Chapter A7: Entrainment Survival

INTRODUCTION

This chapter addresses the issue of survival rates of aquatic organisms entrained by cooling water intake structures. Assessment of ecological and economic consequences of entrainment is based on estimates of the number of fish and shellfish killed as a result of entrainment. Entrainment monitoring programs attempt to quantify the total number of organisms entrained. If 100 percent of entrained organisms are killed by the process, then the consequences of entrainment derive solely from the total number of organisms entrained. However, if some of the organisms survive the process, then the resulting consequences may be less severe.

Information regarding the magnitude of entrainment survival is extremely limited. To calculate benefits associated with entrainment reduction, EPA used the conservative assumption of 100 percent mortality. This same 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. This chapter provides a brief review of the current knowledge regarding entrainment survival, and describes the protocols EPA believes are necessary to conduct a sound entrainment survival study for use in a cost-benefit analysis of entrainment reduction technologies.

CHAPTER CONTENTS

A7-1 ENTRAINMENT MORTALITY AND ENTRAINMENT SURVIVAL

A7-1.1 Entrainment Mortality of Organisms

The most commonly entrained life stages of organisms include eggs, larvae, and juveniles. Adults are seldomly entrained. Eggs and larvae are the most common victims of entrainment because of their small size and their limited swimming ability. Eggs are extremely delicate and therefore are typically produced in high numbers to ensure that a proportion will survive to become reproducing adults. The generally high vulnerability of eggs in the natural environment ensures high mortality rates as a result of entrainment. Larvae are also typically delicate and susceptible to the physical stress of entrainment because, with the possible exception of vision and feeding apparatus, most of their major organ systems are poorly developed. Their skeletons, musculature, and integument (skin and scales) are soft and provide limited mechanical and thermal protection to vital organs. For these reasons, entrained larvae are believed to experience high mortality rates as a result of entrainment.

The presumption on the part of biologists that entrainment and passage through a cooling water intake structure would kill most if not all organisms indicates that any assertions that survival rates are appreciably greater than zero should be viewed with skepticism, and evidence in favor of that assertion must be quite strong to be convincing. Based on the "precautionary principle" in resource conservation, EPA believes that accounting for entrainment survival of entrained fish is unwarranted unless there is a strong foundation of supporting evidence that is clearly relevant to the particular features and ecological situation of the regulated facilities under consideration.

A7-1.2 Understanding Entrainment Survival

Entrainment survivability is species and life stage specific. Survivability is also be affected by the stress on an organism associated with the passage through the cooling water intake structure. Entrainment mortality is generally the result of exposure of the organisms to three types of stress (thermal, mechanical, and chemical) while passing through the cooling water intake structure. These stressors can interact with each other and are jointly affected by the operating characteristics of the power facility. These three stressors can also affect different species and life stages of entrained organisms differently. Since the extent and effect of these stressors can vary at each facility, the results of a study at one facility cannot be assumed to apply to another facility. Also, the results of a study at a facility can only be applied to time periods when the entrained organisms experience the same level of stresses and are not indicative of all times at a facility when stress levels may be different.

Thermal stress

Dose-response models that relate thermal exposure to mortality rate are critical in understanding the extent of the effect of thermal stress on aquatic organisms. The magnitude of thermal stress resulting from passage through the facility depends on several facility-specific parameters such as maximum temperature, intake temperature, discharge temperature, duration of exposure to elevated temperatures through the facility and before mixing with ambient temperature water, the maximum tolerable temperature of the species, and delta T (ΔT, i.e., the difference between ambient water temperature and maximum water temperature within the cooling system). The effect of the values of each of these parameters varies among the species and life stages of entrained organisms. Larger organisms are typically more tolerant than smaller organisms.

The Electric Power Research Institute (EPRI) sorted larval entrainment survival data by discharge temperature and determined 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 $^{\circ}$C.

Mechanical stress

Entrained organisms are also exposed to significant mechanical stress, which can also lead to high 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.

Chemical stress

Chemical biocides are routinely used within cooling water intake structures to remove biofouling organisms. These biocides often contain chlorine, which can negatively affect any potential entrainment survival of entrained species. The timing of any biocide application should be scheduled during times of low egg and larval abundance. The concentration and duration of biocide use need to be fully documented to gain a better understanding of the effect on entrainment survival.

A7-2 Existing Entrainment Survival Studies

Facility studies have tried to estimate entrainment survival (see Table A7-1). These studies varied in study designs and analytical methods. Important aspects of the study designs that differed between studies included sampling gear (e.g., types of nets or other collection devices), sampling locations relative to intake and outflow, sampling frequency, species collected, and observations of latent mortality. Table A7-1 provides a list of entrainment studies reviewed in this chapter by EPA.

A recent report prepared for EPRI (EA Engineering Science & Technology, 2000) summarized the results of 36 entrainment studies prepared for individual power facilities, including the 13 studies listed in Table A7-1. The report concluded that in most cases the assumption of zero entrainment survival is overly conservative. Although these studies indicate that entrainment survival may occur for certain species under certain conditions, the studies were conducted with a variety of sampling and measurement protocols. The fact that existing studies have been conducted using various methods highlights the fact that facilities have some unique features that affect monitoring procedures; it also 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 results presented in the report have limited utility. A more useful analysis would include consideration of aggregated variance components, which could be used to determine confidence intervals around the mean values that the report determined for individual species. Although a description of confidence intervals is always desirable, determining valid confidence intervals in the context of an analysis can be difficult (or impossible) unless the statistics available from each individual study are complete and sufficiently comparable. In EPRI's report, it seems likely that differences among the basic studies with respect to measurement protocols were too large, or descriptions of variance components were too few, to permit a more rigorous statistical summary.

