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# Cooling Water Intake Debris Management: Fish Kills

**Technical Brief — *Debris Management Interest Group***

***Fish as Debris*** — Dead and moribund fish can pose a significant threat to power plant cooling water intake structures (CWIS). In sufficient quantities, dead and moribund fish can block intake screening equipment (e.g., bar racks and traveling water screens) leading to reduced cooling water flow or, in extreme cases, structural failure of the screening equipment. Furthermore, the passage of smaller fish into the circulating water system can result in condenser tube plugging. Cooling water blockage is a concern as it negatively affects facility reliability and results in a loss of revenue. This technical brief provides background on dead and moribund fish as a debris agent at power plant CWIS. It includes information on the biology behind fish kills, control strategies, as well as lists of external resources such as key literature, websites, and contact information for technical experts on fish as a debris issue.

*Thousands of fish found dead in Midwest waters as the summer heat increases water temperatures (image courtesy of Reuters).*

## ISSUE

Fish kills can occur in fresh and salt water bodies and can be linked to a number of causes, including environmental and human activities. Marked changes in environmental conditions can cause fish stress which manifests as behavioral and swimming impairments or morbidity. Masses of stressed, moribund, or dead fish can quickly affect operations at a CWIS, particularly when fish numbers are in the millions or when larger bodied fish are involved. Fish kill events occur more frequently in some areas (so called "hot spots"). Galveston Bay Texas, for example, has been identified as a hotspot in which over 383 million dead fish have been reported during a 55-year monitoring program (Thronson and Quigg 2008).

## CAUSE

Fish kill events can be related to anthropogenic impacts such as accidental spills (e.g., oil, pesticides), toxic discharges (including excess nutrients), coastline construction, and landfill leaching (Thronson and Quigg 2008). Fish kill events have also been linked to environmental factors such as spawning stress, disease, changes in water temperatures (both increases and decreases), uptake of toxic substances from sediment or food supply, and oxygen depletion (i.e., hypoxia resulting from periods of hot weather coupled with low-flow conditions) (Kempinger et al. 1998). In a review of statewide Texas historical fish kill data, the leading cause of mortality was found to be low dissolved oxygen concentrations with the highest number of fish killed occurring during the warmest month, particularly August (Thronson and Quigg 2008). An investigation of recurring fish kills on the Fox River in Oshkosh, Wisconsin concluded that carbon monoxide (CO) from a marine motor endurance testing facility, along with CO concentrating flow patterns, were causing the mortality of numerous fish species within the river (Kempinger et al. 1998). Rapid decreases in water temperature have been found to result in physiological, behavioral, and fitness issues for fish, a stressor commonly referred to as "cold shock" (Donaldson et al. 2008). Griffith (1978) observed a decrease in feeding and response behaviors of threadfin shad (*Dorosoma petenense*) at water temperatures of $10^{0}$C and mortality of all shad tested when temperatures dropped below $5^{0}$C. The magnitude, duration, and frequency of the temperature change can influence the extent of the cold shock effect, resulting in fish behavior issues, morbidity, or mortality (Donaldson et al. 2008).

Fish kill events are typically dominated by one or two species. Affected species are typically those considered "fragile" and more vulnerable

*Figure 1 – A fish kill in a Midwest lake consisting of Clupeidae species (Image from Global Astrology website: http://globalastrologyblog.blogspot.com/2012_08_24_archive.html)*

*Figure 2 – Dead menhaden washed up on a beach in Narragansett Bay. A fish kill resulting from low dissolved oxygen in shallow waters (Image from BeachChair Scientist).*

to rapid changes in environmental conditions. The family Clupeidae includes a number of these more fragile species, including blueback herring (*Alosa aestivalis*), alewife (*Alosa pseudoharengus*), American shad (*Alosa sapidissima*), gizzard shad (*Dorosoma cepedianum*), Atlantic menhaden (*Brevoortia tyrannus*), Gulf menhaden (*Brevoortia patronus*), and threadfin shad. A review of fish kill data recorded in all 22 U.S. coastal states found that Clupeidae species (or clupieds) were involved in 36% of the events and accounted for 61% of the fish killed (Lowe et al. 1991). Many clupeids have narrow thermal and water quality tolerance ranges and sudden and drastic changes can result in behavioral and physiological impacts making them more susceptible to impingement and mortality at CWIS (EPRI 2008). In addition, the schooling behavior exhibited by clupeids increases the likelihood that a single fish kill event will include large numbers of individuals (Figure 1).

