Impingement and Entrainment Survival Studies Technical Support Document

Technical Report

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2
FACTORS INFLUENCING SURVIVAL

This chapter presents background information on factors affecting impingement and entrainment survival and discusses general findings from prior survival studies to provide context for the study plan discussions presented in Chapters 4, 5, and 6. The §316(b) Phase II Rule emphasizes that sampling used to support the compliance demonstration should reliably represent impingement mortality from intake operation; accounting for short-term and long-term variations. The Phase II Rule also allows facilities to use the results of "a well-constructed, site-specific entrainment survival study, approved by the Director", in benefits assessments when seeking site-specific entrainment requirements. Representative estimates of impingement and entrainment survival should account for variations in species survival, which may be caused by a variety of factors. Awareness of these factors provides useful insights for developing monitoring plans for impingement and entrainment survival studies and for identifying potential measures to enhance impingement survival. In addition, some general characteristics and patterns are evident from the results of prior studies that provide those planning new impingement and entrainment survival studies with perspective on what might be expected at their own CWIS.

Impingement imposes physical stresses that may cause mortality because of impacts and abrasion, organism systemic stress and suffocation. Entrained organisms may be exposed to a combination of physical forces (such as changes in pressure and shear), rapid temperature elevations from waste heat rejected at the condensers and, at many facilities, toxic compounds (*e.g.*, chlorine or bromine) being used to control biofouling. The probability of surviving these exposures, or survival rate, depends on various biological, CWIS, and water quality factors that affect the levels of stress from, and organism sensitivity to, impingement and entrainment. These factors have been previously identified and discussed for impingement (EPRI 2003, Jinks et al. 2003), and entrainment (EPRI 2000) as summarized below.

Biological Characteristics

The biological variables that affect impingement and entrainment survival include species type, developmental stage and size, and physiological condition.

Species type

Impingement

Studies at operating power plants have shown that impingement survival is strongly influenced by the inherent sensitivity of species to impingement stresses (EPRI 2003). In general, species types that are found to be hardy in terms of their resistance to collection and handling stress (e.g., crab, killifish, catfish) are also tolerant of impingement stresses, while those that are difficult to collect and keep alive (e.g., herring, anchovy, smelt) tend to be sensitive to impingement. Morphological and behavioral characteristics are important in determining species tolerance to impingement and, in general, demersal species have exhibited higher impingement survival than pelagic species.

Studies that have been conducted at operating power plants indicate that impingement survival rates can vary several-fold among species at a given site, with the reported extremes often approaching 100 percent mortality for very sensitive types and 100 percent survival for very tolerant types. Impingement survival estimates for about two-thirds of the taxonomic families exceed 50 percent when screenwash is continuous. EPRI 2003 grouped the families of fish and shellfish into several categories based on their overall potential for surviving impingement apparent in prior studies (Table 2-1).

Table 2-1
Families of Fish and Shellfish Grouped According to Mean Impingement Survival Rates Observed in Prior Studies (EPRI 2003)

High Survival Rate Potential (~71-100 percent)

- Percopsidae - trout-perches
- Homaridae - lobster
- Fundulidae - killifishes
- Ophidiidae - cusk eels and brotulas
- Cyprinodontidae - pupfishes
- Inachidae - spider crabs
- Catostomidae - suckers
- Bothidae - lefteye flounders
- Gasterosteidae - sticklebacks
- Pleuronectidae - righteye flounders
- Crangonidae - sand shrimps
- Triglidae - searobins
- Rajidae - skates
- Cancridae - rock crabs
- Cottidae - sculpins
- Labridae - wrasses
- Percidae - perches
- Portunidae - portunid crabs
- Ictaluridae - freshwater catfishes
- Cyprinidae - minnows and carps
- Mugilidae - mullets
- Syngnathidae - pipefishes and seahorses
- Xanthidae - mud crabs and stone crabs
- Soleidae - soles
- Centrarchidae - sunfishes
- Penaeidae - penaeid shrimps
- Batrachoididae - toadfishes
- Scorpaenidae - scorpionfishes

Intermediate Survival Rate Potential (~31-70 percent)

