data: were not provided to verify results
Temperature effects: no bay anchovy larvae survived at discharge > 35 °C
Mechanical effects: 18.8% of mortality at discharge temperatures 25.9 - 27.0 °C
Quality control: unknown
Peer review: not mentioned, study was conducted for the facility

Pittsburg Power Plant

Suisun Bay, CA

1976 Study

Stevens and Finlayson, 1978

Sampling: Dates: April 28 - July 10
Samples collection frequency: once per week
Times of peak abundance: unknown
Time: varied, about 25% of all samples collected at night
Number of replicates: typically 3
Intake and discharge sampling: paired at closest time and temperature
Elapsed collection time: 1 - 2 minutes
Method: 505 micron mech conical nylon plankton net with 0.58 m plastic collecting tubes on cod end; towed net on boat at 0.6 ft/sec
Depth: mid-depth
Intake location: in river near intake
Discharge location: in river near discharge
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: Intake temperature: 18 - 30 °C
Discharge temperature 27 - 37 °C
Biocide use was not noted

Survival Estimation:
Number of sampling events: 7
Total number of samples collected: unknown
Total number of organisms collected: 462 (585 at north shore control)
Number of organisms entrained per year: unknown
Fragmented organisms: enumerated in one replicate tow
higher proportion of unidentifiable fragments in intake
43% in intake; 19% in discharge
Equal number of organisms collected at intake and discharge: more at intake
Most abundant species: striped bass
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: not studied
Data: was summarized by mean larval length
Controls: survival in the intake samples was considered to be the control
additional controls in center of river and north shore
control site at north shore away from intake had lower mortality rates
Initial intake survival range: 49 - 93% for striped bass
Initial discharge survival range: 8 - 87% for striped bass
Calculation of Entrainment Survival: paired discharge survival divided by paired intake survival
Confidence intervals / standard deviations: were not presented
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not studied
Larval survival: increased survival with greater larval length
Raw data: were not provided to verify results
Temperature effects: mortality increased with increase in discharge temperature
higher mortality with discharge temp. > 31 and ΔT > 7 °C
linear regression showed that half died at temps >33.3 °C
0% survival at temperatures of 38 °C
Mechanical effects: stated not as much of an effects as temperature;
recirculated water may be cause of some intake mortality
Quality control: not discussed
Peer review: study conducted by California Fish and Game with funds provided by facility

Port Jefferson Generating Station

Long Island Sound, NY

1978 Study

Ecological Analysts Inc., 1978d

Sampling: Dates: April 21 - 26
Samples collection frequency: 4 times in one week
Times of peak abundance: unclear if sampling coincided with peak densities
Time: 1800 - 0200 hours
Number of replicates: varied between 7 - 10 per sampling date.
Intake and discharge sampling: simultaneous collection, equal number at sites
Elapsed collection time: 15 minutes
Method: pump (2 different types) and larval table
Depth: intake: 2 m below mean low water mark
discharge: 1 m below mean low water mark
Intake location: in front of trash racks of intake of Unit 4
Discharge location: in common seal well structure for Units 3 and 4
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: 4
Temperature: Intake range: 7 - 9 °C
Discharge range: 10 - 18 °C
ΔT ranged from 2 - 11 °C
Biocide use: sampling coincided with time of no biocide use

Survival Estimation:
Number of sampling events: 5
Total number of samples collected: 94
Total number of organisms collected: 1104
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: no, quite different
Most abundant species: winter flounder, sand lance, sculpin, American eel, fourbeard rockling eggs
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars in water bath for 96 hours
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 42 - 60% for winter flounder PYSL
11 - 67% for sand lance PYSL
33 - 84% sculpin PYSL
25 - 100% American eel juveniles
11 - 26% fourbeard rockling eggs
Initial discharge survival range:0 - 43% for winter flounder PYSL
12 - 40% for sand lance PYSL
88% for sculpin PYSL
94 - 96% for American eel juveniles
19 - 21% fourbeard rockling eggs
Calculation of Entrainment Survival: Discharge survival / intake survival
Confidence intervals / standard deviations: were not presented.
Significant differences were tested between the intake and discharge survival
Significantly lower survival in discharge: winter flounder PYSL
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: classified by observation only, based on transparency
Larval survival: no information given on length or other life stages
Raw data: were provided to verify results
Temperature effects: no apparent relationship temperature and survival; low numbers collected at a narrow range of discharge temperatures
Mechanical effects: assumed cause of all mortality
Quality control: color coded labeling, checks of sorted samples, and SOPs
Peer review: not mentioned, study was conducted for the facility