Table A7-1: Entrainment Survival Studies Reviewed by EPA

Facility	Waterbody	State	Sampling Dates	Species Studied	Survivability Calculations	Citation
Braidwood Nuclear	Kankakee River	IL	June - July 1988	*Lepomis* cyprinids	initial	EA Science and Technology, 1990
Brayton Point	Mt Hope Bay	MA	April - August 1997 February - July 1998	winter flounder, tautog, windowpane flounder, bay anchovy, American sand lance	initial and 96 hour latent	Lawler Matusky & Skelly Engineers, 1999
PSI Cayuga Generating Plant	Wabash River	IN	May - June 1979	catastomids percids cyprinids percichthyids	initial and 48 hour latent	Ecological Analysts Inc., 1980a
Indian Point Generating Station	Hudson River	NY	March - August 1979	Atlantic tomcod striped bass white perch herrings bay anchovy	initial and 96 hour latent	Ecological Analysts Inc., 1981b
Indian Point Generating Station	Hudson River	NY	April - July 1980	striped bass bay anchovy	initial and 96 hour latent	Ecological Analysts Inc., 1982
Indian Point Generating Station	Hudson River	NY	May - June 1985	bay anchovy	initial	EA Science and Technology, 1986
Indian Point Generating Station	Hudson River	NY	June 1988	striped bass white perch bay anchovy	initial and 24 hour latent	EA Engineering Science and Technology, 1989
Indian River Power Plant	Indian River Estuary	DE	July 1975 - December 1976	bay anchovy	initial and 96 hour latent	Ecological Analysts Inc., 1978a
Oyster Creek Nuclear Generating Station	Barnegat Bay	NJ	February - August 1985	bay anchovy winter flounder	initial and 96hour latent	EA Engineering Science and Technology, 1986
Port Jefferson	Long Island Sound	NY	April 1978	winter flounder, American sand lance, fourbeard rockling, American eel, sculpin	initial and 96 hour latent	Ecological Analysts Inc., 1978b
PG&E Potrero	San Francisco Bay	CA	January 1979	Pacific herring	initial and 96 hour latent	Ecological Analysts Inc., 1980b
Quad Cities Nuclear Station	Mississippi River	IL	June 1978	freshwater drum non-carp cyprinids	initial and 24 hour latent	Hazleton Environmental Science Co., 1978
Quad Cities Nuclear Station	Mississippi River	IL	April - June 1984	freshwater drum carp buffalo	initial and 24 hour latent	Lawler Matusky & Skelly Engineers, 1985

Other specific aspects of the EPRI report that limit its utility include the following (which are primarily features of the source studies rather than the review itself):

- the limited geographic areas in the studies
- the small sample sizes in the studies
- the limited species in the studies
- the variation in sampling procedures
- the absence of information on chemical stresses
- the absence of information on mechanical stress
- the limited data on latent physiological effects on species
- effects from entrainment on growth rates
- increased vulnerability to natural mortality, maturation, and fertility/fecundity.

For these reasons, EPA concludes that the sampling and data in the studies reviewed in the EPRI report are far too limited to justify their use as a screening tool at the national level.

A7-3 Analysis by EPA of 13 Existing Studies

EPA reviewed the following 13 studies to determine if they were conducted in a manner to give an adequate representation of the current probability of entrainment survival at the facility.

Braidwood Nuclear Station

Larval samples for an entrainment survival study were taken from the intake and discharge of the facility in 1988. Although sampling at the discharge determined that the peak densities of larvae and eggs occurred during May, the samples for the entrainment sampling study were taken in June and July, which may have resulted in samples that included fewer and larger entrained organisms. A no. 0 mesh plankton net with a 1.0 m opening was used to collect samples. Samples were taken in areas where the velocities were approximately 0.5 ft/sec. After the sample was taken, the net was placed in a 5 gallon bucket containing water (no water chemistry or temperature data given), untied, and rinsed into the bucket. The larvae samples were sorted within 20 minutes of collection into three classes: live, dead-transparent, and dead-opaque. The dead-opaque larvae were omitted from the calculations of survival proportions as it was suggested that these opaque larvae probably died before collection. It was also assumed that the dead-transparent larvae died during passage through the system. After sorting based on mortality, the larvae were identified by species and separated into life stages. Survival proportions were determined by dividing the number of live larvae by the number of live plus dead-transparent larvae.

The intake survival study samples were collected from the holding pond, into which river water was pumped, during the day of June 1 (10 two minute replicates) and during the night of June 7 (2 two minute replicates) and July 5 (12 two minute replicates). There were no data given to determine that conditions were similar on the three sampling dates. The three intake survival sampling dates yielded a total of 191 individuals. Of these, the primary species sampled were cyprinidae (77 percent) and *Lepomis* sp. (6.8 percent). Of the larvae sampled on the three dates, 128 individuals were classified as dead-opaque and omitted from any calculations of survival proportions, 20 were dead-transparent, and 43 were live. Samples sizes were so small that all data of all species from the three sampling dates were combined to conclude that 68 percent of the larvae survived passage from the river screen house to the holding pond. EPA recalculated this intake survival, including the dead-opaque larvae, to determine that in fact only 23 percent survived. It is misleading to assume that these individuals died prior to pumping into the holding pond. To account for those larvae that may be dead in a sample from natural conditions, EPA suggests a similarly sized sample be collected away from the intake and before the river water is pumped into the holding pond as part of the same sampling event to account for any natural and sampling equipment related mortality.

The discharge samples were taken downstream of the outfall in the discharge canal during the day on the June 1 (11 two minute replicates), June 7 (13 two minute replicates), and June 21 (14 two minute replicates). Water chemistry and facility temperature information were not given to determine if conditions were similar on the three sampling dates. These three discharge sampling dates yielded a total of 103 individuals. Again, since the number of larvae sampled was low, all data from all three sampling dates were combined. Of the larvae sampled on the three dates, 22 individuals were classified as dead-opaque and omitted from any calculations of survival proportions, 20 were dead-transparent, and 61 were live. The study concluded that overall survival rate at the discharge was 75 percent. EPA included the dead-opaque larvae and concludes that the actual overall discharge survival should be recorded in this study as 59 percent. Rather than collecting intake and discharge samples simultaneously, EPA would prefer that the discharge samples be taken after a sufficient lag time from the intake samples to simulate passage through the facility. It is also important to take discharge samples as close to the outfall as possible, rather than downstream, to ensure that the larvae sampled were in fact those that passed through the facility. If sampling mortality due to collection cannot be reduced, then EPA suggests that the percent survival of all individuals sampled from the discharge without correcting for sampling equipment related mortality be used to ensure a fair, accurate, and conservative estimate of entrainment survival.

EPA disagrees with EPRI's determination that this facility experiences 100 percent survival for *Lepomis* sp. larvae based on the 1988 study. EPRI's calculation used the study's survival proportions, which had already corrected for dead-opaque larvae that were assumed to have died prior to passage through the facility, and further corrected for dead larvae by dividing the discharge survival by the intake survival, assuming incorrectly that the intake survival was a control. EPRI calculated the initial discharge survival for *Lepomis* sp. larvae as 80 percent (60 live larvae of 75 live and dead-transparent larvae with four dead-opaque larvae omitted). EPRI then divided this initial survival rate by the intake survival rate for *Lepomis* sp. larvae calculated as 78 percent (seven live larvae out of nine live and dead-transparent larvae) to correct for natural and sampling equipment related mortality to yield an initial entrainment survival of greater than 100 percent (0.80/0.78). Since the dead-opaque larvae were already omitted from the calculation and the initial survival study was not a true control, this overstates entrainment survival of *Lepomis* sp. larvae. While EPA concludes that the entrainment survival of *Lepomis* sp. larvae is not 100 percent, EPA notes that the limited samples collected give an indication that there may be some initial larval survival. Further entrainment survival studies would be needed at this facility using EPA's suggestions above before assuming anything more than 0 percent entrainment survival. Additional studies should also be conducted to determine latent mortality of larvae and egg viability after entrainment.