- Atherinidae - silversides
- Pinnotheridae - pea crabs
- Gadidae - codfishes
- Gobiidae - gobies
- Infraorder Caridea - caridea shrimp
- Sciaenidae - drums
- Percichthyidae - temperate basses
- Salmonidae - trouts
- Anguillidae - freshwater eels
- Scombridae - mackerals and tunas
- Embiotocidae - surfperches
- Cyclopteridae - lumpfishes and snailfishes

Low Survival Rate Potential (~0-30 percent)

- Osmeridae - smelts
- Clupeidae - herrings
- Engraulidae - anchovies
- Lutjanidae - snappers
- Pomatomidae - bluefishes
- Stromateidae - butterfishes
- Loliginidae - squids

Families included in the "high survival potential" group consist mostly of shellfish with hard exoskeletons; fish generally inhabiting shallow, turbid waters and known to be easily held in captivity such as killifishes and minnows; demersal species and species tolerant of low dissolved oxygen levels such as flounders, catfishes, and sunfishes; and species that are heavily scaled or armored such as pipefishes and sculpins. Families in the "low survival potential" group are mostly characterized by soft-bodied pelagic forage species such as anchovies, herrings and smelts. Thus, the survival rate estimates reflect the species' tolerance to impingement that would be expected based on the nature of the impingement stresses and the biological characteristics of the species. With few exceptions, mean survival rates among species of the same family are quite similar (EPRI 2003).

Entrainment

The results of entrainment survival studies indicate that entrainment survival in the absence of thermal effects[5] varies widely among species. For example, a review of ichthyoplankton entrainment survival estimates from 12 power plants sited on freshwater, estuarine, and marine systems indicates up to about a four-fold difference in mean survival rate from physical effects of entrainment among species entrained at each CWIS, and about an eight-fold difference among 21 taxa collected across all 12 sites (Jinks et al. 1981). Of the 13 families of fish represented in these studies, herrings, anchovies, silversides, and sand lances appeared relatively sensitive to physical effects of entrainment (survival of 23-48 percent), while the sensitivity of cods, gobies, and suckers appeared moderate (survival of 52-60 percent). Eels, carps and minnows, temperate basses, perch, drums and flounders appeared highly tolerant of entrainment, with mean survival in the range of 75-100 percent.

A more recent comprehensive review summarized entrainment survival estimates (measured largely in the absence of thermal stress) for approximately 50 different taxa obtained from 35 study reports at 20 different power stations (EPRI 2000). The mean of entrainment survival estimates for most taxa exceeded 50 percent. Mean entrainment survival values were highest (about 72-92 percent) for freshwater and estuarine macroinvertebrates, freshwater suckers, and spot. Striped bass, white perch, Atlantic tomcod, winter flounder, carps and minnows, and freshwater drum had moderate survival values (means of about 47-63 percent), while herrings and anchovies had the lowest survival, with mean values approaching 25 percent.[6]

The inherent ability of entrained individuals to withstand temperature elevations during transit through the cooling water system also varies among species. Immobilization or death resulting from sudden increases in water temperature beyond an organism's upper tolerance limit is often referred to as "heat shock." The upper lethal limits of thermal tolerance for a species are

[5] The terms "mechanical mortality" and "mechanical" or "physical" effects have been widely used when referring to entrainment mortality rates or entrainment survival in the absence of thermal or chemical stresses (i.e., when temperatures experienced during entrainment are below lethal temperatures and no biocidal treatment is underway)(e.g., Jinks et al. 1981, Vaughn 1982, USEPA 2004b) .

[6] Note, however, that USEPA's current position is that the entrainment survival studies conducted to date provide unreliable estimates of survival, and were insufficient to support other than a conservative estimate of zero percent survival at the national level in their benefit assessment for the Phase II Rule (USEPA 2004a; USEPA 2004b; Bain 2003; Garman 2003; Hocutt 2003).

typically determined by laboratory experiments and are defined as the temperature resulting in death of 5, 50, or 95 percent of the test organisms (TL5, TL50, TL95).