PG&E Potrero Power Plant

San Francisco Bay, CA

1979 Study

Ecological Analysts Inc., 1980b

Sampling: Dates: January
Samples collection frequency: unknown
Times of peak abundance: unclear if sampling corresponded with peak densities
Time: unknown
Number of replicates: unknown
Intake and discharge sampling: equal number but timing unknown
Elapsed collection time: 15 minutes
Method: 2 pumps and larval table with filtered ambient temperature water flow
Depth: mid-depth
Intake location: directly in front of intake skimmer wall
Discharge location: at point where discharge enters San Francisco Bay
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: Discharge range: 18 - 19.5 °C
ΔT range not presented
Biocide use: not used during sampling events

Survival Estimation:
Number of sampling events: 11
Total number of samples collected: 25
Total number of organisms collected: 1262
Number of organisms entrained per year: estimated for Units 1-3: 3 billion
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: approx. same
Most abundant species: Pacific herring
Stunned larvae: issue of stunned larvae not discussed in study
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars in water baths for 96 hours
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 22% for Pacific herring
Initial discharge survival range: 16% for Pacific herring
Calculation of Entrainment Survival: Discharge survival/ Intake survival
Confidence intervals / standard deviations: were not presented.
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: no
Egg survival: not studied
Larval survival: Based on results of this study, an estimate of 75% entrainment survival was used for all species and life stages entrained at this facility under all conditions
Raw data: were not provided to verify results
Temperature effects: discharge temps < 30 °C over 99.5% of time
Mechanical effects: most likely cause of mortality due to low temperatures
Quality control: unknown
Peer review: not mentioned, study was conducted for the facility

Quad Cities Nuclear Station

Mississippi River, IL

1978 Study

Hazleton Environmental Science Corporation, 1978

Sampling: Dates: June 19 - 28
Samples collection frequency: varied
Times of peak abundance: unknown
Time: afternoon, evening or nighttime hours
Number of replicates: varied
Intake and discharge sampling: unknown if paired
Elapsed collection time: did not exceed 60 seconds
Method: from boat, with 0.75 m conical plankton net with 526 μm mesh and an unscreened 5 L bucket attached
Depth: mid-depth at intake, near surface at discharge
Intake location: intake forebay
Discharge location: in discharge canal common to all units;
held at discharge temp for 8.5 minutes to simulate passage through canal
then cooled to ambient temp. plus 3.5 °C before sorting
Water quality parameters measured: DO
DOC and POC measured: no
Intake and discharge velocity: exceed 1 ft/sec

Operating Conditions During Sampling: completely open cycle mode
Number of units in operation: power output 41 - 99%, Unit 1 offline on June 22
Number of pumps in operation: all 3 regardless of power load
Temperature: Intake range: 21.5 - 26.5 °C
Discharge range: 28.0 - 39.0 °C
ΔT ranged from 5.5 - 14.8 °C
Biocide use: not used during sampling

Survival Estimation:
Number of sampling events: 5
Total number of samples collected: unknown
Total number of organisms collected: 2587
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: more at discharge
Most abundant species: freshwater drum and minnows
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: assumed dead from natural mortality prior to collection and omitted from further analysis; 27% of all sampled
Latent survival: observed in aerated glass jars for 24 hours on June 22-23, 26-27
Data: combined by % power of station operation
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 0 - 80% for all species
0 - 100% for freshwater drum
48 - 100% for minnows
Initial discharge survival range: 0 - 84% for all species
0 - 71% for freshwater drum
2 - 75% for minnows
Calculation of Entrainment Survival: Discharge survival/Intake survival
(minus dead and opaque individuals)
When discharge survival was greater than intake survival, the study indicated that entrainment survival could not be calculated, rather than assume 100 percent entrainment survival
Confidence intervals / standard deviations: were not presented.
Significant differences were tested between the intake and discharge survival
Significantly lower survival in discharge: throughout study
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not presented
Larval survival: decreased with increasing power output and discharge temperature
3% survival for all species when the facility operated near full capacity (96-99 percent) and discharge temperatures exceeded 37.9 ˚C
Raw data: were provided to verify results, however replicate sample data not presented
Temperature effects: lower survival with higher discharge temperatures > 30 °C
Mechanical effects: suggest mechanical effects cause 20 - 25% of mortality
Quality control: not discussed
Peer review: not mentioned, study was conducted for the facility