Alewife, threadfin shad and gizzard shad are sensitive to low water temperatures and thus prone to winter die-offs, especially during seasons of severe weather (Stanley and Colby 1971; Griffith 1978; Fetzer et al. 2011; EPRI 2008). Due to this sensitivity, some threadfin shad populations are believed to be dependent on the warm water discharges of steam generating plants (Pflieger 1997). Menhaden fi sh kill events appear to be less influenced by temperature stresses and more commonly by disease or depletion of dissolved oxygen caused by overcrowding (EPRI 2008). Menhaden in large numbers can quickly deplete oxygen levels especially as predators pursue schools into shallow waters (Figure 2).

## EXTENT AND OCCURRENCE

Fish kill events occur throughout the U.S. and at various times of the year. In southern states such as Texas, warm summer water temperatures result in low dissolved oxygen levels which can quickly affect fish health (TPWD 2003). While farther north in the Great Lakes, fish kill events of species such as alewife are more commonly the result of cold shock or severe winters (EPRI 2008). Due to the varying causes, fish kills can provide useful information on spatial and temporal distributions of pollutants and environmental stressors resulting from poor water quality (Thronson and Quigg 2008). For this reason, many state agencies (including agencies in Texas, Florida, Iowa, and North Carolina) monitor and track fish kill events.

Since the 1950's the Texas Parks and Wildlife Department (TPWD) has been investigating and recording fish kill events. In 1997, the TPWD began tracking these events in a custom-designed database known as PRISM (Pollution Response Incident and Species Mortality), which includes in-depth data on each incident (TPWD 2003). More than 4,500 incidents have been recorded since the initiation of the program. The majority of those incidents took place in rivers (36%) or streams (29%) where inland pollution incidents tend to enter flowing surface waters (TPWD 2003). Only about 18% of incidents took place along the Gulf of Mexico and 9% in estuaries. The TPWD (2003) stated that while coastal incidents were fewer in number, the total organisms killed per event was higher (51% of the total).

Many state agency websites contain information on reporting fish kills and other abnormalities discovered throughout the state. North Carolina posts annual fish kill reports which summarize each incident and its suspected cause (http://portal.ncdenr.org/web/wq/ess/fish-kills). The Florida Fish and Wildlife Conservation Commission website includes a searchable database of all fish kill events since 1972. This database allows users to search by county, date of incident, and even probable cause (http://research.myfwc.com/fishkill/).

*Figure 3 – Sound and strobe light barrier used at Ontario Power Generation's Lambton Station (Image from Someah 2011).*

## CONTROL AND MANAGEMENT

Further research is required on the most effective techniques for managing fish kills at CWIS. To date, the most successful management approaches have been to monitor environmental conditions in an effort to predict fish kill events and to develop site-specific protocols for minimizing operational impacts. Facility records should include water quality and environmental parameters surrounding fish kill events. This will allow operators to monitor and correlate fish kill events to water temperatures and weather changes in order to predict fish inundation. Monroe Power Plant on the Great Lakes has reported success with this style of mitigation in which operators continuously monitor water temperatures and weather changes to anticipate gizzard shad runs and kill events (EPRI 2012).

Modifications to equipment and changes to CWIS operation have proven to be successful for the management of fish kills. Multiple power generation facilities have reported increasing the frequency of trash rack raking or increasing the rotation speed of traveling water screens during fish kill events (EPRI 2012). The ability to continuously rotate and clean the traveling water screens effectively during an event can reduce CWIS operational issues. The Calvert Cliffs Nuclear Power Plant has implemented various operational changes, including modifications to the spray wash headers of the traveling water screens, in order to improve cleaning and removal of debris and fish from the screen face (EPRI 2012).

Facilities may also benefit from updating screening components or by replacing existing traveling screens with those better designed to handle high loads associated with fish kill events. Dual-flow, center-flow, and rotary screens (i.e., Bilfinger/Passavant-Geiger Multi-Disc™) are designed with the ascending and descending mesh panels on the upstream side of the screen. Such a design effectively eliminates carryover and reduces the risk of downstream concerns. Additionally, variable speed drive units like those found on the Multi-Disc™ screen can operate at higher speeds; (5 to 22 m/min [16 to 71 ft/min]) allowing for an increase in screen rotation during the presence of high fish loads (EPRI 2012).