Brayton Point

Samples were collected in 1977 weekly from April 30 to August 27 and in 1998 weekly from February 26 to July 29. Samples were not collected during times of biocide use. The numbers of samples taken per week varied. The time of day the samples were collected also varied, with samples collected primarily during the day before March 18, 1988 and primarily during the night after that date. A total of 889 samples in 1997 and 1,424 in 1998 were collected at the intake from mid-depth directly in front of the Unit 3 intake screens. A total of 1,803 samples in 1997 and 2,713 in 1998 were collected at the discharge approximately 2 to 4 ft below the surface from either the middle of the discharge canal for Units 1, 2, and 3 or from the Unit 4 discharge pipe. Samples were collected in larval tables by pumping water into the table for approximately 15 minutes. After each sampling period, samples were transferred into 19 L buckets, covered, and transported to the laboratory for sorting. A time of 30 minutes per sample was targeted, but it is unclear how often this target time was met. Dead larvae were counted, identified, and preserved. Live or stunned larvae were transferred to holding cups with plastic spoons, turkey basters, or other unspecified devices, with a maximum of 20 larvae per cup. The holding cups were placed in the racks in the aquariums through which ambient temperature water flowed. Live larvae were held for 96 hours to determine latent survival. This study calculated entrainment survival assuming stunned organisms did not survive entrainment due to the increased risk of predation.

In the 1997 samples, 239 individuals were collected at the intake and 18,998 individuals were collected at the discharge. Bay anchovy was the predominant species, accounting for 71 percent of the total collected. Discharge water temperatures were highly variably and ranged from 13.5 to 35 ˚C. In the 1998 samples, 2,017 individuals were collected at the intake and 8,576 individuals were collected at the discharge. American sand lance was the predominant species, accounting for 38 percent of the total collected. Discharge temperatures were also highly variable and ranged from 10.5 to 45 ˚C. The differences in numbers and species collected at the intake and discharge raise concerns regarding the comparability of the survival estimates at the two sampling locations.

Because of low sample sizes, all data from all sampling conditions from 1997 and 1998 were combined. For American sand lance, total survival at the intake was 0.13 percent and total survival at the discharge was 0.41 percent; for tautog, intake survival was 4.2 percent and discharge survival was 4.4 percent. Since intake survival for these species was lower than discharge survival, it is impossible to distinguish between mortality due to collection and handling, and mortality due to the effects of entrainment. If entrainment survival were calculated as discharge survival divided by intake survival, the result would be an erroneous 100 percent entrainment survival. Survival was negligible for bay anchovy both at the intake (0 percent) and at the discharge (0.04 percent). For windowpane flounder, intake survival was 65 percent and discharge survival was 44 percent which results in an overall entrainment survival of 68 percent. For winter flounder, intake survival was 90 percent and discharge survival was 32 percent, which results in an overall entrainment survival of 36 percent. Survival was also analyzed with regard to discharge temperatures. In general, entrainment survival decreased markedly at discharge temperatures above 20 ˚C. The results of this study seem to indicate that this facility has a negative effect on survival of entrained organisms. The extent of the effect is unclear because of inadequacies and inconsistencies in the sample protocols. EPA recommends that future studies at this site should pair intake and discharge sample locations, times, and sizes to accurately represent the organisms that are entrained in the units of this facility. Also, EPA recommends that only samples collected under similar conditions be combined for statistical purposes.

Cayuga Generating Plant

Larvae samples were taken from the intake and discharge of the cooling system to determine entrainment survival at the facility in May and June of 1979. Samples were also taken from a cooling tower located on the discharge canal. Both initial and 48 hour latent survival were determined. Transit time through the cooling system was given as 2,180 seconds (36.34 minutes) and the ΔT during the sampling events ranged from 8.4 to 11.8 ˚C, with discharge temperatures ranging from 29.4 to 33.3 ˚C. Chlorination occurs daily at this facility, but treatments ceased at least 2 hours before the start of each sampling event. Between 0 and 6 sample pairs were collected at night from May 17 to 31 and June 8 to 22. The highest average densities of organisms sampled were from June 8 to 10. It is unclear why sampling was discontinued June 1 to 7 when densities of organisms may have also been high. Samples were taken simultaneously at the intake and discharge sites rather than stratified to give a lag time to simulate passage through the facility. Samples were collected by pumping water through the pump/larval table collection system for 15 minute intervals, after which the tables were drained and rinsed with ambient or discharge temperature river water, as appropriate, to collect the samples into a transportation container for sorting. The collected larvae were immediately classified as live, stunned, or dead. The dead larvae were preserved for subsequent identification. The live and stunned larvae were sorted by life stage and transferred to 1 L jars containing filtered river water, with a maximum of five individuals per jar. Filtered river water may not accurately simulate the actual conditions under which organisms are exposed after discharge from the facility. The jars were aerated and maintained in an ambient temperature bath for 48 hours after collection. Initial survival at the intake and discharge station was calculated as the proportion of the larvae alive to all larvae collected. Standard error of the survival proportion was calculated, as well as Fisher's exact test for independence to determined if the discharge survival was significantly lower than the intake survival.

The 80 intake survival samples yielded a total of 1,614 individuals in three life stages of 11 families (1,010 yolk sac larvae (YSL), 597 post yolk sac larvae (PYSL), and seven juveniles). Because sample sizes were so low for each sampling event, data were combined across samples to give a total estimate of intake survival by species irrespective of the facility conditions under which the samples were taken. Because of insufficient data, survival estimates were determined for only four taxa, catostomidae (621 YSL and 363 PYSL), cyprinidae (278 YSL and 188 PYSL), percidae (94 YSL and 14 PYSL), and percichthyidae (25 PYSL). The intake samples showed high mortality resulting from either natural conditions or rough handling during sampling. For example, in one sample, 33 larvae (41.25 percent) were classified as dead or stunned out of a total of 80 catostomidae larvae collected. These high mortality rates at the intake need to be reduced to the maximum extent possible. When divided into the mortality rates at the discharge site, high sampling mortality can mask any additional mortality due to passage through the facility.

The 80 discharge survival samples yielded a total of 942 individuals in three life stages of 11 families (463 YSL, 478 PYSL and 2 juveniles). Again, due to insufficient data, survival estimates were determined for only four taxa, catostomidae (306 YSL and 343 PYSL), cyprinidae (95 YSL and 97 PYSL), percidae (53 YSL and 13 PYSL) and percichthyidae (17 PYSL). Densities were sometimes much higher in the intake samples than in the discharge samples for the top three families, ranging from 1.7 to 16.4 times higher in the intake samples. This difference in organism densities can cause problems when comparing mortality rates at the two locations. Using Fisher's Exact Test, all but the percidae PYSL showed an initial and 48 hour latent discharge survival significantly lower than the initial and 48 hour latent intake survival. However, when divided by the intake survival to calculate the survival estimate, this difference is reduced and falsely high survivability estimates without standard errors are reported in EPRI's study.