Quad Cities Nuclear Station

Mississippi River, IL

1984 Study

Lawler Matusky & Skelly Engineers, 1985

Sampling: Dates: April 25 - June 27
July sampling canceled as 100% mortality was suspected
Samples collection frequency: weekly
Times of peak abundance: unknown
Time: unknown
Number of replicates: unknown
Intake and discharge sampling: unknown if paired
Elapsed collection time: unknown
Method: from boat, with 0.75 m conical plankton net with 526 µm mesh and an unscreened 5 L bucket attached
Depth: 1.5 m for intake, surface for discharge
Intake location: intake forebay
Discharge location: in discharge canal; held at collection temperature for 8.5 min. then cooled to 3.5 °C above ambient temperature with an ice bath, in all held for over 20 minutes before sorting
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: samples collected at < 0.8 ft/sec

Operating Conditions During Sampling: operating at 40.2 to 50.7 % capacity
Number of units in operation: Unit 1 offline for refueling; both units offline on May 9
Number of pumps in operation: all 3 on all dates except on May 9
Temperature: Intake range: 11 - 24.4 °C
Discharge range: 12 - 37 °C
ΔT ranged from 9.5 to 14.5 °C; 1 °C on May 9 when offline
Biocide use: not used during sampling

Survival Estimation:
Number of sampling events: 8
Total number of samples collected: unknown
Total number of organisms collected: 3967
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: approx. same total
Most abundant species: freshwater drum, carp and buffalo
Stunned larvae: not discussed
Dead and opaque organisms: omitted from analysis; assumed dead before collection, 2, 979 opaque individuals were collected (75% of total, 87% of all discharge sample. range: 0 to 99% in samples) None were found to be dead and opaque in discharge on May 9 when offline and ΔT was 1 ˚C.
Latent survival: not discussed
Data: combined by species and sampling date
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: results not presented, only number alive 10 - 81% were dead and opaque
Initial discharge survival range: results not presented, only number alive 24 - 99% were dead and opaque
Calculation of Entrainment Survival: Discharge survival / Intake survival
Confidence intervals / standard deviations: were not presented.
Significant differences were not tested due to low numbers collected
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not studied
Larval survival: too little information to make any assumption of survival
Raw data: were not provided to verify results; totals collected per species not presented; actual numbers of dead and opaque not provided
Temperature effects: no sampling in July when discharge temps > 37 °C
Mechanical effects: not discussed
Quality control: 100% reanalysis quality control
Peer review: not mentioned, study was conducted for the facility

Roseton Generating Station

Hudson River, NY

1975 Study

Ecological Analysts, Inc., 1976c

Sampling: Dates: May 29th - November 18th
Collection frequency: varied from 4 times per week to once every 2 weeks.
Times of peak abundance: greater frequency of collection
Time: varied but generally occurred between dusk and dawn
Number of replicates: varied between 3and 14 for each date
Intake and discharge sampling: paired but timing not standardized
Elapsed collection time: not noted
Method: pump/larval table
Depth: mid-depth at both the intake and discharge
Intake location: in front of the trash rack
Discharge location: from the seal well before the end of the discharge pipe
Water quality parameters measured: none mentioned
DOC and POC measured: no
Intake and discharge velocity: not given

Operating Conditions During Sampling:
Number of units in operation: varied between 1 and 2
Number of pumps in operation: varied between 2 and 3
Temperature: ΔT ranged from 3 to 13 °C, intake and discharge T not given
Biocide use: not noted

Survival Estimation:
Number of sampling events: 41
Number of samples: 672
Number of organisms collected: 3,667
Number of organisms entrained per year: not discussed
Fragmented organisms collected: not discussed
Equal number collected from intake and discharge: differed by as much as 3.2X
Most abundant species: striped bass, white perch, alewife and blueback herring
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not mentioned
Latent survival: observed in aerated glass jars for 96 hours.
Data: summarized and averaged over the entire sampling period
Controls: survival in intake sample; no other control
Initial intake survival range: 57 to 80% for striped bass
0 to 71% for white perch
58 to 65% for herrings
Initial discharge survival range: 62% for striped bass
29% for white perch
26% for herrings
Calculation of entrainment survival: Discharge Survival/Intake Survival
Study noted that survival cannot be calculated with insufficient data or when intake survival is very low
Confidence intervals/ standard deviations: not presented
Significant differences: tested between the intake and discharge survival
Significantly lower survival in discharge: striped bass YSL and PYSL
white perch PYSL
herring PYSL and juveniles
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: none alive in either the intake or discharge samples
Larval survival: decreased markedly within 3 hours of collection
Size effects: survival by larval length was not studied
Raw data: were not provided to verify results
Temperature effects: not provided
Mechanical effects: not provided
Quality control: double check after initial sorting; monitoring of data entry
Peer review: not mentioned; study was conducted for the facility