Behavioral barriers such as light and high frequency sound have been found to be effective at deterring Alosid species from entering a CWIS prior to a sudden mortality event, such as a drop in water temperature. Ontario Power Generation's Lambton Station on the St. Clair River in Ontario, Canada demonstrated in 2004–2005 that a system consisting of 18 sound projectors and nine high-intensity light bars (Figure 3) could successfully deter gizzard shad from entering the CWIS (Someah 2011). Other facilities such as D.C. Cook Nuclear Station in Michigan and J.A. FitzPatrick Nuclear Plant in New York (see case study) have had similar deterrent successes using high frequency sound systems.

Barrier nets have also been effectively deployed to reduce impacts on CWIS at several facilities where fish and other aquatic organisms constitute the principal debris issues. The level of engineering and extent of anchoring structure required for a successful barrier net installation is highly dependent on the hydraulic and debris conditions at the site. Chalk Point Generating Station on the Patuxent River Estuary in Maryland has been successfully deploying a barrier net since the summer of 1981 (Figure 4). Monitoring studies conducted before and after barrier net deployment reported a 78% overall reduction in total fish impingement and an 82% reduction in crab impingement relative to annual abundance data (Bailey et al. 2003). A detailed evaluation of existing barrier net installations along with design considerations and guidelines was conducted by EPRI in 2006 (EPRI 2006).

*Figure 4 – Barrier net (double net system with exterior mesh of 1.5 in and interior of 0.75 in stretch mesh) at the mouth of the Chalk Point Generating Station CWIS (Image courtesy D. Bailey)*

# CASE STUDIES

## Response of Alewives to High-Frequency Sound at a Power Plant Intake on Lake Ontario (Ross et al. 1993).

A high-frequency sound deterrent system was evaluated at the James A. FitzPatrick (JAF) plant, an 800-MW nuclear facility located on Lake Ontario near Oswego, New York. Conducted April through June 1991, the objective of the evaluation was to determine if a high-frequency sound system would successfully deter alewives from entering the JAF offshore intake. Annual alewife impingement at JAF ranged between 66,124 to 522,672, with 90% of those becoming impinged during May and June. Historically, cold water temperatures within Lake Ontario had resulted in mass alewife die-offs that impacted the JAF CWIS.

Cooling water at JAF is withdrawn through an offshore intake (< 0.42 m/s [1.38 ft/s] intake velocity) located about 300 m (984 ft) north of the plant in 8 m (26 ft) of water. Water travels through a 4.3-m (14-ft) diameter pipe at 1.7 m/s (5.6 ft/s) to a forebay fitted with a series of traveling water screens (TWS) with 1.25-$cm^2$ (0.19-$in^2$) mesh.

The deterrent system installed on the offshore intake structure consisted of a transducer array of 16 narrow-beam and 4 wide-beam transducers. The nominal (-3 dB) beam widths of the wide-beam transducers were $96^0$ horizontal and $72^0$ vertical, and those of the narrow-beam transducers were $25^0$ horizontal and vertical. One amplifier powered the 4 wide-beam transducers, a second amplifier powered the 16 narrow-beam transducers. Two 396 m (1300 ft) long cables linked the transducer array to the onshore electronics. A computer model designed the system to ensonify the entire JAF intake at a sound pressure level of 190 db (frequency band 122 to 128 kHz) within 1 m (3.3 ft) of the intake opening. Response to the deterrent system was monitored by counting the alewives impinged on the TWS and by visual observation using an underwater camera.

With the deterrent system on and the JAF reactor at full power, the average reduction in density near the intake was 85% and the estimated decrease in impingement was 87%. However, when the system was off and the reactor was at full power, the density reduction was 90% and the estimated decrease in impingement was only 29%. In addition to reactor operation, wind direction, lake temperature, and time of day were all significant variables. The system resulted in a greater reduction in density at night and weaker response by alewives was observed when water temperatures rose above $13^0$C. The authors state that while this evaluation demonstrated as much as 96% reduction in densities at the JAF intake and as much as 87% reduction in impingement of alewives, they believe these numbers could be further reduced by extending the sound field to include the rear, sides, and top of the intake.