Entrainment survivability was also analyzed with regard to discharge temperature. Lower entrainment survival occurred at temperatures above 30 ˚C. The lowest percentage surviving discharge temperatures greater than 34 ˚C were observed for the cyprinidae YSL, with an average of only 4.8 percent ± 4.7 percent surviving in the discharge samples. The facility's report calculates a 17.1 percent ± 16.7 percent entrainment survivability for cyprinidae YSL at temperatures greater than 34 ˚C by dividing the discharge proportion by the proportion surviving the intake under all conditions of 28.0 percent ± 2.7 percent (0.048/0.280). The amount of time the discharge temperatures exceed 30 ˚C was not provided even though this appears to have a profound effect on survivability. Given that samples were taken at different times with different sampling sizes, it is unclear whether the use of the data in this manner results in an accurate depiction of the actual entrainment survivability.

Indian Point Generating Station

EPA reviewed entrainment survival studies conducted at this facility in 1979, 1980, 1985, and 1988.

Atlantic tomcod larvae samples were collected in late winter, March 12 - 22, 1979, using pump/larval table collection systems. Sampling was scheduled to coincide with the time period of greatest abundance of tomcod larvae. Samples were collected at night eight times over a 2 week period. One unit was not operational during three nights of sampling, March 20-22. Intake and discharge samples were collected simultaneously rather than with a lag period to simulate passage through the facility. Samples were delivered to the larval table by two pumps for 15 minutes per sample. The pumps were then turned off and the larval tables were drained and then rinsed with ambient water to concentrate the organisms into the collection box. After collection, the larvae were sorted as live, stunned, or dead based on the extent of activity observed. Live and stunned larvae were transferred with a pipette into 1 L jars containing filtered ambient river water with a maximum of five individuals per jar. The jars were aerated and maintained in an ambient temperature bath for 96 hours. Discharge temperatures during the study period ranged from 12.0 to 21.9 ˚C. These latent mortality experimental conditions may not accurately simulate the actual conditions under which the organisms were exposed to subsequent to entrainment. Initial survival ranged from a low of 7 percent with discharge temperatures greater than 20 ˚C to high of 40 percent with discharge temperatures less than 16 ˚C. After taking into account latent survivability, the overall entrainment survival estimates ranged from a low of 11 percent with discharge temperatures above 20 ˚C and a high of 64 percent with discharge temperatures below 16 ˚C.

Striped bass, white perch, herring, and anchovy samples were collected from April 30 through August 14, 1979, using a rear-draw plankton sampling flume at the intake and a pumpless plankton sampling flume at the discharge. These methods relied on head-induced flow (created by the pressure difference due to the difference in water levels of the river and discharge canal) instead of pumps to collect organisms in an attempt to reduce mortality from collection and handling. The floating sampling gear was also advantageous to sample from the submerged discharge ports at this facility. Only one unit operated continuously throughout the study period. This may result in discharge temperatures which were not representative of the elevated temperatures which could be expected when the facility operates at full capacity. Intake and discharge samples were collected simultaneously. Samples were collected for 15 minutes each for two consecutive nights each week for a total of 32 sampling events. After the 15 minute period, flow through the flume was stopped and ambient water flushed the organisms into collection boxes. After collection, larvae were sorted as live, stunned, or dead based on the extent of activity observed and eggs were sorted as live or dead based on coloration. Live and stunned larvae were transferred with a pipette into 1 L jars containing filtered ambient river water with a maximum of five per jar. The jars were aerated and maintained in an ambient temperature bath for 96 hours. These experimental conditions may not adequately simulate the actual conditions under which the organisms were exposed after entrainment. Eggs were transferred to cups with fine mesh screened bottoms to allow for ambient water flow. Because of insufficient sample size, all data for striped bass eggs were combined so that 124 eggs were collected at the intake and 55 eggs were collected at the discharge. The 96 hour latent intake survival of striped bass eggs was 44 percent and the discharge survival was 33 percent through a range of discharge temperatures of 24 - 28 ˚C. The average entrainment survival estimate for striped bass eggs, calculated as discharge survival divided by intake survival, was 74 percent (0.33/0.44). 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. Initial discharge survival for all taxa ranged from a low of 3 percent for anchovy PYSL to a high of 75 percent for striped bass YSL at discharge temperatures ranging from 30.0 to 32.9 ˚C.

In 1980, additional samples were collected four consecutive nights per week from April 30 through July 10 for a total of 44 sampling events. The sampling gear is this study was modified to reduce the disproportionate stress from the different collection techniques used at the intake and discharge sampling sites. A total of 272 striped bass eggs were collected from the intake and 147 eggs were collected from the discharge over a range of discharge temperatures from 23 to 31 ˚C during the collection. The 96 hour latent intake survival was 82 percent while the discharge survival was 47 percent, resulting in an entrainment survival for striped bass eggs of 56 percent (0.47/0.82). Entrainment survival estimates ranged from a low of 5 percent survival for bay anchovy PYSL at discharge temperatures above 33 ˚C to a high of 97 percent survival for white perch PYSL at discharge temperatures below 29 ˚C.

In 1985, samples were collected with a barrel sampler daily from May 12 through June 29. Throughout the study a small sample set was collected; only 115 larvae and juveniles were collected from the intake and 342 from the discharge. Insufficient numbers were collected at both the intake and discharge for all taxa collected except bay anchovy PYSL, which comprised 83 percent of the total number sampled. For bay anchovy PYSL, 106 were collected at the intake and 274 were collected at the discharge. The survival at the intake was determined to be 23 percent while the survival at the discharge was determined to be 6 percent, resulting in an entrainment survival estimate of 24 percent (0.06/0.23). There was insignificant survival for both the intake and discharge samples to calculate latent survivability.

In 1988, the entrainment survival study was repeated to determine the effect of the installation of dual speed circulating water pumps in Unit 2 in 1984 and variable speed pumps in 1985. Previously calculated entrainment survivability rates demonstrated the effect of entrainment when the older single speed pumps were in use. Samples were collected for 15 minute intervals on 13 days from June 8 through June 30 during afternoon and evening hours using rear-draw sampling flumes. Intake samples were collected from in front of the intake structure and discharge samples were collected downstream from the point where the discharge flow from Units 2 and 3 join. For all samples combined, a total of 1,132 individuals were collected at the intake and 11,201 were collected at the discharge. The reason for the great disparity between intake and discharge organism densities was unclear. Bay anchovy (67 percent), striped bass (26 percent), and white perch (3 percent) were collected in the greatest proportions. At the intake, initial and 24 hour latent survival varied widely with many taxa having 0 percent survival for both. Bay anchovy PYSL was collected in the greatest numbers, 441, and had 8 percent initial survival and 0 percent 24 hour latent survival. Striped bass PYSL, 273 collected, had an initial survival of 90 percent and a 24 hour latent survival of 56 percent. At the discharge, initial and 24 hour latent survival also varied widely, with many taxa having 0 percent survival for both. Bay anchovy PYSL, 6,969 collected, had an initial survival of 2 percent and a 24 hour latent survival of 0 percent. Striped bass PYSL, 2,398 collected, had 68 percent initial survival and 44 percent 24 hour latent survival. The total entrainment survival for bay anchovy PYSL was 0 percent and for striped bass PYSL was 76 percent for initial survival and 79 percent for 24 hour latent survival (calculated as discharge survival divided by intake survival).