Roseton Generating Station

Hudson River, NY

1976 Study

Ecological Analysts Inc., 1978e

Sampling: Dates: June 14th - July 30th
Samples collection frequency: 4 nights per week
Times of peak abundance: coincided with *Morone* spp. spawning season
Time: 1700 to 0300 EST
Number of replicates: actual numbers not give, an average of 12 per night stated
Intake and discharge sampling: pairing unknown
Elapsed collection time: 15 minutes
Method: pump/ larval table combination
Depth: mid-depth for both intake and discharge
Intake location: 1 m in front of trash rack
Discharge location: in seal well near end of discharge pipe
Water quality parameters measured: no
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: varied between 0 and 2
Number of pumps in operation: not given
Temperature: Intake temperature range: 18.7 - 27.5 °C
Discharge temperature ranged 24 - 37 °C
ΔT ranged from 1- 10 °C
Biocide use: not noted

Survival Estimation:
Number of sampling events: 27
Total number of samples collected: unknown
Total number of organisms collected: 3,491
Number of organisms entrained per year: not given
Fragmented organisms: not discussed
Equal number of organisms collected at intake / discharge: no, up to 5.7X more
Most abundant species: herrings, white perch and striped bass
Stunned larvae: were included in initial survival proportion
Dead and opaque organisms: not mentioned
Latent survival: observed in aerated glass jars for 96 hours
Data: combined by discharge temperature range: 34 - 30.5 and 30.6 to 37°C
Controls: Survival in the intake samples; no other control.
Initial intake survival range: 74-100% for striped bass
53-94% for white perch
49-68% for herrings
Initial discharge survival range: 14 - 80% for striped bass
6 - 56% for white perch
5 - 29% for herrings
Calculation of Entrainment Survival: Discharge Survival/ Intake Survival
Data for many taxa or life stages collected were insufficient for analysis
Confidence intervals / standard deviations: were not presented
Significant differences were tested between the intake and discharge survival
Significantly lower survival in discharge: striped bass PYSL
white perch PYSL and juveniles
herring PYSL and juveniles
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: data not presented
Larval survival: decreased markedly within 3 hours of collection.
Size effects: survival by larval length was not studied
Raw data: were not provided to verify results
Temperature effects: significant decrease in survival at discharge temp > 30 °C
Mechanical effects: unknown
Quality control: double check after initial sorting; monitoring of data entry
Peer review: not mentioned, study was conducted for the facility

Roseton Generating Station

Hudson River, NY

1977 Study

Ecological Analysts Inc., 1978f

Sampling: Dates: March 3-17 and May 31st - July 15th
Samples collection frequency: unknown; usually 4 nights per week was stated
Times of peak abundance: coincided with spawning of targeted species
Time: 1700 to 0300 hours EST
Number of replicates: unknown; an average of 8 to 10 per night was stated
Intake and discharge sampling: unknown if samples were collected in pairs
Elapsed collection time: 15 minutes
Method: pump/larval table combination
ambient water flow in table to reduce thermal exposure during sorting
Depth: mid-depth
Intake location: in front of trash racks
Discharge location: from seal well 244 m from end of discharge pipe
Water quality parameters measured: no
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: varied between 2 and 4
Temperature: Intake temperature: 0.5 - 5.5 °C (March); 11-27 °C (June/July)
Discharge temperature: 7 - 17 °C (March); 24 - 36 °C (June/July)
ΔT range: unknown
Biocide use was not noted