The tolerance of organisms to temperature elevations in the cooling water system is influenced by their genetic ability to adapt to thermal changes within their characteristic temperature range and the duration of exposure to the elevated or lowered temperature (Coutant 1972), which is brief for entrainment at many power stations. Genetic ability to adapt to temperature changes differs among species and among life stages within a particular species (Hochachka and Somero 1971; EA 1978a; Kellogg and Jinks 1985). For example, striped bass tolerate higher temperatures than salmon, and juvenile striped bass have higher tolerances than adult striped bass (EA 1978a; Coutant 1970). Therefore, entrainment survival from thermal effects is influenced by the thermal life histories of the relevant waterbody assemblages and the thermal tolerance limits of the species susceptible to entrainment. For example, the community in a waterbody having a narrow natural range of temperatures may have species assemblages with thermal tolerance zones that are relatively narrower than those in a waterbody with widely fluctuating natural temperatures.

Developmental Stage and Size

Impingement

Sensitivity to the physical stresses of impingement may change as organisms grow and develop. Effects on impingement survival rate should be most evident during distinct developmental transitions that significantly alter physical strength and physiological mechanisms (e.g., osmoregulation), and based on prior studies this appears to be the case. Studies of impingement survival on fine-mesh intake screens generally show that survival of fish increases sharply as larvae transition to the juvenile stage. Scale development at this stage in many species likely provides critical protection against the effects of impingement. For example, in an evaluation of 2.5 mm fine-mesh screen installed at the Indian Point Generating Station, no larvae of commonly impinged species, including striped bass, white perch, river herring, bay anchovy and rainbow smelt, survived impingement until the late post yolk-sac stage (EA 1979a). Impingement survival of striped bass increased from 0 percent for early larvae to an estimated 60-68 percent for late post-yolk-sac larvae and to 100 percent for juveniles. Survival of white perch increased from 0 percent for larvae to 71 percent for juveniles.

Similarly, transitional stages in the growth of shellfish may affect impingement survival rates. For example, the absence of a hard exoskeleton during molting increases the sensitivity of decapod crustacea to impingement, resulting in more moderate survival rates of juveniles and adults during the molting season than at other times of the year (NUSC 1987; CP&L 1985; Tatham et al. 1978; Serven and Barbour 1981).

However, for young of year and older fish typically impinged on standard 3/8-inch mesh screens, the relationship of impingement survival to size or age is less clear. Prior studies have reported both increasing and decreasing trends in impingement survival rates with size (EPRI 2003). The ability to observe trends in survival due solely to size or age of impingeable size organisms may be confounded by other factors influencing survival, including seasonal differences in debris loading or cooling system operation (e.g., cooling water flow rates), size-related differences in collection and holding mortality, and environmental variables influencing the physiological state of the organism prior to impingement.

Entrainment

Survival from the physical effects of entrainment may also depend on the life stage or size of the entrained organisms, although data sufficient to quantify the relationship is limited to relatively few species. Where large data sets exist, such as for Hudson River striped bass and white perch, analyses indicate significant positive correlation between entrainment survival and life stage/size of the fish (EA 1989). For example, survival of entrained striped bass increased from 50 percent at about 5.5 mm total length to 90 percent at about 14.5 mm (Figure 2-1). In general, yolk-sac larvae had the lowest entrainment survival and early juveniles the highest. Variation in non-thermal entrainment survival with length may account for a large portion of the temporal variation in entrainment survival observed in prior studies. Thermal tolerance to temperature elevations simulating those experienced during entrainment has also been shown to increase with length for post yolk-sac larvae and early juveniles of several species (Kellogg and Jinks 1985, Kellogg et al. 1984).

Physiological Condition

Impingement

Impingement survival may be influenced by environmental factors that affect the organism's physiology and thus condition it's sensitivity to impingement stresses, though relatively little information is available regarding these factors. Variations in biological factors, such as the nutritional state of the population, and environmental factors, such as water temperatures, likely contribute to interannual variations in impingement survival rate that have been observed at sites where studies have been conducted over several years. Variations in condition of the organisms during the year also may have an influence on seasonal variations in impingement survival. For example, impingement survival of Atlantic tomcod at the Indian Point Generating Station during October to December was higher than during January through April. One possible reason for this difference was the fact that pre-spawning fish collected in late fall and early winter are in better condition and more able to withstand stress than are post-spawning fish present later in the winter (Con Ed 1986). Physiological condition is also affected by water temperature and salinity. The influence of these water quality parameters on impingement survival is discussed below in the subsection on "Waterbody Characteristics".