While these studies were the most comprehensive of all studies reviewed by EPA, they still contain several inadequacies that would need to be addressed before giving a full and accurate depiction of the actual entrainment survival of fish and shellfish at this facility. Further studies would be needed to address the problems of low sample sizes, disparate densities at sampling points, and high intake mortality.

Indian River Power Plant

Samples were taken once or twice monthly and mostly at night from July 21, 1975, to December 13, 1976, using a 0.5 m diameter plankton sled fitted with 505 μm net. The average discharge temperature ranged from a low of 7.7 ˚C in January 1976 to a high of 38.7 ˚C in August 1975, with an average ΔT that ranged from a low of 5.2 ˚C in July 1975 to high of 9.0 ˚C in November 1975. The samples were taken for approximately 5 minutes each until an appropriate number of individuals of each selected species were collected. After collection, the cod end of the net was submerged in approximately 10 L of water of unspecified type and temperature. Samples were poured into enamel pans and individuals of selected species were then removed from the pans with plastic spoons, meat basters, or eyedroppers and placed into holding containers with 10-25 individuals per container. During this process, individuals were assessed as either live or dead; however, for highly abundant species, the number of live versus dead was taken from a random sample of the total sample. To determine latent survivability, larger organisms were held in plastic Dandux boxes in tanks through which intake water flowed. Discharge water for the discharge samples flowed through those holding tanks for the first 4 to 6 hours, after which ambient water was introduced to the tanks. Smaller organisms were held in 250 mL plastic cups which floated in styrofoam frames within Dandux boxes in the holding tanks. Latent survivability was observed for 96 hours during which time the organisms were fed. Both absolute and percent survival data were presented for the seven species of fish and shellfish.

The 25 intake samples were taken from the foot bridge over the intake canal. This study used the same assumption that intake mortality was natural or caused by handling during collection. High approach velocity may also account for high mortality in the intake samples. The 21 discharge samples were taken from the discharge canal under a roadway bridge. It is unclear why discharge samples were not collected each time intake samples were collected. Appendix B, which contained the entrainment study data, was not made available to EPA. Therefore, the survivability calculations could not be verified. As in other studies, very low intake survivability masked any additional mortality due to entrainment. For example, bay anchovy experienced an average of only 21 percent intake survivability, which, when combined with low sample sizes, made it extremely difficult to determine the extent of any additional mortality due to the effects of entrainment. When samples where sorted based on discharge temperatures, all species presented experience reduced survivability at average discharge temperatures above 20 ˚C. Four species experienced 0 percent survival above 35 ˚C. The facility's study attempted to determine the relationship between the times of high facility discharge temperatures with times of greatest species abundance to gain a better insight to the facility induced mortality rates. The extent to which this affects the overall survivability for species throughout the year remains unclear. This information would have been helpful to determine the percentage of time most organisms will experience zero survival at this facility. It is also unclear if the discharge temperatures remain comparable at this time (over 25 years later). Dye studies have also been 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 either natural causes or from sampling from the intake is not known, and thus some intake mortality may be due to the organism's previous passage through the facility, which may further mask entrainment mortality.

Oyster Creek Nuclear Generating Station

An entrainment survival study was performed at this facility from February through August 1985. Entrainment survival was estimated for bay anchovy eggs and larvae and winter flounder larvae. Intake samples were collected at the intake and discharge samples were collected approximately 2 minutes later to simulate the passage of the same portion of water through the facility. Samples were collected for approximately 10 minutes each with a barrel sampler which consists of two nested cylindrical tanks. The inner cylinder has 331 mm mesh screened panels that collect organisms as water is drawn into the inner cylinder and out through the screens and outer cylinder. This design intended to reduce sampling mortality through abrasion from the sampling gear and by minimizing the velocity of the water sampled to 1 cm/sec. Samples were held in flow-through water systems with either ambient or discharge temperature water as appropriate. Organisms were sorted as either live, stunned, or dead. Live and stunned organisms were transferred to flow-through or solid holding containers in water baths to determine 96 hour latent survivability. Larvae were fed throughout the observation period. Eggs were classified as live when clear or transparent in color, and dead if cloudy, opaque, or showed no development during observation. Data were grouped by 3 day long sampling events. It was unclear if conditions remained similar throughout the 3 days of each sampling event. Water quality data such as temperature, dissolved oxygen, salinity, and pH were recorded throughout the 96 hour observation period. Chlorine concentrations were measured during sample collection to determine any mortality due to biocide use, but chlorine was not detected. The raw data were not provided in any appendix to this study, so the calculation of survival estimates could not be verified.

A total of 20,227 bay anchovy eggs were collected from the intake and 26,243 were collected from the discharge from 13 sampling events. During sampling, the discharge temperature ranged from 25.9 to 38.1 ˚C and the ΔT ranged from -0.2 to 12.1 ˚C. It was unclear whether the facility was operating during sampling event 17 when the ΔT was -0.2 ˚C (intake temperature of 26.1 ˚C minus discharge temperature of 25.9 ˚C). Initial survival, calculated as discharge survival divided by intake survival, ranged from 21 to 83 percent. The 96 hour latent survival, calculated as discharge survival divided by intake survival, ranged from 0 to 100 percent. The total survival for bay anchovy eggs, calculated as initial survival multiplied by latent survival, ranged from a low of 0 percent at discharge temperatures above 38 ˚C to a high of 93 percent at a discharge temperature of 26.2 ˚C. Overall, the average survival was below 50 percent at discharge temperatures above 32 ˚C.

A total of 3,396 bay anchovy larvae were collected from the intake and 3,474 were collected from the discharge from 10 sampling events. During sampling, the discharge temperature ranged from 25.9 to 39.3 ˚C and the ΔT ranged from -0.2 to 11.7 ˚C. Initial survival, calculated as discharge survival divided by intake survival, ranged from 0 percent at temperatures above 35 ˚C to 99 percent at a discharge temperature of 26.2 ˚C. Initial survival was generally below 50 percent when discharge temperatures were above 30 ˚C. The 96 hour latent survival could not be calculated due to near zero survival of organisms from both the intake and discharge samples.

A total of 3,935 winter flounder larvae were collected from the intake and 2,999 were collected from the discharge from five sampling events. During sampling, the discharge temperature ranged from 13.5 to 20.3 ˚C and the ΔT ranged from 3.5 to 11.1 ˚C. Initial survival, calculated as discharge survival divided by intake survival, ranged from a low of 36 percent with a discharge temperature of 20.3 ˚C to a high of 96 percent with a discharge temperature of 14.8 ˚C. The 96 hour latent survival, calculated as discharge survival divided by intake survival, ranged from a low of 10 percent with a discharge temperature of 20.3 ˚C to a high of 97 percent with a discharge temperature of 14.8 ˚C.