A reconfiguration of the deterrent system was conducted in the spring of 1997 with eight integrated projector assemblies operating at 187 dB at 1 meter from the source (Dunning and Ross 1998). It was determined that this reconfiguration provided equivalent protection for alewives as the previously evaluated system.

## Tennessee Valley Authority's Fish Kill Event Warning System (TVA 2012)

Fish kills, comprised mainly of fragile shad species (threadfin and gizzard), are a natural occurrence in many of the Tennessee Valley Authority's (TVA) reservoirs. Since these species are sensitive to rapid changes in water temperature, large die-offs can occur when water temperature falls between 40 and 55°F. In addition, local water temperature conditions can be exacerbated by wind and flow characteristics, increasing the risk of fish kills and, consequently, the risk of blockage of and damage to cooling water intakes. In response, TVA developed an intake warning indicator system to prevent power deratings caused by intake blockages associated with debris, particularly large fish kills.

Operators have been trained to identify and interpret key warning indicators, including water temperature, weather patterns, reservoir operations, species abundance, and simple environmental observation (Table 1). The warning system follows a logical stepwise progression from identification of key environmental data to assessment of the level of severity of each indicator (green, yellow, or red) to communication of threat among key personnel (TVA 2012). For example, if one of the warning indicators (e.g., water temperature) is assigned a red severity level (i.e., water temperature is below 45°F indicating that shad die-off is likely), then the operator must notify the operations shift manager to perform the proper procedures for managing this threat. The operator must also communicate to the operations shift manager that the risk multiplier for intake blockage has increased by a certain degree due the low water temperature.

### D.C. Cook Nuclear Generating Station 2003 Fish Intrusion

In April of 2003, D.C. Cook Nuclear Generating Station on Lake Michigan experienced a major fish intrusion event. Water currents resulted in the thermal effluent attracting alewife and their food source to the intake. Approximately 2 million alewife were impinged on the traveling water screens (Figure 5), leading to screen failures and manual trips of both units. In response, a high frequency sound deterrence system and Bilfinger screens were installed to mitigate future fish intrusions events.

In addition, D.C. Cook Nuclear Generating Station now prepares a weekly fish report, which incorporates previous years' fish population trends (including fishing trawlers' reports), lake temperatures, and weather to estimate the probability of an intrusion. Operations personnel assign the intake a vulnerability score and prepare contingency actions for the intakes' operation.

*Table 1 – TVA power plant warning indicators for fish kills (TVA 2012).*

| Severity | Time of Year | River Temperature/ Weather Conditions | Other Factors to Consider |
|---|---|---|---|
| Green | March 1– November 30 | Above 50°F/mild (no arctic fronts are in the forcast) | |
| Yellow | | Between 45.5°F | If large number of seagulls are in the intake area may need to go to red |
| Red | December 1– February 28 | Below 45°F/arctic front is coming (temp. drop is >10°F) | |
| Contingency work order should be initiated to manually clean the intake traveling screens if intake warning indicators are in yellow or red. | | | |

*Figure 5 – Dead alewife during the 2003 D.C. Cook fish intrusion event.*

## KEY RESOURCES

### Websites

**North Carolina Division of Water Resources: Fish Kill Activity Tracker**
http://portal.ncdenr.org/web/wq/ess/fishkillsmain

**Iowa DNR Fish Kill Database**
https://programs.iowadnr.gov/fishkill/default.aspx

**Texas Parks and Wildlife: Kills and Spills Team**
http://www.tpwd.state.tx.us/landwater/water/environconcerns/kills_and_spills/index.phtml

**Florida Fish and Wildlife Conservation Commission: Fish Kill Database**
http://research.myfwc.com/fishkill/

## Experts

Below are experts in various areas of fish and fish kill research and/or management.

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# CONTACT INFORMATION

For more information on EPRI's Cooling Water Intake Debris Management Interest Group activities, contact Douglas Dixon at ddixon@epri.com or 804.642.1025. For general information, contact the EPRI Customer Assistance Center at 800.313.3774 (askepri@epri.com).

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