Entrainment

Interannual variations in conditions required for spawning and growth and development of young undoubtedly affect the physiological condition of the population of eggs, larvae, and early juveniles vulnerable to entrainment, and likely contribute to year-to-year variations in entrainment survival. Two environmental variables that affect physiological function, water temperature and, in the case of estuaries, salinity, have been shown to have especially important influences on entrainment survival. Affects of these variables are discussed below in the subsection on "Waterbody Characteristics".

Implications for Design of Survival Studies

Impingement and entrainment survival measured in site-specific studies should be expected to vary widely among species. The value of including survival studies in the compliance demonstration will therefore depend on the relative sensitivities of the mix of species impinged and entrained at each site and on the species domain being used to measure compliance (see EPRI report 1011280 or 1008470 for further discussion of compliance entities and measures). Variation in survival should also be anticipated among life stages and ages or sizes, especially for entrainment. General implications for planning survival studies include:

- The decision to conduct studies and the selection of species that are the focus of those studies should be based on explicit evaluation of the potential level of impingement or entrainment survival, considering species composition at the site (see Section 3);
- Sampling design should account for seasonal variations in entrainment or impingement to representatively sample all of the primary life stages or age categories impinged or entrained during the period used to characterize the baseline;
- Plans for using impingement survival studies to verify the performance levels of alternative screen technologies should take into account the potential for interannual variations in survival rates. For example, it may be prudent to set performance expectations based on a potential benefit range or to measure average performance over more than one year.

CWIS Characteristics

The impingement and entrainment survival realized by each species and life stage can be influenced by CWIS design and operating conditions. In fact, in the case of impingement, enhancing survival by using existing or alternative intake screen design and operation is one way to achieve compliance with the Phase II performance standards.[7] Physical stresses present during impingement are influenced by screenwash frequency, screen travel time, and screen modifications intended to reduce stress associated with fish separation and handling (EPRI 2003). Entrainment stresses consist of physical forces to which organisms are exposed as they pass through pumps, pipes, condensers and discharge structures, elevated temperatures and, sometimes, exposure to biocides. These entrainment stresses may be influenced by various aspects of CWIS design and operation, including flow velocities, hydraulic pressure profiles, and condenser performance.

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[7] A review of the biological effectiveness, engineering practicability, and costs of fish protection systems, including active screening systems, has been presented in detail in three previous EPRI reports (EPRI 1986, 1994, 1999a) and, more recently, as posted in Volume IV of EPRI's Fish Protection Synthesis Report available to program funders via EPRI's internet home page, accessible at: http://www.epriweb.com/epriweb2.5/eg/316bsynthesisreport/default.html#vol4 .

Impingement

Screenwash Frequency

For vertical traveling screens there is generally a substantial increase in organism survival associated with decreased time between screen washes, with continuous screen rotation providing the highest survival. In reviewing impingement survival studies conducted since the 1970's, EPRI (2003) found that impingement survival rates for most species decreased, often very substantially, as the time between screen washes increased for almost all species tested. It can be assumed based on these studies that very long impingement durations, such as would occur on fixed screens, or traveling screens washed only very infrequently, would lead to near complete mortality for most species[8].

Screen Travel Time

The duration of organism impingement on the traveling screens is also directly related to rotation time of the screen, or in other words, the time of travel required before impinged fish reach the screenwash headers. This travel time is determined both by the speed of screen rotation and the elevation or height of the screen. Faster rotation and/or shorter screens would be expected to decrease stress. Rotation speeds of conventional screens vary according to the screen design at a particular facility, and the design may include operation at more than one speed to help keep the screens clean when debris loads are high. Screen elevation above the intake decking may also affect the length of the drop that fish experience from the screen to the screenwash sluiceway, which could potentially impact impingement survival. Several prior impingement survival studies have found moderate improvements in survival with increased screen rotation speed (EPRI 2003).

Screen Modifications for Fish Separation and Handling

A number of physical modifications to traveling screen systems have been developed specifically to protect fish and other aquatic organisms. Screen systems employing fish holding troughs, continuous operation, and low pressure washes with well-designed fish returns to the waterbody are typically referred to as Ristroph screens, after the original developer of the modified screen. The individual changes that may be incorporated in the modified screen are each designed to reduce some aspect of impingement stress (Table 2-2).

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[8] It should be noted however, that some of the hardiest of species have been found to have relatively high survival rates for screenwash intervals of up to 8-hours.