This facility, like all others, would need to conduct additional studies to sample more species, with larger sample sizes, and with less intake mortality in order to calculate a fair and accurate estimate of entrainment survival. It would also be helpful to determine the percentage of time the discharge temperatures are high enough to cause low entrainment survival.

Port Jefferson Generating Station

Samples taken for an entrainment survival study were taken for four nights in April 1978. Sampling was scheduled to coincide with no biocide use at the facility. It was unclear whether these sampling dates corresponded with times of high egg and larvae abundance. Discharge temperatures ranged from 10 to 18 ˚C, with a ΔT that ranged from 2 to 11 ˚C. It was unclear whether these low discharge temperatures are typical of the facility's year round operation. Samples were analyzed for both initial and 96 hour latent survival. The intake samples were collected at 2 m below mean low water mark in front of the trash racks of the intake. The discharge samples were collected at 1 m below mean low water mark in the common seal well structure for Units 3 and 4 of the facility. Intake and discharge samples were taken simultaneously rather than with a lag time to simulate the passage of water through the facility. Samples were collected from the intake and discharge by pumping water with a Marlow pump into a larval table for 15 minutes after which the pump was turned off and the table drained. The time for the table to drain was approximately 30 minutes. The study did not mention if water was used to help flush the organisms into the transportation container; however, the study does indicate that the organisms were exposed to elevated temperatures in the table and transportation container during the time the table drained. The transportation container was taken to the laboratory where the organisms were sorted in an ambient temperature flow-through bath. Larvae and juveniles were sorted as either live, stunned, or dead. Dead larvae and juveniles were preserved for later identification. Live and stunned larvae and juveniles were transferred with a pipette to 0.9 L glass jars with a maximum of 5 individuals per jar. The jars were aerated and maintained in an ambient water bath. Throughout the 96 hour observation period for latent survivability, the organisms were not fed. The eggs were classified through observation only with the category live assigned when eggs were clear or transparent and dead assigned when eggs were cloudy and opaque. No further study on the actual viability of the live eggs was performed. Initial survival was calculated by dividing the number of live and stunned by the total number collected. Latent survival was calculated by dividing the number of organisms alive by the number of organisms initially classified as live or stunned. The statistical significance of the survivability at the intake and discharge was calculated in the facility's study. This study, like others, used the assumption that the probability of mortality from entrainment and sampling are independent stresses that do not interact, and the intake survival was used as the estimate of surviving sampling.

In the 47 intake samples, 31 winter flounder PYSL, 215 sand lance PYSL, 19 sculpin PYSL, 84 American eel juveniles, and 193 fourbeard rockling eggs were collected. Since sampling sizes were extremely low on each sampling date, all data taken at different times and under different temperature regimes were compiled to estimate survivability. Using EPRI's equation, initial intake survival was calculated as 42 percent for winter flounder PYSL (3 live, 10 stunned, 18 dead), 41 percent for sand lance PYSL (27 live, 61 stunned, 127 dead), 84 percent for sculpin PYSL (14 live, 2 stunned, 3 dead), 83 percent for American eel juveniles (64 live, 5 stunned, 14 dead), and 81 percent for fourbeard rockling eggs (157 live, 36 dead). In the 47 discharge samples, 23 winter flounder PYSL, 166 sand lance PYSL, 17 sculpin PYSL, 71 American eel juveniles, and 102 fourbeard rockling eggs were collected. Again, all samples taken at different times and under different conditions were combined to estimate survivability. Initial discharge survival was calculated as 43 percent for winter flounder PYSL (0 live, 10 stunned, 13 dead), 13 percent for sand lance PYSL (3 live, 19 stunned, 144 dead), 88 percent for sculpin PYSL (8 live, 7 stunned, 2 dead), 94 percent for American eel juveniles (67 live, 4 dead), and 93 percent for fourbeard rockling eggs (95 live, 7 dead). In each case, the sampling sizes were very low and unequal in the intake and discharge samples. Also in many cases, the discharge survival proportions were higher than the intake survival proportions. Because of the nature of the equation for entrainment survivability, this results in an erroneous reporting of 100 percent initial entrainment survival for winter flounder PYSL, sculpin PYSL, American eel juveniles, and fourbeard rockling eggs. Only sand lance PYSL had lower discharge survival than intake survival, which resulted in a calculated entrainment survival of 32 percent. Also, this study assumed that stunned larvae would survive entrainment. More likely, these stunned larvae would be more susceptible to predation after entrainment and should not be included in the proportion surviving entrainment.

Extended intake survival calculated for winter flounder PYSL was 77 percent (10 live, 3 dead), 11 percent for sand lance PYSL (10 live, 78 dead), 44 percent for sculpin PYSL (7 live, 9 dead), 98 percent for American eel juveniles (63 live, 1 dead), and 14 percent for fourbeard rockling eggs (22 live, 135 dead). Extended discharge survival was calculated as 50 percent for winter flounder (5 live, 5 dead), 9 percent for sand lance PYSL (2 live, 20 dead), 33 percent for sculpin PYSL (5 live, 10 dead), 96 percent for American eel juveniles (64 live, 3 dead), and 22 percent for fourbeard rockling eggs (21 live, 74 dead). This results in a calculated entrainment survival of 65 percent for winter flounder PYSL, 80 percent for sand lance PYSL, 76 percent for sculpin PYSL, 97 percent for American eel juveniles, and 100 percent for fourbeard rockling eggs. Again, since sample sizes were unequal in the intake and discharge samples, it is difficult to give a fair and accurate depiction of actual latent mortality from collection and holding stress.

To claim anything more than 0 percent entrainment survival, more studies would be needed at this facility to sample greater numbers of more species with less intake mortality. EPA recommends that samples be taken at times of high larvae abundance and only those samples collected at similar temperatures be combined when calculating survival.

Potrero Power Plant

Survival estimates were determined only for Pacific herring larvae. Sampling for this study was conducted daily for 11 days in January 1979 to assess both initial and latent 96 hour survivability. Sampling was scheduled to avoid periods of biocide use at the facility. It was unclear whether the month of January was the time of highest egg and larvae abundance at this location. Fish larval samples were collected by pumping water with two pumps into a larval table for 15 minutes. Filtered water at ambient temperature was withdrawn from the intake area and flowed through the larval table to aid in the concentration of organisms in the collection box. After 15 minutes, the pumps were turned off and the tables were drained; however, filtered ambient temperature water continued to flow into the collection boxes. The collection boxes were then emptied into screen topped containers for transportation to the laboratory for immediate sorting. Dead larvae where preserved for later identification. The live larvae where transferred using a pipette into 1 L jars with a maximum density of five larvae per jar. These jars where held for observation in ambient temperature water baths and aerated. The organisms were not fed during the 96 hour latent survival study.