Survival Estimation:
Number of sampling events: unknown
Total number of samples collected: unknown
Total number of organisms collected: 6,973
Number of organisms entrained per year: unknown
Fragmented organisms: if >50% present, organism was counted
Equal number collected at intake and discharge: up to 2.3X more in discharge
Most abundant species: atlantic tomcod, herrings, striped bass, white perch
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not mentioned
Latent survival: observed in aerated glass jars for 96 hours
Data: combined by discharge temperature range, <29.9, 30.0 - 32.9, >33 °C
Controls: Survival in the intake samples was considered to be the control
Initial intake survival range: 39% for Atlantic tomcod
0 to 50% for striped bass
0 to 33% for white perch
0 to 59% for herrings
Initial discharge survival range: 16% for Atlantic tomcod
0 to 83% for striped bass
0 to 50% for white perch
0 to 14% for herrings
Calculation of Entrainment Survival: Discharge Survival / Intake Survival
Confidence intervals / standard deviations: were not presented.
Significant differences were tested between the intake and discharge survival
Significantly lower survival in discharge: Atlantic tomcod YSL
striped bass PYSL
white perch PYSL
herring PYSL and juveniles
Survival calculated for species with fewer than 100 organisms collected: yes
number of some taxa and life stage were too low to estimate survival reliably
Egg survival: data not presented
Larval survival: decreased markedly within 3 hours of collection.
increased with larval length
Raw data: were not provided to verify results
Temperature effects: survival decreased at temperatures above 30 °C
very low survival at temperatures > 33 °C (0 to 3%)
Mechanical effects: survival may increase with number of pumps operating
Quality control: color coded labels, immediate checks of sorted sample, SOP's
Peer review: not mentioned, study was conducted for the facility

Roseton Generating Station

Hudson River, NY

1978 Study

Ecological Analysts Inc., 1980c

Sampling: Dates: March 13 - 23 and June 6 - July 13
Samples collection frequency: 3 - 4 nights per week
Times of peak abundance: coincided with spawning of targeted species
Time: 1700 to 0300 EDT
Number of replicates: 4 to 10 per night
Intake and discharge sampling: unknown if paired samples
Elapsed collection time: 15 minutes
Method: pump/ larval table combination with fine mesh
ambient water flow to table to minimize thermal exposure when sorting
Depth: mid-depth
Intake location: in front of trash rack
Discharge location: in seal well 244 m from end of discharge pipe
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: varied between 1 and 2
Number of pumps in operation: varied between 2 and 3
Temperature: Intake temperature: 0.2 - 5.5°C (March), 19.8 - 24.0°C (June/July)
Discharge temperature: 10 - 19°C (March), 24 - 37 °C (June/July)
ΔT range was not given
Biocide use was not noted

Survival Estimation:
Number of sampling events: 30
Total number of samples collected: 256
Total number of organisms collected: 5,308
Number of organisms entrained per year: unknown
Fragmented organisms: counted if >50% of organism was present
22% of Atlantic tomcod could not be identified to life stage due to damage
Equal number of organisms collected at intake and discharge: varied
Most abundant species: herrings, white perch, striped bass, Atlantic tomcod
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not mentioned
Latent survival: observed in aerated glass jars for 96 hours
Data: combined by discharge temperature range <29.9, 30.0 - 32.9, >33 °C
also combined by larval length
Controls: Survival in the intake samples was considered to be the control
Initial intake survival range: 75-84% for Atlantic tomcod
8 - 100% for striped bass
0 - 93% for white perch
0 - 67% for herrings
Initial discharge survival range: 23-33% for Atlantic tomcod
0 - 50% for striped bass
0 - 100% for white perch
0 - 18% for herrings
Calculation of Entrainment Survival: Discharge survival/ Intake survival
Confidence intervals / standard deviations: were not presented
Significant differences were tested between the intake and discharge survival
Significantly lower survival in discharge: Atlantic tomcod YSL and PYSL
striped bass PYSL
white perch PYSL
herring PYSL
Survival calculated for species with fewer than 100 organisms collected: yes
samples sizes of some taxa and life stages were too small to analyze survival
Egg survival: data not presented
Larval survival: decreased markedly within 3 - 6 hours of collection
increased with larval length
Raw data: consolidated data by temp. and length was provided; not by sample
Temperature effects: significant decrease in survival at temperatures > 24 °C
very little survival at temperatures > 30 °C
Mechanical effects: lower tomcod survival in discharge w/o thermal effects
Quality control: color coded labels, checks of sorted samples, SOP's
Peer review: not mentioned, study was conducted for the facility