Intake samples were taken directly in front of the intake skimmer wall at mid-depth. Discharge samples were taken at the point where the discharge enters San Francisco Bay at mid-depth. Twenty-five intake and discharge samples were analyzed for survival; however, information was not provided regarding the timing of these samples, or whether they were taken simultaneously or after a lag period to simulate passage through the facility. The range of discharge temperatures during sampling was 18.0-19.5 ˚C. In the 25 intake samples, 119 Pacific herring larvae were classified as initially alive and 427 were initially dead, resulting in an intake survival of 22 percent. In the 25 discharge samples, 115 Pacific herring larvae were classified as initially alive and 601 were initially dead, which resulted in a discharge survivability of 16 percent. According to EPRI's equation, entrainment survivability would be 75 percent. The 96 hour latent survivability for Pacific herring was 52 percent at the intake (62 survived out of 119 observed) and 49 percent at the discharge (56 survived out of 115 observed). According to EPRI's equation, this would result in an entrainment survivability for Pacific herring of 93 percent with discharge temperatures between 18.0 and 19.5 ˚C. Since samples were taken during January when discharge temperatures were low, higher mortality rates may be observed during other times of the year. Also, since samples were taken at times when biocides where not in use, high mortality rates may be observed when biocides are in use. Further studies would be needed at this location to give a fair and accurate estimate of survival for all species entrained.

Quad Cities Nuclear Station

Entrainment survival studies were performed at this facility in 1978 and 1984. This facility operates as a completely or partially close-cycle cooling system, so its entrainment survival may be very different from other facilities that have once-through cooling systems.

In 1978, samples were taken in the afternoon, evening, or nighttime hours of June 19-26, 1978, when the facility was operating in a complete open cycle mode with a generating output ranging between 41 and 99 percent power. Discharge temperatures during sampling ranged from 28.0 to 39.0 ˚C with ΔT that ranged from 5.5 to 14.8 ˚C. Samples were not taken during times of biocide use. Intake samples were collected at mid-depth from the intake forebay. Discharge samples were taken near the surface from the discharge canal common to all units. It was unclear whether surface sampling was sufficient to capture organisms that may be distributed in other parts of the water column. Samples were collected from a boat for at least 60 seconds with a 0.75 m conical plankton net with no. 0 mesh and an attached unscreened 5 L bucket. After collection, samples were transferred to the laboratory for sorting. Discharge samples were held at discharge temperatures for 8.5 minutes to simulate passage through the discharge canal and then cooled to ambient temperature plus 3.5 ˚C before sorting. Samples were classified within 20 minutes of collection in a sorting tray with a pipette as live, dead-translucent, and dead-opaque. This study also used the assumption that dead-opaque larvae were dead due to natural conditions prior to collection, whereas the dead-translucent larvae died from collection or from effects due to entrainment. In addition, this facility used the assumption that intake samples were a control to determine the rate of mortality from collection and handling and discharge samples indicated mortality from natural mortality, sampling mortality and entrainment mortality.

Survival estimates were determined for freshwater drum and non-carp cyprinidae. Survivability was calculated with and without the inclusion of dead-opaque larvae. EPA believes that the dead-opaque larvae should be included in the calculation because the control will correct for any mortality due to natural causes and no additional correction should be made to the data. The facility's study concluded that the lowest entrainment survival, 3 percent for all species sampled, occurred when the facility was operating near full capacity (96-99 percent) and discharge temperatures exceeded 37.9 ˚C. Entrainment survival was calculated for each life stage separately for each sampling date in order to reduce variability in survival associated with different operating levels of the facility and different life stages of each species. For freshwater drum, entrainment survival ranged from a low of 0 percent for juveniles at temperatures ranging from 38.0 to 39.0 ˚C with the facility operating at 96-99 percent to a high of 71 percent for juveniles at temperatures ranging from 32.5 to 33.0 ˚C with the facility operating at 74-78 percent. 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 as other facilities have incorrectly done in their studies. For non-carp cyprinidae, entrainment survival ranged from a low of 4 percent for larvae at temperatures ranging from 38.0 to 39.0 ˚C with the facility operating at 96-99 percent, to a high of 75 percent for juveniles at temperatures ranging from 30.5 to 31.2 ˚C with the facility operating at 59-68 percent. Variability in entrainment survival under different conditions could also result from the low sample sizes.

In 1984, another entrainment survival study was conducted with the intention of estimating survival for all dominant taxa entrained, including walleye and sauger, which were not represented in significant numbers in the samples in the 1978 study.

However, insufficient numbers were collected to calculate entrainment survival for these species in this study as well. Sampling was conducted weekly from April 25 through June 27. Sampling was not conducted in July when discharge temperatures exceeded 37 percent and survivability was reported to be 0-3 percent in the 1978 study. The facility was operating at 40.2-50.7 percent capacity during the time of the study. The discharge temperature ranged from 12 to 37 ˚C and the ΔT ranged from 9.5 to 14.5 ˚C. On May 9 both units were offline and the ΔT was 1 ˚C. EPA believes that the May 9 data were not representative of normal operating conditions so this data should not be included in the survival estimates. Intake samples were collected from a depth of 1.5 m at the intake forebay and discharge samples were collected from the surface in the discharge canal. The sampling method was identical to the 1978 study. Again, biocides were not used during the study period. Half of each sample was analyzed in the laboratory in an apparent effort to reduce mortality due to collection and handling. Dead and opaque organisms were omitted from the analysis since it was assumed that these died prior to collection. EPA believes this is an erroneous assumption and that the control should correct for any which may have died prior to collection. Organisms were also sorted by life stage as yolk sac larvae, post yolk sac larvae, or juveniles. No statistical analysis was performed because of low sample sizes.

In the intake samples, 481 freshwater drum, 133 carp, and 33 buffalo were collected. In the discharge samples, 64 freshwater drum, 103 carp, and 44 buffalo were collected. In the facilities study, of a total of 3,967 organisms collected in both the intake and discharge, 2,979 opaque individuals were omitted from analysis (75 percent). When so few organisms are collected, the arbitrary elimination of 75 percent seems excessive given that the data are also corrected for natural mortality by dividing the discharge survival by the intake survival. The percentages of dead and opaque individuals ranged from 0 to 99 percent of the total in each sample. It is interesting to note that 0 percent were found to be dead and opaque in the discharge sample from May 9 when both units were offline and the ΔT was 1 ˚C. The specific numbers of dead opaque larvae from each sample were not available to calculate the actual entrainment survival in this study. EPA assumes that if opaque individuals were included the entrainment survival proportions would be significantly lower than those reported in the facility's study and in EPRI's report. The raw data were not provided in this report to recalculate entrainment survival including dead and opaque larvae.

A7-4 Principles to Guide Future Studies of Entrainment Survival

EPA maintains that demonstrations of entrainment survival for selected species under a limited range of experimental conditions are not a sufficient basis for assuming that entrainment survival should be routinely included in biological impact assessments. However, EPA recognizes that accurate quantification of biological impacts should include entrainment survival in cases where entrainment survival rates have been estimated by valid means, and that the conditions associated with those rate estimates are broad enough to reflect the scope of operating conditions at the regulated facilities (e.g., all ambient operating temperatures at which the facility operates, all ages at which an organism is entrained). At a minimum, future studies intended to quantify entrainment survival should address the considerations described below. These considerations are intended to indicate the kinds of factors that collectively lead to results that (a) encompass a realistic range of operating conditions and (b) allow for a thorough understanding of the statistical features (e.g., bias and precision) of entrainment survival rate estimates.

A7-4.1 Protocol for Entrainment Survival Study

To determine entrainment survival rate, a statistically and scientifically rigorous study of site-specific entrainment survival is needed. Such a study would use the best sampling practices (gear selection, sampling location and frequency to capture diel and seasonal patterns), maintain careful records, provide description and quality control of sample processing, and use the appropriate statistical analytical procedures.

Sampling should be carefully planned to minimize any potential bias. Samples should not be combined if they were collected under different environmental factors. Control samples that 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. When control survival is less than discharge survival, no attempts should be made to calculate entrainment survival which would give an erroneous survival result of greater than 100 percent.

Organisms should be counted and sorted by both species, life stage, and size. Initial mortality and extended or latent (96 hour) mortality should both be reported to ensure the best overall survival estimate. Studies need to be conducted throughout the year to determine if the entrainment survival is dependent on life stage and size of each species entrained. Entrainment studies also need to be conducted for 24 hour intervals to determine the time of day entrainment survival will most likely occur. Entrainment survival should be calculated separately for each life stage of each species.

The physical and operating conditions of the facility need to be recorded to determine their associated impact on the three fundamental stressors that affect entrainment survival. The percentage of the maximum load at which the facility is operating needs to be recorded at the time of sampling to give an indication of the extent to which organisms are exposed to stress. To assess the effect on entrainment survival by thermal stressors, the study needs to determine the temperature regime of the facility. Specifically, the study needs to record the temperature at intake and at the discharge point for each component of the facilities system: temperature changes within the system, including the inflow temperature, maximum temperature, delta-T, and rate of temperature change, and the temperature of the water in 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. To determine the effect of mechanical stressors on entrainment survival, the study needs to indicate the impacts caused by 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 units, parallel or in sequence, which may expose organisms to entrainment in multiple structures. To properly account for chemical stressors, the timing, frequency, methods, concentrations, and duration of biocide use (e.g., chlorine) for the control of biofouling need to be determined. The water chemistry conditions also need to be recorded, including 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. These operating conditions can have different effects on different species. It is important to fully understand the species-specific effects of the three fundamental stressors. In particular, different fishes have different critical thermal maxima. The maximum temperature to which an organism may be exposed to while passing through the facility may cause mortality in one species yet be sublethal in another species. When possible, the organisms sampled should be categorized by their cause of death, mechanical, thermal, or chemical. This will give a better assessment of the susceptibility of each entrained species and life stages to the effects of which of the three fundamental stressors. In the future this information will be helpful in the design of cooling water intake structures to reduce entrainment mortality.

EPA recommends that entrainment survival studies be conducted under worst case scenarios, such as times of near full capacity utilization when egg and larvae abundances are high and biocides are in use.

A7-4.2 Statistical Considerations: Direct Estimates of Entrainment Survival Rates

When reporting estimates of entrainment survival rates, a study should address the following statistical considerations. Reliable studies should provide a complete description of sampling protocols as they affect:

- Range of inference (i.e., how are the results of the study relevant to future applications?).
- Identification of independent experimental units.
- Ability to provide quantitative measures of precision (e.g., prediction error and/or confidence intervals).

A7-4.3 Applicability of Entrainment Survival Studies to Other Facilities

To apply the results of an entrainment survival study to other facilities, it is necessary to determine to what degree the physical attributes of facilities are similar. Specifically, do the facilities have similar numbers of cooling water flow routes, are the lengths of flow routes similar in terms of time and linear distance, are the mechanical features the same in terms of abrasive surfaces, pressure changes and turbulence, and are the same number and types of pumps used? Similarities or differences in these physical aspects can profoundly affect the applicability of the study between facilities.

The operating characteristics of a facility can also affect the applicability of entrainment studies to other time periods at the same facility and to other facilities. To determine applicability, it is necessary to know if there is similarity and constancy of the flow rates, transit times, thermal regimes, and biocide regimes.

The ecological characteristics of the environment around the facility should also be considered when determining the degree to which a study of entrainment survival is applicable to other facilities. Specifically, its is important to determine the similarities or differences in the ambient water temperature, dissolved oxygen level, and the species and life stage present.

A7-4.4 Statistical Considerations: Development of Predictive Models of Entrainment Survival Rate

With sufficient entrainment survival data from well designed studies, a model of entrainment survival could be developed that would allow for improved evaluation of survival rates and would aid in the design of the best cooling water intake structures to minimize entrainment mortality.

Model performance objectives should be defined before developing any studies using standardized survival models. The following are examples of statistical considerations that a study should address when reporting models that describe functional relationships between facility operating conditions (e.g., thermal regimes) and entrainment survival rate. Reliable studies describe the model and the basis of modeling procedure with respect to these questions:

- How much precision is required?
- What is the scope of the intended application of the model?
- Which species, life stages, and size ranges are addressed by the model?
- What is the range of physical considerations (e.g., ambient water temperature, temperature, ΔT, maximum temperature, duration of temperature) that are addressed by the model?
- What is the model structure?
- What are the relationships among the submodels (thermal stress, mechanical stress, and chemical stress) of the general model; e.g., are different sources of mortality assumed to act independently, or not?
- What are adequate or levels of precision for estimates of individual model parameters?

A7-5 Conclusions

Although EPA agrees with the conclusion of the EPRI report that an assumption of zero entrainment survival rate for all facilities may be unwarranted for certain species and certain conditions, EPA believes the available data are insufficient to provide the basis for generalizations about entrainment survival rates. EPA concludes that it remains to be determined whether nonzero survival rates are common for cooling water intake structures in general. Furthermore, EPA does not believe that the magnitude of a positive entrainment survival rate at other facilities or under different conditions at the same facility can be predicted with reliability on the basis of existing studies.

After reviewing the EPRI report and other sources, it is clear that the number of relevant variables that collectively determine any entrainment survival rate is so large that the studies conducted to date should be viewed as a provocative set of anecdotes that demonstrate the need for further study, but do not provide a sufficient basis for making predictions. Until such time that the understanding of the general phenomenon is broadened to encompass more of the differences among facilities, including all physical and biological conditions, EPA believes that the precautionary principle with respect to regulation should be maintained: that is, in the absence of sound empirical data quantifying survival, the standard method of impact assessment should not include consideration of nonzero entrainment survival rates. In addition to providing a precautionary stance for conservation of biological resources, assuming a zero entrainment survival rate also implies that the quantification of resource impacts at different facilities should be done in a consistent manner and therefore facilitate between facility, waterbody specific, and regional comparisons.