Roseton Generating Station

Hudson River, NY

1980 Study

Ecological Analysts Inc., 1983

Sampling: Dates: May 26 - July 31
Samples collection frequency: usually 4 nights per week
Times of peak abundance: coincided spawning of striped bass and white perch
Time: 1600 to 0200 EDT
Number of replicates: varied between 1 and 10 per sampling date
Intake and discharge sampling: unknown if samples were paired
Elapsed collection time: 15 minutes
Method: pump/larval table or plankton sampling flume
ambient water injection system to minimize thermal exposure
Depth: unknown
Intake location: from the No. 1B circulating water pump forebay
Discharge location: from discharge seal well or submerged diffuser port
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: varied between 1 and 2
Number of pumps in operation: varied between 3 and 4
Temperature: Intake temperature: 17.0 - 29.0 °C
Discharge temperature: 21.5 - 34.5 °C
ΔT range not given
Biocide use was not noted

Survival Estimation:
Number of sampling events: 42
Total number of samples collected: 1431
Total number of organisms collected: 4,965
Number of organisms entrained per year: not given
Fragmented organisms: counted if >50% of organism was present
7% of all organisms would not be identified to a life stage due to damage
Equal no. of organisms collected at intake/ discharge: more samples at discharge
Most abundant species: herrings, striped bass, white perch
Stunned larvae: were included in initial survival proportion
Dead and opaque organisms: not mentioned
Latent survival: observed in aerated glass jars for 48 hours.
Data: combined by larval length
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 33 - 100% for striped bass
0 - 75% for white perch
30 - 53% for herrings
Initial discharge survival range: 23 - 100% for striped bass
0 - 88% for white perch
0 - 31% for herrings
Calculation of Entrainment Survival: Discharge survival / Intake survival
Confidence intervals / standard deviations: were not presented.
Significant differences were tested for latent survival only
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not studied
Larval survival: decreased markedly within 3 - 6 hours of collection
survival increased with larval length
survival lowest for YSL and highest for juveniles
survival using flume was very low
Raw data: only consolidated data were presented, not by sample
Temperature effects: data not given
Mechanical effects: number of pumps may not affect survival
Quality control: color coded labels, SOPs
Peer review: not mentioned, study was conducted for the facility

Salem Generating Station

Delaware Bay, NJ

1984 Demonstration Study

Public Service Electric & Gas, 1984a

Sampling: Dates: 1977 - 1982
Samples collection frequency: varied, 1 to 4 times per month
Times of peak abundance: highest frequency in June and July
Time: unknown
Number of replicates: varied from 0 to 13 per sampling event
Intake and discharge sampling: usually paired with lag time
Elapsed collection time: 10 minutes
Method: larval table(1977- 1980) or low-velocity flume (1981-1982)
Depth: mid-depth for intake
Intake location: at intake bay 11A or 12B, inboard of traveling screen
Discharge location: discharge standpipe 12 or 22
Water quality parameters measured: unknown
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: Intake temperature: unknown
Discharge temperature: unknown
ΔT range: unknown
Lab simulation studies used to test thermal mortality
Biocide use: three 30 minute periods of chlorination each day
estimated biocide use reduces survival by 6.25%

Survival Estimation:
Number of sampling events: 0 to 12 per year, 38 in all years combined
Total number of samples collected: varied per year, 640 in all years combined
Total number of organisms collected: 5,173 larvae and juvenile fish of 6 taxa
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal no. of organisms collected at intake/ discharge: unknown
Most abundant species: spot and alewife
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not mentioned
Latent survival: tests varied with year, 12 to 96 hours in jars or aquaria
Data: combined data from all years, collected under all conditions
Controls: some fish were introduced into the larval table or low velocity flume directly; unclear if organisms passed through facility
Initial intake survival range: 90.9 % for Spot
12.5% for Herrings
Initial discharge survival range: 74.1% for Spot
7.1% for Herrings
Calculation of Entrainment Survival: Discharge survival / Intake survival
Estimated survival rates from onsite and simulation studies and compared with results in the literature from other waterbodies to select "the most realistic estimates"
Confidence intervals / standard deviations: not presented
Significant differences: not tested
Survival calculated for species with fewer than 100 organisms collected: unknown
Egg survival: none collected
Larval survival: not separated from juvenile survival
Raw data: was not provided to verify results
Temperature effects: unknown
Mechanical effects: tested gear efficiency and related mortality only
Quality control: not mentioned
Peer review: not mentioned, study conducted for the facility